REVISION OF BASIC RESEARCH FOR IMPROVEMENT OF ROAD DEVELOPMENT PROJECTS BY JAPAN'S ODA IN AFRICAN COUNTRIES
- ETHIOPIA, GHANA, TANZANIA -

FINAL REPORT
WORK REFERENCE

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Introduction

The assistance to infrastructure development of developing countries by Japanese Official Development Assistance (ODA) mainly through ODA Loans, ODA Grants, and Technical Cooperation has contributed to the advancement of economic infrastructure and the nurturing of human resources. Specifically, development needs for roads are huge since the roads account for a large portion of transport in many developing countries, and the functions of roads are essential for economic growth, access to medical and educational facilities, improvement of life standards and strengthening of resistance to disasters. Against this background, Japan has assisted the development of many trunk roads and many urban roads to achieve efficient and effective transport. In African countries, poor transport infrastructure hamper economic advancement and are a cause of poverty. To accomplish sustainable advancement and growth, the development of transportation infrastructure, which enables the movement of people and distribution of goods and materials, is indispensable and road development in particular has high needs regardless of economic level. However, since the surrounding condition is different from Japan, road construction projects in Africa have various issues. Therefore, in designing and constructing roads, in order to ensure their quality, it is extremely important to fully understand the local conditions and follow the local know-how and standards, while relying on the technology and experience cultivated in Japan.

Under this condition, JICA conducted “Basic Research for Improvement of Road Development Projects by Japan’s ODA in African Countries -Ethiopia, Ghana, Tanzania-” (hereinafter referred to as “Existing Basic Research”) in 2013, and various standards and methods that can be referred at the design and construction stages of road pavement projects were investigated in the said three countries. And the collected information was compiled as basic data for subsequent road projects under the ODA Grant project. About 6 years have passed since the Previous Basic Research, and the results of research have been effectively used in specifications for preparatory surveys by JICA, for survey and design by consultants, and for construction supervision. Meanwhile, additional knowledge has been accumulated in ODA Grant Aid projects, and progress has been made in road design methods in each country. From these circumstances, it was necessary to revise the report of Previous Basic Research reflecting the latest knowledge.

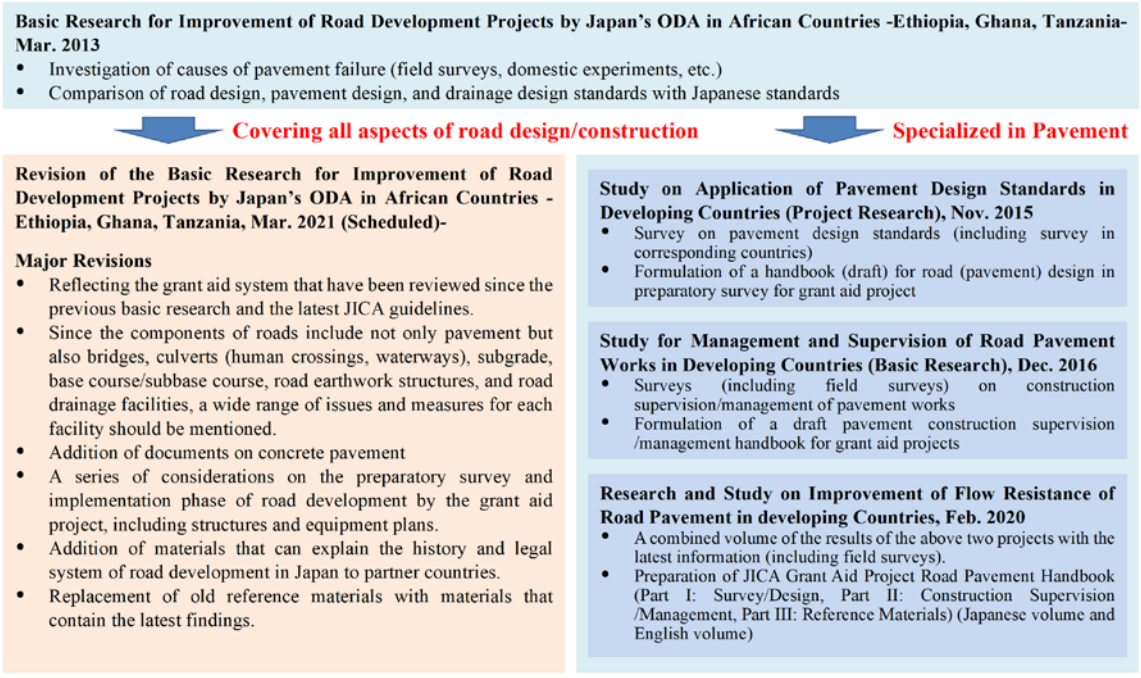
Through this report, by sharing the knowledge necessary to ensure the quality of Grant Aid road projects, more effective implementation and improvement of the quality of road development projects in developing countries will be expected.

■ Purpose and Background of the Revision of the Existing Report

The purpose of this revised report is to provide JICA staffs (Headquarters and overseas staffs) with reference materials for preparing the specifications of the preparatory survey, confirming the contents of the survey, and conducting quality control in the implementation phase of the projects. To provide a wide range of knowledge on road development, the report will cover the flow of Grant Aid road projects, i.e., survey ⇒ outline design ⇒ detailed design ⇒ construction management/supervision, and the contents of each stage, including comparisons with road projects in Japan and overseas.

Commentary

In response to the many unexpected early breakages that occurred, the report on "Basic Research for Improvement of Road Development Projects by Japan's ODA in African Countries -Ethiopia, Ghana, Tanzania-" in 2013 compiled various standards and methods that can be used as reference in the design and construction stages of road pavement projects. Subsequently, the importance of quality control during construction and maintenance management was confirmed through survey to prepare a handbook on pavement. In addition to pavements, not only road design standards both geometric and structural are being revised, but also changes in the road development environment, such as consideration of NMT[1] (Non-motorised Transport), are also underway in many developing countries. And new measures to improve project efficiency, such as the introduction of CIM [2] (Construction Information Modelling/Management), are progressing. On the other hand, in the Grant Aid projects, failure cases have occurred not only in pavements but also in structures. In view of this condition, it was necessary to revise the existing basic research report to reflect the latest findings for the entire road project by Grant Aid.



Relation between Existing Research and This Research

[1] NMT (Non-Motorized Transport): a means of transportation with low environmental impact (walking, bicycling, etc.)

[2] CIM (Construction Information Modelling/Management): An initiative to standardize and utilize a variety of information in civil engineering works. (At present, it mainly uses three-dimensional models.
Visualization of design (early consensus building), optimization of design (elimination of design errors), sophistication of construction (shortening of construction period by information-based construction), efficiency and sophistication of maintenance management, centralization and integration of structural information, etc.

Key Recommendations based on This Research

Subject	Reason	Stage	Recommendation
Incorporate considerations for maintenance into the project.	In order to ensure the continuity of maintenance and management of facilities, "the technology that is most effective for the environment, conditions, and needs given by the developing country" in line with the economic and technical realities of the partner country should be considered from the design stage. It is necessary to adopt structures that facilitate maintenance and management, easily procurable and inexpensive equipment, and production of materials using existing facilities.	Preparatory survey	• Inclusion in work instructions of considerations for maintenance management • Inclusion of maintenance considerations in design reports • Collection and sharing of information on similar projects
		Detailed Design Supervision/Construction	• Explanation to the implementing agency at the construction quality control meeting • Inclusion of notes on maintenance and management in the project completion report, and holding of seminars, etc.
Enrichment of traffic safety measures	A road safety audit (RSA) is defined as "the formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users. This movement is spreading worldwide, and it is necessary to refer to it in the Grant Aid project.	Preparatory survey	• Reflect traffic safety facilities in the design as part of the road structure • Confirmation of road safety using 3D design, etc. • Ensuring an appropriate cross section (width) • Examination of traffic safety measures during construction
		Detailed Design Supervision/Construction	• Implementation of traffic accident prevention measures during the construction period • Implementation of appropriate traffic contorol by patrol officers, etc. • Implementation of appropriate traffic congestion measures including detours • Based on the appearance of the road that is gradually become visible during the progress of the project, take possible measures flexibly to contribute to improving traffic safety after operation
Enrichment of consideration for NMTs	Lately, walking and cycling have been promoted as cost-effective transportation modes. Therefore, in the preparatory survey, it is necessary to examine the development of traffic nodes for safe access to public transportation and the continuity of sidewalks/bicycle paths, and reflect them in the design.	Preparatory survey	• Conducting traffic volume surveys with consideration for NMT traffic (especially traffic lines at intersections) • Comply with the standards of the country regarding NMT (cross section, width, etc.)

Subject	Reason	Stage	Recommendation
Consideration for logistics and transportation	In a road plan that does not consider logistics activities, there will be an impact on road traffic due to on-street parking and an impact on safety for NMT. In addition, since landscapes and the generation of exhaust gas and noise are also problems, appropriate road plan is required in consideration of logistics activities.	Preparatory survey	• Traffic volume survey that can grasp the movement of logistics traffic • Confirmation of parking demand along the roadside of logistics traffic • Road design that takes into account the traffic flow of logistics vehicles (Entering roadside facilities, movement at intersections, etc.) • Pavement design that accurately grasps the demand for heavy vehicles
Countermeasures against premature failure (Improvement of quality)	There are still cases of facilities being damaged unexpectedly and quickly due to inadequate examination at the survey /design stage. Also, there are cases of damage that seem to be caused by insufficient quality control at the construction stage. Therefore, it is necessary to further improve the accuracy of survey and design and to enhance quality management.	Preparatory survey	• Improve the accuracy of natural condition surveys (geology, surveying, etc.) • Conduct sufficient design studies (road surface design, soil structures, hydraulics/sluice gates)
		Detailed Design Supervision/Construction	• Preparation of special specifications that take quality control into consideration • Implementation of necessary quality control tests (proof rolling, extraction tests, etc.) • Allocation of personnel necessary for quality control • Respond flexibly as possible to the various ground conditions found during detailed design or construction
Improve accuracy of cost estimates and bidding price	When bidders examine the bidding prices, there is a possibility that the bidding price is higher than the planned price because the results of the survey are not disclosed and many risks are included. Therefore, it is necessary to disclose as much information as possible necessary to determine the bidding price.	Preparatory survey	• Improvement of natural condition survey accuracy (survey accuracy, material/rock classification, etc.) • Improvement of material procurement condition survey, construction capacity survey
		Detailed Design Supervision/Construction	• Disclosure of survey/design documents • Clarification of assumed conditions • Clarification of cost estimation items

Source: JICA Study Team

Revision of Basic Research for Improvement of Road Development Projects by Japan's ODA in African Countries
- Ethiopia, Ghana, Tanzania -
Final Report
Work Reference

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List of Abbreviation

Abbreviation	Explanation
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ACV	Aggregate Crushing Value
ADB	Asian Development Bank
AE	Air Entraining (agent)
AFCAP	Africa Community Access Partnership
AfDB	African Development Bank
AI	Asphalt Institute
AMF	Accident Modification Factor
A/P	Authorization to Pay
B/A	Banking Arrangement
BM	Benchmark
BQ	Bill of Quantity
BS	British Standard
CBD	Central Business District
CBR	California Bearing Ratio
CCTV	Closed Circuit Television
CIM	Construction Information Modelling/Management
COI	Corridor of Impact
COMESA	Common Market for Eastern and Southern Africa
CSIR	Council for Scientific and Industrial Research
DCP	Dynamic Cone Penetration
DBST	Double Bituminous Surface Treatment
DD	Detailed Design
DMRB	Design Manual for Roads and Bridges
DMS	Detail Measurement Survey
DS	Dynamic Stability

Abbreviation	Explanation
DSRC	Dedicated ShortRange Communications
E/N	Exchange of Notes
EAC	East African Community
EIA	Environmental Impact Assessment
EME	Enrobé à Module Élevé (High Modulus Asphalt)
EMP	Environmental Monitoring Program
EPS	Expanded Polystyrol Construction Method
ESAL	Equivalent Standard Axle Load
EU	European Union
FCB	Foamed Cement Banking
FHWA	The Federal Highway Administration
FS	Feasibility Study
FIDIC	International Federation of Consulting Engineers
FWD	Falling Weight Deflectometer
G/A	Grant Agreement
GBR	Geological Baseline Report
GCC	General Conditions of Contract
GDP	Gross Domestic Product
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HCM	Highway Capacity Manual
HISI	Highway Safety Information Systems
HP	Home Page
HWL	High Water Level
ICT	Information and Communication Technology
IEE	Initial Environmental Examination
ILO	International Labour Organization
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency

Abbreviation	Explanation
JIS	Japan Industrial Standard
KY	Kiken Yochi (risk prediction)
LAA	Los Angeles Abrasion
LED	Light Emitting Diode
LCC	Life Cycle Cost
LOS	Level of Service
LRFD	Load and Resistance. Factor Design
MDB	Multilateral Development Bank
MEPDG	Mechanistic-empirical pavement design guide
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MOW	Ministry of Works
Mr	Resilient Modulus
NETIS	New Technology Information System
NEXCO	Nippon Expressway Company Limited
NGO	Non-governmental Organizations
NMT	Non-motorized Traffic
NPRA	Norwegian Public Roads Administration
OAC	Optimum Asphalt Content
OD	Origin and Destination
O/D	Outline Design
ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
OMC	Optimum Moisture Content
ORN	Overseas Road Note
PC	Prestressed Concrete
Pce, PCE	Passenger Car Equivalents
PCR	Project Completion Report
Pcu, PCU	Passenger Car Unit

Abbreviation	Explanation
PG	Performance Grade
PI	Plasticity Index
PM	Project Management
PMB	Polymer Modified Bitumen
PMR	Project Monitoring Report
P/Q	Prequalification
RAP	Resettlement Action Plan
RC	Reinforced Concrete
RD	Rate of Deformation
RI	Radio Isotope
ROW	Right of Way
RSA	Road Safety Audit
SADC	Southern African Development Community
SANRA	South Africa National Roads Agency
SAPEM	South Africa Pavement Engineering Manual
SATCC	Southern Africa Transport and. Communications Commission
SBST	Single Bituminous Surface Treatment
S/W	Scope of Work
SAPEM	South African Pavement Engineering Manual
SGC	Superpave Gyratory Compactor
SMA	Stone Mastic Asphalt
SPT	Standard Penetration Test
T_A	Total Asphalt
TFV	Ten percent Fines Value
TOR	Term of Reference
TRL	Transport Research Laboratory
TTTFP	Tripartite Transport & Transit Facilitation Programme
UAV	Unmanned Aerial Vehicle

Abbreviation	Explanation
UN	United Nations
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
VFA	Voids Filled with Asphalt
VICS	Vehicle Information and Communication System
VMA	Voids in Mineral Aggregate
WB	World Bank
WHO	World Health Organization
WL	Liquid Limit
WP	Plastic Limit
WT	Wheel Tracking
WWIS	World Weather Information Service

CHAPTER 1 ODA GRANT PROJECT

1.1 Outline of ODA Grant Project

(1) What is ODA Grant Project?

ODA (Official Development Assistance) Grants are types of financial assistance in which funds are granted to a developing country to support construction works or services such as procuring equipment and materials that are necessary for economic and social development. Since ODA Grants are financial assistance with no obligation for repayment, they target mainly developing countries with low income levels.

Assistance is given to development projects that are essential in developing countries' nation building, including: construction of hospitals or schools and increasing access to safe water supply to satisfy basic human needs; improvement of irrigation systems to promote development of communities and agricultural productivity; construction of roads and bridges to build socio-economic foundations; building facilities to promote environmental conservation; and development of human resources. In recent years, assistance has also been provided for peace building, developing business environments, disaster prevention and reconstruction after disasters, and measures to cope with climate change. Where necessary, technical guidance for operation and maintenance, etc. (soft components) is also provided, so that the facilities and other systems financed by ODA Grants are sustainably managed.

Source: JICA HP (https://www.jica.go.jp/english/our_work/types_of_assistance/grant_aid/about.html)

(2) Types and Process of ODA Grants

The types of ODA grants are: 1) Project grants, 2) Sector grants, 3) Grants in association with international organizations, 4) Grants through budget support, 5) Grants for human resource development scholarships. Infrastructure like roads is developed through project grants. Project grants are a type of ODA Grant in which the government of a partner country enters contracts with Consultants or Contractors to build facilities or to procure equipment and materials. They are mainly used for establishing foundations for basic human needs or for building socio-economic infrastructures, etc.

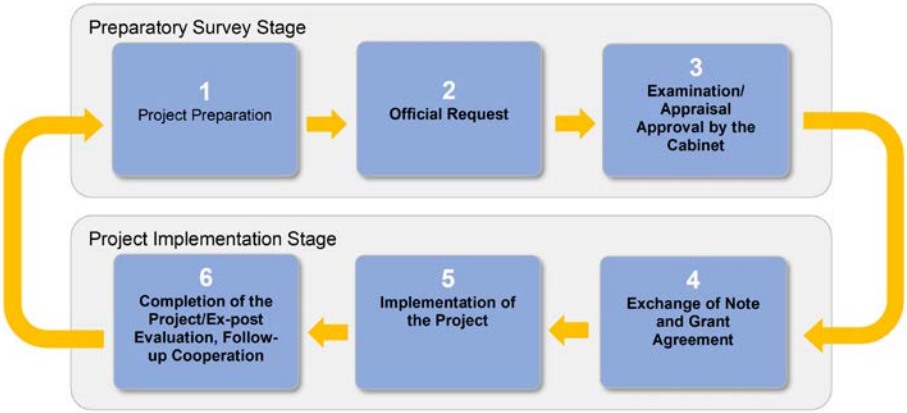
Source: JICA HP (https://www.jica.go.jp/english/our_work/types_of_assistance/grant_aid/types.html)

Project Grants are carried out in a project cycle consisting of six major steps, as described in Figure 1.1.

1) By conducting a preparatory survey for cooperation as part of 'project preparation', JICA examines the appropriateness of the project to be carried out by ODA Grants, and develops a plan of the project through discussions with the government of the partner country.]
2) At the receipt of 'official request' of the project from the partner country, JICA examines and appraises the contents of the project.
3) Based on the result of JICA's appraisal, the Japanese government decides to implement a project financed by ODA Grants through 'approval by the Cabinet'.
4) After approval by the Cabinet, the government of the partner country signs the 'Exchange of Notes' with the Japanese government, then signs a 'Grant Agreement' with JICA.
5) Thereafter, the project starts with the government of the partner country as client. In order to ensure proper and smooth implementation of the project, JICA monitors progress of the project and gives

advice to stakeholders including the government of the partner country, while respecting the project ownership by the partner country.

6) After 'completion of the project', JICA prepares an 'ex-post evaluation', and where necessary, provides 'Follow-up cooperation' in the form of materials and equipment procurement, emergency repair work, etc. The results of the evaluation are also referred to in the preparation of new projects.



Source: JICA HP (https://www.jica.go.jp/english/our_work/types_of_assistance/grant_aid/cycle.html)

Figure 1.1 Project Cycle for Project Grants

(3) Division of Roles within JICA for Grant Aid Projects

The main duties of the departments in JICA Headquarters for Grant Aid Projects are as follows.

Table 1.1 Division of Roles of JICA Departments for Grant Aid Projects

Department	Role
Regional departments (Southeast Asia and Pacific Department, Africa Department, etc.)	Formulation of implementation policies for each region/country in each region, and formation, examination and approval of projects such as technical cooperation, yen loan, Grant Aid.
Infrastructure Management Department	Formulation of implementation policies related to urban development, regional development, transportation, energy, mining, etc., formation of Grant Aid Projects, implementation of technical cooperation projects, etc. (in charge of 1 to 3 in Figure 1.1)
Financial Cooperation Implementation Department	Examination and advice on design and cost estimates of Grant Aid Projects, implementation supervision, etc. (in charge of 4 to 6 in Figure 1.1)
Overseas Offices	Support for the entire cycle in Figure 1.1 from local side.

Source: JICA Study Team based on https://www.jica.go.jp/about/jica/index.html

1.2 Road Development by ODA Grants

(1) Development Effects by Roads

Roads have the potential to be a significant asset to any country - both in terms of physical investment and the social and economic benefits. A well-maintained and managed road network enables movement of people by various travel modes, improves living standards and the region's productive capacity by linking agricultural and mining areas to national or regional markets and factories, ensures safe and secure lives, and encourages economic growth and social integration by bringing cities and villages closer together. In developing countries, there is a strong need for road widening and intersection improvement as countermeasures against traffic congestion in urban areas due to increased traffic volume with economic growth. On the other hand, since the proportion of unpaved roads that are difficult to pass in the rainy season is still high, the need for road maintenance including pavement is also high.

Table 1.2 Paved/Unpaved Ratio in Developing Countries

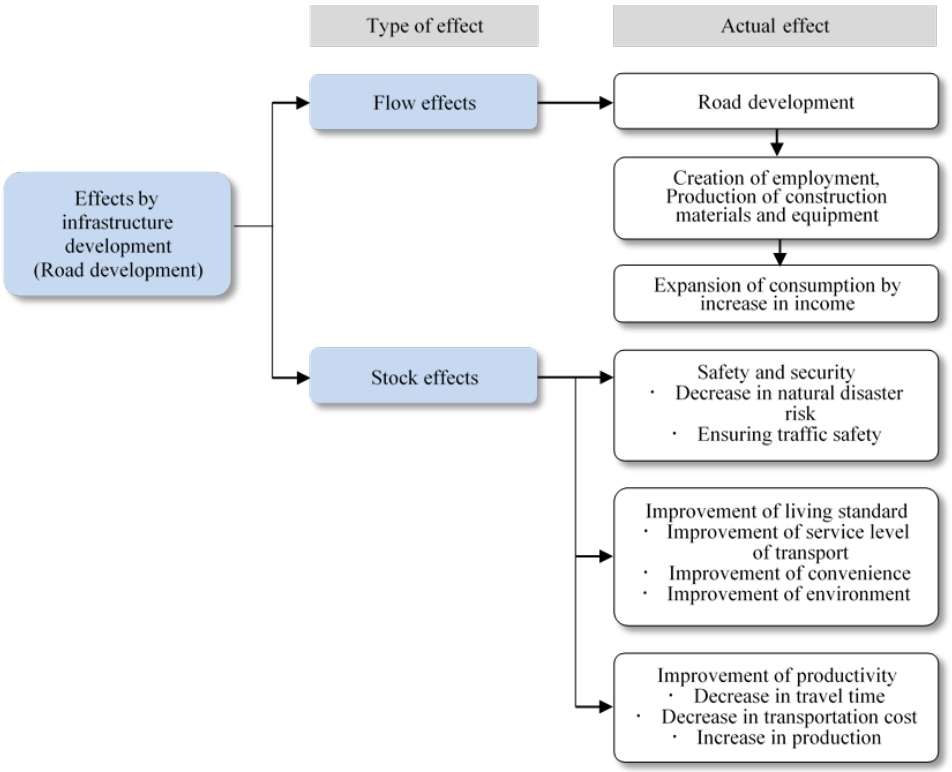
Country	Paved (km)	Unpaved (km)	Paved Rate (%)	Remarks
Kenya	11,197	149,689	7	Road Board 2013
Tanzania	10,025	77,556.0	11	Road fund 2015
Uganda	5,224	124245	4	MOW* 2015
Ghana	21,000	57,000	27	-
Japan (reference)	1,002,489	219,830	82	MLIT

*MOW: Ministry of Works
Source: JICA Study Team

Development effects by roads are divided into stock effects and flow effects.

Flow effects: With the start of a road development project, employment and consumption by the production activities of the construction and manufacturing industries are created, and the production activities will be accompanied by the derivative procurement of materials and equipment. When those economic activities spread to related industries one after another, a short-term effect that expands the economy emerges.

Stock effects: Development of roads will reduce disaster risk and improve quality of life and productivity in the region. Stock effects are the effects that can be achieved from immediately after to the medium and long term continuously. Specifically, they are effects that lead to the safety of life and revitalization of the economy, such as environmental improvement by alleviation of traffic congestion, reduction of traffic accidents by sidewalk development, improvement of landscape, shortening of travel time, activation of tourism by improvement of accessibility through reduction of transportation cost and increase of cargo handling volume, inducement of private investment, and improvement of disaster prevention and mitigation functions.



Source: JICA Study Team based on "Promote social capital development to maximize stock effects", MLIT

Figure 1.2 Development Effects of Roads in Developing Countries

(2) External Diseconomies by Road Development

On the other hand, if economic disadvantages are forced without appropriate compensation due to an increase in vehicle traffic, etc. by the road development, it is called an "external diseconomy" from the viewpoint of the victims. For example, the noise of vehicles makes the lives of residents along the road uncomfortable, and the exhaust gas of vehicles causes the residents to suffer from asthma. The following are the main diseconomies.

- Death or injury due to traffic accident
- Respiratory disease damage due to air pollution
- Noise and vibration damage along the roadside
- Global warming and damage caused by climate change
- Loss due to congestion
- Destruction of nature and greenery by road construction
- Community severance by road construction

In road development by a Grant Aid Project, the road will be planned and designed in consideration of the minimization of these external diseconomies.

👉 External diseconomy

The term "externality" means that the costs and benefits of economic activities extend beyond the parties involved in the business. "External diseconomy" refers to negative externalities, that is, costs to parties other than the parties involved (the opposite is the external economy). Pollution is a typical example. External diseconomies are disadvantages and damages that others are compelled to suffer, and are not damage prevention costs, countermeasure costs, damage restoration/removal costs, or damage compensation costs.

Source: politico-economic thesaurus, KISOKEN Web

1.3 Preparatory Survey for ODA Grants

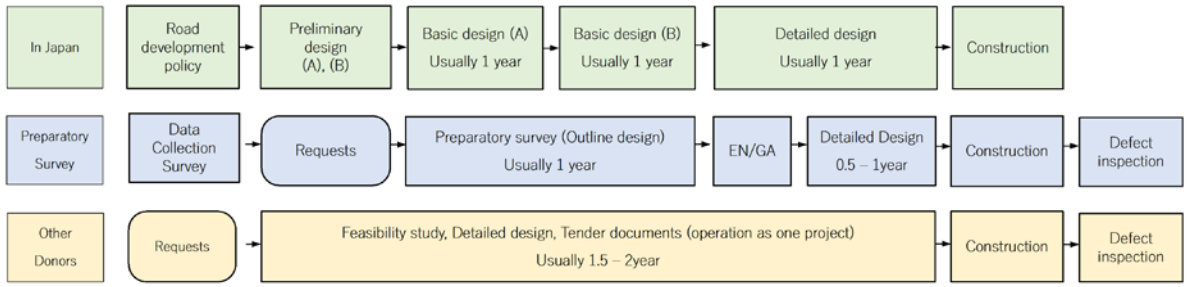
(1) Objectives of Preparatory Survey

The preparatory survey required for the implementation of Japan's project grants is implemented by JICA (Japan International Cooperation Agency). The purpose of the survey is to verify that the implementation by project grants is appropriate according to the country's development plan and to conduct basic design and cost estimates of the optimal plan when the project is selected as an ODA Grant undertaking.

Source: Guidelines for preparing reports, etc. for the Japanese Grants, 2020[1]

(2) Road Development Plan and Design in Preparatory Survey

Figure 1.3 shows a comparison of the procedure of general road development projects in Japan and the procedure of road development through Grant Aid. Of these, the road plan is the stage where the appropriate route and proper road structure (outline plan) are determined based on the higher-level plan, and is the stage up to the road outline design. The stage after the road preliminary design can be called road design. In road design, a road geometric structure is determined keeping in mind that the structure is safe and easy to use, harmonious with the environment, and easy to maintain in consideration of design criteria and reduction of construction costs.



Source: JICA Study Team

Figure 1.3 Comparison of Procedure by Japanese General Road Projects, Grant Aid Projects and Road Projects by Other Donors

In Japanese road projects, in order to clarify design conditions and make decisions step by step, basic design (A) and basic design (B) are carried out before the center line and right-of-way of the target route are determined. In the basic design (A), based on the route determined by the preliminary design, a comparative plan of horizontal and vertical alignment is formulated using 1/1000 aerial survey map, etc., and the road centerline is determined. At this time, comprehensive examination of workability, economy, maintenance, runnability, safety, environment, etc. is carried out. The location, type and basic dimensions of the main structure are also designed. The purpose of the basic design (B) is to determine the right-of-way on the map using the map by the actual measurement survey based on the centerline determined by the basic design (A).

A characteristic of the preparatory survey for Grant Aid Projects is that there is no concept of basic design in the Grant Aid Project, and OD (Outline Design) in the preparatory survey is said to be equivalent to basic design and the survey accuracy of OD is equal to the basic design in Japan. Therefore, the work from basic design (A) to basic design (B) in Japanese road projects is carried out in a short period (one year) of the preparatory survey compared to the basic design of two years. (In some cases,

even the route selection carried out in the preliminary design in Japanese system is carried out during the preparatory survey.) Incidentally, in the case of other donors' projects, from FS (Feasibility Study) to detailed design (DD and preparation of tender document) are often carried out in one survey.

At the stage of preparatory survey for road development by Grant Aid, the survey shown in Figure 1.4 must be conducted.

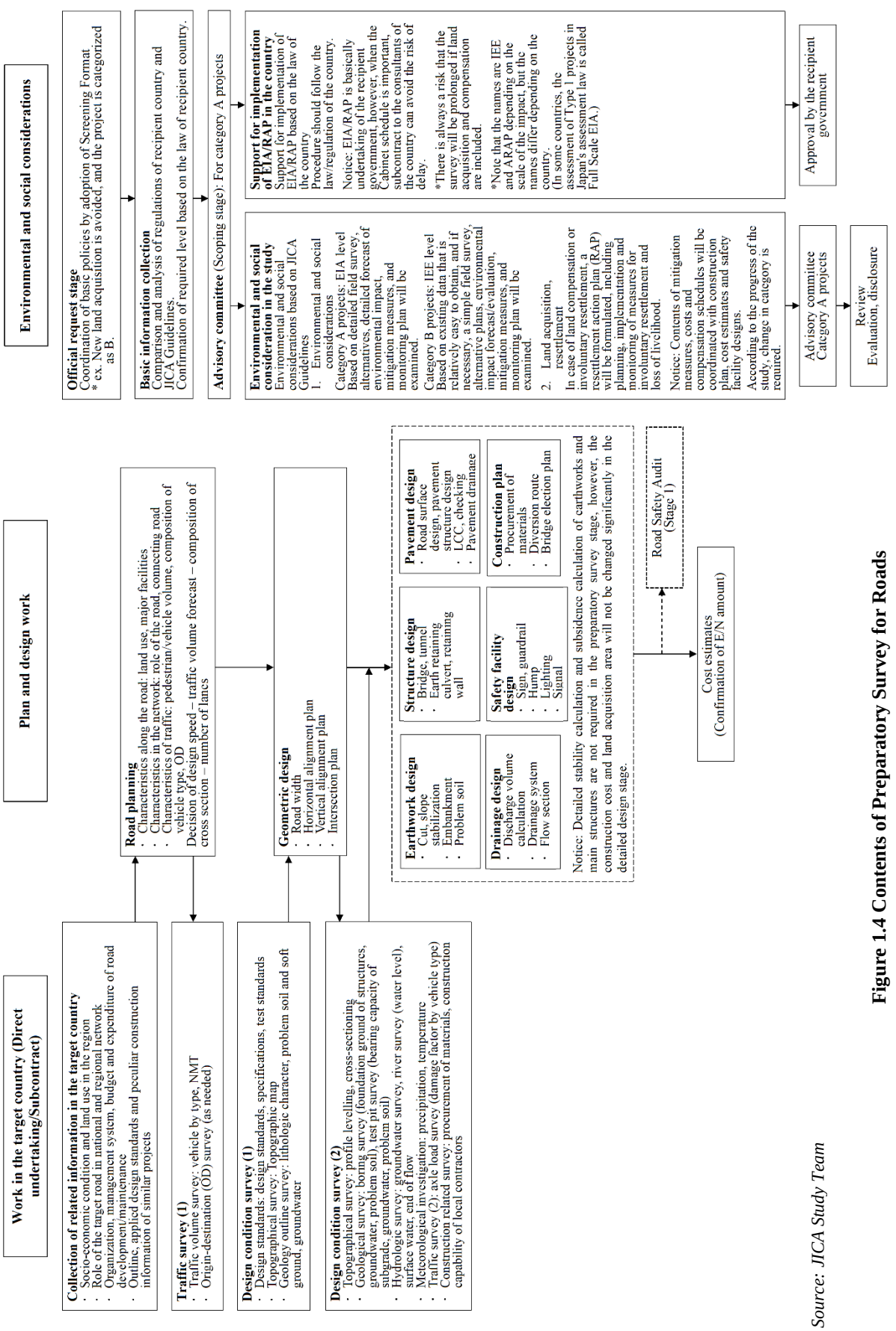


Figure 1.4 Contents of Preparatory Survey for Roads

Source: JICA Study Team

The survey items to be carried out in the preparatory survey on road project by ODA Grant are as follows:

1) The Consultant sets the design conditions necessary for road construction and operation based on local conditions, collected materials, information on other projects, etc., and receives approval from JICA and the government of the partner country.

2) Based on the design conditions, the Consultant conducts Outline Design. Specifically, based on the survey map (scale 1/500 to 1 / 1,000), alternative plans for horizontal alignment are prepared, and workability, economic efficiency, ease of maintenance, drivability, safety, environment, etc. are evaluated. Then, location, outline of structure, and basic dimensions of main structures such as bridges and tunnels are planned, and the centerline of the route and land width are determined based on comprehensive judgment. In addition, the drainage system is planned and the flow rate is calculated based on the existing data and the results of the field survey, and the drainage structure is designed. We will conduct a comparative study of multiple alternatives for major structures (bridges, boxes, etc.) and pavement structures, and carry out the rough design calculations necessary to determine the basic shape for the optimal alternative. Multiple alternatives for major structures (bridges, boxes, etc.) and pavement structures are analyzed and compared, and the rough design calculations necessary to determine the basic shape for the optimal alternative are carried out.

3) Project implementation cost comprising the detailed design, construction supervision and construction of the road is estimated. The accumulated amount based on cost estimates is referred to in Cabinet meeting, and since this determines the upper limit of the project cost in the E/N (Exchange of Notes), appropriate cost is required. On the other hand, uncertainties in design conditions for road design, such as natural condition, traffic condition, material condition, etc., exist, so a thorough survey is required and at the same time assumptions in road design should be clearly indicated and conveyed to detailed design stage if necessary.

4) RSA (Road Safety Audit) is a safety performance inspection of existing or future roads and intersections by an independent team of multi-disciplinary experts to qualitatively estimate potential road safety problems and is an opportunity to improve the safety of road users. Traffic safety audits are standard practice in the United Kingdom and Australia and are coming to be used in the United States. Traffic safety audits are also being conducted by the African Development Bank and the Asian Development Bank, and some developing countries are preparing their own manuals. At the moment, JICA's Grant Aid Projects do not request traffic safety audit, but if requested by the recipient country, discussion with JICA staff is conducted regarding response to the request.

5) Regarding the environmental and social consideration, survey on the environmental and social consideration is conducted based on the JICA guidelines, along with support for the preparation of EIA (Environmental Impact Assessment)/RAP (Resettlement Action Plan) conducted by the recipient government in accordance with the environmental laws and regulations of the country.

Cost estimate by preparatory survey for Grant Aid is the basis for project cost calculation and is reflected in the Cabinet decision amount and in E/N as the maximum amount of grant, therefore it is necessary to improve the accuracy of design and cost estimate, and to appropriately reflect risks.

Source: JICA Study Team based on Road Pavement Handbook for JICA Grant Aid Project[2], 2020

☞ RSA (Road Safety Audit)

RSA differ from traditional road safety surveys in two important aspects.

- Road safety audits are generally conducted as surveys in advance, rather than ex post facto survey of complaint history or problems caused by poor safety performance.
- The members of the survey team are independent of the staffs that design the project and manage the road.

In case planning a road, Road Safety Audit is an assessment of road improvement plans during design, at the end of construction, and after construction. In the UK Design Manual for Roads and Bridges Volume 5 Section 2[10] –'HD19/03 Road Safety Audit' indicates that it will be implemented in four major phases.

- Stage 1: Upon completion of preliminary design before submission of planning permit - preparatory survey stage

Stage 1 Road safety audits are undertaken at the completion of preliminary design, before planning consent is applied for. The end of the preliminary design stage is often the last occasion at which land requirements may be changed.

At Road Safety Audit Stage 1, all Road Safety Audit Team members must visit together the sites of highway improvement schemes:

- that involve permanent change to the existing highway layout or features; and
- where new offline proposals tie-in to the existing highway.

- Stage 2: Upon the completion of detailed design before submission of the bid documents - project implementation stage

Stage 2 Road safety audits are undertaken at the completion of the detailed design stage. The Road Safety Audit Team will be able to consider geometry, street fixtures (such as the position of traffic signs and road restraint systems), carriageway markings, street lighting provision and other issues. At Road Safety Audit Stage 2, all team members must visit together the sites of Highway Improvement Schemes:

- that involve permanent change to the existing highway layout or features; and
- where new offline proposals tie-in to the existing highway.

- Stage 3: Upon completion of construction before opening - project implementation stage

The Stage 3 Road Safety Audit should be undertaken when the Highway Improvement Scheme is substantially complete and preferably before the works are opened to road users. All Road Safety Audit Team Members must examine the scheme site together during daylight. They shall also examine the site together during the hours of darkness at Stage 3 so that hazards particular to night operation can be identified. The Road Safety Audit Team Leader must invite representatives of the police and the maintaining agent to accompany the Road Safety Audit Team to offer their views for the Stage 3 Road Safety Audit.

- Stage 4: Monitoring 12 months after opening the road - Project implementation stage

When a Highway Improvement Scheme is opened to road users, monitoring in the form of Stage 4 Road Safety Audits must be carried out on the number of personal injury collisions that occur, so that any road safety problems can be identified and remedial action taken as soon as possible. Stage 4 Road Safety Audit collision monitoring reports shall be prepared using 12 months and 36 months of personal injury collision data from the time the Highway Improvement Scheme became operational and shall be submitted to the Overseeing Organization. The collision records shall be analyzed in detail to identify:

- locations at which personal injury collisions have occurred; and
- personal injury collisions that appear to arise from similar causes or show common factors.

If collision records are not sufficiently comprehensive for detailed analysis, the police should be contacted to ascertain the availability of statements and report forms.

The Stage 4 Road Safety Audit collision monitoring report should identify any road safety problems indicated by the collision data analysis and any related observations during any site visits undertaken. The report should make recommendations for remedial action as appropriate.

The "Road Traffic Safety Audit" in Figure 1.4 and Figure 1.5 is not formulated in the current preparatory survey, but shows how the work items carried out at each stage of the preparatory survey relate to the audit items of the safety audit.

(3) Guidelines Applied to Preparatory Survey

1) Guidelines for preparing reports and related documents by ODA grants[1], November 2020 (No
2) Design and Cost Estimates Manual for Preparatory Survey[3], March 2009 (Trial version) (No English edition)
3) Supplemental volume for above manual (Civil engineering field)[4], October 2019
4) Design and Cost Estimates Manual, November 2010 (Complement edition)[5]: corresponding to Corona pandemic
5) Operating Policy of Design and Cost Estimates Manual, November 2010 (Complement edition)[6]: corresponding to Corona pandemic
6) Guidelines for the Expenditure of Preliminary Expenses[7], October 2015
7) Manual for Operation Process of Preliminary Expenses[8], June 2016
8) Manual for Operation Process of Preliminary Expenses, Scheduled to be published within FY2020
9) Guidelines for Environmental and Social Considerations[9], April 2010

The guideline provides, "re-examine its way of procedures within five years of their enforcement by hearing the opinions of concerned people". Therefore, the process of re-examination and the result of re-examination have been made public.

- Re-examination of way of procedures for Guidelines for Environmental and Social Considerations, 2014

Publication of the process of re-examination and the result of re-examination.

- Review of Guidelines for Environmental and Social Considerations, 2018

Comprehensive study on the issues raised by the review results.

- Comprehensive study on Guidelines for Environmental and Social Considerations, 2020

Source: JICA HP（https://www.jica.go.jp/activities/schemes/grant_aid/index.html）

1.4 Project Implementation

(1) Project Implementation Process and Role of Parties

Table 1.3 shows the items implemented by related organizations including the Japanese government in the Grant Aid Project. In the case of the Grant Aid Project, the names of the organization in charge of the recipient country are changed depending on the stage of the project, at the time of signing the G/A (Grant Agreement) (Client), after signing and after delegation of authority (implementing organization). The roles and responsibilities of JICA (Japan International Cooperation Agency), Consultants, and construction companies are summarized in Table 1.4.

Table 1.3 Items to be Borne by Related Organizations at the Project Implementation Stage

Items	Japanese Government	JICA	Recipient Government	Consultants	Contractor
E/N and G/A	Conclusion of E/N	Conclusion of G/A	Conclusion of E/N and G/A		
B/A			Conclusion of B/A		
Consultants contract		Recommendation of Consultants Agreement of contract	Consultants contract	Consultants contract	
A/P for the consultant			Issuance of A/P		
Detailed design and Contract document		Approval of contract document		Detailed design Preparation of contract document	
Removal of obstacle objects		Monitoring	Implementation		
Bidding and evaluation			Bidding and evaluation	Assistance of Bidding	
Contract with construction companies		Approval of contract contents	Contract with construction companies		Contract with recipient government
A/P for the contractor			Issuance of A/P		
Construction implementation		Monitoring	Implementation agency[1]	Supervision	Construction and supervision
Maintenance			Maintenance		

E/N: Exchange of Note, G/A: Grant Agreement, B/A: Banking Arrangement, A/P: Authorization to Pay
Source: JICA Study Team

[1] In the JICA Grant Aid Project, the names of the organizations in charge of the recipient country are changed depending on the stage of the project, such as when the G / A is signed (client), after signing, and after the transfer of rights (implementation agency). Regardless, the name of the client is unified.

Table 1.4 Role of JICA, Consultants and Contractor at the Project Implementation Stage

Items		Grant Aid Project
JICA	Relation with recipient country	Defined by E/N and G/A
	Role	In the Grant Aid project, JICA manages the implementation of the project to confirm the preparatory survey is conducted properly and the funds provided to the recipient government are used smoothly and appropriately.
	Method of participation	JICA will be responsible for the implementation management and confirms the following technical aspects. ・ Present at quality control meeting ・ Implementation status examination by JICA personnel ・ Confirmation of progress ・ Confirmation and approval of design change
	Relation with Consultants	JICA recommends Consultants for construction supervision to the recipient country's executing agency, and receive a report on the construction status and design changes from the Consultants acting as a representative for the executing agency. JICA also evaluates the performance of construction supervision Consultants.
Consultants	Status	Representative for executing agency
	Role	The Consultants carry out technical services for the project related to detailed design, cost estimates, preparation of bidding documents, bidding assistance, construction/procurement supervision.
	Responsibility and authority	The final authority and responsibility lie with the implementing agency, however the Consultants are responsible for assisting with the technical aspects of the project in particular.
	Project director	Project leader/resident engineer
	Standards for supervision	Consultants specify the supervision methods and supervision standards in the construction supervision plan, and report to the executing agency.
Contractor	Organization chart	Organization structure to fulfil responsibility.
	Responsibility and authority	Implementation of construction, restoration of defect
	Project director	Field representative
	Quality standards	Construction standard specifications and special specifications included in Bidding documents (In some cases, original standards of the company with strict management values may be used.)

Source: JICA Study Team

Figure 1.5 shows the details of the survey that must be carried out at the stage of implementation of road development project through Grant Aid.

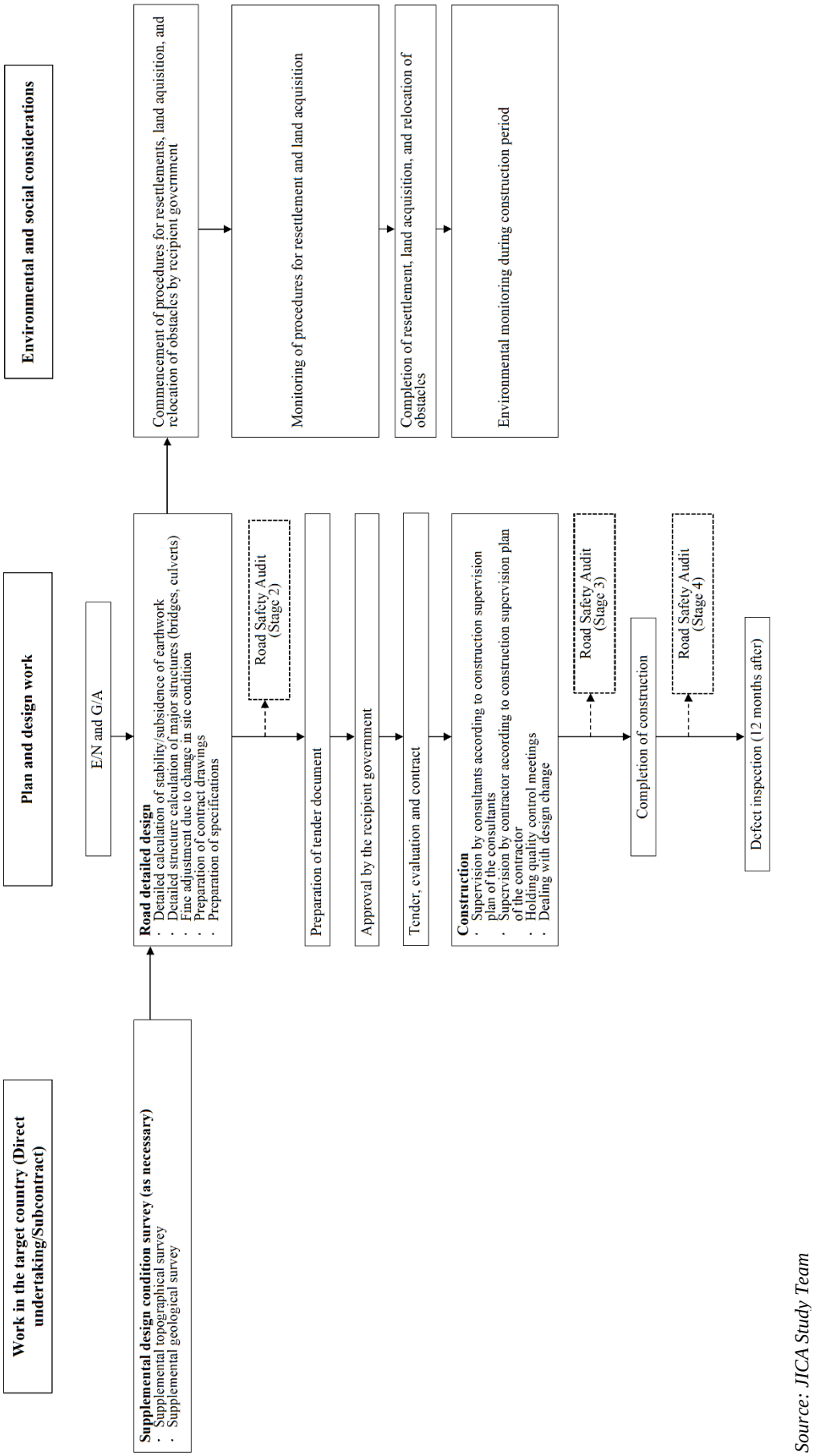


Figure 1.5 Work Contents in Implementation Stage of Road Development Project

Source: JICA Study Team

(2) Notes on the Detailed Design and Bidding Document Preparation Stage

In the detailed design, based on the design results of the preparatory survey, the vertical and horizontal alignment designs and the structural design required for road construction will be conducted, and the quantity survey sheet and design calculation sheet for each work type will be created. Based on the result of this detailed design, a comparison table between the outline design (preparatory survey result) and the detailed design will be created and submitted to JICA. Note the following points in the comparison table between the outline design and the detailed design.

- Regarding the content of the plan, the description should be to the extent that the outline of the item can be understood. For a facility project, it is necessary to show the change in the construction amount due to the detailed design result. Also, the amount of change due to design changes for each item is necessary.
- For the submitted drawings, the number of drawings that were supposed to be necessary for detailed design at the time of O/D (Outline Design) is entered in the O/D column, and the number of drawings actually created as a result of the detailed design is entered in the D/D (Detailed Design) column.
- In case it is judged that the design change is unavoidable, even if it is minor, the request document to the recipient country government, the document for explanation of the reason for design change by the Consultant (including reason of change, technical consideration content, appropriateness of change and review of cost estimates due to changes) should be attached.

(3) Notes on Bidding and Evaluation Stage

At the bidding and evaluation stage, the following points are noted.

- At the bidding stage, questions from bidders are answered, and if it is necessary to change the contract conditions, an addendum is issued to change the contract conditions.
- Instructions for bidders and GCC (General Conditions of Contract) cannot be changed.
- Strict execution of the one-step two-bid system[2] is clearly stated in the bid instructions
- For projects with a bid period of 60 days, the opportunities for questions and answers will be multiple.

(4) Notes on Construction Supervision/Management Stage

In civil engineering works ordered by government in Japan, construction supervision is generally carried out directly by the Client, and Consultants often participate as assistants. On the other hand, in JICA projects, the Consultants act as an agent of the executing agency and supervise the construction.

The Consultants accurately convey the project information obtained from the survey and design stage and the intention of the construction specifications/design drawings to the Contractor and supervise as an agent of the executing agency whether the Contractor is carrying out construction based on the contract document, the specifications, the drawings and the quality control standards described in these

[2] One-step two-bid system: The bidding system consists of two bids, a technical bid and a price bid, and only bidders who pass the technical bid evaluation are allowed to bid on the price bid.

documents. It is necessary for the Consultant to compile the method of supervision as a "construction supervision plan", confirm after consulting with the Client and the Contractor, and carry out smooth operations. The following points should be noted in the construction supervision conducted by the Consultant.

- Holding construction quality control meetings (following construction quality control meeting implementation guidelines)
- If a problem occurs in the undertakings borne by Client (recipient country), consultation with JICA should be conducted promptly.
- Creation of construction supervision plan should be mandatory. (to be specified as Consultants' obligation in contract between Client and Consultants)
- The design change procedure is performed based on the G/A of the project, the procurement guideline[11] (January 2016) and the contract with the Client, however, this requires the confirmation and consent of JICA by application of the implementing agency. Generally, the amount of change will be examined within the range of the amount of money in the order of balance and contingency. The conditions of the modified contract are described in "Procurement Guideline[11]" and "GCC".
- Examine the possibility of application of preliminary expenses (applied to all projects concerning facility construction and some projects involving equipment procurement)
- Clarification of setting safety requirements in construction safety management (Design Stage work in Consultant contract)
- PMR (Project Monitoring Report) and PCR (Project Completion Report) is submitted as a reporting obligation from the Client to JICA, and the Consultant supports the fulfilment of the reporting obligation.

On the other hand, the Contractor is responsible for creating a construction object that fully satisfies the quality standards shown in the contract documents. To this end, the Contractor should create a construction plan that specifically shows the construction method and quality control method, which, after discussion with supervision Consultants, should be submitted to implementation agency. The construction plan is prepared by the Contractor prior to the construction in order to construct the object that satisfies the required performance of the design shown in the contract documents and the design documents.

👉 Feature of Road Development Project by Grant Aid

Generally, in Japanese road construction, construction is carried out based on division of work by specialized companies endowed with an extremely high level of technology, such as a quarrying company that supplies materials necessary for construction, an asphalt plant company that supplies asphalt mix, a pavement specialized company that carries out a series of work from the subbase course to the surface course, and a general Contractor acts as a prime contractor organizing, or purchasing products from, these specialized companies as well as carries out the works by their own forces. Therefore, not only is the construction supervision system enriched, but the quality of the construction is ensured by the experience and knowledge of each company in charge. However, in the Grant Aid

Project, the environment surrounding construction is largely different from Japan; for example, the construction company manufactures and procures everything from the crushed stone to the asphalt mixture, or subcontracts to a local company whose quality control system is different from Japan. In addition, it is not easy to secure a local engineer with technical capabilities, and there may be difficulties in weather conditions (temperature, rainfall, etc.) and traffic management for road construction.

👉 Construction Quality Control Meeting

For civil engineering facility projects in Africa and large civil engineering facility projects in other parts of the world (with a total project amount of 3 billion JPY or more), a Construction Quality Control Meeting was set up from July 2016 in order to share information for ensuring construction quality among implementing agencies, Consultants, construction companies and JICA. The quality control meeting is used as an opportunity to share matters that should be noted in the construction work, and to discuss and decide necessary countermeasures and project implementation policies, regarding important issues and problems that hinder the project such as unexpected obstacles, with the attendance of head office personnel such as project manager. It should be noted that the meeting is used to ensure the smooth progress and quality of the project and has a different purpose and character from the monthly meeting. For road projects, for example, the following items may be discussed.

- Preparatory meeting and pre-construction quality control meeting

To achieve a common understanding of the project and the road construction supervision and management among the Japanese side and the local side (implementing agency, Consultant, Contractor, JICA).

・ Technology and quality control

  - Design contents, construction conditions shown by the Consultants, and answers to questions from the Contractor
  - Construction management method selected by the Contractor (subgrade bearing capacity, selection of asphalt, asphalt plant type and management method, presence of pavement specialist), and construction supervision method of Consultant
  - Explanation of design concept and points to note in construction based on the draft construction supervision plan and draft construction plan
  - Application of Contractor's own quality control standards and technical standards if that are stricter than construction specifications
  - In case of asphalt pavement, confirmation of pavement performance by WT (Wheel Tracking) test (including how to set DS (Dynamic Stability))
  - Explanation of contents such as design considering ease of maintenance, adoption of local technology, extension of structure life, etc.

・ Example of process control and items that cause process delay

A common understanding should be obtained among participants including companies in charge regarding by whom and when undertakings of recipient government will be completed such as utility relocation and land acquisition, that gives largest impact to the progress of the project. In addition, information on materials and equipment whose delay in procurement will greatly affect the overall construction period is shared with the executing agency so that delays in customs procedures should not affect the overall construction period.

- Materials and equipment procured from third countries such as asphalt plants
- Specific materials with export/import restrictions in the recipient country (solvents for extraction tests, etc.)

・ Traffic safety control - Request for cooperation with police and other related organizations

In carrying out the construction, the traffic safety measures for the current traffic of pedestrians and automobiles such as installation of regulatory and warning signs, placement of traffic guides, should be explained to the executing agency to obtain cooperation.

- Request for cooperation to police and other related organizations
- Confirmation of special traffic safety management for night construction

・ Construction safety management

Provide explanations to implementing agencies on safety management at construction sites in order to ensure an exemplary level of Japanese Grant Aid projects.

- Toolbox talks, hazard prediction, trainings and activities, etc.
- Specific safety measures at the site (safety net, scaffolding, handrails, and other measures to prevent falls from high places, etc.)
- Security measures for project sites, etc. (physical protection, surveillance and guard, management of materials and equipment in the night, etc.)

・ Other cases - technical proposals, risk sharing, etc.

- For heavy traffic routes, it is necessary to discuss precautions for flow resistance. For example, the optimum amount of asphalt in tropical countries should be less than in temperate countries like Japan. Therefore, the quality control of the asphalt plant is important.
- When planning temporary opening of road traffic, risks such as process delay due to re-construction of the upper part of the base course and the binder course will be shared in advance with the concerned parties.

• Construction quality control meeting - to be held every 6 months after construction starts

Based on the following, comparison between the initial plan and the actual results for the last 6 months will be made, and the plan and points to be noted for the next 6 months will be shared.

・ Issues in quality control and proposals of technical solutions based on the results of material tests and mix design

- Problem of construction progress and countermeasures related to delay of undertakings borne by the recipient government - problem of utility relocation, delay of related other construction, etc.
- Report and response of accidents including traffic accidents that occurred at the site and on the public roads during transportation of materials, machineries, etc, and future policy
- About design changes and application of contingencies (if necessary)

1.5 Defect Liability in ODA Grants (Facility Procurement)

(1) Definition of Defect

In contract documents for Grant Aid Projects (Facility Procurement), the definition of Defect is specified in Article 1.1 (25) and 11.1 (1) of GCC (General Conditions of Contract) as follows.

- In this Clause 1.1 (25), "Defect" shall be attributable to:

  "Defect" means the failure of any Works or Contractor's Documents to be in the conditions required by the Contract (fair wear and tear excepted.)

- In this Clause 11.1 (1), "Defect" shall be attributable to:

  (a) Any design for which the Contractor is responsible,

  (b) Plant, materials or workmanship not being in accordance with the Contract, or

  (c) Failure by the Contractor to comply with any other obligation under the Contract,

Therefore, "Defect" means contractual nonconformity, which is attributed to the contractor's nonconformity to design/contract of machinery, materials and quality of work, and the contractor's non-performance of contractual obligations. Actions against "Defect" will be taken in accordance with the provisions of other relevant provisions set forth in the contract document. In the absence of such a provision in the contract documents, action shall be taken under Section 1.4 (1) "Governing Law" of Particular Conditions, Part A - Contract Data. In the guidelines for preparing contracts for Grant Aid of the Guidance on Consultancy Services for Grant Aid Projects, it is explained that "The governing law of the contract shall be determined in consultation with the client. If Law of Japan is decided as the governing law, the definition of "Defect" will be interpreted under the Civil Code of Japan and if the governing law is the law of the recipient country, the definition of "Defect" will be interpreted under the contract law or construction law of the country.

👉 FIDIC

FIDIC stands for Fédération Internationale des Ingénieurs-Conseils in French and International Federation of Consulting Engineers in English. FIDIC is an association of consulting engineers in the field of construction. Its objectives are to improve the quality of international work and sustainability in the consulting engineering industry, to raise the status of the industry, to promote business ethics, and to educate young people. In particular, it is well known for its work in preparing contractual clauses for international construction and infrastructure projects. One of the most famous examples is the establishment of general contractual clauses for international infrastructure development projects in developing countries.

The FIDIC General Conditions MDB Edition[12] is a "Conditions of Contract for Construction For Building and Engineering Works Designed by The Employer, Multilateral Development Bank (MDB) Harmonised Edition" and is referred to as the Pink Book or MDB Edition. This edition is a contract document for infrastructure construction projects financed by JICA (Japan International Cooperation Agency, in yen loan) or MDBs such as WB (World Bank), ADB (Asian Development Bank) and AfDB (African Development Bank).

Source: https://judiciary.asahi.com/outlook/2017062300002.html

(2) Expiration Date of Liability for Defects

Since the terms and conditions of the Grant Aid Project do not mention anything about the identification and notification of defects after the expiration of the defect notification period, its operation and application will be interpreted in accordance with the governing law.

The contract clause referenced above clarifies that the Contractor is liable for defects until the expiration date of the defect notification period, however regarding the Contractor's defect liability after the expiration of the defect notification period, GCC Clause 11 Defects Liability has no provisions and provisions regarding liability of Contractors in Article 15.2 (3) of GCC Clause 15 "Indemnities and Liability" is referred to.

- GCC 15.2 Contractor's Care of the Works

  (3) The Contractor shall be liable for any loss or damage caused by any actions performed by the Contractor after the Works are taken over in accordance with Sub-Clause 8.2. The Contractor shall also be liable for any loss or damage which occurs or is revealed after the taking over under Sub-Clause 8.2 and cause of which arose from any event prior to such taking over for which the Contractor was liable under Sub-Clause 15.2 (1).

Table 1.5 Operation of Warranty against Defects (Grant Aid)

	Construction completion	**For 12 months**	**Defect inspection 12 months later**	**For 10 years (Example of the Civil Code)**	**After 10 years**
Contract condition	GCC Clause 11 Defects Liability Sub-Clause 11.1 and 11.2			GCC Clause 15 Indemnities and Liability Sub-Clause 15.2	
Client	Completion inspection Delivery	Road maintenance as the administrator Notification of any problems to the Consultant in charge <Contractually, notification to the Contractor. cc. Consultant>	Defect inspection End of defect notification period <Contractually, the right to claim damages for defects remains.>	If there is a problem, judgement whether it is a defect or not (Verification by Consultant or third party) If judged as a defect, notification to the Contractor or repair by the Client. <Contractually, the right to claim damages for defects remains.>	Termination of liability for defect warranty under the Civil Code Implementation of maintenance as a road administrator
Consultant	Completion inspection	Judgment as to whether there is a defect according to the notification of the Client. Notification to the Contractor in case of defects < Contractually, identification of the defect, report to the Client, and notification to the Contractor>	Defect inspection End of defect notification period Completion of the contract Final payment <Contractually, liability for defects in consulting services remains.>	Request for defect judgment from the Client It is outside the scope of the Consultant's contract and may not be accepted.	Outside the scope of the Consultant's contract <Termination of liability for defect warranty under the Civil Code>
Contractor	Completion inspection Delivery Completion of construction Final Payment	Confirmation of notification from the Client and engineer Implementation of repair	Defect inspection End of defect notification period Contract completed after	Confirmation of notification from the Client As the contract has been completed, it can be interpretable that there is	Termination of liability for defect warranty under the Civil Code

			defect repair <The contractual liability for defects remains.>	no repair responsibility.	
Remark	Exception: In the East Africa region, a 7-year warranty is required in the specifications (contract) regarding the quality of the paint on the road sign, and if the paint deteriorates within 7 years from the delivery of the road sign, it is considered possible to claim liability for defects to the Contractor by the Client.				

Note: The defect notification (collateral) period under the construction contract for defects in the contractor is 12 months from the completion of the construction. The period of liability for damages caused by defects is interpreted as the period of preservation of defects under the Civil Code, and is 10 years from the delivery of the construction work.
Inside < > is comments by JICA Study Team
Source: JICA Study Team

Table 1.6 System for Construction Defect in Japan and Overseas

	Japan	Overseas	
		General project (FIDIC)	Grant Aid Project
Defect notification period	Two years (Civil works and roads)	Basically one year	Basically one year
Defect inspection	Basically not conducted	Conducted	Conducted
Criteria for defect (numerical)	Nil	Nil	Nil
Method of payment	Final payment at the completion of construction	Final payment at the conclusion of defect inspection (retention money system)	Final payment at the completion of construction
Performance Guarantee expiration date	Until the completion of construction	From the expiration date of the defect notification period to 28 days later	Until the completion of construction
Note	In public works, the provisions of the standard contract agreement for public works are applied to shorten the defects liability period specified by the Civil Code.	The defects liability period may differ depending on the type of structure (for example, long span bridge).	-
Defects liability period in major countries	**USA** The Federal Acquisition Regulations (FAR) do not have any provisions regarding the defects liability period, and the defects liability period in Federal Government construction projects follow the individual contract or the state law of the construction site. In reality, most is one year. **UK** The UK agreement for public works provides that there is a requirement for a defect liability period, of which standard period is, however, not specified. In reality, most is one year. **France** According to the French Civil Code (regulations amended or added by the so-called Spinetta Law of 1978), builders, designers, real estate developers, etc., bear 10 year's defects liability period for the defects that impair the durability of buildings and defects that impair the uses of facility that is inseparable from the buildings, and 20 year's defects liability period for the defects that impair the use of facilities inseparable with the above. In addition, the Contractor shall bear the liability of completion which is the responsibility to repair the defects pointed out at the time of delivery to the Client and the defects revealed after delivery, for one year after the completion. However, this system does not apply to public works projects ordered by the government.		

Source: JICA Study Team

(3) Liability of the Consultant

There is no "Defect" provision in the General Conditions of Agreement for Consulting Service (January 2016) for grant aid projects. Defects are described as liability as follows in "5.4 Liability of the Consultant".

5.4 Liability of the Consultant (Summary)

- loss of or damage to equipment and materials provided by the Client.
- responsibility in respect of life, health, and accidents for the Consultant Member
- Patent or license fees due to violations or plagiarism by the Consultant
- Goods and services procured by the Consultant with funds other than those of the ordering party, including the right to use such goods and services in the other party's country, license fees, etc.
- Failure to exercise the consultant's skill and care
  - A) Only items notified by the client within the term of the consultant's contract
  - B) The amount of compensation shall be limited to the amount of the Consultant Contract, but without limit in the event of gross negligence, recklessness or intentional misconduct of the Consultant
  - C) Compensation and reimbursement by the Consultant will be limited to items directly attributable to the Consultant's failure. (If a bridge girder falls and becomes impassable, rehabilitation of the bridge girder will be eligible for reimbursement, but damage caused by detouring to another bridge will not be covered.)
- the Consultant shall, at its own cost and expense, re-perform the Service in the event of the Consultant's failure to exercise the skill and care.
- The Consultant shall not be liable for any damage caused by the Client's request or direction, even though the Consultant does not agree to it.
- The Consultant shall indemnify, protect and defend the Client against any and all actions,
- claims, losses or damages mentioned above regardless of whether the insurance stipulated covers these actions, claims, losses or damages.

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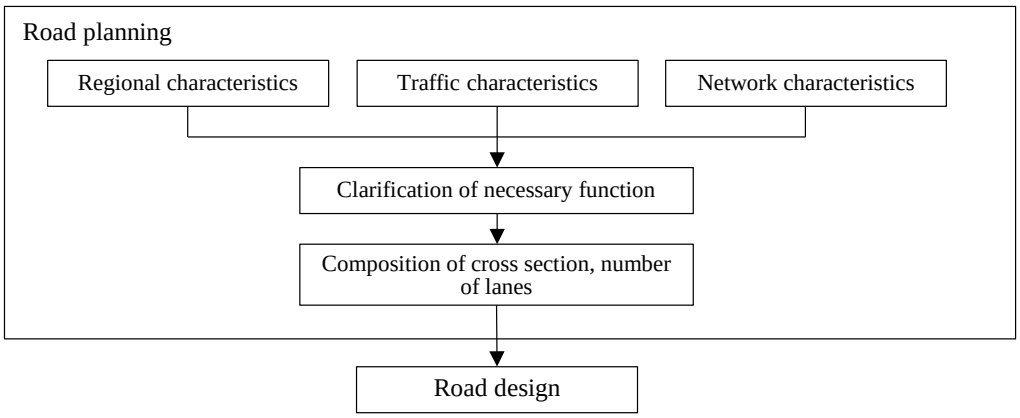
CHAPTER 2 ROAD DESIGN IN PREPARATORY SURVEY

2.1 Road Plan

(1) What is a Road Plan?

Road planning entails planning roads in accordance with regional development direction, future land use plans, etc. while satisfying structural standards in order to exert the effects of roads. Therefore, road planning aims to clarify the functional classification of roads in order to systematically develop and operate a road network consisting of roads with various functions, and based on the classification, decide the class and the basic component of each road. Specifically, design criteria, cross section including the number of lanes, and design speed are decided based on the road classification. The road plan is a matter to be examined by the master plan or regional plan, and the road plan implemented in the preparatory survey is mainly the work of confirming requirements such as number of lanes, lane-width, etc. from recipient country.



Source: Explanation and Operation of Road Structural Ordinance[1]

Figure 2.1 Flow from Road Planning to Design

Regional characteristics: Regional characteristics include local weather conditions, geographical features, history and culture, roadside land use, environment, welfare, disaster prevention, public transportation, lifeline and information communication infrastructure, landscape, and current conditions and plans related to urban development.

Traffic characteristics: Traffic characteristics include the volume and type of vehicles, pedestrians, and bicycles, feature of traffic volume variation, speed distribution, as well as the attributes of pedestrians such as the elderly and disabled, and pedestrian usage patterns such as walking side by side, resting, etc.

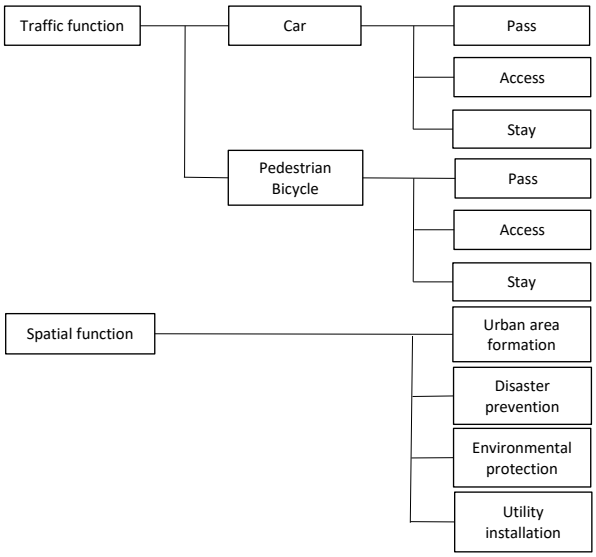
Network characteristics: The network characteristics are the "role/function in the network" of the road in the nation, in a wide area, or within a city. Regarding road network plan, there are regional road network master plan and urban master plan. In these plans, the positioning/role of roads is determined in terms of road classifications ranging from arterial high-standard highways for wide-area traffic to feeder roads for intra-district traffic, as well as the function of road connection to areas and bases is indicated. As plans for networks of pedestrians and bicycle running spaces, there are master plan for facilitating movement of elderly people and persons with physical disabilities, and network plan for

bicycle spaces. Roads that should secure a space for bicycles and bicycles are clarified.

Source: Explanation and Operation of the Road Structure Ordinance[1]

(2) The Functions of Roads

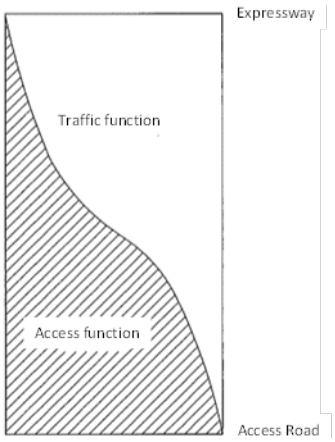
Roads have two major functions: traffic function and spatial function. The traffic function is a primary function of the road with the following functions: a traffic function that allows cars, pedestrians, and bicycles to pass safely, smoothly and comfortably; an access function that allows easy access to roadside facilities; and a retention function for parking cars and holding pedestrians. Spatial functions are as follows: urban area formation such as composing urban framework and promotion of roadside land use, disaster prevention space for fire and earthquake, greening and landscape formation, environmental space for roadside environment protection, and installation space for facilities and lifelines (water, sewerage, electricity, communication facilities, etc.).



Source: Explanation and Operation of Road Structure Ordinance[1]

Figure 2.2 Functions of Roads

In addition, as a common theory in all countries in the world, there is an idea of dividing into a traffic function and an access function. The traffic function is the function as a driving space for vehicles, and the access function is the function for entering and exiting roadside buildings and the function as a pedestrian space. Roads are classified according to which function should be emphasized, and the structure is determined according to the classification.



Source: AASHTO, A Policy on Geometric Design of Highways and Street[2]

Figure 2.3 Concept of Relation between Traffic Function and Access Function

Traffic function: Function as a vehicle running space

Access function: Function as a space for access to roadside buildings and as a space for pedestrians

(3) Road Classification

Roads are not only divided and characterized according to their purpose, character, function, etc., but each type also has suitable form and structure. There are numerous methods for classifying road types, however, the basic methods are legal classification, functional classification, and classification based on management scheme. In legal terms, roads are classified according to the "Road Act", "Road Transportation Act" and "Road Traffic Act", but the classifications based on the "Road Act" are most

widely used. According to the "Road Act", "roads" refer to the following four classifications that are provided for general traffic. These are positioned and classified according to their importance in terms of character in the overall road network:

1) National Expressways, 2) National Highways, 3) Prefectural Roads, 4) Municipal Roads

Source: Transportation Engineering Handbook [3]

Table 2.1 shows the road classifications of major developing countries. The functions of each road classification in Uganda are also listed for reference.

Table 2.1 Road Classification in Major Developing Countries

Ethiopia	Ghana	Tanzania	Uganda	
			Classification	Function
Trunk Road	Trunk Road	Trunk Road	International Trunk Road	Roads that link International Important Centers. Connection between the national road system and those of neighboring countries. Major function is to provide mobility
Link Road		Regional Road	National Trunk Road	Roads that linking provincial capitals, main centers of population and nationally important centers. Major function is to provide mobility
Main Access Road	Feeder Road	District Road	Primary Road	Roads linking provincially important centers to each other or to higher class roads (urban/rural centers). Linkage between districts local centers of population and development areas with higher class road. Major function is to provide both mobility and access
Feeder Road		Feeder Road	Secondary Road	Roads linking locally important centers to each other, to more important centers, or to higher class roads (rural/market centers) and linkage between locally important traffic generators and their rural hinterland. Major function is to provide both mobility and access.
Collector Road			Minor Road	Any road link to minor center (market/local center) and all other motorable roads. Major function is to provide access to land adjacent to the secondary road system.
Urban Road	Urban Road	Urban Road	-	(Roads that form the skeleton of the city)

Source: JICA Study Team

In Japan, facilities necessary to support smooth urban activities, improve convenience for urban residents, and ensure a good urban environment in city planning areas can be determined (by city planning) through procedures stipulated in the City Planning Act. City planning roads are roads that have been decided in accordance with City Planning Act, and are classified into four categories according to the function: motorways, arterial roads, feeder roads, and special urban roads. Furthermore, arterial roads are subdivided into three categories: major arterial roads, urban arterial roads, and auxiliary arterial roads. These are different from the classification of national roads, prefectural roads, and municipal roads, which are defined based on the Road Law. All city planning roads are classified and managed under one of the road categories of the Road Law.

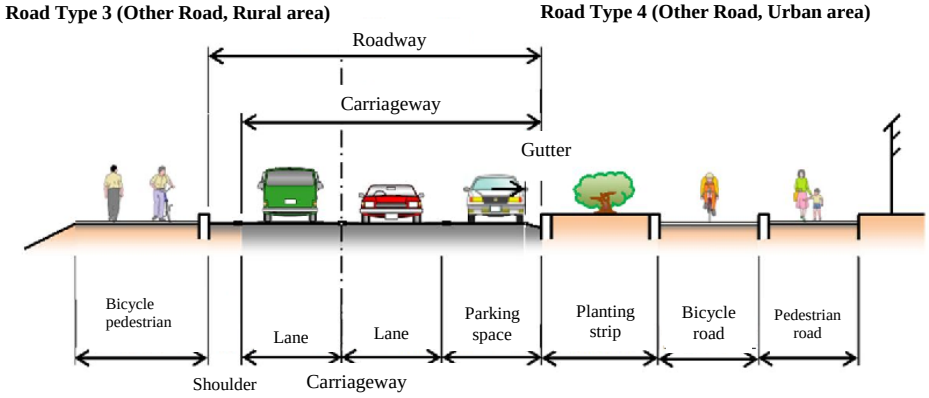
Table 2.2 Category and Function of City Planning Road

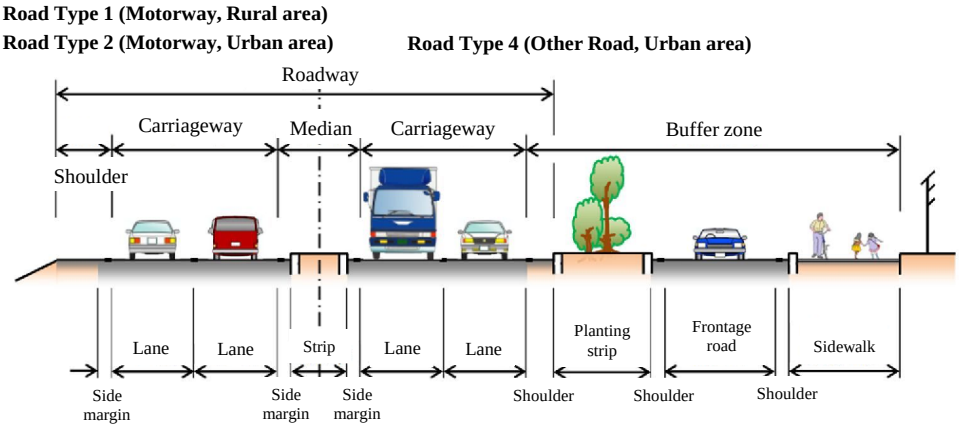
Category		Function
Motorway		Roads used exclusively for motor vehicle traffic such as highways and general motorways.
Arterial road	Major arterial road	Roads that serve as the central transport route for intercity traffic and traffic between major sources of traffic within the city.
	City arterial road	Roads that are the main transportation routes for transportation between districts and major facilities in the city.
	Secondary arterial road	Roads that serve as the main route for arriving and departing traffic in areas surrounded by major arterial roads and city arterial roads.
Feeder road		Roads that provide access services to roadside residential land at the district level.
Special urban road		Roads for non-automobile use such as pedestrians, bicycles, and monorails.

Source: New City Planning Manual for Practitioners[4]

(4) Cross Section of Road

As shown in Figure 2.4, the cross-section components of roads are: roadway consisted of carriageway, median, shoulder, and stopping lane, bicycle road, bicycle pedestrian road, sidewalk, planting strip, frontage road (part of roadway). The combination of components is decided according to the characteristics of the road network, traffic conditions (vehicle traffic volume, design speed, pedestrian / bicycle traffic volume, etc.), roadside conditions (access functions to roadside facilities, parking function), and environmental functions (landscape and greening, etc.). The following are examples of combinations of components by Japanese road standards.





Source: JICA Study Team based on Explanation and operation of road structure ordinance[1]

Figure 2.4 Examples of Composition of Cross Section

The role of each component is as follows:

- Carriageway

  The carriageway is a portion used for the passage of vehicles, and includes car lanes (a strip-shaped portion for running vehicle), stopping lane, emergency stopping lane and refuge lane.

- Median

  A facility to separate up and down traffic for roads with four or more lanes to ensure safe and comfortable driving. The median consists of a central reserve and marginal strip. This marginal strip with a certain width makes the outside of the road clear, guides the line of sight, and forms part of the side margin necessary for driving.

- Shoulder

  The main functions of the road shoulder are the side margin for running vehicles and the parking space for broken vehicles. Generally, a shoulder refers the outside shoulder, however, if the up and down traffic is separated by a method other than the median, the inside shoulder is installed next to the road center.

- Stopping lane

  On roads in the city, the demand for stopping is considerable due to access to the roadside. If the lane is used for such demand, the traffic capacity will decrease and the efficient operation will be hindered. Therefore, stop zones will be installed in places where there is a large demand for stopping.

- Sidewalk, Bicycle path, Bicycle pedestrian path

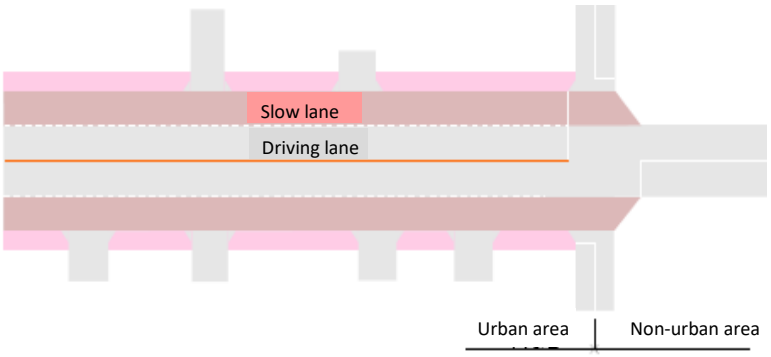
  Roads have various uses, but it is desirable to separate traffic with different characteristics as much as possible, and it is important to separate cars and pedestrians or bicycles from the viewpoint of traffic safety. The bicycle path and the sidewalk are necessary when the traffic volume of the bicycle and the pedestrian are large to some extent, respectively, and when either of them is small, it is realistic to install the bicycle pedestrian path where bicycle and pedestrian share the path. If there is a risk of friction between the bicycles and pedestrians due to traffic conditions, secure a sufficient width to ensure the safety and comfort of pedestrians. It is also effective to differentiate by planting trees or pavement color to ensure a separation between bicycles and pedestrians.

- Tree planting zone

  The tree planting zone is installed for the purpose of separating pedestrian paths, improving the aesthetics of the road, and improving the local environment.

☞ Other special lanes

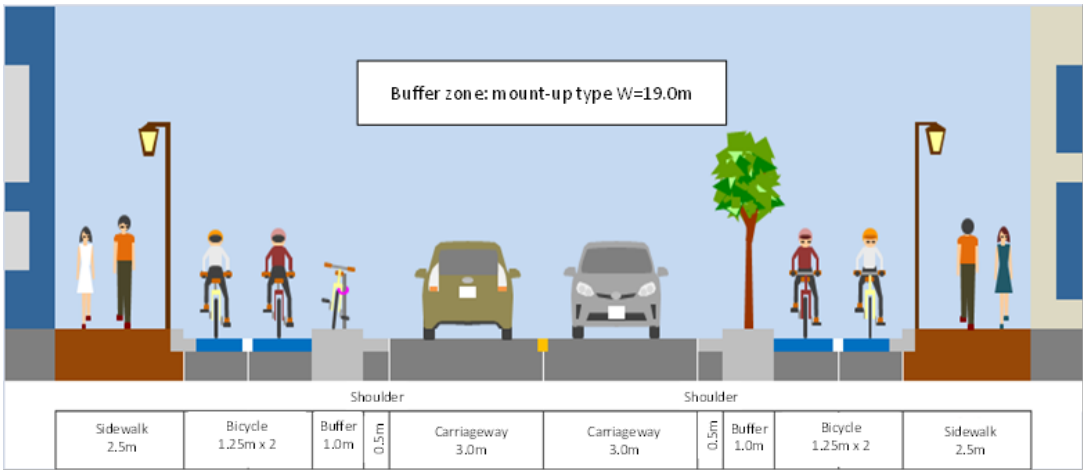
Slow lane: There are slow lanes as special lanes. A slow lane is a lane that is provided in parallel with the main lane for the passage of roadside traffic, and is defined as being clearly separated from the main lane by lane markings, fences, and the like. The purpose of the lane is to restrain the confusion between the access vehicle to the roadside and the main line traffic, improve the safety, and minimize the slowdown of the main lane traffic.



Source: Research on the concept of road structure in Hokkaido[5]

Figure 2.5 Image of Slow Lane

Bicycle lane: Currently, the use of bicycles is expanding as an important means of transportation. Due to its relatively small size and low cost, it requires less space than other vehicles and can be efficiently integrated into the flow of traffic. However, since bicycles are vulnerable on the road, the installation of bicycle lanes is in progress as a safe facility for bicycle use.



Buffer zone: A space that structurally separates the bicycle running area from the roadway to ensure the safety of intersections. This is the "margin width" when a left-turning vehicle and a straight-ahead bicycle intersect.
Source: Cycleplus "Platform for tomorrow" HP

Figure 2.6 Image of Bicycle Lane

(5) Traffic Demand Forecast

Traffic demand forecast is the basis of road planning, and is to predict the demand for use of the roads and railways that are the subject of the plan in considering the future vision of the road and rail networks that support the smooth movement of people and goods. In the forecasting, future changes in population and in socioeconomic conditions and consequently future changes in the flow of people and goods due to the construction of new roads are examined. The future traffic volume is composed by adding various traffic volumes as shown below to the current traffic volume.

Basic traffic volume……Diverted traffic volume: traffic volume diverted from other routes

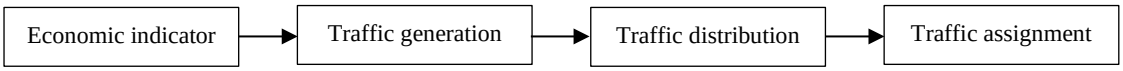
Converted traffic volume: traffic volume shifted from other modes

Increasing traffic volume……Natural increase traffic volume: traffic volume increased by increase in population and car ownership

Induced traffic volume: traffic volume induced by the development of the road

Generated traffic volume: traffic volume generated by the development along the road

The most standard and basic method for the traffic demand forecast of roads is called the 4-step forecast method. As shown below, this method is to estimate traffic volume by four steps: economic indicators, traffic generation, traffic distribution, and traffic assignment, in order.



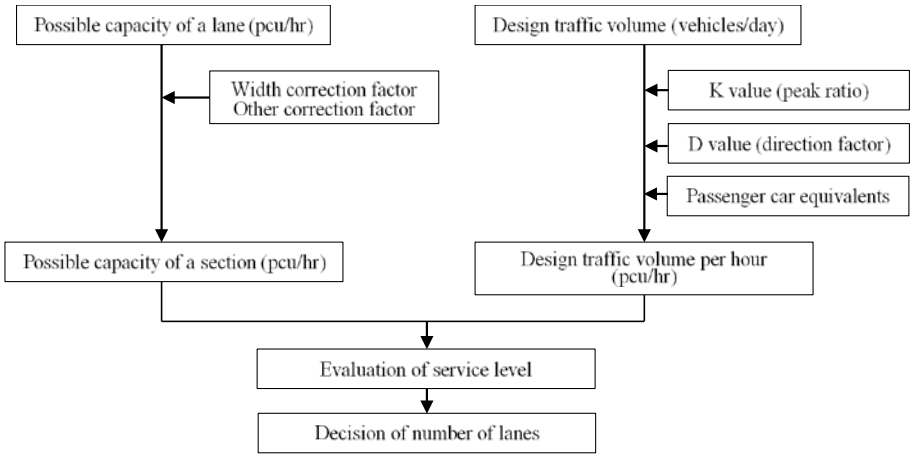
Source: Traffic Engineering Practice Series 2[6]

Figure 2.7 For Stem Traffic Demand Forecast Method

- Economic indicator: The economic indicator shows extent the economic activity in the year of traffic demand forecast.
- Traffic generation: In estimating the traffic volume, the traffic is divided into zonal traffic. The traffic generation is the traffic volume generated from traffic zones. The volume increases along with the economic growth of the zone and increase ratio differs depending on the industrial structure of the zone, such as an industrial zone, a commercial zone, or a residential area.
- Traffic distribution: Traffic distribution is the traffic movement between zones. The volume of traffic moving from a certain zone to each zone is estimated for all zones.
- Traffic assignment: After the traffic volume between zones is estimated by the traffic distribution, the distributed traffic volume is assigned to each road on the given road network. The traffic assignment is the estimation of traffic volume on the road.

(6) Number of Lanes

The number of lanes is determined through setting the traffic capacity of the target road by assuming the number of lanes, and comparing it with the required traffic volume. According to the Road Structure Ordinance[1] of Japan, the number of lanes is decided by the comparison of the design standard traffic volume, which is the passable traffic volume on one day under the given road structure and traffic conditions, and the planned traffic volume, which is the forecasted future traffic volume in target year. This is a method based on daily traffic capacity and daily traffic volume. On the other hand, it is general in overseas to determine the number of lanes by the hourly traffic capacity and hourly traffic volume.



Source: JICA Study Team

Figure 2.8 Process for Deciding Number of Lanes

☞ Target Year of Road Development Plan

The number of years from the present of the target year for road development depends on the feature and importance of the route. Since the period of 20 years is considered to be the limit of prediction in realistic plans, and target year more than 20 years after reduces the credibility of the plan, generally 20 years after the time of planning is set as the target year. For roads with low standards, sometimes the target year 10 years after are selected. For this reason, Road Structure Ordinance[1] indicates that it is desirable to take into consideration the characteristics of the route and the expected time of development when setting the target year. It should be noted that the planned target year of roads and the design period of structures such as pavement are different.

☞ Possible Capacity of Basic Road Section

Possible capacity of a road is represented by passable number of vehicles per an hour. The unit for number of vehicles is indicated by pcu (Passenger Car Unit) which means passenger car equivalent number. In "Traffic capacity of roads[7]" in Japan, the basic traffic capacity of basic road section (sections other than intersections, the intersection is defined separately) is defined: first, 2500 pcu/hour/two lanes on a two-way two-lane road, then 2200 pcu/hr/lane on multi-lane roads and one-way roads. "2500 pcu/hour/two lanes on a two-way two-lane road" means that if the up and down traffic ratio is 1:1 then the traffic capacity is 1250 pcu/hr/lane. However, this is the case of a two-lane road where vehicles can overtake, and in case two lanes is divided by median or overtaking is prohibited, capacity is 1700 pcu/hour/lane or 3000 pcu/hour/both directions.

Source: http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0317pdf/ks0317005.pdf,
http://trafficengnote.hatenablog.com/entry/2014/04/02/135449

☞ PCE: Passenger Car Equivalent

One of the traffic factors that affects the road capacity is the inclusion of large vehicles. The degree of influence of large vehicles is usually grasped as PCE (Passenger Car Equivalents). PCE is described in the Highway Capacity Manual[8] (1985), however it is known that there are considerable variations among the estimation methods. PCE is specified for each vehicle type and for each area in the geometric design standards of each country. Table 2.3 shows the PCE value in representative countries. However, since these conversion factors are influenced by the location of the road (urban area, rural area), the terrain that affects the traveling speed (flat area, hilly area, mountainous area),

the vehicle type (large cargo, small cargo, etc.), the traffic volume and congestion, it is necessary to set it appropriately according to the conditions of the target road.

Table 2.3 Examples of Passenger Car Equivalents of Large Vehicles

Standard	Road type or vehicle type	Area or section						
		Urban area	Rural area	Flatland	Hilly area	Mountain	Junction	
							Roundabout	Signalized
Road Structure Ordinance[1]	Two-lane road	2.1	-	2.1	-	3.5	-	-
	Multi-lane road	1.8	-	1.8	-	3.0	-	-
Road Capacity[7]	Two-lane road	2.0	-	2.0	-	3.5	-	-
	Multi-lane road	2.0	-	2.0	-	3.0	-	-
HCM[8] 1985* Freeway (general section)	Truck	-	-	1.7	4.0	8.0	-	-
	Large bus	-	-	1.5	3.0	5.0	-	-
	Recreational vehicle	-	-	1.6	3.0	4.0	-	-
Geometric Design Guidelines 2002[9]**	Passenger car	1.0	1.0	-	-	-	1.0	1.0
	Commercial vehicle (truck)	2.8	3.0	-	-	-	2.8	1.75
	Large bus	2.8	3.0	-	-	-	2.8	2.25
	Motorcycle	0.75	1.0	-	-	-	0.75	0.33
	Bicycle	0.33	0.5	-	-	-	0.5	0.2

*HCM (Highway Capacity Manual): Detailed PCE by number of lanes and by horsepower of trucks are described.
** PCE is not indicated in SATCC (Southern Africa Transport and. Communications Commission), therefore values by Geometric design standard in South Africa is shown.
Source: JICA Study Team

Table 2.4 PCE for Large Vehicles at Intersection (Example)

Traffic Volume	Demand scenario	PCE by Vehicle Category			
		Truck	Large Bus	Semi-trailer (Short)	Semi-trailer (Long)
Middle	Balanced	1.31	1.58	1.43	1.66
	Unbalanced	1.15	1.49	1.26	1.51
High	Congested	1.72	2.10	1.91	2.26
All scenarios	All scenarios	1.39	1.71	1.53	1.80

Source: Estimating Passenger Car Equivalent of Heavy Vehicles at Roundabout Entry Using Micro-Traffic Simulation, Robert Pajecki[10]

☞ Forecasting and Back Casting

In general road planning, a method called forecasting is applied in which improvement measures are accumulated by considering what kind of improvements can be made to the road traffic problems from the present situation. Forecasting is basically a method to extend past trends to the future and incorporate various situations assumed to occur in the future. This method is applicable for predicting situations that do not change significantly in the short to medium term. On the other hand, back casting is a method that envisions future image and by looking back at the present considers and implements the necessary measures to achieve future image. Back casting is an opposite approach to forecasting, and is a method often used in the fields of environmental policy and urban policy. In road planning, some roads should be planned with a back-casting approach by setting visions and long-term goals. In particular, international trunk roads that cross countries are planned not as roads that solve the problems of individual countries but as roads that aim to enhance regional connectivity and develop the entire region. For this reason, it is often planned through back-cast approach. For example, Trans-African Highways (TAH) being promoted by AfDB (African Development Bank), or Asian Highway being promoted by UN ESCAP (United Nations Economic and Social Commission for Asia and the

Pacific), considers that the number of lanes, access control and pavement type should be determined based on the importance of the road. Therefore, they are set according to the classification as shown in Table 2.5. The EAC (East African Community) also proposes the application of design criteria according to road categories as a strategy for harmonization of roads in the region as shown in Table 2.6.

Table 2.5 Road Classification in Trans-African Highways and Asian Highway

Classification	Description	Pavement Type
Primary	Controlled access highways/ motorways	Asphalt or cement concrete
Class I	4 or more lanes	Asphalt or cement concrete
Class II	2 lanes	Asphalt or cement concrete
Class III	2 lanes (narrow)	Double bituminous treatment

Source: Basic Guidelines for Road Classification and Standards on Trans-African Highways[11]
Asian Highway Classification and Design Standards[12]

Table 2.6 Road Classification in EAC

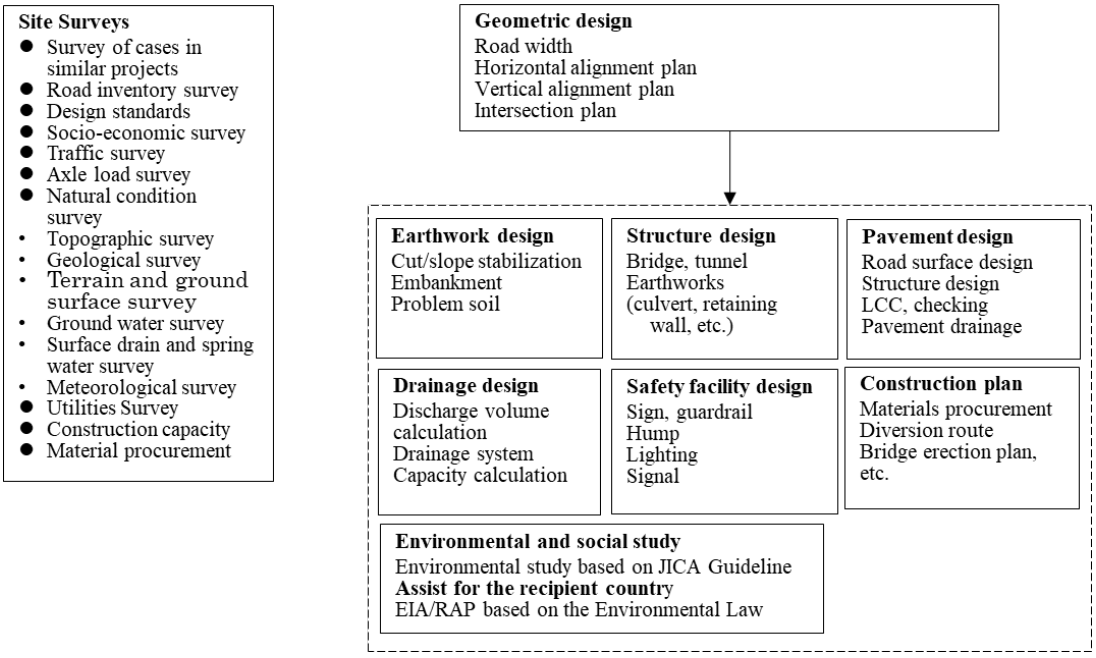
Function	Class	Name conventions		Access control
Mobility roads	Class 1	International trunk roads National trunk road	Principal Arterial/ Freeway/ Expressway (2500 m spacing)	Full
	Class 2	National & Provincial roads Regional & District roads	Major arterial/Highway (800 spacing)	Full or partial
	Class 3	Regional & District roads Secondary roads	Minor arterial (600 m spacing)	Full or partial
Access roads	Class 4	District roads Secondary roads	Collector roads (50 m spacing)	Partial
	Class 5	Minor roads Local streets	Local streets (15 m spacing)	Unrestricted

Source: Preparation of a Transport Facilitation Strategy for the East African Community Final Report[13]

2.2 Road Design for Preparatory Survey

Road design in the preparatory survey is intended to set the design conditions necessary for road construction and operation based on the site conditions, collected materials, and information on the preceding project, and based on the set design conditions to execute the design work equivalent to the road preliminary design in Japan as shown in Source: JICA Study Team

Figure 2.9. Specifically, based on the survey map (scale 1/500 to 1/1000), alternative plan of horizontal alignment and vertical alignment is formulated, and an alignment is selected by comprehensive evaluation of workability, economy, maintenance, runnability, safety and environment. Subsequently, the locations, types, and basic dimensions of major structures such as bridges and tunnels are planned, and the center line of the route and the land width are determined. In addition, the drainage system is planned and the flow rate is calculated based on the existing materials and the results of the field reconnaissance, and the drainage structure is designed. Alternative plans for major structures (bridges, culverts, etc.) and pavement structures are compared and examined, and rough design calculations for the optimum plan necessary to determine the basic shape are carry out, then the rough project cost for project implementation including detailed design, construction and supervision. The accumulated amount based on cost estimates is referred to in Cabinet meeting, and determines the upper limit of the project cost in E/N (Exchange of Notes), therefore it is required to be appropriate. On the other hand, uncertainties in design conditions for road design, such as natural condition, traffic condition, material condition, etc., exist, so a thorough survey is required and at the same time assumptions in road design should be clearly indicated if necessary.



Source: JICA Study Team

Figure 2.9 Survey Items and Road Design Items in Preparatory Survey

2.3 Necessary Surveys for Road Planning

(1) Survey of Cases in Similar Projects

In the pavement design, data of traffic conditions, natural conditions and land use conditions, and the pavement design methods and pavement structures adopted in similar projects should be obtained. Also, interviews are implemented with counterpart agencies and consultants concerned with similar projects regarding design issues, problem points, solutions. Also, if there are any projects in progress that are of reference, interviews are implemented to confirm existing issues in construction. This information is reflected in the preparatory survey results. In the preparatory survey of a Grant Aid Project, "Survey of past similar projects and aid trends of other donors and agencies" is included among the survey items. However in the past, the contents of these surveys are limited to gathering of general information, such as "project scale, project cost, design conditions (design speed, standard cross-section, etc.), and implementation schedule", and oftentimes information gathering has been insufficient because detailed information has not been included. Therefore, concerning at least the items shown in Table 2.7, comparison is implemented between similar projects and the preparatory survey to ascertain the validity of the preparatory survey findings.

Table 2.7 Items to be Compared for Pavement Design (Examples)

Major Item	Minor Item
Project outline	・ Road characteristics from aspect of Urban Plan and Land use ・ Roles in road network ・ Road location (terrain and land use) ・ Source of funds ・ Design year, works period, completed year ・ Road length, Number of lanes (cross section), Design speed
Pavement design	・ Applicable Design standard ・ Design period ・ Contents of traffic volume survey and axle load survey ・ Traffic volume and traffic volume growth rate by vehicle type ・ Damage factor by vehicle type (DF*) ・ Cumulative equivalent axles load (ESAL**) ・ Design CBR and survey method ・ Pavement composition and pavement thickness
Construction information	・ Base/subbase course and binder/surface course materials (quarry) ・ Actual condition of used asphalt plant ・ Mix design method (Marshall method/Superpave method) ・ Used surface course mixture (whether modified material is used, etc.) ・ Particle size distribution of surface course mixture ・ Asphalt penetration, asphalt content, air void, etc. ・ Surface course mixture evaluation method (WT*** test, etc.)

Source: JICA Study Team

(2) Road Inventory Survey

In conventional road inventory surveys, information in a narrow range centered on roads is often summarized mainly in a tabular format, and may not always be fully utilized. In the road inventory survey, the target roads and the conditions along the roads are also investigated. For example, in Japan, it is said that "the place with bamboo grove has a high groundwater level", and likewise in Africa, it is said that "the place with banana trees has a high groundwater level". It is desirable to reflect such vegetation information in the road inventory survey results. Interpretation from place names and

interviews with local elders are also effective. It is desirable to reflect such information in the road inventory survey results. There was a case where valleys in the city were used as garbage dumps. In road construction, it is possible that valleys have formed weak ground such as humus soil. Confirmation of such geological history is also included in the road inventory survey. For this reason, in addition to the tabular format, the information obtained in the inventory will be recorded together with the photograph on the topographic map obtained by the survey. Furthermore, by adding information on natural condition surveys (for example, geological survey point information), it becomes an effective material that can be shared by the parties concerned. It is also conceivable to add information on the detailed design at the implementation stage and finally provide it to bidders as part of the bidding document. The road inventory survey is conducted for the purpose of obtaining the information shown in Table 2.8.

Table 2.8 Major Items of Road Inventory Survey

Survey Item	Survey subject	Method
Road shape	・Cross section (width of carriageway, shoulder, sidewalk) ・Shape of structure (bridge, culvert) ・Road shape (height of embankment, height of cut, gradient of slope) ・Sag and crest ・Shape of crossing (connecting) roads and roadside entrances	Visual observation Measurement
Topography and natural condition	・Topography (flat land, hilly area, mountain) ・Crossing river ・Wetland ・Road flooding ・Vegetation ・Ground history	Visual observation Hearing
Roadside condition	・Topography (flat land, hilly area, mountain) ・Roadside land use (urban areas, villages, cultivated land, wasteland) ・Roadside building (house, store, school, factory, etc.) and vehicle entry ・Right of way (secured or not)	Visual observation Hearing
Drainage	・Existence and shape of drainage ・Condition of existing drainage (damage and sediment) ・Drainage system ・End of flow	Visual observation Measurement Hearing
Pavement condition	・Paved or not ・Pavement condition ・Pavement composition	Visual observation Measurement Test pit
Utility	・Utility pole and cable ・Underground facility	Visual observation Hearing to administrator
Traffic safety facility	・Signal ・Traffic sign ・Hump ・Road marking (pedestrian crossing)	Visual observation Measurement
Other information	・Obstacle (billboard, etc.) ・Car parking condition	Visual observation Hearing

Source: JICA Study Team

(3) Design Standards Collection

When starting the field survey, the consultant gathers the recipient country's pavement design standards, specifications for works, materials test standards, and standards related to geological and topographic survey, traffic volume/axle load survey, etcetera, and examines the field survey plan necessary for the survey of pavement design conditions. The examined site survey plan must stipulate the survey quantities, technical specifications, and standards. It is necessary to secure approval from the recipient country for the site survey plan. Since some countries do not have any standards related to survey, in these cases, interviews are conducted with local consultants that have worked on similar projects to ascertain standard survey contents and technical specifications in the country and reflect them in the site survey plan. It is necessary to obtain the recipient country's approval for this site survey plan before the start of the site survey work. Also, when using multiple standards such as Japanese standards and AASHTO (American Association of State Highway and Transportation Officials), it is necessary to check their mutual consistency.

(4) Socio-economic Survey

The socio-economic survey is intended to grasp the regional characteristics and network characteristics of the three requirements of road planning (regional characteristics, traffic characteristics, network characteristics) and collect the data necessary to forecast the future traffic demand of the road. Since traffic demand changes significantly due to changes in socio-economic conditions, when forecasting traffic demand, it is necessary to consider the socio-economic factors surrounding traffic demand and trends in automobile traffic demand from various angles.

Specifically, in the demand forecast of freight vehicle traffic, the influence of economic activities is large, so gross domestic products, agricultural/industrial production, the number of freight vehicles owned, etc. are candidates for explanatory variables, and in the passenger traffic demand forecast, population, income, number of license holders, etc. are candidates. And land use conditions such as port areas, industrial areas, commercial areas, residential areas, etc. also have a large impact on traffic demand. It is important to grasp the demand after setting the future scenario of the socio-economic indicators of the target area by incorporating a wide variety of traffic data and related data. Table 2.9 shows the parameters for forecasting the traffic volume growth rate.

Table 2.9 Parameters for Forecasting the Traffic Volume Growth Rate (Examples)

Development plan, land use plan	・Urban development master plan, transport master plan ・Land use map (present, future) ・Transport facility layout
Social and economic indicators	・Population growth rate ・Working population growth rate ・Changes in gross domestic product ・Changes in income ・Changes in agricultural and industrial production
Traffic-related indicators	・Changes in automobile ownership ・Changes in number of owned large vehicles ・Changes in number of owned driver's licenses ・Changes in truck transportation tonnage ・Changes in amount of freight handled at ports, etc.

Source: JICA Study Team

(5) Traffic Survey

A traffic survey is a task to grasp the traffic characteristics and network characteristics among the three requirements of road planning (regional characteristics, traffic characteristics, network characteristics), and is the basic survey necessary for all planning and policy formulation related to road traffic. Target plans can be listed as road development/improvement plans, road development effects, intersection plans, road traffic safety plans, traffic congestion countermeasures, road environment countermeasures, regional and area system, traffic control/management plans, road ancillary facilities (safety facilities, road signs, information provision facilities). The specific contents and items of traffic surveys in these plans are various, and the survey results have a great influence on their results. In order to carry out an appropriate survey, it is essential to set the survey items, select the survey location and survey method, and have a great impact on the survey process and survey cost. In particular, regarding the setting of the survey area, if the target road is extended long or in an urban area, it is necessary to conduct a survey in a wide area in consideration of the conversion traffic. The main traffic survey items are shown in Table 2.10.

Table 2.10 Major Traffic Survey Method and Purpose

Name of survey method		Methodology and purpose	Application to Grant Aid Project
Traffic volume survey	Basic road section	The basic road section traffic volume survey is carried out for the purpose of obtaining the traffic volume characteristics in the target road cross section, and traffic volume by direction, survey time, time band and vehicle type are manually counted. Bicycles and pedestrians will also be measured. Vehicle classification is based on the standards of the target country.	A standard survey to set the design conditions for Grant Aid Projects.
	Intersection	The intersection traffic survey is conducted for the purpose of grasping the traffic volume of vehicles by type and direction, pedestrians crossing, bicycles at the intersections for each inflow section to obtain the actual traffic volume. Traffic volume by direction, survey time, time band and vehicle type are manually counted. Vehicle classification is based on the standards of the target country. For pedestrian crossing users, also the number of pedestrians before and after the intersection is investigated to grasp the flow lines of the intersection users.	Standard survey to set the design conditions for the intersection if the target project includes intersection improvement.
OD (Origin and Destination) survey	Roadside OD survey	The roadside OD survey is conducted for the purpose of investigating the origin and destination of traffic passing through the city boundary (Cordon Line) or the target road, the trip purpose, etc., and all target vehicles passing the survey point are interviewed. Generally, the survey is a complete survey of the target vehicle types, however if it is unavoidable to carry out a sample survey, the sampling rate which is statistically credible will be applied.	This survey is conducted when traffic flow will change significantly due to changes in the surrounding network, such as road development in urban areas where the road network is dense.
	Owner interview survey	Owner interview OD survey is carried out for the purpose of obtaining the basic data of future road planning, construction, management, etc. The survey is to directly interview the vehicle owner about origin and destination, trip purpose, etc. and to grasp the actual usage of vehicles, characteristics of road traffic, etc.	Since the survey/analysis period is long and the survey cost is high, it will not be implemented in the Grant Aid Project.

Travel speed survey	The travel speed survey is conducted for the purpose of grasping bottlenecks and traffic congestion conditions between points by measuring the time required between the points. In the survey section, required time between points is measured by running the test vehicle, and the stop time due to traffic lights and traffic jams is also measured.	This survey is mainly conducted to confirm the effect after road development and is conducted when the travel speed improvement effect is high. The survey may be required as a condition for pavement road surface design.
Parking Survey	The parking survey confirms the actual parking situation on the road, and if parking vehicles on the road is a factor in increasing the risk of traffic accidents or decreasing the road traffic capacity, appropriate parking facilities are provided. It is carried out for the purpose of serving as basic data for consideration.	Parking survey is conducted when vehicles parked on the street can cause traffic problems. In particular, it is considered to be an indispensable survey item in urban areas and CBD (Central Business District) areas.

Source: JICA Study Team

(6) Axle Load Survey

In pavement design, design is usually conducted so that damage will not occur under the cumulative equivalent axles load over the design period. The axle load survey is a survey to find the fracture coefficient of "vehicles subject to pavement design (mainly large vehicles)", which is the basic data for calculating the cumulative equivalent axle load. The axle load survey is implemented as a rule, however, if the recent axle load survey is available, these can be utilized. It should be noted that overloaded vehicles frequently travel at night when overloading cannot be grasped in regular overloading control activities (daytime only), leading to under-estimation of the large-vehicle damage factor. Hence it is desirable to conduct 24-hour survey. Moreover, since there are cases where the weight of loads differs on different directions of the same road, it is desirable to conduct survey on both directions.

Survey at axle load survey station

Portable measuring instrument

Photo 2.1 Axle Load Survey

(7) Natural Condition Survey

The natural condition survey is to investigate the natural conditions necessary for the road design, and consists of topographic surveys, geological surveys, meteorological surveys and hydrological surveys.

1) Survey

Surveying is to accurately measure the positions of natural terrain such as mountains and rivers, and structures such as houses and roads, determine the relative positions of points on the earth, display

the terrain and features by scaling, and create maps and drawings. Since road design, etc. is carried out based on the maps and drawings obtained from the survey, it is important to ensure the accuracy required for the purpose.

Table 2.11 Outline of Survey

Name of survey	Outline
Control point survey	Control point survey is the work of determining the basic position and altitude for conducting a survey, and is divided into control point survey in which a control point is set and levelling survey in which a benchmark is set. In the control point survey, the position of the new control point is determined based on the electronic control point, the existing control point. In the survey, a total station or the like is used to determine the angle and distance between related points, and radio waves from artificial satellites is received and record position data. In levelling, the elevation of the new benchmark is obtained based on existing benchmarks by measuring the elevation difference between related points using levels or total stations. Direct levelling is commonly performed by directly combining two or more existing points.
Topographic survey	Topographic survey is the work of creating a topographic map necessary for design, and is generally divided into plane table survey and aerial survey. In topographical surveys, it is standard in Japan to use field surveys when the scale of topographic maps is 1/1000 or more, and aerial survey when the scale is 1/2500 or less. For field surveys, topographical features are measured on-site using a total station or GNSS (Global Navigation Satellite System) surveying instrument, and numerical topographic map data is created. In recent years, as an electronic plane table method, a method of directly measuring and editing an observed point while displaying a graphic on the site using a tablet PC, has also been adopted. Recently, the aerial survey, which was conventionally performed with a manned airplane, has also been performed with a drone. Expanding the measured points, the lines connecting the same height are contour lines, and the lines connecting points with the same attributes are buildings, etc. The final map created is called a plan (topographic map). The scale of the topographic map used in the preparatory survey is generally 1/1000, but for bridges and intersections that require detailed examination, a 1/500 topographic map may be used.
Route survey	A series of surveys from centerline survey, tentative BM (Bench Mark) installation, longitudinal survey, and cross-sectional survey are collectively called route survey. Recently, survey using a total station (three-dimensional survey using GPS (Global Positioning System)) is the mainstream. As a result, the data in the longitudinal direction and the crossing direction (generally 20 m pitch) of the existing road are also measured at the time of the topographic survey, and the terrain is made three-dimensional. Since by this three-dimensional topographic map, vertical sections and cross sections can be acquire automatically at any location, sometimes strict route surveys is not carried out.

Source: JICA Study Team

☞ Drone survey

The aerial survey conducted by satellites and aircraft has changed significantly with the advent of drones. Previously, in order to conduct aerial survey, it was necessary to request an aerial survey company to adjust the schedule, and it was expensive, however it has become easier by using an aerial survey drone. The largest advantage of drone survey is that equipment can be loaded into passenger cars and carried to the site, and pictures can be easily taken by own staff. The captured data can be immediately imported into a personal computer to create 3D point group data and ortho-images, and a 3D terrain model can be created by data analysis.

Point group data: "Information on the XYZ axes acquired by the drone". By combining the altitude information acquired by the drone from barometers and the position information acquired from GPS and GLONASS artificial satellites with the data captured by optical cameras and laser ranging devices, a "group of points" with position information is formed. By processing this data with dedicated

software, it is possible to measure the distance from point A to a specific point B, calculate the volume of the embankment, create a 3D model, create a drawing, manage the finished product, and so on.

Ortho-image: A photo taken by a drone is combined and corrected so that it is displayed in the correct position and size by arranging tilt and distortion, and is called an ortho-image. Although it is different from "surveying" in the direct sense, it may be taken together with the acquisition of point cloud data by a drone.

Source: https://viva-drone.com/drone-uav-surveying/, https://enroute.co.jp/solutions/surveying/

2) Geological Survey

The geological survey is carried out to grasp the geological condition of the point where the planned road passes. The geological survey consists of two surveys: a geological survey to confirm the outcrop condition of soil and rocks in the existing literature and at the site, and a soil test for collected samples from the site. Soil tests are further classified into physical tests, mechanical tests, chemical tests according to their purpose, and the most important subgrade survey in determining the pavement structure is classified into the mechanical test of soil survey.

Table 2.12 Outline of Geological Survey

Test	Contents of test
Soil test	The main type of civil engineering work is earthwork, which is the work of excavating, transporting, levelling, embankment and compacting soil. The material of earthwork is soil, and the properties of soil differ depending on its composition and the place of production. Therefore, it is important to use soil with properties that conform with the purpose of the construction. Soil surveys and soil tests are conducted to confirm the properties of the soil that suits this purpose. For soil surveys and tests to grasp the properties of soil, there are two types of tests: one is in-situ tests conducted at the site where civil engineering work is carried out, and the other is laboratory tests in which soil materials collected on the spot are tested in the laboratory.
Material test	The material test is a part of the soil test, and includes the test of soil which is the material of embankment and subgrade, and the test of aggregate which is the material of concrete and pavement. The survey results report includes: 1) test results, 2) presence or absence of materials that meet the material standards, 3) possible collection locations, and 4) possible collection amount.

Source: JICA Study Team

☞ In-situ test

Since the conditions for civil engineering work vary greatly depending on the site, it is important to conduct on-site surveys and tests. The test conducted at this site is called an in-situ test. The most basic and standard survey method in the in-situ test is the standard penetration test. The main purpose of SPT (Standard Penetration Test) is to obtain a standard ground index (N value) and collect samples. For bridge foundations, it is stipulated in the preparatory survey that a geological survey entailing at least one boring survey on abutment and pier each should be conducted.

☞ Laboratory test

In order to know the properties that cannot be measured in the field, such as the grain size of soil, samples are taken in the field for laboratory tests. When sampling, depending on the purpose of the test, the condition of soil in its original position may or may not be retained. The former is called "undisturbed soil" and the latter is called "disturbed soil". The CBR value used in pavement design is determined by indoor CBR (California Bearing Ratio) testing.

Table 2.13 Sampling Method

Sampled soil	Sampling method	Properties to examine
Disturbed soil	Scoop, etc. (collected from shallow ground) Hand auger (collected from shallow ground) Standard penetration test sampler	Physical properties of soil (Particle size, liquid limit, plastic limit, soil particle density, etc.)
Undisturbed soil	Block sampling (collected from shallow ground) Collection by sampler (collection from deep ground) Frozen sampling (collection of sand and gravel soil)	Mechanical properties of soil (Soil compressibility, strength, etc.)

Source: www.mizunotec.co.jp/index.html

3) Terrain and Ground Surface Survey

In general, with regard to topographical and ground surface conditions, on-site reconnaissance provides detailed data that cannot be obtained from map interpretation alone. The detailed data include, for example, the ground surface condition in the catchment area, slope and changes in the surface condition due to human factors such as the development of the surrounding area.

In addition, when designing roads on slopes such as mountainous areas, it is important to understand the condition of the slopes. Furthermore, especially for slope drainage and underground drainage, it is also important to investigate landslides, the presence or absence of collapse, slope erosion, and vegetation.

4) Underground Water and Underground Drainage Survey

After grasping the outline of the groundwater survey from past literature and field reconnaissance, the groundwater level and movement of groundwater will be investigated by boring or test pits as necessary. When designing drainage facilities for structures such as underground drainage facilities, slope drainage facilities, and drainage facilities for retaining walls, it is necessary to investigate the condition of spring water, the position and permeability coefficient of the permeable layer, and the depth of the impermeable layer. In particular, the condition of groundwater is important information related to the lack of bearing capacity due to the softening of the subgrade and base course/subbase course, but as a practical issue, It's not easy to grasp the condition of groundwater even in the survey over the rainy season and the dry season. Therefore, it is necessary to implement necessary countermeasures through monitoring during the construction period.

The case in Photo 2.2 is not a case of a Grant Aid Project, but it is a road construction carried out in African countries. The section in the photo is a swamp. The improvement range and depth of the soft ground became larger than originally expected, and the project cost increased significantly. According to the results of the geological survey in design stage, it was reported that the groundwater level was low and there was no soft ground, but when excavation was started at the construction stage, groundwater and soft ground were present.

Source: JICA Study Team

Photo 2.2 Springwater Discovered during Construction

Since there were many cases of increased construction costs due to such lack of survey within the country, guidelines for geological survey were established in the project country of Uganda. The following is a description of the survey method and survey interval in wetlands described in the guidelines.

Draft Guideline for Site Investigation at Design Stage (Uganda)

Sampling in Swamps

What tests do you propose for waterlogged/marshy lands? Options include boreholes or hand auger sampling at possibly 50m intervals along the road alignment. This is necessary to identify the extent of the swamp and depth of possible problem soils, as well as identify possible areas with potential expansive clays.

The underground drainage survey is carried out for the purpose of maintaining good pavement by blocking water (rainfall) that permeates the subgrade and base/sub-base from the area adjacent to the road or the road surface in the shortest possible time, and the groundwater level under the road surface is lowered. It should be noted that pavement damage is likely to occur due to poor underground drainage, especially on the mountain side of the cut sections. Underground drainage is also effective as a preventive measure against damage of retaining walls and slopes, or as a measure against landslides. It is planned to use the transversal and longitudinal gradient of the road to remove groundwater in the roadbed, subgrade, and road body to a predetermined water level. In order to properly plan underground drainage, it is important to conduct sufficient surveys of groundwater, topography and geology. The state of underground water should be comprehensively inferred utilizing knowledge on topography and geology based on the results of extensive soil surveys such as boring. It should also be recognized that groundwater affects a fairly wide area, not just near roads.

5) Surface Drainage and Spring Water Survey

The purpose of the current surface drainage system and spring water survey is to maintain the conformity of the current channel and road drainage in the design of drainage facilities, and to obtain materials for stabilizing the embankment or the cut slope. Therefore, the type of current drainage channel, the flow direction, the type and cross-sectional dimensions of the channel structure, the usage of the channel, and also the distribution of spring water and wetlands are investigated.

6) Meteorological Survey

Meteorological surveys are the basis for planning drainage facilities and determining the structure and scale of drainage facilities, and are also important information for pavement design (road surface design, pavement structure design, and pavement drainage). In the meteorological survey, the amount of rainfall, the number of days of rainfall, the temperature, the freezing situation, etc. near the planned area will be investigated.

(8) Obstacles and Utilities Survey

The obstacles and utilities survey includes the location and extension of visible objects such as electric poles, lighting, cemeteries, and signboards, as well as buried objects such as water pipes, gas lines, and communication lines, in order to plan the relocation of facilities that interfere with road construction and calculate removal/relocation costs. For roads in rural areas in particular, it is necessary to conduct sufficient hearings with local residents, as cemeteries may be located in forested areas beside roads. Since the removal/relocation of these obstacle objects are undertakings of the recipient government, it is important to ensure that this process is not critical to the construction schedule. It is necessary to grasp not only the existing obstacle objects but also future plans and reflect them in the road design. Table 2.14 shows the main examples of obstacles.

Table 2.14 Example of Obstacle Object

Location	Obstacle object
Along the road (Visual confirmation possible)	・ Power poles (including overhead lines) and lighting (street lights) ・ Traffic signal control facilities (at intersections) ・ Public water taps (public water supply) and wells ・ Signboards ・ Cemeteries ・ Items valued by local residents such as sacred trees
Underground facility	・ Water supply and sewerage ・ Gas pipes, electric lines (electricity) Communication lines (including optical fibre)

Source: JICA Study Team

(9) Construction Capacity Survey

At the preparatory survey stage, local construction companies that have the ability to carry out the target road construction is selected by hearing from the local government, and interviews will be conducted regarding the construction capacity as a partner company. The contents of the hearing to be conducted are shown in Table 2.15.

Table 2.15 Hearing Items for Local Contractors

Item	Information to be obtained
Capacity of company	・ Amount of orders received, completed construction, completed road construction ・ Number of staff (number of engineers) ・ Number of qualification holders related to construction ・ Owned machineries and equipment ・ Standard construction management system ・ Quality confirmation of under construction or completed construction (based on site survey)
Others	・ Construction results other than road construction ・ Standard construction unit price

Source: JICA Study Team

(10) Material Procurement Condition Survey

The material procurement condition survey is a survey that confirms the possibility for procurement of materials (reinforcing bars, cement, crushed stone, etc.) necessary for the construction of facilities. Of the materials, aggregates used for concrete and pavement, soil for road construction, etc. are generally produced and procured locally. The specifications (strength, etc.) required for these locally produced materials are also defined according to the purpose of use. The material procurement survey also includes confirming that the materials that meet the specifications are available or have sufficient reserves by field surveys and soil tests (physical tests, mechanical tests, chemical tests, etc.). Confirmation of transportation routes for materials and equipment to be procured is also included in the material procurement survey. As for concrete and asphalt plants, if the use of local plants is reasonable from the viewpoint of economic efficiency, in addition to price, quality control methods should be investigated along with the results of quality tests from the viewpoint of quality control.

2.4 Geometric Design of Roads

(1) Design Vehicle

In road design, the size and performance of vehicles give effect to road structure, such as the cross sections, the widening of curved sections, the design of intersections, vertical alignments and sight distances. The design vehicles for road design is defined in each standard as shown in Table 2.16. Geometric Design Highway and Streets[2], AASHTO (American Association of State Highway and Transportation Officials) specifies 20 types of design vehicles.

Table 2.16 Dimension of Design Vehicles

	Dimension (m) / Design vehicle	Length	Width	Height	Front end overhung	Wheelbase	Rear end overhang	Turning radius
Road Structure Ordinance[1]	Small vehicle	4.7	1.7	2.0	0.8	2.7	1.2	6.0
	Small vehicle, etc.*	6.0	2.0	2.8	1.0	3.7	1.3	7.0
	Full-sized car	12.0	2.5	3.8	1.5	6.5	4.0	12.0
	Semi-trailer truck	16.5	2.5	3.8	1.3	Front: 4 Rear: 9	2.2	12.0
SATCC Geometric Design Standard[14]	Passenger Car (P)	-	1.8	-	0.7	3.1	1.0	6.8
	Single Unit (SU)	-	2.5	-	1.2	6.1	1.8	10.0
	Single Unit + trailer (SU+T)	-	2.5	-	1.2	6.7 + 3.4 +6.1	1.8	11.0
	Single Unit Bus (BUS)	-	2.6	-	2.1	7.6	2.6	11.5
	Semi-trailer (WB-15)	-	2.5	-	0.9	6.1 +9.4	0.6	11.0

*Small vehicle, etc.: Small vehicle and other small vehicles similar to this.
Source: JICA Study Team

(2) Carriageway

The width of each component composing the carriageway is determined by the purpose of each component (for example, carriageways are the parts where vehicles pass, shoulders are the side allowances required for vehicles to run), the type of road, the traffic volume, and the design speed. The Road Structure Ordinance[1] defines standard values for the width of each road component. The width of a lane is generally 3.0 to 3.5 m on national roads and 3.5 m on national highways. AASHTO sets the lane width to 12 feet (3.6m) on the motorway (Freeway) and 9 feet to 12 feet (2.7m to 3.6m) on other roads. SATCC (Southern Africa Transport and Communications Commission) applies 3.1m, 3.4m, and 3.7m as normal lane widths. Among them, 3.7m lane width is recommended based on the data that indicates traffic accident rates are high on roads of 3.6m or less width, however, depending on the traffic volume and roadside conditions, it is also permitted to apply 3.4m or 3.1m lane widths. In this way, applicable width differs by the standards, so it is important to confirm discretely the standards and suited conditions of the recipient country. As an example, the width standard shown in Road Geometric Design Manual, Tanzania is shown in Table 2.17.

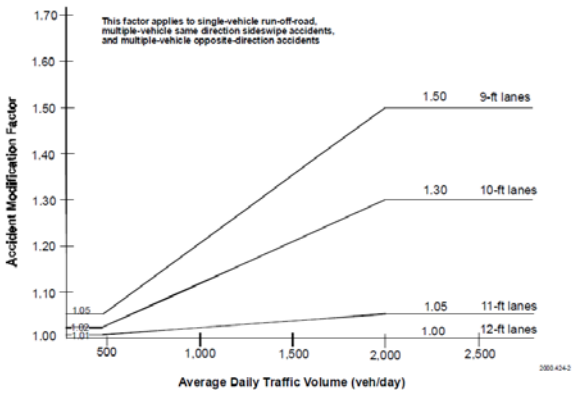
Table 2.17 Roadway Width in Tanzania Design Manual (Paved Road)

Category	ROW	Road width	Carriageway			Shoulder width	Median width
			Width	Lane width	Number of lanes		
DC1	60m	28 – 31m	2 x 7.0m	3.5m	≥4	2 x 2.5m	9 – 12m
DC2	60m	11.5m	7.5m	3.75m	2	2 x 2.0m	
DC3	60m	11.0m	7.0m	3.5m	2	2 x 2.0m	
DC4	60m	9.5m	6.5m	3.25m	2	2 x 1.5m	
DC5	60m	8.5m	6.5m	3.25m	2	2 x 1.0m	

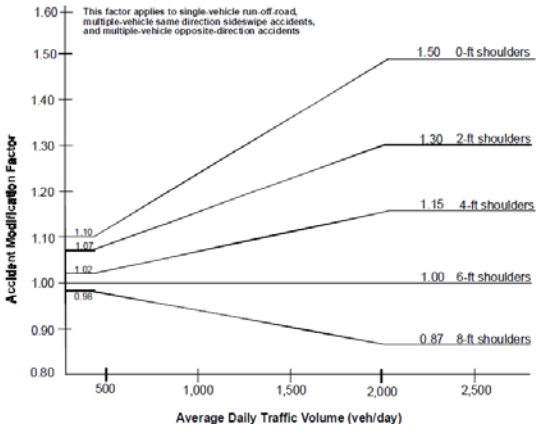
Source: Road Geometric Design Manual 2011[15], Tanzania

☞ Relation between Lane Width and Traffic Accidents

A document (Prediction of the Expected Safety Performance of Rural Two-Lane Highways[16]) published in 2000 by FHWA (Federal Highway Administration) on the relationship between road width and accidents shows that AMF (Accident Modification Factor) increases when the road width is narrower than 12 feet (3.6m). When the road width is 9 feet (2.7m), AMF is 1.5 times that when road width is 12 feet. Similarly with regard to shoulder width, when the shoulder width is 2 feet (1.2m), AMF is 1.3 times of 6 feet (1.8m), and 1.5 times when the shoulder width is zero, AMF is 1.3 times.



Accident Modification Factor by Traffic Volume and Lane Width



Accident Modification Factor by Traffic Volume and Shoulder Width

Source: Prediction of the Expected Safety Performance of Rural Two-Lane Highways, NO. FHWA-RD-99-207[16]

Figure 2.10 Relation between Accident Modification Factor and Width

☞ AMF: Accident Modification Factor

The AMF is a coefficient that indicates the influence of geometric structure and intersection on safety used in accident prediction models. For geometric structures, lane width, shoulder width, horizontal/vertical alignment, etc., and for intersections, intersection angle, control method, right/left turn lane, etc. are used as influence variables. The basic AMF value (standard adopted value) is 1.0 (in Figure 2.10, lane width and shoulder width of 12 feet and 6 feet, respectively, are set to 1.0), and a value greater than 1.0 is evaluated as a high degree of accident occurrence, while a value less than 1.0 is evaluated as a low degree of accident occurrence. The model was analyzed using five years of accident data from the FHWA's HSIS (Highway Safety Information Systems) for five years accident data of approximately 1,130 km of two-lane roads in Minnesota (1985-1989) and three years accident data for 850 km of roads in Washington State (1993-1995).

(3) Shoulder

The main function of shoulders is to provide side room for driving and parking for broken down vehicles, etc. However, it has also been reported that in areas other than urban areas and suburbs, wide paved shoulders may be suitable as a space for pedestrians and cyclists to replace sidewalks [1]. The African Development Bank's "Road Safety Manuals for Africa[17]" recommends paved shoulders that are wide enough, not to be used for overtaking, as a returning/merging space for vehicles that have deviated from the roadway. In this way, the width of the shoulder shall be determined by comprehensively considering the roadside conditions and pedestrian use.

Source: JICA Study Team

Photo 2.3 Shoulder (unpaved) used by Pedestrians

In the case where the shoulder is expected to be used as a pedestrian/bicycle space, it is important to observe the basic design policy of clearly separating the pedestrian/bicycle space from the vehicular traffic space (carriageway). To this end, it is important to pave the surface as well as to secure enough space for pedestrians and bicycles to pass smoothly on the shoulder without sticking out into the carriageway. In order to prevent vehicles from misidentifying the shoulder as a carriageway and deviating from the original carriageway to the shoulder, the height of the road surface is generally changed between the roadway and the shoulder. As a basic measure, it is recommended to install lane markings on the side of the carriageway, as well as to install rumble strips and speed control signs, the effectiveness of which has been widely reported, and to consider other safety measures for pedestrians and bicycles passing on the roadside. In addition, shoulders paved as walking and bicycling spaces in this way need to be maintained in the same way as carriageways to ensure their function over the planning period.

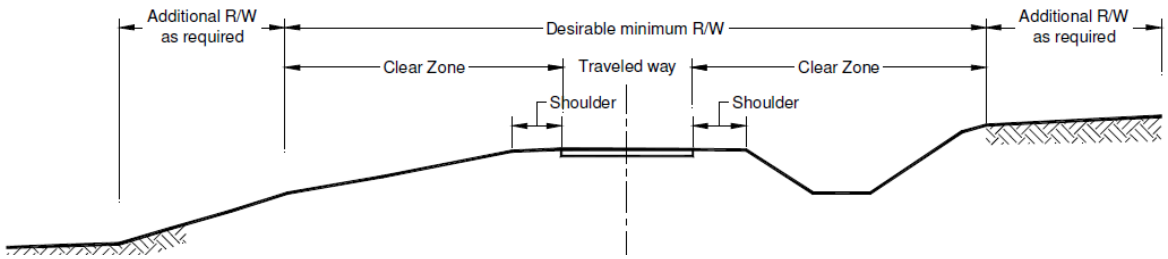
The following items should be considered for the shoulder in terms of ensuring pedestrian safety.

- To evaluate sufficiently safety on arterials roads with high design speed where vehicles and pedestrians share the same cross-section.
- Even in rural areas, sidewalks should be actively installed in the sections where roads pass through villages, or around facilities where people gather, such as schools and medical facilities.
- Considering that in developing countries pedestrians generally travel long distances along arterial roads, even in cases where the shoulder is used as a walking space because villages do not exist in the vicinity, measures for pedestrian safety should be taken, such as widening the shoulder, paving the shoulder, and installing appropriate signs to alert drivers that pedestrians are passing by, so as not to increase the danger of walking.

[1] PEDESTRIAN SAFETY, A ROAD SAFETY MANUAL FOR DECISION-MAKERS AND PRACTITIONERS[19], WHO

☞ ROW (Right-of-Way) and COI (Corridor of Impact)

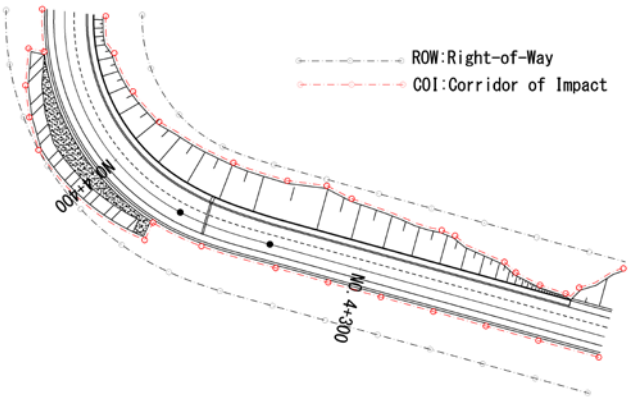
Road geometric Design Manual, Tanzania defines the right-of-way as "A strip of land legally awarded to the Road Authority specifically for the provision of public right of way, in which the road is or will be situated and where no other work or construction may take place without permission from the Road Authority. The width of the road reserve is measured at right angles to the centerline." ROW encompasses a planned road that includes all required cross-section elements and is formed as a public road site or road reserve to improve road safety, operation, and appearance. Therefore width of ROW is different from the total width of the cross section elements.



Source: Road Design Manual Volume I Geometric Design 2010[18], Uganda

Figure 2.11 Conceptual Figure of ROW

In contrast to the ROW, there is a concept called COI, which covers only the area of construction of a road, and when it is difficult to acquire land for the ROW, such as in urban areas, this COI may be used as a target for land acquisition. ROW is interpreted as a road area that restricts private use and includes future anticipated widening, etc., and is set parallel to the centerline of the road, as is the case with city planning roads (roads that have been decided based on City Planning Act) in Japan, whereas COI is set so that only the area affected by the road is used as road land. In Japan, COI is applied to all roads except city planning roads.



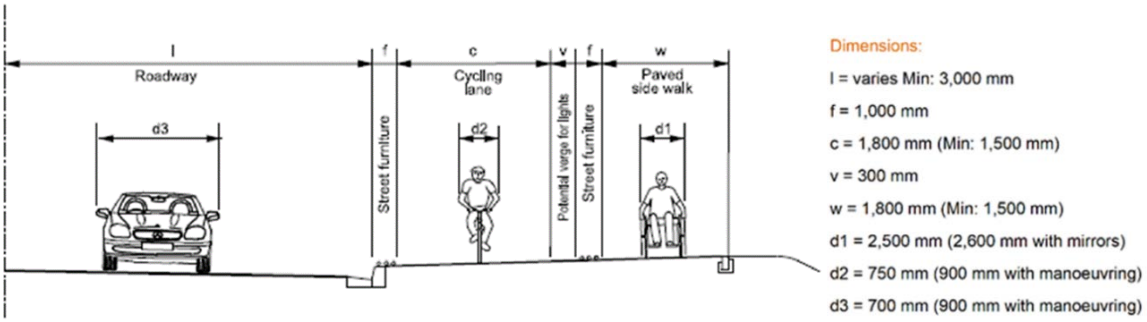
Source: JICA Study Team

Figure 2.12 Concept of ROW and COI

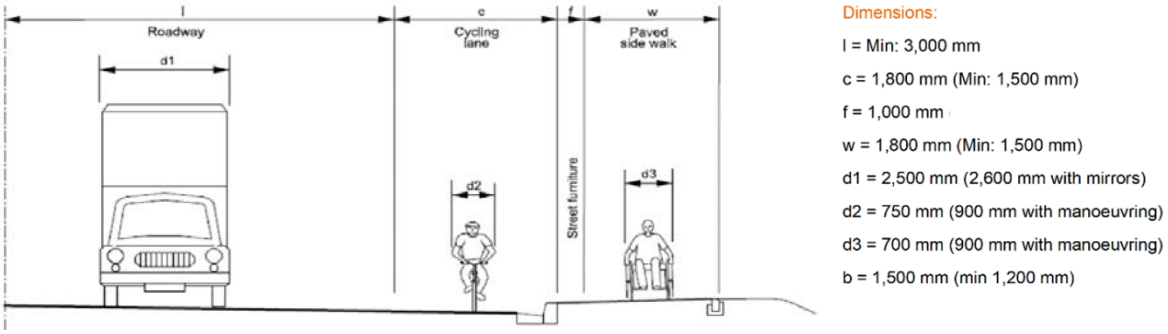
(4) Bicycles and Pedestrians

According to the Road Structure Ordinance[1] of Japan, the width of the bicycle path is 2.0 m or more. The width of bicycle pedestrian path is 4.0m or more when there are many pedestrians and 3.0 m or more when there are few pedestrians. The width of sidewalk is 3.5m or more when there are many pedestrians and 2.0 m when there are few pedestrians. In November 2012, the Road Bureau of the Ministry of Land, Infrastructure, Transport and Tourism and the Traffic Bureau of the National Police Agency formulated "Guidelines for creating a safe and comfortable bicycle use environment[20]". In the guideline, based on the standpoint that "bicycles are vehicles and passing through roadway is basic

principle", method to develop area-wide bicycle network plan covering the primary bicycle traffic routes, and method of design for bicycle traffic space where pedestrians, bicycles and cars are properly separated were presented. In addition, the development of roads in which pedestrians and bicycles are separated is being promoted overseas, including in developing countries, and AASHTO established standard[21] for sidewalks and bicycle paths separately from the geometric structure standards. Also in South Africa, the "NMT Facility Guidelines 2014[22]" was established separately from the geometric structure standards. In Tanzania, the standards for sidewalks and bicycle paths are described in the Road Geometric Design Manual[15] with reference to the case of NPRA (Norwegian Public Roads Administration). In the case of roadways, the width is determined based on future traffic volume, while the width of pedestrians and bicycles should be designed not only for current traffic but also for future trends.



Arterial Roads (80km/hr and above)



Urban Distributors and Collectors (60km/hr)

Source: NMT Facility Guidelines 2014[22], South Africa

Figure 2.13 Conceptual Layout of Bicycle Pedestrian Paths

(5) Design Speed

Design speed is stipulated in the Road Structure Ordinance[1] of Japan as "the speed of the vehicle based on which the road design is formed." In other words, design speed is the basic element for examining and determining the structure of the road, and has a direct relationship with the alignment of the road. The concept of road classification that determines the width of carriageways and shoulders is connected to design speed. The theory of the design speed is introduced almost all over the world, and it is determined by the road classification, the planned traffic volume and the topography.

☞ Design Section

In the Road Structure Ordinance[1], design section is described as follows: "Design section is a section where the same design criteria and design speed are to be adopted according to the surrounding area, the topography and the planned traffic volume, and the same road classification is to be applied. Changing the design section frequently in short section or changing the design section at an unexpected place for the driver will confuse the driver and is not preferable in terms of traffic safety and also reduce comfort, therefore design section should be as long as possible." The Road Structure Ordinance[1] of Japan stipulates the general criteria for the minimum design section length by road category as shown in Table 2.18. This concept of the minimum design section length is often not found in overseas standards, and it may happen that the design speed is changed in a very short section. In such a case, the traffic safety will be secured at safety facilities such as signs as the "Substandard section".

Table 2.18 General Guidelines for Design Section Length

Road classification	Standard minimum design section length	Minimum design section length at inevitable case
Type 1, Type 3 Class 1, Type 3 Class 2	30-20km	5km
Type 2, Type 3 Class 3, Type 3 Class 4	15-10km	2km
Type 4	Distance between major intersections	

Note: Types and Classes are classification defined by Road Structure Ordinance of Japan as follows.
Type 1: National Expressway and Expressway in rural area
Type 2: National Expressway and Expressway in urban area
Type 3: Other road in rural area
Type 4: Other road in urban area
Classes are defined by traffic volume and roadside topography

Source: Explanation and Operation of Road Structure Ordinance[1]

(6) Geometric Design Standards (Horizontal alignment and vertical alignment)

Among road designs, geometric structure design and various road facility designs have a direct influence on traffic operation, therefore both the kinematic characteristics of vehicles and the ergonomic characteristics of drivers and pedestrians are considered in the design. Generally, the minimum value of the geometrical structure is stipulated by the condition of the vehicle characteristic and/or the human characteristic. For example, the minimum sight distance is decided from the sum of the mechanical stop distance of vehicles and the reaction time of drivers. The minimum curve radius is obtained from the mechanical characteristics of automobiles.

shows the major criteria items of the geometrical structure specified in the Road Structure Ordinance[1]. The standard value for each item is not stated because it depends on the design speed adopted. There are many cases where "exceptional values" and "minimum values" are used in geometric structural design, however, "desired values" or "standard values" should be considered first to maintain the safety and smoothness of trunk roads. The reference materials in Chapter 6 show the standard values (Road Structure Ordinance[1] and SATCC) for design speeds of 60km/h and 80km/h, which are often used in Grant Aid Projects.

Table 2.19 Major Criteria Items of Geometrical Structure in Road Structure Ordinance

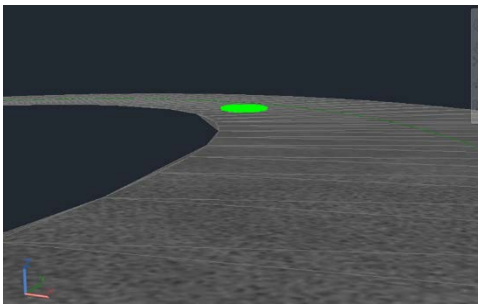
Item				Unit	Explanation
Horizontal alignment	Curve radius	Desirable		m	Curved section of roadway except the transition curve section
		Minimum		m	
		Exceptional		m	
	Curve length	Minimum		m	Length of the centerline of the curved section of roadway (if the transition curve section connecting with the curved section is curved, the length of the transition curve section is added.)
		Exceptional		m	
	Transition curve	Length		m	Transition curve section used for the purpose of connecting a straight with a circular arc or two circular arcs of different radius. (ex. Clothoid curve)
		Curve radius to which transition curve is not required		m	
	Curve radius superelevation is applicable	2.0% (Normal cross slope)		m	Since the centrifugal force becomes smaller as the curve radius becomes larger, the limit curve radius that allows to reverse the cross slope (superelevation).
		1.5% (Normal cross slope)		m	
Vertical alignment	Vertical gradient	Maximum value		%	Up-slope or down-slope gradient
		Exceptional		%	
	Vertical curve radius	Crest	Desirable	m	A curve that is inserted at intersection point of vertical tangent to reduce shock and secure sight distance due to changes in momentum
			Minimum	m	
		Sag	Desirable	m	
			Minimum	m	
	Vertical curve length			m	
Maximum camber				%	The gradient in transverse direction for stable driving in the curved section of road
Combined gradient				%	Gradient that is a combination of vertical gradient and superelevation or cross slope
Sight distance		Stopping sight distance		m	Distance required to brake and stop when an object such as a broken vehicle is found in the same lane ahead
		Passing sight distance		m	A distance that secures the necessary visibility to give a vehicle overtaking opportunity on two-lane road
Headroom clearance				m	Height clearance that structure must not be installed on the road

Source: JICA Study Team

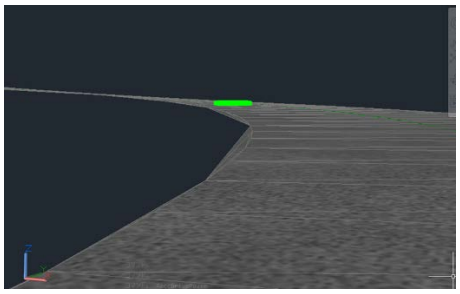
When examining the combination of horizontal alignment and vertical alignment, it is important to 1) consider it as a three-dimensional alignment that integrates horizontal alignment and vertical alignment, and 2) make it a combination that can secure line-of-sight guidance and drainage of highway. And the basics of the combination are the following three points.

- Combination of horizontal alignment and vertical alignment
- Keeping the size balance between horizontal alignment and vertical alignment
- Select a combination of alignment that gives an appropriate composite gradient.

For the combination of horizontal alignment and vertical alignment, it is effective to verify using a 3D model. Figure 2.14 shows the difference in the appearance of the downhill and uphill slopes on curves using the same curve radius. The downhill slope is very safe because the visibility is good and the curve looks small, but the uphill slope tends to increase in speed because the curve looks large even though the visibility is poor. In other words, using 3D makes it possible to understand visually such traffic safety problems and take countermeasures at the design stage.



Downhill and a curve: Good visibility and the curve looks small.



Uphill and a curve: Poor visibility and the curve looks large.

Source: JICA Study Team

Figure 2.14 Verification of Optical Illusion by 3D Model

👉 Combined gradient

The gradient formed by synthesizing the vertical gradient and the cross slope is called a combined gradient, which is the steepest gradient of the road surface. Its size is calculated by Formula 2.1.

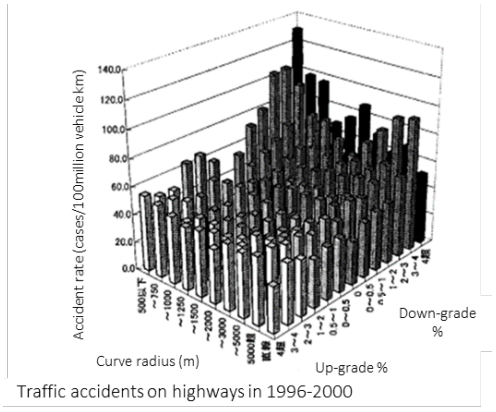
$$S = \sqrt{i^2 + j^2} \qquad \text{(Formula 2.1)}$$

S: Combined gradient (%)

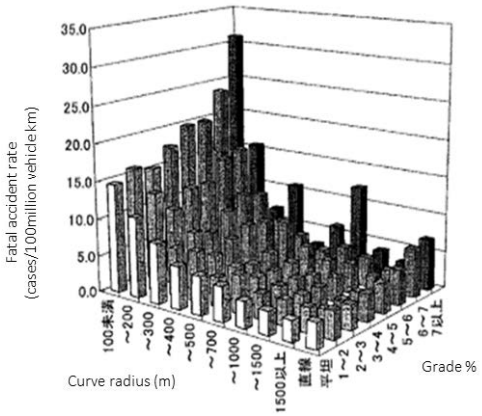
i: Cross slope or superelevation (%)

j: Vertical gradient (%)

When there is a horizontal curve in a section of a road with a vertical gradient, a combined gradient occurs. When the horizontal gradient is steep and the radius of the curve is small, a danger is likely to arise in driving because of larger combined gradient.



Highway



National Road

Remark: The smaller the curve radius, the larger the camber (%).
Source: Explanation and operation of road structure ordinance[1]

Figure 2.15 Relation between Road Alignment and Traffic Accident Rate

The criteria for the combined gradient are hardly described in the geometrical standards of foreign countries, and may be developed in Japan to ensure road safety.

2.5 Design of Intersection

(1) Type of Intersection

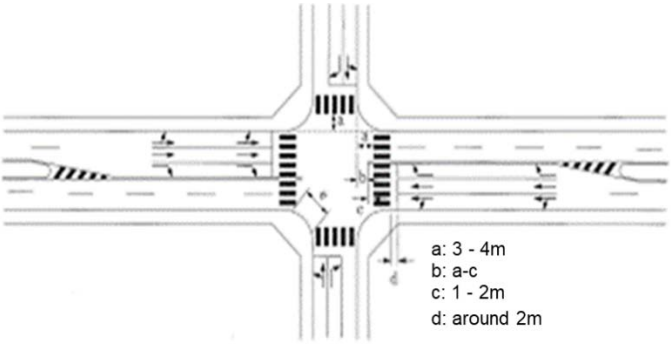
The points where roads intersect each other are called intersections, and those that intersect on the same plane are called at-grade intersections and those intersect on different planes are called grade separated intersections. The explanation and operation of the Road Structure Ordinance[1] states the application of at-grade intersection and grade separated intersection as follows.

1) In principle, when roads with four or more lanes intersect each other, grade separation is applied. However, this does not apply when grade separation is difficult due to topography or other reasons, or grade separation is not suitable because of small traffic volume, from the view point of traffic safety, road network structure or intersection interval, etc.

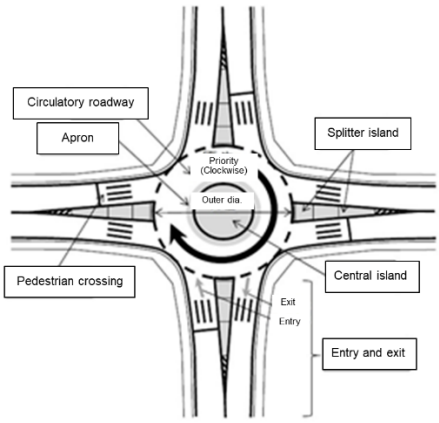
2) In principle, if one of the roads has two lanes, at-grade intersection is applied. However, this does not apply if grade separation is preferable in terms of traffic volume at the intersection, traffic safety, and road functions.

3) When two-lane roads intersect each other or with one-lane roads, and when one-lane roads intersect each other, at-grade intersections are applied.

The intersection of roads not only functions as a node to distribute vehicles and pedestrians to intended direction, but is also a weak point that hinders the safety and smoothness of road traffic. The at-grade intersections are divided into cross intersections, T intersections, Y intersections and ring intersections (roundabouts) according to their shapes, and are classified into three-leg intersections, four-leg intersections, and multi-leg intersections according to the number of legs that gather to the intersections.



Four-leg intersection with signal



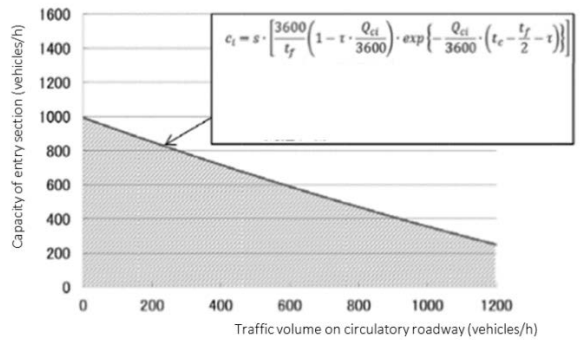
Roundabout

Source: JICA Study Team

Figure 2.16 General Shape of Four-leg Intersection and Roundabout

Roundabout means "One way traffic control method of ring-shaped at-grade intersection where all entry traffic must give way to circulating traffic and circulating traffic is not stopped by stop sign or signal". Roundabouts are subdivided as shown in Table 2.20.

Table 2.20 Types of Roundabouts

	Compact Roundabout	Mini Roundabout	Multilane Roundabout
Outline	The compact roundabout is a roundabout that has a central island and all the passage for inflow, outflow and ring road is one-lane. And climbing onto central island by vehicles are physically hampered. Generally, the outer diameter is about 26 to 40 m.	The mini roundabout is a small roundabout with an outer diameter of about 13 to 22 m, and is applied for the purpose of safely controlling of intersection by speed control at intersection of minor roads.	The multilane roundabout is a large roundabout with multiple lane ring road and the outer diameter is 40 to 60m. Multi-lane roundabouts is said to be effective at intersections with relatively high traffic demand. However, there are safety issues due to the increase in the number of crossing points and the increase in the speed of passing through the ring road. The use rate of inner lanes will be low, and the traffic capacity will not necessarily be increased.
Capacity (Germany)	Up to approximately 25,000 vehicles/day	Up to approximately 20,000 vehicles/day	Up to approximately 40,000 vehicles /day (In case of two lanes)
Capacity (USA)	Up to approximately 25,000 vehicles/day	Up to approximately 15,000 vehicles/day	Up to approximately 45,000 vehicles /day (In case of two lanes)
Method in Japan	Roundabouts in Japan are targeted for compact roundabouts and are applied to intersections with a daily total inflow traffic of less than 10,000 vehicles. At intersections with total daily inflow traffic of 10,000 vehicles or more, introduction of roundabout is determined by comparing the inflow traffic capacity per hour and the inflow traffic volume per peak hour at each access/egress passage. In the figure on the right, the range of inflow traffic volume and ring road traffic volume that can be applied as a roundabout is shown with grey.	 Relation between traffic capacity of entry section and traffic volume on circulatory roadway *Traffic volume on circulatory roadway is volume at upstream of each entry	

Source: Examination of knowledge necessary for planning and designing roundabouts[23] (Ministry of Land, Infrastructure, Transport and Tourism), Roundabout Planning and Design Guide (Draft)[23] (2009), Roundabout Status (Ministry of Land, Infrastructure, Transport and Tourism)

The advantages of roundabouts are as follows:

- Improvement of vehicle traffic safety at intersections
- Improvement of pedestrian traffic safety at intersections
- Reduction of delay time when traffic is less
- Reduction of development cost and maintenance costs
- Improving resilience against disaster

In foreign countries, mainly in Western countries, there are many cases in which signalized intersections are improved to roundabouts in the suburbs, where traffic is relatively light utilizing the advantages of roundabouts. In Japan as well, roundabout was applied by the revision of the Road Traffic Law in

September 2014, and the operation of the roundabout has started. The Ministry of Land, Infrastructure, Transport and Tourism has indicated that the daily traffic volume of less than 10,000 vehicles as a guideline for introducing roundabouts, and there is a possibility that roundabouts will be congested at intersections with heavy traffic. In addition, roundabouts require more space than ordinary intersections, so it is not suitable for urban areas with heavy traffic and land restrictions. When using the roundabout standards of advanced countries, it is necessary to pay attention to the emphasis placed on "smooth driving of vehicles" and "safe driving" in each country. It is noted that the effective design method for the safe and smooth passage of bicycles/moto-cycles is not established and under development.

(2) Intersection Improvement

If the green ratio at a signalized intersection is 50%, the intersection is closed during half a day, and most of the congestion is caused at intersections as bottleneck of roads. Therefore, additional lanes such as "right turn lane" and "left turn lane" are installed to take measures to increase the capacity. However, congestion may occur even at intersections that have been constructed to meet demand. Unlike general road section, intersections often have possibility for improvement because there is a decrease in capacity due to factors such as right/left turn traffic, mixed pedestrians, and turning of large vehicles. Therefore, as a measure against traffic congestion, partial improvement by intersection improvement is implemented. The main points of the intersection improvement are to eliminate the speed reduction elements that causes the capacity decrease, to make the intersection simple and clear, and to make the intersection easier for the users. The specific improvements are as follows:

- Clarify the primary flow and secondary flow of traffic.
- Avoid multi-leg intersections with more than 5 legs.
- Make sure that the intersection angle is close to a right angle.
- Avoid deformed intersections such as staggered intersections and bent leg intersections.
- Make the intersection area as small as possible and not too wide.
- Separate right and left turn traffic from straight traffic
- Clarify the traveling lane by using a channel for left-turning traffic and right-turning traffic.
- Give careful attention to the coordination between the intersection geometry and traffic control methods.
- Examine installation of various traffic safety facilities
- Carefully investigate the locations of road facilities and utilities.

Source: Key points of intersection improvement[24]

If the above measures do not meet the traffic demand, it is proposed to improve the intersection by grade separation. There is a measure while maintaining the shape of at-grade intersection called "optimization of green time ratio" that calculates the intersection degree of saturation and optimizes the current green time ratio according to the actual traffic volume, however this measure alone is not categorized in intersection improvement.

(3) Points to Note in Intersection Design

In general, many pedestrian and bicycle traffic accidents occur at intersections, so when designing intersections, it is necessary to design a road space that allows pedestrians and bicycles to pass safely and smoothly along with automobiles. For this purpose, it is important to set premise that pedestrians cross and bicycles pass on the carriageway, and it should be noted that this is different from the conventional design concept of level crossing. On the other hand, there are some issues that cannot be completely prevented by the facilities, such as crossing outside the crosswalk and vehicles turning left ignoring pedestrians crossing. For these issues, it is also important to recommend that the implementing agencies provide traffic safety education.

(4) Indices for Improvement Effect of Intersections

Major indices representing the effect of intersection improvement is shown in Table 2.21.

Table 2.21 Indices for Improvement Effect of Intersections

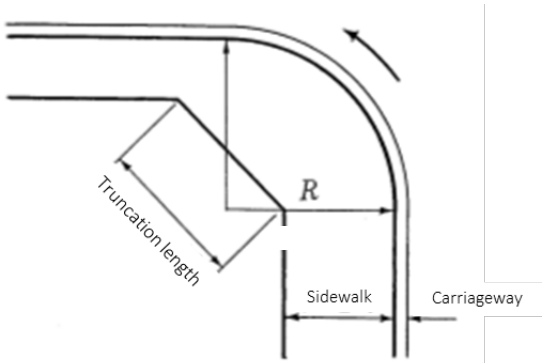
Indicator	Explanation
Degree of saturation	Degree of saturation is an index showing the ratio of the traffic volume flowing into the signalized intersection and the traffic volume that can pass through the intersection. Basically, when the value exceeds 1.0, it means that the capacity at the intersection is insufficient for the traffic demand.
Delay time	Delay time caused by congestion or waiting for a signal. Overseas, the evaluation index is often the "Mean delay" at signalized intersections shown in HCM (Highway Capacity Manual)[8] in the United States.
Storage length	Distance from the stop line to the end of the remaining vehicle when the red light changes to the green light.
Congestion length	Distance between the stop line and the last vehicle that could not pass the stop line when the green light changes to red light.
Number of signal waiting	Passing time of intersection divided by signal cycle time

Source: JICA Study Team

☞ Truncation curve radius of intersection

If the truncation curve radius of an intersection becomes large, there is a concern that traffic accidents will increase. Therefore, the design vehicle for determining the curve radius should be selected in consideration of the followings:

- Traffic conditions such as traffic volume and vehicle type composition,
- Land use around the intersection, particularly facilities where large vehicles generate,
- Surrounding road network, and
- Certainty that emergency vehicles can turn smoothly.



Source: Plan and Design of At Grade Intersection[25]

Figure 2.17 Truncation at Intersection

☞ Traffic Jam and congestion

In Japan, traffic jam is defined as a situation where the average speed per hour is 10 km/hour or less on general roads, 40 km/hour or less on expressway, and congestion is defined as 20 km/h or less on general roads. There is no definition of congestion on expressways.

2.6 Road Earthwork

(1) What is Road Earthwork

Road earthwork is a general term for the construction of structures composed mainly of ground materials such as earth and sand and rocks, and the structures resembling them, in order to construct roads. Structures constructed by road earthwork refer to cuts, embankments, slope stability facilities, culverts, and structures similar to them. Of these, retaining walls and culverts are described in detail in "3.5 Structural Design".

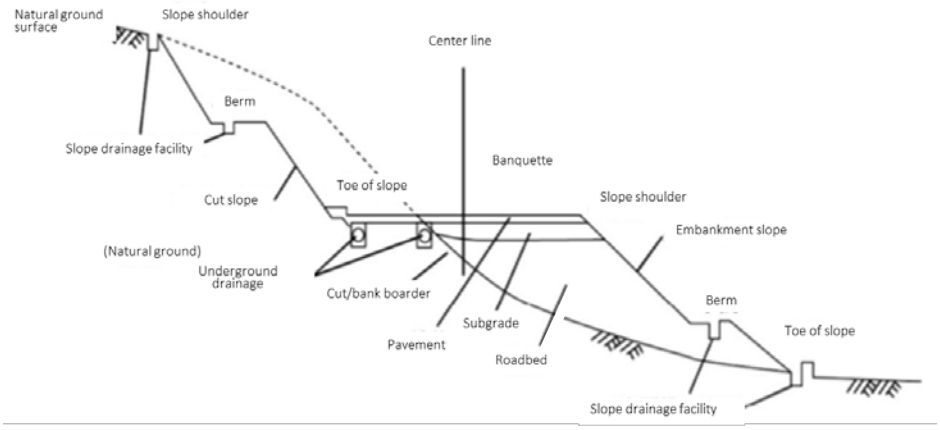
In mountainous hilly areas, the basic idea is to minimize the cost of earth moving by balancing the amount of cut and fill from the standpoint of economic efficiency. However the reality is that not much emphasis is placed on road earthworks because bridge and pavement works are often the main focus of Grant Aid projects. Road earthwork structures are characterized by high uncertainty that the conditions at the actual site differ from the conditions set as the premise of planning and design. For this reason, it is important to take design considerations and construction measures to restrain the impact in case of unpredictable situations such as collapse, etc. during construction.

- Cut and slope stabilization facility

- Embankment
- Culvert

Source: JICA Study Team

Figure 2.18 Major Structures by Road Earthworks



Source: JICA Study Team

Figure 2.19 Name of the Major Part of Cut/Bank Slope

The standard gradient of the of cuts and embankments (hereinafter referred to as "standard slope") that can be regarded as appropriate based on past experience and achievements has been established, and conditions such as scale and materials that can be generally applied are defined. Therefore, it is necessary to meet these conditions for application. Especially in recent years, large-scale road earthwork structures such as high embankments may be constructed due to the development of new technology and consideration of economic efficiency. In designing these structures, it should be carefully judged whether or not the design method regarded as appropriate based on the experience and achievement is applicable, taking into account the contents of the method, the scale of the earthwork structure, materials to be used, construction and maintenance management. If necessary, appropriate and more reliable design methods should be applied.

(2) Embankment

Embankment is raising ground by heaping up soil on low ground or slopes and creating a flat surface or ground higher than the surroundings. The role of road embankment is to support traffic load and the following items are necessary to be considered: 1) stability of foundation ground and restraint of subsidence against embankment load, 2) stability of embankment itself against traffic load (compressive subsidence, slope stability), 3) influence on surrounding nature and human life.

The economic advantage of embankment is that the embankment material is basically soil generated at the site (soil diverted from the cut section), or soil dressing from the borrow pit along the road. However, there are many different types of soil, and the physical property values change depending on the weather conditions and construction period, so it is important to investigate/test the embankment material to be used. It is necessary to conduct a stability analysis in the following embankment cases:

Embankment that requires stability analysis

- In the case of soft ground
- In the case of unstable ground such as places where landslide occurred
- When affected by spring water from the ground
- When affected by groundwater from nearby rivers
- In the case of embankment on steep slopes
- Embankment conditions by height (when the embankment material and the embankment height shown in the standard gradient of the slope with respect to the embankment height are exceeded)
- Conditions by the embankment material (when the embankment material is made of clay with high water content, cohesive soil or other soil with low shear strength, or soil such as silt where pore water pressure is likely to increase)
- Others (when the embankment slope is flooded or the area near the embankment is eroded).

(3) Cut

Cutting is the creation of a flat surface by cutting down slopes and ground with different height. It may also include construction of ground lower than the surrounding area. It may also refer to the earth and sand that was cut out as a result of the construction. By using the earth and sand generated by cutting for embankment, construction cost can be reduced. The natural ground is extremely non-uniform and its strength varies significantly depending on the degree of weathering and cracking, stratification, gaps

and water content. Therefore, the gradient of the slope will be determined by comprehensive judgment taking into consideration the local conditions and the conditions of the existing slope.

When adopting cut work, it is important to clarify the soil soft and hard classification by geological survey, because the excavation unit price varies greatly depending on the soil soft and hard classification of the excavated soil. The soil soft and hard classification is classified based on workability, and the concept is different from the engineering rock classification (index for classifying the bedrock condition). Grounds that cannot be excavated without blasting are called hard rock, grounds that can be excavated with a ripper are called soft rock and grounds that can be excavated with a bulldozer are called gravel.

Soft rocks such as Tertiary mudstone, low-consolidation tuff, and serpentines are rapidly weathered by stress release, water absorption and expansion, and repeated drying and wetting and freezing and thawing after cutting.

(4) Slope Protection Work

Slope protection work is carried out to protect the slope with a structure using plants, concrete, stones, etc. to prevent erosion and weathering of the embankment and cut soil slope, and to stabilize the slope. Table 2.22 shows the types of major slope protection work. Beside these, rock-fall prevention fence work to prevent stones and soil from falling, rock fall prevention network, and slope drainage work to prevent slope scouring due to spring water are also included in the slope protection work in a broad sense. The slope also includes a vertical plane. In addition to the purpose of slope stability, slope protection work is also essential measure for environmental conservation and maintenance of a good landscape.

Table 2.22 Types of Slope Protection Work

Type		Definition	Example
Slope protection by structure	Anti-earth pressure type protective work	Construction method that can cope with earth pressure to some extent	Masonry, block masonry retaining wall, concrete retaining wall
	Sealed protection work	Construction method to prevent surface water penetration	Mortar spraying, concrete spraying
	Open type protection work	Erosion prevention work that allows surface water to penetrate	Crib works filled with cobble stone
Planting	Construction method without structure	Construction method without structure	Planting, Rockfall protection net

Source: Road survey and design know-how[26]

(5) Points to be Noted in Slope Protection Work

Slope protection works are carried out to prevent slope failures due to cuts and embankments associated with road improvement and bridge construction. In many cases, the cause of these collapses is justified easily by unpredictable geological conditions. However, it cannot be denied that it may be foreseen if sufficient research is conducted. The "unforeseeable physical condition" of unobservable underground conditions has become a global issue, and FIDIC (International Federation of Consulting Engineers) has decided that in the FIDIC Emerald Book [2], a contractual agreement for underground structure construction, it is obligatory to prepare GBR (Geological Baseline Report) before bidding for construction work. In addition to the contents described in general geotechnical investigation reports

[2] It shows the contract conditions for underground works designed by the contractor according to the reference design by the owner and the geoengineering baseline report, and the first edition was published in 2019.

such as geology, geological composition, and soil constants, the GBR describes assumed geological and ground-related risks and their countermeasures.

In Japan, technical standards such as "Road Earthwork-Cut and Slope Stabilization Guidelines" determine the standard gradient of the slope of embankment and cut according to the embankment material and soil quality of the ground, and it is common for the standard gradient of the slope of the embankment and cut to be determined at the time of planning and design according to the standards. This "standard gradient of the slope" is a Japanese rule of thumb, and the standard gradient is empirically set by drawing a line between the place where it collapsed on a steep slope and the place where it did not collapse on a gentle slope. However, this is based on the combination with the soil and climate of Japan. Therefore, it should be noted that it is not appropriate to apply an unchanged numerical value without any consideration. In addition, the design technology of slope protection work in Japan tends to have developed independently in Japan, and it is difficult for engineers in Western countries and developing countries accustomed to the knowledge of Western countries to understand. The approach to stability analysis method shown below, parameter setting and calculation method used for slope stability calculation are also different from the standard overseas methods. For this reason, there are many challenges in applying the Japanese method.

Table 2.23 Difference in Method of Slope Stability Analysis

Item	Japan	Overseas
Stability calculation	Inverse analysis	Forward analysis
Soil parameter	Mainstream method is inverse analysis that evaluates the strength of the entire collapse slip surface using the topographical and water level conditions in the critical equilibrium state by engineer.	Mainstream method is forward analysis that set the slope strength from the results of the laboratory tests of collected specimens for laboratory tests on site.
Calculation method	The Fellenius formula is applied to non-arc landslides as a simplified equation. This method, which ignores the force between slices (force acting on the side wall of the slice), is said to be illogical.	Advanced stability analysis formulas such as the Spencer method are used. The Fellenius formula cannot be applied to non-arc slips in Western countries. In Eurocode7 (2013): Geotechnical Design Worked examples, it is clearly stated that the Fellenius formula can only handle the balance of rotational moments.
Evaluation method	Starting moment×α≦resisting moment × β *α and β are extra coefficient, which are individually defined by national standards. **Japan: α=1.25, β=1.00	

Source: http://blog.livedoor.jp/ohta_geo/archives/51854805.html

In addition, "Basic research on slope countermeasure for road disaster prevention" is underway separately, so please refer to the results for more details.

(6) Measures against Soft Ground

Soft ground is generally composed of soil layers such as soft clay, silt, organic soil, or loose sandy soil. Groundwater levels are high on soft ground, which may affect the stability and subsidence of embankments and structures. Generally, cohesive soil has an N value of 4 or less, and sandy soil has an N value of 10 or less. In embankment on these grounds, it is necessary to consider measures for soft ground, depending on the scale of embankment. Specifically, the problems of embankment which occur on soft ground at the construction stage is roughly divided into stability against embankment collapse,

excessive subsidence and deformation of surrounding ground. And in the maintenance stage, residual settlement is a problem. For this reason, when designing embankments on soft ground, it is necessary to make full use of the results of soil surveys, examine the stability and subsidence of embankments, and consider the impact on the surrounding ground.

The following cases are road construction projects carried out in the African region although not cases of Grant Aid Project. The section in the photo below is a wetland (Swamp). In this case, the improvement range and depth of the soft ground became larger than originally expected, and the project cost increased significantly. According to the results of the geological survey, it was reported that the groundwater level was low and there was no soft ground, however when excavation was started at the construction stage, groundwater and soft ground were present.

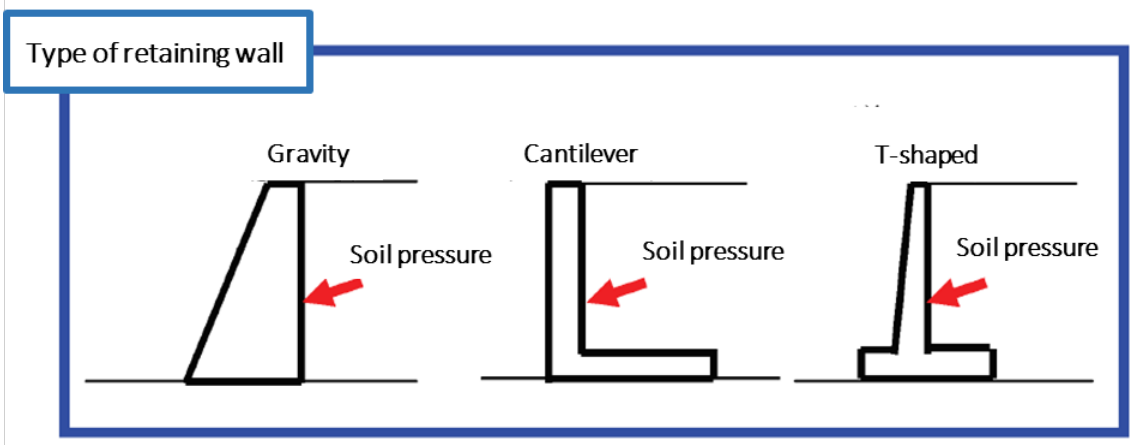
2.7 Structural Design

(1) Target Structure and Design Method

Structural design at the preparatory survey stage is to determine the optimal structure type and basic structural dimensions which is in conformity with basic conditions such as topography, geology, and location conditions, based on the comparative study of structural types for each structure from the viewpoint of stability, workability, maintenance, and economy. No detailed structural calculation is required. It is important to always plan the structure with "overall optimization" in mind over the entire construction production process of survey, design, construction, inspection, maintenance and renewal. The target structures include relatively large-scale structures such as retaining walls, culverts, and bridges.

(2) Retaining Wall

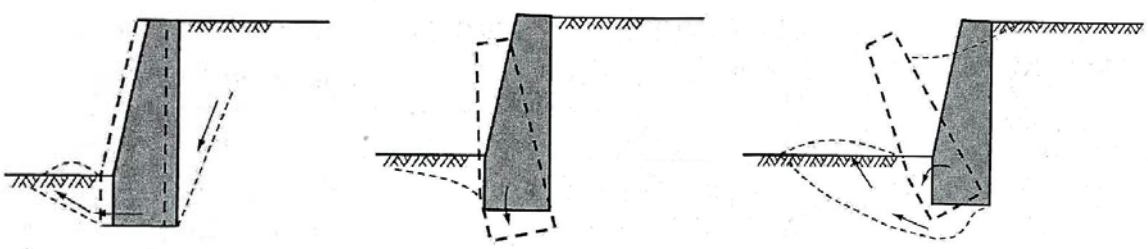
A retaining wall is a wall structure that resists soil pressure by the weight of the wall and the weight of soil on the surface of the bottom slab, and stabilizes the steep slope created by cut or embankment. When selecting a retaining wall, compatibility with the purpose of use, safety and durability of the structure, ensuring construction quality, ease of maintenance, harmony with the environment, and economic efficiency should be considered.



Source: Materials created by Professor Fumio Tatsoka, Department of Civil Engineering[27], Tokyo University of Science

Figure 2.20 Types and Outline of Retaining Wall

The stability of the retaining wall under soil pressure requires three conditions: it does not slide, it does not tip over, and the foundation ground does not break.



Slipping Over-turning Breaking of foundation ground

Source: Materials created by Professor Fumio Tatsoka, Department of Civil Engineering[27], Tokyo University of Science

Figure 2.21 Three elements for Stability of Retaining Wall

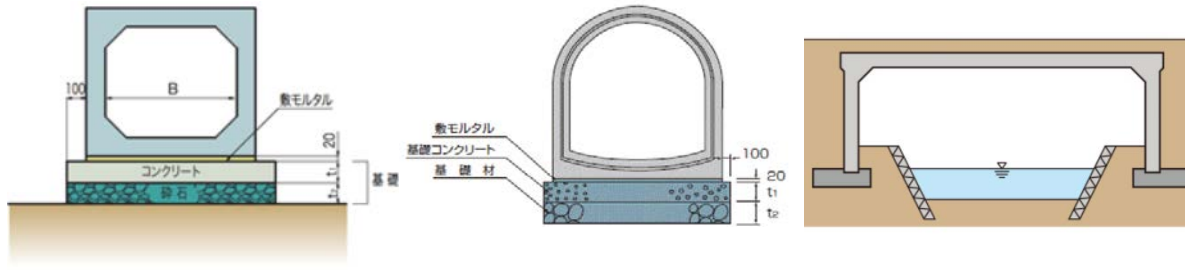
(3) Culvert

In the survey, planning and design of culverts, a structure suitable for road design and construction, and economically advantageous will be planned. The box culverts targeted by the Grant Aid Project are mainly cast in place culverts, and the applicable earth covering is 20 m or less.

Table 2.24 Applicable Range of Culvert

Type of Culverts		Applicable earth covering (m)	Size of cross section (m)
Rigid box culvert	Cast in place box culvert	0-20	Width of inner space: under 6.5 Height of inner space: under 5
	Cast in place arch culvert	10 or more	Width of inner space: under 8
	Portal culvert	0.5-10	Width of inner space: under 8

Source: Road Earthwork - Culvert Work guideline[28]



Box culvert　　Arch culvert　　Portal culvert

Source: JICA Study Team

Figure 2.22 Type of Culvert

In the planning and designing box culverts, the following points are noted.

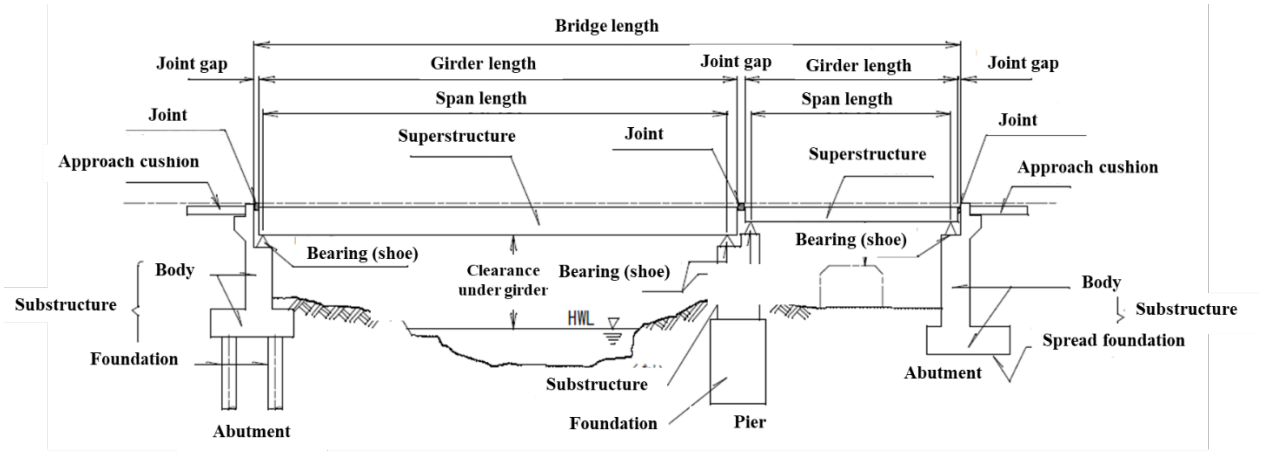
- Backfilling material must be soil/gravel.
- The lengthwise gradient of the culvert must be within about 10%.
- There should be no hinge on the cross section of the structure because a hinge causes large displacement and deformation.
- Culvert should be installed independently, and multiple culverts should not be installed in close proximity.
- In principle, culvert should be directly supported by spread foundation.
- The structure should not be divided into multiple structures by central pillar, because it becomes a structural weakness at the time of an earthquake.
- 50 cm of soil cover should be secured because there is a possibility that the pavement may become uneven.

Source: Road Earthwork - Culvert Work guideline[28]

Box culverts should be designed appropriately in consideration of ground conditions and fluctuations in groundwater level. If the culvert is installed below the groundwater level, the water pressure is considered in designing the cross section. Culvert lift by buoyancy must be considered in a stability check when the culvert is installed below groundwater level.

(4) Bridge

A bridge is a general term for structures constructed to cross obstruction of transport such as rivers, valleys, lakes, straits, roads, railroads, waterways, etc., and is basically composed of a superstructure and substructures.



Bridge length: Length between the front end of the parapet on both ends of the pier

Girder length: Length of superstructure

Span length: Length between bearings

Superstructure: Parts that directly support pedestrians and automobiles, such as floor slabs and girders

Substructure: Parts that support the superstructure (abutments, piers, foundations)

Bearing (shoe): A member installed at the contact point between the substructure and the superstructure to transmit the load from the superstructure to the substructure.

Joint: Members installed between the superstructure and the pier or between the superstructures

Joint gap: Made for the purpose of absorbing expansion and contraction due to temperature changes, etc.

Source: Outline of bridges create[29] *by Kikuchi City, Kumamoto Prefecture*

Figure 2.23 Name of Each Member and Parts of Bridge

There are various classification methods for bridges, such as classification by type, classification by materials used, and classification according to the purpose of the bridge. Table 2.25 shows classification according to the materials used which is the easiest to understand.

Table 2.25 Classification of Bridges by Used Material

Items	Concrete bridge		Steel bridge
Outline	A bridge that uses concrete as its main material. It is classified into three types, RC (Reinforced Concrete) bridges, PC (Prestressed Concrete) bridges, and PRC bridges with intermediate characteristics between RC bridges and PC bridges, according to the presence or absence of prestress and its introduction method, and the amount of prestress given to the cracking characteristics of concrete.		A bridge that uses steel for its main structure. It is often used for bridges with long spans because the bridge can be made lighter than concrete. Steel bridges need to be repainted to prevent rust.
	RC bridge: Reinforced by reinforcing bars in concrete so that the reinforcing bars resist the tensile strength. Some cracks occur in the tensile side of the concrete. If an excessive load is applied, cracks will remain after the load is removed.	PC bridge: A prestress is applied so that tensile strain that causes harmful cracks does not occur when a design load is applied, and the proof stress is also secured by PC steel.	
Weight	Heavy		Light
Strength feature	Strong against compression and weak against tension		Weak against compression and Strong against tension
Maintenance	Few		Many
Production of girder	Factory production, on-site production		Factory production
Introduction to Grant Aid Project	Many		Few
Remark	In Japan, concrete and steel are stably available, so both concrete bridges and steel bridges are widespread and are selected by taking advantage of their respective characteristics. On the other hand, in developing countries, few steel bridges have been adopted because steel is difficult to process and obtain and it is an imported material, and maintenance is difficult.		

Source: JICA Study Team

The following points should be noted when planning and designing bridges.

- Satisfy all road alignment limits such as maximum vertical gradient, minimum vertical curve radius, minimum horizontal curve radius, and plan the bridge considering the obstacle property.
- The height under the girder of the bridge exceeds HWL (High Water Level) + required clearance.
- Avoid sections where river flow conditions change, such as narrow points, water colliding points, confluences, and curves.
- Avoid sections with large riverbed fluctuations such as change points of riverbed gradient.
- The direction of the bridge should be perpendicular to the direction of the flow during the flood.
- Harmonize with the landscape, natural and social environment.

In the comparative selection of bridge spans and bridge types, comprehensive evaluation is conducted from the following viewpoints in Japan.

Table 2.26 Items to be Investigated in Selecting Bridge Span and Type

Judgment index	Evaluation criteria	Points to note
River cross section obstruction rate	A	For general bridges, within 5%. It should be noted that the effect on the water level rise differs depending on the installation position of the pier.
Girder height	A	Satisfying HWL + required clearance under the girder is a prerequisite. If there are restrictions on the road surface height by the vertical alignment, the bridge structure may be restricted.
Passages for river management	A	When piers are installed over the embankment, it is necessary to consider securing a management passage.
Pier installation position	A	It is desirable not to install piers near the toe of slope and the low water riverbank. The installation position of the pier must satisfy the standard span length and the special provisions of the adjacent bridge.
Validity of hydraulic properties	B	Evaluate the impact of the pier placement plan on the river flow and verify its validity.
Economic efficiency	C	For both superstructure and substructure, economic comparison will be made considering maintenance costs, riverbank protection works and environmental countermeasure costs.
Workability	C	Since the superstructure type may be restricted by the erection method, the construction conditions should be carefully considered. Since the structural type of substructure may differ depending on whether construction during the non-flood season is possible, consider the construction conditions.
Maintenance	C	When examining the structural type of PC bridges and steel bridges by the span length, maintenance costs are also considered.
Construction period	C	The construction period is shortened in order to reduce the impact on surrounding traffic and the environment. When carrying out construction during the flood season, consider the degree of hydraulic safety.
Environmental impact	C	Evaluate the difference in noise caused by the bridge type and the impact of installing piers on river ecology.
Impact on the landscape	C	Consider whether the bridge structure is in harmony with the surrounding landscape.

A: Conditions that must be satisfied
B: Conditions to be fully noted from the viewpoint of hydraulic impact
C: Conditions that should be evaluated relative to other items
Source: Guide to planning for bridges that cross rivers (draft)[30]

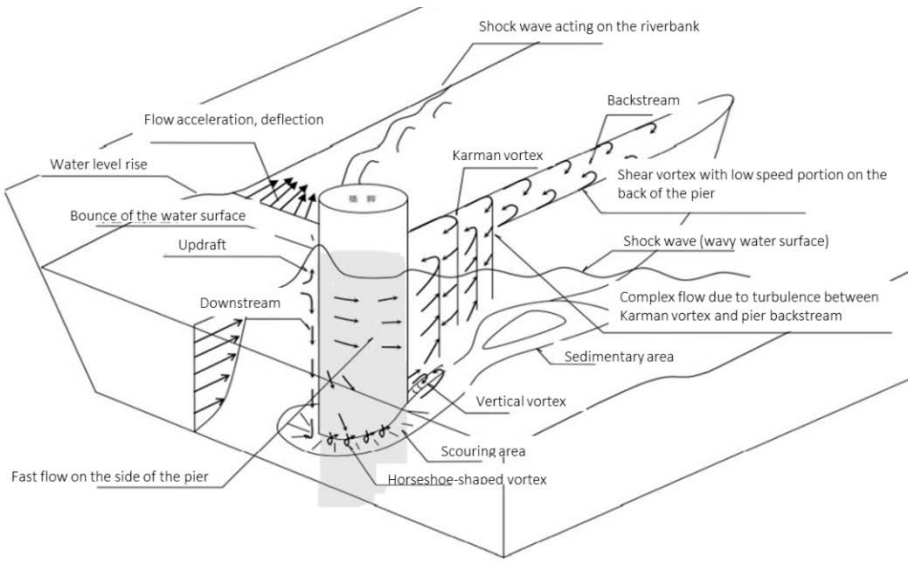
Table 2.27 Type of Superstructure and Applicable Span Length

Bridge Type			Appliable Span (m)	Achievement Maximum Span(m)	Ratio of Span to Girder Height	Unit Cost per Sq. m (USD)
STEEL	Plate Girder	Simple Composite H Girder Bridge		25	1/14 ～ 1/27	-
		Simple I Girder Bridge (Regular)		(44)	1/15 ～ 1/20	1500 ～ 3500
		Simple I Girder Bridge (Small number of main girders)		60		2000 ～ 5000
		Simple Composite I Girder Bridge		60	1/16 ～ 1/21	1500 ～ 3500
		Simple Box Girder Bridge		70	1/18 ～ 1/25	1500 ～ 3500
CONCRETE	Reinforced Concrete	Simple Slab Bridge		10	1/10 ～ 1/15	-
		Contenious Slab Bridge		20	1/11 ～ 1/16	-
		Simple Hollow Slab Bridge		15	1/14 ～ 1/17	-
		Contenious Hollow Slab Bridge		20	1/15 ～ 1/18	-
	Prestressed Concrete	Pre-tensioning Simple Slab Bridge		(24)	1/14 ～ 1/24	1300 ～ 1950
		Pre-tensioning Simple T Girder Bridge		(24)	1/18 ～ 1/20	1200 ～ 1650
		Post-tensioning Simple Slab Bridge		(45)	1/23 ～ 1/26	-
		Post-tensioning Simple T Girder Bridge		(45)	1/13 ～ 1/18	1750 ～ 2600
		Post-tensioning Simple Bulb T Girder Bridge		49	1/14 ～ 1/19	
		Post-tensioning Composite Bridge		45	1/13 ～ 1/17	1800 ～ 2500
		Post-tensioning U Composite Bridge		55	1/16 ～ 1/18	1850 ～ 2500
		Simple Hollow Slab Bridge		37	1/22	1800 ～ 2900
		Simple Box Girder Bridge		70	1/17 ～ 1/20	2200 ～ 3350

Source: JICA Study Team based on Design and Construction Manual (Draft) [Road Bridge Edition] [31]

When designing the structure, the ground that forms the basis of the abutment and piers should be thoroughly surveyed and the survey results will be examined. In particular, there is a possibility that strong rocks that cannot be seen in Japan will appear, so thorough investigation is required. Other important points to note are as follows.

- Select an appropriate external force when designing
- In particular, the vehicle load may vary depending on the target country.
- If the risk of a strong earthquake is expected, set the design seismic force appropriately based on the local data.



Source: Guide to planning for bridges that cross rivers (draft)[30]

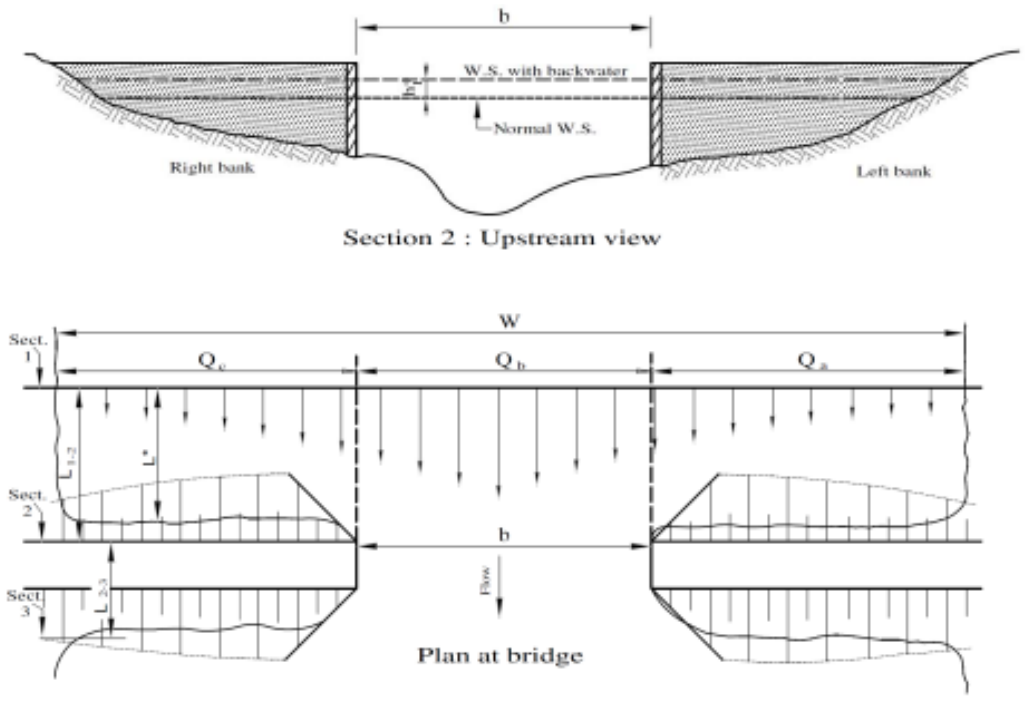
Figure 2.24 Water Flow around Pier

The hydraulic characteristics of the bridge erection point differ depending on various factors, such as the shape and width of the river channel, flood characteristics, the shape of the pier and abutment, and the installation position. When conducting a hydraulic study, it is necessary to anticipate the following hydraulic issues caused by the installation of bridges, which are generally of concern, and accordingly to determine the study items and study methods.

- Water level rise upstream of the bridge point due to pier weir
- Impact of increased flow velocity and drift on the embankment
- Impact on surrounding riverbed fluctuations due to changes in bedload
- Local scouring of riverbanks due to increased flow velocity and turbulence

Regarding the flow velocity of rivers, the "Technical Criteria for Sand Control and River Works[32] in Japan" sets the standard of flow velocity to about 2 to 4m/s. For rivers in urban areas, it is desirable to set it to 2 to 4m/s because the riverbed gradient is gentle, and it is desirable to keep it to about 5m/s even if it is unavoidable in mountainous areas.

In bridge planning in developing countries, river improvement before and after the bridge position may not be implemented, so the abutment may be installed inside the river as shown in Figure 2.25. The most important thing in hydraulic studies in such cases is to determine which of the following two methods be selected for phenomena such as embankment destruction and riverbed scour caused by installation of the bridge. One is to deal with the issue by method of bridge installation, such as the installation position and direction of the pier and abutment, and the other is the countermeasure in the river, such as the installation of protection work by revetment and riverbed protection. It is also important that the embankment of approach section has a structure which can avoid overflow so as not to affect the periphery of the upstream part.



Source: Drainage Manual 6th Edition[33]

Figure 2.25 Relationship between the Position of the Abutment and the Flow

In the U.K., measures to increasing risk of flooding due to global warming and the resulting risk of flooding in areas including roads are taken up as "flooding area". The goals are to 1) secure traffic even during floods (road disaster prevention measures) and 2) not to worsen the surrounding water environment (environmental impact assessment approach). Countermeasures include prevention of overflow by embankments, and appropriate leading of water downstream by culverts, etc., if countermeasures by embankment are impractical.

In developing countries, where rivers are not always developed, overflow water from rivers can cause flooding of roads. Therefore, it is required to take some measures against this risk. As a practical example of a JICA project, in the "Bridge Rehabilitation Project in National Highway 9" in Laos, assuming that the flood flow in the upstream reaches the embankment part of bridge abutment, a large ditch was designed to deter floodwaters from reaching the embankment where the bridge is attached, and a larger cross-sectional culvert was also designed to properly flow downstream and quickly return to the mainstream. It is necessary to incorporate the concept of "protecting roads and surrounding areas from further flood damage in the surrounding areas" by referring to such examples.

Table 2.28 Matters of Concern Caused by Bridge Installation and Contents of Hydraulic Study

Study items	Water level rise upstream of the bridge point due to pier weir	Impact of increased flow velocity and drift on the embankment	Impact on surrounding riverbed fluctuations due to changes in bed load	Local scour of piers and riverbanks due to increased flow velocity and turbulence (every flood)
Contents of hydraulic Study	Prediction of longitudinal water level rise in the upstream section of the bridge point	Prediction of planar flow direction and flow velocity distribution around the bridge installation point	Prediction of short-term and long-term riverbed fluctuations in the upstream and downstream sections of the bridge	Prediction of the degree of local scouring around the bridge point
Examples of evaluation criteria in hydraulic studies	・The predicted water level upstream of the bridge point falls below HWL. ・The safety of the existing embankment upstream of the bridge point is ensured. ・For existing bridges upstream of the bridge point, a certain margin under the girder is secured, etc.	・Flow velocity increment does not increase compared to before installation ・No drift to the riverbank ・High-speed current does not collide with the position that is supposed to be the weak point of the embankment. ・Revetments, etc. are planned within an appropriate range in the predicted water colliding points, etc.	・In the section where the riverbed is expected to lower, the safety of new and existing structures is ensured. ・Flowability is secured in the section where the riverbed is expected to rise, etc.	・The safety of new and existing structures is ensured against the expected local scour. ・Protective work is planned within an appropriate range for the predicted local scour, etc.

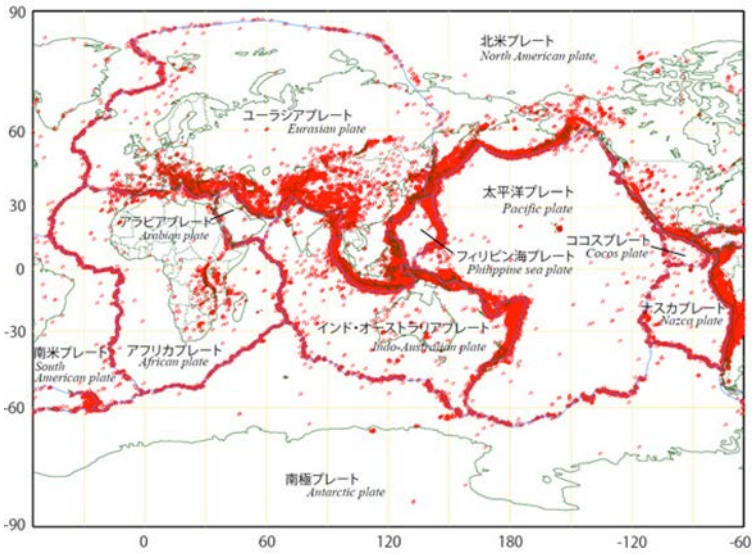
Source: JICA Study Team based on Guide to Planning of Bridges That Cross Rivers (draft)[30]

(5) Seismic Design of Structures

For major structures, it is conceivable to carry out seismic design considering damage caused by the earthquake. In Japan, it is stipulated in the Specifications for Highway Bridges that seismic design should be carried out to satisfy the required seismic performance in the event of a disaster, and appropriate parameters have been set based on the history of damage caused by past earthquakes. And the parameters are revised every time an earthquake occurs that exceeds the earthquake ground motion

assumed in the design.

Thus, Japan has experienced numerous earthquakes, and the importance of seismic design is very significant, as design against earthquakes is the dominant factor in determining member dimensions and material strength. On the other hand, in African countries, the damage caused by earthquakes is extremely small compared to Japan, and the recipient countries are not fully aware of and do not fully understand earthquake-resistant design. On the other hand, it has been confirmed that if the standards of each country were applied as they are, over-engineered structures that are not suitable for the site and structures that have construction problems would be designed.



Source: Japan Meteorological Agency HP

Figure 2.26 Distribution of Major Plates and Earthquakes in the World

Each country has a different approach to seismic design, and the required seismic performance also varies. Therefore, after understanding the concept of seismic design of the applicable standards, it is necessary to stipulate appropriate seismic performance based on the importance of the target structures, routes and regions, and to carry out seismic design by assuming an earthquake that matches the actual conditions of the target country. In particular, when plasticity is taken into account in the design, sufficient attention should be paid to the setting of seismic performance (= allowable plasticity and residual displacement), because the degree of plasticity may be a factor that determines the ease of recovery after a disaster.

It has been reported that when the design horizontal seismic intensity of Level 2 earthquake ground motion in the target country was set based on local earthquake records, elastic design was performed because this parameter was equivalent to the value of Level 1 earthquake ground motion in the Specifications for Highway Bridges of Japan. This is not a problem in itself, but it is important to consider and decide whether plastic or elastic design should be used for seismic response from various viewpoints such as structure, recoverability, and economy, based on the results of both the specifications of the structure based on normal design and the specifications based on seismic design.

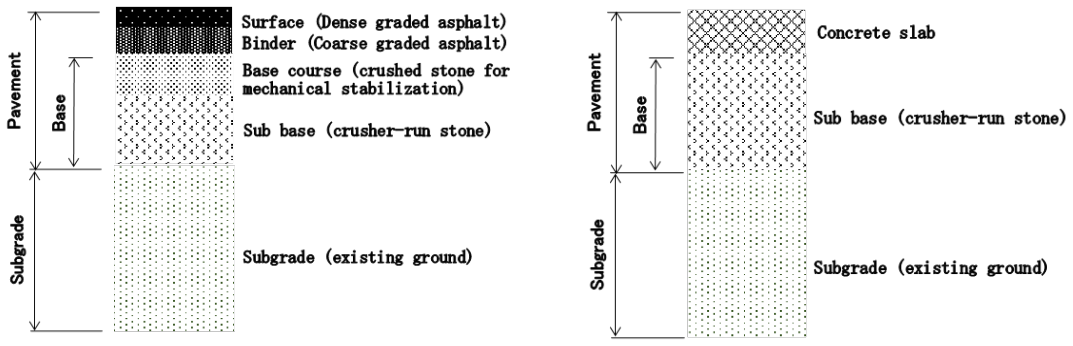
2.8 Pavement Design

(1) Type of Pavement

Pavement is the hardening of the road surface with asphalt or concrete in order to create a durable road, as well as to prevent the road from becoming muddy in the rain, and to increase comfort and safety when driving or walking. In the design, pavement should have the necessary thickness and quality to withstand the effects of traffic loads and the natural environment, and have mechanically and economically balanced structure so that each layer shares the load appropriately according to the bearing capacity of the base course/subbase course.

Pavement is to solidify the surface of the road with stone, brick, concrete, asphalt, etc. to increase the durability of the road. The role of pavement is: i) preventing muddiness in rainy weather and to preventing dust during drying by providing a dense layer on the road surface, ii) improving comfort and safety while driving or walking by flattening the road surface and providing appropriate friction resistance.

The types of pavement have their respective names depending on the surface material, construction method, function, and location, and it is difficult to classify them uniformly. From a practical aspect, type of pavement can be classified to asphalt pavement and cement concrete pavement. The asphalt pavement is a pavement with an asphalt mixture on the surface course, while the cement concrete pavement is a pavement with a cement concrete on the surface course. Asphalt pavement is generally composed of four layers from top to bottom: surface course, binder course, base course, and subbase course, and concrete pavement is composed of three layers: concrete slab, base course, and subbase course. The 1m beneath the subbase course is called the subgrade. Pavement is the part above the subgrade.



Asphalt pavement **Concrete pavement**

Source: JICA Study Team

Figure 2.27 General Composition of Pavement Layers

The role of each layer is as follows:

- Surface course: The top layer of asphalt pavement. The surface course is required to disperse the traffic load and transmit it to the lower part, as well as to have appropriate sliding friction and flatness so that the driver can drive safely and comfortably.

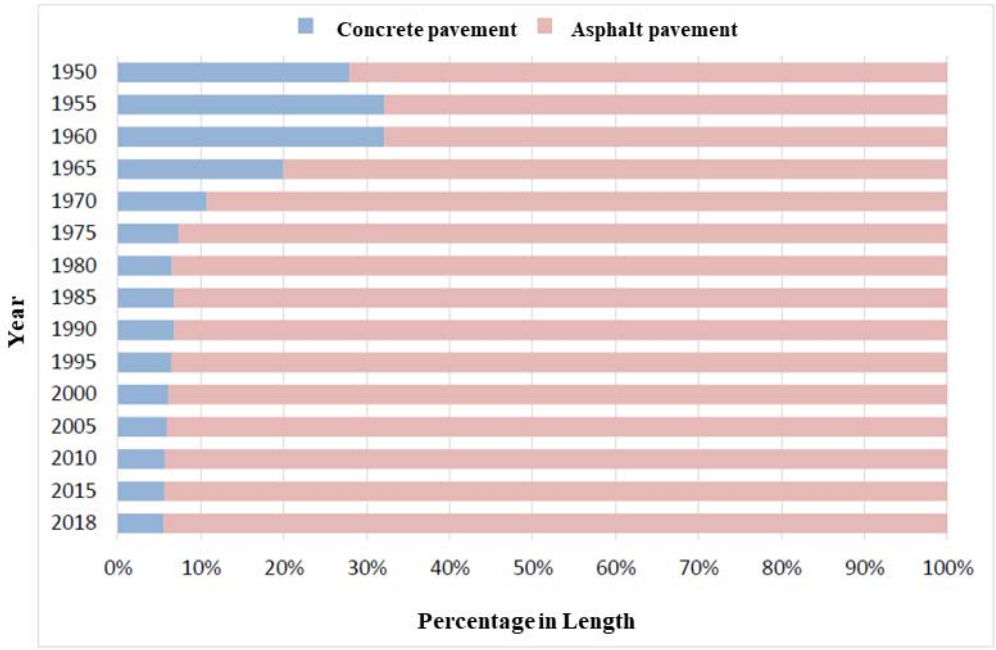
- Binder course: A layer on the base course that corrects the unevenness and that evenly transfers the

load applied to the surface to the base course. It is usually made from a coarse-graded asphalt mixture.

- Base course: A layer on the subgrade that plays a role of distributing the load from the asphalt mixture or cement concrete slab to the subgrade. Generally, it is divided into two layers, a base course and subbase course. The base course is constructed by the bituminous stabilization method, or cement stabilization method. And the subbase course has less stress than the base course, so for economic efficiency, crusher-run, cut gravel, or locally produced stabilized materials are used.

- Subgrade: In Japan, the subgrade is approximately 1 m part from the bottom of the pavement of the ground supporting the pavement. The role of the subgrade is to support the traffic load together with the pavement and to distribute the traffic load to the road body below the subgrade almost evenly. The subgrade also serves as a construction foundation for the pavement constructed on it. It should be noted that the thickness of the subgrade depends on the standard of the country to be adopted.

As shown in Figure 2.28, asphalt pavement accounts for most of the present road pavement in Japan. The ratio of recent concrete pavement remains at around 5%. Looking at the present situation overseas as shown in Table 2.29, it can be seen that asphalt pavement and concrete pavement are used at a certain ratio, and both types of pavements are used according to the characteristics of the site.



Source: Approach for expanding the application of concrete pavement[34]

Figure 2.28 Ratio of Asphalt Pavement and Concrete Pavement in Japan

Table 2.29 Present State of Concrete Pavement in Foreign Countries

Country	Ratio of concrete pavement
USA	Interstate Highway and other arterial roads Concrete Pavement: 13% Composite Pavement: 19%
UK	Highways: 20% Arterial roads: 6%
Germany	Autobahn in former West Germany: 30% Autobahn in former East Germany: 82%
France	Highways: 15%
Belgium	Expressway: 40% National road (arterial): 20% Province roads: 35%
South Korea	National road: 2%, Highway: 60%
China	Highway: 20%

Source: JICA Study Team based on "Use concrete pavements wisely" [35]

Asphalt pavement and concrete pavement differ not only in the surface material but also in the concept of load propagation. In asphalt pavement, each layer shares the stress and sequentially distributes the load. On the other hand, in cement concrete pavement, the loaded weight is borne by the highly rigid concrete slab, and the base course under the slab evenly distributes the surface load. Major role of subgrade is to support and ensure workability. For these reasons, cement concrete pavement is called rigid pavement and asphalt pavement is called flexible pavement.

Photo 2.4 Asphalt Pavement

Photo 2.5 Concrete Pavement

Source: JICA Study Team

Table 2.30 Feature of Asphalt Pavement and Concrete Pavement

Items	Asphalt pavement	Concrete pavement
Design life of pavement	Niigata Prefecture considers that the design period of pavement should be set as long as possible because the impact of pavement work on traffic is large, and the design period is set to 20 years in principle. If the road administrator is different from the developer such as the municipal vicarious project or the replacement road, the period will be designed in consultation with the future administrator. In addition, if there is a plan to replace the pavement due to road widening in the future, another design period will be considered. If there is a plan to install or renew underground facilities such as lifelines, set the design period in consideration of the plan.	
Deformation resistance Abrasion resistance	Easily deforms and causes rutting. Low resistance to wear by tire chain, etc. Potholes and aggregates scattering may occur.	It is resistant to deformation such as rutting, has high wear resistance, and has almost no potholes or aggregates scattering.
Flatness	Better than concrete pavement	Inferior to asphalt pavement.
Skid resistance value	There is no problem.	It may be observed that the surface finish is lost due to running vehicles and that the sliding friction resistance is reduced because of the polishing of the exposed aggregates (polishing).
Noise/vibration	Noise and vibration are less compared to concrete pavement.	Vibration due to joints and noise due to rough surface may be a problem.
Clarity	The road reflection is weak, and it is necessary to consider increasing clarity in tunnels.	Brightness is ensured at night and in tunnels.
Workability	In general, restrictions in construction is less compared to concrete pavement. The construction speed is fast and traffic can be opened in a short time.	Restriction in construction is larger than asphalt pavement due to the long composition of the construction machine. The construction speed is slow and It takes time to open the traffic.
Ease of maintenance and repair	Easy to repair if damaged. Since the pavement follows the ground deformation, it is easy to notice the ground deformation such as landslides and the subsidence of the embankment.	Difficult to repair if damaged. Since the pavement does not follow the ground deformation, it is difficult to notice if a cavity is created due to a ground deformation such as a landslide or subsidence of a embankment. Since it is difficult to dig up, it is hard to maintain/ replace underground facilities.
Construction cost	Cheaper than concrete pavement.	Higher than asphalt pavement
Maintenance costs	Frequent maintenance and repairs are required. In 20 years term, total cost may be higher in than asphalt pavement.	When replacing, it is higher than asphalt pavement.
Comprehensive evaluation	The initial investment of concrete pavement is large and inferior to that of asphalt pavement, but depending on the traffic conditions of the road, it may be superior to asphalt pavement in terms of maintenance and management, and may be comprehensively advantageous. In Niigata Prefecture, concrete pavement is the standard pavement in tunnels, which is expected to improve lighting effects and durability. In addition, regarding to the cut section where subsidence is unlikely to occur after operation, places where the influence of noise is small, and places where underground facilities are not expected in the future, the use of concrete pavement will be examined after considering the lifecycle cost and workability.	

Source: JICA Study Team

In addition, according to the composition, construction method, and expected function to the pavement, many types are classified. Figure 2.29 shows the types of pavement classified by surface material, composition, construction method, and function.

Classification by main material	Classification by construction method and structure
Asphalt pavement	**1) Hot mix asphalt pavement**
	2) Bituminous surface treatment
	3) Simple Pavement
	Semi-flexible pavement
Concrete pavement	Composite pavement
	4) Normal concrete pavement
	5) Continuous reinforced concrete pavement
	6) Roller compacted concrete pavement
	Water permeable concrete pavement
Block pavement	Plate block pavement
	Interlocking pavement
Resin pavement	PRMS pavement
	Heat insulating pavement
	Natural colored Pavement
Natural pavement	Earth pavement
	Wood chip pavement

Classification by mixture type	Classification by mixture type	Type of asphalt mainly used
Continuous graded	Dense graded mixture	1, 2, 3, 4, 5, 6
	Course graded mixture	1, 2, 3, 4, 5
	Fine graded mixture	1, 2, 3, 4, 5
Gap graded	Dense graded gap mixture	1, 2, 3, 4, 5
	SMA	4
	High function pavement type II	4
	Rolled asphalt	1, 2, 3, 4
Open graded	Drainage asphalt pavement (High function pavement type I)	1, 2, 3, 4
	Permeable asphalt pavement	5
Guss asphalt	Guss asphalt	7,8
Base course	Asphalt stabilization base course	1, 2, 3, 9
	Large grain asphalt concrete	1, 2, 3, 9

Source: JICA Study Team

Figure 2.29 Classification of Pavement

Table 2.31 Major Types of Asphalt

No.	Type	Description	Remarks
1	Straight asphalt	40/60	Mainly used for flow resistance measures and in high temperature areas
2		60/80	Most commonly used
3		80/60	Mainly used for wear resistance and in cold regions
4	Modified asphalt	Type II	Most commonly used
5		Type III (-W, -WF)	Used in places where durability is required, such as bridge pavement. There are III-W type and III-WF type with special consideration for waterproofness.
6		Type H (-W)	Used for drainage pavement. There is H-W type that is especially waterproof.
7	Guss asphalt	Straight 20/40＋TLA	Commonly used for Guss asphalt
8		Special modified asphalt	Material with a low environmental load used in a limited way.
9	Others	Recycled asphalt	Used in recycled asphalt mixtures
10		Foamed asphalt	Used for medium temperature and workability improvement mixture
11		PG grade	Compliant with SHRP of US

Source: JICA Study Team

☞ Mixture using high modulus asphalt (10/20)

EME (Enrobé à Module Élevé), a high modulus asphalt mixture, was developed in France in the 1980s and is said to have advantages in reducing pavement thickness and providing long pavement life. It is characterized by the use of harder binders (e.g., 10/20 needle penetration) than conventional mixtures, high binder content, low porosity, high modulus, high rutting resistance and fatigue resistance. Currently, Europe has standardized production of bitumen with needle penetration of 10/20 and 15/25 for use in EME. It is also applied practically in South Africa and Australia.

When using EME, it should be noted that it is generally applied to the base course/subbase course and binder course, and is not recommended for application to the surface course. The following is a list of references for adopting EME.

- Sabita（Southern African Bitumen Association）: Design procedure for High Modulus Asphalt (EME)[36]

- Austroads: Technical Report AP-T283-14[37]
- Austroads: Technical Report AP-T323-17[38]
- Austroads: Test Method AGPT/T212 Gyratory Compactor Test Method[39]

Table 2.32 Comparison of Asphalt Pavement

	1) Hot mix asphalt pavement	2) Bituminous Surface Treatment	3) Simple pavement
Outline	Hot mix asphalt pavementIt is a pavement in which an asphalt mixture (ascon), which is obtained by heating crushed stone, sand, stone dust and asphalt and mixing in a predetermined mixing ratio, is spread and compacted. is the most common pavement. Usually composed of base course, subbase course, binder course and surface course. There are two types of asphalt mixture: room temperature mixture and heated mixture. Room temperature asphalt mixture is used as a repair material, and heated asphalt mixture is generally used in construction work such as roads and airports. In sections where large volume of heavy vehicles pass, or in low-speed sections, steep slope sections, city center intersections, etc., a heated asphalt mixture that has been improved in quality to pavement performance suitable for the purpose of use is used by adding a modifier.	DBST (Double Bitumineux Surface Treatment) is a construction method that is commonly used on general national highways and major local roads in Africa, and the details of requirements are stipulated in the General Specifications of each country. Immediately after spraying the bitumen material, the aggregate is sprayed and compacted while the bitumen material is at a high temperature. SBST (Single Bituminous Surface Treatment), DBST, and TBST (Triple Bituminous Surface Treatment) are used according to the road classification. It has a structure similar to that of the penetration Macadam pavement, and DBST has main aggregate + wedge aggregate and TBST has main aggregate + wedge aggregate + filling-up aggregate.	The simple pavement is a pavement having a simple structure that does not conform with the asphalt pavement guideline, and is usually composed of a surface layer and a base course/subbase course, and the surface layer thickness is generally about 3 to 5 cm. the simplest pavement in column 1) on the left. There are three types of surface layer, the penetration method, the room temperature mixing method, and the heating mixing method, and currently the heating mixing method is common. 2) shown on the left is a type of penetration method.
Design philosophy	In asphalt pavement, each layer from the surface course to the base course/subbase course shares and supports the traffic load. The pavement thickness is designed by the equivalent conversion thickness (TA) method with the equal conversion coefficient of the asphalt mixture set to 1.0 according to the design CBR and the traffic volume classification.	According to the pavement design standards based on Overseas Road Note 31 or SATCC Draft Code of Practice for the Design of Road Pavements, in the design that supports the load by the base course/subbase course and below, the role of the surface layer is cutoff and waterproof of the base course/subbase course, and Surface Dressing is used.	Basically, the TA method is used as in the left column 1). On small roads where large vehicles do not pass except in an emergency, the TA method can be applied by setting the standard load of small freight vehicles to 17 kN.
Application	Wide range of applications from high-standard national highways (expressways) to sidewalks and parking lots, depending on the type of asphalt concrete used and the pavement cross-section configuration.	General national roads and major local roads that support the load by the base course/subbase course and below.	Roads with low traffic and few heavy vehicles such as community roads, private roads, sidewalks, parking lots.
General cost comparison in large-scale construction	High	Low	Not applicable
	The material cost is high because asphalt concrete is used for surface course and binder course.	Material cost is low because asphalt concreteis not used.	Not applicable for trunk roads.
Merit	Wide range of application	Relatively low cost	Simple and inexpensive
Demerit	Since asphalt is a highly temperature-sensitive material, it is necessary to pay attention to prevent problems such as rutting in tropical countries.	Inferior in durability compared to hot mix asphalt.	Not applicable for trunk roads.
Photo of construction	 	 	
Rough Unit Cost Direct Cost	Sub base 30cm：2,500yen/m2 Base 20cm：2,500yen/m2 Binder course (Straight As) 5cm：1,500yen/m2 Surfaxe（Straight As) 5cm：1,500yen/m2 Total 8,000yen/m2	Sub base 30cm: 2,500yen/m2 Base 20cm: 2,500yen/m2 DBST: 500yen/m2 Total 5,500yen/m2	-
	Sub base: 30cm：2,500yen／m2 Base: 20cm：2,500yen／m2 Binder course (Straight As) 5cm：1,500yen／m2 Surfaxe（Modified As) 5cm：1,800yen／m2 Total 8,300yen／m2		

Source: JICA Study Team

Table 2.33 Comparison of Concrete Pavement

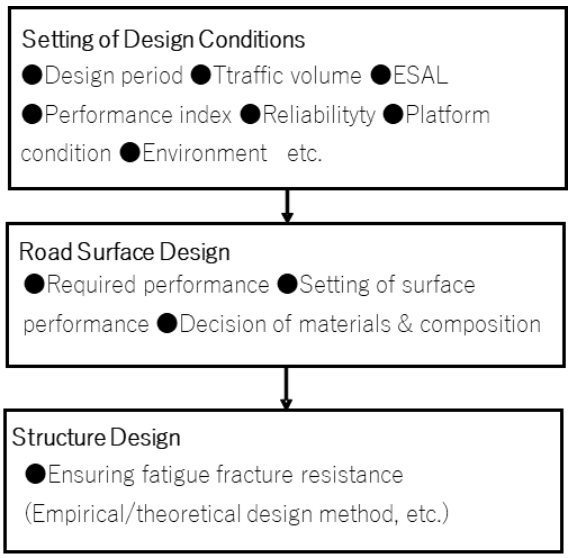
	4) Normal concrete pavement	5) Continuous reinforced concrete pavement	6) Roller compacted concrete pavement
Outline	The set form method which is to pave concrete in a formwork installed in advance on the base course or on the asphalt intermediate layer is generally used . The ready-mixed concrete is spread in the formwork with a spreader or human power, compacted with a concrete finisher or a vibrator, and shaped by a leveler or human power. Joints are provided to prevent irregular cracks and absorb the expansion and contraction of concrete. Transversal joints are provided at intervals of 5-10 m, and dowel bars (round steel) that do not adhere to concrete are used to prevent contraction and expansion of concrete. Tie bars (deformed steel bars) are used for longitudal joints to prevent joints from opening and to prevent the concrete slab from slipping.	A pavement consisting of a concrete slab and a base course, which is continuously arranged with longitudal reinforcing bar of approximately 0.6-0.7% of the cross-sectional area of the concrete slab and no horizontal joints. A pavement in which transversal cracks that occur in a concrete slab are dispersed by longitudal reinforcing bars, and the width of each crack is narrowly distributed so as not to harm traffic vehicles and not to affect the durability of the concrete slab. Compared to normal concrete pavement, vibration and noise due to joints in the transversal direction are reduced, and road surface performance during vehicle running is improved.	It uses hard-mixed concrete, which has a smaller unit water volume than conventional pavement concrete, and can be constructed with the same machine as normal asphalt pavement. Compared to normal concrete pavement, the construction speed is faster and the strength develops faster, so the curing time is shorter, the construction period can be shortened, and traffic can be opened early. By operating the construction machine, it is possible to respond to changes in concrete slab thickness, pavement width, and road surface slope.
Application	・ In tunnels and steep roads ・ Pavement of yards and airports that receive heavy loads ・ New roads with a relatively long construction period ・ Small and medium-sized pavement that requires fluidity resistance, wear resistance, oil resistance, heat resistance, and long-term durability	・ Places where it is not easy to close traffic for repair work, such as heavy traffic roads, highways, container yards, and factory premises. ・ Airport runways, taxiways, parking lots, and other locations where fluidity and oil resistance are required	・ Replacement of concrete pavement in tunnel ・ Places that require rutting measures and early opening, such as intersections with heavy traffic ・ Places where lightness is required, such as in tunnels
Construction machinery	・ Spreading and leveling ... Spreader ・ Compaction ... Concrete finisher ・ Surface finish ... Concrete leveler ・ Human-powered construction site: Simple finisher, vibrator	・ Slip form method: To spread, compact and finish the surface with slip form paver. ・ Set form construction method: Same as normal concrete pavement	・ Spreading ... Asphalt finisher (or base paver) ・ Rolling compaction ... Road roller (vibration roller) ・ Finishing ... Tire rolle
General cost comparison in large-scale construction	High Construction costs are high due to formwork assembly, installation of joint hardware, and a large number of construction machines.	Low The construction cost is smalller than normal concrete pavement, but the amount of reinforcing bars is larger than roller compacted concrete pavement, which increases the labor and material cost for assembly.	Lowest Cost is lowest because it has no reinforcing bars or joint hardware and can be constructed with a general construction machine
Merit	・ The easiest to mix and control the quality of concrete ・ Small machine construction and manual construction can be used to handle narrow areas and distorted areas.	・ Compared to normal concrete pavement, the number of machines is small and it is self-propelled, so it is easy to move.	・ Compared to other construction methods, the concrete curing period is shorter and traffic can be opened earlier. ・ Relatively inexpensive.
Demerit	・ In many cases, the construction machines are not self-propelled, and when moving, additional costs such as cranes and tow-machine are required.	・ Especially in the case of slip form, it is not easy to mix concrete and quality control. ・ Difficult to handle narrow areas and distorted areas	・ Because it is finished only with rollers, care must be taken to ensure flatness. Therefore, it is not suitable for runways and highways where flatness is important
Photo of construction			
Rough Unit Cost Direct Cost	Sub base 30cm: 2,600yen/m2 Concrete slab 25cm: 9,000yen/m2 Total 11,600yen/m2	Sub base 30cm: 2,600yen/m2 Concrete slab 25cm: 8,000yen/m2 Total 10,600yen/m2	Sub base 30cm: 2,600yen/m2 Concrete slab 25cm: 6,200yen/m2 Total 8,800yen/m2

Source: JICA Study Team

(2) Process of Pavement Design and Setting of Design Condition

In pavement design, it is important to ensure durability against the effects of traffic load and natural environment so that the function of pavement is fully exerted. The method of pavement design is: 1) clarifying the requirements for pavement as design conditions, 2) determining the structure of the road surface of the pavement, and 3) determining the appropriate pavement structure so that the

subgrade, which is the foundation of the pavement, can withstand the load on the surface. General process of pavement design is shown in Figure 2.30.



Source: JICA Study Team based on Pavement Design Handbook[40]

Figure 2.30 General Process of Pavement Design

(3) Setting of Design Condition

- Design period

The pavement design period is determined in consideration of the limits of initial investment, maintenance and management system, LCC (Lifecycle Cost), and standards of the recipient country. In addition, it is desirable to set it by comprehensively considering the uncertainty of the predicted value of the cumulative equivalent axle load, the maintenance system, and cases of other projects. The consideration of the maintenance system is to strengthen the pavement structure by adopting a long design period in case proper maintenance work is expected to be difficult due to lack of budget. In Japan, the design period of 10 years for asphalt pavement and 20 years for concrete pavement are usually applied. However, in developing countries, it is expected that the traffic volume will increase more than expected in 10 years and the actual condition will differ from expected condition, therefore reference to project examples of other donors is needed.

- Planned Traffic Volume for Pavement

Planned traffic volume for pavement is the average daily traffic volume of large vehicles in the design period. Technical Standards for Pavement Structure of Japan defines as "Planned traffic volume of the road and for roads with two or more lanes, the daily traffic volume per lane of large vehicles which is determined considering the traffic distribution of large vehicles in each lane."

👉 Effect of small vehicles to pavement

The pavement design theory basically considers only large vehicle traffic and does not consider vehicles with small wheel loads (general passenger cars, etc.) in the design. As a basic principle, the

energy that a load damages the pavement is proportional to the fourth power[3] of the load. This principle was derived by Dr. Harumi Takeshita by analyzing the road test data of AASHTO (American Association of State Highway and Transportation Officials). Based on this principle, the impact of small vehicles (passenger cars, etc.) on pavement is about 1/160,000 of large vehicles (5t wheel load), which can be neglected in the design.

$$f = \left(p/5\right)^4 \qquad \text{(Formula 2.2)}$$

f: Damage factor

p: Wheel load

Table 2.34 Relation between Damage to Pavement and Axle Load

Vehicle type	Axle load (t)	Ratio of axle load to large vehicle (regular)	Damage factor (f)	Ratio of damage factor (f) to large vehicle (regular)
Small vehicle	0.25	0.05	0.00000625	1/160,000
Large vehicle (regular)	5.0	1.0	1.0	1.0
Large vehicles (over loaded)	10.0	2.0	16.0	16.0

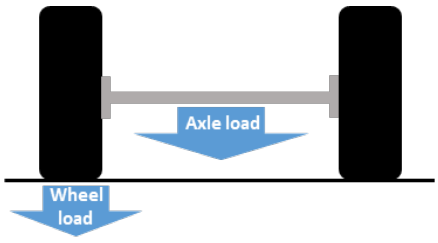
Source: JICA Study Team

- Cumulative Load in Design Period

The most basic conditions for determining the structure and thickness of pavement are traffic conditions and subgrade conditions. Traffic conditions refer to the cumulative value of heavy vehicle loads within the design period (pavement life) set by road standards, etc., and the road foundation (subgrade) is designed so as to withstand this cumulative value and not to destroy. The load used to calculate the cumulative load is generally wheel load in Japan, however overseas, the axle load is mainly used.

Axle load: Vehicle load per axle, sum of wheel loads on one axle

Wheel load: Vehicle load per tire



Source: JICA Study Team

Figure 2.31 Wheel Load and Axle Load

Value for axle load control in major countries is shown in Table 2.35. Currently, there is a strong demand for larger vehicles in Africa, which will be a factor in increasing axle load in the future. On the other hand, especially in Eastern Africa, there is a movement to unify the system for collecting charges from the axle load measurement of passing vehicles in order to maintain road pavement and bridges in good condition. As part of this, EAC (East African Community) has unified the axle load regulation values. When assuming future axle load, it is necessary to pay attention not only to current or past trends but also to such movements. Specifically, with the support of the EU, a program to

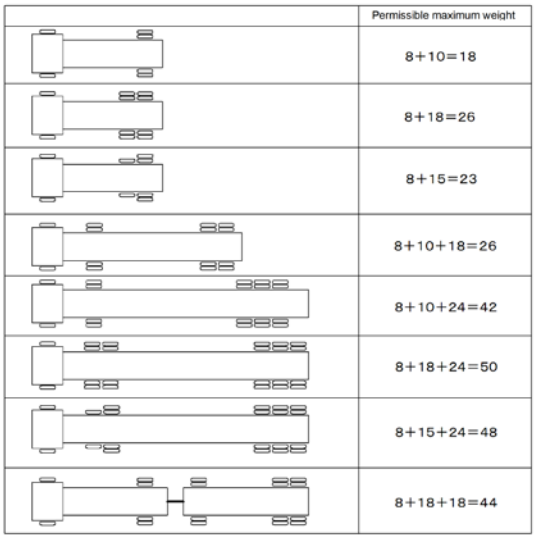
[3] Some countries and standards use the 4.5th power more strictly instead of the 4th power. In addition, it should be noted that the multiplier differs depending on the standard adopted, such as setting the multiplier for each subgrade strength.

unify axle load regulation values (TTTFP[4]: Tripartite Transport & Transit Facilitation Programme) is underway in East Africa, and regulations have already come into effect in EAC. And although it is not regulated as a community in SADC (Southern African Development Community), it is unified as an agreement of the relevant ministers' meetings. In addition, COMESA (Common Market for Eastern and Southern Africa) has joined to this movement. The basic policy is to charge the repair cost of road damage caused by super-heavy vehicles to the super-heavy vehicles, and for that purpose, development of a legal system and a vehicle weight measurement system is in progress.

Table 2.35 Axle Load Control Value in Major Countries

Country	Steering axle	Single axle	Tandem axle	Tridem axle	Combination axle
					-
South Africa	7,700 kg	8,000 kg	16,000 kg	24,000 kg	56,000 kg
Angola	7,700 kg	10,000 kg	16,000 kg	24,000 kg	38,000 kg
Botswana	7,700 kg	8,200 kg	16,000 kg	24,600 kg	50,200 kg
Malawi	7,700 kg	8,200 kg	16,400 kg	24,600 kg	55,000 kg
Mozambique	7,700 kg	10,000 kg	16,000 kg	22,000 kg	38,000 kg
Namibia	7,700 kg	8,200 kg	16,400 kg	21,000 kg	48,400 kg
Zimbabwe	-	8,000 kg	18,000 kg	24,000 kg	56,000 kg
Tanzania	7,700 kg	10,000 kg	18,000 kg	24,000 kg	52,000 kg
Uganda	7,700 kg	10,000 kg	18,000 kg	24,000 kg	52,000 kg
Japan	-	10,000 kg	18,000 kg	-	36,000 kg
United States	-	9,100 kg	15,400 kg	19,300 kg	41,000kg
EU	-	10,000 kg	18,000 kg	24,000 kg	44,000 kg

Source: https://fleetwatch.co.za/previous/magazines/april01/AxleLoad.htm



Source: JICA Study Team

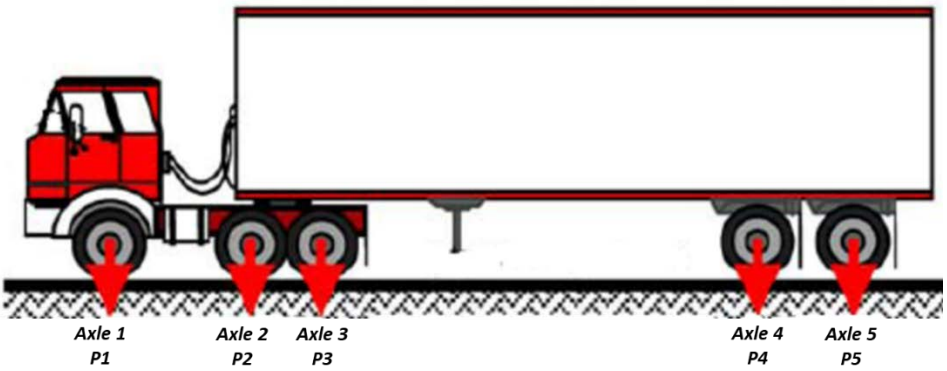
Figure 2.32 Example of Regulation on Axle Load (Uganda)

The damage factor by vehicle type is used to calculate the cumulative load, and a specific calculation example is shown below. The total sum of the damage factors by vehicle type during the design period is the traffic condition for pavement design.

[4] TTTFP: Tripartite Transport & Transit Facilitation Programme

$$\text{SADFi} = \left(\frac{Pi}{SAL}\right)^{n} \quad \text{(Formula 2.3)}$$

SADFi	:	Single Axle Damage Factor (equivalent axle load factor)
Pi	:	Measured axle load of No. I axle (kg or kN)
SAL	:	Standard Axle Load (kg or kN)
n	:	Damage Exponent



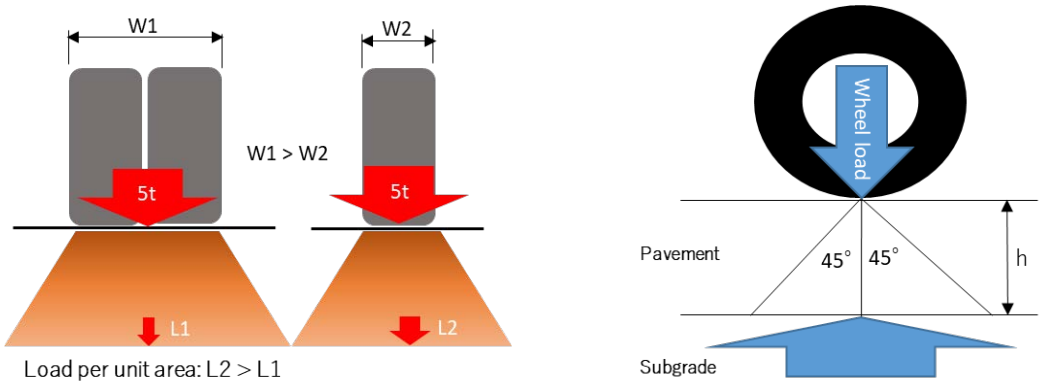
Source: JICA Study Team

Figure 2.33 Conceptual Figure of Single Axle Damage Factor

- Condition of Foundation (Subgrade Strength)

Condition of foundation is the bearing capacity (strength) of the subgrade, and is generally evaluated by the CBR (California Bearing Ratio) test. According to many design standards, if the subgrade is soft with a CBR of less than 3%, it is not possible to secure a work platform for construction such as the base/sub-base, and the bearing capacity after operation is not sufficient, so the subgrade is constructed (replaced or strengthened).

In 1950, the Asphalt Pavement Outline[41] were formulated with reference to AI (American Asphalt Institute), and a theory that wheel load as the concentrated load is dispersed to 45 degrees direction through the pavement as shown in Figure 2.34. This theory indicates: 1) If the subgrade strength is the same, the pavement thickness (h) increases as the load condition increases, 2) if the load condition is the same, the pavement thickness (h) increases as the subgrade strength decreases, and 3) the deeper into the pavement, the smaller the wheel load per unit, therefore the strength of the lower part of the pavement can be small and inexpensive material can be adopted. Pavement design is to determine the most rational pavement type, combination and thickness (h) by considering environmental conditions as well as traffic conditions and natural conditions.



Load to Pavement **Dispersion of Load from Tire to Subgrade**

Source: JICA Study Team

Figure 2.34 Dispersion of Axle Load and Bearing Capacity of Subgrade

- Reliability

The probability that the pavement will not be destroyed during the design period is called the reliability of the designed pavement, and the extent of probability in that case is called the degree of reliability. A reliability of 90% (10% failure probability) means that if there are 100 sections of the same design, 10 of them will be destroyed, or 10% of the area will be destroyed.

- Environmental Condition

Environmental conditions are temperature and rainfall. Pavement is affected by road surface temperature and freezing, drainage conditions are determined based on the rainfall.

(4) Road Surface Design

Road surface design is intended to determine the material, construction method, and layer thickness of the layer (generally the surface layer) forming the road surface of the pavement so as to satisfy the road surface design conditions such as the value of the performance index over the set design period. Since areas that have high temperatures differ from Japan in terms of weather conditions, pavement aggregate materials, etc., survey should be fully conducted on the asphalt mix blend and road surface conditions in local road projects; in particular, it is necessary to consider whether "rutting" countermeasures are required on the target road. Table 2.36 shows examples of pavement performance indicators in Japan. Performance concerning the plastic deformation wheel load is stipulated in the manner shown in Table 2.37 according to the type of road and traffic volume.

Table 2.36 Pavement Performance Indicators (examples in Japan)

Examples of pavement road surface performance		Design outputs
Road surface (surface course) performance	Essential: Fatigue damage wheel load, plastic deformation wheel load, flatness According to necessity: sound level, amount of percolating water, skid resistance value, etc.	1) Surface course used materials 2) Surface course thickness 3) Asphalt base course thickness (if needed)

Source: JICA Study Team based on Pavement Design and Construction Guidelines[42]

Table 2.37 Plastic Deformation Wheel Load Standard Values (ordinary road, standard load 49kN)

Category	Pavement plan traffic volume (Unit: vehicles/day by direction)	Plastic deformation wheel load (Unit: times/mm)
Type 1, Type 2, Type 3 Grade 1 and Grade 2, Type 4 Grade 1	3,000 or more	3,000
	Less than 3,000	1,500
Others		500

Source: Pavement Design Handbook[40]

However, when considering measures against fluid rutting in areas with high temperatures, it is important to refer to the mix in the surrounding road projects and to conduct road surface surveys because the weather conditions and aggregate quality are different from those in Japan. At the same time, the target DS (Dynamic Stability) value is determined by referring to the standards of Japan (or the standards of the recipient country if the recipient country has standards) and the required DS values for each route described in "Calculation of estimated DS", and the use of modified asphalt is judged.

☞ Calculation of estimated DS value

The following formula is presented in the Pavement Design Handbook as a formula for calculating the estimated DS value based on Japan's achievements. This is a formula that incorporates traffic conditions, road conditions, natural conditions, as well as the allowable rutting amount.

$$DS = 0.679 \times \left(\frac{Y \times T \times W \times V \times Ct}{D}\right) \quad \text{(Formula 2.4)}$$

DS : Dynamic Stability (passes mm)
D : Permissible amount of rutting (mm)
Y : Operation period (days)
T : Large vehicle traffic volume (vehicles/day)
W : Wheel load correction factor = equivalent standard wheel load (ESWL)/heavy vehicle traffic volume/day
V : Travel speed correction coefficient
Ct : Temperature correction coefficient

☞ Standard for adoption of modified asphalt

In developing countries as well, the adoption of modified asphalt is increasing including Japan's Grant Aid Project. There are not many design standards that clearly indicate the usage standards for modified asphalt, but there are also examples that indicate the usage standards for hard asphalt containing modified asphalt as standard of Tanzania shown in Table 2.38.

Table 2.38 Standard for Adoption of Modified Asphalt

Use of asphalt binder with penetration "40/50" or modified asphalt is specified in the sections described below:
• Uphill lane with a vertical gradient of over 6% • A section where the vertical gradient is 4% or more and it continues for 1 km or more • Approach section to a large intersection • Routes in all major cities • Areas with continuous traffic and areas where vehicles run at low speeds for reasons other than the above

Source: Pavement and Material Design Manual 1999[43]

(5) Structure Design of Pavement

The structural design of pavement is to determine the material and thickness of each pavement layer so as to satisfy a predetermined performance index value according to the set structural design conditions. In asphalt pavement, determining the pavement thickness (distribution of the thickness of surface course, binder course and base course) according to the traffic volume and bearing capacity of the subgrade is called pavement structure design. In cement concrete pavement, in order to obtain the required bearing capacity of base course, determining the material and thickness of base course according to the bearing capacity of the subgrade, determining the concrete plate thickness and joint spacing, and reinforcing the edges or joints by reinforcing bars are called pavement structure design.

Table 2.39 Design Condition of Pavement by Type and Design Method

Condition	Asphalt pavement			Cement concrete pavement	
	Empirical design method	Theoretical design method	Catalog design method	Empirical design method	Theoretical design method
Planned design traffic volume for pavement	(✓)			(✓)	
Cumulative axle load	✓	✓	✓	✓	✓
Axle load distribution					✓
Wheel running position distribution					✓
Day/night ration of traffic					✓
Design CBR	✓		✓	✓	
Design bearing capacity factor				✓	
Average CBR of test sites		✓			✓
Average bearing capacity factor of test sites					✓
Average modulus of elasticity and Poisson's ratio of test sites		✓			✓
Temperature	✓	✓	✓	✓	✓
Pavement temperature	✓	✓	✓	✓	✓
Rainfall	✓	✓	✓	✓	✓
Material quality standards	✓		✓	✓	
Characteristics or constants of materials		✓			✓

Source: JICA Study Team based on Pavement Design and Construction Guidelines[42]

Representative pavement design methods indicated in various pavement design standards are as follows: 1) empirical design method, 2) mechanistic-empirical method which entails mechanistically analyzing pavement behavior based on traffic load and applying a damage standard linked to the degree of pavement damage, and 3) specification design method which entails stipulating the quality of materials and selecting the pavement composition from the catalog. Table 2.40 shows the features of each method.

Regardless of the design criteria applied, it is important to properly evaluate the materials used when designing subgrade and base course/subbase course. Asphalt surface layer and concrete surface layer are relatively easy to maintain, repair, and improve, but subgrades and base courses/subbase courses are difficult to maintain, therefore stronger durability is required.

Table 2.40 Representative Pavement Design Standards

Design Method	Features, advantages, disadvantages	Representative design standard in each design method	Representative countries of adoption
Empirical design method	Features: Design is performed based on results of tests using actual size traveling and performance of provided pavement. (Mechanistic examination is also considered) Advantages: There is ample performance and the design procedure is simple. Disadvantages: It cannot respond to new materials and structures.	Pavement Design Handbook[40] (T_A method*)	Japan
		AASHTO Guide[44]	U.S.A, Ghana, Thai, etc.
Theoretical or mechanistic-empirical design method	Features: As a prerequisite for mechanistic theory, parts that are unclear in theory (durability, etc.) are augmented through experience. Advantages: It is highly explanatory and has general applicability. Disadvantages: Conventionally a lot of data are required to verify the mechanistic theory (however, it is possible the resilience modulus (MR) will be sought from the CBR and that the damage expression will be substituted with Japanese experience).	Pavement Design Handbook[40] (theoretical design method)	Japan
		AASHTO MEPDG**[45]	U.S.A
		South African Pavement Engineering Manual[46] SAPEM***	South Africa
Catalog design method	Features: It stipulates in detail about the thickness of layers and quality of materials. It is a type of empirical design method, where pavement is selected from the catalog (pavement composition) that is determined according to the subgrade strength, traffic category, climatic conditions, etc. Advantages: The design procedure is simple. Disadvantages: It is difficult to forecast performance.	ORN 31[47]	Former British colony, etc.
		SATCC, Pavement Design Standard[48]	Southern Africa
		South Africa Pavement Design Standard[49]	South Africa

T_A: Total Asphalt, **MEPDG : Mechanistic-empirical pavement design guide, ***SAPEM : South Africa Pavement Engineering Manual

Source: JICA Study Team based on Japan Society of Civil Engineers Pavement Engineering Library 7 "Basics of Pavement Engineering"[50]

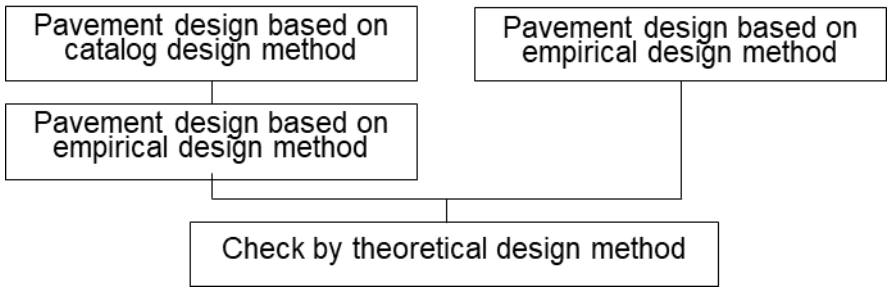
Since there is a limit to the applicability of standards in terms of accumulative axle load such as ORN (Overseas Road Note) 31[47], SATCC (Southern Africa Transport and. Communications Commission) Pavement Design Standard[48], the South Africa Pavement Design Standard[49], etc. and they cannot be used beyond their applicable scope, caution is required. The South Africa Pavement Design Standard[49] is applicable to South Africa where annual rainfall is low, so that it cannot be applied to areas that have a lot of rainfall. In these cases, the SATCC Pavement Design standard[48], which addresses the diverse natural conditions in countries of the Southern African Development Community, are examined. Alternatively, if the catalog is heavily divided, as in Tanzania's pavement design standard[43], it is safer to check with other design methods to prevent under- or over-design. Table 2.41 shows the limits of application and important points regarding each standard. However, since each pavement standard has its own consistency regarding design thinking, it is necessary to avoid changing the pavement standard applied in each design stage.

Table 2.41 Limit of Application, etc. of Each Standard

Standard	Limit of Application	Important Points
Pavement Design Handbook[40]	No limit of application (applicable up to at least 80×10^6 [80kN axle load conversion] or higher)	The applicable load is the wheel load (49kN), while the axle load is 98kN. Since the standard axle load is given as 80kN in numerous other standards, it is necessary to convert to the same standard load when comparing.
AASHTO Guide[44] 1993	No limit of application	The chart upper limit is ESAL 50×10^6
ORN 31[47]	The applicable scope is up to cumulative equivalent axles load (ESAL) of $30x10^6$	In cases where there is a lot of large-vehicle traffic, it is necessary to compare with other standards in advance.
SATCC Pavement Design Standard[48]	The applicable scope is up to cumulative equivalent axles load (ESAL) of $30\ x10^6$	In cases where there is a lot of large-vehicle traffic, it is necessary to compare with other standards in advance.
South Africa Pavement Design Standard[49]	The applicable scope is up to cumulative equivalent axles load (ESAL) of $100\ x10^6$	It cannot be applied in areas that have a large annual rainfall.
Tanzania Pavement Design Manual[43]	The applicable scope is up to cumulative equivalent axles load (ESAL) of $50\ x10^6$	On major urban trunk roads that carry a lot of slow-moving large vehicles and where the Ac layer is susceptible to early damage, separate examination is conducted.

Source: JICA Study Team

To confirm the structural appropriateness of the examined pavement, review is implemented based on multiple design methods, such as the empirical design method, theoretical design method (Pavement Design Handbook[40]), etc. as shown in the following figure. Moreover, review is not done to make the pavement layer thinner, but rather to verify appropriateness and to find out problems regarding durability and economy of each layer in the set pavement composition.



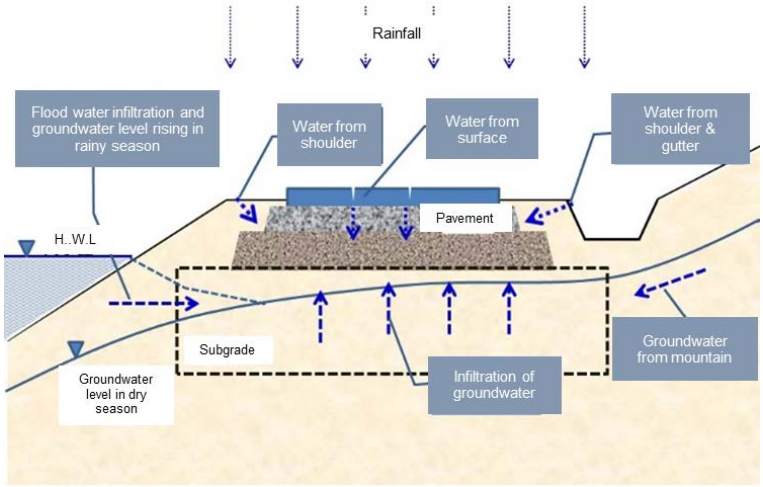
Source: JICA Study Team

Figure 2.35 Flow for Check of Pavement Composition

(6) Pavement Drainage

Appropriate drainage of pavement lead to long-life and consequently economical. Conversely, pavement damage is often caused by poor drainage. In particular, DBST (Double Bituminous Surface Treatment) and asphalt pavement that is not very thick (5 cm or less) are easily affected by surface water, and joints and shoulders of concrete pavement are easily affected by water infiltrating to base course and subgrade. For this reason, the removal of infiltrated water should be considered during design, and there are cases unless structural measures are taken problems cannot be solved by maintenance and management after completion. Water infiltrates to pavement in various ways as shown in Figure 2.36. The adverse effects caused by infiltrating water vary, and they have possibility to cause serious damage and require careful

consideration and countermeasures. Therefore, it is necessary to properly understand these intrusion routes in designing roads and pavement structures.

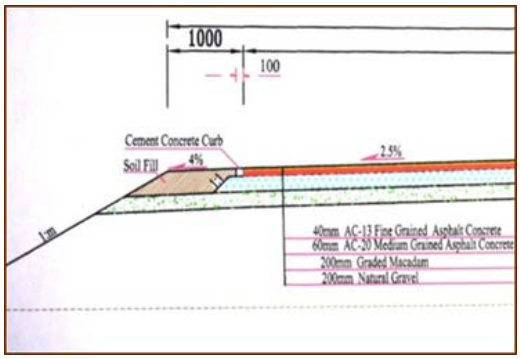


Source: JICA Study Team

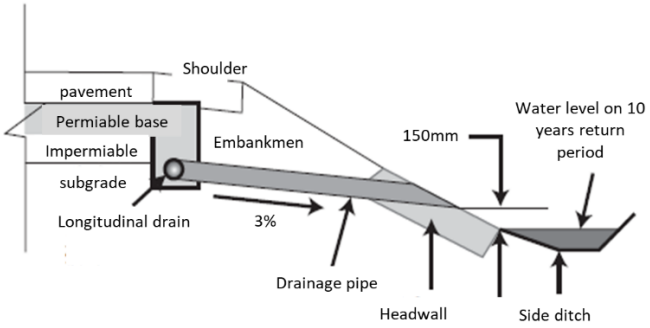
Figure 2.36 Various Water Which Affects Pavement

In pavement standards of many countries, the importance of drainage is emphasized, as poor drainage leads to a decrease in strength of base course/subbase course and decrease in overall bearing capacity. Basically, the structure of the pavement and slope is designed so that rainwater does not penetrate into the base course/subbase course. The concept of "subsurface drainage" is widely used in Western countries to treat water in the base course/subbase course, which has a negative impact on pavements. In order to achieve this goal, material with highly permeability is adopted to base course/subbase course and the base course/subbase course is used as a drainage layer for draining water to the edge of the road. "Drainage within the pavement" to drain water from the pavement is the premise in DMRB[51] (Design Manual for Roads and Bridges), ORN31[47], SATCC[48]. The SATCC[48] cautions that under all circumstances, pavement strength deteriorates rapidly due to the pooling effect of trenches in which the pavement is trapped between continuous impermeable shoulders. For this reason, it is recommended that the base and sub-base is extended beyond the shoulders to the drainage ditch (see Figure 2.37 left). Volume 7: Pavement Design and Maintenance of DMRB [51] also states that there should always be a downward slope from the base course/subbase course to the drainage channel for base course/subbase course drainage, and in road rehabilitation and widening projects, it is necessary to secure adequate base course/subbase course thickness and gradient and to connect new base course/subbase course material from existing base course/subbase course material in order to maintain connectivity.

In the United States, because shoulder widths are wide, a longitudinal drain is installed at the end of the pavement rather than extending the base/sub-base to the slope of the road shoulder (see Figure 2.37 right). If there is concern about the effects of pavement drainage in heavy rainfall areas, it is advisable to design drainage in pavement with reference to these.



Source: Ethiopia Roads Authority



Source: Asphalt No.218[52]

Figure 2.37 Permeable Base with Side Drainage

According to the British Pavement Design Standard[53] (Design Guidance for Road Pavement Foundations, Draft HD25), if the water level is lower than 30 cm below the pavement foundation (base/sub-base), it is not necessary to install a drainage layer. From this, when the groundwater is confirmed, it is desirable to set the water level at least 30 cm below the sub-base.

(7) Comparison of Pavement Structure by LCC

In order to maintain the performance of the pavement above a certain level, pavement is repaired if the performance deteriorates due to the traffic load after operation, and if the performance cannot be improved to the required performance by repair, pavement is constructed again (replacement of pavement). The series of flow from the construction of the pavement to the next construction is called the pavement lifecycle, and the related cost is called the lifecycle cost (LCC). There is no established method for calculating the lifecycle cost of pavement, but the general cost items used to calculate the lifecycle cost are 1) road manager cost, 2) road user cost and benefit, 3) social costs and benefit of roadside and regional society. In the Grant Aid Project, focusing on part of the road administrator costs (construction costs, maintenance costs, repair / reconstruction costs), comparison of the lifecycle costs of surface materials (straight asphalt pavement, modified asphalt pavement, concrete pavement) may be required.

Table 2.42 Items of Pavement LCC

Category	Item	Example of detailed item
Road administrator cost	Construction cost	Construction cost (material cost, execution cost, field overhead expenses, etc.) Note: Procurement method of materials should be clarified
	Maintenance cost	Maintenance cost
	Repair cost, re-construction cost	Repair cost, re-construction cost, Disposal costs, etc.

Source: JICA Study Team

2.9 Drainage Design

(1) Road Drainage Design in Developing Countries

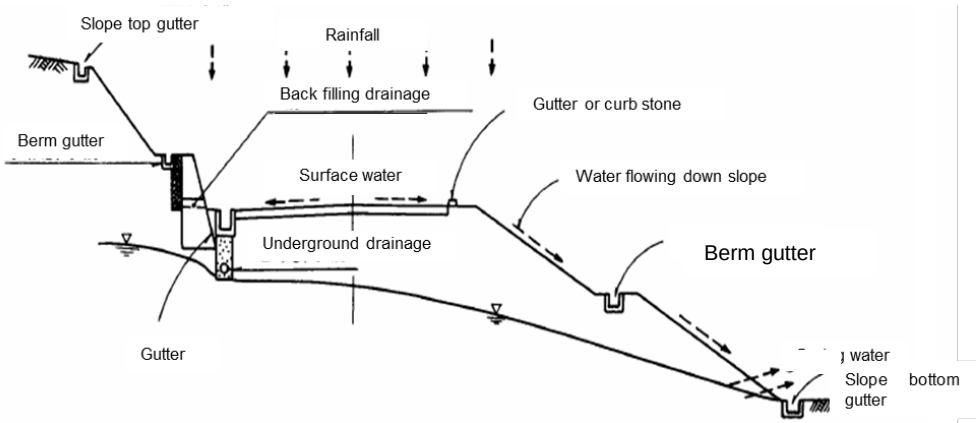
Rainwater and other water directly or indirectly damage roads, such as slope collapse, sediment outflow due to drainage blockage, embankment and retaining wall collapse due to poor drainage, and pavement damage. Even if the road is not damaged, if the drainage on the road surface is poor, water from rainfall or snowmelt will accumulate, causing traffic stagnation and slip accidents, therefore it is necessary to give sufficient consideration to drainage facilities as with pavement and structures in road design, construction and maintenance.

Insufficient data is a major issue when implementing road drainage plans in developing countries. Precipitation data is often missing, river flow (water level) data does not exist, and rainfall intensity data is usually not updated. Therefore, in the drainage plan at the preparatory survey stage, it is necessary to collect data to the extent possible and to collect a wide range of information not only from road administrators but also from other organizations related to rivers. In addition, it is important to carry out hydraulic analysis to the extent possible and create logical corroboration which surpasses qualitative judgment.

(2) Planning of Road Drainage Facilities

When planning road drainage facilities, the targets are surface drainage and underground drainage. Surface drainage refers to drainage from the road surface and adjacent land to the appropriate end of the stream, and underground drainage is installed for the purpose of lowering the groundwater level in order to prevent softening of the road body, subgrade and base course/subbase course. Figure 2.38 shows general types of drainage and examples of installation of drainage facilities. The survey for road drainage plan will be conducted paying attention to the following points.

- Weather conditions in the planned area
- Places where surface water is concentrated and flows
- Places with a lot of spring water and seepage water from the ground
- Situation of downstream end to which collected water is discharged



Source: Road Design Guidelines, Chubu Regional Development Bureau[54]

Figure 2.38 Types of Drainage

- Surface Drainage

Removing surface water from the road surface and adjacent areas of the road caused by rainfall or snowfall. However, although the water flowing down the slope is surface water, it is included in slope drainage.

- Underdrainage

Lowering the groundwater level, and cutting-off or promptly removing water that has permeated from the area adjacent to the road and the road surface or that has risen from the subgrade.

- Slope Drainage

Drainages which prevent erosion of the slope and deterioration of stability due to water flowing down cut slopes, embankment slopes or natural slopes and groundwater springing from the slope.

- Drainage of Structures

Removing water in the back-filling part of the structure, water leaked inside the structure, and surface water on the bridge surface caused by rain or snowfall. In particular, water retention on the bridge slab is the main factor of deterioration of the deck and girders, so it is important to give due consideration to the installation of waterproof sheet.

Surface drainage is generally guided to an appropriate flow end through gutters on the roadside, transverse drain facilities, street gullies, etc. However, in developing countries, maintenance (cleaning, etc.) of drainage facilities is not frequently carried out, so in many cases sediment accumulates on the facilities as shown in Photo 2.6, or it becomes a garbage dump as shown in Photo 2.7. Photo 2.8 shows gutter cover destroyed by heavy vehicles, but this is rarely repaired. These deficiencies in maintenance cause flooding of roads and weaken the subgrade and base course/subbase course.

Photo 2.6 Transverse drainpipe filled with earth and sand

Photo 2.7 A gutter that has become a rubbish dump

Photo 2.8 Gutter cover destroyed by heavy vehicles

Source: JICA Study Team

These surface drainage problems can be avoided to some extent by sufficient field surveys and consideration in design stage. First, it is important to adopt a transversal facility (at least φ900 mm to 1,000 mm) with as larger cross section to make the facility easy to maintain. In addition, if sediment accumulation is expected, it is conceivable to install small check dams (sediment stoppers) before and after the portion concerned. Regarding the problem of dust, measures by using a cover or grating is possible. If a rapid increase in runoff affects the surrounding social environment, it is necessary to consider the installation of a regulating reservoir.

Photo 2.9 shows the river at the end of the drainage. The parts that cross the road are treated appropriately by the structure, but parts away from the road remain natural rivers. Therefore, the river channel may change frequently when water flows in excessively. In addition, if there are residents downstream, it should be noted that an increase in the amount of runoff due to the development of road crossing structures may hinder people's lives.

Photo 2.9 Natural river at the end of drainage
Source: JICA Study Team

(3) Basic Items for Drainage Plan

The planned scale of the drainage facility is expressed by the target value of "the facility is safe for flood that occurs once how many years? (return period)" Generally, for drainage facilities in road projects, 3 years (1/3) to 30 years (1/30) are applied depending on the importance of roads and drainage facilities. The size of the drainage facility is determined based on the amount of runoff obtained according to the return period by the rational formula shown below.

Rational formula: $Q = (1/3.6) \times C \times I \times A$ (Formula 2.5)

Here, Q: Rainwater runoff volume (m^3/sec)
C: Runoff coefficient
I: Rainfall intensity during concentration time (mm/h)
A: Catchment area (km^2)

Among the items in above formula, the item determined by the return period is the rainfall intensity. The rainfall intensity is calculated by converting a rain in a certain period to a rain in one hour, and the unit is mm/h. If there is a continuous rain of 50 mm in one hour on one day and a brief momentary rain of 20 mm in 5 minutes on the next day, the rainfall intensities of these two days are:

Day 1 50mm / (60/60) = 50mm/h
Day 2 20mm / (5/60) = 240mm/h

Due to the effects of climate change in recent years, the number of short-term heavy rainfalls in Japan has increased about 1.4 times compared to about 30 years ago, and since 2012, rainfall per hour has exceeded the highest in the history of observation at about 30% of the points nationwide. Therefore, there is an argument that future rainfall intensity should be considered in light of climate change. In addition, while the forecast of the effects of climate change is uncertain, there is a suggestion that the development procedure should be reviewed in advance so that there will be no rework even if the rainfall intensity changes in the future. Since this calculation of precipitation intensity is processed by hydrological statistics, it is said that the larger the number of data, the higher the reliability. According to the comparison result of the rainfall intensity in Table 2.43 when using the 30-year data and the 10-year data, the rainfall intensity (daily rainfall intensity) with the 10-year data far exceeds the rainfall intensity with the 30-year data reflecting the recent climate change. For this reason, when calculating runoff using a rational formula, it is necessary to consider the recent climate change.

Table 2.43 Comparison of Daily Rainfall Intensity (Tanzania)

Return period	10 years data			30 years data		
	Gumbel	LogP3	Iwai	Gumbel	LogP3	Iwai
2	41.3	33.3	35.1	36.9	34.0	35.0
5	71.9	60.4	64.4	57.5	54.7	55.3
10	92.1	89.9	91.8	71.1	71.3	70.3
20	111.6	131.2	124.8	84.2	89.5	85.8
50	136.7	212.6	178.3	101.1	117.0	107.5
100	155.6	303.9	227.2	113.8	140.7	124.9

Source: JICA Study Team (Using Hydrological Statistics Utility Ver.1.5 (Japan Institute of Country-Technology))

In addition to the rational formula, various methods have been proposed for determining the outflow amount. The South African drainage standard "Drainage Manual 6th Edition[33]: The South Africa Road Agency" describes the applicable limits of the runoff calculation method as Table 2.44. In this way, there are various methods for calculating the outflow amount, so the calculation method will be decided after investigating the actual state of the target country.

Table 2.44 Applicable Limit of Outflow Calculation Method

Method	Input data	Applicable limit (km^2)	Recommended return period
Statistical method	Peak flood record	No limit	2-200
Rational formula	Catchment area, channel length, average gradient, basin natural conditions, rainfall intensity	Area <15 or less is desirable. However, it depends on the calculation method of precipitation intensity (concentration time, etc.).	2-200
Synthesis hydrograph method	Catchment area, channel length, distance from basin center, annual average rainfall, basin type, regional hydrograph *	15-5,000	2-100
Empirical method (RMF: Regional Maximum Flood)	Catchment area, channel length, distance from the basin center, annual average rainfall	No limit	10-100
East Africa Flood Model	Catchment area, channel length, ground conditions, rainfall duration time	Area < 200	-

* Hydrograph: A diagram showing the time change with time on the horizontal axis and flow rate or water level on the vertical axis.
Source: JICA Study Team based on Drainage Manual 6th Edition[33]

👉 Concentration time

The concentration time is the time required for rainwater to reach as a flood from the dropped point to the point where the target drainage facility is located. The rational formula is the method to acquire the maximum runoff (peak flow rate) at the end of the basin when there is a duration of rainfall longer than the flood arrival time (the time when the rain that fell at the farthest end of the basin flows out and reaches the end of the basin). And it is necessary to convert the rainfall intensity from the above-mentioned daily rainfall intensity to the rainfall intensity within the concentration time, and it should be noted that the conversion method and the coefficient used differ depending on the standards of each country.

2.10 Ancillary Facilities for Road

(1) Ancillary Facilities

Facilities attached to road include safety facilities, sign facilities, tree-planting zones, etc., and are facilities installed for road users to safely pass through the road. In particular, traffic signs, pavement markings, carriageway marking, grade separation facilities for pedestrians (pedestrian bridges, etc.), fences (guard rails, guard pipes, etc.), road lighting, deliberators, road reflectors, and blocks to guide the visually impaired, etc. are included. Road information management facilities that provide various information to road users are also included. In order to ensure traffic safety, depending on the local conditions, there is a possibility that the safety cannot be sufficiently achieved only by the geometric structure design such as the width of the road and the horizontal/vertical alignment. Lighting and road information management facilities are designed to be integrated with the road to achieve safety and smoothness of the road, so it is important to reflect them in the design as part of the design of the road.

For traffic signs, pavement markings, and road markings, there are UN signs, and even if a country does not participate in UN signs, each country has its own standards for signs. Therefore, for detailed shapes and descriptions of signs, etc., the standards and practices of the country concerned need to be checked. In some cases, regional communities have established their own standards such as the Road Traffic Signs Manual[55] of SADC (Southern African Development Community), so it is important to confirm the standards, including those of regional communities. The following is a description of the installation standards and locations of facilities attached to road, referring to examples in Japan.

(2) Traffic Sign

Regarding the installation of traffic signs, the classification, type, place to be installed, form and classification of installer are specified in Article 1 to 4 of "Decree on Traffic Signs, Carriageway Markings, and Road Marking" issued by Ministry of Construction in 1960.

Table 2.45 Type of Traffic Sign

Classification			Meaning
Traffic sign	Primary sign	Guide sign	1. Signs that guide the route such as the direction of the destination, distance, route name, route number, etc. 2. Signs that guide the boundaries and points of prefectures and municipalities 3. Signs that guide road facilities
		Warning sign	Signs on the road that inform danger or matters for alert. By installing, it encourages deceleration and careful driving.
		Regulatory sign	Notification to vehicles and pedestrians of prohibitions, regulations, restrictions, etc.
		Indication sign	To inform of the matters to be observed when passing.
	Auxiliary sign		Supplement the primary sign. Mainly represents "vehicle type", "time", "section", etc.

Source: JICA Study Team based on 2003 Construction Technology Transfer Guideline Development Survey (Road Design Standards) Report[56]

(3) Pavement Marking

Regarding the installation of pavement markings, the classification, type, place to be installed and form are also specified in Article 8 to 10 of "Decree on Traffic Signs, Carriageway Markings, and Road Marking" in 1960.

Table 2.46 Meaning and Type of Pavement Marking

Classification		Meaning and type
Pavement Marking	Regulatory marking	To regulate the flow to prevent accidents. ex. no U-turn, no entry to the right side for overtaking, no lane change, no parking and stopping, maximum speed, roadside strip, vehicular lane, priority carriageway, bus priority lane, direction designated lane, lane for right-turn and left-turn, etc.
	Indication marking	To instruct for safe and smooth traffic, or to indicate passable. ex. pedestrian crossing, diagonal crossing permitted, bicycle crossing lane, stop line, centerline (center of road), traffic lane line, safety zone, channelizing strip, streetcar stop, notice of pedestrian crossing or bicycle crossing, etc.

Source: JICA Study Team

(4) Road Marking

Regarding the installation of road markings, the classification, type, place to be installed and form are also specified in Article 8 to 10 of "Decree on Traffic Signs, Carriageway Markings, and Road Marking".

Table 2.47 Type and Installation Place of Carriageway Marking

Type	Place to be installed
Carriageway centerline	The center of carriageway where width is 5.5m or more and center must be indicated (center of carriageway)
Traffic lane line	Lane boundaries of sections where it is necessary to indicate lane boundaries within a section of a roadway with four or more lanes
Carriageway edge marking	Outside the carriageway in the section where the outside edge of the carriageway needs to be indicated
Pedestrian crossing guidance line	Places where guidance for pedestrians to cross the road is needed.
Change of road width	Sections where different widths of carriageway connects and where change in carriageway width needs to be indicated.
Approach to road obstacles	In case it is necessary to indicate the approach to obstacles on the road
Channelizing strip	In case it is necessary to guide the safe and smooth running of the vehicle
On-street parking	Outer edge of street parking lot (excluding those that touch the sidewalk)

Source: Source: JICA Study Team based on 2003 Construction Technology Transfer Guideline Development Survey (Road Design Standards) Report[56]

Source: JICA Study Team

Photo 2.10 Example of Road Marking and Lane Marking

(5) Grade Separation Facilities for Pedestrians

Regarding the installation of grade separation facilities for pedestrians, the standards are described in the technical standards for grade separation facilities for pedestrians (Notice of Director of City Bureau and Director of Road Bureau, Ministry of Construction, 1978). Grade separation facilities for pedestrians includes pedestrian bridge, underpass for cross pedestrians and pedestrian deck.

Among the grade separation facilities for pedestrians, the structure for installing a pedestrian bridge is

defined as follows.

- The effective width of the pedestrian bridge should be 200 cm or more. The effective width of the underground pedestrian crossing should be 300 cm or more.
- A ramp or stairs with ramp should be provided. (Except when installing facilities such as elevating devices)

  Considering the smooth progress of wheelchairs, it is preferable to install elevators, etc., however if installation is difficult due to the high cost, use ramps or stairs with ramps. In this case, the slopes of the ramps and stairs with ramps must not exceed 12% and 25%, respectively.
- If the height of the stairs exceeds 300 cm, a landing should be provided in the middle of the stairs.
- The steps and road surface of the stairs should not be slippery.

  The pavement surface material should be determined not only for use in fine weather, but also for use in bad weather.
- Handrails should be provided on both sides of stairs and landings.

(6) Guard Fence

The standards for installing guard fences are stipulated by the Ministry of Land, Infrastructure, Transport and Tourism Notification "Standards for installing guard fences"[57], 2016. The guard fence is divided into vehicle guard fences and pedestrian bicycles guard fence.

1) Vehicle Guard Fence

Vehicle guard fences are stipulated to be installed in the following sections.

- A section where a vehicle guard fence is installed on the roadside mainly for the purpose of preventing human damage to passengers due to the vehicle's deviation from the road.
- A section where a vehicle guard fence is installed mainly for the purpose of preventing human damage to a third party (hereinafter referred to as secondary damage) due to deviation of the vehicle from the road.
  - A section where a vehicle guard fence is installed on the roadside mainly for the purpose of preventing secondary damage due to the vehicle deviating from the road.
  - On a road with a median, a section where a vehicle guard fence is installed in the median mainly for the purpose of preventing secondary damage due to the deviation of the vehicle into the oncoming lane.
  - A section where a vehicle guard fence is installed at the boundary between the sidewalk and the carriageway, mainly for the purpose of preventing secondary damage due to deviation of vehicles to the sidewalk, bicycle path, and bicycle pedestrian road.
- Section required for other reasons

Types of guard fence includes rigid guard fences that do not deform and are aimed at preventing vehicles from deviating from the road as well as guardrails, guard cables and box beams. As a general

rule, the height from the road surface to the upper end of the guard fence is 0.6 m or more and 1.0 m or less.

Table 2.48 Type of Guard Fence

Type	Description
Guard rail	Guard rail is a structure with beams with a connected wavy cross section supported by columns, and is the most common guard fence.
Guard cable	Guard cable is a structure in which a tensioned wire cable is supported by columns, and cannot be used in curved sections with a small curve radius because the columns will be tilted by tension.
Box beam	Box beam is guard fence that uses one large box shaped steel as a beam, and is suitable for use in narrow medians.
Concrete barrier curb	A protective fence for bridges to prevent cars from jumping out of the bridge. Initially, steel guardrails were used, but they were changed to concrete walls because they are easy to manage and not damaged in case a car collides.

Source: 2003 Construction Technology Transfer Guideline Development Survey (Road Design Standards) Report[56]

- Selection of type and specification

For the selection of the type of guard fence for vehicles, not only performance, but also economic efficiency, maintenance and repair, construction conditions, roadside clearance and median strip width, ensuring visibility, harmony with the surrounding environment, traffic conditions, and predicted traffic volume should be considered.

2) Pedestrian Bicycles Guard Fence

Pedestrian bicycle guard fences are stipulated to be installed in the following sections.

- Sections of sidewalk, cycling road and bicycle pedestrian road where the outside of roads is dangerous, and are deemed necessary to prevent pedestrians from falling.
- A section where pedestrian bicycle fences are installed at the boundary of sidewalk and carriageway for the purpose of preventing pedestrians from crossing.
  - Sections deemed necessary in sections where pedestrian road crossing is prohibited
  - Sections where it is particularly necessary to prevent crossing in places other than pedestrian crossings
  - Of the sections on roads in the city where the traveling speed is low and it can be expected to ensure the safety of pedestrians simply by distinguishing between sidewalk and carriageway.

Fences for crossing prevention are to be installed when it is deemed necessary after examination of other methods such as installation of tree planting zones in consideration of the landscape. The standard height from the road surface to the upper end of the fence of the fence installed for the purpose of preventing pedestrians from falling is 1.1 m, and the standard height from the road surface to the upper end of the fence of the fence installed for the purpose of preventing pedestrians from crossing is 0.7 to 0.8 m.

(7) Delineator

In Japan, the delineator is defined as a road ancillary facility based on Article 2 of the Road Law, and is positioned as a traffic safety facility based on Article 31 of the Road Structure Ordinance[1]. As for the installation section, the standards for national roads and expressways are set as follows.

National Roads: In consideration of the structure of the road and traffic conditions, delineator shall be provided when necessary to ensure safe and smooth traffic.

National Highways: As a general rule, expressways shall be equipped with delineator continuously on all sections. However, if there is a road lighting facility, the installation can be omitted.

The delineator is a facility that guides the driver's line of sight by clearly indicating the road alignment along the side of the carriageway. When a car travels at night, the road alignment is grasped by the headlights, but the range that can be grasped by the headlights is limited, which may hinder the securing of safe and smooth traffic. There is a lane marking that uses retroreflective light, but the amount of reflected light is small, and the line of sight guidance effect may not be expected. For this reason, a delineator is required as a line of sight guidance measure at night.

Delineator

Traffic lane marker

Curb guidance marker

Source: JICA Study Team

Photo 2.11 Delineator

(8) Road Lighting

Road lighting facilities include continuous lighting, spotlighting, and tunnel lighting. Continuous lighting refers to the arrangement of lights at regular intervals in principle in typical road section, and the continuous lighting of that section. Spotlighting refers to the local lighting of necessary locations such as intersections, bridges, sidewalks, interchanges, and rest facilities. Tunnel lighting refers to illuminating tunnels. The purpose of road lighting is to enable safe and smooth travel of road traffic at night and in dark areas, and it shall ensure the following visual environment.

- Road structure such as road alignment and road width
- Left and right and existence positions of intersections and turning points
- Confirmation of existence of obstacles or pedestrians on the road
- Position and movement of the driver himself on the road
- Position and movement of other road users
- Situation around the road

The installation standards for road lighting facilities are described in "Road Lighting Facility Installation Standards"[58] (Notice of Director of City Bureau and Director of Road Bureau, Ministry of Construction, 1981). In road lighting, the following requirements need to be considered in order to ensure a good visual environment.

- The average brightness [5]of the road surface is appropriate.
- The brightness distribution on the road surface has an appropriately uniform.
- The glare given to the driver is sufficiently limited.
- Having a guidance function

Table 2.49 shows the standard average road surface brightness by road classification and by the external conditions according to the installation criteria. Among national highways, on motorways other than national highways, the value in lower column can be adopted depending on the situation.

Table 2.49 Standard for Brightness

(Unit: cd/m^3)

Road classification		Outside condition		
		A	B	C
National highway		1.0	1.0	1.0
		―	0.7	0.5
National road	Major arterial road	1.0	0.7	0.5
		0.7	0.5	―
	Arterial road, secondary arterial road	0.7	0.5	0.5
		0.5	―	―

Outside condition
A: Roadside conditions with continuous light affecting road traffic
B: Roadside conditions with intermittent light affecting road traffic
C: Roadside conditions with little light affecting road traffic
Source: Road Lighting Facility Installation Standards[58]

(9) Road Information Management Facility

Road information management facilities are classified into information collection facilities that collect information such as weather and traffic conditions, information processing facilities that process information and control equipment, and information provision facilities that provide information to road users, etc. The contents and composition are as follows.

Table 2.50 Information Collection Facility

Name of equipment	Information to be collected	Name of device
Meteorological observatory equipment	Precipitation, snowfall, freezing, wind direction, wind velocity, visibility, etc.	Rain gauge, snow gage, freeze detector, anemometer, visibility meter, thermometer
Disaster detector	Earthflow, ground inclination, ground expansion/contraction, ground distortion, rock fall, CO, flood, etc.	Landslide warning signal, inclinometer, rock fall detector, CO gauge, flooding detector
Traffic flow observation equipment	Traffic volume, speed, type of vehicle, etc.	Vehicle detector
Condition monitoring equipment	Traffic condition, visibility, road surface, etc.	CCTV (Closed Circuit Television)
Information communication equipment	Report from road users, etc.	Tunnel warning device, emergency alarm and communication device

Source: Road Design Guidelines, Chubu Regional Development Bureau[54]

[5] Brightness: The indicators of road lighting are brightness and illuminance. Luminance (cd / m2) represents the brightness of a light source, and illuminance (lx) is the degree of brightness at which an object is illuminated by a certain light source.

Table 2.51 Information Processing Facility

Name of equipment	Function	Name of device
Processing equipment	Data collection, data base management, display processing, provision	Processor, server
Monitoring control equipment	Conversion of collected information to a given format, Information exchange control to the provision equipment	Road information board control device, roadside communication control device, radar rainfall meter processing device, CCTV monitoring control device, image processing device, telemeter monitoring control device, vehicle detection processing device, weather monitoring device, etc.
Visual display	Confirmation of collected/ providing information	Display, printer
Control unit	Input of information, operation of equipment	Terminal device

Source: Road Design Guidelines, Chubu Regional Development Bureau[54]

Table 2.52 Information Provision Facility

Name of equipment	Method	Name of device
Road information display	Display traffic rules, disasters, weather conditions, etc. in characters and figures	Road information board
Road communication system	Providing road information, etc. by voice to radio	Roadside communication system, radio rebroadcast
Road information terminal	Providing information on road traffic, weather, tourism, etc. at roadside stations, service areas, etc.	Roadside station information provision system
Vehicle information and communication system	A driving support system that displays a map of the vicinity of the driving location on the display of the car, displays the driving track, and gives information on the destination.	Beacon (VICS), DSRC

Source: Road Design Guidelines, Chubu Regional Development Bureau[54]

👉 ITS

Intelligent Transport Systems (ITS) are being developed to improve information collection, information processing, and information provision through the use of information technology (IT). ITS is a system that integrates people, roads, and vehicles using the most advanced information and communication technologies to improve navigation systems, establish automatic toll collection systems for toll roads, support safe driving, optimize traffic management, and improve the efficiency of road management.

ITS is a system that provides users with the information necessary for safe, comfortable, and efficient transportation in a quick, accurate, and easy-to-understand manner, and also enables the automation of driving operations through the use of information and control technology. In this way, ITS will contribute to the realization of a truly affluent and vibrant life by enabling advanced road use, reducing the burden of driving, walking, and other road use, dramatically improving the safety, transportation efficiency, and comfort of road traffic, and greatly contributing to environmental conservation by reducing traffic congestion and facilitating other traffic flow.

(Source: ITS Overall Concept, Ministry of Land, Infrastructure, Transport and Tourism)

In developing countries, most of the vehicles in use are old, and software in car navigation systems, etc. has not been updated, so it will take time to automate driving operations through the use of

information and control technology, but information provision to users is expected to make progress in the future.

(10) Other Traffic Safety Facilities

In developing countries, "humps" are sometimes used as speed control facilities at the entrance to urban areas, before and after crosswalks and railroad crossings. The main purpose of this facility is to reduce the driving speed and thus reduce the risk of traffic accidents. In the UK, humps can only be installed on roads where the speed limit is less than 50km/h with streetlights. The humps are placed at intervals of 20 to 150 meters, of which interval about 70 meters is usually recommended. The dimensions should be 25 mm to 100 mm high and 900 mm or more in length. It is also recommended that the slope of the hump should not be steeper than 1:10 to reduce the effects of vehicle ground contact[59]. In the case of Japan, the "Technical Standard for Installation of Convex, Narrow, and Bent Sections[60]" sets the standard at 5% on average and 8% or less at maximum.

On the other hand, some countries (e.g., Uganda) are considering alternative speed control facilities to the hump because of the significant damage to the pavement before and after the hump. Therefore, when planning to install a hump, it is necessary to confirm the movement regarding the hump of the government.

Installation of Hump (Example)

Source: https://sacdot.saccounty.net/Pages/NTMP-SpeedHump.aspx

Pavement Damage by Hump

Source: JICA Study Team

Photo 2.12 Example of Hump and Pavement Damage

Table 2.53 Example of Speed Reduction Facilities (Japan)

Type	a. Hump	b. Contraction	c. Crank
Image			
Characteristics	The road was paved convexly, and the driver who see it slows down before hump.	It tries to reduce the speed of the car by narrowing the carriageway or making it look narrow visually.	It tries to reduce the speed of the car by zigzagging or meandering the carriageway.

Source: JICA Study Team based on MLIT HP

2.11 Construction Plan and Cost Estimates

(1) Importance of Construction Plan and Cost Estimates

In Grant Aid Projects, cost estimation implemented in the preparatory survey becomes the basis for calculating project cost and is reflected in the amount decided by the Cabinet and the limit of Grant stated in the E/N (Exchange of Notes). Accordingly, it is necessary to improve the accuracy of design and cost estimation and appropriately reflect risks. For example, care should be taken to bring local plant conditions, test methods, materials procurement, construction procedures, etc., as close as possible to actual conditions and ensure that costs are not underestimated due to any work oversights. At the same time, effort should be made to clarify the preconditions and basis of cost estimation and strive not to leave any ambiguity by specifying conditions that could not be clarified in the survey, such as provisional conditions.

(2) Construction Plan in Road Construction

In light of the contents of the Grant Aid Preparatory Survey Design and Cost Estimation Manual[34] and its Supplement (Civil Engineering Field) [35], concerning roadworks, it is necessary to confirm that no differences exist between the design contents and conditions on the construction site, and then examine the procedures and methods for implementing construction in an efficient, economical and safe manner. The main items that are examined in the construction plan cover a wide range of topics, including the following.

1) Outline of works (confirmation of the contents of various information and materials, such as design drawings, technical specifications, etc.)
2) Project schedule (number of operating days and overall schedule that take weather conditions, such as rainfall, temperature, etc., natural conditions, such as flooding frequency, etc., and social environment including festivals and so on into account)
3) Site organization and labor plan (plan of working personnel, including assignment of personnel by type of works and responsible areas)
4) Designated and main machinery (machine plan and transportation plan indicating the used machines and manufacturers))
5) Main materials (materials use and procurement plan, including the forms, dimensions and quality of main materials)
6) Construction method (construction procedures, used materials/machines, temporary facilities plan, etc., and construction basic policy)
7) Construction management plan (schedule management and quality control)
8) Safety management (safety and health management and security management.)
9) Traffic management (safety countermeasures, such as traffic controls and installation of signs)
10) Environmental countermeasures (environmental countermeasures, including noise, vibration, dust countermeasures, for the neighborhood)
11) Utilization of construction by-products generated at construction sites as recycled resources and disposal as waste

In developing countries, where the development of the network is insufficient, it is also important to

consider the construction of detours and temporary bridges, and it may be necessary to compare the "widening of the current road (widening of the current bridge) + detour (temporary bridge)" plan with the "construction of a new road (bypass) or a new bridge" at the cost estimate. This process is included in the item for examination in construction method. Moreover, in construction plans for roadworks in inland countries, in cases where uncertain elements exist due to inability to sufficiently survey the import and customs processing of equipment and materials through ports in neighboring countries, transportation plans using roads in neighboring countries and so on, provisional conditions are specified and reflected in the cost estimation. Furthermore, since there are cases where the contents of the technical specifications of recipient countries are not reflected in construction plans, it is necessary to confirm the consistency between the standard construction specifications and the contents of the construction plan.

Table 2.54 Important Points when Compiling the Construction Plan

Item	Contents
Construction method	Total cross-sectional works entailing full interruption of traffic ・Detour plan ・Temporary installation management road plan ・Nighttime works implementation Semi-cross section construction to ensure traffic flow Construction methods at intersections that have heavy traffic Construction method when there are villages and houses in the vicinity Traffic control and safety measures necessary for the above
Temporary work plan	If installing a crushed stone, concrete, asphalt plant, etc. ・Candidate site for installation ・Need for acquisition of environmental licenses ・Modified asphalt manufacturing method (when modified asphalt is necessary) ・Crushing machine (primary - tertiary crushing, etc.) composition Temporary installation road plan
Procurement plan	Route clearance survey ・Transportation plan for materials and equipment to be procured from a third country and the number of days required for transportation ・Transport route planning when transportation of large equipment is required Soil quarry, sand quarry, stone quarry, and transportation plan Concrete and asphalt mixture procurement plan (on-site purchase or on-site manufacture) Concrete and asphalt mixture procurement plan (case of on-site manufacture) ・Method for procuring aggregate, bitumen and other materials
Environment (wastes)	Residual soil disposal plan Concrete debris waste and asphalt debris waste disposal plan Special soil and problem soil (black cotton soil , etc.) disposal plan
Conformance with the General Specifications (examples)	・Use of construction machinery that does not meet the requirements specified in the specifications (ex. crane lifting load) ・Use of materials that do not meet the requirements specified in the specifications (ex. aggregate strength) ・Oversight of re-rolling (15-30 cm) of the cut subgrade. ・Construction method of cement stabilization base course (on road or in plant)

Source: JICA Study Team

☞ Route clearance survey

The route clearance survey is the work of confirming the bottlenecks in transportation of large machineries and equipment used in construction and confirming the necessary measures in advance. In developing countries, when roads and bridges are in poor condition, older bridges may have smaller load limits. Therefore, when transporting machineries and equipment that exceed the load limit by road transportation, the transportation route is examined and the load capacity of the structures on the route and the ability to pass of curves on narrow roads in mountainous areas are confirmed. However, there are few examples of implementation in the preparatory survey.

(3) Roadworks Cost Estimation

Since works in Grant Aid construction projects, from survey to execution, generally take a long time, while also accompanying with harsh construction conditions, various difficulties often follow. Against this background, in order to carry out appropriate estimation, the construction method, material procurement method, material manufacturing method, quality control are clarified and reflected accurately in the estimation. The basic items shown in Table 2.55 should be also clarified. Since these items also include contents needed for the design, the survey work should be implemented efficiently while coordinating with the design conditions survey.

Table 2.55 Basic Items necessary for Cost Estimation (for Reference)

Type	Basic Items
(1) Target works contents	Works contents, construction plan (position, scope, scale of facilities, period, construction method, temporary installation method), auxiliary works, related works, undertakings of the recipient government
(2) Record in similar works	Works contents, construction plan (position, scope, scale of facilities, period, construction method, temporary installation method), contract rates, type of contract, etc.
(3) Neighboring environment	・Conditions around the site, land use, existing facilities and structures, underground structures ・Access to the works site, detour routes during the works
(4) Terrain, geology, weather, etc.	・Site terrain: Topographical maps (contour line map), site enlarged views ・Ground conditions: Site histogram, soil type, soil bearing capacity ・Temperature and humidity: Each month's average, maximum, minimum ・Rainfall: Seasonal changes, daily maximum, hourly maximum, annual rainfall, annual days of rainfall ・Wind speed and wind direction: Each month's maximum, average, etc. ・Tide level: High tide level, low tide level, maximum tide level, etc. ・Area of damages caused by past flooding, hurricanes, earthquakes and drought
(5) Project implementing agency	・Organization, budget, personnel, scope of responsibility, technical level, operation and maintenance structure
(6) Equipment and materials procurement	Market prices of works materials, prices and rental charges, etc. of construction machinery, etc.
(7) Site	Conditions of facilities construction-site, lodgings, etc. (responsibility of recipient country, land lease, etc.) Need for site compensation or not Necessary site area
(8) Labor and local contractors	Labor supply base, skill level of construction workers, social insurance, work hours, national holidays and days off, capacity and reliability of skilled workers, etc.
(9) Legislation and customs	Labor and employment-related legislation, tax laws, construction-related legislation, technical standards, general specifications, relevant customs, etc.
(10) Other	Other matters, necessary items according to characteristics of the target project

Source: Grant Aid Preparatory Survey Design and Cost Estimation Manual[61]

As was mentioned above, concerning uncertain elements that are difficult to clarify in the cost estimation, provisional conditions are assumed, and fluctuation risks are incorporated into the estimation. In particular, the common temporary construction cost is calculated based on the common temporary cost rate, but since some are included in the common temporary cost rate and some are not, the items of the common temporary cost are estimated in consultation with JICA (Japan International Cooperation Agency).

Concerning the cost estimation method, referring to the Assistance Preparatory Survey Design and Cost Estimation Manual Supplement (Civil Engineering Field)[62], if the official agency in the recipient country has a cost estimation standard, etc., as a rule this is used. However, since there are many cases where no cost estimation standards are prescribed, official cost estimation standards in Japan are followed while clearly indicating the standards in use.

(4) Estimation of Safety Countermeasure Cost

Of the estimated construction costs, the safety costs in the temporary facility costs include the costs required for necessary safety measures in construction such as 1) traffic management costs, 2) safety facilities, and 3) safety management costs. In addition, among the site management costs, for the following projects that require special consideration for safety, dispatch of construction safety engineers is permitted for both construction companies and consultants. Therefore after checking if the target projects meet this requirement, necessary cost will be reflected in the total cost.

1) Long bridge or continuous elevated bridge: Single bridge (elevated) with an extension of approximately 1,000 m or more (including approach roads)

2) Suspension bridges, cable-stayed bridges, extradosed bridges, or other types of bridges with a maximum span length of 100 m or more.

3) Special terrestrial/underground/underwater construction (tunnel construction, dam (including erosion control dam), harbor construction, ground excavation/coffering construction in river area, construction requiring large-scale temporary structures, large-scale foundation construction, caisson construction, etc.)

4) Construction that requires aerial work (work approximately 20 m or more from the ground surface)

5) Earth retaining works and coffering works that are close to important structures such as railway and road bridge, and that affects the structure and the surrounding area by ground movement.

6) Construction that requires special consideration for public disasters, such as traffic accidents, flying/falling, injuries caused by the entry of third parties other than those involved in the construction site, and construction that provides temporary structures for general traffic.

7) Other works that may cause a serious accident

Source: Preparation survey design/cost estimation manual supplement (civil engineering field)[62]

(5) Estimation of Supervision Cost

The scope of the design and supervision cost is the detailed design cost, the construction supervision cost, and the soft component cost. The design and supervision costs comprise costs for detailed design (site survey, domestic analysis and design, etc.) and bidding assistance work (preparation of bidding documents, approval of bidding documents, public notice, handover of drawings and site explanation, bidding, bid evaluation, etc.) required up to the time of the construction contract. Construction supervision costs include costs for construction supervision, completion inspections, and defect inspections after the construction contract is signed. Soft component costs include costs related to soft aspects such as technical guidance. The scope of the role of Japanese engineers in construction supervision is as follows.

- Project manager: Professional engineer who supervises the entire construction supervision work
- Resident engineer: Professional engineer who is stationed at the site throughout the construction period and supervises the entire construction work.
- Other engineers: Professional engineers who supervise construction work in specialized fields for the required period of time on-site, and professional engineers who perform various inspections such as completion inspections and defect inspections

The assignment of Japanese engineers is to be developed as part of the project implementation plan. The assignment of engineers shall be based on a comprehensive review of the work content, work volume, work period, etc. (construction supervision plan) based on the scale and content of the construction work, technical difficulty, site largeness, length, distance between sites, work schedule, etc. and shall consider an appropriate system based on the following principles, while clearly organizing the division of work between the engineers and the local engineers, and seeking consistency and coordination with the employment plan of local staff.

- Assignment of a project manager: The project manager shall be assigned when supervision by a project manager is required at quality control meetings on site or at important occasions of construction.
- In principle, one resident engineer shall be appointed, but if it is judged that this is difficult due to the scale and content of the work, the distribution of the sites, etc., multiple engineers may be appointed.
- When construction work in a specialized field is to be carried out over multiple sites in parallel, multiple construction supervising engineers may be assigned depending on the necessity (construction process, construction scale, technical difficulty, etc.).
- Supervisory work related to safety management is included in the work of the resident engineer, and in principle, projects that require special attention to safety should be handled at the quality control meeting. If it is necessary to assign a specialist engineer for safety management, the division of roles between the work performed by the resident engineer and the work performed by the resident construction supervising engineer shall be clarified.
- In the case of planning by a Japanese supervision engineer and a local engineer together, both engineers will be assigned after clearly organizing their respective duties.

(6) Approximate Estimate of Project Cost

Figure 2.39 shows the composition of project cost. This figure is for grasping the estimated project cost of road projects, and the following ratios change depending on the site conditions and structural conditions. Therefore, it should be used after understanding that it does not exceed the estimated range.

<table>
<tr><td colspan="8">Project Cost ⑫</td></tr>
<tr><td colspan="7">Construction Cost⑩</td><td>Consultant fee ⑪</td></tr>
<tr><td colspan="4">Direct Cost ⑤</td><td colspan="3">In-direct Cost ⑨</td><td rowspan="6">⑪＝⑩×7%</td></tr>
<tr><td colspan="2">Earth works/pavement</td><td colspan="2">Bridge</td><td>Temporary facility cost ⑥</td><td>Site expense ⑦</td><td>Administration overhead ⑧</td></tr>
<tr><td>Pavement ①</td><td>Earth works and small structures ②</td><td>Superstructure ③</td><td>Substructure ④</td><td rowspan="2">⑥＝⑤×8%</td><td rowspan="2">⑦＝⑤×13%</td><td rowspan="2">⑧＝⑤×10%</td></tr>
<tr><td>see Table 2.32 or 2.33</td><td>②＝①×70%</td><td>see Table 2.27</td><td>④＝③×50% (Co Br.)
④＝③×40% (Me Br.)</td></tr>
<tr><td colspan="4">⑤＝①＋②＋③＋④</td><td colspan="3">⑨＝⑥＋⑦＋⑧</td></tr>
<tr><td colspan="7">⑩＝⑤＋⑨</td></tr>
<tr><td colspan="8">⑫＝⑩＋⑪</td></tr>
</table>

Source: JICA Study Team based on "Regarding the revision of the JICA Road Pavement Handbook[63] (December 2020 issue)", "a comparative example of the lifecycle costs of steel bridges and PC bridges"
(https://www.jisf.or.jp/business/tech/bridge/pr/index.html)

Figure 2.39 Composition of Project Cost for Approximate Estimates of Project Cost

2.12 Environmental and Social Consideration Survey

(1) Definition and Objectives of Environmental and Social Consideration

Definition: "Environmental and social consideration" means considering environmental impacts including air, water, soil, ecosystem, flora, and fauna, as well as social impacts including involuntary resettlement, respect for the human rights of indigenous people, and so on. The environmental and social consideration implemented by JICA (Japan International Cooperation Agency) is distinguished from EIA (Environmental Impact Assessment) and IEE (Initial Environmental Examination) implemented under the laws and regulations of the proponent's country.

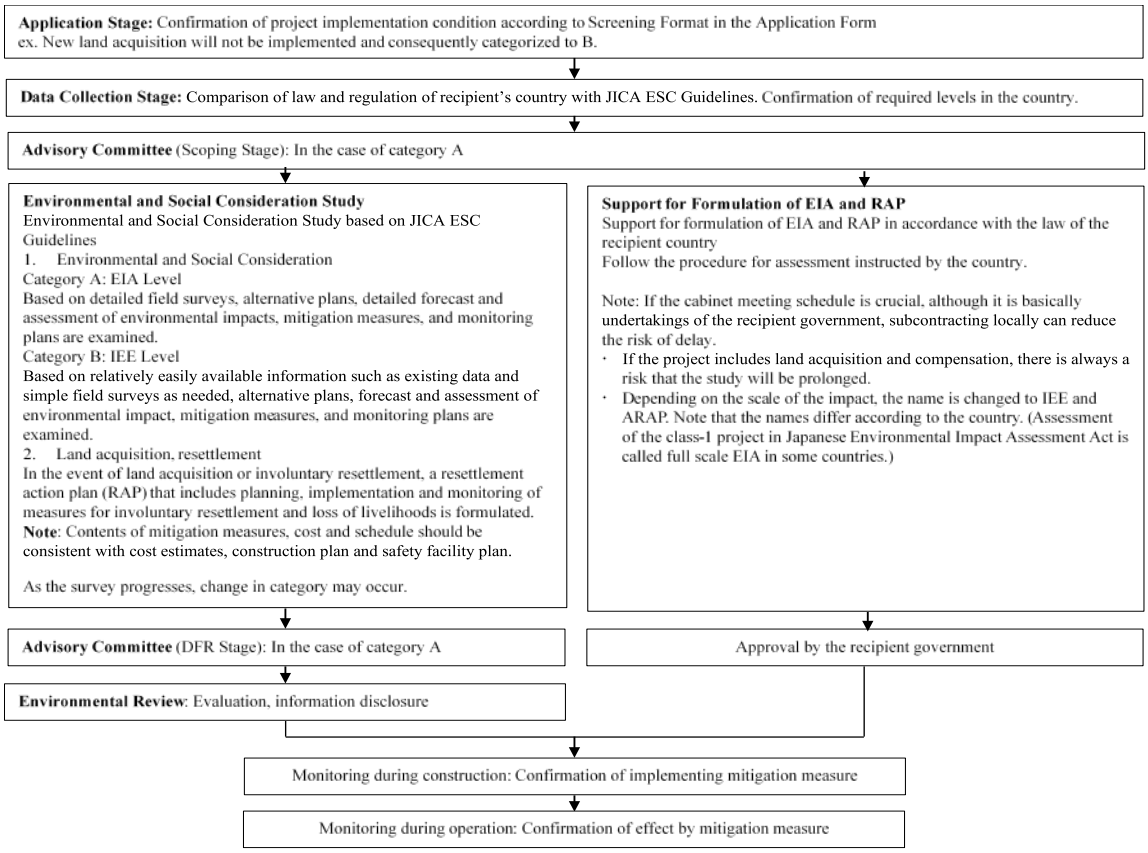
Objectives: The objectives of the guidelines are to encourage Project proponents etc. to have appropriate consideration for environmental and social impacts, as well as to ensure that JICA's support for and examination of environmental and social considerations are conducted accordingly. The guidelines outline JICA's responsibilities and procedures, along with its requirements for project proponents etc., in order to facilitate the achievement of these objectives. In so doing, JICA endeavors to ensure transparency, predictability, and accountability in its support for and examination of environmental and social considerations.

Source: Guideline for Environmental and Social Considerations, (Translation of Japanese Version) [64]

JICA's guidelines for environmental and social considerations[64] are subject to change according to social conditions, so it is necessary to use the latest guidelines.

(2) Implementation Detail of Environmental and Social Consideration

Environmental and social consideration activities in the preparatory survey can be broadly divided into two types: environmental and social consideration studies and support to recipient government.



Source: JICA Study Team

Figure 2.40 Flowchart for Environmental and Social Consideration

☞ Environmental Preliminary Survey

The preliminary survey is a survey conducted by JICA before the full-scale survey, which confirms the request contents of the recipient country, examines the possibility of the full-scale survey and procedures, and collects information. As a result of the preliminary survey, detailed implementation rules in the form of S/W (Scope of Work) will be exchanged between JICA and the executing agency of the country. After the preliminary survey, a survey/study instruction that reflects the results of the preliminary survey will be formulated, in which the specific environmental survey to be conducted in the full-scale survey will be specified.

1) **Environmental and Social Consideration Study** - Implementation of the environmental and social consideration survey required by the JICA Guidelines for Environmental and Social Considerations[64]

Determining/screening the extent and category of environmental and social consideration according to the scale of the project, the surrounding environment, and the requirements of laws and guidelines. In the event of land compensation or involuntary resettlement, RAP (Resettlement Action Plan) including planning, implementation, and monitoring plans for measures related to involuntary resettlement and loss of livelihoods is created.

- Category A: EIA level

For projects that are judged to require detailed examination of environmental impacts by scoping or IEE, alternatives, detailed forecast and evaluation of environmental impacts, mitigation measures, EMP (Environmental Monitoring Plan) are examined based on detailed field surveys.

- Category B: IEE level

Based on relatively easily available information such as existing data and simple field surveys as needed, alternative plans, forecast and assessment of environmental impact, mitigation measures, and EMP are examined. The objectives of IEE are as follows:

- ✓ To determine the necessity to conduct an environmental impact assessment, and if determined necessary, to clarify the content of the survey.
- ✓ For projects that require environmental consideration but do not require an environmental impact assessment, to consider measures to mitigate the impact from the viewpoint of environmental consideration.

2) **Support to Recipient Government** – Support for formulation of EIA and RAP in accordance with the law of the recipient country

If the Cabinet meeting schedule is crucial, although it is basically undertakings of the recipient government, subcontracting locally can reduce the risk of delay.

- If the project includes land acquisition and compensation, there is always a risk that the study will be prolonged.
- Depending on the scale of the impact, the name is changed to IEE and ARAP. Note that the names differ according to the country. (Assessment of the class-1 project in Japanese Environmental Impact Assessment Act is called full scale EIA in some countries.)

☞ Environmental Impact Assessment Act of Japan

The projects subject to environmental impact assessment under the Japanese Environmental Impact Assessment Act are 13 types of project such as roads, dams, railways, airports, power generating structure, etc., and among them, large scale projects which may have significant impact on environment are classified as "class-1 projects", and it is obligatory to conduct environmental impact assessment. A project of a scale equivalent to the "class-1 project" is defined as a "class-2 project", and necessity of the procedure for environmental impact assessment is individually determined. In other words, all the "class-1 projects" and those of "class-2 projects" that are judged to be required to carry out the procedures will carry out the procedures for environmental impact assessment based on the Environmental Impact Assessment Act. Table 2.56 shows the specific types and scales of road projects required to carry out the procedure.

Table 2.56 Target Projects for Environmental Impact Assessment in Japan (Roads)

Type of project		Class-1 project	Class-2 project
1 Road			
	Highway	All	-
	Metropolitan Expressway, etc.	4-lanes or more	-
	National road	4-lanes or more and 10km or more	4-lanes and 7.5km-10km
	Forestry road	Width 6.5m or more and 20km or more	Width 6.5m or more and 15km-20km

Source: JICA Study Team

☞ Environmental Impact Assessment in Major Recipient Countries

The table below shows the projects targeted for environmental impact assessment in major recipient countries that are implementing road development through Grant Aid Projects.

Table 2.57 The Targets of Environmental Impact Assessment in Major Recipient Countries

Country	Target project of EIA
Thailand	**Basic law** Enhancement and Conservation of National Environmental Quality Act (1992) **Classification od project** Highway or road as defined by the Highway Act, passing through following areas: 1) Wildlife sanctuaries and wildlife nonhunting areas as defined by the Wildlife Conservation and Protection Act 2) National park as defied by the National Park Act 3) Watershed area classified as class 2 by the Cabinet Resolution 4) Mangrove forests designated as the National Forest Reserve 5) Coastal area within 50 meters of high tide level 6) Areas adjacent to RAMSA Sites or World Heritage Sites inscribed on the World Heritage List according to World Heritage Convention within a distance of 2 kilometers **Size of project** All projects equivalent to or above the minimum standard of rural highway, including road expansion on existing route *Source: http://www.onep.go.th/eia/wp-content/uploads/2018/08/KM_18.pdf*
Laos	**Basic law** The Lao Environmental Protection Law (1999) **Classification of project** Road construction through national or provincial protected area: Category 2 New road construction project (national, provincial, district, urban, extra construction): Category 2 Road improvement project (national, provincial, district, extra road improvement): Category 1 Road rehabilitation or upgrading project (national, provincial road rehabilitation): Category 1 Category 1: Investment projects that are small or create few impacts on the environment and society require IEEs Category 2: Large investment projects that are complicated or create substantial impacts on the environment and society require EIAs *Source: https://openjicareport.jica.go.jp/pdf/12144762.pdf*
Tajikistan	**Basic law** Law on Environmental Protection (2011) **Classification of Project** Category I: applied for the facilities and activities which have high possibility of impact on the environment such as highways, etc. Category II: applied for the facilities and activities which have medium possibility of impact on environment such as roads of regional significance, etc. Category III: applied for the facilities and activities which have low possibility of impact on the environment such as roads of local importance, etc. The development of full EIA report is required for the project Category I and is not required for the other categories, the Section "Environmental Protection" in the Draft of Work Plan is required for Category II and III. *Source: https://libopac.jica.go.jp/images/report/12246633.pdf*
Tanzania	**Basic law** Environmental Management Act (2004) **Classification of project** Category A: Transport and infrastructure Construction, expansion or rehabilitation of new trunk roads Category A: Project where EIA is mandatory Category B: Project where preliminary environmental assessment is required *Source: https://libopac.jica.go.jp/images/report/12040127.pdf*
Uganda	**Basic law** The National Environment Act (2019) **Classification of project** Category I: a) routine maintenance works such as pavement repairs, clearing of culverts and drains and roadside vegetation, b) periodic maintenance works such as grading and re-gravelling, sealing, surface dressing and road marking and furniture

	Category II: a) partial rehabilitation works, such as reconstruction of small sections of existing paved roads, b) projects involving upgrading from earth to gravel Category III: a) major rehabilitation/improvement projects for existing roads, b) projects involving pavement strengthening, c) projects involving upgrading from earth or gravel to bitumen standard Category IV: a) construction of new roads, b) all road rehabilitation projects with new alignments, c) all road projects requiring relocation of people through acquisition of land for easement, d) all road construction and rehabilitation projects passing through environmentally sensitive area Category I: Projects normally exempt from EIAs Category II: Projects for which mitigation measures are easily identified Category III: Projects requiring limited environmental analysis (EIR) Category IV: Projects requiring full environmental analysis (EIA) *Source: http://www.works.go.ug/wp-content/uploads/2016/05/EIA-Guidelines-for-Road-Sector-Latest-latest.pdf*
Kenya	**Basic law** The Environmental Management and Co-ordination Act (1999) **Classification of project** Low Risk Projects: local roads and facility access roads Medium Risk Projects: construction and rehabilitation of roads including collectors and access roads, construction of bridges High Risk Projects: all new major roads including trunk roads Low risk project or medium risk project shall submit to the Authority a summary project report of the likely environmental effect of the project. High risk project shall submit EIA study reports to the Authority *Source: https://www.nema.go.ke/images/Docs/Notices/Legal%20Notice%20No.%2031%20%2032%20of%202019.pdf*
Ghana	**Basic law** Environmental Assessment Regulations (1999) **Classification of project** Large scale and significant impacting undertakings and Small and medium scale activities

Source: JICA Study Team

(3) Implementation of Environmental and Social Considerations

1) Formulation of Environmental and Social Considerations Draft Report

After conducting necessary surveys and analysis for environmental assessment, an environmental and social consideration report (in the case of support to recipient government, EIA report and RAP report (if necessary)) is prepared and discussed with related organizations.

Table 2.58 Contents of Environmental and Social Consideration Report

Report	Contents
I. Environmental and social consideration	1. Project components which may cause environmental and/or social impacts 2. Base environmental and social conditions 3. Laws, regulations, and organizations related to Environmental and Social Considerations 4. Alternatives analysis (including zero-option) 5. Scoping and TOR for Environmental and Social Impact Assessment Study 6. Result of Environmental and Social Consideration Study (including prediction results) 7. Impact assessment 8. Mitigation measures and cost 9. Environmental monitoring plan (EMP) 10. Implementation structure of EMP 11. Stakeholder meeting
II. Land acquisition and resettlement	1. Necessity for land acquisition and resettlement 2. Legislative framework on land acquisition and resettlement

	3. Size of land acquisition and resettlement 4. Compensation and assistance to the affected persons 5. Grievance redress mechanism 6. Implementation structure (identification of responsible agency for resettlement and its duty) 7. Implementation schedule (Physical relocation is started after completing compensation payment for lost assets.) 8. Cost and budget 9. Monitoring scheme, monitoring form 10. Public meetings
III. Others	1. Draft monitoring form 2. Environmental checklist 3. Tor for construction supervision consultants 4. Others

Source: JICA Study Team

☞ Resettlement Action Plan (RAP Report)

The RAP Report describes relocation procedures, livelihood recovery measures, grievance redress mechanism, etc. when there are many involuntary resettlements (in the case of JICA, approximately 200 or more people).

☞ Scoping

Scoping is the process for confirming Scoping Document, which determines the evaluation framework such as procedure and method in environmental impact assessment. The purpose is to disclose the method of environmental assessment and to ensure the fairness of the method. At this stage, the following two points are important.

- Selection of evaluation items that are considered important and determination of survey method
- Discussion with stakeholders (consensus building and reflection of opinions)

For the items for scoping, the items shown in Table 2.59 are examined.

Table 2.59 Items for Scoping

Category	Affected items
Pollution	Air pollution, water pollution, solid wastes, soil contamination, noise and vibration, land subsidence, offensive odor, bottom sediment
Natural environment	Protection area, ecosystem, hydrological situation, topography and geographical features
Social environment	Land acquisition and resettlement, vulnerable social groups such as indigenous and ethic people, local economy and employment, land use and utilization of local resources, water use, public infrastructures and services, social capital and decision making organizations at local, misdistribution of benefit and equity, local conflict of interest, cultural heritage, landscape, gender, children's right, hazards (risk) infectious diseases such as HIV/AIDS and Malaria, working conditions and occupation safety, sanitation
Others	Accident, transboundary/climate change

Source: JICA Study Team

☞ Points to Note in Environmental and Social Consideration Study

In Grant Aid Projects for roads, design study and environmental study are often carried out at the same time, and time may be not sufficient to reflect the "environmental mitigation measures" proposed in the EIA report in the design. In particular, when the environmental impact assessment is conducted by the recipient government, there are cases where the EIA report is submitted after the completion of design work because of the time required to contract the EIA. Therefore, scheduling to reflect the results of the environmental study in the design is essential.

2) Information Disclosure to Stakeholders and Consensus Building

The JICA Guidelines for Environmental and Social Considerations[64] require stakeholder meetings at scoping and draft EIA preparation, and consensus building with the local stakeholders is important.

- At the time of scoping: Providing project information, explaining the outline of environmental surveys, hearing opinions, and building consensus on basic project implementation.
- At the time of draft EIA: Providing detailed project information, reporting EIA results, final consensus building.

*Local stakeholders: Third-party organizations (local NGOs (Non-Governmental Organizations)), project affected peoples (individuals, organizations, etc.), etc. (It may include the project execution agencies (ministries or agencies), the responsible organization of the project (the central governments), or the local government.)

(4) Mitigation Measures

1) Examples of Environmental Mitigation Measures of Road Project in Japan

- Noise reduction

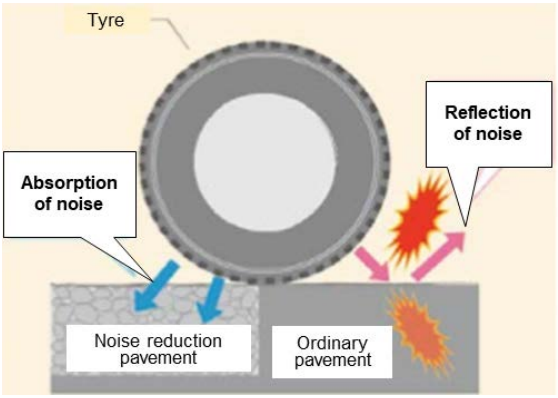


Figure 2.41 Noise Reduction Pavement

Photo 2.13 Sound-insulating Wall

Source: https://www.city.nagoya.jp/kankyo/cmsfiles/contents/0000080/80387/004Lownoise-pavement.pdf (Figure 2.41)
MLIT HP (https://www.mlit.go.jp/road/soudan/soudan_07_01.html) (Photo 2.13)

- Countermeasure for noise, air pollution and vibration

Photo 2.14 Buffer Zone

Source: MLIT HP (https://www.mlit.go.jp/road/soudan/soudan_07_01.html)

- Countermeasure for air pollution, heat islands and global warming

Photo 2.15 Planting Street Trees

Photo 2.16 Greening of Slopes

Source: MLIT HP (https://www.mlit.go.jp/road/soudan/soudan_07_01.html)

2) Examples of Environmental Improvement in Grant Aid Road Project

Project road: Inner ring road development in Lusaka City, Zambia

Current condition: During rainy seasons, poor hygiene and hindrance to access to basic social facilities such as hospitals and schools due to underdeveloped drainage facilities.

Plan and design: All-weather road (paved: 15km)

Objectives: The objectives of the project are to improve access to workplace and to improve the social infrastructure by improving access roads to the inner ring road and special economic zone and improving accompanying drainage facilities, and thereby to contribute to the smooth distribution and improvement of the living environment in the capital city of Lusaka.

Photo 2.17 Road before improvement

Photo 2.18 Road after improvement

Photo 2.19 Developed shopping mall

Source: JICA HP

■ Environmental improvement effect (ex-post evaluation report)

- Reduction of disease due to improved hygiene

  The improved drainage channels have eliminated flood, reduced mosquitoes in most areas, and reduced malaria infection rates.

- Reduction of dust due to unpaved roads

  The problem of dust during the dry season was serious, but after the implementation of this project, the amount of dust decreased in the area around the road, and symptoms such as coughing decreased.

- Improvement of security around the road

  Before the project was implemented, robbery and rape were frequent, but security was improved because the forest was cut down due to the construction of the road. In addition, the installation of streetlights has reduced robberies at night.

- Revitalization of economic activities by road development

  The construction of the road has stimulated economic activity in the region, with the construction of new homes around the road, the increase in retail stores, and the construction of new shopping malls.

3) Examples of Environmental Mitigation Measure in Road Project by Grant Aid

Project road: a road approaching national park and agricultural area

Present condition: parts of the road section are blocked in rainy season.

Development plan: all weather road (paved length: 77km)

Issue: The World Bank has already implemented EIA at the upper level plan (MP/FS) stage. For this reason, the question of how to reflect the EIA results (environmental mitigation measures) in the design was important. In particular, due to the passage through national parks and nature reserves, sufficient consideration for wild animals has become an issue.

● Preservation of trees with large diameter

Photo 2.20 Before Construction

Photo 2.21 After Construction

Photo 2.22 After Construction
Source: JICA Study Team

- Avoidance of fragmentation of Animal Pathway

Photo 2.23 Low Embankment with Low-gradient Slope

Photo 2.24 Animal Passing after Completion

Source: JICA Study Team

- Installation of drift to avoid impact on water balance and to avoid runover deaths

Photo 2.25 Drift with Function of Speed Control Facility

Photo 2.26 Traffic Sign before Drift

Source: JICA Study Team

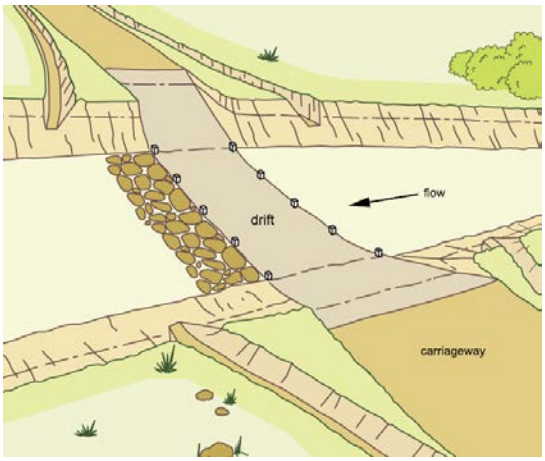


Figure 2.42 Installation of Drift
Source: BUILDING RURAL ROADS Chapter 7 Drainage[65]

Drift is a road crossing structure in a large drainage channel or a small river. It is used for small rivers and drainage channels where there is no water in the dry season. In this project, a drift was set up at the intersection of the animal corridor of wild animals (large animals) and the road, which became a small river in the rainy season, and it was also planned as a facility for roadkill[6] countermeasures by reducing speed.

- Prevention of traffic accidents by installing speed control equipment such as humps and signs

Photo 2.27 Speed Control by Hump

Photo 2.28 Hump for Warning

Source: JICA Study Team

- Traffic education through traffic safety seminars

Photo 2.29 Traffic Safety Education at Elementary School

Source: JICA Study Team

[6] Roadkill is the death of wild animals due to the influence of the road, such as runover death caused by a vehicle, collision death, drowning death by falling into a drainage ditch, dry death, etc.

2.13 ICT and CIM

(1) Definition of ICT and CIM

In Japan, "Quality Infrastructure Partnership" was announced in May 2015. The first of the four pillars supporting it is "expanding and accelerating the volume of assistance by mobilizing all of Japan's economic cooperation tools". In order to export high-quality infrastructure, the use of ICT (Information and Communication Technology) is expected as a tool to improve the efficiency, sophistication, and quality at each stage of design and construction, as well as to improve the overall efficiency and sophistication of a series of road projects from the design and construction stage to the future maintenance and management stage. Among the many types of construction works, the first to apply ICT is earthwork, which has a large room for improvement, and ICT will be used in all processes including surveying, construction, and inspection. The new cost estimation standards for public surveying manuals will be formulated by referring to the knowledge obtained from the trials of information-oriented construction and CIM (Construction Information Modeling/Management), which links and develops 3D models between processes. It is intended that, in principle, ICT will be fully applied to large-scale earthworks conducted by the government by applying this standard. As a result, the environment for utilizing 3D data, or in other words, the environment for utilizing CIM, has been considerably improved in the field of earthwork, from the investigation and design stages to the construction, supervision, and inspection stages. Currently, based on the verification of the use of CIM in ICT earthwork, trials are underway for other construction types and structures such as bridges and tunnels.

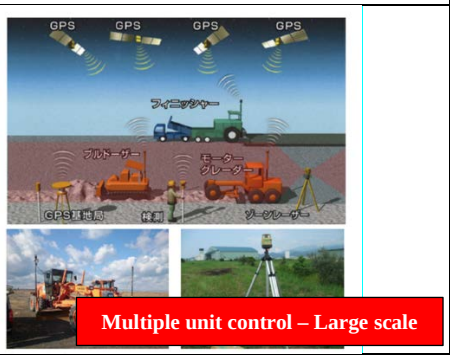
(2) Information-based Construction Technology

As mentioned above, information-based construction is a new type of construction that utilizes ICT. It is a generic term for technologies that improve the productivity of the entire construction production process, the quality of construction work, and the reliability of construction projects by focusing on the construction process in a series of construction production processes, such as survey, design, construction, and maintenance management, and by mutually linking various information related to construction work with each other.

Source: Informatization Construction Promotion Strategy, Ministry of Land, Infrastructure, Transport and Tourism https://www.mlit.go.jp/common/000993270.pdf

In the past, surveying work could only be done to measure the position of a stationary point. The new development of technology that enables highly accurate positioning of moving objects using satellites and instruments with automatic tracking functions has made it possible to put into practical use numerical control systems for constantly moving construction equipment.

Table 2.60 Positioning and Control Method

	GNSS (Global Network Satellite System) Method	TS (Total Station) Method
Advantage	Stand-alone positioning, operation with multiple devices, data sharing between sites	Precise positioning, transmission of control information, utilization as a surveying instrument
Disadvantage	Limitations in surveying accuracy, limitations due to satellite conditions, reliance on foreign satellites, need to set up base stations	Limited effective working radius, one-to-one control, limited use by weather
Outline of work	 Multiple unit control – Large scale	 One-to-one control – Small scale

Source: Information-based Construction Technology for Pavements, JICA Web Technology Roundtable Document[66]

There are two specific operation methods: AMG (Automated Machine Guidance) for explicitly indicating operation values (indication operation) and AMC (Automated Machine Control) for control by operation values (automatic operation).

Table 2.61 Positioning and Control Method

Operation method	Outline
AMG Explicitly indicating operation values (indication operation)	Technology using TS and GNSS measurement technology to support operation by providing the operator with difference between the design value (3D design data) and positional information of the construction machine, construction information, and the site condition (construction condition) through the in-vehicle monitor (the operator controls the machine).
AMC control by operation values (automatic operation)	Combining machine guidance system technology with hydraulic control technology of construction machinery, this technology automatically controls machinery in real time according to design values (3D design data) to carry out construction.

Source: Information-based Construction Technology for Pavements, JICA Web Technology Roundtable Document[66]

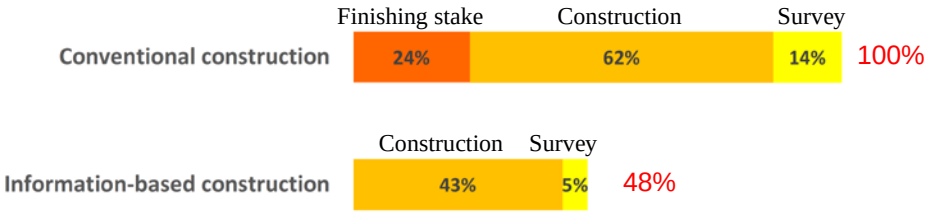
Table 2.62 Major Information-based Construction Technology

Machine control and machine guidance technology for construction machinery	• Machine guidance technology for bulldozers, hydraulic shovel, etc. • Machine control technology for graders, bulldozers, etc. (leveling)
As-built Management Technology Using TS and GNSS	• As-built management technology by measuring dimensions and distance using TS and GNSS
New quality control technology using ICT	• Area quality control technique by roller trajectory control (compaction) • Area quality control technology using bulldozers, etc. (thickness) • As-built management technology using TS (thickness) • Surface quality control technology using a non-contact infrared thermometer (temperature)
Integrated management technology for construction information	• Precision construction management technology using operation records of construction machinery and production equipment • Integrated management technology using 3D CAD

Source: What is Information-based Construction?[67]

As an effect of the information-based construction, there is no need to set up indicators such as finishing stakes to guide the work as in the conventional construction method, and since these are no longer necessary, interference with the operation of construction machinery is avoided, and work efficiency is

improved. Furthermore, the inspection work of the finished product can be reduced, and the construction quality and productivity can be greatly improved. These systems are used in a wide range of applications, from large sites such as highways and airports to parking lots and general base course/subbase course shaping work. Moreover, since radio waves and laser beams are used for positioning and tracking of construction equipment, high work efficiency can be achieved in night-time work as well as in daytime work. In addition, electronic data is used for construction and management, which facilitates the recording of information during the construction process, and this data can be used for repair planning after the facility is in service.



Source: What is Information-based Construction?[67]

Figure 2.43 Difference in Construction Period between Conventional Construction and Information-based Construction

(3) Application to ODA (Official Development Assistance) Projects

The effects of introducing CIM are wide-ranging, including tunnels, shields, underground structures, large-scale civil engineering works, roads, bridges, rivers, demolition and repair, and maintenance. In particular, it is effective for complicated construction where many facilities are congested. However, introducing CIM into complex projects requires a lot of modeling effort, and is risky because it may not lead to verification of the original effects of CIM (Project Management tools). In order to utilize it as a PM (Project Management) tool, it is desirable to verify the issues and effects in a series of works from surveying, planning and design to construction. Therefore, in order to promote CIM, the implementation of pilot projects within technical cooperation projects is proposed. For example, for a bridge in need of replacement that is discovered in a technical cooperation project for quality improvement of construction or road and bridge maintenance, replacement work will be carried out in the technical cooperation project as a pilot project using CIM.

Source: JICA Study Team based on the "Research on ODA projects in the road sector using ICT technology in developing countries"[68]*, JICA, 2018*

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CHAPTER 3 PROJECT IMPLEMENTATION STAGE

3.1 Detailed Design

(1) Objectives and Contents of Detailed Design

In the DD (Detailed Design) carried out at the project implementation stage, in order to improve the accuracy of the preparatory survey results, the detailed structure of the road required for construction is economically and logically designed based on the road centerline and right-of-way determined in the preparatory survey. And for structures that require stress calculation, stability calculation and cross-sectional stress intensity calculation will be performed according to the design conditions based on the main structural dimensions of the structural type determined in the preparatory survey.

The purpose of the detailed design is after carrying out the above design work, to create bidding documents such as drawings, reports, construction specifications, draft form of contracts, etc. necessary for contracting construction. The composition of standard bidding documents, including Japan's Grant Aid Projects, is shown in Table 3.1. However, from the viewpoint of providing fair information to bidders, avoiding high bids due to lack of information on basic design conditions, avoiding discrepancies in the content of bids, and ensuring high quality, it is necessary to specify the design conditions and construction conditions which are considered to affect the bidding cost substantially in the bidding documents as much as possible. Therefore, the bidding documents for the JICA (Japan International Cooperation Agency) project should include the standard bidding documents such as contract conditions, technical specifications, construction drawings and specifications, as well as the appendices shown in Table 3.1. It should be noted that the technical report is a reference material, and it is clearly stated that the consultant is not responsible for any damage caused by the reference material.

Table 3.1 Composition of Contract Documents for Road Project (Example)

Category		Contract document to be prepared
Contract document (Draft)	Standard bidding document	1. Draft Form of Contract 2. Conditions of Contract 3. Specifications 4. Drawings 5. Instruction to Bidders 6. P/Q: Prequalification
	Appendix Technical report	7. Detailed Design Report including work quantities 8. Structural calculation sheet, Stability calculation sheet 9. Pavement design calculation sheet (pavement design, pavement structure design) 10. Alignment calculation sheet 11. Traffic survey report including Axle load survey report 12. Geological survey report including Material survey report 13. Land related data such as DMS (Detail Measurement Survey) 14. JICA Pavement Handbooks (Draft)

Source: JICA Study Team

In general construction bidding, it is the Client's duty to disclose all site information and survey/test results held by the Client to the bidder. In the event that the Client fails to disclose information that has already been obtained and some defect or failure occurs during construction, if it is proven that it would have been possible to construct the countermeasure work in advance if such information had been disclosed, the additional construction period and additional cost for the countermeasure work will be

covered by the Client's responsibility.

(2) Type of Drawings

The type and definition of drawings related to construction work are basically classified into five types as shown in Table 3.2.

Table 3.2 Types of Drawings at Implementation Stage

Type	Definition	Time of preparation
Design drawing	The "design drawing" is a drawing that clearly shows the dimensions specifications of the construction object and the conditions under which the design and the construction is carried out. The designer creates "design drawings" and delivers them to the Client. If there a defect in the delivered drawing is found out after ordering the construction work, the designer will repair the drawing. Drawings for examination of the construction plan (construction method, construction procedure, etc.) are not included in "design documents" when ordering construction.	Detailed Design Stage
Reference drawing	A "reference drawing" is construction plan drawing such as equipment layout and traffic control layout and is presented as a reference at tender notice. In the "reference drawing", the approach for cost estimates is clarified and presented at the tender notice. The Contractor may use the "reference drawing" as a reference in quantity calculation and cost estimates for calculating the construction price (bid price), and in construction.	Detailed Design Stage
Changed design drawing	A "changed design drawing" is a drawing to make a design change in case where the conditions specified in the initial design drawing do not coincide with the actual site conditions and it is inappropriate to construct according to the initial design drawing as a result of the survey and inspection performed by the Contractor, or a new survey / design is required due to site condition.	Construction Stage
Working drawing (Shop drawing)	A "working drawing" is a drawing that the Contractor voluntarily creates at its own discretion as necessary for construction. It is not a "design document" because it is created voluntarily at the discretion of the Contractor.	Construction Stage
As-built drawing	"As-built drawing" is a drawing that records the completed state of the construction object with respect to the initial design drawing, changed design drawing, and reference drawing (if necessary). As-built drawing is created by the Contractor and delivered to the Client when the construction is completed.	After completion

Source: Easy-to-understand design and construction drawings[1]

Table 3.3 Report and Drawings of Detailed Design Result Product (Example)

Type	Bidding document prepared	Remark
Reports	1. Detailed Design Report 2. Bill of Quantities 3. Structural calculation sheet/stress calculation sheet 4. Alignment calculation sheet	The construction conditions required for cost estimates is described for each applicable work type in the report.
Drawings	1. List of drawings	
	2. Location map	
	3. Alignment	
	4. Plan (1:1,000 or 1:500)	
	5. Profile (V=1:200, H=1:1,000 or V=1:100, H=1:500)	
	6. Standard cross section (1:50 or 1:100)	
	7. Cross section (1:100 or 1:200), (every 200m and point of variation)	
	8. Structure design (structure general drawing, structure dimensional drawing, bar arrangement drawing, detail drawing)	Structures requiring structural/stress calculation
	9. Small structure drawing	Structures not requiring structural calculation (clarification of application condition)
	10. Irrigation and drainage drawing (drainage system drawing, detail drawing)	
	11. Road ancillary structure drawing	
	12. Pavement structure drawing (pavement developed view, pavement detail drawing)	
	13. Temporary structure drawing	Designated temporary structure[1]
	14. Others	
	15. Construction plan drawing (equipment layout drawing, traffic control drawing)	Reference drawing

Source: JICA Study Team

(3) Supplemental Natural Condition Survey

In the Grant Aid Project, since sufficient natural condition surveys are carried out in the preparatory survey stage, the addition of natural condition surveys at the detailed design stage is not approved in principle. However, supplemental natural condition surveys may be conducted in the following cases.

Table 3.4 Examples of Natural Condition Survey

Type of survey	Definition
Geological survey	・ When there is a change in the alignment or span of the bridge depending on the result of the preparatory survey, a geological survey at the just point of the structure (bridge, pier, etc.) is required. ・ When there are survey points such as CBR (California Bearing Ratio) that could not be confirmed due to site restrictions during the preparatory survey ・ When there are places where the survey such as CBR survey has not been conducted because of change in the route from the preparatory survey result.
Topographic Survey	・ When the terrain is altered due to a disaster after the preparatory survey. ・ When there are survey points that could not be confirmed due to site restrictions during the preparatory survey. ・ When there is a change in the route etc. after the preliminary survey result and additional survey is required.
Traffic volume survey	・ When there is a large change in the traffic volume or movement of the target route due to the operation of new facilities or the development of new road which are not confirmed at preparatory survey.

Source: JICA Study Team

[1] Temporary structures are generally treated as reference drawings, but temporary structures that are particularly necessary for construction or safety assurance may be specified in the design documents. In this case, the drawing of the designated temporary structure is treated as a design drawing. Contractor can change the design of these temporary structures. In any case, the contractor is responsible for the damage caused by the design of these temporary structures.

(4) Points to Note in Preparing Special Specifications

The concerning items that are not mentioned in the General Specifications of the recipient country, it is necessary to supplement in the Special Specifications. Table 3.5 shows examples of the types of items that are stated in Special Specifications for road works. It should be noted that the examples shown here are not all of them.

Table 3.5 Items Stated in Special Specifications (Examples)

General Specifications Contents	After-notes to Special Specifications	
Work types not stated	Those that require higher standards or specifications than standard specifications	E.g., When treating soft ground by adopting countermeasures not described in the standard specifications, etc.
	High Performance Concrete	Materials, Mixing, Quality control
	Waste disposal	Disposal method and management,
	Base course recycling	Specifications, construction method
	Surface recycling	Specifications, construction method
	Modified asphalt pavement	Specifications, producing method, construction method
Review for quality control	Cement stabilized base/subbase course	Clarification of equipment used in the case of in-situ mixing (for the description of machine construction, specify the road mixing by stabilizer and the machine in consideration of quality control, etc.)
Test items that are not listed or subject to Bill of Quantities settlement in General Specifications	Mix design method (Superpave method, refusal density method, etc.)	Superpave method, refusal density method
	Performance evaluation test (Wheel Tracking test, labeling test, etc.)	Testing machine specifications, test method, performance stipulated values
	Proof rolling	Timing, specification
	CBR Test	Timing, specification, interval
	Extraction Test (Plant)	Frequency, specification

Source: JICA Study Team

- Material test

As for the material tests to be conducted in the initial stage of each construction project, the standard specifications for construction projects applied by recipient country require the Contractor to obtain adjustment certificates of the test equipment. When the test is outsourced to an external organization such as a national organization stipulated by the government of the recipient country, it shall be clearly stated in the special specifications that any failure to adjust and certify the testing equipment owned and used by the outsourced organization is the responsibility of the Contractor. And the approval of test results in the case of outsourcing to a private testing organization as a highly reliable testing organization shall also be specified in the special specifications.

- Review of BQ items in standard construction specifications such as additional tests

In the standard specifications of each country, some items such as additional tests (e.g. proof rolling (see P3-19)) may be stipulated as "required by the Engineer" based on BQ system (adjusted by unit price and quantity). However, since the Grant Aid Project does not assume BQ system based on the final quantity, the description of BQ settlement in the standard specification of construction owned by the government of the partner country shall be deleted by special specification. The

following is a description example of the standard specifications (Uganda) regarding proof rolling. "Required by the Engineer" in the text should be changed to "must be implemented" in the special specifications created by the Grant Aid Project.

> (c) Proof rolling
> Proof rolling of any earthworks layer or roadbed using loaded trucks or suitable rollers shall be carried out as required by the Engineer. The equipment and method of operation shall be as directed by the Engineer and the Contractor shall make all required equipment available for proof rolling at any time as required by the Engineer.

Source: P3000-21, GENERAL SPECIFICATIONS FOR ROAD AND BRIDGE WORKS, UGANDA[2]

(5) Notes on Bidding and Contract Stage

In addition, the following points should be taken into consideration when tendering and contract.

- In the bidding stage, questions from bidders are answered, and if it is necessary to change the contract conditions, an addendum is issued to change the contract conditions. In addition, the answers to the questions will be disclosed to all bidders.
- Payment is based on lump-sum contract, while costs arising from design and contract changes are paid based on the agreed unit rates. The design change requires the confirmation and consent of JICA by application of the implementing agency. Generally, the amount of change will be examined within the range of the amount of money in the order of balance and contingency.

3.2 Construction Management and Construction Supervision

(1) Features of JICA Projects

In civil engineering work in Japan, construction supervision is generally carried out directly by the Client, but in JICA (Japan International Cooperation Agency) projects, a Consultant acts as an agent for the executing agency, and "supervises" if the Contractor is carrying out the construction according to contracts, specifications, drawings, etc. The Contractor "manages" the construction for the purpose of efficiently producing construction objects that satisfy the quality standards stipulated in contract documents.

- Contents of construction supervision
  - Checking of construction plan (construction schedule, quality control plan, safety management plan, etc.) prepared by Contractor
  - Supervision of construction work in progress (process, on-site confirmation of quality, site safety, etc.)
  - Dealing with issues occurred during construction
  - Pointing out default in the construction by the Contractor
  - Issuance of certificates according to the contract
  - First judge on change request submitted by the Contractor
- Contents of construction management

  The construction company shall prepare a "construction plan" and submit it to the implementing agency. The construction plan shall describe the best construction methods (provision of labor force, materials, construction methods, machinery, etc.) and quality control methods in order to construct the construction objectives according to the design specifications within the construction period in an economical, safe and efficient manner with minimal adverse effects on the local community and the environment, based on the terms of the contract. The construction company shall implement the following management based on the construction plan.
  - "Process control" to manage the progress and process of construction
  - "As-built management" to manage the shape and dimensions of construction object
  - "Quality management" to control the strength and quality of materials
  - "Safety management" to control the safety of the workplace and third parties
  - In addition, "cost management"

Construction management is responsible for managing the entire construction work and proceeding with the construction economically and safely.

(2) Role of JICA in Supervision

JICA is in charge of implementation supervision and confirm the technical aspects as follows. The role of JICA is defined by E/N (Exchange of Notes) and G/A (Grant Agreement).

- Attendance at the construction quality control meeting (Client, JICA, Consultant, Contractor)
- Implementation status survey by JICA inspectors
- Confirmation of progress
- Confirmation and agreement of design change

(3) Extent of Responsibility of Consulting Engineer

- Project Leader

The Project Leader exercises all the authority belonging to the Consultant company on behalf of the Consultant company. The Project Leader may delegate his authority to assistants, including a resident supervisor. However, the following matters cannot be delegated.

- Determination of matters specified in Sub-clause 5.5 of GCC (General Conditions of Contract)
- Instructions to the Contractor regarding contract changes that require the approval of the Client
- Decision to commence the work
- Decision to postpone the completion (delivery) deadline
- Issuance of certificate of confirmation of achievement and certificate of completion
- Agreement of construction plan (by construction type)

- Resident engineer

The resident supervisor receives the delegation of authority from the Project Leader and exercises the authority related to daily construction supervision. The specific authority is as follows.

- Supervision of quality and finished shape based on construction specifications and approved construction plans (including attendance at inspections).
- Supervision of safety measures of Contractor and confirmation of correction of nonconformance based on "safe construction plan" (assumed to be included in construction plan by construction type in principle).
- Instructions of implementing corrections for problems associated with the above (including nonconformance of safety measures)
- Review before approval of construction plan (confirmation of consistency of contract document including construction specifications with site conditions, and report to Project Leader)
- Sending and receiving documents related construction
- Other instructions within the delegated scope

In addition, the resident supervisor is a person who plays an important role of the construction

supervision organization necessary for the proper and smooth implementation of the Grant Aid Project, and satisfies the following requirements.

- Having the experience and ability necessary to supervise the target construction work.
- Having the communication skills necessary to work with executing agency and local related companies such as local Consultants, and ability to build a relationship of trust.

- Local assistant

The local assistant, under the supervision of the resident supervisor, is entrusted by the resident supervisor to perform quality supervision, finished shape supervision, and attendance to inspections.

Source: Guidance for Consulting Services in Grant Aid Projects[3]

(4) Contents of Construction Supervision Plan

The "Construction Supervision Plan" is specified as "elaborating the supervision plan" which is one of the Scope of the Services of Consultants in the General Conditions of Agreement for Consulting Service applied to the projects decided by the Cabinet after November 2015.

The construction supervision plan should be described concretely and clearly, not in general terms, in full consideration of the conditions specific to the project, the content of the construction, and its progress. The construction supervision plan plays the following roles.

- After survey/design contents, design documents and construction method proposed by the Contractor are confirmed and the construction supervision method is determined within the Consultants (Project Leader, deputy Project Leader, Japanese staffs involved in the design, and resident supervisor), common understanding of method of construction supervision by the Consultants is obtained among executing agency, Contractor and Consultants.
- By responding to the construction plan submitted by the Contractor and new information, the required supervision contents can be optimized, and the important points can be clarified.
- The obligations (contents of services to be provided) of the Consultants to the Client during the construction period will be clarified. In addition, it is expected to have the effect of promoting a deeper understanding of Japanese quality control / safety management and the business procedures borne by the Client among Client and parties concerned, and to enhance communication.

(5) Contents of Construction Plan

The Contractor must prepare a construction plan that concretely shows the construction method, quality control method, etc., and submit it to the executing agency after discussion and coordination with the construction supervision Consultant. The construction plan is prepared by the construction company prior to construction in order to build the construction object in accordance with the requirements of the contract document. In preparing the construction plan, after properly understanding the contract conditions and site conditions, in order to formulate a construction plan that is economical, safe, and efficient with the least adverse effects on the local community and the environment at that time, the following basic points are considered.

- Condition of contract instructed by the executing agency

- Site condition and site constraints
- Construction implementation organization
- Basic construction schedule
- Construction method and procedure
- Selection of machinery and equipment and delivery plan
- Selection of materials and delivery plan
- Planning and placement of temporary equipment
- Safety management (daily safety and health management system, emergency system, etc.)
- Security management (physical defense of the site, surveillance and guard, movement system of project staff, etc.)
- Traffic control (including layout plan of guard fence, security lighting and traffic guide)
- Environment preservation measure
- Construction waste disposal plan

When significant change in the contents of the construction plan occurs, the changed plan will be submitted to the executing agency after consultation and agreement with the construction supervision Consultant.

The construction plan will describe the materials to be used, construction method, and construction schedule, and especially regarding quality control, details such as confirmation and witness method by Consultants, quality confirmation test, and inspection standard will be shown. The construction plan should be described concretely and clearly, not in general terms, in full consideration of the conditions specific to the project, the content of the construction, and its progress.

(6) Construction Quality Control Meeting

As described in Chapter 1, for civil engineering facility projects in Africa and large civil engineering facility projects in other regions, a "Construction Quality Control Meeting" is stipulated to share information among the implementing agencies, consultants, construction companies and JICA to ensure construction quality. It should be noted that this meeting is to be used for ensuring smooth progress and quality of the project and is different from the monthly meeting in the purpose and the character. (See Chapter 1 for details.)

(7) Project Completion Report

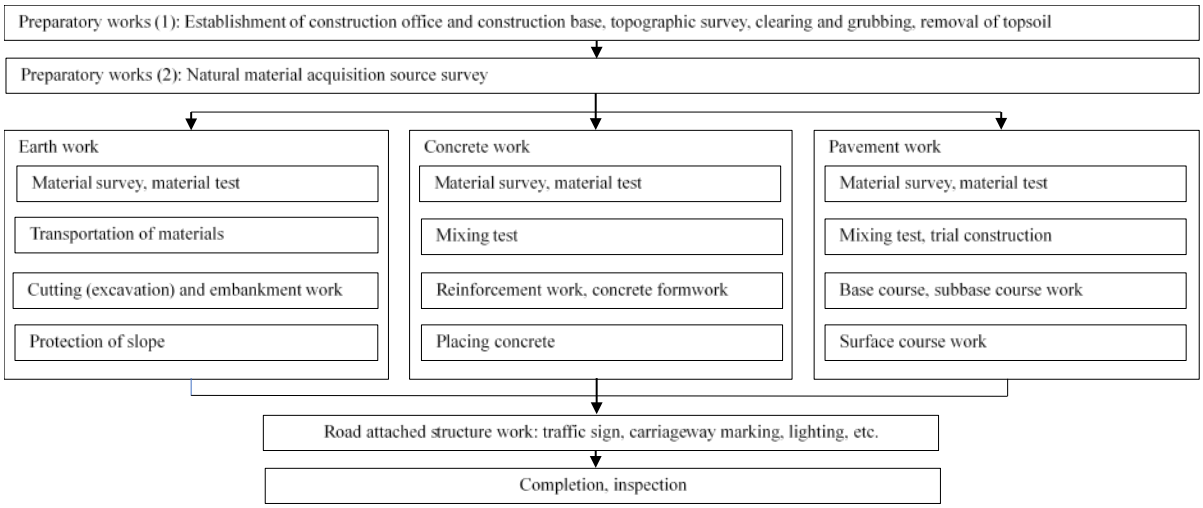
In the PCR (Project Completion Report) to be submitted at the end of the project, in addition to the specified contents of the report, points to be noted for the proper implementation of the maintenance and management of the object, and measures (technical cooperation) necessary for the continuous implementation of the maintenance and management by the implementing agency shall be reported. In particular, points to note on maintenance and management points identified during the construction phase should be shared with the implementing organization by holding a seminar upon completion. For example, if information on the areas where water inflow occurred during construction, or the areas where drainage conditions are poor at intersections is shared, special attention can be paid to these areas during maintenance and management.

3.3 Preparation Stage of Road Construction

3.3 to 3.8 are described for road construction in general sections (earthwork sections), excluding structural sections such as bridges and tunnels.

(1) Procedure of Road Construction

Road improvement and new construction by Grant Aid Project is generally implemented according to the procedure shown in Figure 3.1.



Source: JICA Study Team

Figure 3.1 Standard Procedure of Road Construction

(2) Establishment of Construction Office and Construction Base

After the contract is concluded, the Contractor arranges for a performance bond, advance payment guarantee, and various types of insurance, notifies to the government of the establishment of a business office and submit tax registration. At the same time, the Contractor sets up an office and a construction base at the construction site. The facilities and equipment illustrated below will be installed at the construction base

Facilities for construction

- Material Test laboratory
- Goods and cement storage warehouse
- Concrete production equipment
- Concrete aggregate (crushed stone / sand) storage area
- Water storage tank
- Power receiving and generating equipment
- Fuel supply facility (gas station)
- Machine repair shop and spare parts store
- Formwork, rebar and other material storage and processing plants
- Parking lot

Facilities for safe and health

- Security guard room
- Outer fence
- Medical office (First Aid)

These facilities are to be set up not in the main construction area acquired by the Client, but at a site leased by the Contractor in the vicinity. The installation work begins usually after the notice to proceed has been issued (after the start of the count of the construction period). This work is carried out using

general purpose machinery (e.g., tire backhoe, tire shovel, truck crane, etc.) that is easily delivered to and from the site.

Tire Backhoe

Tire Shovel

Truck Crane

Source: HP of each company

Photo 3.1 Examples of Heavy Machinery Used in Establishment of Construction Office and Construction Base

Since the construction base installation work will be the first work to be carried out before the project organization is established, it is necessary to thoroughly prepare safety education and safety signs and protective equipment in advance. Not only as a security measure indicating the site boundary but also it is necessary to install fence to divide the periphery and restrict access by anyone other than those involved in the construction after installation of construction base. Especially in cases near conflict areas or in areas with poor security, the support of police and military organizations of the partner country may be required as the security measures.

(3) Topographic Survey

After the conclusion of the construction contract, once the notice to proceed is issued by the Client to the Contractor, the first work to be carried out by the Contractor in the construction area is the topographical survey in the presence of the Consultant, which includes the control point survey, centerline and site boundary surveys, and profile leveling/cross-section survey by actual survey on the ground. In Japan, since the surveying method using drones became available for public construction works from March 2016, each construction company is also promoting the development of more efficient construction surveying technology. In the case of construction works by Grant Aid carried out in developing countries, there are issues such as communication environment, accuracy of drone surveying (the error becomes larger when the height difference from the flight height becomes larger at large change points such as the shoulder and toe of the slope), securing of engineers, and procurement of hardware equipment that handles 3D data, so conventional measurement surveying on the ground is the mainstream at present. However, it is expected that there will be a chronological shift to drone surveying in the future.

1) Control point survey/reference point survey

The Consultant will install survey control points at several locations in the construction area based on the national control points owned and managed by the government agencies of the partner country (Ministry of Land, Ministry of Works, etc.) during the preparatory survey and detailed design.

However, until the handing over of the construction site to the Contractor and the start of construction, some control points may have been broken or moved slightly, so all survey control points are resurveyed and restored to their correct positions. This survey is carried out with an instrument called Total Station (a surveying instrument that incorporates the function of a rangefinder into an instrument

called a theodolite that measures horizontal and vertical angles) with built-in software to analyze the survey data and accurately measure the distances and angles between the control points. The elevation of the control points will be checked by conventional Auto Level as well as by Total Station.

Total Station

Auto Level

Source: HP of each company

Photo 3.2 Control Point Survey

2) Center-line survey, land boundary survey

Based on the control points restored to their exact position by control point survey, center-line survey of the road is conducted and the survey points of the road center at normally 20m intervals and the site boundary of construction area acquired by the Client are restored. In the survey, the survey point of the road center given by coordinates is converted into the distance and angle from the control point, and the site boundaries on both sides of the road are converted into the distance from the road center. The survey is conducted by Total Station.

3) Profile leveling/cross-section survey

The vertical topography along the road centerline and the transversal topography of each survey point of the road center are surveyed during the preparatory survey or detailed design, and are shown in the tender/contract drawings. However, in a construction project, generally remeasurement is carried out after the start of construction, and construction management is performed based on the results of remeasurement. In this survey, Total Station or Auto Level and tape measurement is used.

(4) Clearing and Grubbing, Removal of Structure

Based on the results of profile leveling/cross-section survey, the area occupied by the main construction work will be clearly indicated on the site, and the trees will be cut and rooted up and existing structures will be removed only within the occupied area. These works are carried out by using a bulldozer or backhoe.

Bulldozer

Backhoe

Source: HP of each company

Photo 3.3 Machinery used in Clearing and Grubbing, Removal of Structure

(5) Removal of Topsoil

As the topsoil covering the ground surface with vegetation is soft soil and contains grass roots and other impurities, soil with a depth of 150-200mm from the ground surface will be removed from the entire area occupied by the main construction work and disposed of to an approved soil-bank. The topsoil will be stripped by a bulldozer or backhoe and transported to the soil-bank by dump truck.

Bulldozer

Backhoe

Source: HP of each company

Photo 3.4 Machinery used in Removal of Topsoil

(6) Natural Material Acquisition Source Survey

The natural materials to be used in the road works include good soil for embankment, sand and crushed stone, all of which will be obtained from the vicinity of the worksite. The information on candidate material acquisition places obtained by the Client and Consultants during preparatory survey or detailed design will be provided to the bidders through the Soil and Material Report at the time of bidding, however, this information does not designate the places of the natural materials to be acquired. It is at the discretion of the bidder (Contractor). The Contractor will begin this survey during the bidding period and decide the places of the materials within 1-2 months after the completion of contract. However, since the quality of these materials and the transport distance to the places will have a significant impact on the quality and cost of the work, the survey will continue thereafter and may be changed to a more advantageous location even during construction. This survey is primarily handled by manpower and does not require construction machinery. Surveys on acquisition destination of crushed stones are often conducted at existing quarries or at quarry sites used in past projects.

Regarding the mining of these natural materials, permission from the Ministry of the Environment and the Ministry of Resources of the recipient country government must be obtained, and it may take a considerable time to obtain the permission, so mining permit should be obtained by the executing agency before the tender notice.

3.4 Earthwork of Road Construction

(1) Soil Survey and Soil Test

Before carrying out the construction, soil surveys and soil tests will be conducted to confirm that the properties of the soil and materials are adequate for the purpose of the construction. In this stage, some soils listed in Table 3.6 are problematic for road construction.

Table 3.6 Soil Problematic for Road Construction

Name of soil	Feature	Problem in road construction	Distribution area	Remark
Dispersive soil	Soil that has a higher content of sodium ions dissolved in gap water than ordinary clay, and has the property of being easily eroded, in which the bonds between soil particles are lost and dissolved by rainfall and flooding.	When used as an embankment material, erosion causes gullying, slope collapse and perforations called dragon holes (dragon holes in Cambodia, also called tunnel erosion or sink holes).	Many cases have been identified in Southeast Asia.	See Chapter 4, 4.7 (5) for details.
Expansive soil	It is a blackish-gray expansive soil, often called black cotton soil. The name was given because of its suitability for cotton cropping.	This soil is hard and has great bearing capacity in the dry state, but as the moisture content increases, it becomes clay-like and swells, completely losing its strength held in the dry state. Shrinkage cracks occur during the drying process from the wet state, and this material poses a serious problem in road construction.	Many cases have been identified in South Asia and East Africa.	See Chapter 4, 4.7 (5) for details.
Organic soil	Soil of thick accumulation of the remains of hygrophyte that have not decomposed due to excessive humidity. When squeezing a lump of soil with hand, water drips down like a watery sponge.	Compared to sandy soil, it has a higher void ratio and water content, and is also fibrous and easily compacted, which causes ground deformation such as settlement and lateral flow when embankments and structures are constructed.	Found worldwide. It is distributed mainly in alluvial areas, hinterland wetlands of coastal dunes, valleys, and high mountains.	-
Saline soil or presence of saline water	Acid sulfate soils are soils with abnormally high levels of sulfur compounds that become highly acidic under oxidizing conditions.	A large amount of soil excavation causes the use of marine clay, and the acidic water that flows from the clay affects the ecosystem, and when used as embankment material, the covered vegetation works die out.	Found worldwide. Mainly a prominent problem in dry and semi-arid areas	-

Source: JICA Study Team

If such soil is found during the construction period, soil tests should be conducted to identify the soil properties, and countermeasures should be discussed with local experts and reported to the implementing agency and JICA (Japan International Cooperation Agency). And the quantity of work required for these measures (e.g., replacement quantity, etc.) should be recorded with photographs of the site.

(2) Excavation and Embankment

After topsoil removal is completed, the ground is excavated or filled to the height of the subgrade of the pavement over which the pavement work (subgrade, base course/subbase course and surface course) will begin. Of these, the actual embankment work is rather difficult. Even if rigorously tested, the soil is not a uniform material by nature, so the larger the amount (large-scale embankment), the more the influence of the borrow pit and compaction management will appear. In addition, if the foundation ground of the embankment is soft, it will be difficult to stabilize the embankment structure, so countermeasures against soft ground will be implemented. In the construction of embankment, the material of the embankment and the compaction of the embankment are the most important. The following are general points to note during construction.

- To spread the soil in compliance with the specified spreading thickness (usually about 30 cm per layer).
- The compaction will be carefully performed while adjusting the moisture content. No embankment work will be done during rainfall.
- A simple drainage gutter will be installed around the construction area to prevent rainwater from entering the construction area from the outside. And measures such as taking a drainage gradient will be taken to prevent water from accumulating on the surface.
- In order to prevent adverse effects on the structure due to vibration of a large compaction machine in the immediate vicinity of the structure, compaction will be carefully done by small compaction machine with a spread thickness of 15 cm or less per layer to prevent insufficient compaction.
- The boundary of cutting or embankment or the boundary between cutting and embankment will be constructed with particular care so that the upper part of the embankment will not subside after completion.

As for the embankment material, generally, the material of the borrow pit near the site is used mainly for economic reasons. However, due to the nature of the material, it may not be possible to obtain a suitable soil near the site. Improper materials will immediately affect workability and finished quality. Therefore, it is necessary to carefully consider the selection. The required qualities of general embankment materials are as follows.

- The content of fine particles such as clay and silt is below the specified value.
- The trafficability of the construction machine can be ensured.
- The prescribed compaction can be easily performed.
- The compacted soil has high shear strength and low compressibility.

Soil is composed of soil particles, water, and air (gas), so when soil is loosened, spread, and heaped up into the required shape, it will still contain air more than in the natural ground. In the case of a subgrade or a road body on which a heavy object is placed, this causes subsidence and cannot achieve the purpose as a soil structure. Therefore, in order to minimize the amount of compression settlement by expelling the air to make the soil dense and increase the density, increasing the homogeneity, making water content close to the optimum state that gives the highest strength, the work of compaction is performed.

Compaction means to evacuate the air in the soil and increase the density by applying an external force (energy) to the soil. The dry density when the soil gap is minimized in this way is called the maximum dry density, and the water content at this time is the optimum water content. Summarizing above, the purpose of compaction is as follows.

- To reduce the air void in the soil, reduce the permeability, and reduce the softening and expansion caused by the ingress of water, thus making the soil the most stable state.
- To equip the strength characteristics required for embankment, such as stabilizing the slope of the embankment and strengthening the bearing capacity against loads.
- To reduce deformation such as compression settlement after completion.

In order to realize the above, when designing and constructing the embankment, the criteria for compaction such as the extent of compaction, the water content at the time of compaction, and the thickness of the construction layer should be set, and the embankment work should be managed according to the criteria. There are two types of management methods: method of quality regulation and method of construction method regulation.

1) Method of Quality Regulation

- Method specified from the maximum dry density and optimum water content of the standard test: This is the most common method for defining the degree of compaction, which is the ratio of the dry density of the soil compacted in the field to the maximum dry density of the standard compaction test.
- Method of defining the air void ratio or saturation ratio by the construction water content ratio: A method of defining the air void ratio or saturation ratio within a certain range as a condition for the compacted soil to be in a stable state.
- Method to specify the strength or deformation characteristics of compacted soil: A method in which the strength or deformation characteristics of compacted soil are specified by values such as penetration resistance, field CBR (California Bearing Ratio) value, bearing capacity (ground coefficient), or deflection by proof rolling.

2) Method of Construction Method Regulation

- Method to specify the type of compaction machine to be used or the number of compactions: This is a convenient method at sites where the soil quality and water content of the embankment material hardly change, but it is necessary to conduct a site compaction test in advance to confirm that the embankment can secure the required properties. Table 3.7 shows the relationship between the test methods specified in both regulations.

Table 3.7 Main Laboratory Test (for Earth Work)

Regulation method	Name of regulation	Name of test	Stipulated value	Applicable soil
Method of quality regulation	Strength regulation	Plate loading test, CBR test, cone penetrator test	K value, CBR value, qc value	Gravel and sand
	Deformation volume regulation	Proof rolling	Settlement	
	Dry density regulation	Compaction test, unit weight test	Compaction degree	General soil, sandy soil, rudaceous soil
	Saturation degree regulation	Density test of soil particles	Saturation degree	Cohesive soil with high water content
	Air void ratio regulation	Density test of soil particles	Air void ratio	
Method of construction method regulation	Construction method regulation	Construction test	Weight and number of running	Rock lump, cobble stone

Source: www.mizunotec.co.jp/index.html

However, the method of conducting laboratory tests on a sample collected at the site does not confirm that the entire construction area has achieved the predetermined quality because the quality is limited to the section where the sample is collected. Therefore, many construction specifications require that the condition of the embankment constructed in accordance with the regulations of the method of construction method regulation be confirmed by the test of the method of quality regulation, and that the presence or absence of weak points in the entire construction area be confirmed by the proof rolling.

Since roadwork site will be narrow and long in many cases, the combination of construction equipment will be as follows.

Excavation:

- Excavation by bulldozer – collection point – loading by backhoe – carrying out by dump truck
- Excavation by backhoe – loading by backhoe – carrying out by dump truck

Bulldozer

Loading by backhoe

Loading by backhoe

Source: HP of Contractors

Photo 3.5 Machinery used in Excavation

Embankment: Works are carried out using soil satisfied requirement from borrow-pit and embanked at t=150-200mm per layer.

- Loading soil from borrow-pit by backhoe/tire shovel – transport of soil by dump truck – temporal laying and levelling by bulldozer – humidification by road sprinkler – stirring and levelling by motor grader – compaction by vibrating roller (10-12 ton) or tire roller (8-20 ton)

Backhoe

Dump truck

Bulldozer

Road sprinkler

Motor grader

Vibrating roller and tire roller

Source: HP of each company

Photo 3.6 Machinery used in Embankment

👉 Measures against rainfall at earthwork sites

The standard construction specifications oblige construction companies to take drainage and disaster prevention measures such as installing temporary drainage channels and drainage pumps at construction sites (especially earthworks sites) for road construction. And it is also stipulated that these drainage and disaster prevention measures should be taken by the construction company prior to other main and temporary construction works, and the construction supervision of the consultant must also confirm the completion of these measures. Therefore, it is necessary for construction companies to take measures against rainwater and drainage, recognizing that when earthwork materials become unusable due to inadequate disaster prevention and drainage measures, they must be replaced at their own expense and responsibility. This also applies to pavement construction (base course/subbase course construction, surface course construction).

(3) Leveling of Pavement Foundation

After the completion of the excavation and embankment work, the top layer of the pavement foundation (t=150-200mm) is corrected in order to increase the accuracy of the height and compaction of the pavement base.

- Scraping by motor grader - humidification by road sprinkler - stirring and levelling by motor grader – compaction by vibrating roller (10-12 ton) or tire roller (8-20 ton)

Scraping by motor grader

Road sprinkler

Stirring and levelling by motor grader

Vibrating roller

Source: HP of each company

Photo 3.7 Machinery used in Correction of Pavement Foundation

(4) Construction of Subgrade

On the pavement foundation that has been corrected, construct two layers or more with each thickness t=150-200mm by good quality soil excavated from the borrow-pit.

- Collection and loading of good quality soil by backhoe/tire shovel – transport of soil by dump truck – temporal laying and levelling by bulldozer – humidification by road sprinkler – stirring and levelling by motor grader – compaction by vibrating roller (10-12 ton) or tire roller (8-20 ton)

In the construction of subgrade, the following points are noted.

- To avoid unnecessary heavy machinery work so as not to disturb the subgrade soil.
- To compact or improve the soft ground or embankment carefully so that the bearing capacity of the subgrade becomes uniform.
- When passing a work vehicle after the shape of subgrade has been adjusted, the first layer of the subbase course should be finished.

Partial soft spots on the subgrade can later become fatal defects. For this reason, a proof rolling test will be conducted, and appropriate construction will be confirmed visually.

☞ Proof Rolling

The purpose of proof rolling is to detect defective parts which cause harmful deformation in subgrade or base course/subbase course at an early stage. The method of proof rolling is to slowly (about 2 km/h) run a dump truck or the like on the constructed subgrade or base course/subbase course and measure the amount of surface subsidence (crack) due to the wheel load. Normally, quality control tests for compaction and bearing capacity of the subgrade and base course/subbase course is to judge the entire section based on the measured values at a limited part of the representative points. On the other hand, proof flooring can check the entire section (generally for each lane) uniformly, enables management without overlook, and so is the significant method.

Proof Rolling (1)

Proof Rolling (2)

Source: About supervision and inspection of public works[4]

Photo 3.8 Proof Rolling

In Japan, the test method is shown in the Handbook of Pavement Research and Testing Methods[5] (G023 Proof Rolling Test Method), and each contracting agency has established individual provisions in their construction specifications. Since many standard construction specifications in developing countries do not specify proof-rolling test methods, the consultant should instruct the test method in the special specifications for construction. In the Japanese proof-rolling test, deflection is observed and measured to identify defective locations. In developing countries, however, repair work is sometimes carried out on defective locations where deflection is visually observed to the extent that cracks occur.

3.5 Pavement Work of Road

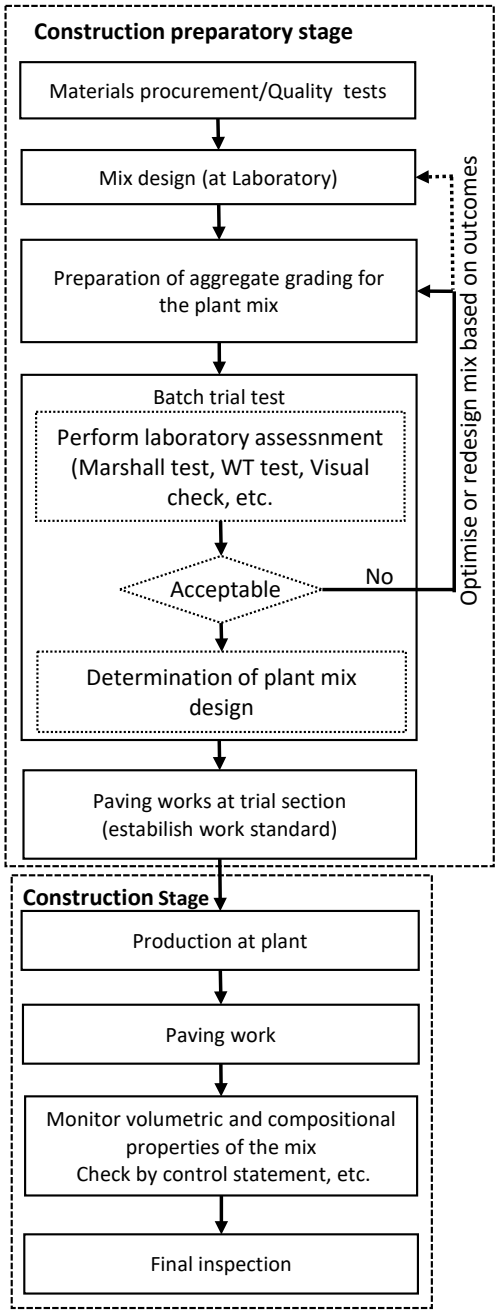
(1) Preparation of Asphalt Pavement Work

The preparatory stage for asphalt pavement work consists of tests to confirm the quality of materials, tests to obtain standard values such as standard density and standard aggregate particle size, and trial construction to obtain working standards.

Mix design at laboratory: The mix design conducted at laboratory is a procedure for selecting the mix ratio of aggregate and filler (aggregate synthetic particle size) and determining the appropriate asphalt amount based on the required performance of the asphalt mixture, and is evaluated by Marshall Stability test. The formulation determined here is called laboratory mixing.

Test mixing (onsite mixing): In the asphalt plant, the asphalt mixture is produced by adjusting the flow rate at the cold hopper and the mixing amount in the hot bin for each aggregate so as to match the laboratory mixing, and the validity of the particle size, the amount of asphalt, etc. is evaluated. The mixing that passed evaluation and produced is called onsite mixing. If various test results, such as void, saturation, stability, or target DS value, do not meet the specified standard values, the particle size and asphalt amount will be adjusted finely. At the same time, the management targets (mixing time, set temperature) at the asphalt plant will be determined.

Trial construction: The trial construction is to lay pavement on site experimentally using onsite mixing. By trial construction, working standards onsite (site management standards such as construction temperature and construction thickness, and standards such as compaction machine/number of compactions, working sequence, precautions for equipment used, etc.) will be established. In addition, if there is a problem with quality (surface texture, color gloss, etc.) or workability, the onsite mixing may be adjusted finely as necessary.



Source: JICA Study Team

Figure 3.2 Flow of Pavement Construction

(2) Procurement of Materials and Tests for Quality Confirmation

The asphalt mixture is produced by combining aggregates and fillers with asphalt. The roles of the materials used in the asphalt mixture are shown in Table 3.8.

Table 3.8 General Materials Composing Asphalt Mixture

Material	Type	Usage
Aggregate	Crushed stone, screenings, river sand, etc.	Forms the skeleton
Filler	Collected dust, mineral powder dust, cement, lime	Improves the viscoelasticity of the binder, fills gaps and improves exfoliation resistance
Binder (Asphalt)	Straight, polymer modified, PG*, etc.	Adheres aggregates and fillers. As it is a highly temperature-sensitive material that has a large effect on the mixture, care must be taken.

*PG: Performance Grade
Source: JICA Study Team

By weight, a normal asphalt mixture is composed of about 90% aggregate and about 5% filler, and the rest is asphalt. The quality and durability of an asphalt mixture, which is composed of about 95% aggregate and filler, largely depends on their properties and mixing ratio. Table 3.9 shows the role of aggregates and filler.

Table 3.9 Role of Aggregate and Filler

Materials	Definition	Role
Coarse aggregate	Contents that remain in a 2.36mm sieve	This forms the framework of the asphalt mixture. It supports the traffic load and disperses it in the lower layer.
Fine aggregate	Contents that pass through a 2.36mm sieve but remain in a 0.075mm sieve	This fills the gaps in coarse aggregate, thereby enhancing stability and water tightness.
Filler	Fine particles that pass through a 0.075mm sieve	This fills the gaps in aggregate, thereby boosting resistance to stripping. It also reduces temperature sensitivity.

Reference: Pavement Engineering Library 7, Basics of Pavement Engineering[6]

The test method to confirm the properties of aggregates is shown in Table 3.10.

Table 3.10 Tests to Confirm Properties of Aggregates

Property	Test method
Grading	Sieving test, washing test
Shape (flat and long-thin rate)	Aggregate angularity test
Durability	Los-Angeles test, stability test, Aggregate crushing test
Impurity content	Organic substance content test, sand equivalent test

Source: JICA Study Team

A suitable crushed stone for an asphalt mixture is a spherical shape with abundant ridges. However, at overseas sites, the rock contains a lot of quartz, the equipment of the crushing plant is poor, and the equipment of the plant is often inadequate, resulting in the production of flat and elongated crushed stone. If there are many flat and elongated crushed stones, the crushed stones will lay flat like stacked bricks when kneaded by tire roller or vehicle. As a result, the aggregate gap ratio and porosity decrease. Therefore, when producing crushed stone, due consideration should be given to the equipment of the crushing plant.

Table 3.11 Facilities in Crushing Plant

Facility	Function	Standard facility	Desirable facility
Grizzly feeder	Elimination of mud and small rough stone		✓
Jaw crusher	Primary crushing of large lump of rough stone	✓	✓
Cone crusher	Secondary crushing Improving grain shape by rubbing	✓	✓
Impact crusher	Crushing by impact Grading effect		✓
Screen	Classification	✓	✓

Source: JICA Study Team

The test method for confirming the properties of the binder is shown in Table 3.12.

Table 3.12 Tests to Confirm Properties of Binder

Type	Test method
Straight (bitumen)	Penetration, softening point, kinematic viscosity
PMB (Polymer Modified Bitumen)	Toughness, tenacity, bending test of binder
Performance grade (Bitumen for Superpave)	RV (Rolational Viscometer), BBR (Bending Beam Rheometer), DTT (Direct Tension Test), DSR (Dynamic Shear Rheometer), etc.

RV: handling
DSR: permanent deformation (rutting), fatigue cracking (structural cracking)
BBR: temperature crack (cold crack)
DTT: temperature crack (cold crack)
Source: JICA Study Team

👉 Rock type

Rocks used as raw materials for pavement aggregates are broadly classified into igneous, hydrogeological (sedimentary), and metamorphic rocks according to their formation. Among igneous rocks, acidic rocks (specific gravity less than 2.75) containing more than 66% silica content generally have higher affinity to water than asphalt and do not adhere well to asphalt. Basic rock with silica content less than 52% (specific gravity greater than 2.75) is called hydrophobic aggregate and adheres well to asphalt. Thus, aggregates with high specific gravity are often suitable for paving materials because they are generally solid and often absorb less water. However, it should be noted that many overseas aggregates have a high specific gravity but are brittle due to iron content. In particular, when using them for surface asphalt mixtures, it is necessary to thoroughly check them during material testing, compounding design, and test kneading, and be careful not to use soft aggregate.

(3) Mix Design (Laboratory Mixing)

1) Method of Mix Design

The mix design is to determine the amount of asphalt and the amount of aggregate so that the required quality such as fluid rutting resistance can be obtained by using a material of a designated quality.

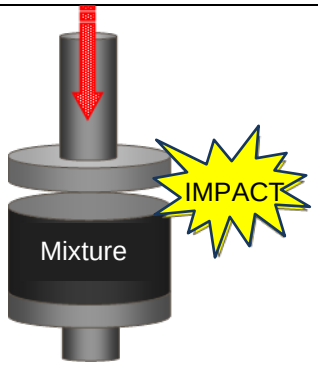
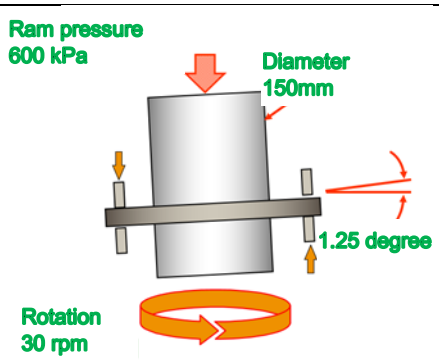
Mix design refers to the determination of the amount of asphalt and aggregate to achieve the required quality, such as flow rutting resistance, using materials of a given quality. In Africa, where the temperature is high, it is important to prevent flow rutting, but it is also necessary to satisfy the original wear resistance and crack resistance. In addition, it should be noted that different countries have different approaches on how to improve resistance to flow rutting, especially in Europe. For example, there is an understanding that it is common for West African countries to use the French approach. Specifically, hard asphalt with a penetration of 10/20 is used. Since this is a method that has not been

used in Japan, it is necessary to carefully examine whether it can ensure crack resistance, long-term wear resistance, and whether it is consistent with the structural design including the base course/subbase course.

In Japan, the Marshall mix design method is applied. Also in developing countries, the Marshall mix design method is used as a pavement design standard, however the Marshall test standard value in mix design differs depending on each country's standard.

A new mix design method available for asphalt mixtures is the Superpave method. This method is called a volumetric design method. Noticeably, the method associates vehicle behaviors and the mix design. Table 3.13 shows the comparison with the Marshall mix design method that is generally used at the present time.

Table 3.13 Major Mix Design Methods

Design method	Marshall design mix method	Superpave method
Overview	The type of the mixture and materials to be used for the mixture are selected based on the weather conditions and traffic conditions and the aggregate mix ratio is determined so as to satisfy the granularity specification. Sample pieces are produced by changing the asphalt content with compacting cycles according to the traffic conditions. The designed asphalt content is set within the range (in general median value) that satisfies the mixture standard. This method is widely used globally as per the Pavement Construction Handbook and ORN19[7].	Asphalt, aggregate, and granularity of the specified PG (Performance Grade) are selected, the mixture is compacted according to the compaction parameter (turning cycles, etc.) according to the traffic volume by using a gyratory compactor with the roller compaction simulation, and the asphalt content to be used for the design is set based on the volume standard.
Specimen making method		
Applied material selection method	① Asphalt: Selected based on the weather, region, traffic conditions, and applied section. ② Aggregate: The aggregate that complies with the specification and is available for the required volume is selected.	① Asphalt: Selected based on the maximum and minimum pavement temperatures. ② Aggregate: The aggregate that complies with the Superpave aggregate specification is selected.
Designed asphalt content selection method	Mixture standard: Selected from the asphalt content range that satisfies the air void, percent Voids Filled with Asphalt (VFA), volume of voids in mineral aggregate, stability, and flow. In general, a median value of the range is selected. The standard items and values vary depending on the institution.	The designed asphalt content is set to satisfy the volume standard according to the traffic level (air void based on the compaction parameters $N_{ini,}$ $N_{design,}$ and N_{max}, volume of voids in mineral aggregate in $N_{design,}$ VFA, and dust binder ratio).
Flow resistance assessment method	The plastic deformation wheel passes is verified as required (Pavement Construction Handbook). Alternatively, the Refusal density method (ORN19[7], 31[8]) is applied.	-

Source: JICA Study Team

☞ The definitions of each indicator of Asphalt Mix

Voids in mineral aggregate (VMA): This is the total percentage of non-aggregate materials (asphalt) and air within the asphalt mixture. This is regarded as one of the most important parameters in asphalt mix design[19]. As the asphalt content increases, this displays a V-shaped curve, initially declining but then rising.

Air void: The ratio of air (gaps) in asphalt mixture. This is around 4% when conducting Marshall stability test on general pavement. To ensure the stability of asphalt mixture, a minimum air void must be retained.

Voids filled with asphalt (VFA): This indicates the degree to which asphalt fills the gaps between aggregate in asphalt mixture. If the voids filled with asphalt (VFA) is too small, this will lead to early hardening and deterioration, while excessively high VFA and low air void may indicate that there is too much asphalt. In these cases, flow resistance will be low. However, there are somewhat large disparities between standards and thinking in each country, and in some countries, it is not even used as a standard in the Marshall stability test.

Stability: This indicates the degree of resistance to flow rutting and waveform deformation caused by vehicular traffic load when the mixture temperature is high. Testing is conducted by placing a cylindrical sample on its side and pressing on it with the equipment of the Marshall stability test. However, it is said that correlation with flow rutting is poor[9].

Flow: This is the degree of deformation in a sample when the maximum load is placed on it. It is necessary to secure a value in the appropriate range since an excessively high value will lead to rutting while an excessively low value will lead to cracking. A value between 20-40 (2.0-4.0mm) is recommended.

Table 3.14 Standard Values for Marshall Test (Pavement Construction Handbook[10])

Type of mixture		a	b		c	d	e
		Coarse graded Asphalt mixture	Dense graded Asphalt mixture		Fine graded Asphalt mixture	Dense graded Gap asphalt mixture	Open graded Asphalt mixture
		(20)	(20)	(13)	(13)	(13)	(13)
Number of blows	1,000≦T	75					
	T＜1,000	50					
Air void (%)		3-7	3-6			3-7	-
Saturation (%)		65-85	70-85			65-85	-
Stability (kN)		4.90 (7.35) or more	4.90 (7.35) or more		4.90 or more		3.43 or more
Flow (1/100cm)		20-40					

1. T is the pavement plan traffic volume (vehicles/day by direction). The pavement design traffic volume is the average volume of large-size vehicle traffic (per day, by direction) during the design period.
2. Figures in parentheses ( ) for stability are standard values in the case of a compaction of 75 times.
3. The recommended VMA (Voids in Mineral Aggregate) is 15% or more when the aggregate maximum particle size is 20mm and 16% or more when it is 13mm. The recommended stability /flow is in the range of 2000~4,900 kN/m in general areas.
4. The recommended design quantity of asphalt in surface layer mixture when flow rutting is predicted in general areas is in the range of the median value and lower limit quantity of asphalt that satisfies the Marshall test standard shown in the table.
5. These standards are applicable under Japanese conditions; however, local standards should be applied in overseas countries.

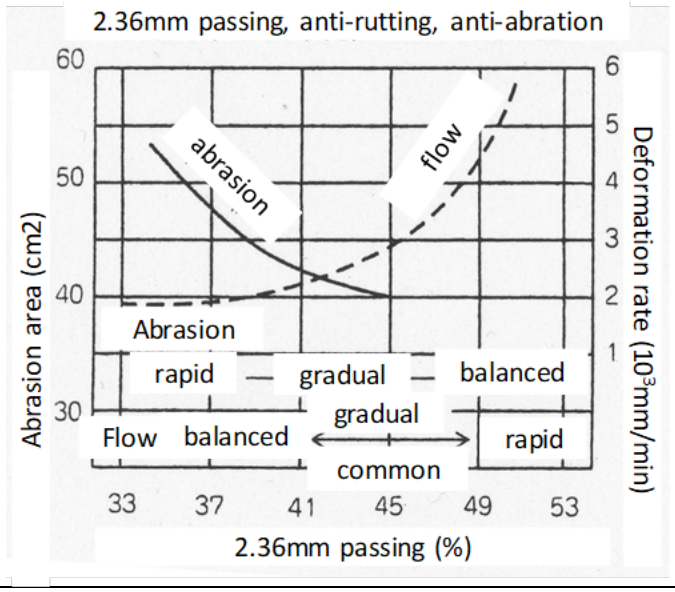
Source: Pavement Construction Handbook[10]

These indicators are not always independent of one another but rather are inter-dependent. Accordingly, sometimes when one indicator is satisfied, another indicator changes and it is difficult to satisfy both. This trend is especially marked in foreign countries' materials, and there are even

cases where order of priority is applied to indicators. For example, air void > VMA > Marshall stability ≧ flow, etc.

2) Mix Design (Particle Size Distribution)

Concerning aggregate particle size, basically the particle size in the mix design is determined within the particle size range that is stipulated in the Specifications. The flow resistance and abrasion resistance durability of asphalt mixture varies largely by the setting of the target aggregate combined grading. Figure 3.3 shows the relationship between the percentage passing 2.36mm sieve size and the durability of asphalt mixture. In the Marshall stability test, the optimum aggregate combined grading is generally deemed to be the median value in the particle size range, however, if focusing on the flow resistance in Figure 3.3, the median value is not preferable.

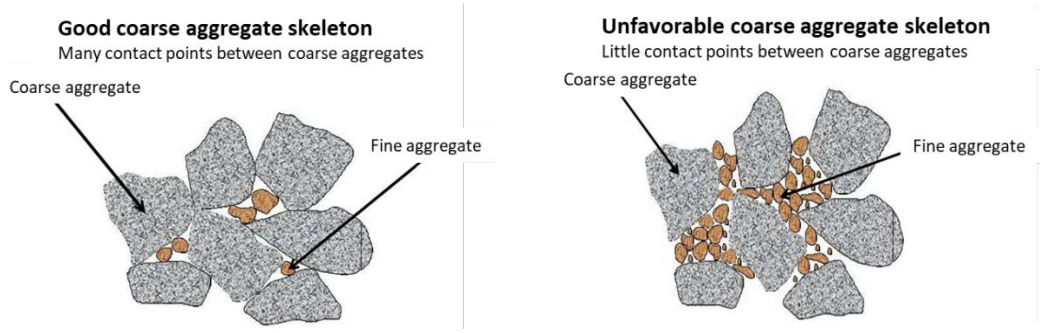


Passing 2.36mm sieve: Small (coarse particles) ⇒ Flow rutting resistance ◎, abrasion resistance X
Passing 2.36mm sieve: Large (fine particles) ⇒ Flow rutting resistance X, abrasion resistance ◎

Source: Technical Handbook: 1998 Japan Highway Public Corporation Research Institute[11]

Figure 3.3 Relationship between Flow Resistance, Abrasion Resistance and Percentage Passing 2.36mm Sieve Size

To counter flow rutting, interlocking of the coarse aggregate in asphalt mixture is the basic theory not only in the Superpave method but also the pavement technical literature of Australia, South Africa and elsewhere. This concept is illustrated in Figure 3.4: the figure on the left shows the state where coarse aggregate particles form a skeleton, while the figure on the right shows the state where coarse aggregate particles do not rest against each other and cannot form a skeleton. Although it isn't possible to directly measure the degree of skeleton of coarse aggregate, it is possible to judge by the air void. If the air void following compaction is a fixed value (for example, 4% in the Marshall mix design method and 2~2.5% (final value) in the Superpave method), skeleton is deemed to be maintained. It should be understood that the basic principle in securing resistance to flow rutting lies in the skeleton of the coarse aggregate.

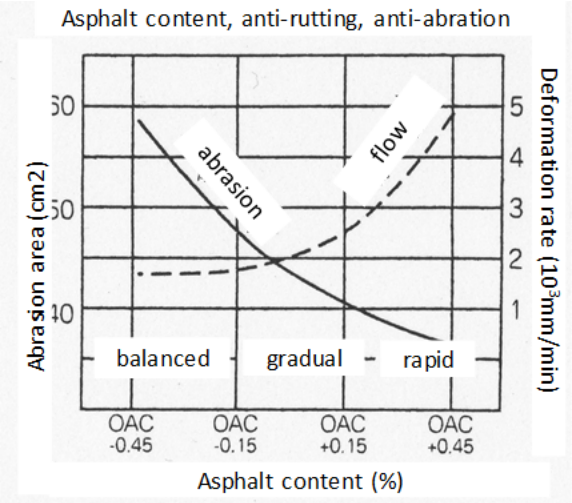


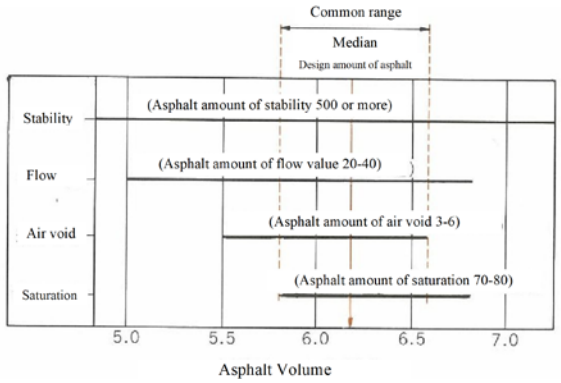
Source: Crushed Stone Mastic Pavement- SMA[12]

Figure 3.4 Conditions of Skeleton formed by Interlocked Aggregate Meshing

3) Mix Design (Amount of Asphalt)

Similar to the impact of the "percentage passing 2.36mm sieve size", the asphalt content has a major impact on durability of the mixture. Figure 3.5 shows the relationship between the asphalt content and durability of the mixture. The median value within the common range (range of the asphalt content that satisfies all standard values) is generally regarded as the design asphalt content, however, on roads that have heavy traffic volume, the design asphalt content may be reduced to a value between the median and the lower limit. Moreover, by adopting aggregate with appropriate angularity and Voids in Mineral Aggregate (VMA), the voids filled with asphalt (VFA) falls even if the asphalt content is the same, however, it is possible that the asphalt covering of aggregate will be sufficiently thick not to adversely impact the durability and workability.





Common range of Marshall test standard values (for dense graded asphalt mixture)

Asphalt content: Small ⇒ Flow rutting resistance ◎, abrasion resistance X
Asphalt content: Large ⇒ Flow rutting resistance X, abrasion resistance ◎

OAC: Optimum Asphalt Content, the amount of asphalt that will give the asphalt mixture optimum performance for a given specification. It is usually determined by Marshall test. For example, OAC-0.45% means 0.45% less asphalt content than the optimum asphalt content.

Source: Technical Handbook: 1998 Japan Highway Public Corporation Research Institute [11] Knowledge of asphalt mixture [13]

Figure 3.5 Relationship between Flow Resistance, Abrasion Resistance, and Asphalt Content

4) Degree of Impact on Flow Resistance of Parameters based on JICA Testing in Japan

Table 3.15 and Figure 3.6 show the results of tests implemented by JICA (Japan International Cooperation Agency) in 2019 to confirm mix design that considers flow resistance. Since high-quality aggregate was used in this testing, there is no guarantee that similar DS[2] (Dynamic Stability) values can be obtained under different environmental conditions, however, a trend can be recognized from the results. The salient observations are described below.

First, as is shown in Table 3.15, from the viewpoint of flow resistance, the DS value can be improved by using coarse aggregate that has square-shaped particles (tertiary crushing) and filler composed of limestone dust or crushed sand (artificial sand), rather than recycled dust. Concerning mix, as is shown in Figure 3.6, results suggest that it is effective to reduce the asphalt content by 0.4~0.5% from OAC (Optimum Asphalt Content) and adopt asphalt that has small penetration (40/60).

Table 3.15 Degree of Impact of Parameters on Test Items

Items / Parameter	Marshal stability small	⇔	large	Impact
CAA	round		angular	minimum
	flat		aquare	
Fine aggregate	Natural	Mixed	Crushed	slightly large
Filler	Cement	Stone powder	Recovery dust	minimum

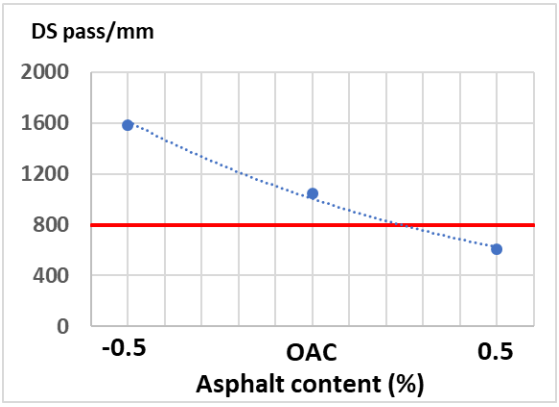
Items / Parameter	Residual stability small	⇔	large	Impact
CAA	angular		round	minimum
	flat		aquare	slightly large
Fine aggregate	Natural	Crushed	Mixed	middle
Filler	Stone powder	Recovery dust	Cement	small

Items / Parameter	DS small	⇔	larde	Impact
CAA	round		angular	minimum
	flat		aquare	maximam
Fine aggregate	Natural	Mixed	Crushed	large
Filler	Recovery dust	Cement	Stone powder	maximam

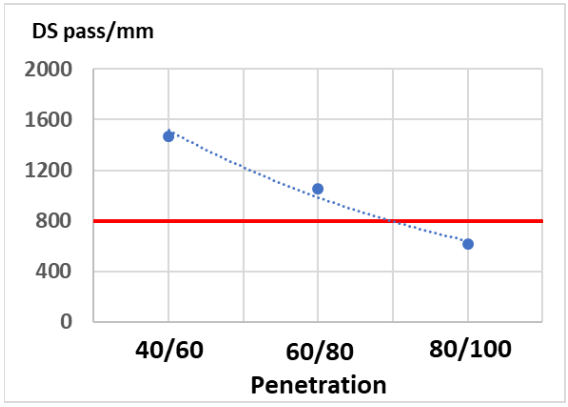
Note: Degree of impact

minimum	～3%
small	3～5%
middle	5～10%
large	10～20%
maxmum	20%～

Source: JICA Study Team



Relationship between asphalt content and DS



Relationship between penetration and DS

Source: JICA Study Team

Figure 3.6 Relationships between Main Parameters and DS

[2] DS (Dynamic Stability) is the number of wheel passes required for the specimen to deform 1 mm (45 minutes and 15/60 minutes after the start of the wheel tracking test).

(4) Evaluation of Designed Mixture

The main methods for evaluating flow resistance of asphalt mixture are the WT (wheel tracking) test, unconfined compression test, triaxial test, creep test, etc. In Japan, evaluation based on WT test is mostly commonly adopted. Overseas, the HWT (Hamburg Wheel Tracking) test, refusal density test, etc. are also used.

When adopting Superpave, since the type of asphalt is determined according to the road surface temperature, the WT test is used to confirm to make sure. However, if following the Japanese procedure, since the required DS value is one of the target values, the WT test is essential. The WT test is implemented after installing the necessary equipment for the test in the project test facility. As is shown in the WT test outline indicated in Table 3.16, to conduct this test, in addition to the WT testing machine, a roller compactor for preparing samples, a mixer with capacity of 20kg or more (a model with high mixing capacity for kneading the modifying additive), and molding boxes are needed.

Table 3.16 Outline of WT Testing Machine

Standard		Pavement Survey and Test Method Handbook[5] B003
Device (example)		Wheel tracking device Mixer Roller compactor for making specimens
Form of samples		300×300×50mm (Lab samples) 300×150×50mm (samples excavated on-site)
Sample curing conditions		Unsoaked (Air)
Compaction		100%±1%
Test objective		Plastic deformation (rutting resistance) evaluation
Test temperature		60±2℃
Test time (loading completion conditions)		60minutes after the start of loading or until the sample becomes deformed by 25mm
Device	Tire type	Solid tire (JIS hardness 84)
	Tire form	W=5cm, φ=20cm
	Load	686±10N
	Cycle	42±1passes/min (two-way 21.0±0.5 times/min)
	Travel distance	230mm
Organizing of results		Dynamic stability: DS (passes/mm)

Source: JICA Study Team

(5) Production of Asphalt Mixture

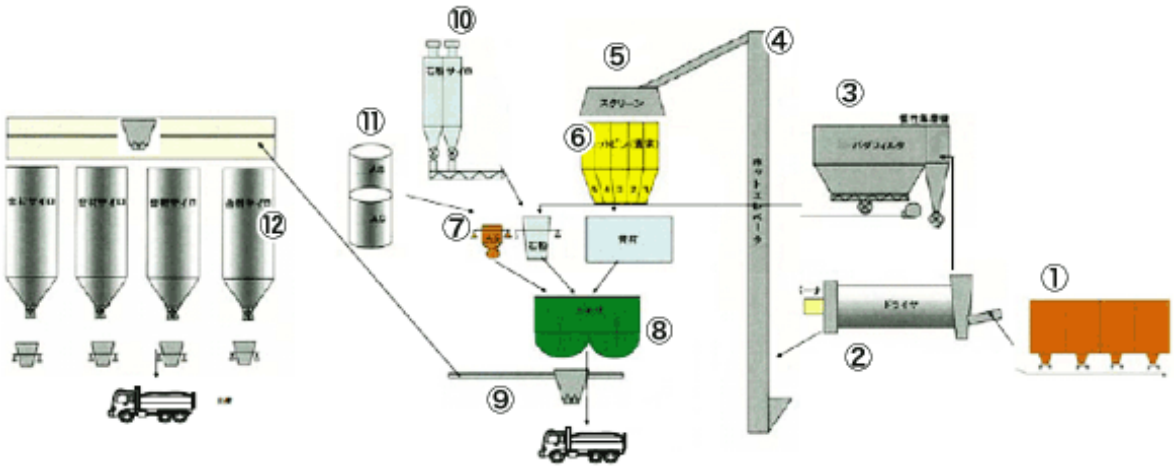
Most asphalt plants operating in Japan are the batch type, while those in developing countries are largely the continuous type. Table 3.17 shows the characteristics, merits and demerits of each type of asphalt plant.

Table 3.17 Types of Asphalt Mix Plant

Item	Batch asphalt plant	Continuous asphalt plant
Characteristics	・Each material is weighed one batch at a time in a weighing tank and then mixed in the mixer.	・Materials that are fed at the set flow rate are continuously mixed.
Advantage	・Since materials flowing from a cold hopper are weighed after being separated in a screen, it is generally easy to perform quality control. ・This type can easily respond to the manufacture of various types of mixture in small quantities.	・Equipment items such as screen, hot bin, hot elevator, etc. are not needed. The equipment is more compact and less expensive, and it is easier to increase the manufacturing capacity. ・If just one type of mixture is needed, a large amount can be supplied stably.
Disadvantage	・Compared to the continuous type, more equipment is needed.	・The results of cold hopper management directly impact the quality of the discharged materials. ・It is not suited to the manufacture of various types of mixture in small quantities.

Source: JICA Study Team

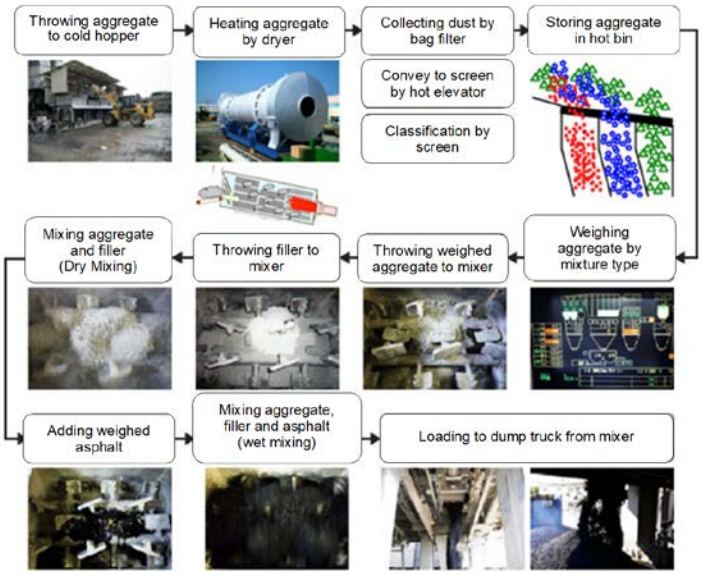
Figure 3.7 and Figure 3.8 shows the standard composition of the batch type asphalt plant.



① Temporary storage apparatus for feeding aggregate to the manufacturing line (cold hopper)
② Device for heating and drying aggregate (drier)
③ Device for collecting dust, etc. by passing through exhaust gas (bag filter)
④ Device for carrying heated aggregate to the screen (hot elevator)
⑤ Device for grading the aggregate carried to the hot elevator into the specified particle sizes (screen)
⑥ Apparatus for maintaining temperature and temporarily storing the screened aggregate (hot bin)
⑦ Device for separately weighing the aggregate, stone dust and asphalt (weighing device)
⑧ Device for uniformly mixing the weighed aggregate, stone dust and asphalt (mixer)
⑨ Device for conveying the mixture discharged from the mixer (trolley)
⑩ Apparatus for temporarily storing the stone dust for feeding to the weighing device (stone dust silo)
⑪ Temporary storage device equipped with insulating feature for holding asphalt in liquid form (asphalt tank)
⑫ Apparatus for maintaining temperature and storing the manufactured mixture (hot silo)

Source: The Japan Asphalt Association homepage (http://www.askyo.jp/knowledge/07-1.html)

Figure 3.7 Standard Composition of Batch Type Asphalt Plant



Source: Japan Asphalt Association HP (http://www.askyo.jp/knowledge/07-1.html)

Figure 3.8 Production Process of Mixture by Batch Type Asphalt Plant

(6) Quality Control of Asphalt Mixture

For asphalt pavement work in Japan, asphalt mixtures can be procured from quality certified asphalt plants almost anywhere in Japan. However, in the case of countries for Grant Aid, even if a local asphalt plant exists, it may be necessary to investigate in advance and include an inspection process for quality. And unlike in Japan, when a Contractor brings in an asphalt plant by itself, it is necessary to manage the quality of the asphalt plant by itself, and the management of the asphalt plant becomes a big challenge. In the Grant Aid Project, hot bin sieving tests and extraction tests will be conducted as daily management.

Table 3.18 Quality Control Method of Asphalt Mixture

Test method	Method and feature
Sieving test	If the particle size of the aggregate changes in the base course/subbase course or the asphalt mixture, the feature of material will change, so the "sieving test" is important. The method of the sieving test is to give the sieve vertical and horizontal movements so that the sample constantly moves evenly on the sieving surface and to shake the sample until 1% of the sample does not pass through in each sieve.
Extraction test	Asphalt extraction tests include centrifugal separation extraction method, Soxhlet extraction method and combustion extraction method. The extraction test is a test for quality control to measure the asphalt content and the aggregate synthetic particle size by extracting asphalt from the asphalt mixture.

Source: JICA Study Team

For the plant mixing of asphalt mixture, the Consultant should witness the weighing and mixing of the entire batch, and if the weighing or mixing fails, immediately reject the batch and instruct to dispose it.

(7) Pavement Construction

1) Construction of Base course/subbase course

Roadbeds are classified into two types, Subbase course (lower-layer) and Base course (upper-layer), and the materials used and construction methods differ depending on the pavement design of each project, so the materials used will be described separately.

a) Natural granular material

Natural granular material is used for the subbase course and rarely used for the base course. Subbase course using natural granular material has one or two layers with thickness t=150-200mm by good quality soil provided from borrow-pit.

Machinery used for the construction is the same as subgrade.

b) Crusher-run

Among the crushed stone materials produced at the quarry, the material with a particle size of 0-40mm or 0-50mm of which particle size is not controlled is called crusher-run. Crusher-run is used for the subbase course and is rarely used for the base course. A subgrade using crusher-run is constructed with one layer with thickness t=150mm.

- Loading crushed stone by tire shovel – transport of crushed stone by dump truck – temporal laying and levelling by motor grader - humidification by road sprinkler – stirring and levelling by motor grader – compaction by vibrating roller (10-12 ton)

Tire shovel

Temporal laying and levelling by motor grader

Stirring and levelling by motor grader

Vibrating roller

Source: HP of each company

Photo 3.9 Machinery used in Construction of Base Course/Subbase course

c) Crushed stone for mechanical stabilization

Crushed stone for mechanical stabilization is crushed stone with a particle size of 0-28 mm or 0-40mm produced in a quarry, and the particle size distribution is adjusted so that the maximum compaction density is obtained. Crushed stone for mechanical stabilization is used for both the base course and the subbase course and constructed with one layer with thickness t=150mm.

- Loading crushed stone by tire shovel – transport of crushed stone by dump truck – temporal laying and levelling by motor grader - humidification by road sprinkler – stirring and levelling by motor grader – compaction by vibrating roller (10-12 ton)

d) Cement stabilized base course/subbase course

Cement stabilized base course/subbase course is made by mixing cement with good natural granular material (Low PI (Plastic Index)). Cement stabilized material is used for both the base course and subbase course and constructed with one or two layers with thickness t=150-200mm.

- Collecting and loading good quality soil by backhoe and tire shovel – transport of good quality soil by dump truck – temporal laying and levelling by motor grader – dispersion of cement by manpower – stirring of good quality soil, cement and water by stabilizer – levelling by motor grader - compaction by vibrating roller (10-12 ton) - tire roller (8-20 ton)

Dispersion of cement by manpower

Stabilizer

Motor grader

Vibrating roller

Source: HP of each company

Photo 3.10 Machinery used in Construction of Cement Stabilized Base Course/Subbase Course

e) Interlocked crushed stone base course

Interlocked crushed stone is used for base course, not subbase course. Interlocked crushed stone base course is a base course with one layer with thickness t=150mm made up with crushed stone for mechanical stabilization with a particle size of 0-28 mm or 0-40mm produced in a quarry. In constructing interlocked crushed stone base course, different from the base course using crushed stone for mechanical stabilization, a large amount of water is supplied at the time of compaction and a very large vibration is applied in compaction (slashing), so that excess moisture and excess fine particles are levitated (breathing) and crushed stone coarse particles are made interlocked with each other.

- Loading crushed stone by tire shovel – transport of crushed stone by dump truck – laying and levelling by motor grader – supplying large amount of water by road sprinkler –compaction by vibrating roller (10-25 ton) – curing - excess fine particle removal and cleaning by bloomer

Loading crushed stone
at crushing plant

Motor grader

Laying and levelling
by motor grader

Road sprinkler

Vibrating roller

Bloomer

Source: HP of each company

Photo 3.11 Machinery used in Construction of Interlocked Crushed Stone Base Course

Since the base course/subbase course is the foundation that supports binder course and surface course above it, it is important to compact it well, and it is necessary to pay attention to the following points.

- To ensure the specified degree of compaction, it should be constructed near the optimum water content (excluding interlocked crushed stone base course).
- To compact carefully near edges and structures that are prone to weaknesses.
- To construct flatly to improve the flatness of the surface layer and reduce material waste.

2) Prime coat spraying

In order to prevent scouring of base course/subbase course by rainfall and infiltrating of surface water, to block capillary rise of water from base course/subbase course and to enhance adherence of base course/subbase course and asphalt mixture constructed above it, a predetermined amount of emulsion is sprayed promptly and uniformly as the prime coat. In particular, it should be noted that crushed stone base course is highly permeable, and there is a high risk of water infiltration into the base course or rising to the road surface, thereby weakening the pavement. Cutback asphalt, which is petroleum refined asphalt diluted with light oil or kerosene, is used for prime coat.

Cutback asphalt heated by an asphalt kettle (or asphalt heater) is installed in a special vehicle called a bitumen distributor and transported to the spraying site. The method of spraying at the site depends on the condition of the site. Since the spraying area is large in the suburbs/village section of the national highway, spraying with a bitumen distributor is advantageous. Manual spraying by a hand sprayer is advantageous in small site in urban areas and built-up areas or on the bridge surface, because manual spraying can take protection measures to prevent adhesion to private property in the vicinity or other facilities/structures other than the surface of base course.

Spraying prime coat by machine

Spraying prime coat by manpower

Source: HP of each company

Photo 3.12 Spraying of Prime Coat

3) Binder course asphalt pavement

When the asphalt pavement thickness is 100mm or more, the asphalt pavement is divided into two layers, a binder course and a surface course. The first layer, binder course, is constructed coarse grade asphalt concrete with a large grain aggregate, and the second layer is constructed by fine-graded (or dense-grade) asphalt concrete with a small grain aggregate to improve running performance.

The heated asphalt mixture produced at the heated asphalt mixing plant is transported to the construction site by a dump truck, is laid by asphalt finisher (paver) to the area where prime coat has been sprayed, compacted initially by a 10-ton macadam roller, and compacted finally by 8-20-ton tire roller.

Asphalt finisher

Macadam roller

Tire roller

Source: HP of each company

Photo 3.13 Machinery used for Binder Course Pavement

The order of construction is to compact construction joints first, then sequentially from the lower to the higher in the transverse direction. In addition, asphalt pavement is basically continuous work, and interruption of construction causes deterioration of finished shape and quality, so it is necessary to pay attention to the following points.

- Reconfirmation of mixture type, quantity (unit), arrival time
- Arrangement of construction machines and tools
- Cleaning of construction sites, repair of defective parts, installation of pavement formwork (ruler), etc.

4) Tack coat spraying

In order to improve the adhesion between the surface course and the binder course, which are constructed in two layers, and to increase the rigidity by unifying two layers, and to reduce the horizontal strain on the underside of the binder course, thus reducing the load on the base course, tack

coat is sprayed on the surface of the binder course asphalt before the surface course asphalt is applied. As a material for the tack coat, an asphalt emulsion which is processed from petroleum refined asphalt to handle at normal temperature is used.

The spraying method is the same as the prime coat spraying, and spraying by sprayer on the asphalt distributor or manual spraying by a hand sprayer is selected according to the site conditions.

5) Surface course asphalt pavement

Work method for surface course asphalt pavement is the same as binder course. In the surface course asphalt pavement, unevenness of the lower layer is levelled and surface is completed especially flatly. Attention is paid to the weather, and if it starts to rain, the levelling work should be stopped immediately, and the mixture laid down so far should be promptly compacted and finished. Unlike the binder course, the construction joints created on the surface layer remain on the surface. Construction seams impair flatness and tend to be weak points, so it is necessary to make a construction plan to reduce them as much as possible. Since the construction joints gradually opens after in service, it is necessary to sufficiently adhere it with a tack coat and a seal coat, and to execute rolling compaction sufficiently at the beginning of construction. In addition, it is important that the construction joints of the upper and lower layers do not overlap with each other.

In pavement work, it is often necessary to open traffic as soon as the compaction of the binder course and surface course is completed, but if the traffic pavement temperature at opening traffic is high, it may cause rutting or the pavement surface may become rough.

👉 Pavement temperature at traffic opening

The traffic opening after the completion of compaction should be done after the temperature of the pavement surface is about 50°C or less. According to the Pavement Construction Handbook[14], the traffic opening temperature has a great effect on the initial rutting of the pavement, so it should be done after the temperature of the pavement surface becomes about 50°C (softening point) or less after the completion of compaction. By setting the temperature of the pavement surface to 50°C or less, the deformation of the pavement at the initial stage of opening traffic can be reduced. In high temperature areas overseas, it takes a considerable time for the pavement temperature to drop below 50°C, and continuous construction may not be possible, which may affect the progress of pavement work. When immediate traffic opening is necessary, sprinkling water is used for cooling. Power cooler is used for spraying water.

Source: Seikitokyu Kogyo Co., Ltd.

Photo 3.14 Power Cooler

(8) Quality Control in Asphalt Pavement Construction

- Temperature management of mixture

Quality control of pavement work is invisible as far as the completed road is seen, such as the temperature and particle size of the mixture or the degree of compaction. However, if this is not done properly, the road after service will deteriorate very fast, and will become a road full of holes and

complaints. In particular, temperature control of the mixture is important. Since the asphalt mixture has an "optimal temperature" at which asphalt is compacted most, it is the role of the supervisor to strictly control the temperature of the mixture that drops steadily over time, to change the construction speed, and to order the asphalt mixing plant to change the temperature of asphalt mix. In addition, if the temperature is recorded in real time, it is possible to detect quality abnormalities at an early stage. The criteria for temperature control are as follows. (Optimal temperature depends on the type of asphalt mixture and weather conditions.)

1. Temperature at the time of laying and levelling: 120° - 150°
2. Temperature at initial compaction: 110° – 140°
3. Temperature at secondary compaction: 80° - 120°

- On-site density test

A test that measures the degree of compaction of the base course/subbase course. The sand replacement method is common. Density is calculated by digging a hole in the compacted base course/subbase course, adding sand and examining the volume. Alternatively, in countries where the import and use of RI (Radio Isotope) moisture meters is permitted, RI moisture meters such as Troxler are used in sites with a large number of test sites.

Table 3.19 Requirement for the On –site Density Test (example of Base course)

Test Method	Standard	Test Criteria
Pavement survey and test manua[5] Sand replacement method（JIS A 1214） Sand replacement method is applicable only when the large particle size is 53mm or less.	93% or more (MDD) X10 more than 95% X6 more than 95.5% X3 more than 96.5%	・ Each measured value of compaction shall satisfy 93% or more of the maximum dry density and the average value shall satisfy the following. ・ The average value X10 of ten measured values satisfies the standard value. If it is difficult to obtain ten measurement values, it is assumed that the average value X3 of the three measurement values satisfies the standard value. If X3 deviates from the standard value, it is sufficient that the average value X6 obtained by adding 3 data. ・ If more than 3,000 m^2 is required for one construction, 10,000 lots or less shall be considered as one lot, and measurement shall be performed for 10 lots (10 holes) per lot.

Source: MLIT Construction Management Standards and Tollerance (Draft)[15]

- Core sampling test

Cores of the pavement are randomly collected after construction. After that, it is heated and extracted in laboratory, and the particle size of the aggregate, asphalt amount, and compaction degree are measured. As the finished shape, thickness is measured.

- Flatness test

It is categorized as finished shape control rather than quality control. A test to check the flatness of the road, which is conducted only after the surface layer is constructed. A 3m profile meter is run for the investigation.

Source: http://one-b.com/wakaru/hosou/index4.html

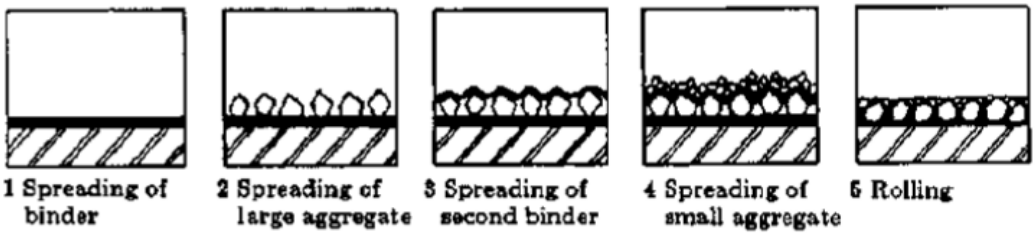
Table 3.20 Requirement for the Core sampling and Flatness Test

Test Items	Criteria	Tolerance (mm)	
		Each peace	Average (10 peace)
Thickness (t)	1 per 1000m^2	-7	-2
Width (w)	1 per 80m	-25	
Flatness	3m Profile meter	Less than 2.4mm	

Source: MLIT Construction Management Standards and Tollerance (Draft)[15]

👉 DBST (Double Bituminous Surface Treatment)

The surface treatment method can be applied both by manual construction and mechanical construction, and mechanical construction is currently the mainstream. In the surface treatment method, bituminous binder material is applied on the base course/subbase course prepared in advance, and aggregate is spread on top of the binder and compacted. When pavement is constructed in a single layer, it is called SBST (Single Bituminous Surface Treatment), and when it is constructed in two layers, it is called DBST. In DBST, the aggregate of lower layer (usually 14-19 mm) is larger than the aggregate of upper layer (usually 6-10 mm). Where possible, the use of bituminous emulsions of permeation grade bituminous binder material dispersed in water is recommended for environmental and safety considerations.



Source: SURFACE DRESSINGS Synthesis of international experiences [16]

Figure 3.9 DBST Construction Step

Mechanical Construction

Labor Based

Source: The Design Guide for Surface Dressing - Road Note 39[17] (Youtube)Low Volume Rural Road Surfacing and Pavements, A Guide to Good Practice [18]

Photo 3.15 Aggregate Dispersal

3.6 Concrete Work

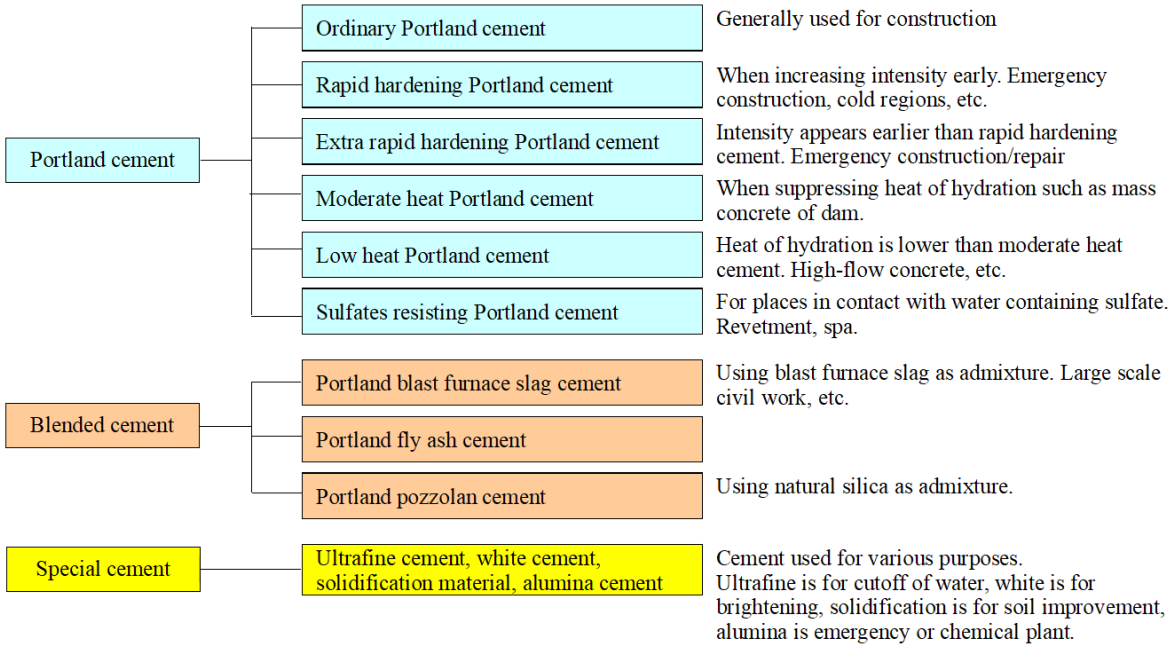
This section describes concrete work required for road construction, including retaining walls, culverts, and drainage ditches.

(1) Material of Concrete

Concrete is produced by mixing cement, aggregate and water. The aggregates are divided into gravel and sand. The former is called coarse aggregate and the latter is called fine aggregate. A small amount of admixture may be added in order to change the properties of concrete according to the purpose of use. As for the admixtures, those that are included in the volume at the time of weighing for mixing are mineral admixtures, those not included are chemical agents.

1) Cement

Concrete is the most basic material and is formed by hardening through the hydration reaction between cement and water. Cements have a wide variety of properties which are regulated by the industrial standards of each country. Even if it has accepted by the industrial standards, caution is necessary because it may be weathered due to imperfections such as state of storage. The main raw material for cement is limestone, which is abundant in Japan.



Source: Japan Cement Association HP

Figure 3.10 Types and Usages of Cement

Generally used types are roughly classified into three types: Portland cement which is generally used, blended cement made by mixing Portland cement with admixtures (blast furnace slag, fly ash, silica, etc.) and special cement developed for various purposes.

2) Coarse Aggregate and Fine Aggregate

Aggregates are classified into fine aggregates and coarse aggregates with the following measurement. Aggregate dimensions are an important factor influencing the properties of concrete.

- Fine aggregate refers to sand that passes through 10mm sieves completely and 85% or more by weight passes through 5mm sieves.
- Coarse aggregate refers to gravel which 85% by weight remains in a 5mm sieve.
- The maximum size of coarse aggregate is represented by the smallest sieve that passes 90% or more by weight in a sieving test.

The following are points to be noted regarding aggregates.

- When using crushed stone as the aggregate, avoid those with a large degree of angularity, elongated grains, or many flat grains.
- When crushed stone is used, the unit water volume increases and the optimum fine aggregate ratio value increases because the angular burrs and surface roughness are larger than in the case of river gravel.
- Chloride adhering to sea gravel causes rust on the reinforcing bars in the case of reinforced concrete. If there is no choice but to use sea gravel, wash it with water to keep the chloride content below the permissible limit.
- To suppress the alkali aggregate reaction, aggregate that has been confirmed to be harmless in the reactivity test should be used.

👉 Alkali aggregate reaction

When aggregates containing certain minerals are used, the minerals react with the alkali metals (Na, K) contained in cement, admixtures or mixed water, expand abnormally over time and causes cracks in concrete. This phenomenon is called the alkaline aggregate reaction. The alkali aggregate reaction includes an alkali silica reaction, an alkali carbonate reaction, and an alkali silicate reaction depending on the type of mineral to be reacted. In Japan, the alkali silica reaction accounts for most of the reaction.

The reason why concrete has become a common construction main material was that the concrete was made up of gravel, sand and water which were inexpensive and readily available anywhere in the world. However, recently, due to the need for environmental protection, in projects where gravel and sand mining sites are restricted, it is forced to transport materials of 100 to 200 km or more, and construction costs may rise.

3) Mineral Admixture and Chemical Agent

Admixtures are materials that are added as needed before casting in order to give concrete special properties such as improved workability, improved strength and durability, and adjustment of setting speed.

👉 Workability of concrete

Workability of concrete is the nature of fresh concrete (concrete that has not yet hardened), which indicates the degree to which operations such as transportation, casting, compaction, and finishing can be easily performed without causing material separation.

The admixtures are mainly classified into mineral admixtures and chemical agent according to the amount of addition. There is no clear boundary in the classification, and according to JIS (Japan

Industrial Standard) A 0203 (concrete terminology), mineral admixtures are defined as "among mixed materials, mixture materials in which the amount used is large and the volume of the admixture itself is included in the mixed volume of concrete or the like". The chemical agents are defined as "among mixed materials, mixture materials in which the amount used is small and the volume of the admixture itself is not included in the mixed volume of concrete or the like".

4) Water

If the water used for kneading the concrete is tap water, no particular test is necessary. Water other than tap water shall be tested and conform to the standards. In general, natural water such as groundwater, river water, and lake water are suitable. However, in Africa, depending on the region (especially around the Great Rift Valley of East Africa), those water may not be available for concrete because groundwater contains specific chemical substances (fluorine, chlorine, etc.) above the standard value, or water pollution of rivers and lakes in urban areas and suburbs exceeds the standard. There are projects where water is acquired from a water source several tens of kilometers away and construction costs rise.

(2) Concrete Mix

The mix is to determine the volume of various materials in producing 1.0m^3 of concrete in order to secure the strength and durability that concrete should have. The water-cement ratio and the unit amount of water have the greatest effect on the quality of concrete. The water-cement ratio is the ratio of water to cement in the concrete mix, and is expressed as a percentage of "W/C" when the amount of water is W and the amount of cement is C. The unit water volume is the amount of water used to produce 1.0m^3 of concrete. Concrete with a larger amount of water than necessary requires a large amount of cement, which is uneconomical, and material separation is likely to occur, resulting in large shrinkage.

1) Expression of Mix

Mix is expressed by specified mix and field mix.

- Specified mix

The specified mix is a composition mix that can obtain concrete of a predetermined quality, and is instructed by the specifications. Aggregates are shown as surface dry and water-saturated, with fine aggregates passing through all 5mm sieves and coarse aggregates staying in all 5mm sieves. The admixture is shown in the condition before diluting with water.

- Field mix

The field mix is a mix determined according to the condition of the material and the weighing method at the site so that concrete with the indicated mix (specified mix) can be obtained.

2) Mix Design

In construction work in Japan, concrete is rarely manufactured at construction sites except for a fairly large site or a special site such as a dam, and it is common to purchase ready-mixed concrete from an existing licensed factory. On the other hand, in concrete construction in developing countries, it may be difficult to procure (purchase) concrete from near the site. In this case, the mix design is conducted at the site. The points to be noted in the mix design are shown below.

- In the mix design, the ratio of the material is not determined only to obtain the design standard strength, but the workability according to the specific usage is also considered.
- It is economical to make the maximum size of the coarse aggregate larger, as the unit water and unit cement content can be decreased, but in reinforced concrete, it may be difficult to fill the concrete due to the spacing between the bars if the aggregates are too large.
- The Japan Society of Civil Engineers has set the standard value of the maximum size of coarse aggregate as 20mm or 25mm for general structures and 40mm for large cross sections or unreinforced concrete.
- When the quality of concrete fluctuates, the degree to which the target strength (the target concrete strength when determining the mix) is increased so that the minimum strength does not fall far below the specified compressive strength is called the rate of increase. When the variation in compression strength is large, the rate of increase must be increased.
- The unit amount of water should be as small as possible within the range where the required quality and workability suitable for the work can be obtained.
- If the fine aggregate ratio (s/a: the value obtained by dividing the fine aggregate volume by the total aggregate volume x 100) is large, material separation is unlikely to occur during construction, however the strength decreases. Therefore, the fine aggregate ratio is minimized within the range where material separation does not occur.
- When the minimum size of the member to be placed is small, or when the reinforcing bars are densely arranged, it is necessary to improve the workability and increase the slump.
- Increasing the amount of air with an AE (Air Entraining) agent increases workability and improves frost damage resistance, but decreases strength. Therefore, within the range where the required workability can be obtained, the amount of the AE agent used should be the minimum necessary and the amount of air should be as small as possible. In addition, a water reducing agent is used in combination to ensure strength.

👉 Specified compressive strength

The strength of concrete includes design standard strength and mix strength. The design standard strength is the target strength of concrete in structural calculation. The strength of the concrete actually casted at the construction site must not be lower than this strength. The mix strength is the target strength when deciding the mixing of concrete. In consideration of variations during production, it is common to add a certain value to the design standard strength.

(3) Reinforcing Bar

Concrete structures are often constructed as reinforced concrete. Of the strengths of concrete, the tensile strength and bending strength have values that are considerably smaller than the compressive strength, and the tensile side of a beam or slab may not be able to withstand the tensil stress. Therefore, the reinforcing bars are used to resist the stress. And since the thermal expansion coefficients of concrete and reinforcing bars are almost the same, they have the property of being able to maintain integration even in an environment where the temperature changes. These are the reasons why reinforced concrete is the main material in the construction.

Reinforcing bars include round bar and deformed bar. Round bar has a round cross-sectional shape, and deformed bar has knots on the surface to increase the degree of adhesion stress with concrete. Deformed steel bars are generally used for reinforced concrete structures.

Round bar

Deformed bar

Source: Homepages of makers

Photo 3.16 Types of Reinforcing Bar

Table 3.21 Name and Nominal Diameter of Deformed Bar

Name	D4	D5	D6	D8	D10	D13	D16	D19	D22	D25	D29	D32	D35	D38	D41	D51
Nominal diameter (mm)	4.23	5.29	6.35	7.9	9.53	12.7	15.9	19.1	22.2	25.4	28.6	31.8	34.9	38.1	41.3	50.8

Source: www.mizunotec.co.jp/index.html

(4) Formwork and Form Timbering

The formwork and formwork timbering are intended to ensure that the concrete structure has the shape and dimensions shown in the design documents. Since the formwork is generally used only for a short period of time until the concrete hardens, the safety factor may be low in examining the strength and the like.

The material of the formwork includes wood board, plywood, steel material and plastic. The material of the formwork is suitable or unsuitable depending on the properties of the material, and it cannot be said unconditionally which material is good. Considering the difference between large planes and small aspects, it is necessary to select a strong and less deformable material that is suitable for the purpose and shape of the structure and requires little processing (ready-made or factory-made).

Wood Formwork

Steel Formwork

Source: Homepage of Companies

Photo 3.17 Types of Formwork

(5) Construction of Concrete

1) Transportation of Concrete

Trucks are generally used to transport fresh concrete. These trucks are equipped with a mixing drum on the bed, can contain ready-mixed concrete, and can transport with mixing while running. These are called "truck mixers," "mixer trucks," "ready-mix trucks," "agitation trucks," "truck agitators," "mobile mixers," and so on. Among these, a mixer truck is a car that runs while mixing cement, aggregate, water, etc. which are put into the drum directly, while an agitator truck is a car that carries ready-mixed concrete that has been kneaded in advance at the factory and stirs the drum so that the concrete does not harden and material does not separate. Now that control standards have become stricter, agitator trucks are used to ship ready-mixed concrete that has passed various tests. Other means of transportation include belt conveyors, buckets and chute used at short distances. Concrete pumps are used in high places and places where vehicles cannot access directly. In addition, dump trucks are also used for pavement work such as transporting pavement concrete with a slump of 2.5 cm. Since these transportation machines are not equipped with agitating device, sufficient consideration for material separation is required, and usually used only in the construction sites.

It is necessary to pay attention to the following points when transporting concrete.

- Attention is paid to material separation.
- If the material has been separated during transportation, it should be thoroughly re-kneaded to make a homogeneous concrete. (Re-kneading means re-mixing before it starts to harden.)
- As a general rule, the time from mixing to the end of casting should not exceed 1.5 hours when the outside air temperature is over 25℃ and 2 hours when the outside temperature is under 25℃. Therefore, it is necessary to select a concrete factory based on this time. Therefore, it is necessary to select a concrete factory based on this time. This time can be changed by consultation between the manufacturer and the purchaser.
- At the time of unloading, the purchaser conducts an acceptance inspection to confirm that the quality of the fresh concrete meets the regulations.

2) Casting Concrete

The points to note regarding concrete driving are as follows.

- Prior to driving concrete, the dimensions and arrangement of the reinforcing bars and formwork should be inspected. In addition, clean the inside of the formwork and moisten the places in advance where there is a risk of absorbing water from the concrete. When casting directly on the ground, levelling concrete should be laid beforehand.
- If the location of casting is flat and wide, casting will start farther from the concrete source and end closer.
- When casting from a high place, not an oblique chute but a vertical chute is used to avoid material separation. Keep the distance between the lower end of the chute and the concrete surface within the specified value (about 1.5 m) in the construction specifications.
- If it is unavoidable to use an oblique chute, the standard gradient is 1/2 or less.

- The surface of the concrete should be kept horizontal as much as possible, and the thickness of one layer should be 50cm or less. When casting two or more layers, as a general rule, the upper concrete is casted before the lower concrete begins to solidify.
- Concrete should not be moved within the formwork. Concrete in one section is continuously casted.
- Concrete should not be mixed when it begins to harden.
- Bleeding (a phenomenon in which water rises in fresh concrete) and laitance (fine substances that float and settle on the surface due to bleeding) that appear on the surface during casting should be removed. When removing, use a dipper or sponge and do not flush the concrete surface.
- The casting speed in the vertical direction should be about 1 to 1.5m per 30minutes so that excessive lateral pressure does not work on the formwork.
- Joints between slabs or beams and walls or columns are prone to weaken due to the different subsidence rates of concrete. After the subsidence of the walls and columns is almost completed, the concrete of the slabs and beams is casted.

Concrete casting

Concrete casting by concrete pump

Source: Homepage of Companies

Photo 3.18 Casting Concrete

3) Compaction

If concrete is not compacted sufficiently to make it solid, a structure with inferior water-tightness and durability will be constructed, and the required quality cannot be obtained. An internal vibrator is usually used for compaction. By this machine, a vibrator is inserted into concrete and directly vibrated to compact the concrete. Other vibrators include formwork vibrators, surface vibrators, and table vibrators.

- Formwork vibrator: a vibrator attached to the outside of the formwork and make compaction
- Surface vibrator: a vibrator attached to the concrete surface to compact and surface the concrete. Used for concrete pavement
- Table vibrator: a formwork is placed on a table-shaped shaking table, and the concrete is compacted by the vibration of the entire formwork. Used for concrete secondary product

4) Curing

Curing is to develop sufficient strength after casting concrete, protect the concrete from vibration, shock, load, etc. so that cracks do not occur, and maintain an appropriate temperature and humidity for a certain period of time. As a curing method, a method called a wet curing is generally used. Wet curing means that after the concrete is hardened to the extent that it can be worked without damaging the surface, to cover the exposed surface with a wet curing mat, cloth, etc. or to sprinkle or stagnate the water to keep it moist. Most of the effects of wet curing are limited to the early curing period. If only the surface dries rapidly due to direct sunlight or wind after casting concrete, it may cause cracks, so measures are taken to keep it moist. Table 3.22 shows the standard wet curing period.

Table 3.22 Standard Wet Curing Period

Daily mean temperature	Ordinary Portland cement
15℃ or more	5 days
10℃ or more	7days
5℃ or more	9days

Source: www.mizunotec.co.jp/index.html

☞ Hot weather concrete

When construction is expected to be carried out during periods of high average daily temperatures (exceeding 25°C), such as in the African region and Southeast Asian region, it is standard practice to construct as hot weather concrete. When constructing hot weather concrete, appropriate measures should be taken for materials, mixing, kneading, casting, and curing to prevent deterioration of concrete quality due to high temperature. When the temperature at the time of casting exceeds 30℃, the changes in the properties of concrete become more prominent, so special consideration (e.g. night work) is necessary to keep the temperature of concrete as low as possible. In the mix design of hot weather concrete, appropriate measures should be taken to prevent excessive unit water and cement contents within the range where the required strength and workability can be obtained. When ice is used as a part of the mixing water, it should be confirmed in advance that the ice melts completely during the mixing. In principle, the time until the end of casting in hot weather concrete should be within 1.5 hours.

Source: http://civileng.ec-net.jp/concrete/shocyuucon.html

(6) Quality Control of Concrete

It takes some time for concrete to harden to the required quality necessary for the structure. Therefore, at each stage from production to casting, it is necessary to inspect the product to confirm that it has the required properties. Quality control at the plant is important for the concrete used in construction. In the production of concrete in developing countries, the contractor himself often manages the entire process from crushed stone production, procuring sand and cement to kneading, and the contractor himself is responsible for the quality control of concrete. This also applies to purchases from local concrete manufacturers. If the fresh concrete does not have the required properties, it will not achieve the required quality even after hardening, so the acceptance inspection at the concrete casting site is important for the contractor. The first step in quality control for the contractor is the acceptance inspection. The acceptance inspection of concrete at the casting site should be carried out as follows:

- Acceptance inspection is conducted at the time of unloading.

- The inspection is basically carried out according to the methods and criteria shown in Table 3.23.
- The engineer of the accepting side must visually confirm that the concrete has good workability at the time of unloading. Concrete that has been judged to be inadequate in workability should not be casted.
- It is standard that the inspection of the unit water amount of fresh concrete is carried out after the inspection method and judgment criteria is discussed by both the accepting side and the producing side in advance.
- The standard method for mix inspection is to confirm from the measurement printing record that the mix is produced with designated material volumes. The standard method for inspecting the unit water volume is to calculate it from the measurement printing record of water and the correction amount of the surface water of the aggregate.
- The standard method for inspecting the water-cement ratio is to confirm unit cement volume from measurement printing record and unit water amount. Unit water volume is calculated by the measurement printing record of water and the correction amount of the surface water of the aggregate.
- The standard inspection for alkaline aggregate reaction countermeasures is to check the concrete composition table.
- The strength inspection is based on the compressive strength test. If this inspection fails, the strength of the concrete in the structure must be inspected.
- For important structures, shrinkage strain is checked as needed.
- For super plasticized concrete, it is standard to carry out a slump and air volume test of base concrete and concrete after plasticized once every $50m^3$.

Concrete that is judged to be unacceptable as a result of inspection shall not be used.

Table 3.23 Method and Criteria of Acceptance Inspection of Ready-mixed Concrete (Japan)

Item		Inspection method	Time and frequency	Judgement criteria
Condition of fresh concrete		Visual inspection by a professional technician or a technician with equivalent technology	At the time of unloading As required	Good workability and stable properties
Slump		Method indicated by JIS A 1101	At the time of unloading Once a day or once every 20 to 150m^3 according to importance and scale of the structure. And when a change in quality is observed at the time of unloading	Permissible error Slump 5cm or more and less than 8cm: ± 1.5cm Slump 8cm or more and less than 18cm: ± 2.5cm
Air volume		Method indicated by JIS A 1116 Method indicated by JIS A 1118 Method indicated by JIS A 1128		Permissible error: ±1.5%
Temperature of fresh concrete		Method indicated by JIS A 1156		Meeting the specified conditions
Unit weight volume		Method indicated by JIS A 1116		Meeting the specified conditions
Concrete chloride content		Method indicated by JIS A 1144, or a test method authorized by a reliable institution	At the time of unloading Twice a day when sea sand is used. Once a week in other cases.	Basically 0.3kg/m^3 or less
Alkali aggregate reaction countermeasure		Confirmation of mix table	At the beginning of construction and when the material or the mix is changed.	Countermeasures are taken.
Mix	Unit water volume	Method to obtain from the surface water content of the aggregate and the measurement print record of the unit water amount	At the time of unloading. More than twice in the morning, more than twice in the afternoon.	Within the permissible range
	Unit cement volume	Measurement print record		
	Water-cement ratio	Method to obtain from the measurement print record of cement and the measurement print record of the surface water content and unit water amount of aggregate	At the time of unloading. At the beginning of construction and when the material or the mix is changed.	
	Unit volume of concrete material	Measurement print record of concrete material	At the time of unloading. More than twice in the morning, more than twice in the afternoon.	
Compression strength		Method indicated by JIS A 1108	At the time of unloading. Once a day or once every 20 to 150m^3 according to importance and scale of the structure.	Possibility to estimate that the probability of falling below the design standard strength is 5% or less by an appropriate producer risk factor.

Source: www.mizunotec.co.jp/index.html

- Slump test

The concrete slump test is a test for examining the fluidity of concrete when casting concrete, and concretes with large slump value have high fluidity. The test method is to fill the slump cone on the slump base plate with a specified number of layers of ready-mixed concrete, tamp each layer a

specified number of times, then pull up the slump cone vertically in about 3 seconds, and measure the sunken length of the top.

- Air volume test

Since the amount of air has a great effect on the workability and strength of concrete, it is confirmed at the time of unloading. The air volume test is usually conducted with an air meter, and the quality of the concrete is judged by the amount of air contained in the concrete. By the air volume test, the fluidity and compressive strength of concrete are inspected, and the greater the amount of air, the lower the compressive strength.

- Chloride content test

In the chloride ion concentration measurement, the concentration of chloride ions contained in concrete is measured, and the susceptibility to rust (rusting degree) is inspected. When the concentration of chloride ions is high, the reinforcing bars in the reinforced concrete tend to rust. The inspection method is to insert a ready-mixed concrete salinity meter into the ready-mixed concrete and measure the concentration. In Japan, the chloride content is stipulated to be 0.3 kg/m^3 or less.

- Compression strength test

Among the major qualities of concrete, compressive strength takes time to be ascertained. Normally, after the acceptance inspection is completed, 6 test pieces are prepared and soaked in water for 28 days (called 28 days material age). After 28 days, the strength is measured with a concrete compression tester, and the strength is derived from the average value. In general construction specifications, 28-day age confirmation of compressive strength is stipulated for approval of concrete work. In order to enable the subsequent work to be continued at the appropriate timing and construction cycle, it also approves that a strength test for test pieces of 7 days material age may be conducted to judge the concrete strength at an early stage.

In countries that refer to BS (British Standard), the shape of the specimen for the compressive strength test is a cubic specimen, which is 20-30% stronger than a cylinder, which is a Japanese specimen. Therefore, if the test is to be carried out using cubic specimens for reasons such as the inability to prepare testing equipment for cylinder specimens at the site, it is necessary to explain and agree in advance on the conversion reduction ratio to cylindrical specimen strength at the time of contract discussion, or at least at the first technical meeting.

Reference: JISA1132:2020 Preparation of specimen for concrete strength test

3.7 Concrete Pavement Work

(1) Procedure of Concrete Pavement Work

Concrete pavement work is carried out by the procedure shown in Table 3.11.

Source: Concrete pavement technical data[19]

Figure 3.11 Construction Procedure of Ordinary Cement Concrete Pavement

Table 3.24 Standards for Concrete Slab and Joint

Pavement design traffic volume (vehicle/day)	Design of concrete slab			Interval of contraction joint	Tie bar, Dowell bar
	Design standard bending strength	Thickness	Wire mesh		
T<100	4.5N/mm^2	15cm	Use in principle 3kg/m^2	8m	Use in principle
100≦T<250		20cm			
250≦1,000	4.5N/mm2	25cm		10m	
1,000≦T<3,000		28cm			
3,000≦		30cm			

Source: Concrete pavement technical data[19]

☞ Function of wire mesh

In ordinary concrete pavement, even if joints are provided on the concrete slab, cracks may still occur due to various causes. A wire mesh is laid to suppress the progress of this crack.

Source: Explanation and outlook of concrete pavement technology[20]

Photo 3.19 Laying Wire Mesh

(2) Construction of Continuous Reinforced Concrete Pavement

Construction of continuous reinforced concrete pavement will be carried out according to the procedure shown in Table 3.12.

Survey and bar arrangement | Laying and levelling | Compaction and shaping | Rough surface finishing | Curing

Source: Nippon Road HP (https://www.nipponroad.co.jp/method/?p=2322)

Figure 3.12 Construction Procedure of Continuous Reinforced Concrete Pavement

Table 3.25 Slab and Reinforcing Bar of Continuous Reinforced Concrete Pavement

Classification of traffic volume	Pavement design traffic volume (vehicle/day direction)	Design of concrete slab		Reinforcing bar			
				Longitudinal		Transversal	
		Design standard bending strength	Thickness	Diameter	Interval (cm)	Diameter	Interval (cm)
$N_1 – N_5$	T<1,000	4.5N/mm^2	20cm	D16	15	D13	60
				D13	10	D10	30
N_6, N_7	1,000≦T	4.5N/mm^2	25cm	D16	12,5	D13	60
				D13	8	D10	30

Note:
1. The dimensions and spacing of the longitudinal and transversal reinforcing bars are generally used in the combinations shown in the table according to the plate thickness.
2. If the longitudinal joints are matching joints, use screwed tie bars.

Source: Concrete pavement technical data[19]

(3) Quality of Concrete for Pavement

For pavement concrete to be constructed in Japan, there are cases where standard ready-mixed concrete specified in JIS (Japan Industrial Standard) standards is used, and cases where special concrete and other concrete are individually mix designed. Table 3.26 shows the types of standard pavement concrete products specified in JIS A 5308 (ready-mixed concrete), and Table 3.27 shows the quality standards.

Table 3.26 Types of Concrete foe Pavement (Standard Type)

Maximum size of course aggregate (mm)	Slump (cm)	Strength (N/mm^2)
40	2.5 and 6.5	Bending strength 4.5
25		
20		

Note: Slump 2.5cm and 6.5cm are applied mechanical construction and Labor based, respectively.
Source: JICA Study Team based on JIS A 5308 (Japanese Industrial Standards Committee)

Table 3.27 Quality Standard of Ready-mixed Concrete for Pavement

Item of quality	Quality standard
Permissible range of slump cm)	2.5 ± 1 6.5 ± 1.5
Permissible range of air volume (%)	4.5 ± 1.5
Chloride content (Chloride ion amount) (kg/m^3)	0.3 or less 0.6 or less (when approved by purchaser)
Bending strength	The result of one test is 85% or less of the strength specified by the purchaser. The average value of the three test results is equal to or higher than the strength specified by the purchaser.

Source: JICA Study Team based on JIS A 5308 (Japanese Industrial Standards Committee)

In the African region, quality control based on bending strength is not implemented, so it will be controlled based on compressive strength. In Japan, the strength control of concrete for pavement, which is based on bending strength, may be substituted by compressive strength or splitting tensile strength, which are recognized to have a correlation with bending strength. Table 3.28 shows this conversion factor.

Table 3.28 Relationship between Bending Strength and Other Strengths of Pavement Concrete

Bending strength MPa		Conversion formula*	3.5	4.0	4.4	4.8	5.0	5.3
Splitting tensile strength MPa	Φ12.5	$f_t = (f_b/2.21)^{1.40}$	2.0	2.4	2.8	3.1	3.2	3.4
Compressive strength MPa		$f_c = (f_b/0.42)^{1.5}$	24	29	35	39	41	45
Nominal strength in JIS A 5308		-	24	30	36	40	-	-

* The strength conversion formula is based on the research results of the former Ministry of Construction Civil Engineering Research Institute and the Cement Association. f_b, f_t and f_c indicate bending strength, split tensile strength and compressive strength, respectively.
Source: Pavement Design and Construction Handbook[21]

In most Grant Aid Projects, the standard mix of pavement concrete has not been established in the existing concrete manufacturing plant, or the existing manufacturing plant does not exist at the construction site. In some cases, the Contractor himself individually designs and uses the standard ready-mixed concrete specified in the JIS standard or the special concrete specified in the specifications of the project.

Whether the concrete is manufactured by the Contractor himself or outsourced to an existing producing plant, the composition design and quality control must be carried out under the responsibility of the Contractor.

(4) Construction

The points to be noted in the general construction process are as follows.

- The selection and combination of construction machines should be the most economical as long as the prescribed shape, quality and performance are guaranteed, taking into account the construction conditions.
- Prior to the construction of the concrete slab, the condition of the subgrade or asphalt middle[3] layer, the installation progress of the formwork, the maintenance condition of the construction machine, the placement position of the wire mesh and bar assembly (joint plate, slip bar, tie bar, etc.), etc. are confirmed.
- When accepting concrete, it is required to make sure that the specified quality concrete has been delivered before unloading, and if it is defective, it should be disposed.
- Unloading is carried out by a method of directly unloading from a transport vehicle onto a subgrade or an asphalt intermediate layer using an unloading machine, or a method of using a

[3] The asphalt middle layer is laid between the base and the concrete slab, and by installing this middle layer, the workability of the concrete slab, the durability of the pavement, and the water resistance of the base can be improved.

bucket such as a backhoe. Unloading work should be done carefully because the quality of the unloading affects the homogeneity and flatness of the concrete slab.

- The concrete is levelled using a spreader, and an appropriate surplus is added so that the density of the concrete is as uniform as possible.
- The levelled concrete is compacted and rough-finished to a designated height. Concrete is generally compacted in one layer with or without iron mesh.
- The surface of concrete is finished tightly and flatly using a surface finishing machine.
- The surface of concrete finished flat is roughened by a roughened surface finishing machine or manually. Rough surface finishes include broom finishes, tine grooving finishes, and aggregate exposed (washed out) finishes.

Table 3.29 Criteria and Tolerance for the As-built Inspection (example)

Criteria	Standard	Tolerance (mm)		Remarks
		Per each	Average (in 10)	
Thickness (t)	3 or more points at every 200m in the crossing direction per line by the tracing tape or level	-10	-3.5	
Width (w)	1 per 80m	-25		
Levelling (σ)	Whole length per each lane	Less than 2.4mm		Less than 3mm for Labor based
Uneven (t)	Adjacent joints, road centerlines and edges	±2		

Source: MLIT Construction Management Standards and Tollerance (Draft)[15]

3.8 Environmental and Safety Measures during the Construction

(1) Mitigation Measures and Monitoring during Construction and Operation

The EIA (Environmental Impact Assessment) is only a documentary approval, so it is important to ensure the effectiveness of the EIA by fully implementing and monitoring the aversion of risks which were concern in the EIA by mitigation measures.

Project implementation status and environmental impact monitoring are carried out while the project is implemented. This is basically an inspection to ensure that the project complies with the guidelines and recommendations contained in the environmental assessment. These inspections are also conducted to confirm the accuracy of the impact forecasted by the environmental assessment after the project is completed as shown in Figure 3.13.

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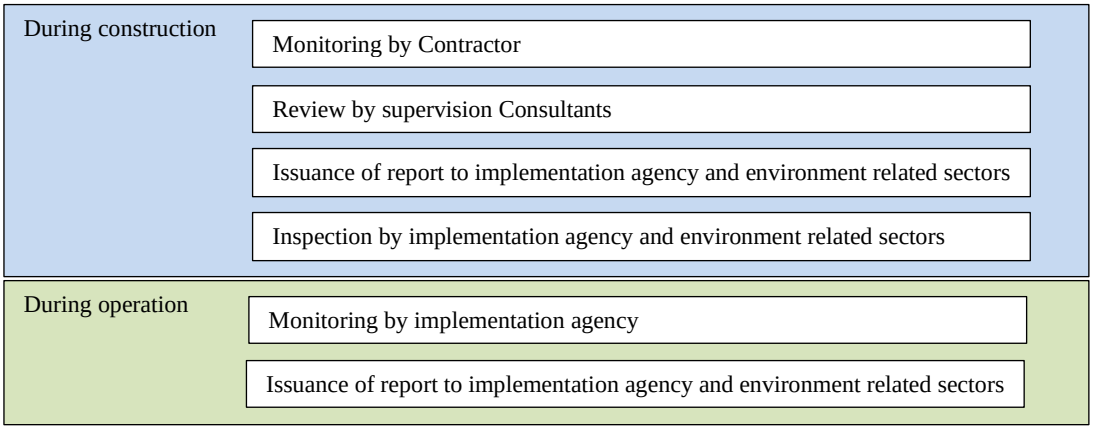

Source: JICA Study Team

Figure 3.13 Implementation of Mitigation Measures and Monitoring during Construction and Operation

(2) Environmental Conservation Measures during Construction

Environmental conservation plan includes the following measures.

- **Traffic Accidents Prevention Measures**

・ For the roads for transportation vehicles such as materials and equipment, routes with sidewalks will be selected as much as possible so as not to affect pedestrians.
・ For parts of the operation route for transportation vehicles where there is no signal, measures such as assigning traffic control staff will be taken.
・ Sufficient waiting area for trucks will be prepared in the construction area so that vehicles for transport do not wait on the road.
・ Ample safety education will be provided to drivers of transportation vehicles and workers who commute by car, and safety driving will be enforced to prevent traffic accidents.

- **Traffic management**

・ When traveling on general roads, the transportation vehicle will be covered by safety sheet and sufficient attention will be paid to prevent disasters to third parties, damage to the road or contamination of the road due to falling loads.
・ Traffic signs, guide signboards and protective facilities will be installed to prevent general vehicles from entering the roads in the construction area.

- Traffic control staff will be assigned at locations where construction vehicles exit to general roads and where construction vehicles and general vehicles are concentrated to ensure smooth and safe traffic.
- Since accidents caused by heavy machinery are common among construction disasters, education and training for drivers of heavy machinery will be provided and thorough safety management will be implemented.
- When carrying in or out materials, carrying more than the maximum load weight will be prohibited and the Contractor will be instructed in advance.

Photo 3.20 Construction Sign

Photo 3.21 Traffic Control Staff

● **Countermeasures for Traffic Congestion**

- As for measures against traffic congestion during construction, consider the combination of road closure and detours.
- Consider the increase in traffic volume on the circuit side and the accompanying decrease in safety.

● **Countermeasures for Air Pollution, Noise and Vibration**

- The construction plan will be formulated based on the environmental impact assessment of noise and vibration and environmental standards, and the construction plan will be implemented infallibly.
- Sufficient inspection and maintenance will be carried out when using construction machinery. In addition, the construction machinery will be operated carefully, and no idling will be done.
- The temporary road will be maintained so that there is no unevenness. If the road surface is rutted or has large unevenness, repair it immediately.
- Rutting or unevenness of the road surface, if it occurs, will be repaired immediately.
- The vehicles for transporting materials will travel at a low speed and will not idle.

● **Countermeasures for Dusts**

- Cover sheets will be applied to earth and sand transport vehicles to prevent scattering of soil from bed of truck.
- A soil removal facility will be installed at the entrance and exit of the transportation vehicle to remove soil adhering to the tires.
- If dust is generated due to construction, water will be sprinkled.

● **Countermeasure for Water Pollution**

- Grit chamber will be installed before the construction to prevent turbid water from flowing directly into public water due to rainwater drainage of the construction site.
- If it rains heavily, earth work such as cutting, embankment, and excavation will be suspended.
- If leaks of fuel or oil from heavy machinery or construction vehicles, the cause will be found out immediately and the leaked fuel and oil will be disposed completely.
- Washing water for concrete pump trucks, etc. will be stored in a fixed location so as not to pollute public water, and treated after the construction is completed.

Photo 3.22 Turbid Water Treatment Facility

Photo 3.23 Water Sprinkler

(3) Safety Management at Construction Site

At the construction site, it is important to create an organization to manage the safety of the site, hold toolbox meetings to manage the safety and conduct risk prediction trainings and risk prediction activities. Specifically, aiming for a level that can serve as a model for Japan's financial assistance projects, safety nets, scaffolding, handrails and other fall prevention measures, fire prevention measures, cut collapse prevention measures, crane safety measures, on-site construction vehicle running speed limit, putting in order around the site, cleaning, water spraying, etc. should be implemented. And also regarding security measures in the project site, necessary measures should be taken such as physical protection of sites, surveillance/guard, night-time equipment management, the movement system of people, communication equipment.

In order to prevent occupational accidents and public accidents in construction projects such as public facilities by ODA (Official Development Assistance), JICA (Japan International Cooperation Agency) established "ODA Construction Safety Management Guidance[22]" that summarizes basic policy and specific technical guidelines for safe construction. The guidance shall be utilized for safety management at construction sites.

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CHAPTER 4 ANALYSIS ON ROAD DAMAGE IN GRANT AID PROJECTS

4.1 Projects for Analysis

Among the road projects implemented through JICA's financial cooperation, focus is directed to cases where some problems occurred after the construction completion, and then the damage shapes, causes, and items and measures to be confirmed for prevention are systematically studied. The projects taken as examples are the 18 projects shown in Table 4.1.

Table 4.1 Projects to be Analyzed for Problem Cases

No.	Project name	Country	Damage Type			
			Equipment	Earthwork	Structure	Pavement
1	The National Road No.6 and No. 7 Improvement Project	Cambodia				✓
2	The Project for Improvement of the National Road Route 9 (Phase 1, Phase 2)	Laos				✓
3	The Project for Rehabilitation of Trunk Road (Phase 2)	Ethiopia				✓
4	The project for Improvement of Intersections in Kathmandu City	Nepal	✓			
5	The Project for Improvement of Trunk Roads in Kampala	Uganda	✓			
6	The Project for Bridge Construction in the Province of NUSA TENGGARA TIMUR	Indonesia			✓	
7	The Project for Widening of Kilwa Road (Phase 1, Phase 2)	Tanzania		✓		✓
8	The Project for Rehabilitation of Trunk Road (Phase III)	Ethiopia				✓
9	The Project for Improvement of Livingstone City Road	Zambia				✓
10	The Project for the Improvement of Dusty-Nizhniy Pyandzh Road	Tajikistan				✓
11	The Project for Widening of New Bagamoyo Road (Phase 1)	Tanzania				✓
12	The Project for Rehabilitation of National Trunk Road N8.	Ghana			✓	
13	The Project for Rehabilitation of Trunk Road, Phase IV	Ethiopia				✓
14	Projet d'aménagement d'un pont sur la route nationale N°1 (Kaaka Bridge)	Guinea				✓
15	Ngong Road Development Project Phase I	Kenya				✓
16*	The Construction of a New Bridge across River Nile at Jinja (loan)	Uganda				✓
17*	Bridge Improvement on NR6	Mozambique		✓	✓	
18*	Bridge Improvement in rural area	Mozambique			✓	

**The projects of 16 (Loan), 17 and 18 (other donors) are not Grant Aid Projects of Japan but are described because they will be meaningful knowledge for future project implementation.*
Source: JICA Study Team

Table 4.2 Completion year and damage confirmation of each Project

No.	Project name	Construction completion year	Damage confirmation
1	The National Road No.6 and No. 7 Improvement Project	Jun. 1998	2004
2	The Project for Improvement of the National Road Route 9 (Phase 1, Phase 2)	Phase 1: Mar. 2001 Phase 2: Dec. 2002	2012
3	The Project for Rehabilitation of Trunk Road (Phase 2)	Oct. 2004	2012
4	The project for Improvement of Intersections in Kathmandu City	Feb. 2003	2006 (Post-evaluation)
5	The Project for Improvement of Trunk Roads in Kampala	Feb. 2005	2007 (Post-evaluation)
6	The Project for Bridge Construction in the Province of NUSA TENGGARA TIMUR	Apr. 2008	Apr. 2011
7	The Project for Widening of Kilwa Road (Phase 1, Phase 2)	Phase 1: Apr. 2008 Phase 2: Sep. 2009	Time of opening (Pavement) 2018 (Earth work)
8	The Project for Rehabilitation of Trunk Road (Phase III)	Jan. 2009	Time of opening
9	The Project for Improvement of Livingstone City Road	Mar. 2010	Time of opening
10	The Project for the Improvement of Dusty-Nizhniy Pyandzh Road	Nov. 2010	2011 (6 months after completion)
11	The Project for Widening of New Bagamoyo Road (Phase 1)	May. 2014	2018
12	The Project for Rehabilitation of National Trunk Road N8.	Dec. 2013	Apr. 2017
13	The Project for Rehabilitation of Trunk Road, Phase IV	Mar. 2014	2018 (Post-evaluation)
14	Projet d'aménagement d'un pont sur la route nationale Nº1(Kaaka Bridge)	Jun. 2017	2011 (9 months after completion)
15	Ngong Road Development Project Phase I	Jan. 2018	2011 (7 months after completion)
16	The Construction of a New Bridge across River Nile at Jinja (loan)	Sept. 2018	During construction
17	Bridge Improvement on NR6	2018 (assumption)	Mar. 2019 (Cyclone Idai)
18	Bridge Improvement in rural area	Unknown	Mar. 2019 (Cyclone Idai)

Source: JICA Study Team

There is an example that explains the causes of the trouble cases introduced in this chapter by classifying them into external factors and internal factors. External factors here are factors that are difficult to eliminate technically, such as natural conditions namely weather and geography, and social conditions namely traffic volume and customs. So external factors should be considered mainly at the design stage. Internal factors are factors that can be eliminated technically, such as construction defects and material defects, and should be considered mainly at the construction stage.

4.2 Issues on Introduction of Equipment (Traffic Signal)

Urban road development and improvement projects often involve the improvement of intersections, and in that case, traffic lights are often used to rectify traffic while making effective use of existing facilities. However, some of the past projects have had the following problems.

(1) The Project for Improvement of Intersections in Kathmandu City, Nepal

Table 4.3 Operation Status of Signals

Item		Explanation
Completion year		Feb. 2003
Problem confirmation		2006 (Post evaluation)
Caused problem		Signals are not operated properly
Cause of problem	External factor	Neglect of traffic rules
	Internal factor	Difference between forecasted traffic and actual traffic
Intersection control by police officers (no traffic lights)		Same as on the left

Source: Ex-post Evaluation Table for Grant Aid, JICA

- Cause of Problem

The following three points are indicated as the reasons why the installed traffic signals are not used, including the issue of traffic demand forecast.

- Traffic volume greatly exceeds the demand forecast and the capacity of signal-controlled intersection.
- Traffic volume is far below the demand forecast, so control by traffic signals is unnecessary.
- Existence of cars and pedestrians who ignore traffic rules and traffic lights.

- Response to Problem:

In 2011, "Ex-post status Survey for Kathmandu Intersection Improvement Project" was conducted for a follow-up on various issues that arose after the facilities were put into service, and provided advice to the counterpart government on how to ensure the sustainability of the effects of the intersection improvement.

(2) The Project for Improvement of Trunk Roads in Kampala, Uganda

Table 4.4 Operation Status of Signals

Item		Explanation
Completion year		Feb. 2005
Problem confirmation		2007 (Post evaluation)
Caused problem		Signals are not operated properly
Cause of problem	External factor	Power shortages, spare parts shortage, technician shortage
	Internal factor	Difference between forecasted traffic and actual traffic
Intersection control by police officers (no traffic lights)		Same as on the left

Source: JICA Study Team

- Cause of Problem

The following three points are indicated as the reasons why the installed traffic signals are not used, including the issue of traffic demand forecast.

- Traffic volume greatly exceeds the demand forecast and the capacity of signal-controlled intersection.
- Traffic signals cannot be operated due to power shortages.
- Spare parts cannot be supplied due to budget shortage.
- Traffic signals cannot be repaired or maintained due to the outflow of trained technicians from the agency.

- Response to Problem

At the time of this study, a follow-up survey was scheduled to be conducted. In the follow-up survey, repairs were carried out to the extent possible with local materials and equipment; technical training was given to the staff of the department in charge; and securement of a budget for the procurement plan of necessary spare parts was requested to executing agency.

(3) Points to be Noted When Introducing Traffic Signals

As can be seen from the above two project cases, when installing traffic lights in a project, appropriately forecasting the inflow traffic to the intersection is the key to the success of the project. In addition, the facility administrator's system, budget, and power situation for maintenance after installation should be thoroughly investigated at the preparatory survey stage, and if problems remain in maintenance and operation, it is necessary to reconsider the adoption of signalized intersections.

4.3 Damaged Cases of Earthworks

(1) The Project for Widening of Kilwa Road (Phase 1, Phase 2), Tanzania

Table 4.5 Outline of Embankment Damage

Item		Explanation
Completion year		Sept. 2009
Damage confirmation		2018
Type of damage		Slip of embankment
Cause of problem	External factor	-
	Internal factor	Problem in stabilization calculation, inappropriate drainage
Slip of embankment (crack in pavement) 		Slip of embankment (subsidence of guard rail)

Source: JICA Study Team

- Cause of Damage

The embankment shown in this case is not a high embankment (15 m or more) but has a height of 5 m or more. The damage that has occurred has not yet caused complete collapse at this time, but it could slip significantly in the near future. Possible causes from the situation confirmed on site include insufficient drainage pipes and insufficient drainage facilities under the embankment (erosion of the lower part of the embankment by water, etc.). In addition, regarding the results of the embankment stability calculation by the consultant in charge, it is unclear whether the geological survey and embankment stability calculation were carried out.

- Response to Problem

As of 2018, when the damage was confirmed, the road was under widening work by the local government, so the fact that the damages were found out was reported to the government by the consultant (Japan) that supervised the Project under ODA of Japan.

(2) Bridge Improvement on NR6, Mozambique

Table 4.6 Outline of Embankment Damage

Item		Explanation
Completion year		2018 (assumption)
Damage confirmation		Mar. 2019 (Cyclone Idai)
Type of damage		Embankment collapse
Cause of problem	External factor	Flooding beyond expectations
	Internal factor	-
Runoff of embankment section		Same as on the left

Source: JICA Study Team

- Cause of Damage

The cause is that the area was extensively submerged due to flooding of the basin caused by the cyclone "Idai". The area is a vast plain, with some swamp. The embankment structure was also severely damaged by the unexpected flood flow, and the entire road collapsed. It seems that the flood flow overflowed from the left side of the above left photo.

This road was improved with third-country funding. For the construction, the company in the funding country constructed whole sections including this damaged section. Roads pass through the flat terrain of vast basins, which are floodplains during flooding. In addition, obstruction on the downstream side was confirmed. From the experience of past floods, it is probable that the entire line was raised as an embankment structure and a large number of crossing box culverts were installed. The partial collapse of the embankment seems to be the trace of the flood flow at the time of the flooding of the river on the south side (on the left side of the right photo, right side of the left photo).

- Response to Problem

Restoration was carried out by emergency repairs funded by the local government with a series of pipe-culvert.

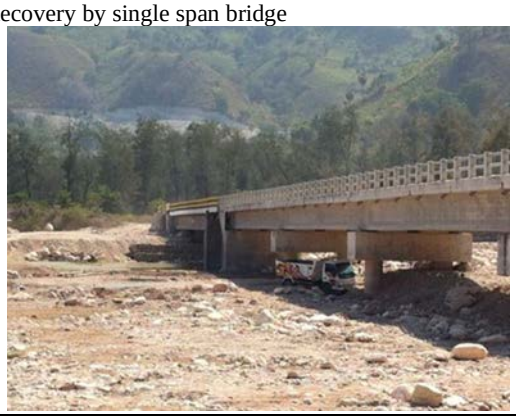
(3) Points to be Noted When Planning Earth Structures

From the above two projects, it is shown that it is important to carry out stability calculation based on the results of geological survey and to treat water in the embankment, both on the surface and under the embankment for high embankments. In addition, when adopting an embankment structure for river approach roads, it is necessary to confirm the water impact area using river simulation software, analyze weaknesses, and investigate the current and past flood conditions.

4.4 Damaged Cases of Structures

(1) The Project for Bridge Construction in the Province of Nusa Tenggara Timur, Indonesia

Table 4.7 Outline of Structure Damage

Item		Explanation
Completion year		Apr. 2008
Damage confirmation		Apr. 2011
Type of damage		Runoff of approach road due to riverbank erosion
Cause of problem	External factor	Riverbank erosion by heavy flood
	Internal factor	Decrease in cross-sectional area of river by bridge pier
Runoff of approach road		Situation of approach road runoff
Recovery by single span bridge 		Recovered condition (bridge surface)

Source: JICA study group document, "Roads across natural rivers"[1]

- Cause of Damage

As is understood from the lower left photo, the bridge structure is divided into two types. The foreground is the original bridge. The bridge in the distant view was originally an approach road. The approach road was washed away along with the erosion of the riverbank due to the great flood, but it was later rebuilt as a single-span bridge. The causes of damage can be divided into internal factors and external factors.

<u>External factor: riverbank erosion by heavy flood</u>

The causes of riverbank erosion that led to the runoff of the approach road are the rapid rivers in the mountains, the geological and topographical environment in which a large amount of sediment is likely to be generated, and accumulation of a large amount of sediment that flowed into the river due to the collapse of large-scale slopes of the upstream in the past.

<u>Internal factor: decrease in cross-sectional area of the river</u>

The river was a natural river in the mountains where water always flowed down, and a large amount

of water and earth and sand flowed down during floods. Due to the movement of the river channel caused by no embankment and the bridge built by narrowing the river channel, the bridge section became a narrowed part (weak point) and the approach road on the back of the abutment flowed out.

- Response to Problem

Reconstruction as bridge with simple span was carried out by emergency repairs funded by the local government.

(2) The Project for Rehabilitation of National Trunk Road N8, Ghana

Table 4.8 Outline of Structure Damage

Item		Explanation
Completion year		Dec. 2013
Damage confirmation		Apr. 2017
Type of damage		Crack in abutment, inclination of abutment
Cause of problem	External factor	Under survey
	Internal factor	Under survey
Crack in abutment A1		Crack in masonry revetment of abutment
Crack in abutment A2		Inclination of abutment A1

Source: JICA Study Team

- Cause of Damage (Under investigation)

・ Crack in abutment

The cracks in the abutment, which were confirmed in April 2017, were found to have a possibility of alkali silica reaction when an alkali silica reactivity test was conducted in Ghana, and in addition, the influence of pyrite contained in the aggregate was pointed out. Currently, a comprehensive analysis of the cause of the occurrence is being conducted through domestic analysis in Japan, various field investigations, and domestic analysis (alkali-silica reactivity tests, etc.).

・ Inclination of abutment

An inclination of the abutment and the accompanying deformation of the rubber bearings was confirmed. The cause of the deformation is currently under investigation, but problems with the material of the backfill soil and the applied foundation type (simple column pier) are possible.

- Response to problem

In the follow-up survey, the cause of the damage will be investigated, the repair plan necessary for maintaining the function of the bridge will be formulated, and the repair/reinforcement work utilizing the local contractor will be carried out with Japanese funds.

(3) Bridge Improvement on NR6, Mozambique

Table 4.9 Outline of Structure Damage

Item		Explanation
Completion year		2018 (assumption)
Damage confirmation		Mar. 2019 (Cyclone Idai)
Type of damage		Subsidence and inclination of abutment by scouring of foundation
Cause of problem	External factor	Flooding beyond expectations
	Internal factor	-
Subsidence and inclination of abutment by scouring of foundation 		Same as on the left

Source: JICA Study Team

- Cause of Damage

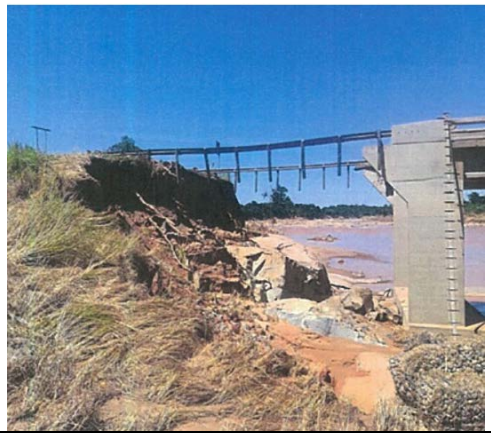
The foundation of the second pier from the front of the photo was scoured, and it inclined and subsided. The cause was that the whole area was submerged due to the flood in the basin caused by the cyclone "Idai". The area is a vast plain, with some swamp. It is probable that the ground of the foundation was eroded by the concentration of the flood current on the bridge.

- Response to problem

Minimum restoration such as the re-building of the protection of the abutment was carried out through emergency repairs funded by the local government.

(4) Bridge Improvement in Rural Area, Mozambique

Table 4.10 Outline of Structure Damage

Item		Explanation
Completion year		Unknown
Damage confirmation		Mar. 2019 (Cyclone Idai)
Type of damage		Embankment washout of the back of abutment
Cause of problem	External factor	Flooding beyond expectations
	Internal factor	-
Embankment washout		Same as on the left
		

Source: JICA Study Team

- Cause of Damage

The cause of the washout of the back embankment is considered to be the movement of the embankment-free river channel by the cyclone "Idai" and the narrowing (weakness) of the river by the bridge.

- Response to problem

Restoration including re-embankment at the back of the abutment was carried out through emergency repairs funded by the local government.

(5) Points to be Noted When Planning Bridge on River

From the above case studies, for concrete structures, quality control at the time of construction (selection of appropriate materials), no uncertainties due to sufficient geological survey, and stable calculation (structural calculation) based on the survey results are important. In addition, for problems caused by unexpected increases in river flow, as in the case of approach roads, it is necessary to implement confirmation of the water collision part using river simulation software, analysis of weaknesses, investigation of the current situation and past flood conditions, etc.

4.5 Damaged Shape of Pavement

(1) Damaged Shape of Pavement

In general, pavement damage is roughly divided into "road surface damage" and "structural damage".

And the main types of pavement damage in Grant Aid Projects are cracks, rutting, flatness deterioration, potholes, shoving and peeling.

Table 4.11 Damaged Shape of Pavement

Damaged asphalt pavement		Classification of damage
Crack	• Linear cracks Fatigue cracks Rutting Construction seams cracks Reflection cracks Thermal stress cracks Cracks due to frost heaving	Surface, structure
	• Alligator crack Cracks due to reduced bearing capacity and subsidence of subgrade and base course/subbase course Cracks due to peeling of the binder course	Surface, structure
	• Cracks due to frost heaving/freezing and thawing	Structure
	• Cracks due to deterioration and aging of asphalt mixture	Surface, structure
	• Cracks around the structure	Surface, structure
Rutting	Rutting due to compression deformation of the subgrade and base course/subbase course	Structure
	Rutting due to plastic deformation of asphalt mixture	Surface, structure
	Rutting due to wear on asphalt pavement	Surface
Flatness deterioration	Unevenness in the longitudinal direction	Surface, structure
Other damage	Level difference	Surface, structure
	Pothole	Surface, structure
	Abrasion	Surface, structure
	Polishing (decrease in skid resistance)	Surface
	Corrugation	Surface
	Pit	Surface, structure
	Wrinkle	Surface, structure
	Gulley	Surface, structure
	Shoving	Surface

Source: JICA Study Team

- Cracks

・ Linear cracks

Linear cracks run in longitudinal and transverse directions and include several crack patterns. In the well-known reflection crack that is induced in the base layer joints and cracks, cracks are developed in the asphalt surface layer immediately above the base layer. In addition, when shrinkage cracks occur in the cement stabilized subbase, they induce cracks in the asphalt surface layer immediately above them. These are also called reflection cracks. Other cases include those caused by "Problem soil (expansive soil)". This longitudinal crack in the shoulder area is a typical early symptom of pavement damage due to expansive soil.

・ Alligator cracks

Alligator cracks are caused by settlement and/or decreased bearing capacity of the base/subbase and subgrade due to the influence of water, etc. Linearly generated cracks develop into an alligator skin pattern. It is common that cracks mainly occur around the travelling path. As the crack progresses in the entire asphalt layer, rainwater propagates through the crack and penetrates into the base/subbase and subgrade. As a result, the bearing capacity of the base/subbase and subgrade decreases. Then, the linear cracks that have occurred proceed to alligator cracks.

● Rutting

Rutting refers to a deformation in the traverse direction caused by vehicle load.

・ Flow rutting

The asphalt mixture (aggregate particle size, type and content of binder, etc.) and, as external factors, the traffic load and temperature are the largest factors causing deformation of asphalt. Therefore, they can be found in relatively tropical areas on roads with heavy traffic. The flow (plastic deformation) of asphalt mixture due to high temperatures and heavy traffic are the main causes. It is characterized by ruts along the travelling position of the tire and outward swellings.

・ Rutting due to the decreased bearing capacity of the subgrade and base/subbase course (settled rutting)

Rutting due to settlement of the base/subbase and subgrade occurs when an excessive traffic load is applied to the pavement structure, in addition to the decreased bearing capacity of the base/subbase and subgrade caused by groundwater, etc. and insufficient compaction of the base/subbase and subgrade during construction.

● Others

・ Pothole

A pothole is a hole of 10 to 100cm in diameter formed on the pavement surface. It often occurs as a result of advancement of other damage such as aggregate loss of alligator cracks or abrasion of asphalt pavement. In addition, in a thin pavement such as surface treatment, this is often caused by abrasion, breakup, and dissipation (stripping, peeling off) of the asphalt pavement on the surface. When the damage progresses, potholes not only hinder driving but also rapidly damage the base/subbase and subgrade. Therefore, immediate maintenance and repair are required without waiting periodical repair work.

・ Abrasion

The abrasion is peeling-off of pavement due to inadequate drainage facilities, or thin road shoulder pavement (DBST (Double Bituminous Surface Treatment) pavement) is damaged and peeled off due to the passage of vehicles or the frequent passage of vehicles into side road.

・ Corrugation

Corrugation is a wave-like irregularity that continuously occurs on the road surface at a relatively short wavelength in the longitudinal direction of the road. This is likely to occur when the road surface is periodically pressurized due to the effects including repeated braking/stopping and vibrations generated by automobile traffic. Therefore, it occurs at intersections, curves, downhills,

congested traffic routes, etc.

- Gulley

A gulley is a vertical hole in the embankment and is called a dragon hole ("dragon hole" is a Cambodian expression, also referred to as tunnel erosion and/or sinkholes) found in Cambodia and Laos. These holes are generated vertically on the tops and slopes of the embankment, and its size develops from 20cm in diameter to sometimes more than 1m. The occurrence of dragon holes is due to the nature of the embankment material (dispersive soil).

- Shoving

Asphalt pavement shoving (peeling and slipping) occurs when the shear force between layers of pavement (or asphalt pavement) generated by traffic load causes shoving in the asphalt pavement, thus losing the structural unity resulting in cracks and irregularities on the pavement surface. The damage is mainly due to poor adhesion between layers. Examples of factors of poor adhesion may include a decrease in adhesive strength due to intrusion of water between layers, application of excessive/insufficient amount of tack coat, and poor construction execution. It also occurs when a thin asphalt layer is placed on the cement stabilized base.

(2) Cause of Pavement Damage

The causes of pavement damage, which is a problem in Grant Aid Projects, can be divided into external factors and internal factors. External factors are addressed in the preparatory survey stage, and internal factors are items that should be considered in the construction stage.

External Factors (mainly to be addressed in preparatory survey)

Pavement damage is caused by the traffic of large vehicles including overloaded vehicles, and the influence of road surface temperature is large. In places where many low-speed large vehicles pass, the asphalt pavement will be damaged faster than expected. In addition, in areas where the annual average temperature is high, the road surface temperature rises, leading to a decrease in the elastic modulus of the asphalt mixture and fluidization. These factors are summarized as external factors as follows.

- Low-speed vehicles (running condition)
- Excessive traffic volume and traffic load (traffic condition)
- Long-term high temperature (natural condition)
- Decrease in subgrade bearing capacity due to problem soil (pavement structure design)
- Decrease in bearing capacity of subgrade and base course/subbase course due to water, impact of groundwater (drainage design)

Internal Factors (mainly to be addressed in construction stage)

Internal factors to be addressed in construction stage are as follows.

- Insufficient confirmation of material properties
- Inappropriate mix design (aggregate particle size, asphalt volume, air volume, saturation, etc.)
- Poor construction (selection and management of asphalt and aggregate)

4.6 Case Analysis of Pavement Damage

(1) The National Road No.6 and No. 7 Improvement Project, Cambodia

Table 4.12 Outline of Pavement Damage

Item		Explanation
Completion year		Jun. 1998
Damage confirmation		2004
Type of damage		Gulley
Classification of damage		Road surface damage
The time when the damage was confirmed		Unknown
Possible cause of damage	External factor	Insufficient material survey (before landmine removal and so unavoidable)
	Internal factor	Use of inappropriate materials (dispersive soil), (before landmine removal and so unavoidable)
Damage caused by dispersive soil (shoulder)		Damage caused by dispersive soil (embankment)

Source: JICA Study Team

- Possible Cause of Damage

Dispersive soil, which is distributed in Cambodia, Laos, Myanmar, Australia, the United States, etc., is a problematic soil for road construction. When embankment materials and slope materials containing dispersed soil are used, the soil dissolves due to the infiltration of water, causing gully erosion, collapse, and perforations and depressions called "dragon holes, or tunnel erosion and sinkholes" which are not observed in Japan. The damage in such cases is due to the use of this dispersive soil as a material for roads.

- Response to problem

JICA has conducted test work on dispersive soil countermeasures in Cambodia and proposed countermeasures such as a simple dispersive test that allows local engineers to easily identify dispersive soil and implement improvement by additives. (See details in "4.7 Factor Analysis of Pavement Damage".)

(2) The Project for Improvement of the National Road Route 9 (Phase 1, Phase 2), Laos

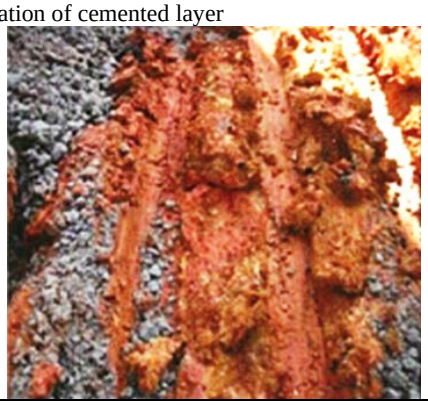
Table 4.13 Outline of Pavement Damage

Item		Explanation
Completion year		Phase 1: Mar. 2001, Phase 2: Dec. 2002
Damage confirmation		2012
Type of damage		Alligator crack
Classification of damage		Road surface damage (structural damage)
The time when the damage was confirmed		Unknown
Possible cause of damage	External factor	Lack of material survey Unexpected volume of overloaded vehicles
	Internal factor	-

Alligator cracks on surface

Test pit for investigation

Argillation of cemented layer



Overloaded vehicle on the project road

Source: JICA Study Team

- Possible Cause of Damage

<u>External factor: overloaded vehicles</u>

Traffic load exceeding expectations at the time of planning (1990s) and especially overloaded vehicles carrying timber are one of the causes of damage. After that, by the strong enlightenment activities of the construction company and the policy change of the government, the extreme overloading disappeared.

In Laos, the regulatory axle load was changed from 9.1t to 11t in 2006 after the project road was put into service. But there were still many overloaded vehicles due to low awareness of axle load control. In order to grasp the actual condition of overloaded vehicles, an overloaded vehicle survey was conducted at the start of repair work. The results are shown in the table below. The survey period in this table was approximately one year from May 20, 2013, to May 25, 2014, and the survey was conducted in 24 hours. As a result of the survey, the ratio of overloaded vehicles during this survey period was about 20%.

Table 4.14 Result of Overloaded Vehicle Survey (24hrs)

Survey item	Survey result	Unit
(a) Number of large vehicles surveyed	9,591	(vehicles)
(b) Number of overloaded vehicles	2,118	(vehicles)
(c) Number of passed vehicles without survey	4,454	(vehicles)
(d) Percentage of overloaded vehicles (d)= (b)/(a)x100	**22**	(%)
(e) Percentage of overloaded vehicles not unloaded (Ratio of vehicles that went on Route 9 in overloaded)	80	(%)

Source: Documents created by the construction office of the project

External factor: cement stabilization

Deterioration of the cement stabilization layer also contributes to pavement damage, and damage like alligator cracking occurs extremely frequently. In the national highway repair project, a problem was found that the strength of the existing subbase course that had been cement-stabilized was smaller than expected. The cement mixing rate of the cement stabilization carried out in the initial construction was 3%. In general, there are various causes of deterioration of this cement stabilization layer, such as the existence of groundwater and improper material selection.

- Response to problem

In response to the increased traffic of large vehicles due to mining development, and the increased damage to the road, "The Project for Improvement of National Road No.9 as East-West Economic Corridor of the Mekong Region" was conducted in order to strengthen the paving structure of the severely damaged Seno - Muang Ping section and upgrade the road structure with drainage facilities. A pavement damage survey was conducted during this reconstruction, and the survey results (issues of cement stabilization, material, etc.) were reflected in the planning and implementation of the reconstruction.

(3) The Project for Rehabilitation of Trunk Road (Phase 2), Ethiopia

Table 4.15 Outline of Pavement Damage

Item		Explanation
Completion year		Phase 2: Oct. 2004
Damage confirmation		2012
Type of damage		Alligator crack
Classification of damage		Road surface damage (structural damage)
The time when the damage was confirmed		Unknown
Possible cause of damage	External factor	Inadequate drainage facility
	Internal factor	-

Alligator cracks on surface

Water blowoff from damaged point

Water blowoff from damaged point (macro)

Stagnant water on road side

Source: JICA Study Team

- Possible Cause of Damage

<u>External factor: inadequate drainage facility in sag section</u>

Rainwater that infiltrated from the shoulders of the road traveled along the base course/subbase course and concentrated in the sag, causing damage symmetrically across the river. As a result, the base course/subbase course became soft and pumping occurred. It is a damage that can be prevented by draining the water in the base course/subbase course by installing a transversal culvert.

<u>External factor: inadequate drainage facility at cut section</u>

When constructing a slope section with cut or embankment, if the drainage and spring water on the cut side are not properly treated, the low bearing capacity due to the inundation of the base course/subbase course will cause damage to the pavement. In the case of above photograph, repair trace can be seen on the road surface on the mountain side, and it seems that deterioration of base course/subbase course has occurred due to poor maintenance of the drainage gutter.

- Response to problem

The local government continues to carry out maintenance work to repair damaged sections, but no fundamental measures such as rebuilding drainage facilities have been taken. The Government of Japan is considering the provision of asphalt and other materials by non - project Grant Aid, and is also providing support for continuous repair measures through the Road Asset Adviser Project (2021).

(4) The Project for Widening of Kilwa Road (Phase 1, Phase 2), Tanzania

Table 4.16 Outline of Pavement Damage

Item		Explanation
Completion year		Phase 1: Aug. 2008, Phase 2: Sept. 2009
Damage confirmation		Time of opening (Phase 1 & 2)
Type of damage		Rutting, wrinkle, pothole
Classification of damage		Road surface damage
The time when the damage was confirmed		At the time of operation
Possible cause of damage	External factor	Difference between predicted value and actual value of traffic volume and axle load
	Internal factor	Mix design: air void is small

Flow rutting of surface

Flow rutting of surface (swell)

Flow rutting and pot hole

Repair by modified asphalt (crack repair by sealing)

Source: JICA Study Team

- Possible Cause of Damage

<u>External factor: difference in traffic volume between actual and forecasted</u>

Table 4.17 shows the comparison of actual traffic volume and forecasted traffic volume. There is a large difference between the actual and forecasted values of heavy vehicle traffic in 2014. Actual traffic volume is 78 times the predicted value for large buses, about twice the predicted value for trucks, and about eight times for trailers. The difference in trucks and trailers was caused by rapid increase in freight volume due to the relaxation of import restrictions and high economic growth.

Table 4.17 Comparison of Actual Traffic Volume and Forecasted Traffic Volume

Year	Motor-cycle	Small vehicle	Minibus, pick-up	Medium/ large bus	2-axle truck	3-axle truck	Truck trailer	Others	Total large vehicles	Remark
2005	422	5,128	4,629	11	566	222	100	22	899	Actual（by JICA)
2006	441	5,359	4,837	12	591	232	105	23	940	Forecasted
2007	461	5,600	5,055	12	618	242	110	24	982	Forecasted
2008	482	5,852	5,282	13	646	253	115	25	1,027	Forecasted
2009	504	6,115	5,520	14	675	264	120	26	1,073	Forecasted
2010	527	6,390	5,768	15	705	276	125	27	1,121	Forecasted
2011	-	18,029	13,526	3,066	2,568	2,070	1,977	-	9,681	Actual (by contractor)

Source: JICA Study Team

Internal factor: low air void and particle size distribution deviation

For the Kilwa road, core sampling was carried out and the properties of the asphalt mixture were tested in Japan. As a result, the following issues have been pointed out.

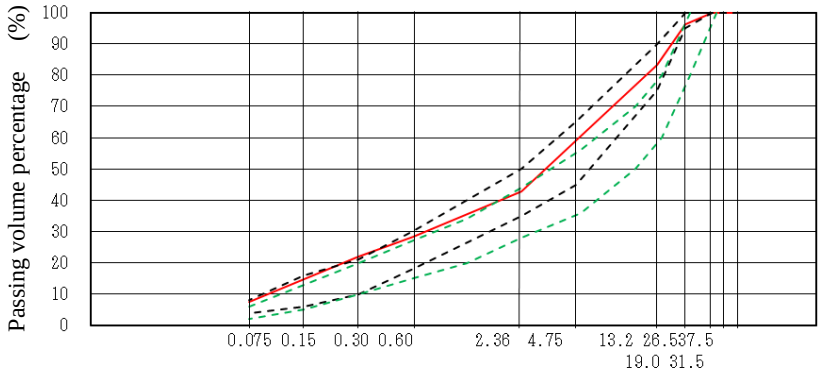
- Density/air void: The air void was 1.5%, which is too small. The air void of the dense graded asphalt concrete mixture is around 7% at the time of pavement, and gradually decreases with repeated loading. In the state of the test pit, rutting due to consolidation is apt to occur.

Table 4.18 Result of Core Sampling Test (2013)

Test items	Tanzania			
	Kilwa Road	Nelson Mandela Road (good condition)		
	1st-layer	1st-layer	2nd-layer	3rd-layer
Layer thickness (cm)	6.5	6.5	8.3	9.0
Maximum density (g/cm3)	2.593	2.626	2.618	2.593
Bulk density (g/cm^3)	2.555	2.492	2.571	2.498
Air content (%)	1.5	5.1	2.0	4.0
Stability (KN)	5.82	10.64	20.22	14.93
Flow value (1/10mm)	30	52	55	49
Penetration (1/10mm)	45	15	33	19
Softening point (℃)	54.5	63.5	59.0	54.5
Asphalt content (%)	4.55	4.50	4.37	4.01

Source: JICA Study Team

- Particle size: Figure 4.1 shows the particle size distribution obtained by the test. The particle size distribution is close to that of Japan's dense graded asphalt concrete (TOP20mm), but the particle size distribution is far above the particle size range of the construction specifications of Tanzania, resulting in a finer particle size distribution.



Red full line: particle size distribution obtained from the test
Black dashed line: dense graded asphalt concrete (maximum grain diameter 20mm) [Japan]
Green dashed line: particle size range of AC (Asphalt concrete) 20 (maximum grain diameter 20mm) (in specifications of Tanzania construction).
Source: JICA Study Team

Figure 4.1 Particle Size Distribution of Kilwa Road

- Response to problem

Of the road rehabilitation projects, the section implemented in rehabilitation project phase 1 was completely repaired with local government funds. For the section implemented in rehabilitation project phase 2, a full repair (removal of the surface course and resurfacing) was carried out by the construction company (Japan) as the failure occurred during the defect period. In the repair work, modified asphalt by plant mix was applied, but due to reflection cracks caused by the cement stabilized layer used in the base course, the base course was repaired by sealing.

(5) The Project for Rehabilitation of Trunk Road, Ethiopia

Table 4.19 Outline of Pavement Damage

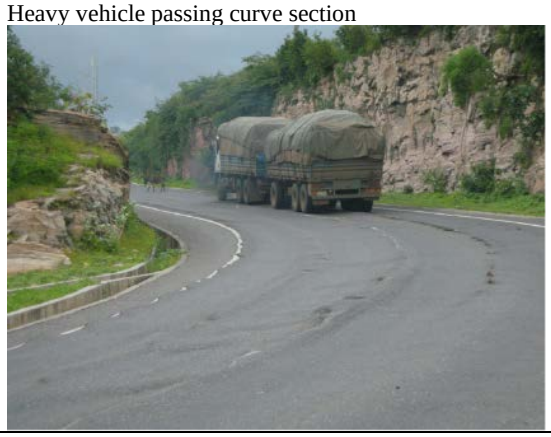
Item		Explanation
Completion year		Jan. 2009
Damage confirmation		Time of opening
Type of damage		Rutting corrugation
Classification of damage		Road surface damage (structural damage)
The time when the damage was confirmed		2 months after completion
Possible cause of damage	External factor	High temperature (surface temperature rise) Low-speed heavy vehicles
	Internal factor	Interlocking of aggregates

Rutting on slope section

Rutting on curve section

Corrugation on flat section

Heavy vehicle passing curve section



Source: JICA Study Team

- Possible Cause of Damage

External factor (1): higher temperature than expected

In tropical countries where the temperature is high throughout the year, the pavement surface temperature exceeds the softening point and reaches 60°C or higher. Therefore, the asphalt mixture becomes easy to flow and causes deformation such as rutting, wrinkle, and corrugation. On the target road, a road surface temperature exceeding 60°C was observed.

Table 4.20 Thermometry Result of Pavement Surface

Survey point: The Project for Rehabilitation of Trunk Road (Goha Tsion - Abay), Survey date: 28th Aug.
Survey hour: 14:30～16:30, Weather: cloudy after rain

Time		14:30	14:35	14:40	15:10	15:30	15:40	16:00	16:10	16:30
Distance from origin		700m	1200m	3200m	4900m	10500m	12000m	14000m	17800m	19500m
Altitude		2410m	2375m	2253m	2135m	1760m	1636m	1493m	1177m	1070m
Measurement	1st	25.6	25.4	43	48.7	48.4	48.6	48.6	48.4	44.6
	2nd	25.2	25.2	43.9	49.1	48.6	48.8	48.4	48.4	44.8
	3rd	25.5	26.4	44.9	49.1	48.4	48.9	48.5	48.9	44.7
Average (℃)		25.4	25.7	43.9	49.0	48.5	48.8	48.5	48.6	44.7

Survey point: The Project for Rehabilitation of Trunk Road (Dejen - Abay), Survey date: 29th Aug.
Survey hour: 11:00～12:30, Weather: sunny after cloudy

Time		11:15	11:30	11:40	11:45	11:52	12:10	12:20	12:25	12:30
Distance from origin		39600m	38000m	34000m	32000m	29100m	25300m	22000m	21550m	20000m
Altitude		2445m	2407m	2120m	1997m	1823m	1513m	1261m	1215m	1070m
Measurement	1st	36.9	38.1	37.2	48.6	51.1	54.5	58.9	57	61.6
	2nd	37.1	38.2	36.9	48.4	51.6	54.3	57.8	57.2	59.8
	3rd	36.8	38.2	37	48.5	51.6	55.1	58.3	58.1	60.5
Average (℃)		36.9	38.2	37.0	48.5	51.4	54.6	58.3	57.4	60.6

Source: JICA Study Team

External factor (2): steep downhill (heavy vehicle with low speed)

On the target road, many large vehicles traveling at low speed were observed. It was confirmed that the traveling speed of these vehicles was 20 km/h or less, and that it dropped to 10 km/h or less in sections with steep vertical gradients. When descending a steep slope section, the vehicle brakes to push the pavement forward, and by repeating it in small steps, continuous small waves like a washboard are generated. The phenomenon is corrugation. On the other hand, on the uphill, the traveling speed of the vehicle decreases, so that the traffic load acts on the road surface for a long time, and rutting is promoted.

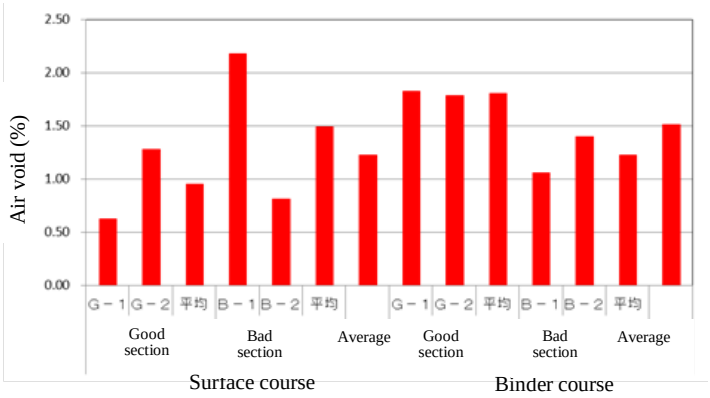
Internal factor (1): interlocking of aggregates

The test of refusal density described in the specification was not implemented. In developed countries such as Europe and the United States, it is widely known that the interlocking of aggregates contributes to the improvement of deformation resistance. Refusal density (ultimate density) is a method for ensuring the residual void (=interlocking of pavement aggregate) after compaction and after operation. Ensuring the residual void is ensuring the deformation resistance of the pavement. Inhibition of pavement deformation cannot be guaranteed without confirming deformation resistance. Though the specification stipulated the refusal density test, the standard value was not determined. Considering the intention of refusal density, it should be carried out at regular control (during mixing test) as a quality confirmation of the materials used, and a standard value should be determined.

Internal factor (2): low air void and high asphalt content

In this project, core sampling was carried out and the properties of the asphalt mixture were tested in Japan. As a result, the following issues have been pointed out.

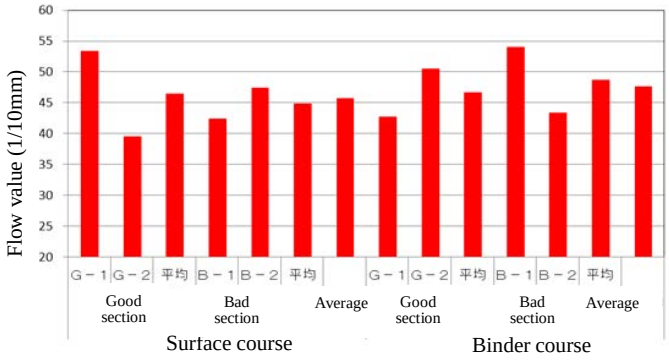
- Air void: The air void of both the surface course and the binder course is 2% or less, and it is considered that rutting due to consolidation is likely to occur.



Source: JICA Study Team

Figure 4.2 Test Result of Air Void

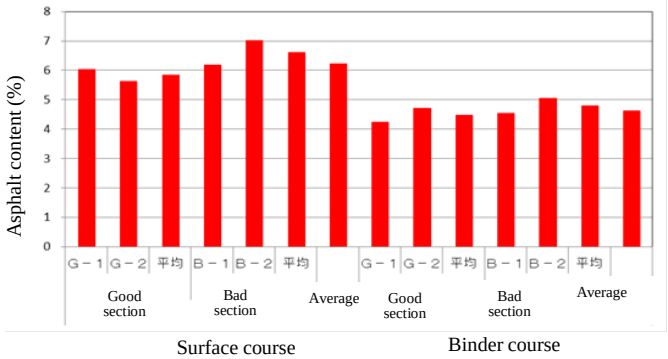
- Flow value: Average flow value in both the surface course and the binder course exceeds 45 (the standard value at the time of mix design of the usual surface course and binder course is 20 to 40 1/10 mm), and it is considered that the mixture is more easily deformed at high temperatures.



Source: JICA Study Team

Figure 4.3 Test Result of Flow Value

- Asphalt content: In the surface course, the asphalt content in the defective section was 7.1%, and there is a possibility that a large amount of asphalt was mixed in for some reason. Excluding that, the asphalt content was about 6%. In the base layer, the value also has some variations, but the average is 4.6%.



Source: JICA Study Team

Figure 4.4 Test Result of Asphalt Content

- Response to problem

Provision of materials and equipment for road maintenance and management through Grant Aid project and technical cooperation projects for landslide prevention are implemented continuously. Currently the Government of Japan is considering the provision of asphalt and other materials by non - project Grant Aid, and is also providing support for continuous repair measures through the Road Asset Adviser Project (2021).

(6) The Project for Improvement of Livingstone City Road, Zambia

Table 4.21 Outline of Pavement Damage

Item		Explanation
Completion year		Mar.2010
Damage confirmation		Time of opening
Type of damage		Rutting
Classification of damage		Road surface damage
The time when the damage was confirmed		Soon after operation
Possible cause of damage	External factor	
	Internal factor	Deviation of particle size distribution
Photo a: serious damage		Photo b: partial damage
Photo c: good condition		After repairing by recipient country (reappearance of rutting)

Source: JICA Study Team

- Possible Cause of Damage

<u>Internal factor: deviation of particle size distribution</u>

In this case, the degree of deviation of the aggregate particle size distribution and the damage situation are clearly related. In Source: JICA Study Team

Figure 4.5, a), there are many small grain components (especially 0.6 mm or less), so it is considered that the coarse aggregates were not sufficiently interlocked with each other, which was the main cause of damage. From this, it is shown that the particle size distribution or the interlock of coarse aggregate is important as a factor of rutting. The deviation of particle size distribution from the specifications

in this case is believed to be due to improper management of the asphalt plant. This case shows the importance of proper management of particle size. When the road surface temperature is extremely high, fluidization may occur in straight asphalt even if the aggregates are sufficiently interlocked.

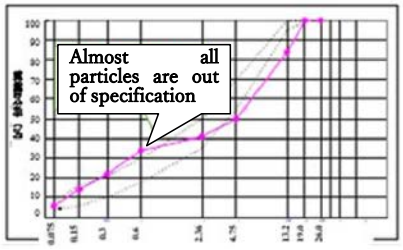


Photo a (serious defect)

The average particle size deviation rate is 11.4%. Significant flow rutting is observed in seriously defective sections.

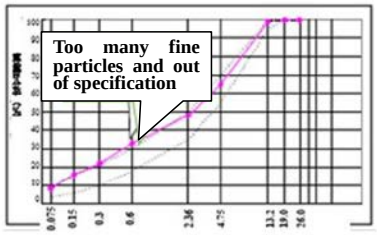


Photo b (partial defect)

The average particle size deviation rate is 6.9%. In the partially defective section, local flow is seen at the side end of the road, but it is in better condition than in the seriously defective section.

Photo c (good condition)

The average particle size deviation rate is 2.3%. Near the lower limit of the allowable range.

Source: JICA Study Team

Figure 4.5 Comparison of Particle Size Distribution

Result of interview in Zambia

In this case, an interview was conducted with a local consultant who was in charge of design and construction supervision of repair work of this road. According to the analysis results of the local consultant, the causes of the construction defects were as follows.

- Regarding the improvement project conducted by Japan, as a result of checking the proof rolling and the material report, it was confirmed that there were no problems with the base course/subbase course but some problems with the surface asphalt such as 1) High amount of asphalt, 2) Use of limestone (very weak stone) for asphalt aggregate, and 3) Particle size distribution outside the specifications.
- The traffic volume survey results conducted by BCHOD[1] were very large compared to the traffic volume used in the Japanese design.

- Response to problem

Although the defects occurred immediately after the road was put into service (within the defect period), the construction company (Japan) did not repair the road, but instead defects were repaired by the South African construction company under supervision by a local consultant with local government funds. Even after repairs by the local government, rutting reappeared around the intersection.

[1] Local consultant in Zambia

(7) The Project for the Improvement of Dusty-Nizhniy Pyandzh Road, Tajikistan

Table 4.22 Outline of Pavement Damage

Item		Explanation
Completion year		Nov. 2010
Damage confirmation		2011 (6 months after completion)
Type of damage		Lateral flow, slipping (interface between surface course and binder course, interface between asphalt concrete layer and cement-treated base course)
Classification of damage		Road surface damage
The time when the damage was confirmed		6 months after completion
Possible cause of damage	External factor	Annual range of temperature (large difference in temperature) Overloaded vehicle
	Internal factor	Adoption of cement treatment to base course

Surface shoving

Flow rutting

Scattered surface on alligator crack

Surface shoving

Source: JICA Study Team

- Possible Cause of Damage

External factor (1): annual range of temperature

Asphalt is a temperature-sensitive material. When the temperature is high, the viscosity weakens, and when the temperature is low, it hardens. That is, it is easily deformed at high temperatures and vulnerable to cracks at low temperatures. Particularly in areas where the temperature drops sharply, cracks occur at almost regular intervals in the transverse direction due to the shrinkage of the asphalt pavement. This type of thermal stress cracks are more likely to occur in cold regions, and are more prominent in portions where the asphalt pavement is thin.

External factor (2): overloaded vehicles

The pavement design is designed by 10t equivalent axle load. Overloaded vehicles with axle loads over 10 tons promote premature damage to the pavement. In developing countries, legislation for overloading is often delayed.

Internal factor: adoption of cement treatment to base course

Since the rigidity (flexibility) of the cement stabilized base course and the asphalt concrete layer are different, the interface between layers is likely to slip. And if the base course surface is smooth, it causes further slippage. As a countermeasure, when adopting cement stabilization treatment to the base course, the following countermeasures are applied: 1) the minimum thickness of the asphalt concrete layer is specified, 2) it is specified that a chip seal is applied to the interface to prevent the asphalt concrete layer from slipping.

- Response to problem

Defects in this road were reported during post-completion monitoring, and the local government indicated that early repairs and overlays were needed. In order to confirm the situation, a follow-up survey was conducted to analyze the cause of the damage and develop a repair plan. In addition, as technical support for the repair plan, the road maintenance and management equipment upgrade plan (Grant Aid) and the road maintenance and management improvement project were implemented.

(8) The Project for Widening of New Bagamoyo Road (Phase 1), Tanzania

Table 4.23 Outline of Pavement Damage

Item		Explanation
Completion year		May. 2014
Damage confirmation		2018
Type of damage		Rutting, lateral flow
Classification of damage		Road surface damage
The time when the damage was confirmed		Unknown
Possible cause of damage	External factor	Slow heavy vehicle
	Internal factor	Low air void

Flow rutting on hump approach

Flow rutting after hump section

Flow rutting on intersection approach

Flow rutting on intersection approach

Source: JICA Study Team

- Possible Cause of Damage

External factor (1): low-speed heavy vehicles and repeated braking

In the target road, a hump (speed control facility) was installed at the pedestrian crossing by the local government after the opening. Rutting occurred in the front and rear sections of this hump and in the inflow section of the intersection. It is considered that the cause is low speed running of large vehicles and repeated braking before and after the hump and at the intersection inflow section.

External factor (2): interlocking of aggregate

Table 4.24 shows the results of core sample test of the target road. It is understood that the amount of air in the asphalt mix is very small in the rutting area. It means that fluid rutting due to consolidation is likely to occur.

Table 4.24 Results of Core Sample Test

Grain size (mm)	Rutting	Good condition
28	100	100
20	100	100
14	99.8	99.7
10	85.1	81.1
5	54.5	56
2.36	35.1	36.3
1.18	28.1	29.6
0.6	24.6	26.2
0.3	21	21.6
0.15	16.1	16.4
0.075	12	13.1
Asphalt volume (%)	3.7	3.9
Air volume (%)	2.2	3.7
Flow value (mm)	2.0	2.0
Stabilization degree (kN)	18.0	16.0

Source: JICA Study Team

- Response to problem

The "hump," which is one of the causes of the failure, was installed not in the Japanese aid but by the local government after the delivery. For this reason, no support from the Japanese side for this problem is being considered.

(9) The Project for Rehabilitation of Trunk Road, Phase IV, Ethiopia

Table 4.25 Outline of Pavement Damage

Item		Explanation
Completion year		Mar. 2014
Damage confirmation		2018 (Post evaluation)
Type of damage		Clack, level difference
Classification of damage		Structural damage
The time when the damage was confirmed		Dec. 2018
Possible cause of damage	External factor	Problem soil
	Internal factor	-

Flow rutting

Flow rutting and alligator cracks

Simple repair (patching) and alligator cracks

Under repair (removal of damaged points)

Source: JICA Study Team

- Possible Cause of Damage (result of site survey by employed engineer)

<u>External factor: problem soil (black cotton soil)</u>

According to the result of visual observation after completion, it is highly possible that the early damage to the pavement is mainly due to the subsidence of the base course/subbase course due to the swelling effect of the problem soil (expansive soil). Black cotton soil, called expansive soil, expands and softens when it contains water. If the problem soil like this exists in the subgrade, it loses its bearing capacity and cannot withstand the traffic load.

- Response to problem

No action has been taken at the time of this study as the problem has just occurred. Technical support to the local government by the Road Asset Advisor Project (2021) is expected.

(10) Bridge Reconstruction Project on the National Highway No.1 (Kaaka Bridge), Guinea

Table 4.26 Outline of Pavement Damage

Item		Explanation
Completion year		Jun. 2017
Damage confirmation		2018 (9 months after completion)
Type of damage		Flush, rutting
Classification of damage		Road surface damage
The time when the damage was confirmed		9 months after opening
Possible cause of damage	External factor	High temperature (surface temperature rise) Low-speed heavy vehicles
	Internal factor	Inadequate mix (excessive amount of asphalt, excessive fine particles) Deficiency in production process in plant (measurement accuracy) Range of tolerance
Rutting on surface 		Repair work (defect liability period)
Repair completion 		Reflow on repaired section

Source: JICA Study Team

- Possible Cause of Damage

External factor (1): high temperature (surface temperature rise)

When the road surface temperature exceeds 60 degrees, the deformation resistance becomes extremely weak, causing deformation such as rutting, wrinkle (hump), and corrugation. The annual average temperature at this site is 31.0°C, and the pavement temperature is predicted to exceed 60°C.

External factor (2): low-speed heavy vehicles

At this site, the vertical gradient is 9%, the horizontal alignment is the S curve of 130R and 57R with poor visibility, and the cross-fall is 6%, and the traveling speed of large vehicles including overloaded vehicles becomes about 10 km/h, which is very slow.

Internal factor (1): inadequate mix

Flush, also called bleeding, is a phenomenon in which asphalt mortar seeps out onto the pavement surface. It occurs when the amount of asphalt in the asphalt mixture is excessive or when the amount

of fine particles is excessive. It may be prevented by carefully observing the specimen compacted during the mixing test and the mixture created during the test mixing, and by confirming weather they are not glaring, the asphalt film thickness is appropriate, and the mixture is not excessively darkened.

Internal factor (2): deficiency in production process in plant

If there are no problems with the asphalt mixture during the mixing test and test mixing, there are many cases where there is a problem with process control in the production by plant. In the case of a continuous plant, it occurs when the asphalt injection amount and aggregate flow rate are not stable. In batch plants, this happens when the accuracy of the scale is low.

Internal factor (3): Range of tolerance

In this case, the standards of the Ministry of Land, Infrastructure, Transport and Tourism are seemed to be adopted. The handbook recommends NEXCO (Nippon Expressway Company Limited) standards[2].

- Ministry of Land, Infrastructure, Transport and Tourism standards: asphalt amount ± 0.9%, 2.36mm passage amount ± 12%, 75μm passage amount ± 5%
- NEXCO standard[2]: Asphalt amount ± 0.3%, 2.36mm passage amount ± 4%, 75μm passage amount ± 1.5%

- Response to problem

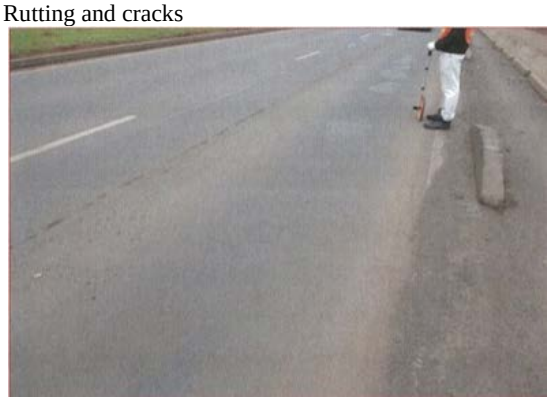
As the failure occurred during the defect period, the contractor (Japan) carried out a full repair (removal of the surface course and resurfacing), but rutting occurred again in the repaired section. Therefore, due to problems with the procurement of asphalt plants, etc., repairs were finally carried out using concrete pavement.

(11) Ngong Road Development Project Phase I, Kenya

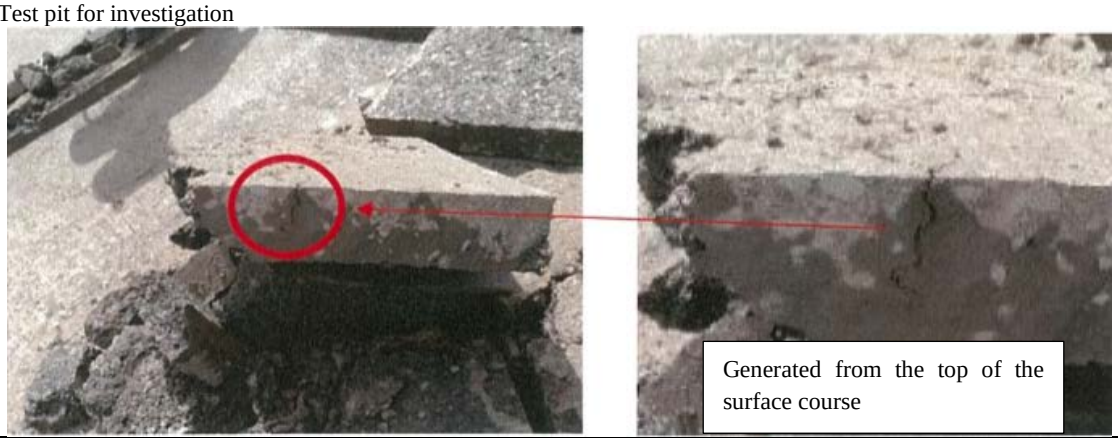
Table 4.27 Outline of Pavement Damage

Item		Explanation
Completion year		Jan. 2018
Damage confirmation		2019 (7 months after completion)
Type of damage		Alligator crack
Classification of damage		Structural damage
The time when the damage was confirmed		7 months after opening
Possible cause of damage	External factor	-
	Internal factor	Pavement deterioration (defective material, asphalt overheating)

Rutting and cracks



Test pit for investigation



Source: JICA Study Team

- Possible Cause of Damage

Internal factor: pavement deterioration

It is a phenomenon of pavement deterioration (aging) that alligator cracks are generated from the pavement surface and extend inward. As asphalt deteriorates over time, it loses its viscosity and becomes vulnerable to cracks. Like in this case, the cause of alligator cracks generated in young pavement is considered to be poor quality of asphalt used or thermal deterioration due to overheating during plant manufacturing. When longitudinal linear cracks are generated from the surface on the wheel trajectory, it is a phenomenon called rutting cracks, and external factors such as excessive large traffic volume can be considered.

- Response to problem

As for the defects on this road, full repair (removal of surface course and resurfacing) was carried out by the construction company (Japan) as "the defects occurred during the defect notification period".

(12) The Construction of a New Bridge across River Nile at Jinja (loan), Uganda

Table 4.28 Outline of Pavement Damage

Item		Explanation
Completion year		Sept. 2018
Damage confirmation		During construction
Type of damage		Wrinkle, rutting of bridge surface
Classification of damage		Road surface damage
The time when the damage was confirmed		Soon after opening
Possible cause of damage	External factor	-
	Internal factor	Inadequate waterproof material

Flow rutting on bridge (inbound lane)

Flow rutting (macro)

Flow rutting on bridge (outbound)

Source: JICA Study Team

- Possible Cause of Damage

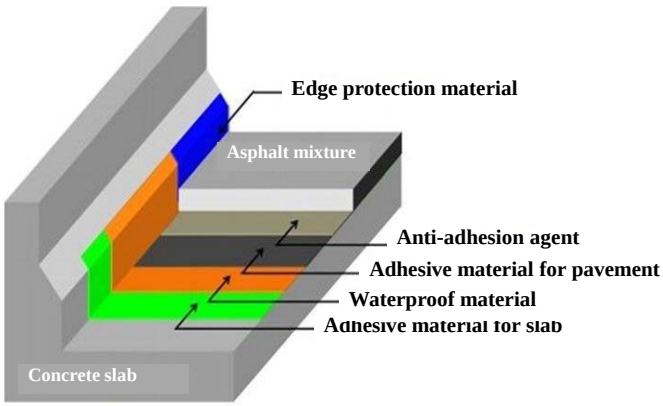
Internal factor (1): inadequate waterproof material

Between the urethane-based waterproof material and asphalt-based waterproof material proposed by the contractor, the waterproofing material selected by the client was the urethane-based waterproof material. Urethane-based waterproof materials have been widely used on the Shin Tomei Expressway in Japan and achieve satisfactory results. However, in the initial construction section (section in Shizuoka prefecture), a problem occurred in the pavement due to poor adhesion of the adhesive layer that adheres the urethane waterproof layer and the asphalt concrete layer. In the Ugandan case as well, the cause is assumed to be poor adhesion between the urethane waterproof layer and the asphalt concrete layer.

- Response to problem

The defect in this road occurred during the construction period, and the construction company (Japan) completely redid the pavement work. At the time of re-pavement, the adhesive layer was improved,

and the problem of poor adhesion is now solved. Figure 4.6 shows an example of the structural cross section of the urethane waterproofing method.



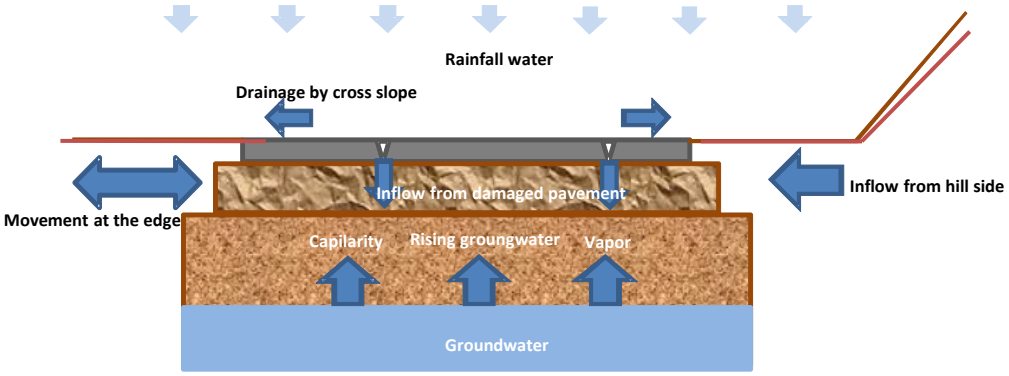
Source: NETIS (New Technology Information System)

Figure 4.6 Structural Cross Section of Urethane Waterproof Method

4.7 Factor Analysis of Pavement Damage

(1) Inadequate Drainage Facilities (Internal Factor)

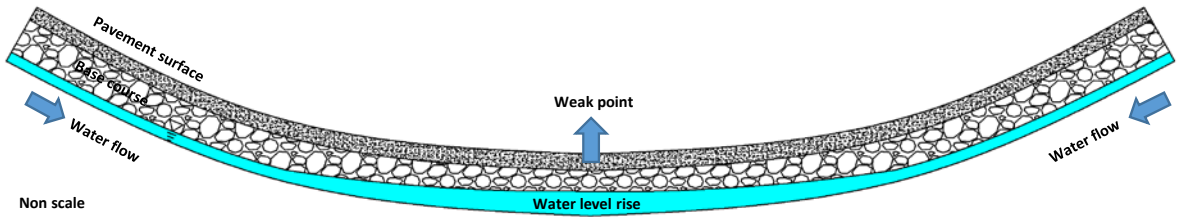
Road drainage is divided into surface drainage and underground drainage. As characteristic pavement damages due to the influence of water, groundwater in the cut section and groundwater in the base course/subbase course near the sag are prominent. In addition, it is known that the cause is also the softening of the subgrade and base course/subbase course due to the infiltration of surface water and the flooding of lowlands.



Source: JICA Study Team

Figure 4.7 Water Movement Affecting Pavement

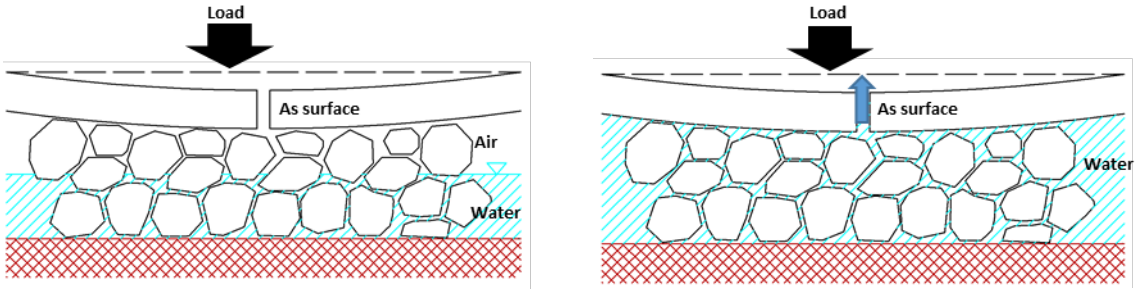
Specifically, when the depth of the gutter is insufficient with respect to the volume of groundwater from the highland side, the groundwater may enter the base course/subbase course and reduce its strength. In addition, the raising up of groundwater level during the rainy season and the water that flowed into the base course/subbase course may raise the water level at the sag, reducing the strength of the base course/subbase course (see Source: JICA Study Team
Figure 4.8).



Source: JICA Study Team

Figure 4.8 Water Flow in Sag (Mechanism of Pavement Destruction)

Especially when the base course/subbase course is a crusher run, the permeability coefficient is about 10^{-3}, and it is estimated that if rainwater or groundwater flows into the base course/subbase course from the outside, the amount of water will be easily saturated during the rainy season. The base course/subbase course saturated with water is sandwiched between asphalt on the top and the subgrade on the bottom, both of which have extremely low permeability coefficient. Therefore, when a slight deformation occurs by a load applied from the surface layer, it is considered that saturated water in the base course/subbase course moves while entraining small particles. That is a kind of pumping phenomenon, Once a small crack occurs on the surface layer, the pressurized water (see Figure 4.9) that finds an escape route becomes muddy water and spouts out, leading to rapid fatal damage.



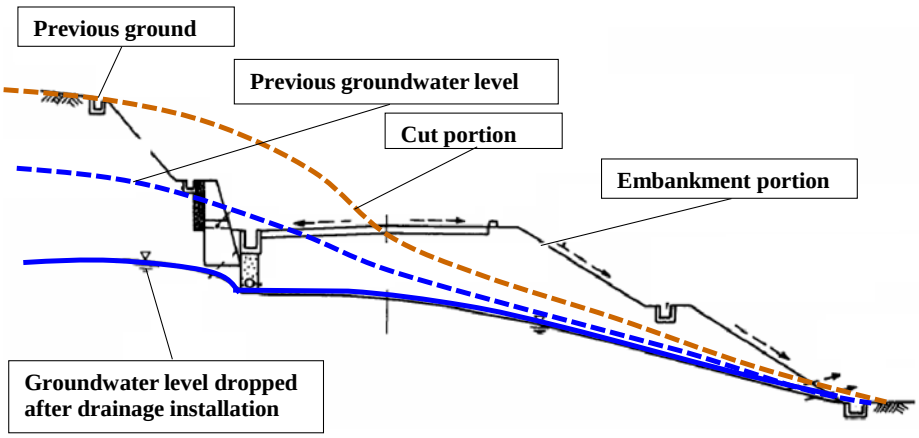
Unsaturated state in dry season　　Saturated state i rainy season

Source: JICA Study Team

Figure 4.9 Pumping Phenomenon Caused by Pressurized Water

Source: JICA Study Team

Figure 4.10 shows the decline of the groundwater level after the installation of the longitudinal drainage facility at the cut/embankment boundary. If no drainage facility is installed, the intrusion of groundwater into the base course/subbase course on the cut side causes a decrease in bearing capacity, causing road surface damage.

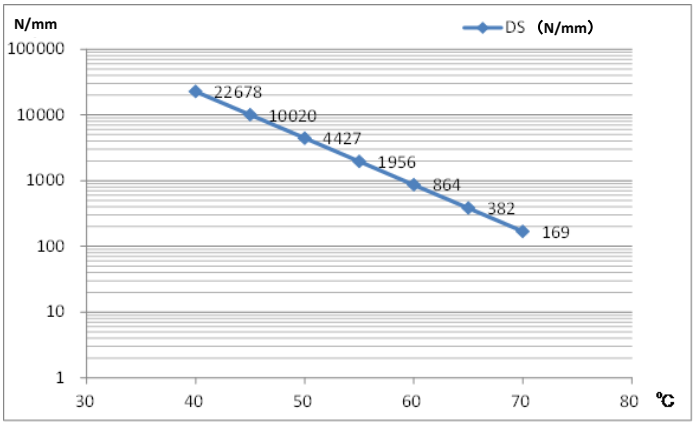


Source: JICA Study Team

Figure 4.10 Water Flow at Cut Section

(2) Problems Caused by High Temperature on Pavement Surface (External Factor)

Asphalt, which is the main material for pavement, has a temperature-sensitive property, and its viscosity changes with temperature. At high temperatures, the viscosity decreases (becomes a fluid) and at low temperatures, the viscosity increases (becomes an elastic body). Asphalt mixtures take advantage of these properties of asphalt. Generally, when the asphalt temperature is at 140°C or higher, it is easy to mix, spread and compact, and at 50°C or lower, it is difficult to deform. Asphalt generally has a softening point of around 50°C, and its viscosity changes significantly at that temperature. At extremely high temperatures exceeding 200°C, it is carbonized (oxidized) and loses its viscosity and becomes fragile. On the contrary, at extremely low temperatures such as below freezing, it loses elasticity and easily breaks (low temperature cracks). For this reason, in areas such as African countries where high road surface temperatures are expected throughout the year, surface fluid rutting becomes a major problem. In Japan, the following relational expression has been obtained based on the wheel tracking test regarding the relationship between the pavement temperature and the strength (DS (Dynamic Stability) value) of asphalt pavement using straight asphalt.



Source: JICA Study Team based on Q & A on pavement technology[3]

Figure 4.11 Relation between Pavement Temperature and Dynamic Stability

$$\text{Log}_{10}(DS) = 8.656 - 0.07095T - 0.2285P \quad \text{(Formula 4.1)}$$

DS: Dynamic Stability (passes/mm)
T: Temperature (°C)
P: Contact pressure (kgf/cm2)

Source: Q & A on pavement technology No.7[3]

Figure 4.11 shows the relation between pavement temperature and dynamic stability. According to this figure, compared to the DS value of 864 passes/mm at the normal test temperature (60°C), the DS value shows 382 passes/mm at 65°C and 169 passes/mm at 70°C, reducing the strength to 44% and 20% respectively. From this, it can be understood that the asphalt pavement is prone to rutting when high temperature days continue.

(3) Effect of Large Vehicles to Pavement (External Factor)

There is a law that the energy that a vehicle load damages a pavement is proportional to the fourth power of its wheel load. This law was derived by Dr. Harumi Takeshita by analyzing the road test data of AASHTO (American Association of State Highway and Transportation Officials).

$$\text{Damage factor of pavement: } f = (P/5)^4 \quad \text{(Formula 4.2)}$$

f: Damage factor of pavement

P: wheel load

Table 4.29 Relation between Pavement Damage and Axle Load

Vehicle type	Wheel load (t)	Ratio of wheel load to large vehicle (regular)	Damage factor (f)	Ratio of damage factor (f) to large vehicle (regular)
Small vehicle	0.25	0.05	0.00000625	1/160,000
Large vehicle (regular)	5.0	1.0	1.0	1.0
Large vehicles (over loaded)	10.0	2.0	16.0	16.0

Source: JICA Study Team

As can be seen from Table 4.29, for a heavy vehicle with a wheel load of 5 tons (10 tons of axle weight), the pavement fracture energy is 160,000 times greater than that of a light vehicle (e.g., passenger car), compared to a wheel load of 20 times. In addition, assuming that a large vehicle is overloaded, and the wheel load is 10 tons, the damage factor is 16 times that of a normally loaded vehicle, far larger than twice of a wheel load. It can be easily understood that the impact on the pavement is very large.

(4) Problem of Slow Running Heavy Vehicles at Steep Gradient Section (External Factor)

Many large vehicles were seen traveling at low speed. It was confirmed that the traveling speed of these vehicles was 20 km/h or less even in flat section, and that it dropped to 10 km/h or less in the section with a steep vertical gradient. The damage given by these vehicles to the pavement is expected to be greater than the vehicles traveling at normal speed of 40 km/h or higher. In order to clarify this possible problem, a wheel tracking test was conducted in Japan in this survey.

Table 4.30 WT (Wheel Tracking) Test Result

Asphalt volume (%)	Type	Loaded weight		Travel speed (times/min)	Dynamic stability (DS) (passes/mm)	Variation coefficient (%)	Deformation rate (RD*) (mm/min)
		Wheel load for test (KN)	Contact pressure (MPa)				
5.3	Normal	686	0.63	42	492	18.4	0.085
	Heavy vehicle	980	0.90	42	348	17.7	0.121
	Slow vehicle	686	0.63	21	294	6.8	0.143

*RD: Rate of Deformation
Source: JICA Study Team

According to the results of this test, 1) when the traveling speed is halved (42 times/min→ 21 times/min), the wheel loading time is doubled, and the deformation rate (RD) increases about 1.7 times (0.085 mm/min → 0.143 mm/min), 2) when the loading load is 1.4 times (0.63Mpa → 0.90Mpa), the deformation rate (RD) is about 1.4 times (0.085mm/min → 0.121mm/min), and the deformation rate is considered to be proportional to the loading load. From this, it is inferred that the deformation of the asphalt pavement is affected not only by the weight of the vehicle but also by the traveling speed. The conclusion obtained from the results of this test is that a low-speed (1/2 of the normal speed) heavy vehicle (wheel load is 1.4 times of normal vehicle) is equivalent to about 2.4 heavy vehicles in the normal speed (1.7 multiply 1.4).

It is said that usually when the vertical gradient of a road is 7 to 8%, asphalt pavement can be constructed without problems under a normal construction method. When asphalt pavement is constructed at a section where the vertical gradient exceeds 7 to 8%, problems occur such as uneven construction thickness due to slippage of construction machinery and loading of heavy machinery not vertically on

the road surface, and insufficient rolling compaction.

Source: No.6 Q & A for the Pavement[4]

(5) Pavement Damage Caused by Problem Soil (External Factor)

1) Type of Problem Soil

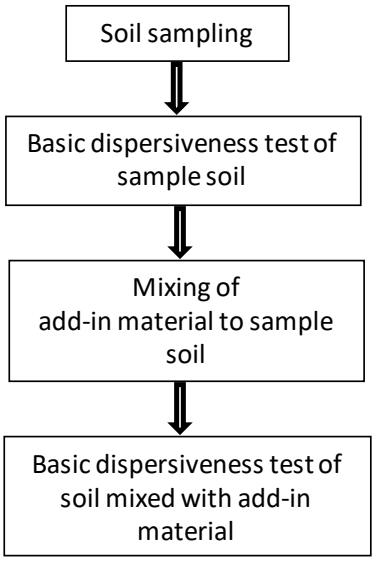
In general, the soils that cause problems in road construction include the following.

- Dispersive soil
- Expansive soil
- Organic soil
- Saline soil or presence of saline water

2) Dispersive Soil

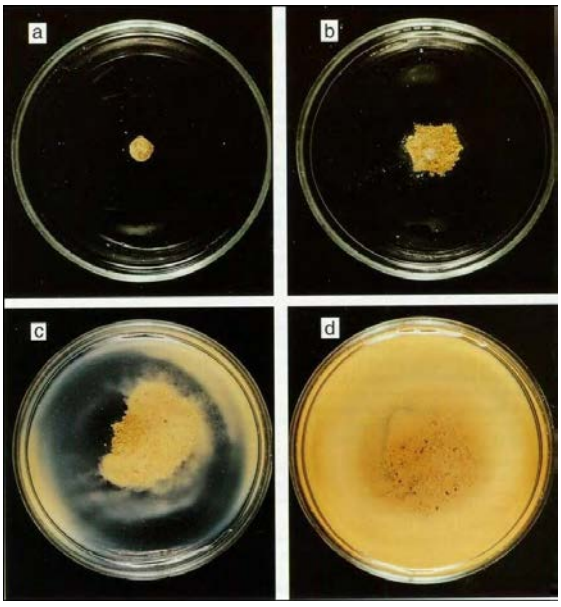
Dispersive soil is soil in which, compared to normal clay soil, there is a high content of sodium ion dissolved in pore water, leading to soil particles losing their cohesiveness and becoming susceptible to dissolution and erosion at times of rainfall and flooding. When such soil is used as embankment material in roadworks for example, erosion can lead to development of gullies and perforation such as dragon holes ("dragon hole" is a Cambodian expression, also referred to as tunnel erosion or sinkholes) and greatly impact the quality of roads.

As for the method for judgement of dispersed soil, the knowledge derived from the test construction carried out by JICA in Cambodia can be utilized. In this test construction, a simple dispersibility test was adopted for easy judgement of the dispersibility of the original slope soil and the cement mixed soil. This method allows local engineers to easily identify the dispersive soil, and sample soil was collected from the test construction site and dispersibility was judged by local engineers according to the procedure shown in Figure 4.12.



Source: Measures for dispersed soil in road construction in Cambodia[5]

Figure 4.12 Test Process



a: None, b: Little, c: Middle, d: Large

Photo 4.1 Examples of Extent of Dispersibility

As a countermeasure to the problem caused by dispersive soil, the dispersive soil should be found out in advance by preparatory survey, detailed design or material test during construction, and if found out, the dispersive soil should not be used as the material. This judgment method is described in detail in "Pavement Construction and Supervision/Management Handbook, Part 1 Survey and Design". When contacting with new water, dispersive soil is dissolved by ionic effect. Therefore, when it is unavoidable to use dispersed soil as a road material, a water impervious layer is installed near the embankment surface (road shoulder, etc) by placing cement mixed soil or high-quality soil.

[JICA Cambodia: Test works in Technical Cooperation "Construction Quality Control Strengthening Project"]

- The chemical countermeasure method adopted in the test works is a method to substitute sodium ion with calcium ion by using add-in material (gypsum, cement and lime).
- A dispersiveness prevention effect can be obtained by adding 1~3% of add-in material (gypsum, cement and lime).
- The test works were conducted with different mix ratio of add-in material and different mix time. The improvement layer had thickness of 0.5m or 1.0m.
- The improvement effect is more dependent on the add-in material mix ratio than the mixing time. For example, the improvement effectiveness is 100% when the add-in material mix ratio is 2.5% and the mixing time is 3.3 minutes/cubic meter.
- As a result of follow-up survey of this test work, it was revealed that many dragon holes were found in the surface soil without cement improvement, but they were also found in several parts of soil with cement improvement. It is thought that these were caused by insufficient mixing.

3) Expansive Soil (Black Cotton Soil)

Black cotton soil is a black-gray expansive soil that is widely distributed in East Africa, and the name was given because the soil is suitable for cotton planting. Expansive soil is hard and possesses strong bearing capacity when it is dry, on the contrary, when its water content increases, it swells, causing it to entirely lose its dry strength. In the process of changing from the wet state to the dry state, shrinkage cracks are formed, leading to serious problems for road construction.

Photo 4.2 Black Cotton Soil in Wet State
(Low strength and plastic)

Photo 4.3 Black Cotton Soil in Dry State
(High strength may appear in CBR tests.)

Source: JICA Study Team

Black cotton soil is classified as A-7-6 in the AASHTO soil classifications. Moreover, if the degree of swelling becomes too high, volume change in excess of 30% is observed. As a compositional substance, expansive soil is characterized by low organic content despite its black-grey color and a high content of expansive minerals such as montmorillonite. It also shows high alkaline responsiveness.

The form of road destruction by black cotton soil is almost patterned, with longitudinal cracks occurring at the pavement edge at first, and then the pavement being destroyed staring from these cracks as weak points.

As shown in the photograph, the black cotton soil is black-gray and has many cracks in the dry state. When the soil in such a state is identified, the simplest method is to add water to the sample and confirm the expandability. Even if the black cotton soil is not exposed on the ground surface, when many cracks are found in the topsoil during drying, it is necessary to suspect the presence of black cotton soil in the sub-surface layer.

Photo 4.4 Black Cotton Soil in Unsaturated State

Photo 4.5 Black Cotton Soil in Saturated State

Source: JICA Study Team

The vegetation which covers the black cotton soil is characterized by Gramineae and Asteraceae as grasses and acacia as trees. It is important to grasp the existence of black cotton soil by vegetation as well as by information collected from local engineers.

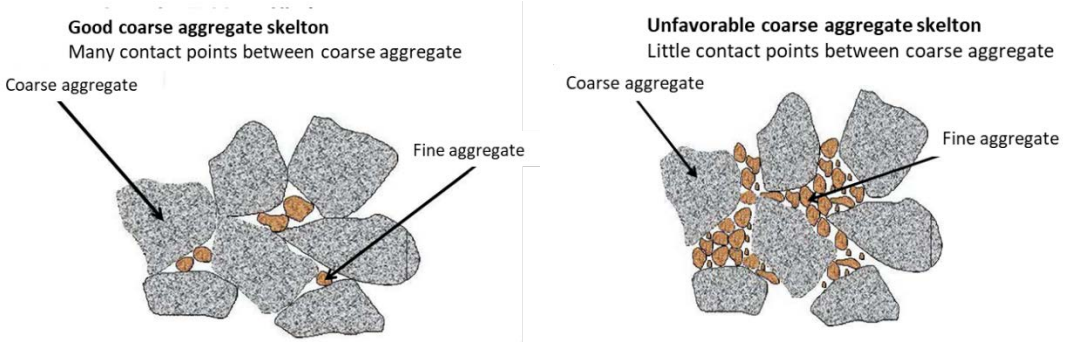
(6) Problem of Air Void (Internal Factor)

There are three main factors in rutting, which is a typical form of damage to asphalt pavement: 1) that caused by compressive deformation of the base course/subbase course, 2) that caused by plastic deformation of the asphalt mixture, and 3) that caused by wear of the asphalt mixture. Of these, the predominant problem in tropical countries is the plastic deformation of 2), the so-called flow rutting. The index used for evaluating plastic deformation resistance (flow resistance) is dynamic stability (DS), which is mainly obtained by wheel tracking tests.

The asphalt pavement slab is an elastic body, and the air voids in the mixture play an important role as a restoring force, like the soles of sneakers. The air void acts like a cushion when the pavement is compressed by a traffic load, and the pavement will return to its original state after the load is removed. However, when the loading and unloading of the traffic load is repeated, the air voids in the mixture gradually decrease due to consolidation. Air voids decrease especially from the pavement surface, and when the air voids decrease to a certain amount, the air voids between the aggregates disappear at the

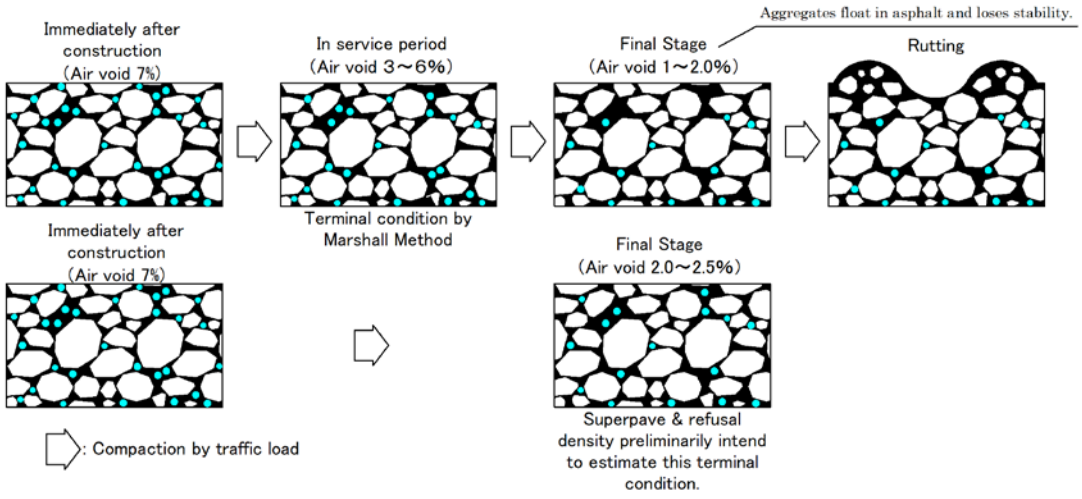
upper part of the pavement. When that happens, the aggregate becomes in a floating state in the asphalt mortar, loses the resilience, and undergoes plastic deformation. Since the traffic load is concentrated on the wheel track, the wheel path is dented and both sides are raised. The flow rutting occurs by this mechanism.

If the aggregates interlock with each other, the consolidation will stop at certain level and the voids will not decrease further. In other words, in order to improve the flow resistance, it is important to maintain the particle size and shape of the aggregate so that voids remain.



Source: Crushed Stone Mastic Pavement- SMA[6]

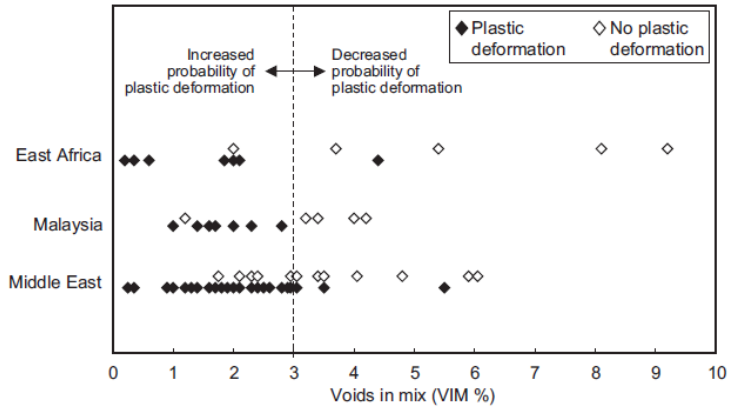
Figure 4.13 State of Interlocking of Aggregates (Left: good, right: bad)



Source: JICA Study Team

Figure 4.14 Difference between when the Final State of Air Void is Small (upper row) and Large (lower row)

The relationship between in-situ air void and asphalt deformation observed in countries experiencing high road temperatures is illustrated in Figure 4.15 in ORN (Overseas Road Note) 19[7]. According to ORN, it is necessary to ensure that air void remains greater than 3% if plastic deformation is to be avoided. This is in agreement with the recommendations of AI (Asphalt Institute of United States). By the explanation by ORN, when the air void in the AC layer decreases to less than approximately 3%, the stress transmission due to the interlocking of the coarse aggregates is lost, and when the compression continues further, the contact between the aggregates further decreases and plastic deformation occurs.



Source: ORN19[7]

Figure 4.15 Occurrence of Plastic Deformation in AC Wearing Courses

Furthermore, when the theoretical maximum density is used as calculation method in mixing test, air void includes voids inside the aggregate (voids that absorb water but not asphalt). This void does not contribute to flow resistance of aggregate. On the other hand, if the maximum density obtained by actual measurement (Rice method) is used, the voids inside the aggregate are excluded. Therefore, when determining the ultimate air void, the maximum density by the actual measurement method should be used. For this reason as well, the actual measurement method is recommended for mixing tests focusing on flow resistance.

(7) Problem of Particle Size (Internal factor)

The flow phenomenon of the asphalt mixture is caused by change of relative position of the coarse aggregate (which remains in the 2.36 mm sieve). In other word, the interlocking of aggregates is mainly borne by coarse aggregates as mentioned in the previous section (6). The mix design method by "Superpave" or "Refusal Density" is intended to eliminate the harmful effects of excess asphalt, promote the meshing of aggregates, and avoid fluidization by appropriate mix design. In this case, even if the air volume is 3% or more, when the fine aggregate (those that pass through the 2.36 mm sieve and stay at the 0.075 mm sieve) and filler (those that pass through the 0.075 mm sieve) are excessive, the surface area of the aggregate coated with the asphalt binder increases as shown in Figure 4.16, and the amount of asphalt increases accordingly.

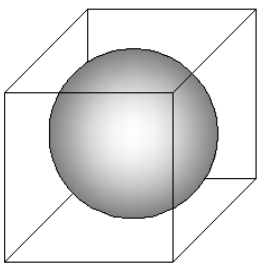


Image of Coarse Aggregates

The area of a sphere (coarse aggregate) in a cube with a side length of 1cm is 3.14cm^2.

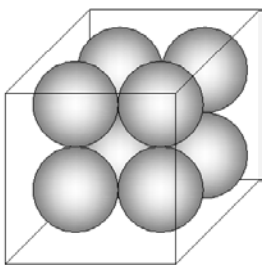


Image of Fine Aggregates

The area of a sphere (fine aggregate) in a cube with a side length of 1cm is 6.28cm^2.

Source: JICA Study Team

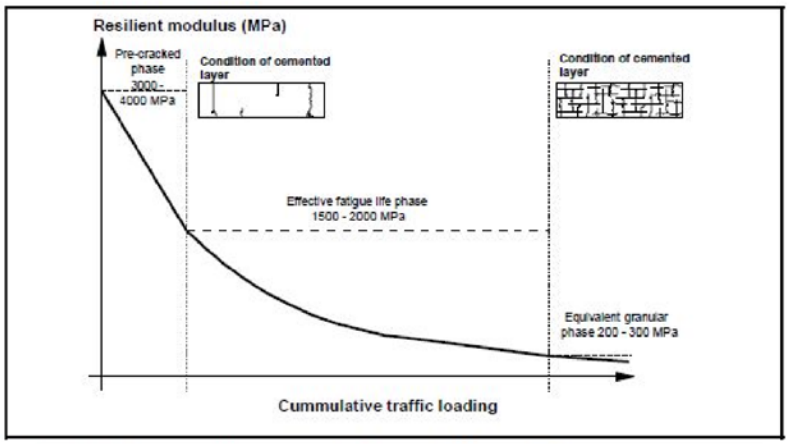
Figure 4.16 Relation between Particle Size and Sphere of Aggregates

(8) Problem of Interlocking by Shape of Aggregates

If the coarse aggregate is flat, it becomes impossible to obtain sufficient VMA (Voids in Mineral Aggregate), leading to an unstable mixture. Concerning the coarse aggregate angularity, each standard respectively indicates an upper limit regarding the mix ratio of thin or flat stone particles. As for fine aggregate, the natural sand that is used often has a round shape, whereas artificial sand, which is made by crushing rocks, etc., often has a lot of sharp corners (sharp corner sand). It has been confirmed that use of sharp-cornered sand enhances the durability and flow resistance of mixture. On the other hand, it has been confirmed that sufficient compaction of sharp cornered aggregate is difficult to perform, thereby leading to reduced workability, and decreased crack resistance.

(9) Problem of Materials for Cement Stabilization (Internal Factor)

When adopting a cement-stabilized base course, careful attention must be paid to the plasticity index PI[2] (Plastic Index) of the base course material. There are many reports on insufficient strength and deterioration of cement stabilized base course. And since the use of materials with poor grain size distribution of aggregates and materials with a large PI* may cause insufficient strength development and deterioration, many standards specifies that adoption of cement stabilized base course using these materials should be avoided as much as possible. It should also be noted that the South African design method takes into account that the cement stabilized base course will change to granular due to aging.



Source: Overview of the South African mechanistic design method[8]

Figure 4.17 Long Term Behavior of Lightly Cemented Material

In addition, regarding cement stabilization treatment, in order to prevent problems caused by an increase in the amount of cement at the construction stage, when using locally generated defective materials, the material must pass the following quality control tests (based on the South African Pavement Guidelines 2013).

- Setting the upper limit of uniaxial compression strength after improvement
- Adoption of deterioration test

[2] Plasticity Index: Referring to the degree of water content in soil or base/subbase course materials while fine particles (0.425mm or less) are in the plastic state, this is expressed as the disparity in water content ratio between the liquid limit and plastic limit. PI=WL-WP, where PI: Plasticity index (%), WL: Liquid limit (%), WP: Plastic limit (%). In sandy soil that includes no clay, the plasticity index is 0, indicating good quality materials.

- Adoption of indirect tensile test
- Adoption of test mixing in the laboratory
- On-site trials

Source: South African Pavement Engineering Manual, Chapter 3, Materials Testing[9]

(10) Application of Cement Stabilization to Base Course (Internal Factor)

There were cases that thin asphalt pavement (10cm or less) on the cement stabilized base course was damaged early, but the damage mechanism has not been fully clarified. Regarding the utilization of the cement stabilized base course, Volume 1 (Pavement)[10] of NEXCO's (Nippon Expressway Company Limited) Design Guidelines shows the following information. "In lane pavement, the total thickness of the asphalt mixture layer when paving the asphalt mixture directly on the cement stabilized base course must be at least 15cm."

The reasons for this 15cm are not clear, but the following information may be helpful.

a) From the results of the "Survey on performance of asphalt pavement using soil cement" by the former Ministry of Construction Public Works Research Institute:
   - Many asphalt pavements using soil cement with a large amount of cement are damaged.
   - Soil cement pavement with high compressive strength is prone to breakage. Therefore, it is better to use the minimum amount as possible of cement required and the compressive strength to be 30 kg/cm^2 or less.
   - The thickness of soil cement is preferably 15cm or more. Soil cement with a compressive strength of more than 30 kg/cm2 with thin upper layer is prone to transversal wide cracks. The upper layer of soil cement should be asphalt concrete layer (surface course and binder course) of at least 10cm or more.

b) In response to the above results, the revision of the Asphalt Guidelines[11] in 1967 stipulates the following points. 1) When cement stabilization treatment is used for the base course, the cement stabilization treatment should be at a position 10cm or deeper than the pavement surface. 2) Cement volume should be selected to be equivalent to the uniaxial compression strength of 30 kg/cm^2. In addition, it is stated cement stabilized base course is determined to be deeper than 10cm, based on the fact that if the cement stabilization treatment is used below the pavement surface in less than 5cm, the surface layer tends to flow and the cracks in the soil cement tend to appear directly on the surface.

c) From "Reflection crack prevention method for overlays on concrete pavement":
   - When overlaying concrete pavement with asphalt mixture, problematic phenomenon occurs that reflection cracks appear on the overlay surface at joints or at cracks of the concrete slab become a problem. This is considered to be similar to the case where more asphalt pavement was constructed on the soil cement road surface.
   - In that case, overlaying with an asphalt mixture with a thickness of about 10cm on the concrete pavement cannot prevent reflection cracks, and in conclusion, it is said that the problem would be solved if the thickness of the asphalt mixture is about 15cm in 3 layers.

In addition, foreign literature[12] reported that minimizing crack width with proper construction and curing procedures can reduce the possibility of wide cracks. This method of reducing the crack width is called "pre-cracking," a method that generates hundreds of small micro-cracks instead of a single transverse crack. The method has been applied successfully in several projects in the United States. In this method in United States, a large vibrating roller is passed several times over a cement-stabilized base course 1-2 days after the final compression. This creates a network of tightly spaced linear cracks in the cement stabilized material, relieving shrinkage stresses in the early stages of curing and providing a crack pattern that minimizes the development of wide shrinkage cracks. Furthermore, since pre-cracking is carried out immediately after placement, the overall structural strength of the pavement is said to stay unaffected because the "micro-cracks" subside, and the cement stabilized material continues to gain strength over time. Also in France, pavement companies develop various pre-cracking techniques.

On the other hand, South African Pavement Engineering Manual, Chapter 10: Pavement Design[13] states that certain pavement types may not be suitable for some road categories[3] or traffic classes, and pavement structure is recommended as shown in Table 4.31. As shown in this table, the adoption of cement stabilized base course is not recommended for almost all categories of roads although it is used for subbase course in some types of base course.

Table 4.31 Recommended Pavement Structure by Road Classification

Pavement Type		Road Category & Design Traffic Class								Reasons for Exclusion
		A		B			C			
Base	Subbase	ES100	ES30	ES10	ES3	ES1	ES3	ES1	< ES0.3	
Concrete	Granular	×	×	✓	✓	✓	✓	✓	✓	Granular subbases prone to erosion at joints and cracks
	Cemented	✓	✓	✓	✓	✓	✓	✓	✓	
Granular	Granular	×	✓	✓	✓	✓	✓	✓	✓	Uncertain behaviour for high traffic demand
	Cemented	✓	✓	✓	✓	✓	✓	✓	✓	
Hot mix asphalt	Granular	✓	✓	✓	✓	×	✓	×	×	Cost effectiveness
	Cemented	✓	✓	✓	✓	×	✓	×	×	
Cemented	Granular	×	×	×	×	×	×	×	✓	Cracking, crushing, rocking blocks and pumping unacceptable
	Cemented	×	×	×	✓	✓	✓	✓	✓	
BSMs	Granular	×	✓	✓	✓	✓	✓	✓	✓	Cost effectiveness, permanent deformation

ES: ES: Equivalent Standard Axle (80 kN) class e.g., ES100 means a road class with a cumulative axle load of 100 million ES or more, and ES30 means a road class with a cumulative axle load of 30 million ES to 1 million ES.
Cemented: Cement stabilization

Source: South African Pavement Engineering Manual, Chapter 10: Pavement Design[12]

(11) Problem of Waterproof Material in Bridge Pavement (Internal Factor)

Regarding the waterproof work for concrete floor slabs, urethane-based waterproof work used in the past originally had a problem in adhesiveness with the asphalt concrete layer. At present, each manufacturer has accumulated quality improvements to solve this problem. The material for the waterproof layer should be carefully selected by checking the characteristics and specifications of each product and the latest construction results.

[3] The South African Pavement Design Manual classifies roads into categories A, B, and C according to the cumulative axle load (ES) used in the design.

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CHAPTER 5 POINTS TO CONSIDER IN DRAFTING SPECIAL SPECIFICATION FOR PREPARATORY SURVEY

5.1 Notes for Drafting Terms of Reference in Preparatory Survey

In the proposal competition for the preparatory survey, JICA presents a "Planning Competition Explanatory Statement" and draft special specifications are shown as part of the explanatory statement. The draft special specifications include the background, purpose, and scope of the work, the implementation policy and points to be noted, the contents of the work, reports to be submitted and the work process, and indicate the conditions necessary for estimating the cost of the work and for preparing the technical proposal.

The draft special specifications will be finalized as Appendix II "Special Specifications" of the contract document, based on the discussions between the client and the successful bidder on the matters proposed in the proposal. The followings are the basic knowledge necessary for drafting special specifications of a preparatory survey. Since the draft special specifications are the basic material for the consultant to prepare a proposal, it is necessary to clearly indicate the items to be implemented in the survey and the items for which proposals are requested.

(1) Collecting Information on Similar Projects and Checking Existing Materials and Past Projects

Design standards are standards that should be complied with so that structures of the same degree can be designed even if the designers are different. Similar to Japan, various design standards for civil engineering structures have been established in the African region, and it is important to properly understand and adequately operate them. In this case, it is necessary to confirm that the design standards properly reflect the local condition such as traffic volume and geological condition.

For this reason, when planning / designing roads, it is necessary to obtain design standards and design methods adopted for adjacent projects and projects with similar traffic conditions, natural conditions, and land use conditions. In addition, conduct hearings with people in charge of similar projects in counterpart organizations and related consultants about issues, problems, and solutions at the time of design. If there is a project under construction that can be used as a reference, conduct hearings to confirm construction problems. Reflect this information in the plan. The obtained design materials shall be compared with the plans and design contents (design conditions and outputs) of this survey and reflected in the report.

(2) Road Inventory Survey

Road surveys serve as basic data showing the target roads and their roadside conditions. Conventionally, in road inventory surveys, only limited information within the narrow area along project road is often collected and is not always fully utilized. For this reason, regarding road condition surveys, not only surveys of facility conditions and land use in a narrow area around the planned roads, but also natural conditions (vegetation, etc.), wetlands along the roads and ground history in a wide area are also investigated. Finally, the information of the natural condition survey (survey location, survey contents, etc.) will be added, and the topographic map obtained by the survey will be compiled together with the image information to cover the current situation information as much as possible. By doing so, it

becomes an effective material that can be shared by the parties concerned. It is also recommended to add information obtained during detailed design stage and finally provide it to bidders as part of the bidding document.

(3) Socio-economic Survey

The socio-economic survey is to hear opinions on road maintenance issues (concerns about increased traffic accidents, etc.) and expectations for development (securing year-round passability, improving safety, etc.) from road users and residents along the target road. It also collects the data needed to forecast future traffic demand.

Specifically, among the three requirements of road planning (regional characteristics, traffic characteristics, network characteristics), the regional characteristics and network characteristics are grasped. When forecasting traffic demand, it is necessary to consider the socio-economic factors surrounding traffic demand and trends in automobile traffic demand from various angles, because demand changes significantly due to changes in socio-economic conditions. For example, in the demand estimation of freight vehicle traffic, the gross domestic product, agricultural/industrial output, the number of freight vehicles owned, etc. are candidates for explanatory variables because the influence of economic activities is large. Similarly, in estimating passenger traffic demand, candidates include population, income and the number of license holders etc. In addition, land use conditions in port areas, industrial areas, commercial areas, residential areas, etc. also have a large impact on traffic demand. It is important to grasp the demand after setting the future scenario of the socio-economic indicators of the target area by incorporating a wide variety of traffic data and related data as much as possible.

(4) Traffic Demand Forecast

In developing countries, there are often no officially recognized design traffic volumes, and it is necessary to set the traffic conditions required for traffic demand in each project. In many projects in developing countries so far, the future traffic volume has been obtained by simply multiplying the current traffic volume by a certain growth rate (natural increase). However, in estimating traffic volume, it is necessary to consider not only national and regional development plans, but also the function of roads (designation as international trunk roads such as the Asian Highway), land use due to road development, and changes in urban structure. In addition, when developing roads around the border, consider the development plans and road plans of neighboring countries. For this reason, the data obtained from the socio-economic survey will be thoroughly examined, and appropriate parameters that anticipate the margin rate will be selected and used for traffic demand forecasting.

(5) Road Design

When designing a road, the design speed and cross section will be examined at the same time as the comparison of horizontal alignment and vertical alignment. When examining the design speed and cross section, consider the safety of motorcycles, bicycles, pedestrians, flow lines, and traffic volume. In particular, when setting the width of sidewalks and shoulders, consider not only the current mixed traffic, but also the purpose of sidewalks and shoulders and the safety of various traffic modes such as the need for future cycle lanes especially in urban areas. At this time, interviews with other donors such as WB (World Bank), ADB (Asian Development bank), AfDB (African Development Bank), EU (European

Union) and UN (United Nations) will be conducted to confirm safety measures for pedestrians and bicycles and the existence of related projects, which will be reflected in the plan.

(6) Road Design (Structure Design)

In designing structures (including geotechnical structures), comprehensively evaluate structural safety, functionality including user's safety, environment, simplicity, and certainty of maintenance and economic efficiency during design period, as well as workability, worker's/neighbor's safety in construction stage, and determine position, structure type, the basic dimension of main structures. At this time, the contents, items, and quantities of the natural condition survey are proposed so that the uncertainties represented by problem soil, soft ground, or slope disaster prevention are minimized, and the uncertainties of estimation are minimized.

In particular, since many developing countries do not strictly manage rivers and watersheds as Japan does, bridge design should be carried out after conducting sufficient river surveys and hydraulic studies to (1) ensure that roads and bridges are not damaged by floods, and (2) ensure that the project does not cause widespread flood damage in the region (i.e., damage to others). In addition, in case of applying Specification for Highway Bridges[1] (2012) with the approval of the government of the partner country for the design method, the "partial coefficient design method" based on new Specification for Highway Bridges[1] (2019) will be used for verification.

(7) Drainage Design/Pavement Design

In considering the drainage plan, not only the surface drainage of the road, but also the underground drainage and the drainage basin of the adjacent land should be thoroughly investigated. In particular, since there are many cases where inadequate drainage design leads to pavement failure, pavement design and drainage design should be carried out in an integrated manner. Specifically, consideration should be given to long-term water retention in the subgrade and base course, functional deterioration due to the influence of groundwater, and base course drainage to treat water flowing in from the surface. Taking these conditions into account, drainage system planning, and flow calculations are carried out, and drainage structures are designed.

In the pavement design, the required performance of the road surface is set by the road surface design, and the material of the surface layer forming the road surface (selection of asphalt, presence or absence of modified material, quality of aggregate) is determined. In case the use of modified asphalt is indispensable as a result of the survey and the scale of the pavement works is small (e.g. bridge works), the possibility of adopting concrete pavement will be considered based on workability and LCC (Life Cycle Cost) comparison, etc. In order to confirm the structural adequacy of the considered pavement structure, verification using different design methods from method used in the design, such as theoretical design methods, shall be carried out. The verification is not used to reduce the thickness of the pavement, but to verify the validity and problems of the durability and economic efficiency of each layer of the pavement structure.

(8) Survey on Obstacles and Utilities

The government of the recipient country is responsible for the removal / relocation of obstructed properties and utilities. However, explain to the government of the recipient country that this removal / relocation work will not be critical to the process. For this reason, in the survey of obstructing properties and utilities, the contents of the target obstructing properties and utilities, the administrators, the procedures for removal / relocation, and the deadlines for removal / relocation will be clarified. In addition, the removal / relocation drawings, the necessary quantities, and required costs will be prepared. It is possible to carry out the survey of obstructing properties and utilities by subcontracting, but the survey team, the implementing agency of the recipient country, and the facility administrator should confirm the results of the final removal / relocation plan and have a common understanding.

(9) Material Procurement Survey

The purpose of the material procurement survey is to obtain data that supports the procurement and transportation of necessary materials (reinforcing bars, cement, crushed stone, etc.) and equipment for the construction. For this purpose, material surveys, material tests, and route clearance surveys will be conducted. In addition, surveys on local concrete and asphalt plants will be conducted as necessary. However, due to the limited time and budget for the survey, the necessary surveys and tests will be conducted efficiently after obtaining information from local counterparts and local consultants who are familiar with the material procurement situation. If, as a result of the investigation and testing, it is found that there is a risk in material procurement, the risk shall be described in the report and a proposal for re-investigation at the implementation stage shall be made.

(10) Construction Planning/Cost Estimates

Based on the Design and Cost Estimation Manual and the Supplementary Volume (Civil Engineering) of the Cooperative Preparatory Survey, it is necessary to check whether there are any differences between the design and the site conditions, and then to consider the procedures and methods for efficient, economical and safe construction. The main items to be considered in the construction plan are as follows.

1) Construction outline (confirmation of the contents of various materials and information, such as design documents and standard construction specifications)
2) Planned schedule (number of working days and overall process, taking into account the local social environment, such as rainfall, temperature and other weather conditions, natural conditions such as frequency of flooding, and festivals)
3) On-site organization and labor plan (personnel plan for operation, such as assignment of personnel by type of construction and responsibilities)
4) Designated machines and main machines (machine plans and transportation plans of machines to be used, manufacturing companies, etc.)
5) Main materials (material use and procurement plan, including shape, size, quality, etc. of main materials)
6) Construction methods (basic construction policies such as construction procedures, materials/machinery to be used, and plans for temporary facilities)
7) Construction management plan (process control and quality control)

8) Safety management (management of health and safety and public safety)
9) Traffic management (safety measures such as traffic control and installation of signs)
10) Environmental measures (environmental measures against noise, vibration, dust, etc.)
11) Use of recycled resources and disposal of construction by-products

In the construction plan for road works in landlocked countries, when sufficient investigation cannot be carried out and uncertainties are involved, such as the import of materials and equipment using the ports of neighboring countries, customs processing, or transportation plans using the roads of neighboring countries, hypothetical conditions should be placed and these conditions should be clearly indicated and reflected in the cost estimate. In addition, since the construction plan may not reflect the contents of the standard specifications (e.g., General Specification for Road Works) of the partner country, in case there is a shortfall in the original construction plan, the consistency of the contents of the standard specifications and the construction plan should be investigated and confirmed.

Construction works for funded cooperative projects generally require a long period of time from survey to construction, and the construction conditions are harsh, which may cause various difficulties. In light of this background, the basic items for implementing appropriate cost estimation should be clarified in detail. Since these items include items necessary for design, they should be coordinated with the design condition survey to ensure efficient survey. As mentioned above, uncertainties that are difficult to clarify at the time of costing should be estimated under hypothetical conditions, and the variable risks should be taken into account and the hypothetical conditions used in estimation be clarified.

(11) Introduction of Appropriate Technology

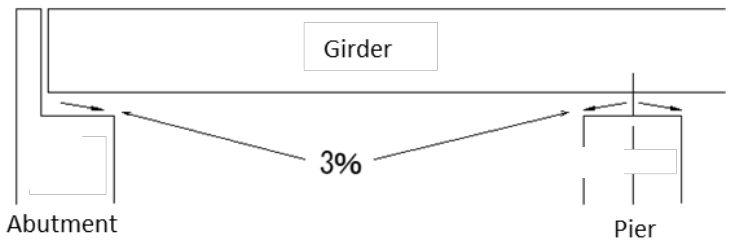
Japan's infrastructure development technology is characterized by a technological system supported by abundant finances, and the sophistication, specialization, and division of labor of reliable technology. These technologies have been standardized by incorporating the latest knowledge at that time, and their application has been institutionalized. Japan's infrastructure has been developed by an advanced production system that has been elaborately formulated in the system prepared in this way. On the other hand, in developing countries where the natural environment, construction conditions, maintenance capacity, etc. are different from Japan, Japan's technical standards are not always the optimal solution. In the developing countries, problems that cannot be solved by Japanese standards often appear. In order to solve the problem, it is necessary to fully understand Japanese technical standards and customize them, or to create sustainable technologies that are most effective for the environment, conditions and needs of developing countries. In the preparatory survey, the contrivance (adoption of a structure that is easy to maintain, customization and application of local technology, etc.) implemented for the issues under the constraints encountered in the partner country will be described in the report.

Source: JICA Study Team based on "Basic research on evaluation methods for appropriate technology in civil engineering infrastructure development in developing countries"[2]

Table 5.1 Examples of Contrivance for Maintenance Management and Extending the Service Life of Structures

Purpose	Object	Example of contrivance
Contrivances for easy maintenance and management	Bridge	Adoption of integral abutment, installation of inspection pathway, securement of inspection work space
	Road	Weed control by adopting flat blocks on soft shoulders and slopes.
	Drainage	Adoption of a large diameter cross-sectional pipe that can be cleaned by manpower
	Road lighting	Adoption of LED lighting
Customization of local technology	Structure	Adoption of earth retaining structure by Gabion
	Protection of slopes	Slope protection using local vegetation
	Guard rail	Adoption of wooden pole
Extending the service life of structures	Bridge/structure	Installation of drainer, provision of drainage slope to bridge seat, painting of girder edge/bridge seat
	Pavement drainage	Adoption of drainage measures such as base course/subbase course drainage and groundwater control
	Pavement	Adoption of anti-rutting measures (concrete pavement or modified asphalt) (however, it is important to use the right materials in the right places)

Source: JICA Study Team

Installation of drainer (overhanging part of slab)	**Drainage at bridge seat**
	
By shutting out rainwater at the edge of the floor slab, it is possible to reduce rainwater intrusion into the superstructure and bearing support. It has been clarified that the floor slab was destroyed 100 to 300 times faster in the wet state than in the dry state.	In addition to water leakage from the expansion joint, the top of the substructure is generally poorly ventilated around the bearings support, and is in an environment that is prone to corrosion and deterioration due to the accumulation of dust and moisture. For this reason, a 3% gradient is provided in the direction of the bridge axis so that water does not pool as shown in the figure above.

Source: JICA Study Team

Figure 5.1 Example of Measures Enabling Easy Maintenance at Design Stage

5.2 Points to Note in Natural Condition Surveys[1]

At the start of the field survey, the consultant shall collect the country's design standards for pavements, etc., as well as the country's standard specifications for construction, geological survey, traffic/axial weight survey, material testing standards, surveying, etc., and prepare a field survey plan necessary for establishing the road design conditions. The prepared site investigation plan shall specify the quantity, specifications (i. e. investigation methods and techniques), and applicable standards for the investigation.

In some countries, there may be no set standards for the survey. In this case, the field survey plan should be developed by interviewing local consultants who have experience in similar projects and confirming the standard survey contents and specifications in the country. This field survey plan must be approved by the country concerned before the start of the field survey.

(1) Traffic Volume Survey / Axle Load Survey

For the traffic survey, the survey area, survey date, and survey time should be set appropriately, and the survey should be planned to reflect changes in the day of the week, seasonal changes, and the amount of converted traffic from other roads after the road is put into service. In the case of border areas, it is also important to grasp the amount and the characteristics inflow traffic from neighboring countries. The survey of traffic volume also includes the survey of GDP (Gross Domestic Product) and other indicators of economic activities and development plans of the country concerned or neighboring countries that may affect the traffic volume.

In principle, an axle-load survey for pavement design should be conducted, but the results of a recent axle-load survey conducted by other project or data from a constant observation point can also be used. Overloaded vehicles, main cause of pavement destruction, often pass through at night, when overloading measurements are not conducted. Therefore, a 24-hour axle load survey is preferable because a normal survey (only during daytime) cannot reflect overloaded vehicles in the survey results and tends to underestimate the destruction factor of heavy vehicles. In addition, since the quality (weight) of vehicle loads may differ by up/down direction of a road, the survey should be conducted for each direction on the same route.

[1] In the natural condition survey in preparatory survey of JICA, hydrological survey, topographical survey, geological survey, meteorological survey and traffic survey are included.

Table 5.2 Example of Subcontract Cost for Traffic Survey

No.	Item	Unit	QTY	Unit cost (USD)	Condition
1	Preparation, clearance	Set	1	3,000～5,000	• Although it varies depending on the travel distance to the survey point and the scale of the survey, the range is generally as shown on the left.
2	Roadside traffic counts (12h)	Point	1	1,500～2,000	• Generally, 5persons/1 point (2 persons per direction and 1 assistant)
3	Roadside traffic counts (24h)	Point	1	2,000～3,000	• Generally, 5persons/1 point (2 persons per direction and 1 assistant)
3	Roadside OD* interview	Point	1	1,500～2,000	• Generally, 5persons/1 point (2 persons per direction and 1 assistant) • Sample size of about 10%. • Since the vehicle needs to be stopped, assistance by police officers is often requested.
4	Intersection traffic count (peak hours)	Inter-section	1	3,000～4,000	• Generally, peak hours survey (morning 3h, evening 3h) • Four times as many surveyors as roadside traffic count is needed.
5	Parking vehicle survey	km	1	800～1,000	• Targeted to roadside parked vehicles
6	Axle load survey(12h)	Point	1	2,000～3,000	• Generally, a portable axle load meter is used, and the survey is conducted at the same time as roadside traffic counts. 12 hours is standard, but if there is a lot of night traffic, a 24-hour survey is conducted. In many cases, the presence of a police officer is requested.
7	Reporting	Set	1	1,000～3,000	• Depends on the size and content of the survey

*OD: Origin and Destination
Note: This is a reference unit price based on the analysis of the data held by the survey team and is a rough estimate of the survey cost.
Source: JICA Study Team

(2) Topographic Survey

The scale of the topographic map to be prepared in the surveying shall be 1/1,000, and the scale shall be 1/500 for areas that require detailed study, such as the layout of major structures and intersections. The surveying method for preparing the topographic map shall be based on actual measurement on the ground, but surveying by navigation (drone, etc.) is also possible if the same accuracy as actual measurement on the ground can be secured. The surveying accuracy and accuracy control method shall be proposed in the proposal.

Table 5.3 Example of Subcontract Cost for Topography Survey (Surveying)

No.	Item	Unit	QTY	Unit cost (USD)	Remark
1	Preparation, clearance	Set	1	3,000～5,000	• Although it varies depending on the travel distance to the survey point and the scale of the survey, the range is generally as shown on the left.
2	Control point survey	Set	1	4,000～5,000	• Confirmation of national control point and installation of control point
3	Topographic survey (actual survey)	km^2	1	40,000～ 50,000	• Preparation of topographical map (scale: 1/1,000) • More accurate than UAV*
4	Road center-line survey (pitch: 20m)	km	1	800～1,000	• Can be substituted by cross-sectional surveying since 3D data is used with total stations, etc. (This may not be done in some cases.)
5	Road cross-section survey (width: 60m)	Line	1	80～100	• The width varies depending on the width of the planned road and other conditions. (30m to 100m) • Basically, measurement pitch is 20 meters.
6	Installation of benchmark	Point	1	100	• Fixed structure installation by concrete. • Visibility at site needs to be considered. (1 location / 200m to 500m)
7	Single point survey	Point	1	50	• If there is a complex terrain that cannot be captured by the above, supplementary survey is conducted.
8	Reporting	Set	1	2,000～3,000	• Depends on the size of the survey
Ref.	Topographic survey (Survey by UAV*)	km^2	1	5,000～6,000	• Preparation of topographical map (scale: 1/1,000) • Less accurate than actual survey
Ref.	River center-line survey	km	1	5,000	• Conducted to determine the height of the centerline of the river channel. • Basically, a vessel is used, and staff and poles are used. • For rivers with high transparency, laser-based drones can be used for measurement.
Ref.	River cross-section survey (width: 500m)	Line		500～700	• Conducted to determine the cross-sectional shape of the river at arbitrary intervals. • The survey widths on both sides are set to cover both river banks. • If there is a significant change in the river channel in the vicinity of the bridge, the pitch should be increased or decreased as appropriate.

*UAV: UAV: Unmanned Aerial Vehicle
Note: This is a reference unit price based on the analysis of the data held by the survey team and is a rough estimate of the survey cost.
Source: JICA Study Team

■ Error range of topographic map

When creating a topographic map or drawing by topographic survey, the error range of the drawing is defined. In the example of Japan, the position accuracy and map information level of numerical topographic map data are based on Table 5.4.

Table 5.4 Accuracy of Numerical Topographic Map Data

Accuracy of numerical topographic map data

Article 80 The following table is the standard for the position accuracy of numerical topographic map data and the map information level.

Map information level	Standard deviation of horizontal position	Standard deviation of elevation points	Standard deviation of contour lines
250	within 0.12m	within 0.25m	within 0.5m
500	within 0.25m	within 0.25m	within 0.5m
1000	within 0.70m	within 0.33m	within 0.5m
2500	within 1.75m	within 0.66m	within 1.0m
5000	within 3.50m	within 1.66m	within 2.5m
10000	within 7.00m	within 3.33m	within 5.0m

2. The "map information level" indicates the accuracy of map representation of numerical topographic map data, and refers to an index indicating the average total accuracy of the data in the map.

3. The relationship between the map information level and the scale of the topographic map is as shown in the following table.

Map information	Scale
250	1/250
500	1/500
1000	1/1, 000
2500	1/2, 500
5000	1/5, 000
10000	1/10, 000

Source: Regulations of Public Surveying Work Regulations[3]

■ Measurement of terrain and features

The standard density of elevation points used for topographical measurement is one point in a grid whose side length is the value obtained by multiplying the map level by 4 cm (example: 20 m for 1/500) for ground surveying. For topographic maps that support CIM (Construction Information Modeling/Management) and i-construction, point data of at least 4 points/m^2 is essential. In addition, the information such as features to be included in the survey map depends on the map information level. In Japan, the information to be described is defined by the "Public Survey Standard Diagram Numerical Topographic Map Data Acquisition Classification Criteria Table".

(3) Geological Survey

Geological surveys include confirmation surveys of support layers of major structures, soft ground, rock/soil classification of cuts, stability of natural slope, groundwater, and subgrade strength. Regarding the in-situ test (boring survey, CBR survey, etc.) conducted for these confirmations, the purpose, position, quantity of the survey, and the items of the laboratory test are proposed. If it is expected that the subgrade strength will differ depending on the rainy season / dry season, survey in rainy season is proposed.

■ Survey for support layer of structures

The foundation of a structure should be supported on a good supporting layer with sufficient thickness. Therefore, the necessary thickness of the support layer should be sufficiently confirmed during the ground investigation. And the survey locations and quantities will be proposed so that changes in the bridge type, etc. will not occur during detailed design due to changes in ground conditions. For example, when planning a long span bridge and the geology of both riverbanks is not very strong, an arch bridge is not suitable. In case the riverbed is strong, it is more economical to use multiple piers. On the other

hand, in case the riverbed is uneven or not strong, it is possible to reduce the number of piers. The evaluation of mechanical strength of the support layer is determined not only by the N value, but also by considering the surrounding sedimentary environment and the continuity of the strata. The guideline for good quality support layers and layer thickness depends on the scale of the structure, foundation type, etc., but there are some examples in Japan as shown in Table 5.5.

Table 5.5 Guideline for Confirmation of Support Layer by Each Organization in Japan

Organization and source	Upper structure, foundation type	Guideline for good support layer		Remark
		Cohesive soil	Sandy soil	
Road geotechnical - Retaining wall - temporary structure guideline, Japan Road Association	Retaining wall, culvert, etc.	N≧10～15 qu≧10～20 tf/m2	N≧20	The depth of the survey is until the thickness of the support layer to be at least 2m.
Design Manual, Tohoku Regional Construction Bureau	Bridge - spread foundation	N≧20	N≧30 (The same applies to bedrock and gravel layers.)	The layer thickness must be at least 5 m and there must be no soft layers below.
	Bridge – pile foundation	20≦N≦30 (Solid layer is N>30)	30≦N≦50 (Solid layer is N>50)	The layer thickness must be at least 5 m and there must be no soft layers below.

Source: Road Survey and Design Know-How Book, Road Survey and Design Research Group[4]

Table 5.6 Example of Subcontract Cost for Geological Survey (1 point, depth 20m)

No.	Item	Unit	QTY	Unit cost (USD)	Remark
1	Preparation, clearance	Set	1	10,000 – 15,000	• It varies depending on the transportation distance of materials and equipment, and the condition of the survey area (flatland, mountainous area, underwater, etc.).
2	Boring	m	20	On the ground 150 – 200/m Underwater 200 – 250/m	• Depth is assumed based on the surrounding conditions. • The data is divided into the in-river survey and the on the ground survey.
3	Standard penetration test	Time	20	50 – 60/m	• Conducted to determine the N value. • Conducted once at each depth of 1m.
4	Laboratory test*				• Tests on undisturbed samples collected. • Consideration needs to be given as to which layer each test should be performed on.
4.1	Grain size test	Sample	10	20 – 40	• A test to grasp the particle size distribution and fine grain content. • It is used to determine liquefaction in the target ground.
4.2	Density test of soil particles	Sample	10	20 – 40	• A test to determine the density of soil particles. • It is used to establish the geotechnical constants for earthwork materials.
4.3	Moisture ratio test	Sample	10	20 – 40	• A test to determine the moisture content ratio of soil.
4.4	Liquid limit and plastic limit test of soil	Sample	10	20 – 40	• A test to determine the liquid and plastic limits of a soil. • It is used to determine the liquefaction of the target soil.
5	Reporting	Set	1	2,000 – 3,000	• Depends on the size and content of the survey

*Laboratory test: It is determined by the soil layers identified by the boring survey. The example in this table assumes that a different layer appears every 2 m. For laboratory tests, it is assumed that the final liquidation will be based on the test quantity, etc.

Note: This is a reference unit price based on the analysis of the data held by the survey team and is a rough estimate of the survey cost.

Source: JICA Study Team

■ Subgrade strength survey

The design CBR (California Bearing Ratio) test used for pavement design should be conducted by taking samples at appropriate intervals to determine the soil properties/subgrade CBR. If the sampling interval of the design CBR test is long, there is a risk of overestimating or underestimating the design CBR and overlooking soil weaknesses such as soft ground and problem soil. In addition, when the road width is large or the change in soil properties is expected to be large, the investigation in the cross direction should be considered. However, if it is clear from the previous data that there is little change in soil properties to the extent that it can be judged almost uniform, the number of surveyed sections should be reduced, or efficient survey will be proposed using a simple measurement method such as DCP (Dynamic Cone Penetration).

There are three types of CBR tests in Japan: the "design CBR test" for cut-earth subgrade, etc., the "modified CBR test" for materials used in compaction such as embankments and base course/subbase course, and the "field CBR test" conducted in the field (see Table 5.7). On the other hand, in many overseas cases, the modified CBR test is used even in the case of cut-earth subgrades. This is because of the differences in natural conditions and compaction rules of the existing subgrade in each country (it is common to re-compact the top 20 to 30 cm of the cut subgrade as well as the embankment subgrade), etc. Therefore, test methods that do not match local conditions should be avoided.

Table 5.7 Outline of Typical CBR Tests

CBR test method		Feature
Indoor CBR test	Design CBR test	A test to evaluate the subgrade soil when the undisturbed existing ground is used as the subgrade (the test is conducted on disturbed samples). The natural moisture content ratio is used for the test.
	Modified CBR test	A test to evaluate the strength of materials used in compaction, such as disturbed subgrade and materials for base course/subbase course. The moisture content ratio used in the test is the optimum moisture content ratio or the equilibrium moisture content ratio (depending on the standard).
Field CBR test		It is used to directly measure the bearing capacity of the subgrade soil at the present location or stabilized soil after construction, and is mainly used for construction management.

Source: JICA Study Team

Table 5.8 Types of Moisture Content Ratio

Type of moisture content ratio	Detail
Natural moisture content	Water content that soil retains in its natural state. It varies over a wide range depending on the soil type, groundwater level, and other factors, but is approximately 5% to 30% for sandy soils and 30% to 80% for clayey soils. Because of seasonal variations, it is necessary to consider not to be on the dangerous side.
Optimum moisture content	The moisture content ratio of the soil in the state of best compaction when it is compacted by a certain method and a certain compaction energy. In general, the soil with a higher maximum dry density has a lower optimum moisture content ratio, and the finer the particle size, the lower the maximum dry density.
Equilibrium moisture content	The subgrade is considered to be in a constant state of water content because the flow of water in and out of the subgrade occurs until it is paved and after it is paved, the flow is cut off.

Source: JICA Study Team

Table 5.9 Standards of Representative Subgrade Strength Surveys

Country	Subgrade Strength Survey Standards
Pavement Design Handbook[5]	In road projects in Japan, a geological preliminary survey is implemented before the detailed CBR survey. If there are changes in the subgrade soil as a result of the preliminary survey, the section over which pavement thickness is changed is presumed in advance. On sections deemed to have little change, the number of design CBR tests is reduced, while tests are increased on sections deemed to have numerous changes. However, even when the survey section is relatively short or the subgrade soil is thought to be almost totally uniform, CBR tests are implemented in at least three positions on the road. (Based on the Pavement Design Handbook ("minimum length of 200m section having the same pavement structure is desirable"), it is common to implement at intervals of 200m).
Site Investigation Manual (Ethiopia) [6]	Modified CBR test:1 sample/km Soil test: 500m intervals
Pavement design Manual (Ghana) [7]	New road: Modified CBR test 4samples/km (trunk road) On low-specification roads, the number of samples can be reduced. Existing road: FWD test maximum 50m interval (combined with DCP test)
Field Testing Manual (Tanzania) [8]	Modified CBR test: 2samples/km (paved trunk road), 1sample/km (other paved road), 1sample/2km (gravel road) Soil test: 4samples/km (paved trunk road), 2samples/km (other paved road), 2 samples/km (gravel road)

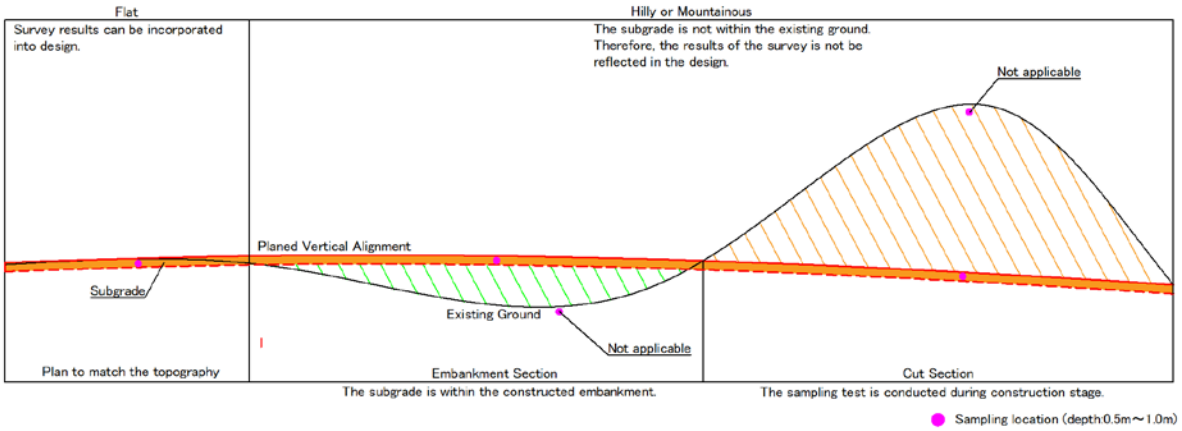
FWD: Falling Weight Deflectometer
Source: JICA Study Team

Table 5.10 Example of Subcontract Cost for CBR Test and Material Test

No.	Item	Unit	No.	Unit cost (USD)	Remark
1	Preparation, clearance	Set	1	3,000 – 5,000	• Although it varies depending on the travel distance to the survey point and the scale of the survey, the range is generally as shown on the left.
2	Sampling, transportation				• It varies depending on the distance to the testing laboratory
2.1	Subgrade	Point	1	200 – 300	• Required **test volume**
2.2	Borrow-pit	Point	1	200 – 300	• 2 samples/1 point (required test volume/sample)
2.3	Quarry	Point	1	300 – 400	• 2 samples/1 point (rock excavation)
3	Laboratory test Subgrade/borrow-pit test				
3.1	Grain size test	Sample	1	30 – 40	
3.3	Density test of soil particles	Sample	1	30 – 40	
3.4	Moisture ratio test	Sample	1	30 – 40	
3.5	Liquid limit and plastic limit test of soil	Sample	1	20 – 30	
3.6	Swelling test	Sample	1	100 – 150	
3.7	CBR test	Sample	1	100 – 150	• 4 days immersion
4	Laboratory test Aggregate test				
4.1	LAA	Sample	1	60 - 80	• Los Angeles Abrasion: Abrasion test of aggregate using Los Angeles testing machine
4.2	ACV	Sample	1	60 – 80	• Aggregate Crushing Value
4.3	TFV	Sample	1	80 – 100	• Ten percent Fines Value**:** Crushing load when 10% of the total aggregate passes through a 2.36 mm sieve
4.4	Density test of aggregate	Sample	1	50 – 60	
5	Reporting	Set	1	2,000 – 3,000	• Depends on the size and content of the survey
Ref.	Trial pit test	M	1	60 - 80	• Depth: 1m
Ref.	DCP test	Point	1	80 - 100	• Dynamic Cone Penetration • Depth: 1m

Note: This is a reference unit price based on the analysis of the data held by the survey team and is a rough estimate of the survey cost.
Source: JICA Study Team

The sampling of the subgrade strength survey depends on the topography and the planned vertical alignment of the road, as shown in Figure 5.2. When designing a vertical alignment in flat areas and along the terrain, the subgrade is often 50 cm to 100 cm from the site surface. On the other hand, in hills and mountains, the subgrade may be 100 cm or more deep from the existing ground in cutting section, or a new embankment may be the subgrade (constructed subgrade) instead of the existing layer in embankment section. Therefore, it is efficient to collect a sample for confirming the strength of the subgrade after the rough alignment is planned.

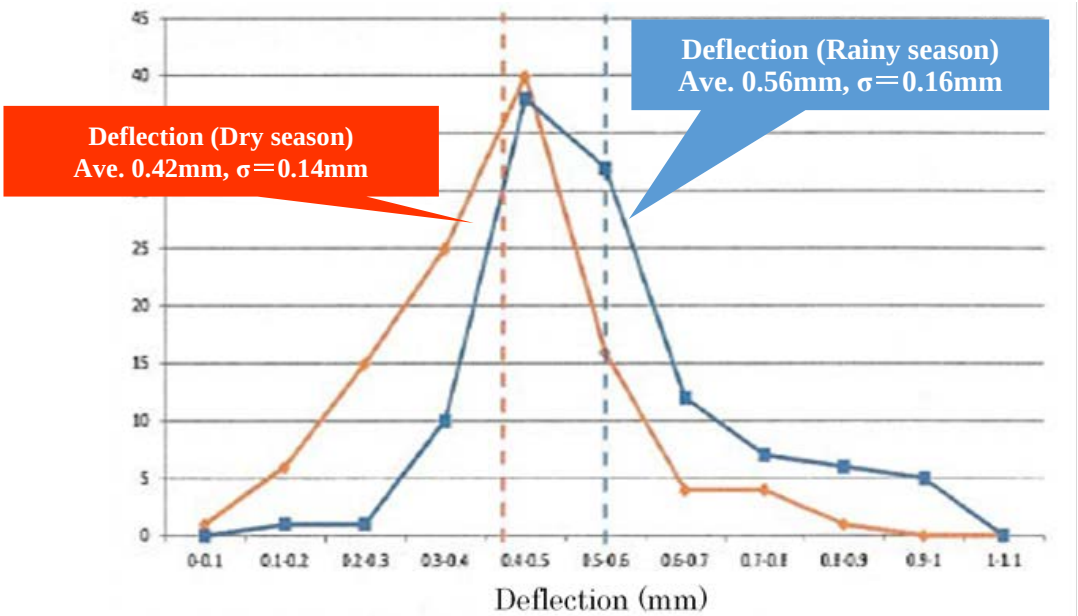


Source: JICA Study Team

Figure 5.2 Consideration for Subgrade Sampling

■ Differences in subgrade strength depending on the season (Notes on CBR test)

Figure 5.3 shows the difference in subgrade strength (deflection) between the rainy season and the dry season measured in Laos. In the rainy season, the deflection of the subgrade increases by about 33%. That is, it has been shown that the bearing capacity is reduced, leading to damage to the road surface. Similarly, it is known that the bearing capacity of the subgrade is significantly reduced during the thaw period in cold regions. There are cases as in the Australian Pavement Design Standards shown in Table 5.11, soaked CBR test is conducted 10 days at the maximum depending on the annual rainfall.



Source: JICA Study Team

Figure 5.3 Example of Difference in Subgrade Bearing Capacity Between Rainy Season and Dry Season (Laos National Highway No. 9, according to JICA research)

Table 5.11 Main CBR Test Methods

Standard	Features	Important Points
ORN* 31 [10]	Modified CBR test (BS*** standard: equilibrium water content, etc. water content appropriate for the site conditions)	Soaked (4 days)/Unsoaked CBR test is determined according to conditions of rainfall and groundwater.
SATCC** pavement design Standard [11]	Modified CBR test (AASHTO**** T-99)	Soaked (4 days)/Unsoaked CBR is determined according to conditions of rainfall and groundwater.
Australia Pavement Design Standard[12]	Modified CBR test (OMC: Optimum water content) If the annual average rainfall median value is greater than 800mm, and the drainage facilities are insufficient : 1.0~1.15 x OMC	If the annual average rainfall median value is greater than 800mm, and the drainage facilities are insufficient, soaked CBR test is conducted for 4~10 days If the annual average rainfall median value is 500~800mm, and the drainage facilities are insufficient, soaked CBR test is conducted for 4~7 days

*ORN: Overseas Road Note, **SATCC: Southern Africa Transport and Communications Commission, ***BS: British Standard, ****AASHTO: American Association of State Highway and Transportation Officials
Source: JICA Study Team

(4) Meteorological survey

Rainfall data for the target area will be collected for the past three to five years to understand the trend of weather conditions and to calculate the rainfall intensity necessary for designing drainage channels such as gutters.

In areas where the temperature of the road surface is high due to high temperature, flow rutting of the asphalt layer is a major problem. For this reason, data on the annual average monthly temperature in the target area will be collected to calculate the road surface temperature and then the required DS (Dynamic Stability) value.

Meteorological data should be obtained from public sources such as meteorological agencies and airports in the country. However, even official data may be inaccurate, so the accuracy should be checked by comparing data from multiple years (about 3 to 5 years) or by comparing data from different sources. In addition, if it is difficult to obtain observation data in the vicinity of the project area due to reasons such as the project area being in a remote area, the data can be obtained from Web sites after confirming its reliability.

WWIS (World Weather Information Service) is a website that provides weather data from government weather stations (actual measurements) around the world. In reality, the temperature can change according to the topography, etc. Therefore, it is desirable to confirm the temperature by actually measuring the temperature and road surface temperature at the project site.

(5) Hydrographic survey

In general, detailed on-site information on topography and ground surface conditions that cannot be obtained from map reading alone can be obtained by conducting field surveys. For example, information can be obtained on the surface condition and ground slope in the catchment area, or on changes in ground surface conditions due to human factors such as development in the surrounding area. It is also important for slope and subsurface drainage to investigate the presence or absence of landslides, collapses, slope

erosion, and vegetation conditions. The purpose of the investigation of the existing channel system and spring water is to maintain consistency between the existing channel and road drainage in drainage facility design, and to obtain data for stabilizing the embankment or cut slope. Therefore, the type of current drainage channel, direction of flow, type of channel structure and cross-sectional dimensions, and use of the channel will be surveyed, as well as the existence of springs and wetlands.

In addition, actual groundwater and groundwater movement surveys are also included in the hydrological survey. If it is expected that the hydrological conditions (groundwater level, river water level, spring water from slopes, etc.) will differ depending on the rainy season / dry season, in principle, it will be proposed that the survey be conducted at a time when the groundwater level or water content ratio is likely to be most unfavorable, e.g. at the end of the rainy season.

5.3 Items to be Reported to the Implementation Stage

If it is necessary to report risks and issues assumed in the design of the preparatory survey to DD (Detailed Design) or SV (Construction Supervision), the assumed risks shall be described in the preparatory survey report. In this case, items that pose a risk after the detailed design are described as "site conditions" in the detailed design report. If an event occurs that exceeds expectations, it will be addressed at the construction stage as a "change in site conditions". Examples of possible risks reported from preparatory survey to DD/SV stage is shown in Table 5.12.

Table 5.12 Possible Issues to be Addressed at the Preparatory Survey Stage (Example)

Major item	Item	Assumed risk (example)	Items to be transferred to DD/SV
Structure design	Support layer	Since there are some places where the boring survey is insufficient due to the increase in river flow in the rainy season, there is a possibility that the support layer line is different from the assumption. For some culverts, no boring survey has been conducted.	At the time of detailed design, additional geological surveys at the lacking points or just points will be proposed, and the unclear support layer will be confirmed.
	Bridges (river channel)	In torrent rivers, changes in the river channel occur when the flow rate increases in the rainy season, and it is necessary to review the results of the hydrological analysis conducted.	If changes in the river channel are observed during the detailed design, a river survey will be added, a hydrological analysis will be conducted that reflects the results of the additional survey, and the plan at the preparatory survey will be reviewed as necessary.
Earth structure design	Stability analysis	Since embankment height is lower than the standard value and an appropriate embankment material can be obtained, geological survey and stability calculation was not conducted, but if the embankment is destroyed, it is possible to seriously affect the surrounding area (residential area).	At the time of detailed design, a geological survey (boring) will be conducted at the target site, and the validity of the plan will be confirmed by the stability calculation of the embankment based on the assumed material conditions. And at the construction stage, compaction conditions such as selection of appropriate embankment materials, compaction machines, compaction specifications will be fully confirmed and supervised.
Pavement design	Ground water level	According to the rise in groundwater level in low sections, the subgrade may be flooded for a long period of time and the subgrade strength may be lower than expected. (When the field survey in the rainy season could not be conducted because of the survey schedule)	At the time of detailed design, a groundwater survey will be conducted in the target section, and if necessary, the preparatory survey plan need to be reviewed so that the groundwater does not affect the pavement structure.
Obstacle object	Underground pipe	Regarding the ongoing new/relocation work of water pipes, the laying position has not been determined, so the design was carried out on the assumption. Depending on the location of the water pipe, it may be necessary to change the road center line or the right of way.	The laying position will be reconfirmed at the time of detailed design, and if the plan requires excavation after road construction, the government of the partner country should be requested to change the laying position.
Cost estimates	Classification of gravel/rock	At the preparatory survey stage, the rock classification was set by geological reconnaissance by visual inspection without conducting geological survey, but as a result of the design, the cut may extend to the unweathered hard rock part. Therefore, the gravel/rock classification of the cut	When the amount of cut is large and sand/rock classification has a significant impact on construction cost, additional geological survey should be conducted at the time of detailed design on typical cut sections to clarify the sand/rock classification. And if the sand/rock classification that differs from the

		used for the cost estimates may be different.	contract conditions is identified during construction, it should be dealt with as a change in the site conditions.
	Material	The candidate sites for quarry and borrow pit with the shortest transportation distance were adopted for the cost estimates based on the results of the material survey. The collected material meets the specifications, but it may not be possible to secure the required amount for the project.	Possibility of securing of required amount will be reconfirmed by conducting necessary additional survey. If the required amount cannot be secured, a new material collection point will be specified by additional investigation, or it will be clearly stated as a hypothetical condition in the bidding document.

Source: JICA Study Team

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CHAPTER 6 REFERENCES

6.1 References for Geometric Design Standard of Roads

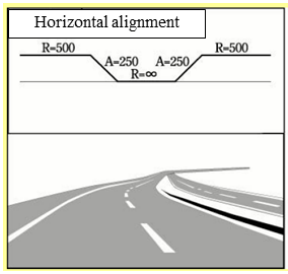
(1) Points to Note in Alignment Design

■ Points to note in horizontal alignment design

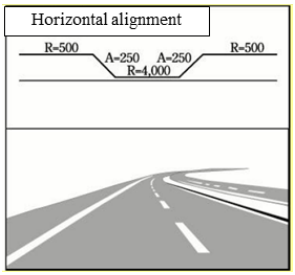
- Avoid long straight lines
- Appropriate ratio of curve radii between continuous circular curves
- Balance the transition curve with the radius of the front and back circular curves

■ Combinations of horizontal alignment to be avoided

- Inserting a short straight line between curves that bend in the same direction (broken back curve)
- Inserting a circular curve with a short radius at the end of a long straight line.
- Inserting a circular curve with a short curve length when the road intersection angle is small.



Broken Back Curve



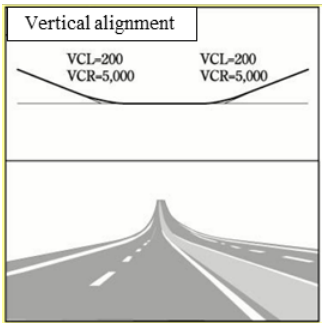
When a straight section is replaced with a composed curve

Source: Explanation and Operation of the Road Structure Ordinance[1]

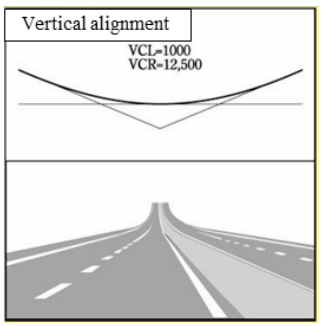
Figure 6.1 Example of Using a Straight Line between Horizontal Curves in the Same Direction

■ Combinations of vertical alignment to be avoided

- Inserting a short straight line between vertical curves that bend in the same direction (broken back curve)
- Vertical alignment that repeats unevenness in a short section
- Inserting a large vertical curve into sag section



Broken Back Curve



When a straight section is replaced with a vertical curve

Source: Explanation and operation of the Road Structure Ordinance[1]

Figure 6.2 Example of Using a Straight Line between Vertical Curves

(2) Geometric Design Standards (Example)

Among the geometric design standards of roads, the geometric structural standards of design speeds of 80km/h and 60km/h, which are most applied in Grant Aid Projects, are shown as follows.

Table 6.1 Geometric Design Standards at 80km/h

Item				Unit	SATCC[2]	Road structure ordinance[1]
Visual range		Stopping		m	115	110
		Overtaking		m	540	550
Horizontal alignment	Sideways-force coefficient numbers				0.13	0.12
	Maximum straight-line length			m	-	2,000-600
	Minimum curve radius SATCC: crossfall (%)	Desirable		m	250 (6%)	400
		Minimum		m	230 (8%)	280
		Exceptional		m	210 (10%)	230
	Minimum curve length	Θ<7°		m	300	1,000/ Θ
		Θ>7°		m	150	140
	Maximum curve length	Standard		m	800	-
		Exceptional		m	1,000	-
	Curve radius to which superelevation is terminated (crossfall 2%)			m	1.600 – 2,000	3,500
	Transition curve length			m	40	70
	Curve radius to which transition curve is required			m	900	900
Crossfall	Standard crossfall	1 lane for 1 direction		%	2.0 – 2.5	1.5
		2 lanes for 1 direction		%		2.0
	Maximum superelevation			%	6, 8. 10	10
Vertical alignment	Minimum K value	Convex curve			33	-
		Concave curve			25	-
	Minimum vertical curve radius	Convex curve	Desirable	m		4,500
			Standard	m		3,000
		Concave curve	Desirable	m		3,000
			Standard	m		2,000
	Minimum vertical curve length			m	140	70
	Maximum vertical gradient	Flat land		%	5	Standard: 4 Absolute: 7
		Hilly area		%	6	
		Mountain		%	7	
	Limit of vertical curve length	3%		m	500	-
		4%		m	300	-
		5%		m	240	600
		6%		m	200	500
		7%		m	170	400
		8%		m	150	-
	Minimum vertical gradient			m	-	0.3
Combined gradient				%	-	10.5
Headroom clearance		Carriageway		m	4.5 – 5.0	4.5
		Sidewalk		m	2.5	2.5

**SATCC: Southern Africa Transport and. Communications Commission*
Source: Road structure ordinance[1], Draft Code of Practice for the Geometric Design of Trunk Roads[2]

Table 6.2 Geometric Design Standards at 60km/h

Item				Unit	SATCC[2]	Road structure ordinance[1]
Visual range		Stopping		m	80	75
		Overtaking		m	410	350
Horizontal alignment	Sideways-force coefficient numbers				0.14	0.13
	Maximum straight-line length			m	-	1,500-400
	Minimum curve radius SATCC: crossfall (%)	Desirable		m	140 (6%)	200
		Minimum		m	125 (8%)	150
		Exceptional		m	110 (10%)	120
	Minimum curve length	Θ<7°		m	300	700/ Θ
		Θ>7°		m	150	100
	Maximum curve length	Standard		m	800	-
		Exceptional		m	1,000	-
	Curve radius to which superelevation is terminated (crossfall 2%)			m	1.000 – 1,200	2,000
	Transition curve length			m	35	50
	Curve radius to which transition curve is required			m	500	500
Crossfall	Standard crossfall	1 lane for 1 direction		%	2.0 – 2.5	1.5
		2 lanes for 1 direction		%		2.0
	Maximum superelevation			%	6, 8. 10	10
Vertical alignment	Minimum K value	Convex curve			16	-
		Concave curve			16	-
	Minimum vertical curve radius	Convex curve	Desirable	m		2,000
			Standard	m		1,400
		Concave curve	Desirable	m		1,500
			Standard	m		1,000
	Minimum vertical curve length			m	100	50
	Maximum vertical gradient	Flat land		%	6	Standard: 5 Absolute: 8
		Hilly area		%	7	
		Mountain		%	8	
	Limit of vertical curve length	3%		m	500	-
		4%		m	300	-
		5%		m	240	
		6%		m	200	600
		7%		m	170	700
		8%		m	150	800
	Minimum vertical gradient			m	-	0.3
Combined gradient				%	-	10.5
Headroom clearance		Carriageway		m	4.5 – 5.0	4.5
		Sidewalk		m	2.5	2.5

Source: Road structure ordinance[1], Draft Code of Practice for the Geometric Design of Trunk Roads[2]

(3) Climbing Lane

In order to prevent the decrease in traffic capacity caused by slow-running large vehicles at climbing section of roads with heavy traffic and a high large vehicle ratio, and to improve the road traffic capacity, safety, and comfort, climbing lanes are provided and low-speed vehicles are excluded from the main lane. The regulations regarding climbing lanes are decided by the standards of each country.

Road structure ordinance[1]

◆ Requirement for provision

Climbing lanes shall be provided as necessary on roads with a vertical gradient of more than 5% on ordinary roads. (3% for national expressways and ordinary roads other than national expressways with a design speed of 100 km/h or more)

◆ Width: 3m

SATCC: Draft Code of Practice for the Geometric Design of Trunk Roads[2]

◆ Requirement for provision

The necessity is examined by LOS (Level of Service) analysis, but generally, climbing lane is separated from the main lane before the speed drops by 20 km/h from the normal running speed, and returns to the main lane when the speed drop is below 20 km/h from the normal speed.

◆ Width: 3.1m or 3.4m

6.2 References for Earthwork of Roads

(1) Selection of Slope Protection Work

Regarding the selection of the type of slope protection work, if the slope surface is vegetable soil and slip does not occur, it is said that use the vegetation work is better from both economical aspect and landscape aspect.

- If the slope is soil that is prone to erosion or surface slip, use vegetation works together with wicker works and cribwork. In addition, block pitching and masonry may be used.
- Cribwork is effective in places with spring water. In areas where surface water may concentrate and flow down, or where it is not exposed to sunlight or rain, vegetation does not grow well, so block pitching or stone pitching is adopted.
- Mortar or concrete spraying is suitable for slopes where weathering progresses if left unattended, but avoid it in places with spring water or on wet slopes. The method of filling the cribwork with stone concrete, or block is also used for the same purpose as the spraying work, but it can be expected to have a reinforcing effect on the slope compared to the spraying work. Slope anchoring is used for rock slopes with cracks and slopes with large floating stones.
- Gabion works are used to cover the slopes which have a lot of spring water and prevent the outflow of earth and sand.
- For slopes with springs or wet slopes, underground drainage facilities such as horizontal drainage and underground drains, and surface drainage facilities such as slope shoulder drains and vertical drains should be constructed.
- Retaining walls are used when a stable gradient earth cannot be used due to adjacent structures or topography, or when it is more advantageous to make the overall slope steep by using retaining walls than to make a long slope.
- Reinforced earth walls are constructed by placing reinforcing materials such as steel bars, steel strips, geotextiles, etc. in the embankment, at the boundary between the ground and the embankment, or in the ground to reduce earth pressure, stabilize the embankment and slope, or increase the bearing capacity of the ground. Reinforced earth walls include reinforced earth retaining walls, reinforcing earthworks at cut slopes and at natural slopes, as well as embankment reinforcement in soft ground.

As described above, there are many different methods of slope protection, and they are often used in combination. The following photographs show examples of slope protection works.

Vegetation sheet

Retaining wall of concrete block

Mortal spraying and rock bolt work

Cribworks and mortal spraying

Planting

Reinforced earth work

Source: http: //www.mizunotec.co.jp/index.html

Photo 6.1 Types of Slope Protection Work

(2) Selection of Measures against Soft Ground

There are various methods of soft ground countermeasures, each of which has its own characteristics, construction methods, and countermeasure effects. Therefore, it is necessary to select the most appropriate construction method by fully considering the following points.

- Reasons why countermeasures are needed, objectives, and expected effects
- Properties of the ground
- Characteristics of the structure
- Site condition, surrounding environment

Table 6.3 shows the types of soft ground countermeasures and the applicable ground and their effects.

Table 6.3 List of Measures against Soft Ground

Construction Method	Type	Summary of Construction Method
Surface Treatment Method	Surface Drainage Method	A trench with a width of 0.5 m and a depth of 1.0 m will be installed / backfilled with high-quality sand and gravel, and it's used for underground drainage.
	Sand Mat Layning Method	For ensuring trafficability, and it's used for drainage layer, lay 0.5m to 1.2m of sand on soft ground.
	Plate Material Laying Method	Trafficability and stability of the embankment in initial state will be ensured, but it's not to be a permanent measure.
	Shallow-Soil Mixing Treatment Method	Improve the surface ground with quicklime, cement, etc. to ensure trafficability and increase bearing capacity.
Replacement Method	Excavation / Replacement Method	The soft layer is entirely or partially replaced by good quality material.
	Embankment Forcibly Replacement Method	The soft layer is forcibly pushed out and replaced by the weight of the embankment of good quality material.
Counterweight Fill Method		Press the side part of the embankment to stabilize it.
Reinforcement Banking Method		By arranging a tensile reinforcing material in the embankment, the expansion of the bottom surface of the embankment due to the lateral flow of the ground is restrained, and the destruction of the embankment is suppressed.
Slow Loading Method		Fill at a speed that does not destroy the fill.
Surcharge Method	Loading Banking Load Method	Load above the planned height, leave it to stand, and increase the strength by consolidating the soft layer.
	Groundwater-Level Decreasing Method	By lowering the groundwater level, the effective stress is increased and the consolidation of the soft layer is promoted.
	Vacuum Consokidation Method	By providing an airtight layer on the ground surface and changing the air pressure inside the sand mat, it is forcibly drained and consolidated.
Vertical Draing Method	Sand Drain Method	A vertical drainage column will be installed on the clay ground to shorten the drainage distance and promote consolidation.
	Card-Board Drain Method	A vertical card-board will be installed on the clay ground to shorten the drainage distance and promote consolidation.
Sand Compaction Pile Method		By applying impact or vibration to the ground, sand is press-fitted into the ground to form sand piles.On clay ground, bearing capacity can be improved and subsidence can be reduced, and on sandy ground, liquefaction can be reduced.
Vibration Compaction Method	Vibroflotation Method	The vibrator is inserted to the underground ground and compacted while injecting water, and the voids created by compaction are filled with sand.
	Rod Compaction Method	The rod is inserted by vibro hammer to the underground ground and compacted by vibration, and the voids created by compaction are filled with sand.
	Dynamic Consolidation Method	A weight with a weight of 10tf to 25tf and a low area of 2㎡ to 4㎡ is freely dropped from a height of 10m to 30m and compacted.
Solidifying Method	Deep-Layer Mixing Method	Stabilize by forcibly mixing lime / cement stabilizer with soft soil.
	Quicklime Pile Method	Quicklime is cast into a columnar body on clay ground to reduce the water content of the ground, increasing strength and reducing settlement.
	Chemichal Feed Method	Injection materials such as chemicals and cement milk are press-fitted into the sandy ground to create consolidated soil, which reduces the hydraulic conductivity of the ground and increases its strength.
	Freezing Method	This is a temporary construction method that temporarily freezes soft ground and ground with a lot of groundwater to prevent spring water and stabilize the excavated surface.
Structure Construction	Pile Method	Combine RC slabs, RC caps, geotextiles or reinforcing bars on the pile top to increase bearing capacity and prevent settlement.
	Sheet Pile Method	By placing A sheet pile on the side of the embankment, circular rupture of the embankment is prevented and lateral displacement of the ground is reduced.
	Culvert Method, Viaduct Method	In order to reduce the load on the pier approach section and reduce the displacement of the pier, culverts are continuously arranged to reduce the weight.
Soil Pressure Reduction Method	Expanded Poly-Styrol Method	In order to reduce the load on the abutment approach section and reduce the displacement of the abutment, EPS are applied to reduce the soil pressure.
	Foamed Cement Banking Method	In order to reduce the load on the abutment approach section and reduce the displacement of the abutment, FCB are applied to reduce the soil pressure.

**EPS : Expanded Polystyrol Construction Method*

**FCB : Foamed Cement Banking*

Source: Road Soil Engineering - Guidelines for Soft Ground Control Work[3]

6.3 References for Road Structure

(1) Design Method of Structures

In the design of the structure, various conditions (load, structural dimensions, materials used, etc.) are determined so as to satisfy the defined limit state for the load bearing performance. Then, while confirming[1] the safety using various design methods, it is necessary to secure the required durability performance for the design life.

Table 6.4 Design Method for Major Structures

Item		Retaining Wall	Culvert	Bridge
Definition		A retaining wall is a structure installed to prevent the collapse of soil and to support the soil when filling or excavating (cutting) the ground where the stability of the slope cannot be maintained with normal soil due to site or topographical constraints and to retain the traffic function of the road .	A culvert is a structure that is placed in an embankment or in the original ground to provide a space for a waterway under a road and classified to rigid culvert and flexible culvert according to its dynamic characteristics.	A bridge is a general term for a structure constructed to cross a transportation obstruction such as river, valley, lake, strait, other roads, rail, or waterway. In urban areas, an elevated bridge that is constructed continuously over a space on a road or river for the purpose of efficient land use is a form of bridge.
Design standard	Japan	Road Earthwork-Retaining Wall Construction Guidelines[4]	Road Earthwork-Culvert Construction Guidelines[5]	Specifications for Highway Bridges[6], 2017
	USA	AASHTO*	AASHTO	AASHTO
	Europe	Eurocode	Eurocode	Eurocode
Design method	Japan	Allowable stress method	Allowable stress method	Partial factors design procedure
	USA	LRFD: Load and Resistance. Factor Design	LRFD: Load and Resistance. Factor Design	LRFD: Load and Resistance. Factor Design
	Europe	Partial factors design procedure	Partial factors design procedure	Partial factors design procedure
Design life	Japan	100 years (from durability)	100 years (from durability)	100 years
	USA	75 years	75 years	75 years
	Europe	100 years	100 years	100 years
Design vehicle load	Japan	250 kN		
	USA	325 kN		
	Europe	440 kN		

*AASHTO: American Association of State Highway and Transportation Officials
Note: The design life of retaining walls and culverts in Japan is not described in the Guidelines for Road and Soil Engineering, but the description of salt damage durability states 100-year durability, so 100 years was used.
Source: JICA Study Team

* Specifications for Highway Bridges [6] (2017)
The design standard for road bridges in Japan is the Specifications for Highway Bridges [6], revised in 2017, and the partial factor design method was introduced as a new design method with the revision of the standard in 2017. In the 2012 Specifications for Highway Bridges that

[1] Limit state design method: The state in which the bridge should stay to meet the required performance. The limit states in the Road Bridge Specification (2019)[6] are layered into "bridge limit states", "superstructure / substructure, structure joint limit states", and "members and other limit states". Ultimately, it is necessary to design so as to satisfy the "limit state of the bridge".

had been used until then, the "allowable stress method" was adopted as the design method. Bridge projects implemented by the Grant Aid project are currently being designed using the 2012 specifications, but it is expected that they will gradually shift to the 2017 partial factor method considering the active introduction of new materials in the future. However, since it is a new design method, it is necessary to correctly understand the provisions of the specification including the procedure such as its features and verification method. For this reason, in the Grant Aid project, although designing by the allowable stress method is applied for the time being, it is desirable to carry out verification by the partial factor design method.

Allowable stress method: The allowable stress method is a method of design that uses the allowable stress as the value obtained by dividing the limit state (generally the yield point strength) by an empirically determined reduction factor only on the material side. It is a design method based on the theory of elasticity, because the allowable stress is generally a value divided back by a safety factor based on the yield strength.

Partial factors design procedure: In contrast to the conventional method (allowable stress method) where safety is ensured by multiplying the yield strength by a safety factor, the partial factors design procedure is a method to ensure reliability more reasonably by using multiple safety factors for both load and strength according to the uncertainty of material properties and loads. The limit state, the method of setting the coefficients, and the types of coefficients are determined independently based on the standards of each country, and there is no uniformity.

(2) Seismic Design for Structures

The Draft Code of Practice for the Design of Road Bridges and Culverts [7] (SATCC: Southern Africa Transport and. Communications Commission) is a standard for seismic design in Africa. In this report, the distribution of seismic acceleration by region and the formula for calculating inertia force in southern Africa are described, which can be used as a reference for design in the region. Materials on the seismic design of SATCC are provided in Figure 6.3.

The plastic design method is used when the bridge structure must be designed to withstand a large earthquake that is not safe using the normal elastic design method (allowable stress method) because the material does not stay within the elastic limit status which is the assumption of allowable stress method. However, there are some differences in the content and application of the plasticity design method between Japan and other developed countries, and the resulting structures may differ in size, amount of reinforcing steel, and its arrangement. Therefore, it is necessary to understand and agree in advance with the implementing agency on the differences in the design method to be used.

Maximum acceleration on surface

Table 3.16: Modified Mercalli classification

Modified Mercalli Intensity at epicentre (MM)	Maximum ground acceleration (A) at epicentre (g)
ii - iii	0.003
iv - v	0.01
vi	0.03
vii - viii	0.1
ix	0.3
x - xi	1.0

Map of Seismic strength

Formula of Seismic inertia force

3.10.3.1 Nominal Earthquake Forces

The equivalent horizontal static earthquake force F_x to be applied to the portion m_x of the bridge structure at a height h_x above the base or pile cap, can be represented by the following equation:

$$F_x = .S.A.\xi.I.f.m_x.h_x \left[\frac{\sum_{i=1}^{n} m_i}{\sum_{i=1}^{n} m_i\, h_i} \right]$$

where

A = horizontal ground acceleration (see Table 3.16)

S = the seismic response factor for the structure which shall be equal to $0.5\sqrt{T}$ but need not exceed 1.0

where

T = fundamental period of vibration of the structure in seconds in the direction under consideration as defined below. Except for structures that are vulnerable or complex, the fundamental period T may be determined according to the approximate method in Appendix D.

ξ = numerical factor that reflects the structural configuration and the mechanical properties of the material including damping, ductility and/or energy-absorptive capacity of the structure as given in Table 3.17.

I = importance factor of the structure which shall vary from 1.0 to 1.3 depending on the importance of the structure.

f = foundation factors which are given in Table 3.18. The product 1.3 need not exceed 1.0.

$\sum_{i=1}^{n} m_i$ = mass of the dead load plus the mass of the superimposed dead load of the structure or part of the structure being considered, conveniently subdivided into n portions.

h_x = the height above base level of the portion m_x of the structure being considered.

i = 0; refers to base level.

i = 1....n refers to the relative levels of the n portions of the structure considered.

Source : Draft Code of Practice for the Design of Road Bridges and Culverts[7], SATCC 1998

Figure 6.3 Example of Aseismic Design Standard (SATCC)

(3) Selection of Type of Retaining Wall

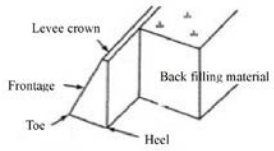
The selection of the structural type of the retaining wall shall be made after conducting the various investigations and studies described in Figure 6.5 below.

Table 6.5 Classification of Retaining Wall

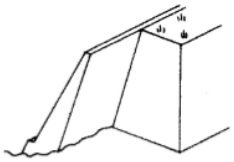
Type	Applicable wall height	Feature	Main points to note
Gravity retaining wall	5m or less	・ The cross-section shall resist earth pressure by its own weight and no tensile stress is generated in the cross-section of the wall.	・ Used where the foundation ground is good. ・ Often used as a small-scale retaining wall. ・ Not suitable for pile foundations.
Supported type of retaining wall	Around 10m or less	・ Leaning against the ground or cut soil, resist soil pressure with its own weight while.	・ The foundation ground should be solid. ・ Used in relatively stable ground or cut-earth areas.
Block masonry retaining wall	7m or less	・ Used to prevent minor collapses at the bottom of the slope and to protect the slope.	・ Used when soil pressure is small, such as in stable mountains or embankments. ・ Poor earthquake resistance.
Large block masonry retaining wall	8m or less	・ Used to prevent minor collapses at the bottom of the slope and to protect the slope. ・ If the connection between the blocks is made strong, it can be applied as a supported type of retaining wall.	・ In the case conforming with a supported type retaining wall, it is desirable to have a solid foundation. ・ Used in relatively stable ground or cut-earth areas.
Cantilever wall (inversed T-type, L-type, inversed L-type, buttressed type)	Around 3m – 10m	・ Resist earth pressure by the weight of the frame itself and the weight of the soil on the heel slab. ・ The vertical wall, heel slab and toe slab resist each load as a cantilever. ・ When the height of the retaining wall is high, the counterfort type is advantageous.	・ Used in the case of pile foundations. ・ Many precast products are available. ・ In the case of the counterfort type, it is difficult to construct the frame and to compact the backfill soil.
U-type retaining wall	-	・ There are two types of U-shaped retaining walls: Cut-in type U-shaped retaining wall and a filled-in type U-shaped retaining wall. ・ When the wall height is high in the cut-in type, struts may be installed between the side walls	・ In the case of cut-in type below the groundwater level, it is necessary to consider the effect of water pressure and stability against uplift.
Crib retaining wall	Around 15m or less	・ Precast concrete members are assembled in the shape of a well curb and filled with a filling material, and having good water permeability.	・ Design is in conformity to cantilever wall.
Reinforced earth wall	Around 3m – 18m	・ The soil is reinforced by the friction between the reinforcing material and the soil and the bearing pressure of the anchor plate to form the wall body, and there are various construction methods.	・ As the structure is flexible, it may be deformed to some extent. ・ As the scale of the wall may be larger than that of a concrete retaining wall, it is necessary to conduct a detailed ground survey. ・ The stability of a retaining wall depends on the mutual restraining effect of the embankment material, reinforcement material and wall surface, so it is necessary to use high-quality embankment materials and to ensure construction and construction management.

			・ In comparison with normal embankments, it is inferior in terms of repairability against deformation. ・ Appropriate drainage facilities should be provided since it is easily affected by water.
Retaining wall using light materials	-	・ A variety of construction methods are available depending on the type of lightweight material. ・ It may be possible to construct a retaining wall on soft or relatively unstable ground.	・ The strength degradation and increase in weight of lightweight materials may occur due to water infiltration. Therefore, adequate drainage facilities are necessary.

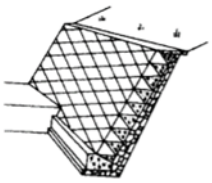
Source: Road Earthwork-retaining Wall Construction Guidelines[4]



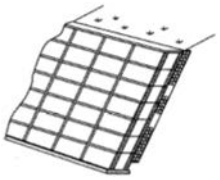
Gravity retaining wall



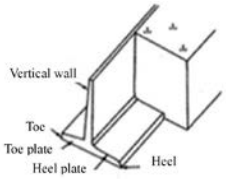
Supported type of retaining wall



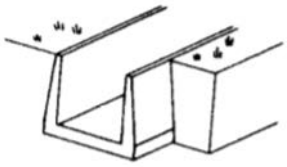
Block masonry retaining wall



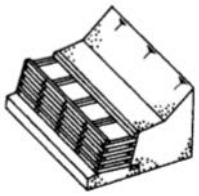
Large block masonry retaining wall



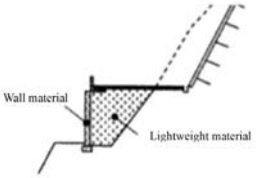
Cantilever wall



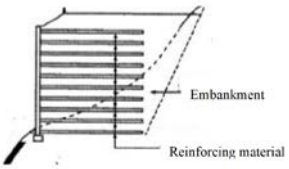
U-type retaining wall



Crib retaining wall



Retaining wall using light materials



Reinforced earth wall

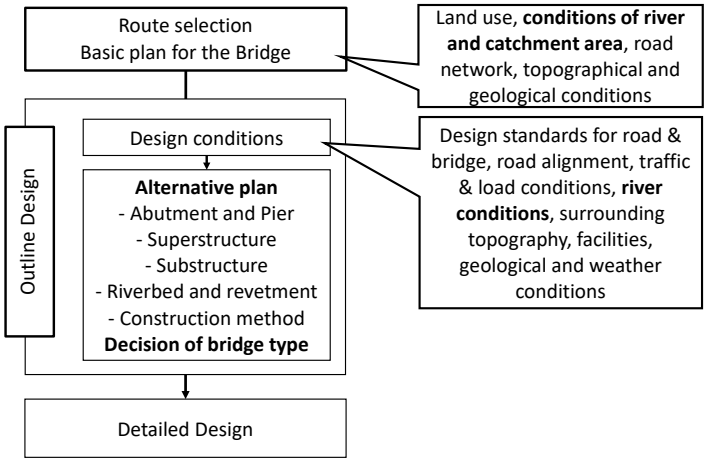
Source: JICA Study Team

Figure 6.4 Type of Retaining Wall

6.4 References for Road Bridges

(1) Flowchart for Bridge Design (Draft)

Figure 6.5 shows the flowchart of standard bridge design. In Japan, because rivers are managed and standards such as the "Structural Ordinance for River Management Facilities, etc." are in place, design conditions can be determined through consultation with river administrators. However, rivers in developing countries often have no fixed administrators nor specific standards relating to the facilities installed in the rivers. In many cases, natural rivers are targeted. Therefore, the design will be under different conditions than in Japan.



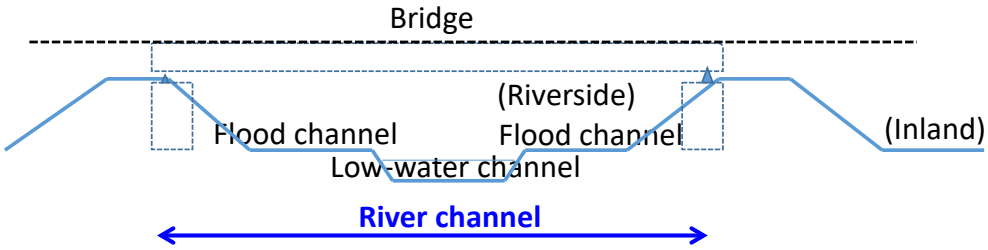
Source: JICA study group document, "Roads across natural rivers"[8]

Figure 6.5 Flowchart of Bridge Design (Draft)

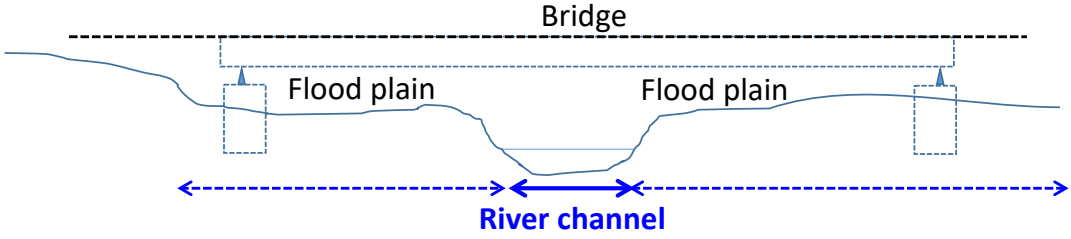
(2) What is Natural River?

A natural river is a river that has been left in its natural state and has not been subjected to human intervention (also called a pristine river). A "flood floor" exists in the channel of a controlled, artificial river, but not in a natural river.

Artificial Japanese rivers (double cross section)



Natural river (without embankment)



Source: JICA study group document, "Roads across natural rivers"[8]

Figure 6.6 Cross-section of a River and Name of Each Part

(3) Ground Conditions

Ground conditions refer to the condition of the excavated ground, the inclination and depth of the supporting ground, etc. and when designing a bridge, an appropriate foundation structure is selected for the superstructure and ground conditions. If plural types of foundation structure were considered appropriate from a technical viewpoint for the given condition, the decision should be made carefully in consideration of the time required for construction and economic efficiency. The foundation of the structure should be supported by a good supporting layer with sufficient thickness. The standard for a good supporting layer varies depending on the scale of the superstructure, foundation type, etc., but some examples are shown in Table 6.6.

Table 6.6 Target for Support Layer by Bodies Concerned

Organization and source of regulation	Superstructure, type of foundation	Standard for a good support layer		Remark
		Cohesive soil	Sandy soil	
Specifications for Highway Bridges [6], Japan Road Association,	Bridge, Direct caisson, etc.	N≧20 （qu*≧0.4 N/mm^2）	N≧30 (Generally the same in gravel layers.)	Even when the layer is considered to be a good support layer, if the layer is thin, or if there is a soft or compacted layer underneath, the influence of the layer should be considered.
Design Scheme Vol. 2, Japan Highway Public Corporation	Bridge, Spread foundation and pile	N≧20 (Within 5 m below the ground surface for spread foundations)	N≧30 (Within 5 m below the ground surface for spread foundations)	Even when the layer is considered to be a good support layer, if the layer is thin, or if there is a soft or compacted layer underneath, the influence of the layer should be considered.
Design Manual, Touhoku Regional Development Bureau	Bridge, Spread foundation	N≧20	N≧30 (The same in rock and gravel layers)	When the layer thickness is at least 5 m and no soft layers below.
	Bridge, Pile	20≦N≦30 (N>30 For solid layers)	30≦N≦50 (N>50 For solid layers)	When the layer thickness is at least 5 m and no soft layers below.

*qu: uniaxial compressive strength (kN/m^3){kgf/cm^2}
Source : Road survey and design know-how, Road Survey Design Study Group[9]

(4) River Condition (River Structure Ordinance[10])

In Japan, the "Government Ordinance for Structural Standard for River Administration Facilities[10]" establishes standards for the design of bridges, which are river structures, from the side of river administrators. Since these standards are based on Japanese experience and knowledge, they cannot be used uniformly as it is in developing countries, but many of the findings can be used as a reference.

- River Structure Ordinance[10] Article 64, Girder height

Margin height under the girder ≧ Margin height of embankment: The structural margin of an embankment to prevent floodwaters from overflowing the embankment even when the water level rises temporarily due to waves or driftwood. However, in a section where the ground level of the landside of the river adjacent to the embankment for flood protection is higher than the planned high-water level and where it is recognized that there is no problem in flood control depending on the topographical conditions, the margin height may be 0.6m or more even when the planned high water flow rate is 200m^3 /s or higher.

- River Structure Ordinance[10] Article 63, Span length

The following equation shall be satisfied, except in the case where it is recognized that where it is recognized that there is no problem in flood control depending on the topographical conditions such as the narrowing area between mountains.

$$L = 20 + 0.005Q \qquad \text{(Formula 6.1)}$$

L : Span length (m)
Q : Design flood discharge (m^3/s)

Note: Except in exceptional cases, "there have been no cases of river being blocked by obstacles at the bridge span is more than 20 meters in length".

(5) Selection of Bridge Type

When selecting a bridge type, the following requirements are comprehensively considered.

- If the external conditions (fit for the purpose of use) are satisfied.
- If the results of consultations with related organizations, etc. are satisfied.
- If it is structurally safe and sufficiently durable.
- If it is economical (including maintenance and management costs).
- If construction works are reliable and easy (construction quality can be easily ensured).
- If maintenance and management after putting in service for traffic are reliable and easy.
- If it is in harmony with the surrounding environment and landscape

■ Selection of Type of Superstructure

There are many types of superstructures depending on the combination of bridge type and form, and each has its own characteristics. Therefore, the characteristics of each type should be judged accurately, and an appropriate type should be selected in consideration of seven requirements described above, applicable span length shown in Table 6.7 and 6.8, and various conditions at the bridge site.

Table 6.7 Structure Type, Standard Applicable Span Length, and Standard Girder Height

(Concrete Bridge)

Bridge Type			Construction Method	Appliable Span (m) 20 40 60 80 100 150 200 250 300	Achievement Maximum Span(m)	Ratio of Span to Girder Height	Remarks
RC Bridge	Reinforced Concrete (Cast in Place)	Slab Bridge	Fixed Timbering Construction Method		10	1/10 ~ 1/15	
		Continuous Slab Bridge			20	1/11 ~ 1/16	
		Hollow Slab Bridge			15	1/14 ~ 1/17	
		Continuous Hollow Slab Bridge			20	1/15 ~ 1/18	
Simple Girder Bridge	Prestressed Concrete (Pre-cast)	Pre-tensioning Slab Bridge	Erection by Crane		(24)	1/14 ~ 1/24	JIS A5373
		Pre-tensioning T Girder Bridge	Erection by Crane		(24)	1/18 ~ 1/20	JIS A5373
		Post-tensioning Slab Bridge	Erection by Crane Erection by Erection Girder		(45)	1/23 ~ 1/26	
		Post-tensioning T Girder Bridge	Erection by Crane Erection by Erection Girder		(45)	1/13 ~ 1/18	
		Post-tensioning Bulb T Girder Bridge	Erection by Crane Erection by Erection Girder		49	1/14 ~ 1/19	
		Post-tensioning Composite Bridge	Erection by Crane Erection by Erection Girder		45	1/13 ~ 1/17	JIS A5373
		Post-tensioning U Composite Bridge	Erection by Crane Erection by Erection Girder		55	1/16 ~ 1/18	
	Prestressed Concrete (Cast in Place)	Hollow Slab Bridge	Fixed Timbering Construction Method		37	1/22	
		Box Girder Bridge	Fixed Timbering Construction Method		70	1/17 ~ 1/20	
Simple Rigid-Frame Bridge		Portal Rigid Frame Bridge	Fixed Timbering Construction Method		50	1/30	
Girder Connecting Bridge	Prestressed Concrete (Pre-cast)	Pre-tensioning Slab Bridge	Erection by Crane		(24)	1/14 ~ 1/24	
		Pre-tensioning T Girder Bridge	Erection by Crane		(24)	1/18 ~ 1/20	
		Post-tensioning Slab Bridge	Erection by Crane Erection by Erection Girder		(45)	1/23 ~ 1/26	
		Post-tensioning T Girder Bridge	Erection by Crane Erection by Erection Girder		(45)	1/13 ~ 1/18	
		Post-tensioning Bulb T Girder Bridge	Erection by Crane Erection by Erection Girder		47	1/14 ~ 1/19	
		Post-tensioning Composite Bridge	Erection by Crane Erection by Erection Girder		(45)	1/13 ~ 1/17	
		Post-tensioning U Composite Bridge	Erection by Crane Erection by Erection Girder		42	1/16 ~ 1/18	
Continuous Girder Bridge		Hollow Slab Bridge	Fixed Timbering Construction Method Moving Timbering Construction Method		49	1/22	
		Box Girder Bridge	Fixed Timbering Construction Method		77	1/17 ~ 1/20	
			Moving Timbering Construction Method		50	1/17 ~ 1/20	
			Incremental Launching Method		66	1/15 ~ 1/18	
			Overhang Erection Method		170	1/15 ~ 1/35 Span Centre	
		Slab Girder Bridge	Fixed Timbering Construction Method Moving Timbering Construction Method		39	1/15 ~ 1/17	
Rigid Frame Bridge	T-Shape Rigid Frame	Hollow Slab Bridge	Fixed Timbering Construction Method		30	1/20	
		Box Girder Bridge	Fixed Timbering Construction Method		48	1/18	
			Overhang Erection Method		121	1/10 ~ 1/30 Span Centre	
	Continuous Rigid Frame	Hollow Slab Bridge	Fixed Timbering Construction Method		30	1/22	
		Box Girder Bridge	Fixed Timbering Construction Method		71	1/17 ~ 1/20	
			Overhang Erection Method		175	1/15 ~ 1/35 Span Centre	
Cable Stayed Bridge		Hollow Slab Box Girder Edge Girder	Fixed Timbering Construction Method		96	1/40 ~ 1/100	
			Overhang Erection Method		261	1/40 ~ 1/100	
Extra-Doused Bridge		Box Girder	Fixed Timbering Construction Method		85	1/25 ~ 1/30	
			Overhang Erection Method		220 [275]	1/30 ~ 1/50 Span Centre	[] indicates composite structure
Arch Bridge		Hollow Slab Slab Girder Box Girder	Fixed Timbering Construction Method		150	1/4 ~ 1/8 Span - Rise Ratio*	
			Overhang Erection Method		265		
			Lowering Erection Method		135		
			Concrete Lapping Method with Pre-Erected Composite Arch (CLCA Method) etc		125		
Composite Structure		Steel Corrugated Web Box Girder Bridge	Fixed Timbering Construction Method		115	1/17 ~ 1/20	
			Incremental Launching Method		56	1/15	
			Overhang Erection Method		150	1/15 ~ 1/35 Span Center	
		Steel Truss Web Box Girder Bridge	Fixed Timbering Construction Method		60	1/12 ~ 1/18	
			Overhang Erection Method		119	1/10 ~ 1/30 Span Center	

*Span - Rise Ratio = H/L; H=Rise, H=Span

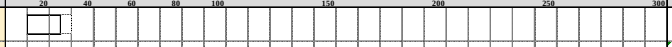
Shows generally applicable span length

Shows considerable span length

Note: The numbers in parentheses indicate the maximum span of the standard design.

Source: Design and Construction Manual (Draft) [Road Bridges][11]

Table 6.8 Structure Type, Standard Applicable Span Length, and Standard Girder Height (Steel Bridge)

Bridge Type		Appliable Span (m)	Achievement Maximum Span(m)	Ratio of Span to Girder Height	Remarks
Plate Girder Bridge	Simple Composite H Girder Bridge		25	1/14 ～ 1/27	
	Simple I Girder Bridge (Regular)		(44)	1/15 ～ 1/20	
	Simple I Girder Bridge (Small number of main girders)		60		
	Simple Composite I Girder Bridge		60	1/16 ～ 1/21	
	Simple Box Girder Bridge		70	1/18 ～ 1/25	
	Simple Composite Box Girder Bridge		75	1/19 ～ 1/26	
	Continuous I Girder Bridge (Regular)		65	1/16 ～ 1/22	
	Continuous I Girder Bridge (Small number of main girders)		91	1/15 ～ 1/20	
	Continuous Box Girder Bridge		190	1/20 ～ 1/30	
	Box Girder of Open Section				
	Box Girder of Small Width				
	Plate Girder Bridge with Steel Deck		80		
	Box Girder Bridge with Steel Deck		300	1/22 ～ 1/28	
Pie-Shape Rigid Frame Bridge			124		
Rigid Frame Bridge (Rigid-Connecting Structure of Superstructure and Pier)			263		
Truss Bridge	Simple Truss Bridge		227	1/7 ～ 1/9	
	Continuous Truss Bridge		548	1/8 ～ 1/10	
	Rationalized Truss Bridge				
Arch Bridge	Langer Girder bridge		150	1/6 ～ 1/7 Span - Rise Ratio	
	Deck Langer Girder Bridge		140	1/6.6 ～ 1/6.8 Span - Rise Ratio	
	Lohse Girder Bridge		329	1/6.0 ～ 1/7.3 Span - Rise Ratio	
	Deck Lohse Girder Bridge		330	1/6.0 ～ 1/7.3 Span - Rise Ratio	
	Langer Truss Bridge		518	1/6.8 ～ 1/6.9 Span - Rise Ratio	
	Trussed Langer Girder Bridge		175	1/6.8 ～ 1/6.9 Span - Rise Ratio	
	Nielsen System Bridge		550	1/6.5 Span - Rise Ratio	
	Arch Bridge		518	1/5.3 ～ 1/6.3 Span - Rise Ratio	
Cable Stayed Bridge			890	1/4.7	
Suspension Bridge			1991	1/8.4	

Note) () shows maximum span of standard design

Shows generally applicable span length

Shows considerable span length

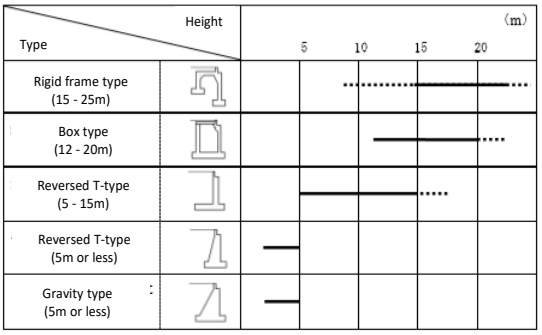
Note: The numbers in parentheses indicate the maximum span of the standard design.

Source: Design and Construction Manual (Draft) [Road Bridges][11]

■ Selection of Type of Substructure

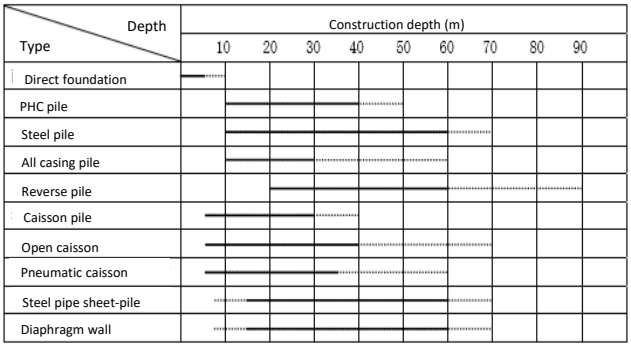
The substructure type shall be suitable for various conditions such as superstructure type, load, topography, geology, and environment, and shall be easy to construct and structurally stable. Note that this table does not apply for bridge in the sea.

Table 6.9 Type of Substructures



The solid line indicates the range with the most actual use.

Type of Abutment and Height



The solid line indicates the range with the most actual use.

Type of Foundation and Construction Depth

Source: Design and Construction Manual (Draft) [Road Bridges][11]

6.5 Reference on Road Pavement

(1) Subgrade Evaluation

It should be noted that the subgrade strength test method (CBR (California Bearing Ratio) test, etc.), sampling method, and subgrade strength evaluation method differ depending on the standard accepted. Table 6.10 shows typical subgrade evaluation methods, which can be roughly divided into five methods: soil classification method, CBR method, DCP (Dynamic Cone Penetration) method, plate loading test, and triaxial test. Of these, the CBR method and soil classification method, which are easy to evaluate, are the mainstream in the world. The test results of subgrade strength vary depending on the section (location), sampling time, and so on. Therefore, pay attention to overestimation of subgrade CBR, such as considering the decrease in the rainy season.

Table 6.10 Subgrade Evaluation Method

Name	Method/Case study/Advantage/Disadvantage		Remarks
Soil classification	Method	A method of classifying and evaluating subgrade soil according to particle size, liquid limit (LL), plastic limit (PL), etc.	The ORN31[12] and SATCC standards also describe CBR evaluation based on soil classification and groundwater level.
	Case	AASHTO Soil Number Method, etc.	
	Advantage	No special equipment is required, the test is easy and the results are easy to understand.	
	Disadvantage	It is not a method to directly evaluate the bearing capacity of subgrade.	
CBR	Method	A method of evaluating subgrade soil by a laboratory test. There are on-site CBR tests, but few countries are currently conducting them.	There are subdivisions due to differences in water content, in-water and in-air.
	Case	Pavement Design Handbook (Japan) and so on (Numerous adoptions)	
	Advantage	The engineering properties of subgrade can be evaluated with a relatively simple test.	
	Disadvantage	It is not possible to evaluate the undisturbed subgrade soil.	
DCP	Method	DCP (Dynamic Cone Penetration) is a method developed in South Africa. A method of measuring the penetration resistance of soil by penetrating a cone into the base course or subgrade.	Analysis software that considers soil classification, etc. has been released by TRC (Transport Research Laboratory) (UK) and CSIR (Council for Scientific and Industrial Research) (South Africa).
	Case	ORN (Overseas Road Note), SATCC (Southern Africa Transport and. Communications Commission), etc.	
	Advantage	It is a simple measuring device and can collect a large amount of data at low cost. In addition, many conversion formulas for CBR have been proposed.	
	Disadvantage	Evaluation of soil classification and changes in soil properties during the rainy / dry season is an issue.	
Plate loading	Method	A method of directly determining the bearing capacity of the subgrade by conducting a plate loading test at the current position.	The K30 value from the flat plate loading test can be converted to CBR by the conversion formula*.
	Case	In the Pavement Design Handbook (Japan), it is a method of designing the base course thickness based on the bearing capacity coefficient of the subgrade for concrete pavement (also described as the CBR method).	
	Advantage	The bearing capacity of the subgrade is directly evaluated	
	Disadvantage	This test has an unrealistic aspect because it is a test on the actual subgrade surface.	

Triaxial tests	Method	Method of compacting the subgrade and evaluating it by a triaxial compression test (often the lateral pressure is constant).	The resilient modulus (Mr) of the subgrade can be measured. Many conversion formulas to CBR ** have been proposed.
	Case	Beam stabilizer method in California, etc.	
	Advantage	The mechanical properties of the subgrade are evaluated.	
	Disadvantage	Test is a bit cumbersome and generally require skill.	

*Formula by UESHITA: Bearing capacity coefficient K30 = 0.555 x CBR + 2.2 (K30 = 20kg / cm3 or more is desirable on forest roads.)
**Mr (psi) = 1500 x CBR, Mr (MPa) = 10 x CBR, Mr: Resilient modulus, CBR: California Bearing Ratio (%)
Source: Created by JICA Study Team with reference to the latest asphalt pavement technology[13]

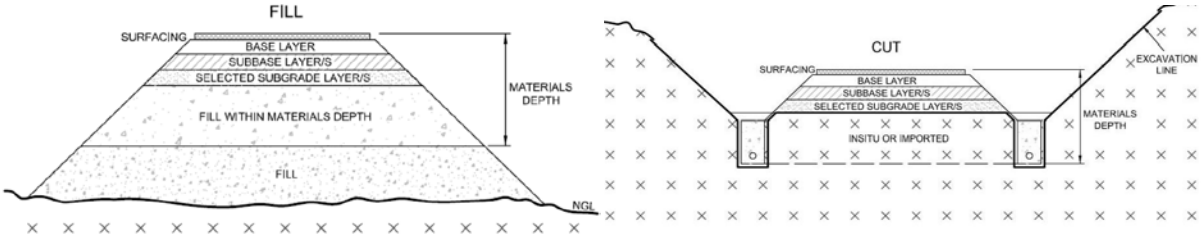
Table 6.11 Definition of Subgrade

Item	Pavement Design Handbook [14]	AASHTO Guide 1993[15]	ORN 31[12]	SAPEM* (South Africa) [16]
Definition of subgrade	Thickness provisions: Part of the ground that provides support to the pavement structure (generally regarded to be 1m below the pavement). Definition of subgrade: This unites with the pavement to support the traffic load and uniformly disperse the said load through the road body.	Thickness provisions: No mention. Generally speaking, the top 150mm (6 inches) is regarded as the subgrade. Definition of subgrade: The part over which the pavement structure or shoulder is constructed. Definitions of adjustment subgrade soil are as follows: the layer of compacted subgrade soil, or selected soil that has been compacted to a specific density.	Thickness provisions: No mention. (In the case of existing ground, it is stipulated that the top 250mm be re-compacted and regarded as subgrade.)	Settings are given according to road classification Material Depth* A: 1000 – 1200mm B: 800 – 1000mm C: 800mm D: 700mm
Evaluation of CBR	If the subgrade has a soft CBR of less than 3, stabilization or replacement with good quality soil is applied.	There is no description about specific numerical standards.	If the subgrade has a soft CBR of less than 2, stabilization or replacement with good quality soil is applied.	If the subgrade has a soft CBR of less than 2, stabilization or replacement with good quality soil is applied.

* SAPEM[16]: South African Pavement Engineering Manual
Source: JICA Study Team

☞ Material Depth

South Africa's "SEPEM (South African Pavement Engineering Manual)[16], Chapter 9: Materials Utility and Design" adopts the standard named "Material Depth", which specifies control the effect of moisture is necessary in the range of 700 to 1200 cm from the road surface (depending on the importance of the road).



Source: SAPEMl[16], Chapter 9: Materials Utilization and Design

Figure 6.7 Material Depth

(2) Evaluation of Asphalt Mixture

In addition to flow resistance, indicators of the properties of the asphalt mixture include water resistance (water tightness), deflection followability, and crack resistance. In general, they may show a conflictive relationship with fluid resistance, so the required performance is determined in a well-balanced manner in consideration of natural conditions and road conditions. "DS (Dynamic Stability)" is used as a performance index of fluidity resistance. As the test method, the wheel tracking test, which has a proven track record in Japan, is used. This test method reproduces the phenomenon whereby viscous flow is generated by repeated wheel load under high temperature conditions on the actual pavement surface, and Japan has abundant past records and accumulated data. In addition, there are many tests for properties other than rutting resistance as shown for the evaluation method of the asphalt mixture.

- Water immersion WT (Wheel Tracking) test: A test to confirm peeling resistance under water immersion conditions
- Bending test: A test to confirm the flexibility at low temperature
- Splitting test: A test to confirm the cracking properties of the mixture

In addition, there are many other tests on the evaluation method of asphalt mixture as shown in Table 6.12.

Table 6.12 Another Evaluation Test for Asphalt Mixture (road surface) (reference)

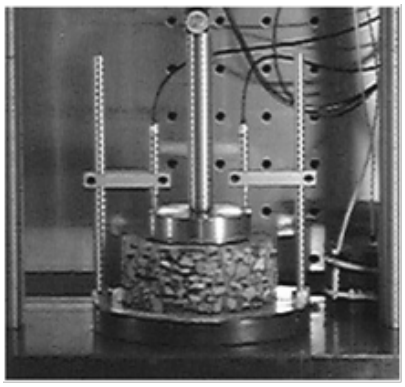
Performance	Test	Application
Plastic deformation resistance	Wheel Trucking Test Dynamic triaxial compression test Asphalt Pavement Analyzer* Superpave Shear Tester* Creep test (repeated indirect tensile test)	Wheel type, standard in Japan, dynamic stability Dynamic modulus, static creep, residual deformation Wheel type, rutting depth Shear resistance assessment, static, dynamic, repeatable Creep characteristics at low temperatures
Crack resistance	Bending test Bending fatigue test Direct tensile test	Fracture strain under low temperature conditions Number of breaks due to repeated bending action Strain at breakage at room temperature
Abrasion resistance	Labelling test	Evaluation for tire chains
Scattering resistance of aggregate	Cantabro test Torsional resistance test	Evaluation for impact load Evaluation of surface shearing action by tires
Separation resistance	Wheel tracking test in water Marshall stability test in water	Evaluation of moisture and repetitive load Evaluation for moisture
Others	Splitting test (indirect tensile test) Uniaxial compression test	Evaluation for freezing and thawing, deterioration and aging, Resilient Modulus, Creep, etc.

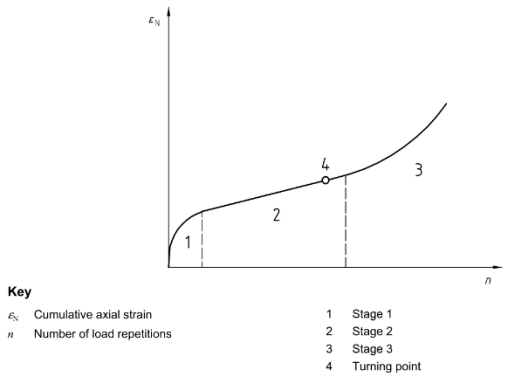
* Tests conducted in the United States

Source: Pavement Engineering Library 7, Basics of pavement engineering[17]

ORN (19[18], 31[12]) describes the evaluation method by the Refusal Density method. The Refusal Density method is a method in which the number of hammer blows is increased (about 500 times) from Marshall test based on the evaluation that the number of hammer blows (75 times) in the Marshall test does not represent the final state of compaction by the wheel after in-service. Therefore, it is proposed to adopt the Refusal Density method in the case of severe load / running conditions such as high temperature, large axle load action, and slow running of heavy vehicles. Besides, ORN[12][18] also proposes the application of Superpave when the cumulative axle load exceeds 1 million ESAL, as well as the implementation of dynamic creep test and elasticity test when the cumulative axle load exceeds 5 million ESAL.

The dynamic creep test is a test method in which a load is repeatedly applied in order to understand the creep characteristics of hot mix asphalt. There are two types of namely uniaxial loading (A) and triaxial loading (B), and the test method is specified in BS (British Standard) EN 12697-25 (Bituminous mixtures - Test methods for hot mix asphalt - Part 25: Cyclic compression test). Creep characteristics are expressed by the number of repeated loads and cumulative axial strain, and are said to have a higher correlation with rutting than the results of static creep tests.





Source: BS EN 12697-25: 2005

Figure 6.8 Example of Dynamic Creep Test Equipment (Single Axis) and Creep Curve

(3) Pavement Design Standard

Table 6.13 shows the pavement design standards used in the countries surveyed. For Ethiopia and Tanzania to which the specification design method is applied, the specifications of the materials to be used are specified, so it is necessary to confirm that the specified materials can be obtained by material surveys.

Table 6.13 Pavement Design Standard used in the Countries Surveyed

Country	Japan	Ethiopia	Ghana	Tanzania
Standard	Pavement Design Handbook[14]	Pavement Design Manual 2012[19]	Pavement Design Manual 1998[20]	Pavement and Material Design Manual 1999[21]
Referenced Standards	-	ORN3[22] and 31[12] AASHTO Guide 1993[15]	AASHTO Guide 1993[15]	AUSTROADS (1992): Pavement Design BOTSWANA ROAD DESIGN MANUAL (1994)[23] TECHNICAL RECOMMENDATION FOR HIGHWAYS (TRH): South Africa
Applicable limit (Total axle load)	No limitation	30×10^6	No limitation	50×10^6
Deign method	Performance Specification Design Method	Specification design method	Empirical design method (Adopts American AASHTO design method)	Specification design method
Remarks	Any design method may be used as long as the required performance is satisfied. For reference, the empirical design method (TA method) and the theoretical design method (multilayer elasticity theory) are described.	The standard has been revised as the 2011 edition in order to respond to changes in social conditions, progress in road development, increase in traffic volume, and evolution of pavement technology, however, it has not been announced yet.	Standards are scheduled to be revised to support new pavement materials (modified asphalt, etc.) and methods for mixing/evaluation test, but so far they have not been supported.	In order to ensure flow resistance, Interim Design Guidelines for HMA-Final November 2018[24], which describes new mix designs, evaluations, etc., were created instead of pavement design.

Source: JICA Study Team

Table 6.14 also describes the difference in the design concept among "AASHTO Guide 1993[15]", which is the most widely used standard in the world, and "ORN 31[12]", which was a general standard in the African region. Many countries in Africa follow the design philosophy of "ORN 31[12]" because there are no other standards that reflect the reality of tropical and subtropical countries and their ease of use is widespread. Currently, the application limit of "ORN 31[12]" is 30×10^6, which is less than the lower application limit of the pavement design standards of each country, so it is rarely used for pavement design of roads in urban areas with heavy traffic. However, when making a thin layer (5 cm) of asphalt concrete on a rural highway or surface layer, "ORN 31[12]" may be the applicable standard.

Table 6.14 Comparison of AASHTO Guide 1993[15] and ORN 31[12]

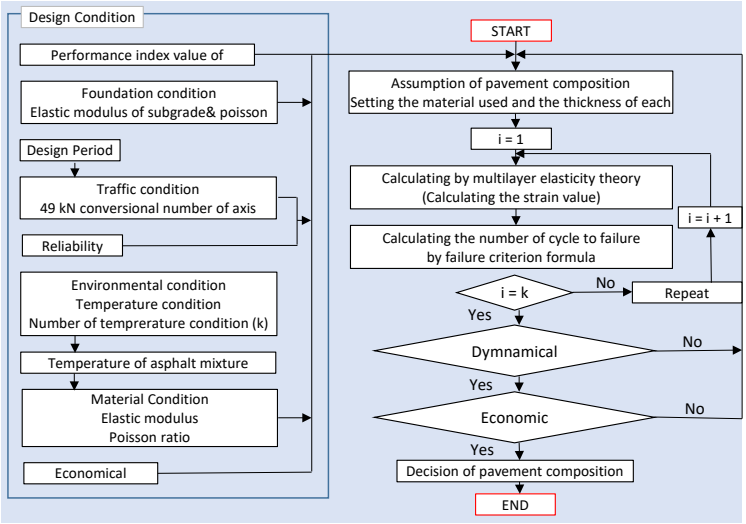
Standard	AASHTO Guide 1993[15]	ORN 31[12]
Country	USA	UK
Publish	1993	1962 (First Edition), 1966, 1977 (Revision)
Outline	The AASHTO pavement design method is a method created by making full use of statistical analysis technology based on the results of the AASHTO road test conducted in the 1950s. From the observed fracture morphology, the relationship between the pavement structure and the traffic load was clarified. The design method based on the experience of this site is called the empirical design method, and the AASHTO pavement design method is a typical example.	Standards created by the Transport Research Laboratory (TRRL: now Transport Research Laboratory) in the United Kingdom. It has been used in many British territories so far, and ORN 29 to 31 is the basis for road design (including structure and pavement).
Design Method	Empirical Design Method	Specification Design Method
Limitation (ESAL)	No limitation (The upper limit of the chart is 50×10^6)	30×10^6
Feature	(1) From the empirical information obtained in the AASHTO road test, a basic formula related to "reliability", "subgrade bearing capacity", and "pavement composition" for "traffic volume" and "design and serviceability" has been proposed. (2) The composition of the pavement is determined so that the sum of the thickness obtained for each layer and the product of the layer coefficient and the drainage coefficient satisfies the required structural index.	(1) Set traffic volume, equivalent axle load, and design period (2) Evaluation of the bearing capacity of the target ground that will be the subgrade. (3) Select the pavement composition from the catalog based on the conditions (1) and (2) and the materials used.
Loading Support	The surface asphalt is a powerful support layer, and the support capacity is shared according to the strength of each layer.	The asphalt layer on the surface has a sealing function such as rainwater intrusion prevention and dustproof, and the mainstream load is supported below the base course/subbase course (the asphalt concrete can be selected as the main load support).
Load	18kip (8.2tf) (ESAL) ESAL : Equivalent Standard Axle Load	8.2tf (ESAL) ESAL : Equivalent Standard Axle Load
Composition	Surface course, binder course, base/ sub-base course	Surface course, binder course, base/sub-base course
Basic Formula	The basic design formula is derived from the AASHTO road test, and each pavement layer thickness is determined from the formula.	All designs are cataloged and selected from axle load class, subgrade strength, and materials used.
Design Flow	First, the surface thickness is determined from the traffic load and the elastic modulus of the base, and then the base is determined from the remaining load after subtracting the force in charge of the surface layer and the elastic modulus of the sub-base. Each layer thickness is uniquely determined.	Selected from a catalog (pavement composition chart) derived from experience based on traffic volume and subgrade bearing capacity (CBR value).
Subgrade	Subgrade thickness: N/A Definition: The upper surface of the road body on which the pavement structure or shoulder is constructed (the subgrade and the subgrade soil are distinguished).	Subgrade thickness: N/A When the bearing capacity of the subgrade is 2 to 7%, a Capping Layer (material with CBR ≥ 15%) is provided on the upper surface of the subgrade. (Replace 2% or less with good quality material)
Subgrade Evaluation	The conventional CBR evaluation has shifted to the evaluation by Resilient Modulus (MR), which considers the change in water content in each season. MR is obtained by a laboratory test, etc.	Supportability evaluation is CBR. The design CBR uses 90% tile values from the survey results. It is classified by S1-S6 (CBR2-30).

Drainage	Drainage is important and requires consideration of surface drainage, underground drainage and structural drainage. There is a background that frost heaving is fatal and requires special attention.	Since it is impossible to prevent rainwater from entering the base, it is clearly stated that it is important to drain the water in the base to the slope as soon as possible.
Remarks	In 2004, as a Mechanical-Empirical Pavement Design Guide, design method is shifted from empirical design method to mechanical design method.	Compared to the AASHTO design, it is necessary to pay attention to the drainage of subgrade and base course/subbase course. For the evaluation of the mixture, refusal density (which emphasizes the interlocking of aggregates) is proposed as a measure against rutting.

Source: JICA Study Team

(4) Outline of Theoretical Design Method

The empirical design method is highly reliable because it is based on a huge amount of test data on actual roads, and it may be possible to design if the basic conditions such as the bearing capacity of the subgrade and the traffic conditions such as traffic volume are determined. So far, most roads have been designed by this method. However, it also has the problem that it is difficult to apply to new materials and structures that have not been used in the test. The theoretical design method is a method that dynamically analyzes the behavior of the pavement due to traffic load and determines the pavement cross section so that structural destruction of the pavement does not occur within the design period. , There is a method by the finite element method.



Source: Structural design of asphalt and concrete pavements, Toa Road Industrial Co., Ltd.

Figure 6.9 Flow of Theoretical Design Method

In recent years, the needs for pavement have diversified, and designs that meet individual road conditions are required. In the pavement field as well, the conversion from specification regulations to performance-based design regulations were attempted, and the 2001 "Technical Standards for Pavement Structure" was notified to road managers. The shift to performance regulation has made it possible to select a variety of materials and structures, making it easier to meet diverse needs such as cost reduction and utilization of other industrial materials. On the other hand, since it is difficult for empirical design methods to deal with such new materials and structures, the need for theoretical design methods is increasing. In addition, the advantage of the theoretical design method is that it can explain the influence of the subgrade, the influence of the thickness of each layer, LCC (Life Cycle Cost), etc. well. Table 6.15 shows an example of structural verification using the theoretical design method.

Table 6.15 Structural Verification based on the Theoretical Design Method

Pavement Composition	Materials	Equivalent conversion coefficient (T_A)	Weather condition (Tokyo) A : Japan Design #1		Weather condition (South-eastaern Asia) B: Japan Design #1		C: Japan Design #2		D: Test Design	
			Thickness (cm)	T_A	Thickness (cm)	T_A	Thickness (cm)	T_A	Thickness (cm)	T_A
Surface	Hot mix asphalt	1.00	5	5	5	5	5	5	7	7
As interlayer	Hot mix asphalt	1.00	0	0	0	0	5	5		
As base	Hot mix asphalt	1.00	5	5	5	5	5	5	0	0
Base	As stabilized	0.80	9	7.2	9	7.2	0	0	0	0
	Granular	0.35	0	0	0	0	12	4.2	27	9.45
Subbase	Crusher-run	0.25	30	7.5	30	7.5	20	5	30	7.5
	Cemented	0.25	0	0	0	0	0	0	0	0
Total			49	24.70	49	24.70	47	24.20	64	23.95
Pavement Composition			HMA 10cm / As stabilized base 9cm / Granular subbase 30cm / Existing ground CBR 16%		HMA 10cm / As stabilized base 9cm / Granular subbase 30cm / Existing ground CBR 16%		HMA 15cm / Granular base 12cm / Granular subbase 20cm / Existing ground CBR 16%		HMA 7cm / Granular base 27cm / Granular subbase 30cm / Existing ground CBR 16%	
Examination point			Centre of Dual Tyre	Beneath a Tyre	Centre of Dual Tyre	Beneath a Tyre	Centre of Dual Tyre	Beneath a Tyre	Centre of Dual Tyre	Beneath a Tyre
Tensile Strain εt As undersurface			1.18.E-04	1.13.E-04	1.71.E-04	1.64.E-04	1.69.E-04	1.67.E-04	2.39.E-04	2.66.E-04
Compressive Strain εz top of subgrade			1.78.E-04	1.66.E-04	2.24.E-04	2.07.E-04	2.55.E-04	2.34.E-04	2.61.E-04	2.40.E-04
Nfad			23.9E+06	28.6E+06	21.2E+06	25.2E+06	29.2E+06	30.9E+06	3.0E+06	1.9E+06
Nfsd			148.4E+06	194.5E+06	70.0E+06	94.3E+06	43.7E+06	60.2E+06	40.0E+06	54.3E+06
Deflection Uz (cm) Top of As surface			2.49.E-02	2.48.E-02	2.89.E-02	2.92.E-02	3.06.E-02	3.06.E-02	4.29.E-02	4.42.E-02
Deflection Uz (cm) Top of subgrade			1.77.E-02	1.72.E-02	1.96.E-02	1.90.E-02	2.07.E-02	2.00.E-02	2.25.E-02	2.18.E-02
Unit cost: yen/m2			-		5831		5060		4044	
Examination conditions			Existing ground CBR=16% ESWL=16.5×10＾6 Required T_A=24 (reliability 90%) As elastic modulus E=7500 x 10^0.368(20-T/20) (T=pavement temperature) Source: Temperature distribution and design strain of asphalt mixture layer[6] As layer VFA=70% As stabilized layer VFA=56%							
Reults Japan Design#1 (Weather condition: south-eastern ais)=1.0	Nfad		1.13	1.13	1.00	1.00	1.38	1.23	0.14	0.07
	Nfsd		2.12	2.06	1.00	1.00	0.62	0.64	0.57	0.58
	Uz (cm) As layer top		0.86	0.85	1.00	1.00	1.06	1.05	1.49	1.52
	Uz (cm) Subgrade top		0.90	0.91	1.00	1.00	1.05	1.05	1.15	1.15

Source: JICA Study Team

■ Examination results

1) Since the allowable number of wheels for the asphalt mixture layer and the subgrade depends on the temperature conditions and the materials used for each layer, it is necessary to check the temperature conditions of the target country and the materials used in order to confirm the balance of each.

2) It is mainly the thickness of the asphalt mixture layer that controls the acceptable number of wheels of the asphalt mixture layer. This is because the correction coefficient (Ka) of the crack propagation speed has a large influence. Thickening the asphalt mixture layer contributes to an increase in life. On the other hand, it leads to an increase in cost. In addition, if it is too thick, the acceptable number of wheels on the subgrade will come before the acceptable number of wheels on the asphalt layer is reached, so it is necessary to adopt a pavement composition that takes into consideration the balance of maintenance (overlay, etc.).

3) This case is a verification against fatigue damage. In fact, thick asphalt mixture layers facilitate the development of rutting. This needs to be examined in the road surface design described separately.

Of these, verification of the pavement structure in consideration of the maintenance of 2) is very important, and a well-balanced pavement structure can be planned by verifying the service life of each layer of pavement. Although it is an example of Japan, the design procedure of the Metropolitan Expressway sets the target value of the replacement cycle for each of the surface

course, binder course, and base course/subbase course of the pavement. (Surface layer: 15 years, surface / base layer: 30 years, subgrade: 60 years)

(5) Comparison of Marshall Method and Superpave Method

Table 6.16 shows a comparison of the mix test results by the Marshall method (hereinafter referred to as MS method) and the Superpave method (hereinafter referred to as SP method) using coarse aggregates with the same maximum particle size.

Table 6.16 Comparison of Marshall Method and Superpave Method

Tendency / Parameter	Small (little) ⇔ Large (much)	General knowledge on fluidity resistance	General knowledge on durability
Appropriate asphalt volume	MS SP	Smaller is better	More is better
Void ratio	MS SP	Larger is better	Smaller is better
Aggregates void ratio	SP MS	Larger is better	Larger is better
Saturation degree	SP MS	Smaller is better	Larger is better
Final void ratio	Same level	Larger is better	-
DS	MS SP	-	-

Note: Durability includes water-tightness, wear resistance, degradation resistance, crack resistance, etc.
Source: JICA Study Team

The results regarding the optimum asphalt amount shown in Table 6.16 from the general knowledge in Japan. In addition, in the SP method, DS was improved when mixed sand (natural sand: manufactured sand = 50: 50) was used, rather than when only crushed sand was used. This is also different from general knowledge in Japan. The SP method, which is designed focusing on the aggregate skeleton, has possibility to create a mixture with good workability and excellent flow resistance while ensuring durability such as suppression of aging deterioration and crack resistance. In the mixing test by the SP method, standards are set for the materials used (especially fine aggregates), and specimens are prepared by compaction by kneading instead of compaction by blowing, and air void is specified in each stage (during construction, in service and after the completion of design period). As a result, there is a possibility that a mixing design that emphasizes flow resistance can be performed without impairing durability because the actual pavement condition is highly reproducible, and the combination and particle size of the employed materials can be selected to form a good aggregate skeleton. In addition, since the SP method defined by a constant value of 4.0% air void in the design number of turns (Ndes) , the OAC is defined by a constant value. Unlike the Marshall method, there is no selection range (common range) when determining OAC, and it is highly possible that the same result can be obtained regardless of the experience and subjectivity of the designer when applying SP method. However, it is assumed that a good aggregate skeleton cannot be obtained depending on the materials, and all required performances cannot be satisfied by either the MS method or the SP method. In that case, it is possible to consider the most rational mixture in consideration of the priority index. Table 6.17 shows an example of the priority of each index.

Table 6.17 Example of Priority of Indices

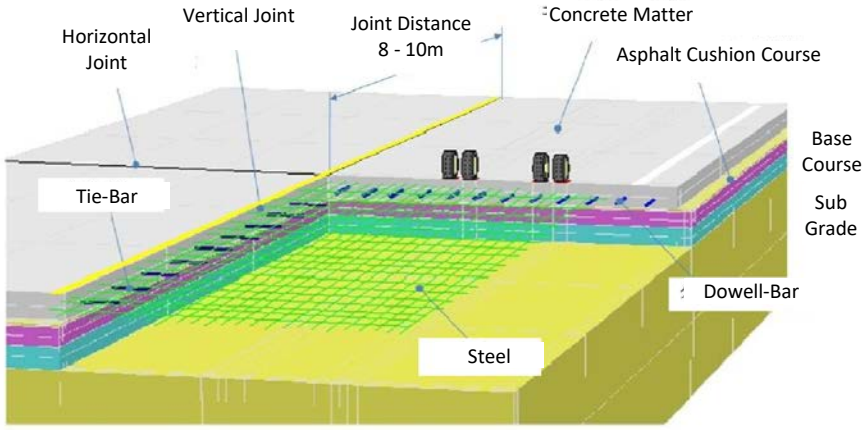
Priority / Index	High ⇔ Middle ⇔ Low
DS	✓
Void ratio	✓
Aggregates void ratio	✓
Saturation degree	✓

Source: JICA Study Team

As an outlook in near future, it is expected that the SP method will be specified in the JICA project when required by the design and construction management standards of the counterpart country or by the implementing agency. Japanese engineers should keep that in mind.

(6) Design of Concrete Pavement

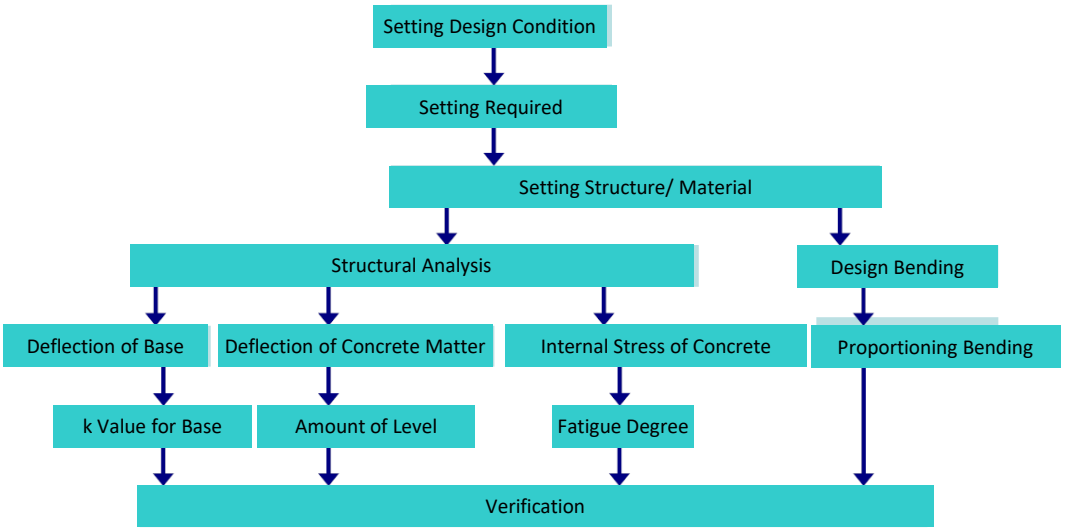
The structure of a typical concrete pavement is shown in Figure 6.10. Concrete pavement generally consists of concrete slabs and base course and is built on the subgrade. An asphalt intermediate layer may be provided at the top of the base course. Depending on the value of the set performance index, a surface layer may be provided on the concrete slab for the purpose of holding it. The role of the concrete slab is to support the traffic load and evenly distribute the load to base course and consequently to subbase.



Source: Concrete Pavement Guidebook 2016[25]

Figure 6.10 Structural Example of Concrete Pavement

The concrete slab forms the road surface and supports the action of external factors such as traffic wheel load mainly by the bending resistance of the concrete slab. The concept that the bending fatigue fracture is the limit state of concrete pavement is the basis when designing mechanically. In concrete pavement, the purpose of the design is to warrant the design life against repeated external loads.



Source: Concrete pavement working group, Japan Society of Civil Engineers

Figure 6.11 Design Flow for the Concrete Pavement

Table 6.18 Design Conditions for the Concrete Pavement

Performance	Evaluation Index
Load support performance	Subgrade / base support capacity → Concrete slab deflection Fatigue cracks on concrete slab → Fatigue
Driving Stability	Uneven→ amount of unevenness
Driving Comfortability	Uneven→ amount of unevenness
Limit of each performance	• Co version design deflection limit wdl: 2.5mm • Design bending fatigue limit FDdl: 1.0 • Limit value of design step amount (safety) FTSdl: 15mm • Design limit value of uneven (comfort) FTdl: 10mm

Source: JICA Study Team

Base K value: Used as an index showing the magnitude of bearing capacity on the subgrade surface or the base course surface, and the bearing capacity coefficient (K value) indicates resistance to deformation of the subgrade or the base course due to traffic load. It is also called a coefficient subgrade reaction. Obtained by flat plate loading test.

Fatigue analysis: On concrete pavement, load stress and temperature stress from the vehicle are repeatedly applied at the same time many times during the service period. Daytime tensile temperature stress is generated on the bottom surface of the concrete slab, and load stress is applied each time when a car passes through it. Even if these stresses are small compared to the strength of concrete, after a number of repetitions, they will break and cracks will occur in the concrete slab. This is called fatigue cracking. The calculated load stress and temperature stress are applied to the fatigue curve (curve showing the relationship between load and fatigue life) to predict how many cars the pavement will crack (lifetime). Such a prediction is called fatigue analysis.

6.6 Reference on Drainage Design

(1) Drainage Design Standard

In general, the collapse of soil structures such as embankments is very often caused directly by water, and the collapse can proceed from scouring of the slope by surface water and from slippage of the slope by erosion or seepage water. Drainage works are installed to prevent both of these problems, and it is important to design and construct drainage works so that they are most effective, based on sufficient investigation. In cases where roads are constructed by excavating the original ground with a high groundwater level, the subgrade and base course/subbase course may be softened by seepage water from the ground, and the pavement may be severely damaged. Therefore, it is important to maintain the subgrade and base course/subbase course in sound condition by blocking or excluding water flowing in from the original ground under beneath the subgrade or adjacent areas and lowering the groundwater level[26].

Thus, the installation of appropriate drainage facilities is important for maintaining roads in good condition, and planning and design should be carried out with reference not only to the standards of developed countries but also to those of the target countries. Table 6.19 shows the drainage design standards used in each country.

Table 6.19 Drainage Design Standard

Target Countries	Japan	Ethiopia	Ghana	Tanzania
Design Standard	Road Earthwork - Drainage Works Guideline[26]	Drainage Design Manual 2012[27]	Highway Drainage Manual (Second Edition)[28]	Nothing
Calculating Method of Discharge	①Rational Runoff Formula	①Rational Runoff Formula ②SCS Synthetic Unit Hydrograph*	①Rational Runoff Formula ②The Natural Resources and Conservation Service Methods*	①Rational Runoff Formula ②The TRRL** East African Flood Model
Scope of Application	Seethe Remarks	①< 0.5km^2 ②> 0.5km^2	①< 25.0km^2 ②> 25.0km	①<1.0km^2 .0km^2< ②<200.0km^2
Rainfall Intensity	Calculated by 2-1-2 of "Guideline for Drainage Design on Road Earth Work"	Short-time rainfall intensity for each region by return period are described in the Manual as a diagram.	Short-time rainfall intensity for each region (14 points) by return period are described in the Manual as a diagram.	For Dar es Salaam, rainfall intensity is available from the Weather Observation Station where located on Dar es Salaam airport.
Remarks	The generally applicable range of the rational formula is a basin of about 40 km2 or less, but practically, as long as the surface and rainfall conditions of the basin are considered to be almost uniform, it can be used up to about 200 km2. (Technical standard for River and erosion control). Care must be taken when using in basins over 200 km2.	For rainfall intensity, it is also recommended to apply Log Pearson Type III to calculate the precipitation intensity for each return period. However, it is limited to the case where rainfall data is available for at least 10 years.	The short-time rainfall intensity data is shown in "Maximum Rainfall Intensity-Duration Frequencies in Ghana (1974)" and was created about 40 years ago.	Although the East African Flood Model is an effective method in the inland areas of East Africa, there are opinions that it is not suitable for use in coastal areas with heavy rainfall.

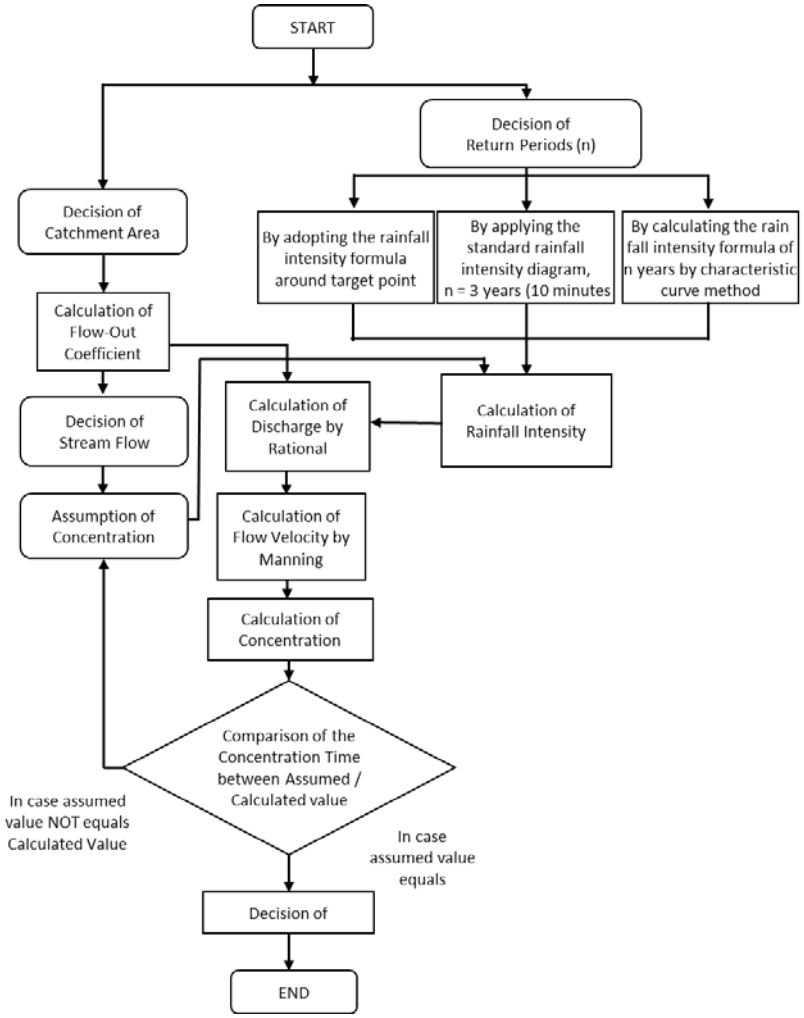
* The old name of NRCS (Natural Resources and Conservation Service) is SCS, which is a calculation formula by the United States Department of Agriculture.

**Transport and Road Research Laboratory, the predecessor organisation to the current Transport Research Laboratory (TRL).

Source: JICA Study Team

(2) Calculation of Discharge Volume (e.g. Japan)

The calculation method of rainwater runoff according to Japan's "Road Earthwork-Drainage Works Guidelines[26]" is shown below. If there is water other than rainwater, add the flow rate as well.



Source: Road Earthwork-Drainage Works Guideline[26]

Figure 6.12 Step of Calculation for Discharge Volume

In the Road Earthwork-Drainage Works Guideline, the criteria for selection of drainage capacity categories by road classification are given in Table 6.20, and the standard adopted reoccurrence period of rainfall for each category of drainage facilities are shown in Table 6.21.

Table 6.20 Selection of Drainage Capacity by Road Classification

Traffic volume Per day	Expressway	National Highway	Prefectural Road	Municipal Road
More than 10,00	A	A	A	A
10,000~4,000	A	A, B	A, B	A, B
4,000~500	A, B	B	B	B, C
Less than 500	-	-	C	C

Source: Road Earthwork-Drainage Works Guideline[26]

Table 6.21 Applicable Rainfall Intensity

Classification	Capacity	Rainfall Intensity	
		(a)	(b)
A	high	3 years	More than 10years (c)
B	middle		7 years
C	low		5 years

Note: (a) Applies to general road drainage facilities such as road surfaces and small slopes.
(b) Applies to important drainage facilities such as crossroad drainage facilities that remove water flowing out from long natural slopes and crossroad drainage facilities in flat urban areas where inland water drainage is important.
(c) For road crossing drainage facilities, which are highly important for road management, it is recommended to set it to about 30 years.

Source: Road Earthwork-Drainage Works Guideline[26]

(3) Cross-sectional Design of Box Culverts for Drainage

When crossing small rivers or mountain streams, there are cases that culverts are used instead of bridges. The method of designing the internal cross section of the drainage culvert can be roughly divided into the following two cases.

a) when a culvert with the same width as the waterway is installed because the cross section and slope of the waterway are uniform from upstream to downstream.
b) Other than a), especially when connecting to irregular waterways such as mountain streams. See Figure 5.12 below as a model of the plan of a culvert vis-a-vis upper-/down-stream.

In Japan, the waterways before and after the culvert are controlled by the installation of the river revetment, and the cross-sectional design of the culvert is mainly carried out according to the situation a) above. In other words, the design of culverts is almost the same as that of the bridges.

On the other hand, in developing countries, even in flat area, the waterways of small rivers before and after the culvert are often underdeveloped (see photo 2.9 in Section 2.9) and with the culvert width become narrower than that of river/streams, the water flow situation in the culvert area differs a lot from the situation in Japan. For example, as the situation may be, watering on the upstream side of the road embankment may have serious adverse effects on the embankment such as scouring, infiltration, and flooding of the road structure and/or of the upstream riverside area if the width or height of the culvert entrance is narrow or low, and this should be avoided. In overseas operations, it may be required to consider this hydraulic condition when designing the cross section of the channel culvert.

In any case, it is recommended to secure the inner area of the box culvert bigger than calculated, to some extent, to ensure the smooth water flow in considering the blockage by the debris such as floating logs, and the accumulation of the sands on the invert of the culvert.

It should be noted that even in the case b), the allowable upstream depth is lower than natural river flow, that means, a kind of back water situation is supposed. When there is a constraint situation in terms of the water depth upstream such as the existence of houses, important facilities, the

designer must consider those situations. This situation tends to occur when designing culvert crossing the small river in the flat area where the gradient of the riverbed is gentle.

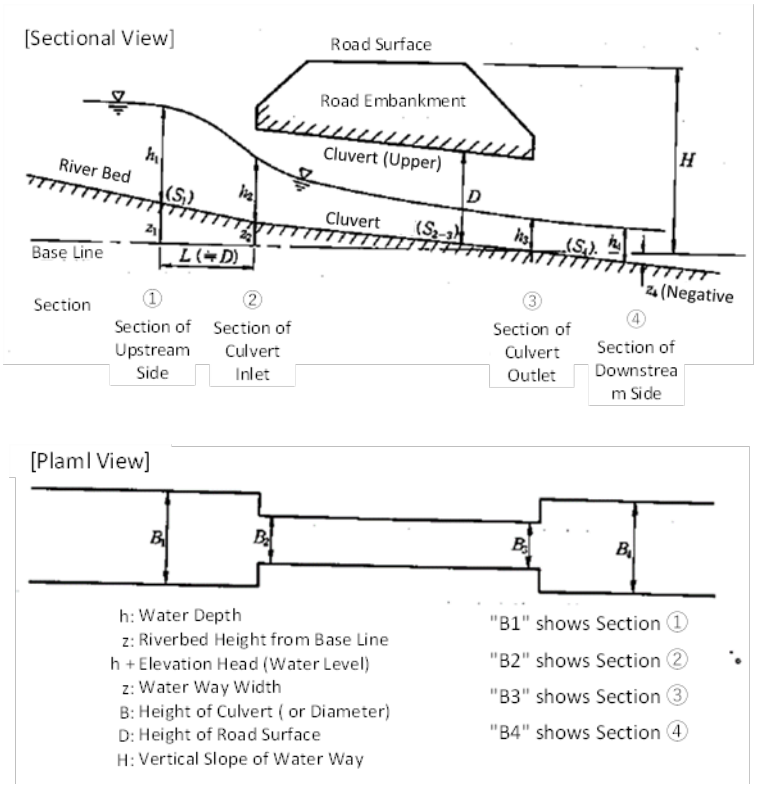


Figure 6.13 Culvert Flow Structure

(4) Design of RC (Reinforced Concrete) Pipe Culvert

Pipe culverts are often used as traversal drainage structures. The risks that can arise when planning a pipe culvert in Africa are summarized below.

- Concrete pipes manufactured by a different manufacturing method from Japan will be supplied.

In Japan, Hume pipes (centrifugal reinforced concrete pipes) are used as RC pipe culverts. However, in African countries, there are cases where concrete pipes formed into a cylindrical shape with a circular formwork without utilizing centrifugal force are supplied because there is no such manufacturing technology.

In Japan, the roller a lower part of the photo rotates the cylindrical formwork at high speed, and concrete is poured from the inside of this formwork to form the pipe with centrifugal force.
The concrete inside the formwork is compacted with a force of about 40G. As a result, and the compressive strength as a structure increase.

- Concrete pipes with specifications (dimensions, shapes and strengths) different from those in Japan will be supplied.

In Japan, JIS (Japan Industrial Standard) stipulates the structural dimensions and ultimate bending strength of concrete pipes. In African countries as well, each country has established standards, and some structures have structural dimensions and ultimate bending strength that conform to these standards. On the other hand, there are specific type called "sidewalk concrete pipes" aiming to be economical only, with less than the specified ultimate bending strength, making them economical.

From the above, concrete pipes available in African countries have different dimensions and shapes from Japanese JIS standards, and their strength may be insufficient. Therefore, when procuring these concrete pipes from local vendors, it is important to confirm whether it has enough inner section and the ultimate bending strength specified in the specifications. If it is difficult to obtain a pipe that meets the specifications, before accepting the procured pipe, it is necessary to certify its ultimate bending strength by test and to verify by structural calculation whether the procured pipe has enough strength for use as well as to design suitable foundation structure for the procured pipe.

☞ Problems that occurred when using pipe culverts (examples)

The factors that determine how much load a pipe culvert can withstand are;

- Ultimate bending strength (breaking strength) of the pipe
- The type and structure of the foundation ground (sand foundation, Co foundation (120 °, 180 °, 360 °)).

In this example, the specifications did not specify the breaking strength of the pipe. In addition, only a typical structural drawing was created for the foundation ground, thus it was not specified where and which foundation structure (material, type and size) should be applied. The lessons to learn are that the specifications should clarify the important factors that determine the strength of the pipe.

* Often, the relevant specifications are specified with description such as "in accordance with BS OOOO", but such description are apt to cause mistakes.

6.7 Reference on Natural Conditions Survey

(1) Topographic Survey

There are "aerial survey" and "actual site measurement" as commonly used methods when creating a plan view by topographic survey. The survey accuracy and expression method of "aerial survey" and "actual site measurement" must be the same.

Currently, thanks to its advantages described below, in drone technology, most aerial surveys are shifting to drone surveys. Surveying by drone can be carried out in a short period of time and at low cost. In addition, since the drone flies at a low altitude (about 100 m), it is possible to acquire point data more closely and improve the accuracy of 3D data. On the other hand, there are some areas where drone surveying cannot be carried out due to restrictions of the Aviation Law.

Table 6.22 Comparison of Topographic Survey Method

Surveying method	Measurement Survey on Ground	Aerial Survey (Conventional)	Drone Survey	
			Photographic Survey	Laser Survey
Surveying Area	Narrow Range	Wide Range	Narrow - Middle Range	Narrow ~ Middle Range
Scale	1/200~1/500	1/500~1/10,000	1/200~1/1,000	1/200~1/1,000
Accuracy	High	Low	Middle	High - Middle
Working Period	Long	Short	Short	Middle
Control Point	Control Point	Control Point	Control Point	Control Point
Accuracy Control	Conducting the Checking Survey	Confirmation by Verification Point	Confirmation by Verification Point	Confirmation by Verification Point
Advantage	High-precision surveying is possible and there are no time constraints. In particular, it is suitable for surveys that accurately measure the current state of urban roads.	It's good at making topographic maps of small and medium scale over a wide area.	Drone survey can be do the surveying for quick and safe surveying even in places where it is dangerous for people to approach. Also, point cloud data can be created from photographic data.	Even in an environment with thick trees, which was difficult to measure by photogrammetry, detailed topographical data can be obtained by using laser survey.
Disadvantage	There are many surveying which survey in private area such as control point surveying, plate table surveying, and Total Station surveying. Also, there are places that are difficult to approach, such as mountain streams. Accidents such as corruption and falls occur.	In order to conduct aerial laser surveying, it is necessary to commit a specialized company, which is expensive. It is easily affected by the weather. In addition, there are places that cannot be approached such as valleys and narrow areas.	"Forests before felling / grasslands before mowing", "riverbeds with running water", "snow cover", etc. are not suitable for aerial survey by UAV (Unmanned Aerial Vehicle). Also, it is not suitable for measuring the details of urban roads (side ditch shape, etc.).	Missing data may occur depending on the conditions of obstacles such as trees in mountainous areas. Also, although it is more accurate than photogrammetry, it is not suitable for measuring details of urban roads (side ditch shape, etc.). The on-board laser surveying equipment is expensive, and the surveying cost is also high.

Source: JICA Study Team

(2) Geological Survey

■ In-situ Test

The in-situ test is to examine the properties of the ground using boring holes and test pits in order to confirm the soil properties of the site. In the preparatory survey, the in-situ test shown in Table 6.23 is generally conducted.

Table 6.23 Major In-situ Tests (for earthworks)

Test Name	Obtained Value	Utilization of Results
Boring	Layer composition of soil on site Ground Water	This is a method of directly checking the geological condition and strength by rotating a pipe with a blade at the tip called a boring machine to perform mining and making an elongated hole called a boring hole in the ground. Since it can be dug up to about 100 m, it is used as a basic ground survey method.
Standard Penetration Test	N-value	This is a type of test performed in a boring hole, and is generally examined every 1 m in depth. It is possible to check the hardness, tightness, and stratum composition of the soil in the original position. It is used to judge the hardness and tightness of the soil layer and the ground bearing capacity.
On-site Permeability Test	Hydraulic conductivity *k* [cm/s]	This is a test for easily obtaining the hydraulic conductivity of the ground, and the hydraulic conductivity of the ground is obtained by using the boring hole. There are two types of test methods, "unsteady method" and "steady method". The purpose is to grasp the natural water level (pressured head) and the hydraulic conductivity k, which are the basis of groundwater information.
Test Pit	Layer composition of Pavement Ground Water	The excavation survey is to excavate the road surface and directly investigate all layers. By excavating, the cause of damage can be identified by performing a CBR test or material test on the thickness of each layer and the collected sample. This survey is a large-scale survey because the road surface is excavated, however it is possible to evaluate in detail the properties of the subgrade and base course/subbase course by visual inspection and sampling, the bearing capacity of each layer by DCP* and small FWD**, and the influence of groundwater.
Dynamic Corn Penetration Test (DCP test)	N-value and CBR-value (By conversion formula)	This is a test to easily measure the dynamic cone penetration resistance of the ground, and by converting the penetration amount into CBR etc., the existing strength of each layer of pavement can be confirmed.

*DCP: Dynamic Cone Penetraion
**FWD: Falling Weight Deflectometer
Source: JICA Study Team

Of these, the N value obtained in the standard penetration test is a numerical value that serves as a reference for determining the tightness and strength of the soil, and is widely used for the work of estimating the support layer of the structure as well as the properties of the soil.

Table 6.24 Estimated N Value

Soil Type	N-value	Hardness	Utilization of Results
Cohesive Soil	0 - 4	Soft	It is a soft ground that requires caution, and it is necessary to conduct a precise soil survey.
	5 - 14	Middle - Hard	There is generally no problem with stability, however there is a possibility of settlement.
	15 -	Very Hard	It does not have to be the target of stability and subsidence, however 20 or more is desirable as the foundation ground for small and medium-sized structures.
Sandy Soil	0 - 10	Loose	Settlement ends in a short period of time; however it must be taken into consideration, and there is a risk of liquefaction at the time of earthquake.
	10 - 30	Middle - Dense	It can be the foundation ground for small and medium-sized structures, but it is generally insufficient.
	30 -	Very Dense	50 or more (very dense) is desirable as the foundation for large structures.

Source: JICA Study Team

In addition, there are FWD (Falling Weight Deflectometer) and Benkelman Beam as "non-destructive measurement" surveys of pavement. In these surveys, the "deflection amount" of pavement can be measured, and the results can be numerically analyzed to evaluate the structure of the pavement.

Table 6.25 Method of Structural Survey (Example)

Method	Outline
FWD: Falling Weight Deflectometer	The FWD includes placing a loading plate on the road surface and dropping weights from above to impart load of 49kN to the asphalt pavement road surface, and measuring the warpage that arises in the road surface by multiple displacement sensors. Capable of evaluating the structure of existing pavement in a non-destructive way, this method is used for estimating the elastic modulus in each layer of pavement and the fatigue damage wheel load of asphalt pavement.
Benkelman beam	This is used to measure asphalt pavement warpage resulting from vehicle traffic and to assess the bearing capacity. In tandem with the excavation survey described below, it can also identify the degree of bese/subbase course compaction and weak parts in subgrade.

Source: JICA Study Team

■ Laboratory Test

The laboratory test is to investigate the soil quality of locally collected soil with specialized equipment. This is to know various properties of soil by examining the components of soil such as soil density, water content, and saturation degree in detail.

Table 6.26 Main Laboratory Test (Physical Test of Soil)

Test Name	Obtained Value	Utilizing Method
Moisture content test	Moisture content w (%)	Compaction control for embankment
Density test of soil particles	Void ratio e Saturation degree Sr (%)	Compaction control for embankment
Grain size test	Uniformity coefficient Uc	Classification of soil
Liquid limit test	Liquid limit wL (%)	Stabilization of fine soil
Plastic limit test	Plastic limit wp (%)	Stabilization of fine soil

Source: JICA Study Team

Table 6.27 Main Laboratory Test (Dynamics Test of Soil)

Test Name	Obtained Value	Utilizing Method
Uniaxial Compression Test	Uniaxial Compressive Strength qu [Mpa]	Bearing capacity of fine-grained soil
Triaxial Compression Test	Adhesion C [kN]	Bearing capacity of ground
Direct Shear Test	Angle of Internal Friction φ	Slope stability
Consolidation Test	Compressibility Coefficient av Consolidation Coefficient Cv	Settlement amount, consolidation time
Indoor Water Permeability Test	Hydraulic Conductivity k [cm/s]	Calculating the transmissibility

Source: JICA Study Team

Table 6.28 Min Laboratory Test (Stabilization Test)

Test Name	Obtained Value	Utilizing Method
Compaction Test	Optimum Moisture Content Wopt[%] Maximum Dry Density ρmax [g/cm2]	Management of Compaction Degree
CBR Test	CBR Value [%]	Embankment Material, Bearing capacity of subgrade

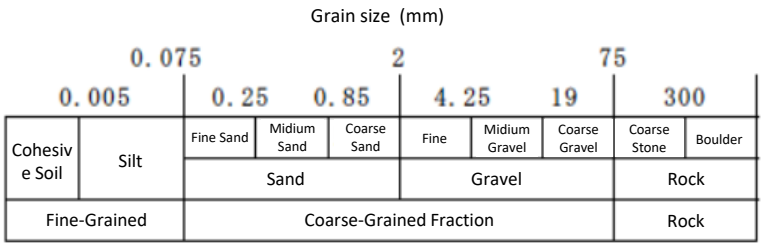
Source: JICA Study Team

Table 6.29 Main Laboratory Test (Aggregate)

Test Name	Obtained Value	Utilizing Method
Abrasion Test	Abrasion [%]	Evaluation of abrasion resistant for aggregate
Crushing Test	Compression Crushing Value [kN]	Evaluation of compression crushing strength for aggregate
Density / Water Absorption Test	Density [g/cm3] Water Absorption Rate [%]	The higher the water absorption rate, the lower the density of the aggregate and the more brittle it is.
Aggregate Test	ellipticity	Judgment of the shape of aggregate
Alkali / Silica Reactivity Test	Average Expansion Coefficient [%]	Judgment of "harmful" and "harmless" of aggregate used for concrete

Source: JICA Study Team

■ Classification by soil particle size



Source: Chugoku Geological Survey Association HP

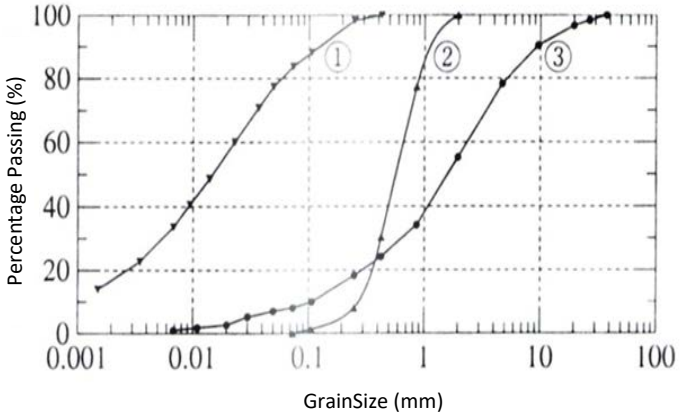
Figure 6.14 Classification by Soil Particle Size

■ Soil particle size accumulation curve

The particle size test is a test to measure the ratio of the mass of soil particles by particle size to the total mass. The distribution of particle size obtained from this result is shown in Figure 6.15

as Particle size accumulation curve. The general characteristics of soil depending on the particle size are as follows.

① Soil with a lot of fine particles
② The particle size is concentrated in a narrow range. Soil with poor compaction characteristics (classified)
③ The particle size is distributed over a wide range. Soil with good compaction characteristics (wide particle size distribution)

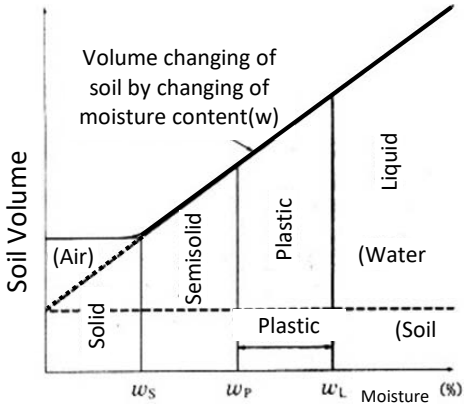


Source: www.mizunotec.co.jp/index.html

Figure 6.15 Soil Particle Size Accumulation Curve

■ Soil consistency

The properties of fine-grained soil change depending on the proportion of water contained in it (water content ratio). When the water content becomes large, the soil becomes mud and liquid. In this case, it is fluid, but as the water content decreases, it becomes more viscous and becomes plastic. When further dried, it enters into a solid state through a semi-solid state. At this time, the total volume of soil also changes, and the volume decreases when it changes from liquid to semi-solid. However, there is a water content ratio at which the total volume does not shrink any more when it becomes solid. These properties of soil dependent on the water content are called soil consistency. The water content ratio has a limit at which the previous state changes to the next state, and the water content ratio at this boundary is called the "liquid limit", "plastic limit", and "shrinkage limit", respectively. Especially the range of water content that keeps the soil plastic is indicated by the difference between the liquid limit and the plastic limit, which is called the Plastic Index (PI).



Source: www.mizunotec.co.jp/index.html

Figure 6.16 Soil Consistency

6.8 Background and Trends of Road Development in Japan

(1) Background of Road Development in Japan

■ History of Road Development (Post-WWII)

Year	Events	Outline
1952	Enactment of New Road Law	It is intended to enhance the function as a transportation network by improving the road network, and the Road Law stipulates the roads to realize this by classifying them into four types (National Expressway, National Highway, Prefectural Roads and Municipal Roads).
	Enactment of the "Act on Special Measures for Road Development"	This established legislation on systems related to the construction and rebuilding of roads on which tolls can be levied.
1953	Opening of Sangu Toll Road in Mie Prefecture	Japan's first toll road, constructed and operated based on the Road Transport Vehicle Act.
	Enactment of the "Act on Temporary Measures concerning Funding to Cover Costs of Road Development"	This stipulated about formulation of a five-year plan of road development and allocation by the national government of an amount equivalent to revenues from gasoline tax for road development earmarked tax.
1954	Formulation of the "First Five-year Road Development Plan"	
1955	Full revision of the "Act on Special Measures for Road Development"	This abolished the system of toll roads directly executed by the national government and adopted the system of toll roads by Japan Highway Public Corporation.
1956	Enactment of the "Japan Highway Public Corporation Act"	
	Submission of the Watkins Report to the government	This recommended fundamental improvement of Japan's road development system.
1957	Enactment of the "National Development Longitudinal Expressway Construction Act"	The scheduled route of the National Development Longitudinal Expressway was specified as the Chuo Expressway section from near Komaki City to Suita City.
1958	Enactment of the "Act on Urgent Measures for Road Development"	In response to the Watkins Report, concerning Japan's road development system, 1) the "Five-year Road Development Plan" having the role of planning and management, and 2) "Road Funding System" having the role of raising funds and bearing expenses were established. The Act on Urgent Measures for Road Development is a law that stipulates procedures and financial resources for a Five-year Road Development Plan. Financial resources of the road development is the gasoline tax.
1962	Opening of the first section of the Metropolitan Expressway between Kyobashi and Shibaura (4.5 km)	
	Formulation of the Comprehensive National Development Plan	
1963	Opening of the Meishin Expressway section between Rittou IC and Amagasaki IC (71.7 km)	
1966	Enactment of the "Act on National Development and Arterial Highway Construction"	As well as abolishing individual laws concerning improvement of expressway routes, this legally established the 7,600km of roads indicated in the separate table as scheduled routes.
1969	Full opening of Tomei Expressway	
1971	Establishment of motor vehicle weight tax	This was instigated out of the need to fund implementation of the Sixth Five-year Road Development Plan.

Year	Events	Outline
1998	Enactment of the "Basic Act on Central Government Reform"	
2000	Cabinet decision on the Fundamental Principle of Administrative Reform determined by the Cabinet	This dealt with reform of special public corporations, etc.
2001	Amalgamation of the Ministry of Transport, Ministry of Construction, Hokkaido Development Agency, and National Land Agency to form the Ministry of Land, Infrastructure, Transport and Tourism	
2003	Formulation of the First Infrastructure Development Priority Policy Plan	
2004	Enactment of the Four Acts on Privatization of Four Highway Corporations	
2005	Privatization of Four Highway Corporations	
2008	Cabinet decision on the "Basic Policy concerning Revenues Earmarked for Roads"	
	Integration of the Japan Bank for International Cooperation (JBIC) Yen Loan Division and Japan International Cooperation Agency (JICA)	
2009	Enactment of the "Act for Partially Revising the Act, etc. concerning Special National Fiscal Measures concerning Road Development Projects"	Funds earmarked for road development were transferred to the general fund.

Source: JICA Study Team

(2) Major Events

■ Watkins Report

The Japanese government requested that the U.S. send a study team to solidify the legitimacy of the construction of the Meishin Expressway and to extract a loan from the World Bank. The study team was led by Ralph J. Watkins, a guest professor of economics at Massachusetts Institute of Technology, and after conducting a survey in Japan lasting 80 days from May 1956, the team submitted the "Report for the Government of Japan Ministry of Construction concerning the Study on the Nagoya-Kobe Expressway" on August 8. This report is referred to as the Watkins Report[29]. "The Roads of Japan are incredibly bad. No other nation has so completely neglected its highway system." This opening phrase became a buzzword at the time and changed the Japanese people's consciousness about roads. At that time, 77% of Japan's first class national roads (the most important roads in Japan) were not paved. More than half of this road network had never been improved and were narrow, unpaved and not in safe condition. Ninety to ninety-six percent of the secondary national roads and prefectural roads that form the main part of the road network were unpaved, and 75-80% of these roads were completely unimproved.

The Watkins Report[29] is summarized below, and it set the direction for subsequent logical and

systematic road development in Japan.

i. The methodology of grasping gross national product and the corresponding approach to traffic systems is clearly specified, and the concept of rate of growth of the national economy plays an important role throughout the entire analysis.

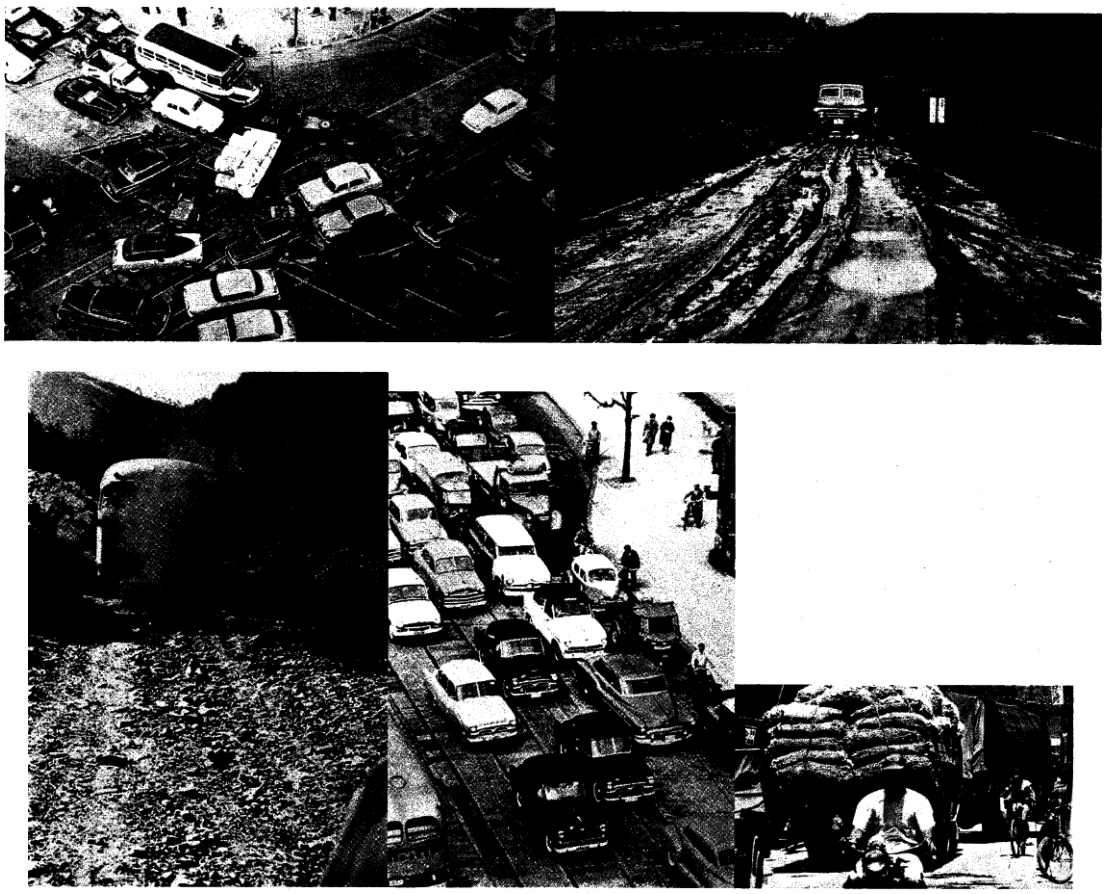
ii. In other words, through examining the present and future projected nationwide traffic demand within the overall national economy, it indicated that the transportation system would not be able to handle the traffic volume arising out of the gross national product of approximately 7.9 trillion yen at that time (1955). It thus indicated the need to direct urgent attention to a road development plan based on construction of expressways. Moreover, based on the assumption that the national economy of Japan would grow at a rate of 5-6%, it suggested that road expenditure of at least approximately 180 billion yen per a year would be essential.

iii. Concerning the Nagoya-Kobe Expressway, it clarified the present and future projected traffic demand between Nagoya-Kobe, conducted a technical review of the Nagoya-Kobe Expressway plan, and also conducted a review of profitability to determine whether the project cost was recoverable through toll road revenues. As a result, since this showed that it would not be possible to recover expenses through toll road revenues alone for the first few years after going into service, it proposed that the deficit should be supplemented through gasoline tax and other motor vehicle taxation, but otherwise affirmed construction of the Meishin Expressway on the grounds that ample profitability could be secured after the initial period.

iv. Regarding the economic impact of expressway construction, it suggested that major impacts could be obtained in terms of 1) manufacturing industry, 2) inventories, 3) agriculture, forestry and fisheries, and 4) foreign trade and international balance of payments, etc. Moreover, since the investment required for expressway construction accounted for just 0.2% of the gross national product, it concluded that construction of the Nagoya-Kobe Expressway was extremely desirable in terms of the national economy.

The Watkins Report has been a powerful source of support for obtaining loans from the World Bank. At the time, the World Bank had no experience in financing highway construction, and the amount of the loan was extremely large, so it was not easy to adopt, but finally the loan from the World Bank came into effect with a loan agreement on May 25, 1960.

Source: Road Policy in Japan: An Analysis from Economics and Political Science[30]



Source: The Study of the Kobe-Nagoya Expressway Survey Report by a Group of Experts Headed by Ralph J. Watkins (facsimile edition)[29]

Photo 6.2 The State of Roads in Japan at that Time

■ Comprehensive National Development Plan

The Comprehensive National Development Plan, based on the National Land Comprehensive Development Act (enacted in 1950), was the comprehensive and basic plan for the utilization, development and conservation of Japan's national land, and it set the long-term direction for the development of housing, cities, roads and other transportation infrastructure. Starting from the First Comprehensive National Development Plan compiled in 1962, five such plans were formulated up the "Grand Design for the 21st Century" in 1988. Table 6.30 outlines these plans with the focus on road sector.

Table 6.30 Outline of Comprehensive National Development Plans

Plan	Target Year	Basic Goals	Transportation System Improvement
Comprehensive National Development Plan (1962)	1970	<Inter-regional balanced development> Achieve a comprehensive solution for problems created by urban expansion and regional productivity disparities.	1) Realize construction, improvement and expansion of important inter-regional arterial highways. 2) To realize construction, improvement and expansion of arterial highways in regions, first conduct improvement of road networks that organically connect different development districts centering on existing major concentrated belts and large-scale regional development cities. 3) In overcrowded cities, construct, improve and expand streets and urban expressways to alleviate urban transport. 4) First construct and improve branch roads for complementing arterial highway networks, for development of industry, etc.
New Comprehensive National Development Plan (1969)	1985	<Creation of an affluent environment> Aiming for a high-level welfare society, create an affluent environment for humans.	1) Establish a high-speed transportation system for linking regions to major urban centers, and rationally improve related transportation systems inside directly linked regions and transportation systems between regions. 2) Development of transportation systems in major urban centers In addition to constructing and improving transportation facilities of outer ring roads and coastal ring roads, widely arrange logistics centers, etc. Since routes between the major urban centers of Tokyo, Nagoya and Osaka are expected to become even busier, construct multilayered high-speed transportation facilities.
Third Comprehensive National Development Plan (1977)	Approximately 10 years from 1977	<Comprehensive environmental improvement for human residence> Systematically improve the comprehensive environment for stable, healthy and cultural human residence in harmony with nature.	[Development of arterial transportation systems] The high-standard arterial highway network will comprise national development arterial expressways (approximately 7,600km) as well as another roughly 10,000km comprising the Sea of Japan Coastal Highway, East Kyushu Development Longitudinal Expressway, Shikoku circulatory and other arterial routes, the Honshu-Shikoku Bridge Expressway route, major urban circulatory highways, etc. [Development of arterial transportation facilities during the plan period] Concerning expressways, the target for development over the coming 10 years, including sections already open, will be 4,500km-5,000km. Survey will be advanced on arterial loop transportation systems in the Tokyo region, etc. A road and rail bridge will be constructed on the route between Kojima and Sakaide with a view to ensuring early completion of the Honshu-Shikoku Bridge Expressway route.
Fourth Comprehensive National Development Plan (1987)	Approximately 2000	<Development of a multipolar dispersed national land> Establish numerous characteristic poles and form the	[Formation of domestic arterial transportation systems] Concerning the arterial high-standard highway network, approximately 14,000km will be constructed to enable regional centers, core cities, core regional cities for local development, surrounding areas, etc. to be reached in around 1 hour. High-standard highway comprise of Expressways and a part of National

		national land so that there is no over-concentration of functions in any specific areas, there is mutual supplementation and exchanges are triggered between areas and countries.	Highways. [Measures during the plan period] Concerning the high-standard arterial highway network, promote development of approximately 8,000-9,000km, including 7,600km of the existing national development arterial expressways and three routes of the Honshu-Shikoku bridges.
Grand Design for the 21st Century (1988)	2010-2015	<Laying foundations for forming a multiaxial national land structure> Build the foundations for realizing the "Grand Design for the 21st Century" with the aim of forming a multiaxial national land structure.	[Long-term plan for transportation system improvement] The 14,000km arterial high-standard highway network and completely local high-standard highways that promote inter-regional exchange will be integrated to form a main high-speed land transport network comprising a national framework. Out of this, it is intended to promote development of 6,000-8,000km of local high-standard highways. [Measures during the plan period] Promote development with emphasis on arterial high-standard highways and local high-standard highways. Concerning the arterial high-standard highway network, promote development with emphasis on the completion of roads for connecting major urban centers and ring roads, etc. inside major urban centers by the start of the 21st century; while concerning other regions, promote development with emphasis on longitudinal and traversal routes that can become axes of wide-area linkage.

Source: Prepared by the JICA Study Team based on materials of the Ministry of Land, Infrastructure, Transport and Tourism

■ Five-year Road Development Plan

In Article 2 of the *Act on Urgent Measures for Road Development* that was enacted in 1958, the following was stipulated concerning the Five-year Road Development Plan.

> Article 2 The Minister of Construction must compile a plan and seek Cabinet decision concerning the construction, rebuilding, maintenance and repair of National Expressways, the First grade National Highways, the Second grade National Highways, ordinance-designated prefectural roads, and other roads (hereafter referred to as "road development") over the period of five years from fiscal 1958.
>
> 2 The following items must be stipulated in the Five-year Road Development Plan.
>
> 1) Targets for road development to be implemented over five years
>
> 2) Quantity of road development projects to be implemented over five years

The First Five-year Road Development Plan (plan period: fiscal 1954-1957) was compiled prior to this in 1954. The Act on Urgent Measures for Road Development systematically prioritized the implementation of projects based on the Five-year Plan. Twelve five-year plans were subsequently formulated, ending in 2002.

In 2001, in order to address the various problems of social infrastructure development (high costs, inefficient projects, effects on economic recovery, etc.) from a medium- to long-term perspective and to clarify what social infrastructure is truly needed, the First Priority Social Infrastructure Development Plan was formulated as a comprehensive development plan for nine areas (roads, traffic safety facilities, airports, harbors, urban parks, sewerage systems, flood control, steep slopes, and coasts), which had been established separately. The fourth plan has been formulated to date.

(3) Outline of Japan's Road Development System

■ Motor vehicle-related taxes

The gasoline tax was established under the "Act on State's Tentative Financial Measures for Road Construction Projects" in 1953 with the intention of raising funds for national road development, and thereby advance the urgent and systematic improvement of Japan's roads, which were poorly developed at that time. The act was repealed in 1958 and replaced by "Act on Urgent Measures for Road Development."

Based on the benefit principle and the principle of burden by damaging parties, this system aimed to secure road development funds (revenue source set aside for road construction) from motor vehicle users corresponding to their benefit from road use (travel distance) or the degree of damage they impart to roads (vehicle weight).

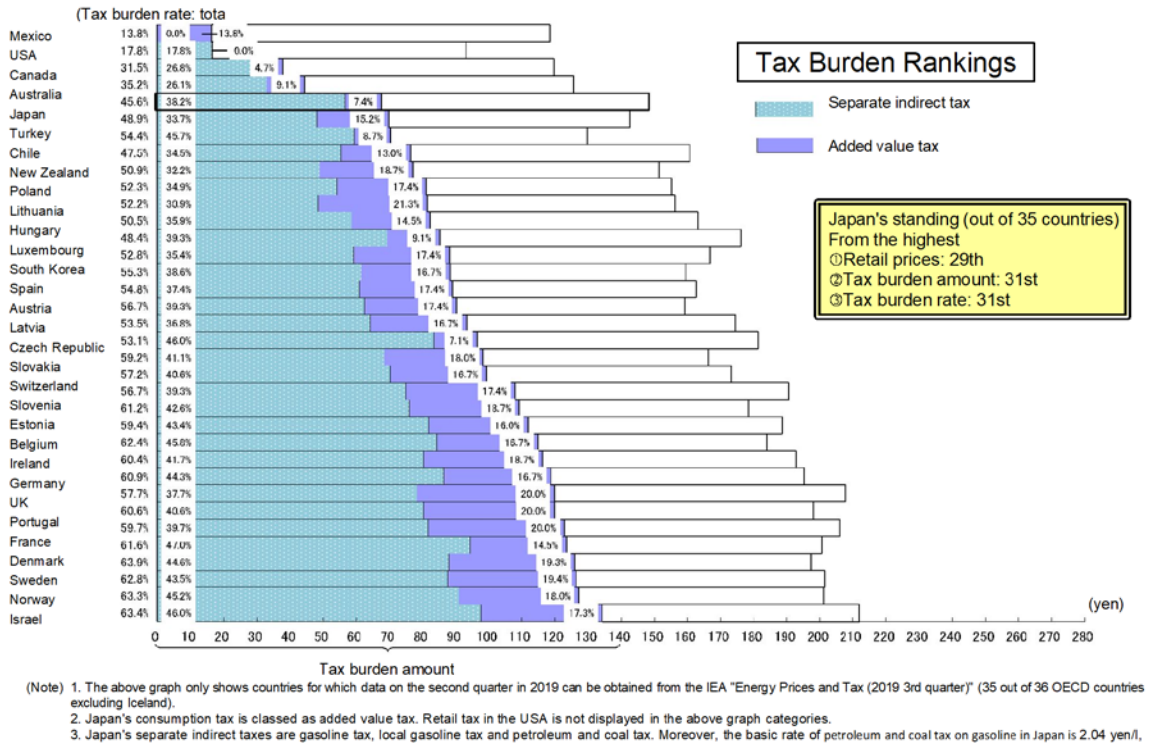
This ensured that revenue from the gasoline tax would be set aside for road development, and new tax systems have consistently been established and tax rates raised to respond to subsequent needs for road development. Table 6.31 shows the types of taxes that have been used as revenue sources set aside for road construction.

Table 6.31 Motor Vehicle-Related Taxes

Title	Year Established	Basic Law and Targets	Tax Rate in the First Year	Current Tax Rate
Gasoline tax	1954	Based on the Gasoline Tax Act (1957), this national tax on volatile oil, i.e., gasoline, is levied on manufacturers of oils or dealers from bonded areas. The tax rate is proportional to the usage. Moreover, volatile oil is also subject to local road tax (see below), and these taxes are generally referred to as gasoline tax.	13.0 yen/liter	48.6 yen/liter
Local Road Tax	1955	Based on the Local Road Tax Act (1955), this national tax on petroleum refined gasoline volatile oil is levied on manufacturers or dealers from bonded areas. The tax rate is proportional to the usage. The tax revenues are allocated as funds to cover road expenses to prefectures and designated cities specified in the Road Act.	2.0 yen/liter	5.2 yen/liter
Light Oil Delivery Tax	1956	Because an imbalance had developed in the tax burden between light oil (fuel used in diesel engine vehicles) and volatile oil (fuel used in gasoline vehicles), the Light Oil Delivery Tax was established as a local tax earmarked for roads. Out of the light oil received from special contract distributors and primary oil distributors, this tax is levied on actual deliveries of light oil.	6.0 yen/liter	32.1 yen/liter
Petroleum Gas Tax	1966	Based on the Petroleum Gas TaxAct, this national tax is levied on specific liquefied petroleum gas (taxable petroleum gas). The target is petroleum gas that is filled into LPG motor vehicle petroleum gas containers. Specifically, the fuel gas that is mainly used in taxis and other business vehicles is targeted for taxation.	5.0 yen/liter	17.5 yen/liter
Motor vehicle Acquisition Tax	1968	Based on local legislation, this local tax is levied on persons acquiring a motor vehicle when the acquisition price is 500,000 yen or more. "Acquisition price" refers not to the amount that is actually paid when buying a vehicle, but rather is the amount obtained upon multiplying a reference amount established for each vehicle model, grade and specification by the ratio of remaining value that corresponds to the number of years elapsed since purchase as a new vehicle.	3% of "acquisition price"	Abolished when the consumption tax rate was increased to 10% in 2019
Motor vehicle Weight Tax	1971	Based on the Motor vehicle Weight Tax Act, this national tax is levied on inspected vehicles and notified light motor vehicles. Obligation to pay the tax lies with persons who are issued a motor vehicle inspection certificate or persons who receive a designated vehicle number, and the tax is paid when newly registering or notifying a vehicle or when receiving a continuing inspection or inspection of structural revision, etc. or receiving issue of a motor vehicle inspection certificate or certificate of notification.	2,500 yen/weight 0.5t year	Private vehicle: 4,100 yen/weight 0.5t year Business vehicle: 2,600 yen/weight 0.5t year

Source: JICA Study Team

☞ Gasoline Prices and Taxes in OECD (Organization for Economic Co-operation and Development) Nations



Source: Ministry of Foreign Affairs (https://www.mof.go.jp/tax_policy/summary/consumption/133.pdf)

Figure 6.17 Gasoline Prices and Taxes in OECD Nations

Revenue sources set aside for road construction, based on burden of motor vehicle users, thus had the intention of raising funds for national road development, and thereby advancing the urgent and systematic improvement of Japan's roads, which were poorly developed at the time. However, as the level of road development was enhanced in subsequent years, and because of the need to suppress overall public expenditure, the "Act to Partially Revise the Act on Special Measures of National Finance on Road Development" was enacted in 2009, leading to the funding of road development from the general account.

■ Toll roads system

1) Outline of the toll roads system

The Act on Special Measures for Road Development (old law) was enacted in 1952 for urgent road projects that incurred extremely large funding that could not be covered by tax revenues alone. Under this law, the toll road system was introduced whereby, when the central government or local authorities implement road improvement projects, they would borrow funds to make up for financial shortfalls, and return the loans through tolls levied on road users travelling on thus completed roads.

2) Types of toll roads

(a) National expressways

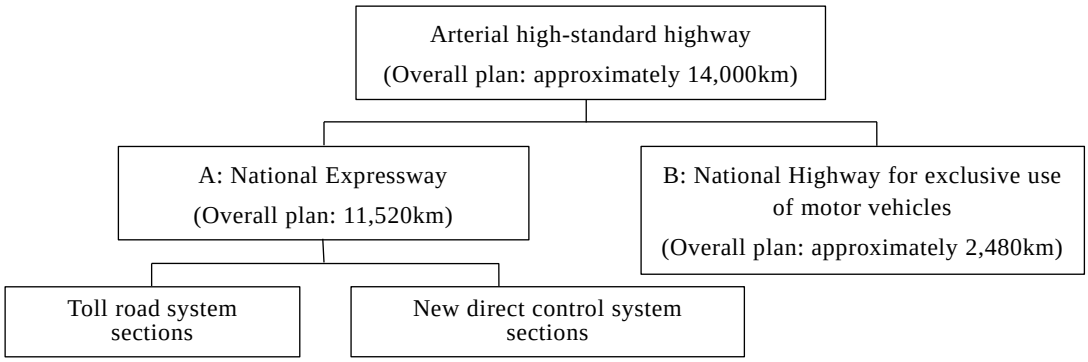
National expressways are highways for the exclusive use of motor vehicles, provided based on the National Expressway Act. The law defines national expressways as "roads provided for the high-speed transport of motor vehicles, they comprise the key portion of the nationwide motor vehicle transport network and play an especially important role in connecting areas of particular political, economic and cultural importance and serving other national interests". Many national expressways are operated as toll roads by expressway companies.

(b) Urban expressways

Urban expressways are urban facilities stipulated in the Urban Planning Act. They are toll highways for the exclusive use of motor vehicles constructed in major cities and their environs. Basically, urban expressways are not national highways, but they are prefectural roads or designated city roads and they are located within the six major metropolitan centers of Tokyo, Nagoya, Osaka, Hiroshima, Kitakyushu, and Fukuoka.

(c) General toll roads

General toll roads are toll roads other than national expressways and urban expressways. In functional terms, they are divided into two types: the first is network-type general toll roads which are operated integrally with national expressways, and these include the Metropolitan Inter-City Expressway (Ken-O Expressway) and so on. These roads correspond to B in Figure 6.18. The other type is bypass-type general toll roads which are not operated integrally with national expressways or urban expressways. Figure 6.18 shows the business schemes of arterial high-standard highways.



New direct control system sections	Similar to national highways, these sections are constructed by the Ministry of Land, Infrastructure, Transport and Tourism regional development bureaus and are opened free of charge following completion. Accordingly, they impart a rapid improvement effect and are frequently adopted as a substitute bypass for parallel-running national highways yet to be improved. As a supplementary measure for road development conducted by expressway companies, this system is conducted with financing of construction and maintenance provided by the central government and prefectures.

Source: Ministry of Land, Infrastructure, Transport and Tourism (https://www.mlit.go.jp/road/ir/ir-council/hw_arikata/chu_matome/m01_data03.pdf), etc.

Figure 6.18 Business Schemes for Arterial High-standard Highways

■ Expressway funding schemes

Toll road systems in Japan are operated based on two approaches: the full-cost recovery principle, and the national pool system of Japan Highway Corporation. Based on these two approaches, expressway tolls are set in such a way that the total amount of toll revenue is equivalent to the total amount of construction cost and maintenance cost (borrowed funds and interest) at the end of the toll collection period.

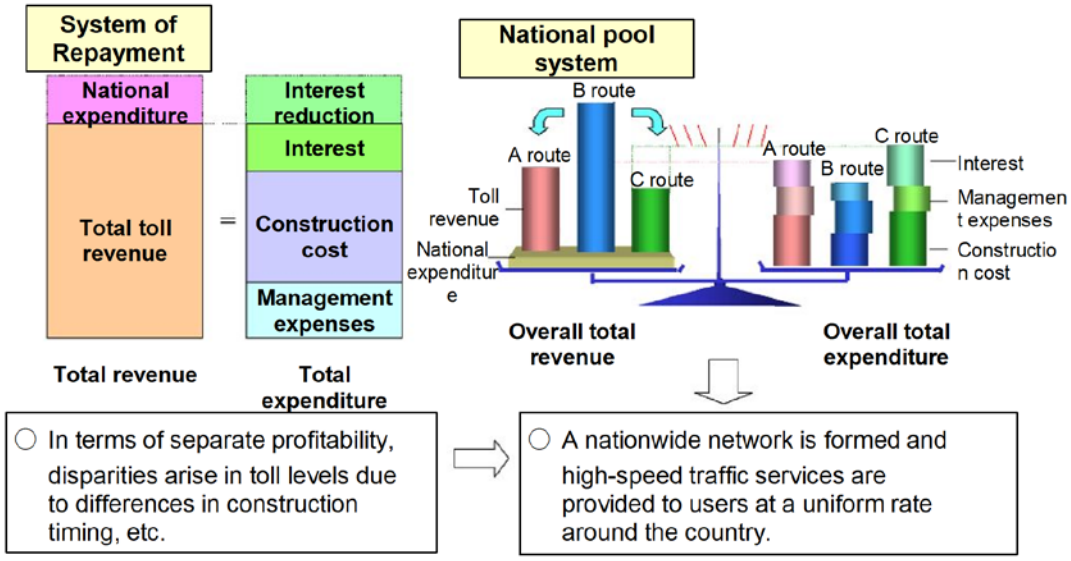
(a) Full-cost recovery principle

The full-cost recovery principle refers to "the covering of all necessary costs of expressway construction and maintenance by means of toll revenue acquired during the set toll collection period (redemption period)". Specifically, this means: "Commencing construction of an expressway upon borrowing the necessary funds. Following completion of the expressway, tolls will be levied from users for a certain period, and the toll revenue will be used to pay for the loan, interest and costs arising from road maintenance".

(b) Pool system of Japan Highway Corporation

As work progressed on building the nationwide expressway network, when redemption plans were compiled for each expressway route, although belonging to the same network, inflation in land prices, personnel expenses, material costs and so on caused construction costs to become more expensive and tolls to be set higher on the later routes. Accordingly, if individual repayment plans continued to be set, there was a risk that the ideal of a uniform nationwide

network would fail due to differences in the timing of toll-free opening on each route and so on. Accordingly, in 1972, a national pool system was adopted whereby repayment plans for national expressways all over Japan were unified and it became possible to travel along all national expressways under the same toll system.



Source: Recent Trends concerning Reform of Special Corporations, Ministry of Land, Infrastructure, Transport and Tourism (https://www.mlit.go.jp/road/singi/kousoku/011031.pdf)

Figure 6.19 System of National Expressway Tolls

■ Current expressway operators

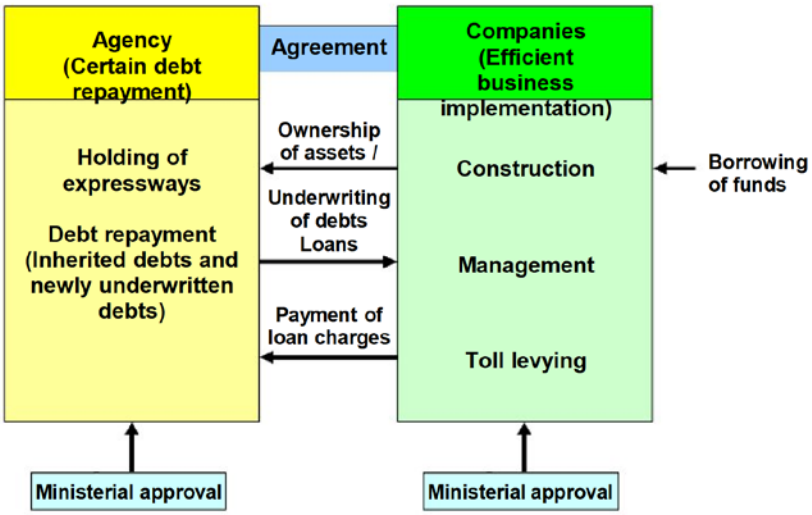
There are currently six expressway operators as follows: East Nippon Expressway Company Limited, Metropolitan Expressway Company Limited, Central Nippon Expressway Company Limited, West Nippon Expressway Company Limited, Hanshin Expressway Company Limited, and Honshu-Shikoku Bridge Expressway Company Limited (hereafter referred to as "the Companies"). In addition, there is the Japan Expressway Holding and Debt Repayment Agency (hereafter referred to as "the Agency").

The Agency has the objective of holding and leasing expressway assets as well as quickly and steadily repaying debts and thereby mitigating the burden of expressways on citizens, while also facilitating the smooth execution of expressway projects by six expressway Companies.

The Companies primarily implement maintenance, repair, disaster recovery and other management on the expressway assets leased by the Agency. Based on consignment by the central government and local public authorities, the Companies construct new roads and implement rebuilding, maintenance, repair, disaster recovery and other management as well as road-related survey, quantity surveying, testing and research.

When constructing new expressways, from the viewpoint of respecting the autonomy of the newly established Companies, the Companies execute construction, etc. based on "agreements" with the

Agency. This replaces the former system whereby the Highway Public Corporation constructed expressways in response to unilateral directives from the central government.



Source: Background, etc. of Privatization of Four Highway-related Public Corporations (https://www.mlit.go.jp/road/ir/ir-council/gyomu_tenken/pdf01/7.pdf)

Figure 6.20 Expressway Business Implementation Scheme by the Companies and the Agency

Systems for Expressway Development in Foreign Countries

Item	Japan	USA	France	Italy	Germany
Expresswayservice length	7,363km ('05.10)	90,712km ('03)	10,383km ('04.06)	6,491 ('04,06)	12,044km ('03.12)
Toll expressways (out of the above)	7,363km	6,003km	7,840km	5,597km	
Toll ratio	100%	7%	76%	86%	—
Formulation of expressway plans	Central government	Central government	Central government	Central government	Central government
Belonging after the end of the toll period	Central government	Central government	Central government	Central government	—
High-speed road development system	・Expressways are basically intended to be free, however, for financial reasons, the Companies construct expressways using loans, and following construction, thecompleted expressway assets and liabilitis are transferred to the Agency. ・Concerning roads in service, the Companies lease the road assets, levy tolls and pay rental charges. ・The Agency repays existing and new liabilities using the rental charges received from the Companies. (Since 2003, the direct control system has been introduced whereby the central government and local authorities carry the burden, allowing roads to be opened free of charge following completion)	・State governments construct interstate highways (interstates) as toll-free roads from the outset. There are some cases where in-service toll roads are treated as interstate highways. ・Apart from interstate highways , there are some toll roads The funding for road improvement is the Highway Trust Fund. The system was established in 1956 and is a specific revenue source that uses federal gasolin tax as a source of revenue.	・In principle, expressways are supposed to be toll-free, however, in the interests of realizing rapid development, it is common to borrow funds and construct expressways as toll roads. ・In western areas (Britanny, etc.), expressways are toll-free in the interests of regional development.	・Due to financial reasons, expressways are generally constructed as toll roads using borrowed funds. ・In the south of the country where developnent has been slow, the central government constructs expressways as toll-free roads	・Federal autobahns are constructed by states under central government funding and provided as toll-free-roads. ・In January 1995, it became obligatory for large trucks weighing 12t or over to purchase vouchers (payment certificates) (with the objective of levying taxes for throughtraffic arising from EU unification). ・In January 2005, the transit-based toll system was switched to a distance-based system.
Toll level (ordinary vehicles) [Japan=100]	(Uniform distance-based) 24.6yen/km+150 yen [100]	—	(Average of 3 mixed economy companies) 0.062 Euros/km (8.3 yen/km) [34]	(Aststrade Inc.) 0.047 Euros/km (6.4 yen/km) [26]	(Only trucks of 12t or over that use autobahns) 0.124 Euros/km (16.8 yen/km)
Toll expressway business entities	East Nippon, Central Nippon, and West	States and public corporations, etc. based on state law	Mixed economy companies (SEM) and private	Private companies that have received license from the	—

	Nippon Expressway Companies		companies that have received license from the central government	central government	
Target routes	National Expressways	Interstate highways, other freeways, and toll expressways	Auto routes	Autostrades	Autobahns

Source: Current Conditions of Funding Systems for Road Construction , Improvement and Management (https://www.mlit.go.jp/road/ir/kihon/16/6.pdf)

(4) Road Administration in Japan

■ Types of roads

Roads are not only divided and characterized according to their purpose, character, function, etc., but each type also has suitable form and structure. There are numerous methods for classifying road types, however, the basic methods are legal classification, functional classification, and classification based on management scheme.

In legal terms, roads are classified according to the "Road Act", "Road Transportation Act" and "Road Traffic Act", but the classifications based on the "Road Act" are most widely used, because solely the roads under the road act (law) are the public roads, and roads under Road Transportation Act do not form network and are not necessarily public roads and many of them are operated as private assets independently. Road Traffic Act is the act for road traffic safety, and not has own assets.

According to the "Road Act", "roads" refer to the following four classifications that are provided for general traffic:

i. National Expressways
ii. National Highways
iii. Prefectural Roads
iv. Municipal Roads

These public roads are defined and classified according to their character and importance in the overall road network. National expressways and national highways together comprise the nationwide arterial highway network, and routes are designated by the central government based on ordinances. Prefectural Roads form the regional arterial highway network and are authorized by prefectural governors, while Municipal Roads serve as road networks within municipal jurisdictions and are authorized by mayors.

Concerning functional classifications, these differ in functional and structural terms depending on whether roads are for dedicated use by specific passing entities (motor vehicles, other vehicles, pedestrians, etc.) or for use by mixed entities.

Concerning classification based on management scheme, one example is classification based on whether or not tolls are levied from vehicles, etc. that use a road. Since roads are frequently used

for multiple purposes, free passage has been the historical principle all over the world, however, there have also been cases throughout history where tolls have been collected from users of road facilities intended for specific services with the toll revenues being used to repay construction costs and cover management expenses. Such roads are generally referred to as toll roads.

Source: Transport Engineering Handbook[31]

■ Road management

Road management refers to all of the work that is implemented by road managers to ensure that roads that are provided as public facilities for general transport display their intended functions. The contents of road management, in positive terms, include preparing the form of roads intended for general transport, maintaining them in good condition, and imposing a public burden to road users for the sake of the road assets according to necessity. Viewed in a negative sense, road management includes preventing and removing obstructions and imposing other regulations to ensure that roads serve the purpose of facilitating road transport in general. Road managers, in principle, are as indicated in Table 6.32.

In terms of the length of roads according to each road classification, municipal roads account for 84.1% of road length, prefectural roads for 10.6%, and national highways for 6.2%. National expressways only account for 0.7%.

Table 6.32 Types of Roads and Road Administrator

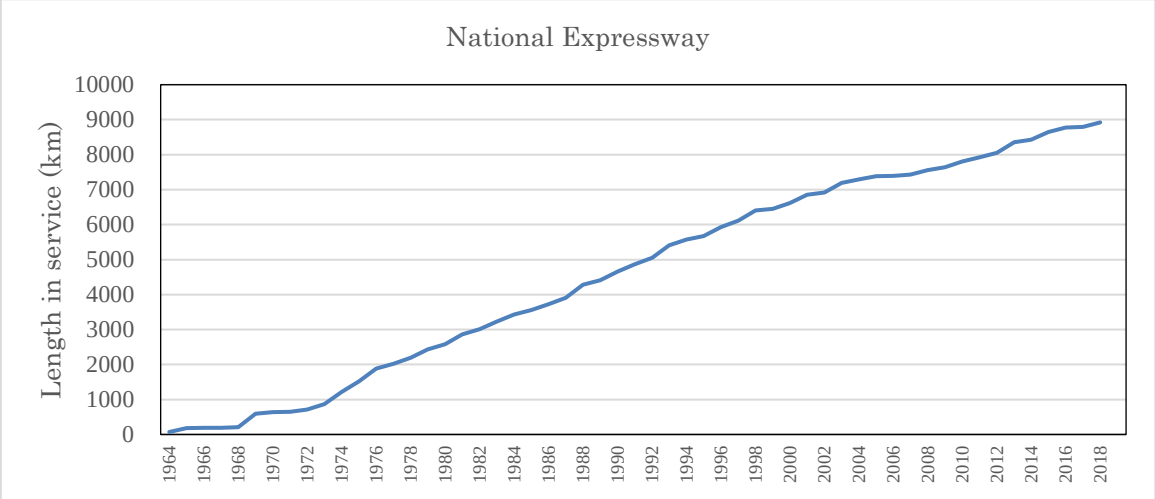
Road Type		Definition	Road Manager	Cost Burden	Rough Service Length (Composite ratio)
National Expressway		Roads that comprise the key portion of the nationwide motor vehicle transport network and play an especially important role in connecting areas of particular political, economic and cultural importance and serving other national interests	Minister of Land, Infrastructure, Transport and Tourism	The Companies (Central government, Prefectures (Ordinance-designated cities))	8,900km (0.7%)
National Highway	Directly controlled National Highway (designated section)	Roads that, together with national expressways, comprise the nationwide arterial highway network and, moreover, meet certain statutory requirements [Road Act Article 5]	Minister of Land, Infrastructure, Transport and Tourism	Central government Prefectures (Ordinance-designated cities)	23,700km (1.9%)
	Subsidized National Highway (non-designated section)		Prefectures (Ordinance-designated cities)	Central government Prefectures (Ordinance-designated cities)	32,000km (2.6%)
Prefectural roads		Roads that comprise regional arterial highway networks and, moreover, meet certain statutory requirements	Prefectures (Ordinance-designated cities)	Prefectures (Ordinance-designated cities)	129,700km (10.6%)
Municipal roads		Roads that exist inside municipal areas	Municipalities	Municipalities	1,029,800km (84.1%)

Source: Simple Commentary on Road Administration, Ministry of Land, Infrastructure, Transport and Tourism (https://www.mlit.go.jp/road/sisaku/dorogyousei/0.pdf)

■ Road Development Conditions

1) National Expressways

Starting from opening of the Meishin Expressway section between Rittou IC and Amagasaki IC (71.7 km) in 1963, development of expressways in Japan subsequently advanced until the total length of expressways stood at 8,922km in January 2018.

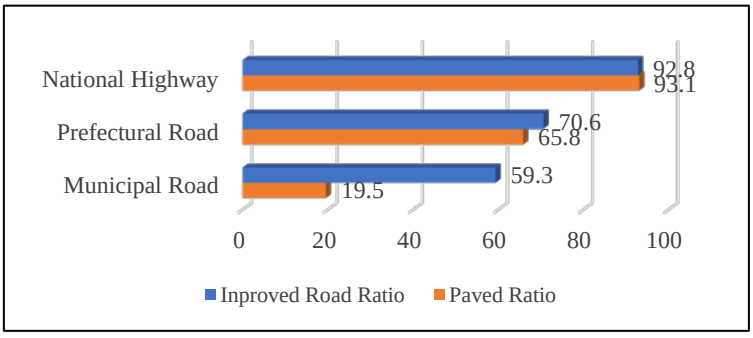


Source: Prepared by the JICA Study Team based on the Statistical Annual Report on Roads 2019[32], Ministry of Land, Infrastructure, Transport and Tourism

Figure 6.21 Transitions in Constructed Length of National Expressways

2) National highways, prefectural roads, and municipal roads

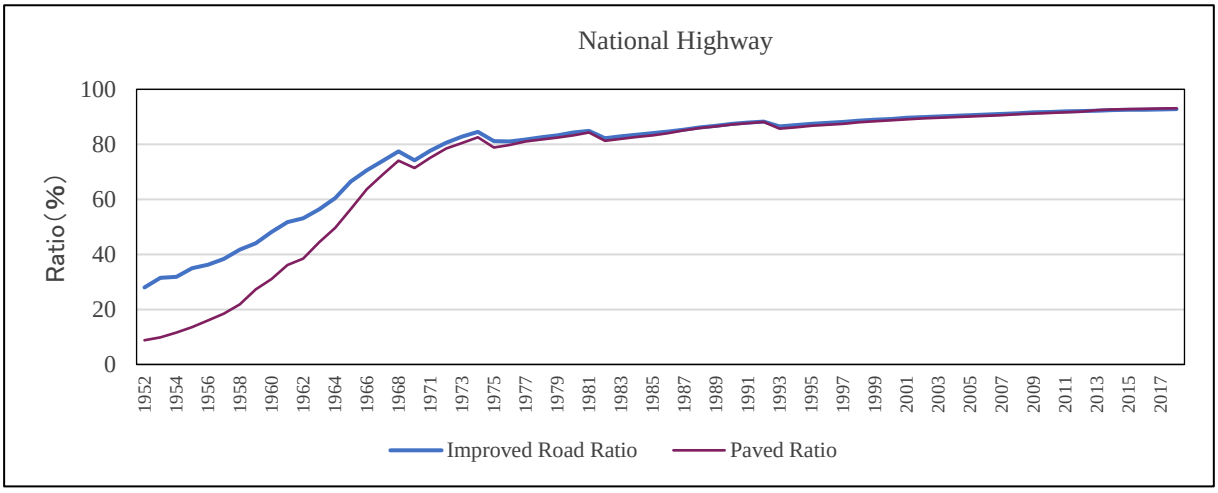
Figure 6.22 shows recent improvement rates and pavement rates of national highways, prefectural roads and municipal roads. Concerning national highways, the improvement rate and pavement rate are 90% or more, however, on municipal roads, the improvement rate is less than 60% and the pavement rate is less than 20%.



Source: Prepared by the JICA Study Team based on the Statistical Annual Report on Roads 2019[32], Ministry of Land, Infrastructure, Transport and Tourism

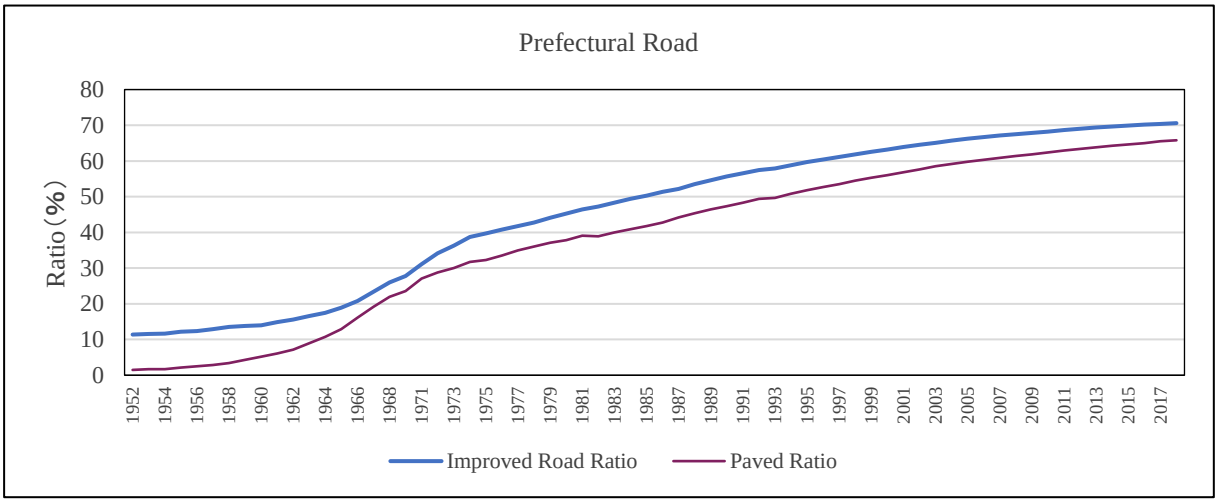
Figure 6.22 Improvement Rates and Pavement Rates on National Highways, Prefectural Roads and Municipal Roads

Table 6.24Figure 6.23 through Figure 6.25 show the history of the improvement rates and pavement rates of national highways, prefectural roads and municipal roads. The development of national highways advanced rapidly between 1952, when the Act on Special Measures concerning Road Development was enacted, and 1966, when the Act on National Development and Arterial Highway Construction was enacted; however, work on municipal roads is still in progress.



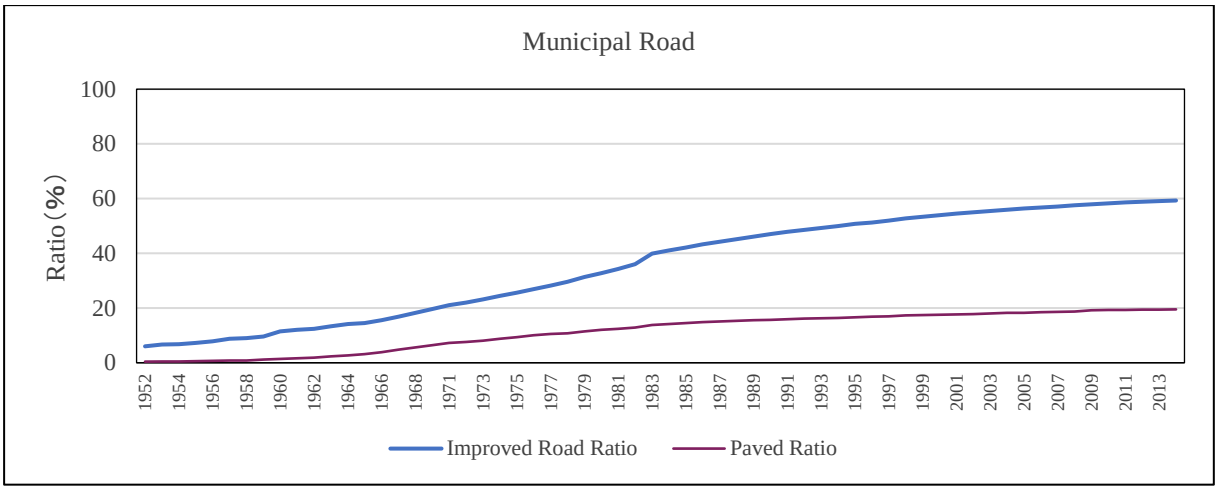
Source: Prepared by the JICA Study Team based on the Statistical Annual Report on Roads 2019[32], Ministry of Land, Infrastructure, Transport and Tourism

Figure 6.23 Transitions in Improvement Rates and Pavement Rates on National Highways



Source: Prepared by the JICA Study Team based on the Statistical Annual Report on Roads 2019[32], Ministry of Land, Infrastructure, Transport and Tourism

Figure 6.24 Transitions in Improvement Rates and Pavement Rates on Prefectural Roads



Source: Prepared by the JICA Study Team based on the Statistical Annual Report on Roads 2019[32], Ministry of Land, Infrastructure, Transport and Tourism

Figure 6.25 Transitions in Improvement Rates and Pavement Rates on Municipal Roads

☞ Comparison of road pavement rates with foreign countries

Country	Road length (km)				Road density (km/km²)		Pavement ratio (%)	
	Total	Major arterial road (incl. Highways)	Secondary road	Others				
Asia								
09 Japan	1,207,867	62,432	129,377	1,016,05		3.20		80.11
09 Korea	104,983	17,595	18,138	69,250		1.05		79.25
06 Thai	180,053	51,855	44,000	84,198		0.35		…
09 China	3,860,823	124,517	300,686	3,435,62 0		0.40	08)	53.50
North and South								
09 USA	6,545,839	95,500	1,930,104	4,520,23		0.67	08)	100.00
09 Canada	1,409,000	103,000	115,000	1,911,00		0.14	04)	39.87
04 Brazil	1,751,868	93,071	276,776	1,382,02 1		0.21		…
Europe								
09 UK	419,665	52,706	122,543	244,416		1.72	05)	100.00
05 Italia	487,700	28,200	147,400	312,100	03)	1.62		100.00
08 Swiss	71,371	19,925	51,446	…		1.73		100.00
07 Spain	667,064	25,846	140,165	501,053	03)	1.32		…
09 Germany	643,969	52,700	178,269	413,000		1.80		…
09 France	951,260	20,260	381,000	550,000		1.73		100.00
09 Russia	982,000	…	…	…		0.06	07)	80.06
Africa								
01 South Africa	364,131	3,126	60,027	300,978		0.36		17.30
Oceania								
09 Australia	817,089	…	…	…		0.11		43.45
09 New Zealand	94,301	11,092	83,209	…		0.35		66.20

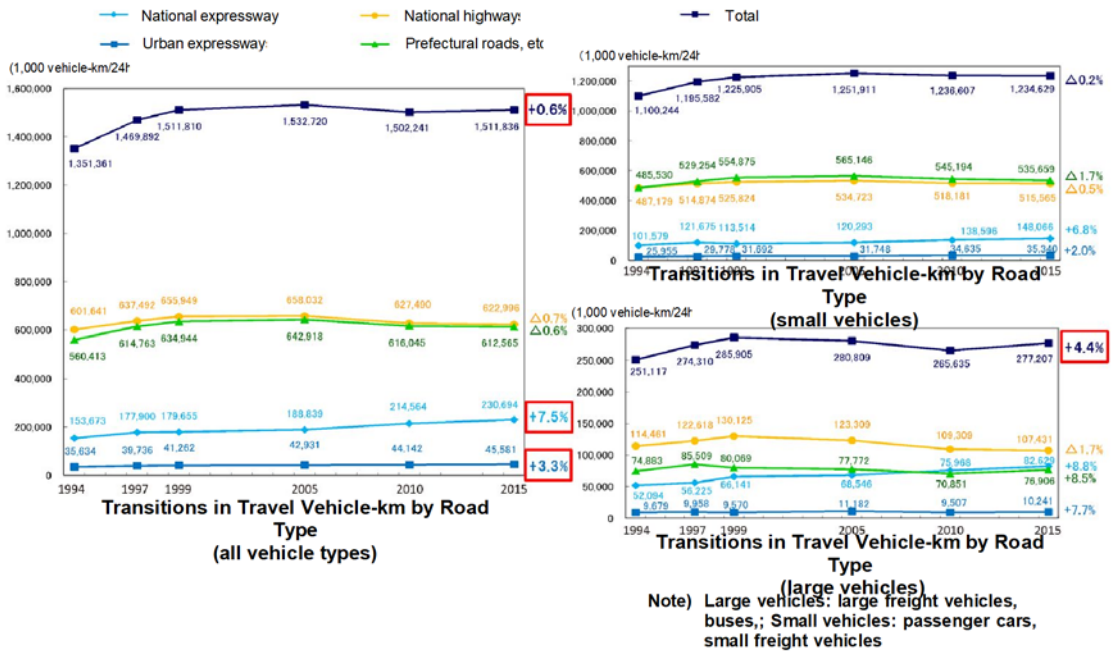
Note: Number before coutry name is year of the data.

Source: Ministry of Land, Infrastructure, Transport and Tourism (https://www.mlit.go.jp/statistics/pdf/23000000x023.pdf)

■ Road traffic volume

Figure 6.26 shows transitions in motor vehicle travel vehicle-kilometers according to type of road (excluding municipal roads) and type of vehicle. The figure for overall travel vehicle-kilometers remained more or less the same between 2010 and 2015, however, travel vehicle-kilometers for

large vehicles and on expressways increased.

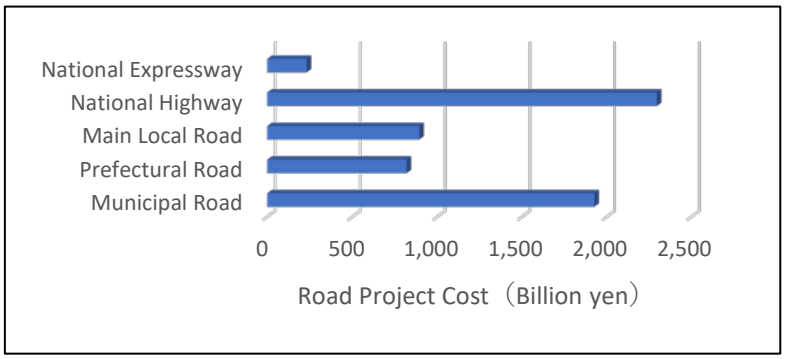


Source: Outline of the FY2015 Nationwide Survey of Highway and Street Traffic Conditions and Survey of General Traffic Volume, Road Bureau, Ministry of Land, Infrastructure, Transport and Tourism

Figure 6.26 Transitions in Travel Vehicle-kilometres by Type of Road and Type of Vehicle

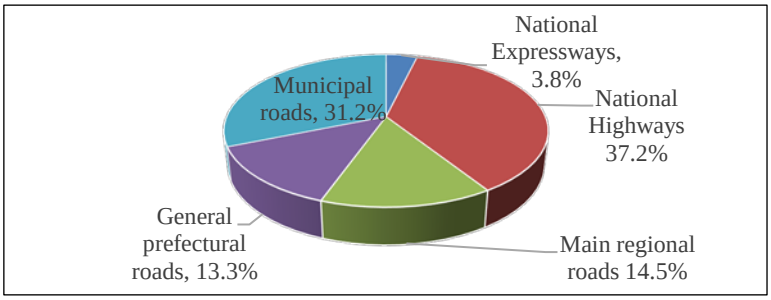
■ Road project costs

Road project costs in FY2017 were 6,169.7 billion yen. Of this, national highways accounted for the largest share, followed next by municipal roads.



Source: Prepared by the JICA Study Team based on the Statistical Annual Report on Roads 2019[32], Ministry of Land, Infrastructure, Transport and Tourism

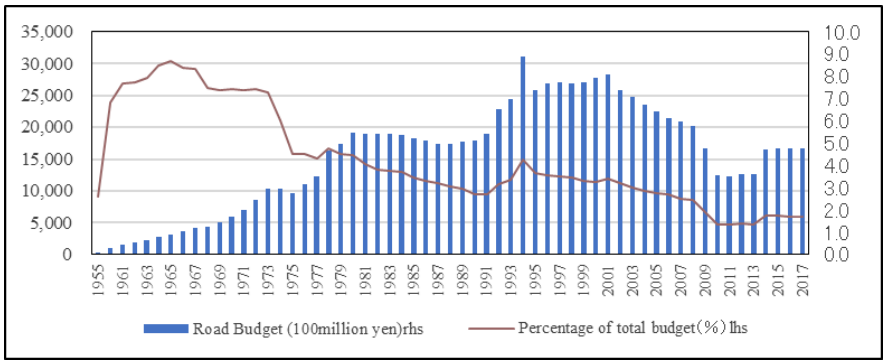
Figure 6.27 Road Project Costs by Type of Road



Source: Prepared by the JICA Study Team based on the Statistical Annual Report on Roads 2019[32], Ministry of Land, Infrastructure, Transport and Tourism

Figure 6.28 Composite Ratios of Road Project Costs by Type of Road

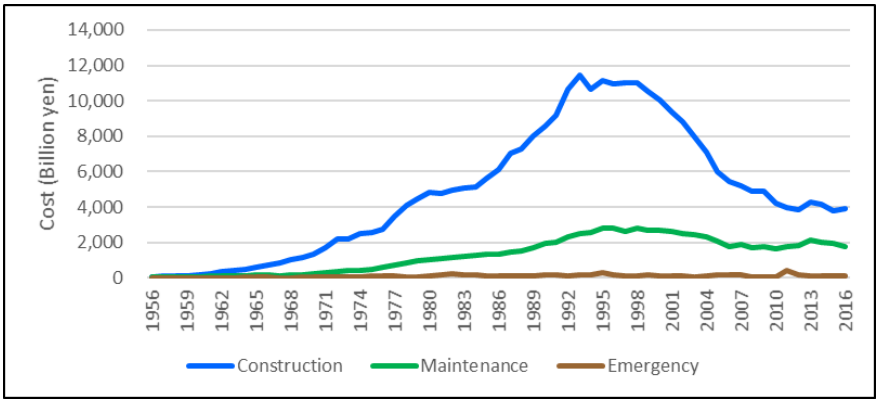
Figure 6.29 shows transitions in the budget amount of the central government. The ratio of budget for road out of the total national budget reached a peak of 8.7% in 1965 immediately after the Tokyo Olympic games, however, it has been around 1.7% in recent years.



Source: Prepared by the JICA Study Team based on the Statistical Annual Report on Roads 2019[32], Ministry of Land, Infrastructure, Transport and Tourism

Figure 6.29 Transitions in the National Road Budget

Figure 6.30 shows transitions in the overall road investment amount including central and local budget. Construction-related costs exceeded 10 trillion yen between 1992-2000, however, the figure has been around 4 trillion yen in recent years.



Source: Prepared by the JICA Study Team based on the Statistical Annual Report on Roads 2019[32], Ministry of Land, Infrastructure, Transport and Tourism

Figure 6.30 Transitions in Road Investment

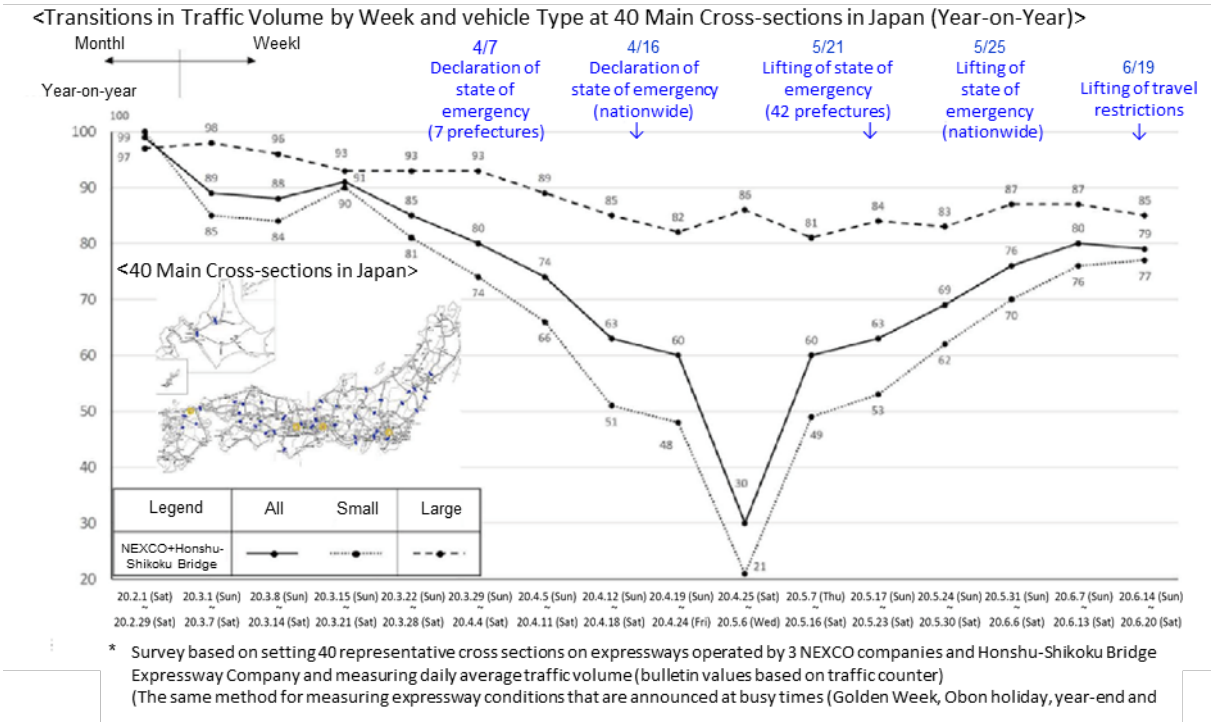
6.9 Reference on Policy of Road Transportation under Post Covid-19

In developing countries, the epidemic of coronavirus has been giving a great impact on road management and the implementation of public works. This section describes the changes in road traffic caused by the coronavirus in Japan, and Japanese road development/management policy in the post-corona era.

(1) Changes in Traffic Volume

■ Expressway traffic volume

- Expressway motor vehicle traffic volume dropped to 30% immediately after a state of emergency was declared. After restrictions on movement were relaxed, it recovered to 79%. (Figure 6.31)
- Within this, large-vehicle (freight vehicle) transport remained over 80% even during declaration of the state of emergency. Moreover, it is thought that the reduction to 80% or more was caused by the slowdown in economic activity more than the effects of declaration of the state of emergency. (Figure 6.32)



Source: "Concerning Expressway measures corresponding to Measures to Address Covid-19", Ministry of Land, Infrastructure, Transport and Tourism (https://www.mlit.go.jp/policy/shingikai/content/001351206.pdf)

Figure 6.31 Transitions in Expressway Traffic Volume

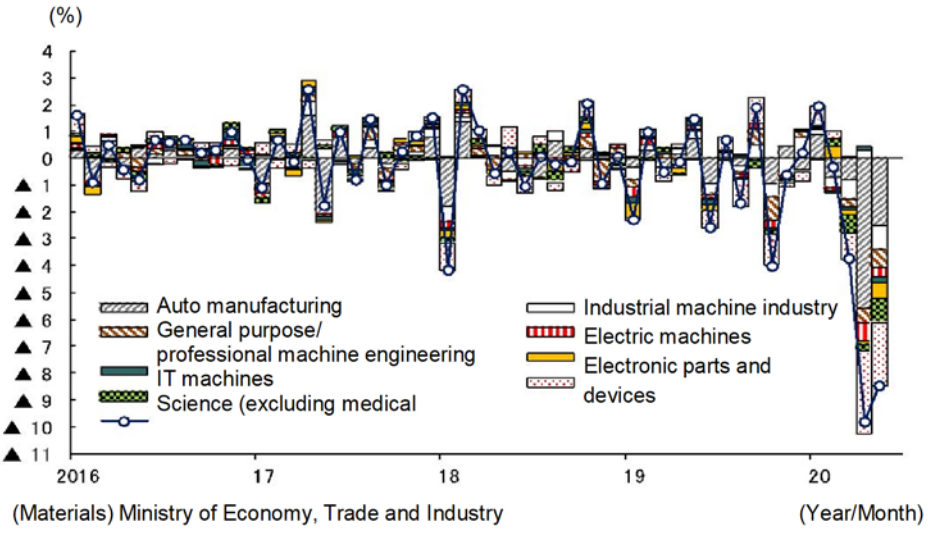
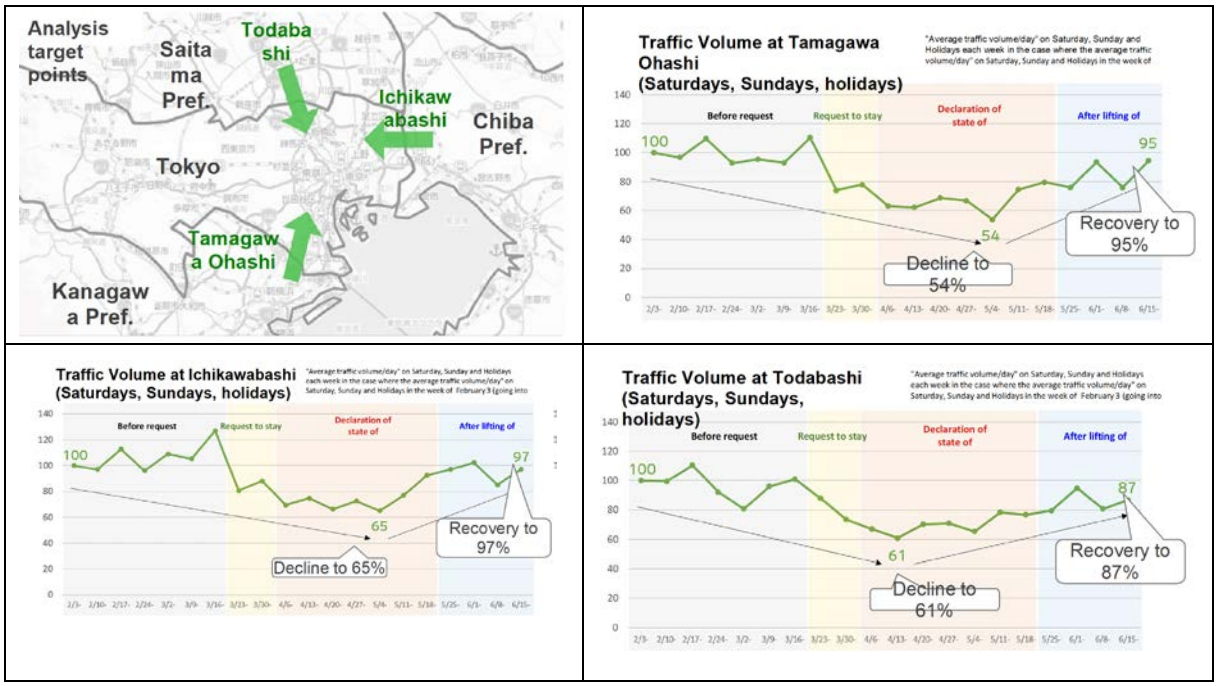


Figure 6.32 Transitions in Mining and Industry

■ Metropolitan area motor vehicle traffic volume

- Below are indicated materials indicating transitions in traffic volume entering Tokyo viewed according to three aspects.
- The incoming traffic volume during declaration of the state of emergency dropped to 54-65%, however, it recovered to 87-97％ after the declaration was lifted.
- Moreover, this drop of 3-13% is deemed to be caused by the slowdown in economic activity.



Source: NAVITIME "Analysis of changes in traffic volume and destination searches due to declaration of the state of emergency " (https://corporate.navitime.co.jp/topics/pr/202006/30_5265.html)

Figure 6.33 Changes in Traffic Volume Entering the Metropolitan Area

■ Freight motor vehicle traffic volume

- Concerning the truck freight transportation volume, figures are lower than in the same months the previous year for mixed load trucks and general trucks, however, they are 10% or higher for home delivery freight.

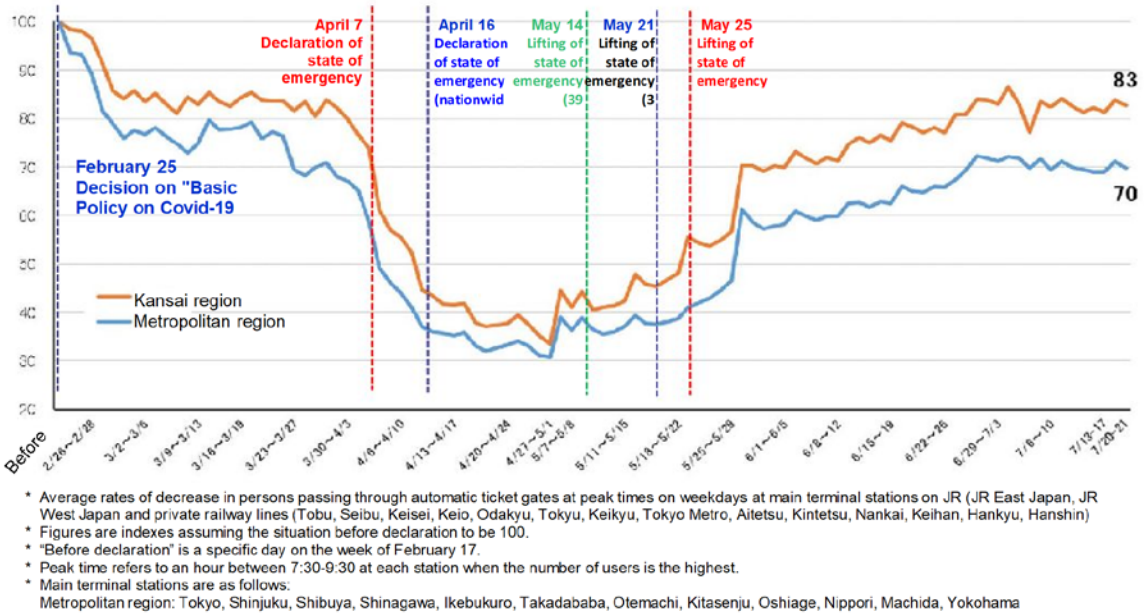
Table 6.33 Transitions in Truck Freight Transportation Volumes

			Special mixed load trucks		General trucks	Number of pieces of home delivery freight	
			(Tons)	Comparison with the same month the previous year (%)	Comparison with the same month the previous year (%)	(1,000 pieces)	Comparison with the same month the previous year (%)
Month	2019	March	5,622,842	△ 5.6	0.2	349,174	3.0
		April	5,601,729	1.9	0.9	341,192	4.3
		May	5,015,036	△ 3.9	△ 2.8	333,709	△ 1.7
		June	5,120,320	△ 5.3	△ 3.5	339,789	△ 1.9
		July	5,898,468	0.9	0.1	397,838	1.9
		August	4,911,540	△ 5.8	△ 2.6	327,487	△ 1.8
		September	5,403,846	4.9	3.6	347,269	8.8
		October	5,491,067	△ 7.2	△ 4.6	343,816	△ 4.5
		November	5,504,260	△ 6.6	△ 3.5	361,227	△ 2.4
		December	6,074,691	△ 2.5	△ 4.3	458,841	△ 0.6
	2020	January	4,748,950	△ 2.2	△ 1.3	324,159	1.3
		February	4,833,970	△ 2.8	△ 3.3	315,034	2.9
		March	5,578,303	△ 0.8	△ 0.1	368,025	5.4
		April	5,348,972	△ 4.5	△ 3.6	377,206	10.6

Source: Ministry of Land, Infrastructure, Transport and Tourism, Monthly Economy of Land and Transport (June 2020) https://www.mlit.go.jp/statistics/details/R02_geturei_.html

■ Public transportation

- The following materials show transitions in railway use based on the number of users passing through automatic ticket gates.
- During declaration of the state of emergency, the number of railway users dropped to approximately 30%, however, after the declaration was lifted, it recovered to 70% (metropolitan area) and 83% (Kansai area).



* Average rates of decrease in persons passing through automatic ticket gates at peak times on weekdays at main terminal stations on JR (JR East Japan, JR West Japan and private railway lines (Tobu, Seibu, Keisei, Keio, Odakyu, Tokyu, Keikyu, Tokyo Metro, Aitetsu, Kintetsu, Nankai, Keihan, Hankyu, Hanshin)
* Figures are indexes assuming the situation before declaration to be 100.
* "Before declaration" is a specific day on the week of February 17.
* Peak time refers to an hour between 7:30-9:30 at each station when the number of users is the highest.
* Main terminal stations are as follows:
Metropolitan region: Tokyo, Shinjuku, Shibuya, Shinagawa, Ikebukuro, Takadababa, Otemachi, Kitasenju, Oshiage, Nippori, Machida, Yokohama

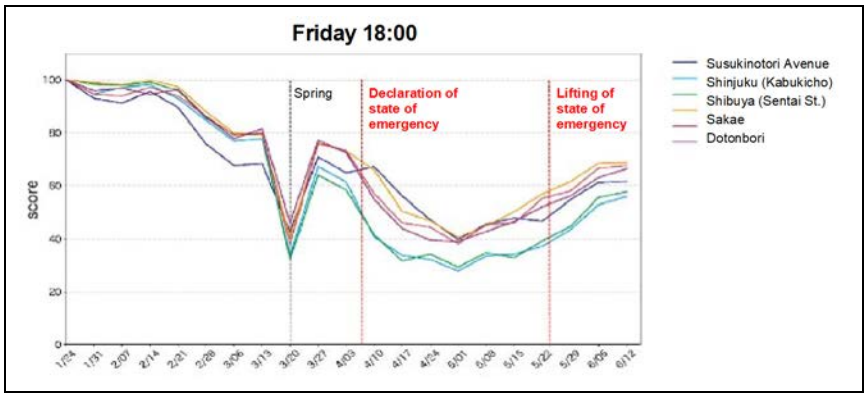
Source: Ministry of Land, Infrastructure, Transport and Tourism(https://www.mlit.go.jp/tetudo/tetudo_fr1_000062.html)

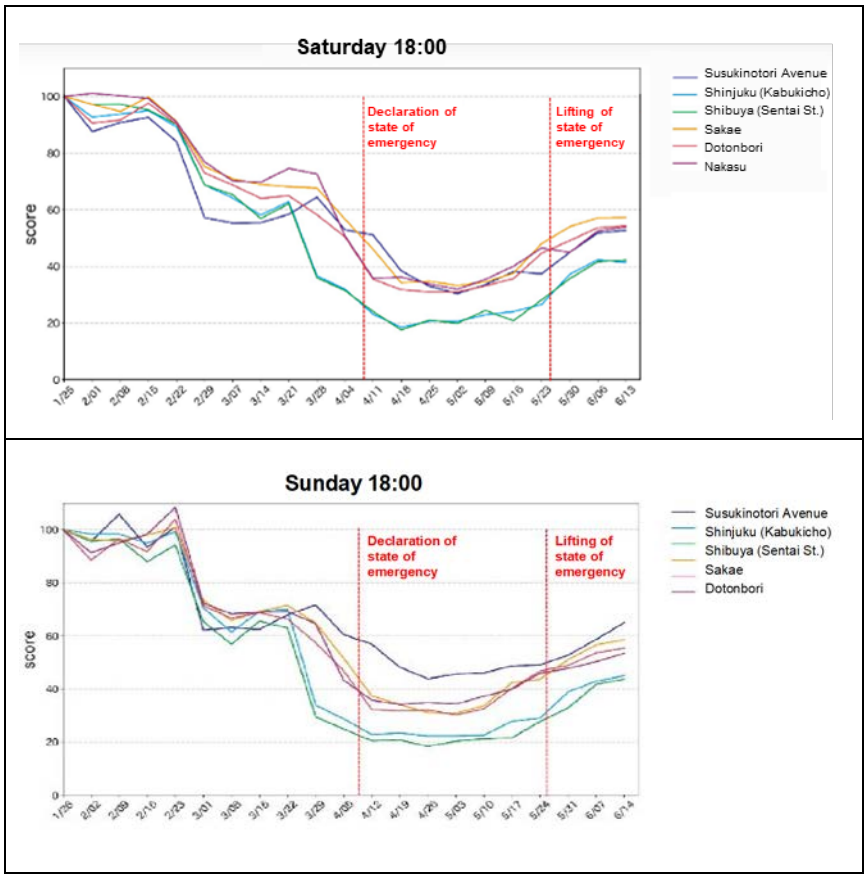
Figure 6.34 Transitions in Station Use at Peak Times following Calls to Conduct Telework and Staggered Work Hours

(2) Pedestrians and Bicycles

■ Pedestrians

- Although not materials related to the number of pedestrians, below are indicated materials showing changes in estimated population in the main entertainment districts.
- Looking at Shinjuku and Shibuya, the figure on Fridays, Saturdays and Sundays dropped to around 20-30% during declaration of the state of emergency, but recovered to 40-50% after the declaration was lifted.



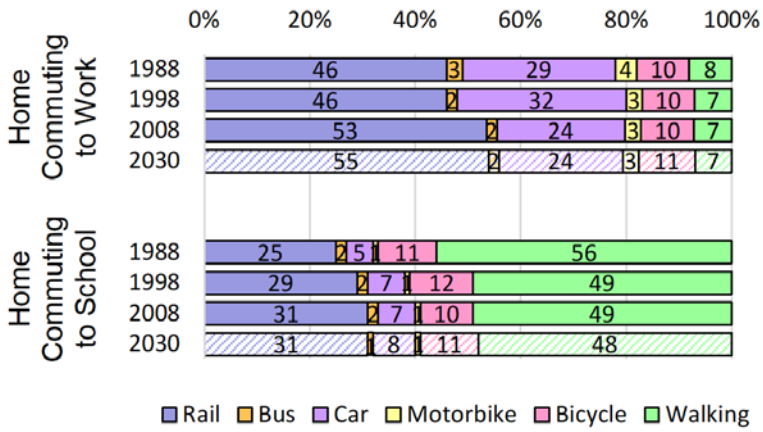


Source: "How have human movements changed since declaration of the state of emergency was lifted?Changes in movements as seen through Yahoo big data" (https://about.yahoo.co.jp/info/blog/20200617/bigdata.html)

Figure 6.35 Transitions in Estimated Population in Entertainment Districts

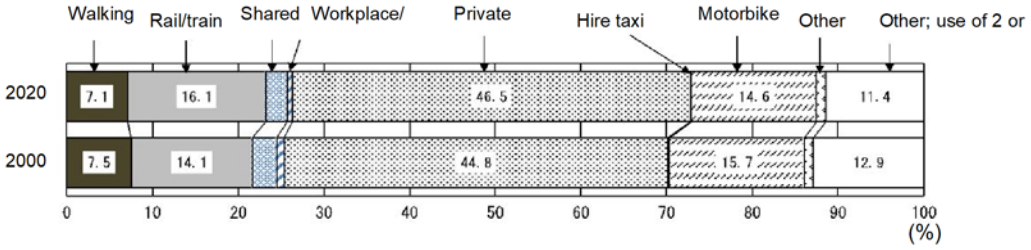
■ Bicycles

- The following materials indicate changes in means of transport used for commuting to work/school based on questionnaire survey.
- The target population, and timing before and after the Covid-19 pandemic are unclear; moreover, differences between means of transport used in the Tokyo metropolitan area PT (Figure 6.36) and means of transport used for commuting to work/school based on the national census (Figure 6.37) are especially large for motor vehicles and walking, however, the number of people using bicycles increases twofold from 20% to 40%.
- When viewed in terms of distance, the increase is prominent when the distance increases to 10km or more.



Source: Issues and Directions of Measures concerning Urban Transport in Tokyo Metropiolitan Area as viewed in Person-trip Survey[33] (https://www.tokyo-pt.jp/static/hp/file/publicity/pt_120201.pdf)

Figure 6.36 Means of Transport used for Commuting in the Tokyo Metropolitan Area



Source: Statistic Bureau, Ministry of Internal Affairs and Communications (https://www.stat.go.jp/data/kokusei/2010/final/pdf/01-11_5.pdf)

Figure 6.37 Means of Transport used for Commuting in Japan

Table 6.34 Ratios of Means of Transport Before and After the Covid-19 Pandemic

Means of Transport Before the Covid-19 Pandemic

Distance to workplace/school	Bicycle	Train	Car	Bus	Walking	Motorbike	Other	Total
15km or more	32	102	2				1	137
	23.36%	74.45%	1.46%	0.00%	0.00%	0.00%	0.73%	100.00%
10km-less than 15km	45	65	5	1				116
	38.79%	56.03%	4.31%	0.86%	0.00%	0.00%	0.00%	100.00%
5km-less than 10km	37	38	3	3			1	82
	45.12%	46.34%	3.66%	3.66%	0.00%	0.00%	1.22%	100.00%
Less than 5km	49	13	2	4	8	1	1	78
	62.82%	16.67%	2.56%	5.13%	10.26%	1.28%	1.28%	100.00%
Less than 1km	12				6			18
	66.67%	0.00%	0.00%	0.00%	33.33%	0.00%	0.00%	100.00%
Working at home	3	4	1		1		6	15
	20.00%	26.67%	6.67%	0.00%	6.67%	0.00%	40.00%	100.00%
Total	178	222	13	8	15	1	9	446

Means of Transport After the Covid-19 Pandemic

Distance to workplace/school	Bicycle	Train	Car	Bus	Walking	Motorbike	Other	Total
15km or more	55	75	4			1	2	137
	40.15%	54.74%	2.92%	0.00%	0.00%	0.73%	1.46%	100.00%
10km-less than 15km	74	38	3			1		116
	63.79%	32.76%	2.59%	0.00%	0.00%	0.86%	0.00%	100.00%
5km-less than 10km	55	21	3	1	1		1	82
	67.07%	25.61%	3.66%	1.22%	1.22%	0.00%	1.22%	100.00%
Less than 5km	54	7	1	3	9	2	2	78
	69.23%	8.97%	1.28%	3.85%	11.54%	2.56%	2.56%	100.00%
Less than 1km	12				6			18
	66.67%	0.00%	0.00%	0.00%	33.33%	0.00%	0.00%	100.00%
Working at home	6	1	1		1		6	15
	40.00%	6.67%	6.67%	0.00%	6.67%	0.00%	40.00%	100.00%
Total	256	142	12	4	17	4	11	446

15km or more				+16.8%
Bicycle:	23.4%	⇒	40.2%	
Train:	74.5%	⇒	54.7%	
				-19.8%
10Km-less than 15km				+25.0%
Bicycle:	38.8%	⇒	63.8%	
Train:	56.0%	⇒	32.8%	
				-23.2%
5Km-less than 10km				+22.0%
Bicycle:	45.1%	⇒	67.1%	
Train:	46.3%	⇒	25.6%	
				-20.7%
Less than 5km				+6.4%
Bicycle:	62.8%	⇒	69.2%	
Train:	16.7%	⇒	8.97%	
				-7.73%

Source: "Survey and Analysis of Bicyle Transport After Lifting of the Declaration of State of Emergency. Although there is a trend of increase in urban areas, the critical condition is averted" (https://news.yahoo.co.jp/articles/48a13ad8125cd56848ae2654999115be772d5d15)

- In addition, it is reported that use of bicycle sharing increased following declaration of the state of emergency, however, no statistical figures have been obtained.

(3) Summary of Traffic Volume Trends

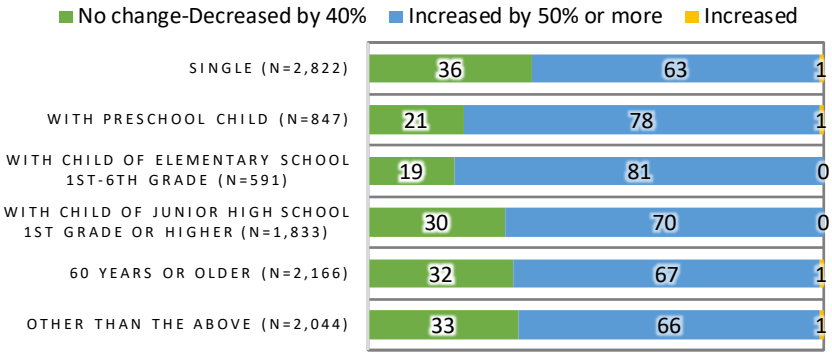
Since Covid-19infections still pose a risk, it is difficult to foresee the situation after Covid-19 (post-Covid-19[2]), however, the following points are clear.

- Looking at the overall motor vehicle traffic volume, it cannot be considered that traffic volume will dramatically decrease after the Covid-19 crisis is over.
- Within motor vehicle transport, freight transport has been maintained as a pillar of economic activity and lifestyles, and securing these functions will continue to be important.
- Concerning public transportation, a trend of decrease has been gauged during and after declaration of the state of emergency, but it is not yet clear how much telework and staggered working hours will become established after Covid-19.
- Concerning use of bicycles, which has increased during the Covid-19 pandemic, it is thought that bicycles will continue to be used from now on, although it is not clear how

(4) Awareness of Users

■ Awareness concerning use of motor vehicles

It is clear that the Covid-19 pandemic has caused people to stop going out, and this has also been reported in various surveys.

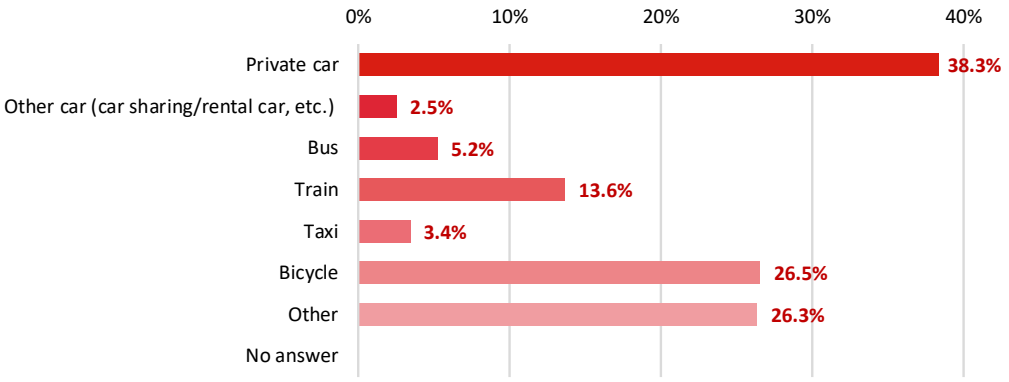


Source: Nikkan Kogyo Shimbun (https://www.intage.co.jp/information/pdf/yjJBZWf.pdf)

Figure 6.38 Frequency of Going Out after the Covid-19 Pandemic (%)

[2] Here, based on the following quote from WikiDiff, the period during the Covid-19 pandemic is termed "with-Covid-19", the entire period since the start of the Covid-19 pandemic is termed "post-Covid-19", and the period after the Covid-19 pandemic has abated is termed "after-Covid-19".
Post is: after; especially after a significant event that has long-term ramifications while after is subsequently to; following in time; later than.

However, in spite of this situation, motor vehicles have increased the most as the means of transport used when going out.

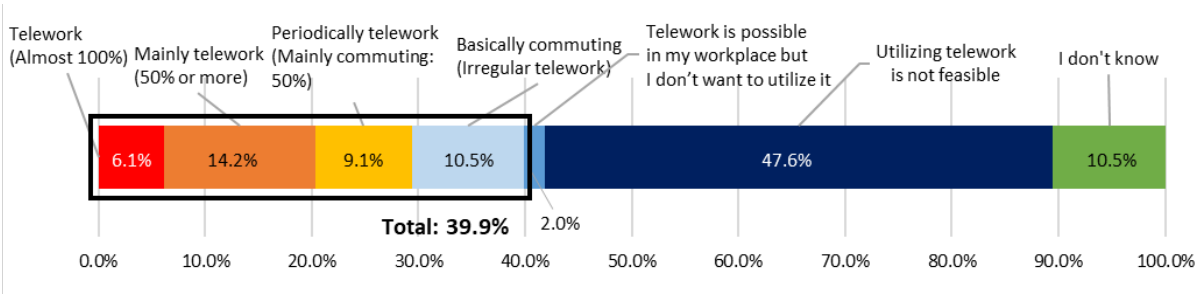


Source: MOTA (Move on Travel Around)(https://autoc-one.jp/special/5007388/photo/0002.html)

Figure 6.39 Means of Transit that have Increased During Declaration of the State of Emergency

■ Awareness regarding working mode (telework)

- The following figure indicates how far telework that was implemented during declaration of the state of emergency will become permanently established.
- Looking at how far telework is conducted, the combined ratio of telework, completely telework, mainly telework, and periodically telework is 29.4%, of which 6.3% implement completely telework.
- However, even assuming that telework is continued at this level, there is currently no clear data to show which means of transport will decrease.



Note: Survey period: May 25-June 25
Source: Cabinet Office, "Survey on Changes in Life Awareness and Behavior under the Impact of the Covid-19 Pandemic" (https://www5.cao.go.jp/keizai2/manzoku/pdf/shiryo2.pdf)

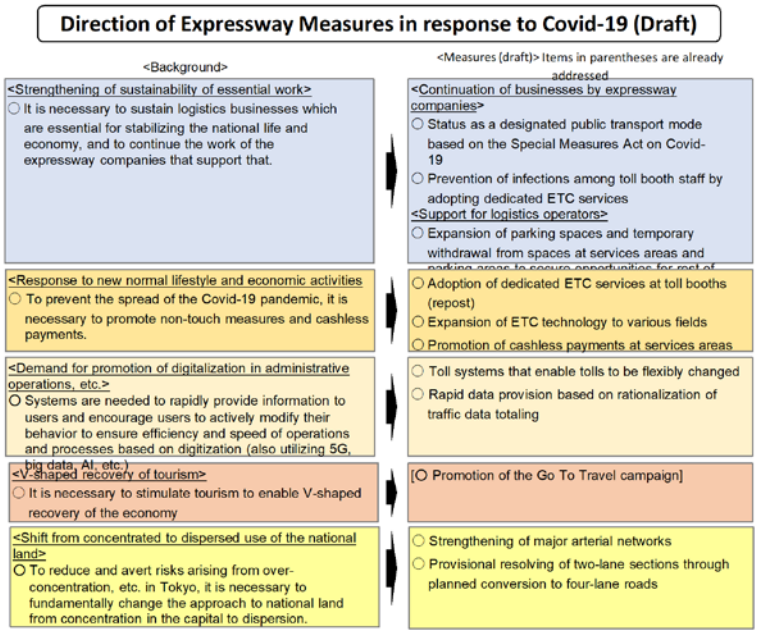
Figure 6.40 Desire to Use Telework (Workers)

(5) Transport Measures in the Age of Covid-19

The Ministry of Land, Infrastructure, Transport and Tourism is proposing a number of measures for responding to Covid-19. These are introduced here (announced on June 18, 2020).

■ Expressway measures

The Council for Social Infrastructure Highway Subcommittee is conducting examination with a view to proposing an interim summary of expressway initiatives in the Age of Covid-19 (draft) by around the fall of 2020. The direction of measures is indicated in the following chart.



Source: Ministry of Land, Infrastructure, Transport and Tourism(https://www.mlit.go.jp/policy/shingikai/content/001351206.pdf)

Figure 6.41 Direction of Expressway Measures in Response to Covid-19

■ Promotion of bicycle commuting

Measures are composed of the following three components.

- Promotion of introduction of a system of bicycle commuting in companies, organizations, etc.
- Promotion of development of bicycle passage spaces
- Expansion of share cycling

Moreover, promotion of bicycle use is being advanced around the world. Some examples are given below.

"In China, share cycle users are increasing rapidly as a means of preventing the spread of Covid-19"

(https://cyclejapan.club/china-sharecycle-covid19/)

"Experiment on small-scale community development in the post-Covid-19 age. "Tactical Urbanism" in Barcelona"

(https://ideasforgood.jp/2020/05/21/tactical-urbanism/)

"Italian cities announce plans to maintain reduced car use after lockdown"

(https://www.eltis.org/in-brief/news/italian-cities-announce-plans-maintain-reduced-car-use-after-lock-down)

■ Improvement of the rest facilities environment for use by logistics operators

To benefit logistics operators who are essential for maintaining functions in the midst of the Covid-19 pandemic, as was seen in the section on expressway traffic volume, parking spaces are being expanded and double-articulated truck parking reservation systems are being introduced to rest facilities on expressways.

■ Temporary and provisional utilization of streets as a "Three Cs (Crowded places, Close-contact setting and Confined and enclosed spaces)" measure when bars and restaurants reopen

As an urgent measure to support bars and restaurants that have been hit by the Covid-19 pandemic, road occupancy authorization criteria have been relaxed concerning utilization of streets for takeout deliveries and business operations on street terraces, etc.

(6) Post-Covid-19 Road Measures

The Ministry of Land, Infrastructure, Transport and Tourism has proposed the above initiatives as "road measures for responding to the new way of life in the immediate future". In addition, it has proposed the "post-Covid-19 road measures" described below, and the Council for Social Infrastructure, etc. will conduct examination based on these.

The "2040 Vision for Roads in Japan" that is quoted here was deliberated by the Basic Policy Section Meeting of the Highway Subcommittee, the Council for Social Infrastructure in the Ministry of Land, Infrastructure, Transport and Tourism. Deliberation was commenced in the 70th subcommittee meeting on September 27, 2019, and the main text was compiled in the 73rd subcommittee meeting on February 21, 2020. Accordingly, although examination of changes in transport in the post -Covid-19 age are not adequately covered, this report demonstrates the future appearance of roads including deployment of 6G and automatic driving and will contribute to future road measures.

Moreover, on the website of the Ministry of Land, Infrastructure, Transport and Tourism, the said vision is compiled as proposals by the Basic Policy Section Meeting of the Highway Subcommittee, the Council for Social Infrastructure, and opinions will be invited from the public as it is evolved and improved from now on. Accordingly, this vision will be regarded as a "presentation of problems" as the future examination of post-Covid-19 transport measures is conducted.

(1) Viewing the "2040 Vision for Roads in Japan" issued by the Minister today (June 18) as a presentation of problems, examination will also be conducted on post-Covid-19 road measures for supporting the new normal and socioeconomic in the post -Covid-19 age.
(2) In conducting examination, proposals for "road initiatives in the post -Covid-19 age" will be sought from companies, universities, etc. with a view to enabling the opinions, etc. of

various persons to be referred to.

◆Application period: June 18, 2020 (Thursday) – July 17, 2020 (Friday)

◆Details can be confirmed at the following link:

https://www.mlit.go.jp/road/vision/03-1.html

[Outline of the "2040 Vision for Roads in Japan"]

① The Vision compiles the vision of Japanese society in 2040 that is aimed for through road policies, and it also indicates policy directions.

② While setting the universal value of "achieving people's happiness" as the start point, the Vision proposes goals based on the concepts of "evolution and restoration".

③ It predicts five images for the future showing how "travel" and "road scenery" will change, while also proposing easy to understand 10 policy directions with illustrations.

④ In compiling the proposals, the opinions of experts and experienced staff in the Road Bureau (Note) were reflected.

Note) Proposals by experienced staff in the Road Bureau were presented in the 70th Basic Policy Section Meeting.

https://www.mlit.go.jp/policy/shingikai/content/001310306.pdf

"2040 Vision for Roads in Japan" top page

https://www.mlit.go.jp/road/vision/index.html

"2040 Vision for Roads in Japan" main text

https://www.mlit.go.jp/road/vision/pdf/01.pdf

Source: https://www.mlit.go.jp/report/press/road01_hh_001332.html

The proposal of problems concerning transport measures in the post-Covid-19 age is described in the following foreword.

Foreword

Modern society is placed in an age of ubiquitous change characterized the acronym VUCA, which stands for volatility, uncertainty, complexity, and ambiguity. Amidst rapidly advancing technical innovation, there are numerous sudden and unforeseen events, such as pandemics, making it extremely difficult to predict a clear future vision. However, the future is not something that just inevitably happens, but rather it is made as a result of the accumulation of the decisions we make.

The unparalleled crisis of the Covid-19 pandemic has imparted immense impacts on the lives and lifestyles of citizens and economy. Meanwhile, amidst the environment of prolonged restrictions on travel and interchange, many companies, governments and authorities are engaging in telework. Moreover, we have been reminded of the universal value of interpersonal communication and importance of stable physical distribution.

It is forecast that measures to address Covid-19 will continue for the long term, however, roads, which are essential for securing stability of people's lives and economy, will need to serve as

lifelines on a continued basis. Road administration is today faced with the issues of continuing to implement road management amidst efforts to control the pandemic and securing nationwide physical distribution while suppressing the nonessential movement of people. To achieve co-existence withCovid-19, it is first necessary to quickly establish measures for addressing such issues.

Even if the Covid-19 crisis does settle down, work methods including telework will not return to normal. The Covid-19 crisis will accelerate changes in lifestyles and socioeconomic structures and become the driving force behind emergence of the "New Normal". Already in the countries of Europe and America, with a view to society in the post-Covid-19 age, initiatives are being announced to redesign urban road spaces, widen spaces for pedestrians and bicycles, and innovate road infrastructure and methods of use to ensure social distancing. Considering that the world has experienced repeated pandemics throughout history, roads must also change at an unprecedented rate as the foundation for supporting the new normal in the face of future pandemics. Japan is also confronted with an urgent need to discuss such developments.

"2040 Vision for Roads in Japan" proposes the vision for society and medium- to long-term policy directions to aim for in road administration with an eye on Japanese society in around 20 years from now, while also considering the post-Covid-19 new normal and socioeconomic changes. It is hoped that this Vision will provide a base for discussions on Japan's social vision in the medium- to long-term including changes in post-Covid-19 society, thereby allowing road policies to be examined and deployed with an open mind unfettered by preconceived ideas.

It is also hoped that this Vision will reach road users and encourage them to think about the role of roads and ways to transform road scenery, and that it will be widely shared among road policymakers, related government agencies, local governments, industry, universities and other research agencies, private sector organizations, etc., thereby encouraging debate and cooperation among related parties, stimulating concrete measures and deepening road policy.

This Vision was compiled as proposals by the Basic Policy Section Meeting of the Highway Subcommittee in the Council for Social Infrastructure, however, it will undergo further improvements as debates are conducted between related parties from now on.

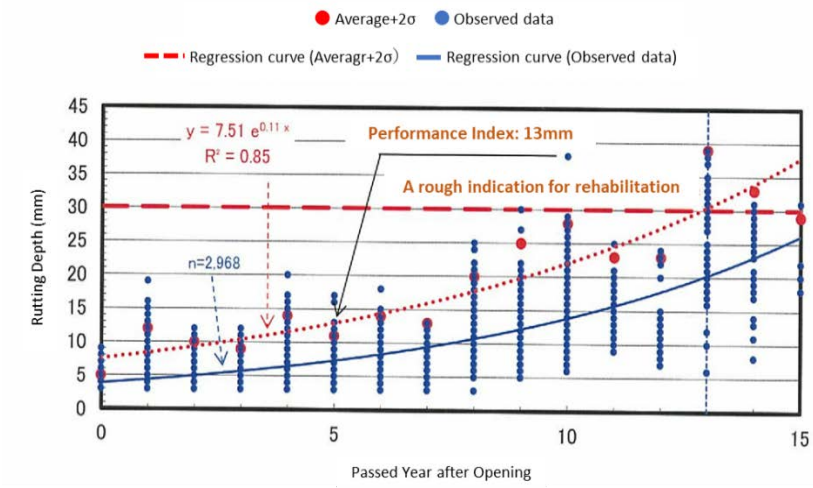
6.10 Reference on Long-term Warranty for Road Pavement in Japan

(1) Purposes of Long-term Warranty

Currently, the long-term warranty system is applied in principle for new asphalt pavement construction carried out by the Ministry of Land, Infrastructure, Transport and Tourism. The long-term warranty system referred to here is a contractual act that stipulates, based on past knowledge, a threshold value for the performance of a constructed structure after a certain period of use and expects the contractor to fulfill. The basic principle of the long-term warranty system is that both the client and the contractor are aware of the need to ensure the long-term quality of the target products, and seek issues and solutions to achieve this. The purpose of the system is to ensure long-term quality by controlling and managing the initial deformation through more accurate construction, and to facilitate the smooth functioning of performance-based contract and to develop and introduce lower-cost and higher-quality private sector technologies.

(2) Performance Index

The Tohoku Regional Development Bureau examined the relationship between each performance index item and service life by using approximation curves based on past actual data. As a result, the approximate curve that almost matches the "rutting amount of 30 mm" with the "target value of pavement service life of 13 years" was "average value + 2σ," as shown in Figure 6.42. Therefore, the performance index value is set at "rutting amount of 13 mm" when the service life is 5 years.



Source: Guidebook on Long-Term Pavement Warranty System[34]

Figure 6.42 Investigation of Performance Indices for Rutting Based on the Actual Condition of Road Surface (Dense-Grained Asphalt Pavement)

(3) Provisions on Security Deposit and Recovery Measures

Failure to satisfy the performance index value does not constitute itself a contract default, as long as the contractor pays the deposit and implements recovery measures in accordance with the contract terms. The contractor should fully understand the contents of the contract in advance.

- Security Deposit

The security deposit is set at the discretion of the client when the long-term guaranty system is applied. For example, there are some cases where regional development bureaus of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) are applying the security deposit when the amount of rutting exceeds the set performance index and is less than 30 mm, and when the crack ratio exceeds the set performance index and is less than 30%.

- Recovery Measures

The recovery measures are set at the discretion of the client when the long-term guaranty system is applied. For example, there are some cases where the regional development bureaus of the Ministry of Land, Infrastructure, Transport and Tourism are applying recovery measures when the amount of rutting reaches 30 mm or more, or when the crack ratio reaches 30% or more. The method of recovery is generally determined by the client or road administrator with reference to the proposal of the contractor.

(4) Long-Term Warranty System and Defects

In Japan, in the case of public works, generally, the liability period for non-conformity to the contract is two years (ten years in the case of intentional or gross negligence). If an event occurs during this period that makes it unacceptable for normal use and negligence on the part of the contractor is confirmed, the contractor will be subject to penalties such as compensation for damages, suspension of nomination, and reduction in points for construction performance as "contract nonconformity".

On the other hand, in the long-term warranty system, even if the performance index value is not satisfied, it is assumed that it will not lead to contractual nonconformity if there is no obstacle in normal use. In such cases, the payment of the deposit and the implementation of recovery measures imposed on the contractor are to avoid non-conformity of the contract due to the failure to satisfy the contract terms, and are not meant as penalties.

Table 6.35 Difference between Long-term Warranty and Defect

	Duration	Propriety of normal use	Presence of negligence	Measure
Failure to meet the performance index	5years	Normal use is possible	No negligence in materials or construction	Security money or recovery measures
Non-conformity of the contract	General billing period: 2years In case of intentional or gross negligence: 10years	Cannot withstand normal use	There is negligence in materials and construction.	Indemnity Suspension of nomination Reduction of points for construction performance

Source: Guidebook on Long-Term Pavement Warranty System[34]

(5) Expanded Applicable Scope

The long-term warranty system was subsequently attempted to be extended to other structures. Under the jurisdiction of Chubu Regional Development Bureau, trials were conducted for PC bridge construction, and under the jurisdiction of Chugoku Regional Development Bureau, trials were conducted for tunnel construction. Performance warranties were imposed on cracks in concrete, and performance warranty values after a certain period of time were set for PC bridges for concrete at the girder ends and for tunnels for lining concrete. However, since then, it has not been widely applied as in asphalt pavement.

Source: Preparated by JICA Study Team based on "Guidebook on Long-Term Pavement Warranty System[34]" and "Long-term Warranty and Technical Evaluation[35]"

(6) Applicability to Grant Aid Project

As is the case of several similar contract type proposed such as Performance Based Contract, in case of introducing Japanese long-term pavement warranty system to Grant Aid projects, there are many issues to be addressed and changes to the system are necessary. The general approach of contractors who implements road construction projects by Grant Aid is to bring in the used construction machinery necessary to complete the project, complete it quickly, and move out quickly (hit and leave method), not considering operating many years in the country. On the other hand, in Japan, asphalt plants and pavement construction machines are owned locally for a long period, so long-term quality assurance is possible. Since the definition of liability for defects in overseas civil engineering works is "fair wear and tear excepted", while the long-term warranty system requires long-term quality assurance including fair wear and tear, it is necessary to drastically review the contract terms. For example, in road construction, local companies that are capable of supporting the long-term warranty system should be appointed as subcontractors for subgrade, base course/subbase course, and pavement work, and the subcontractors should be requested to provide long-term quality assurance instead of the main contractor. It is also the duty of the construction company to carry out the work to meet the minimum level required by the client as specified in the specifications, and the design consultant must clarify how many years the service life of the road will be at that required level. Furthermore, if the responsibility of the items exempted from

the construction company under the long-term warranty system is the responsibility of the client, there is also a problem that the client's ability to respond is low. This applies to situations where there is insufficient control of overloading and there are many overloaded vehicles on the road. In such a case, the long-term warranty system will no longer be viable.

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