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

Site Survey Report

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JAPAN INTERNATIONAL COOPERATION AGENCY

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GL
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Site Photos in Ethiopia

1) NR No.3 (Phase I section by Japanese ODA)

Good condition with respect to large number of heavy vehicles

Adopted concrete pavement at Bus Bays

2) NR No.3 (Phase II section by Japanese ODA)

Damaged section where has large catchment area, it may be responded by ground water.

Damaged section where is identified at cut area, it may also be responded by ground water.

3) NR No.3 (Phase III section by Japanese ODA)

Flow rutting was identified at lowland in Abay, because of high temperature and heavy vehicle with low speed.

Flow rutting at sharp curve might be caused by side slip of rear tires.

In several portion, pavement was destroyed because small and/or large scale land-slides have been occurring in Abay

Heavy vehicles hauling lime-stone have been passing in Abay. Travelling speed is lower than walking speed.

4) NR No.1

Large number of flow rutting is identified on climbing lane in lowland located around 1,000m in height.

Bypass for NR No.1 is under construction by Chinese contractor.

5) Weighbridge on NR No.1

Axle load check has been strictly doing in cooperation with police.

Axle load is measured by each axle, regulated value for front and rear axle is 8ton and 10ton a axle, respectively.

Site Photos in Ghana

1) NR No.1 (Accra – Tema Highway)

Four-lane concrete pavement which is improved under leadership of the first president

Good condition after completion is kept by optimum maintenance.

2) NR No.1 (George Bush Highway)

Six-lane road financed by Millennium Challenge Corporation (MCC)

Adopted concrete pavement at Bus Bays

3) NR No.1 (Suburban Area)

Shoulder pavement destroyed by traffic for small access road, because of thin layer (DBST)

Four-lane road with wide median strip which has center drainage facilities

4) NR No.8

Reappeared pot hole on repaired section

Trace of repair at sag point

New As binder course under construction by Japanese ODA, qualities such as flatness are high.

New surface As pavement under construction by Japanese ODA, As content of 5.1% is relatively high.

5) Tema Weighbridge

Layout of Tema weighbridge is same as highway parking in Japan.

Not each axle but total weight is measured at weighbridge.

1) Kilwa Road in Dar es Salaam (Improved by Japanese ODA)

Flow rutting with large scale on outside lane of carriage way

Bus Bay along Kawawa road, Semi-flexible pavement was adopted for huge number of buses.

Center drainage on median strip, drainage system was carefully designed.

Large pot hole and flow rutting on straight section This phenomenon may be caused from thin layer with flow rutting.

Side drainage was filled with water because of breakage of crossing pipe.

Same as left photo. Downstream side of crossing pipe was blocked with broken piece of pavement.

Site Photos in Tanzania

2) Challinze-Tanga Road (Rehabilitated by DANIDA)

Pavement slip was occurred at interlayer between new surface and old surface. Thin new surface of 4cm may be caused this slip.

Same as left picture

3) Kibaha-Challinze Section (Rehabilitated by TANROADS)

Long flow rutting on Kibaha-Challinze section. It occurred after repair work by own budget.

A line of heavy vehicles on Kibaha-Challinze section. (from Dar es Salaam to outside)

4) Kibaha Weighbridge

Weighbridge is located on both side of road.

Under measuring, Axle load is measured by each axle.

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LIST OF ABBREVIATIONS

AASHTO	: American Association of State Highway and Transportation Officials
AC	: Asphalt Concrete
AfDB	: Africa Development Bank
As	: Asphalt
BBR	: Bending Beam. Rheometer
BS	: British Standard
CBR	: California Bearing Ratio
CIA	: Central Intelligence Agency
CML	: Central Material Laboratory
Co	: Concrete
DANIDA	: Danish International Development Agency
DBM	: Dense Bitumen Macadam
DBST	: Double Bitumen Surface Treatment
DCP	: Dynamic Corn Penetration
DD	: Detail Design
DFR	: Department of Feeder Roads
DMS	: Detail Measurement Survey
DS	: Design Standard
DS	: Dynamic Stability
DSR	: Dynamic Shear Rheometer
DT	: Direct Tension
DUR	: Department of Urban Roads
EN	: Exchange of Note
ERA	: Ethiopian Roads Authority
ERCC	: Ethiopian Roads Construction Corporation
ESAL	: Equivalent Single Axle Load
EU	: European Union
FAR	: Federal Acquisition Regulation
FIDIC	: Fédération Internationale Des Ingénieurs-Conseils
FS	: Feasibility Study
GA	: Grant Agreement
GCW	: Gross Combined Weight
GDP	: Gross Domestic Product
GHA	: Ghana Highway Authority
GNI	: Gross National Income
GVW	: Gross Vehicle Weight
HDM	: Highway Development and Management
HIPCs	: Heavily Indebted Poor Countries
HWL	: High Water Level
ITP	: Inspection and Test Plan
IRF	: International Road Federation
IRI	: International Roughness Index
ISOHDM	: International Study of Highway Development and Management System
HGV	: Heavy Goods Vehicle
JICA	: Japan International Cooperation Agency
JIS	: Japan Industrial Standard
JTF	: Joint Task Force
JV	: Joint Venture
LCC	: Life Cycle Cost
MDL	: Maximum density line
MGV	: Medium Goods Vehicle
NEXCO	: Nippon Expressway Company
NMT	: Non-motorized Traffic
NTP	: National Transport Policy
OD	: Outline Design
ODA	: Official Development Assistance
ORN	: Overseas Road Note
PAV	: Pressure Aging Vessel
PFI	: Private Finance Initiative
PG	: Performance Grade
PI	: Plasticity Index

PI : Professional Indemnity

PIARC : Permanent International Association of Road Congress

PMA : Polymer-modified Asphalt

PSI : Present Serviceability Index

PQ : Pre-qualification

QAM : Quality Assurance Manual

QAP : Quality Assurance Plan

QC : Quality Control

RCCP : Roller－compacted Concrete for Pavement

RD : Rate of Deformation

RFI : Request for Inspection

RRL : Road Research Laboratory

RSDP : Road Sector Development Programme

SA : South Africa

SATCC : Southern Africa Transport and Communications Commission

SBS : Styrene-butadiene-styrene

SCS : Soil Conservation Service

SGC : Superpave Gyratory Compactor

SHRP : Strategic Higway Research Program

SN : Structure Number

TANROADS : Tanzania Road Authority

TICAD : Tokyo International Conference on African Development

TOR : Term of Reference

TPB : Treated Permeable Base

TRH : Technical Recommendations for Highways

TRL : Transport Research Laboratory

TRRL : Transport and Road Research Laboratory

TSDP : Transport Sector Development Programme

TSIP : Transport Sector Investment Programme

UEMOA : Union Economique et Monetaire Ouest Africaine

UN : United Nation

VEF : Vehicle Equivalent Factor

VHGV : Very Heavy Goods Vehicle

VMA : Voids in Mineral Aggregate

WB : World Bank

WC : Wearing Course

WT : Wheel Trucking

1. Outline of the Basic Research

1.1 Background

It is commonly recognized in African countries that the transport sector is still underdeveloped. Delays of development in this sector are one of the major barriers to economic growth and one of the reasons for poverty. For this reason, development of the transport sector for transfer of people and goods is an absolutely necessary condition for sustainable development and growth. In particular, there is a high demand (need) for road improvement regardless of economic level.

Given this background, improvement of international roads, major urban roads and regional roads has been promoted by continuous efforts of respective countries, and with cooperation of development partners.

The Japan (JAPAN) is one of the major donors that have contributed to road development in African countries. The road projects under Japan's grant aid scheme are highly valued from the aspects of quality control, schedule control and safety control due to the use of Japanese standards in general.

In addition, JAPAN has continuously convened the Tokyo International Conference on African Development (TICAD). Notably at TICAD IV in 2008, JAPAN committed to double the rate of Official Development Assistance (ODA) for African countries until 2012. Under this momentum, Japan International Cooperation Agency (JICA), the implementing arm of Japan's ODA, has been actively extending assistance for African countries, and road development / improvement projects are given high priority.

In the operation of Japan's ODA, it is important to assure a suitable level of product quality. In this regard, any project should start with proper understanding of local conditions. Weather conditions (temperature, rainfall, etc) and road management conditions (safety rules, over loading, etc) in African countries are sometimes more severe than those observed in Japan. Level and frequency of road maintenance are typically not the same as in Japan.

Under these conditions and in this construction environment:

A) Technical know-how and/or standards for design and construction based on experience in Japan may not be applicable as defined, due to significant deviation of surrounding environment such as weather conditions, soil conditions, axle load (control), traffic manner, maintenance. Thus, standards for design, construction and quality control should be carefully chosen to suite major local conditions, and various local expertise accumulated based on past experiences and experiments must be sufficiently utilized.

B) Implementation system for construction works should be adequately organized by the contractor/consultant with proper understanding of local resources such as sub-contractors.

C) Procurement of materials and equipment should also be arranged in accordance with actual production and delivery conditions on site (in Japan, delivery networks of materials and equipment are highly developed and such supply is usually quite predictable in terms of schedule and quality).

Of these points, A) can be commonly applied in the design and execution stages of road improvement projects under Japan's ODA. Therefore, in order to address this, Basic Research is aimed at collecting country-specific (indigenous) and useful information on above A).

Note: This Research is solely meant for collection of locally available data, knowledge and know-how related to road construction (pavement). The output of this Research is expected to contribute to capacity development of JICA staff, and betterment of product quality of road development projects under Japan's ODA. There is no function of project formulation.

1.2 Objectives

The objectives of this Research are as follows:

To study road conditions from the viewpoint of road surface by comparing Japan's ODA projects with similar type of projects executed by the government and other donors, in order to grasp what design, construction and maintenance will achieve in the road conditions after completion.

To compare the said road projects by analyzing the effects of differences between both projects in project cost items (unit cost), contract conditions, design conditions and specifications, etc.

To confirm the countermeasure and/or action for early damage of pavement from the viewpoint of axle load, bituminous material (use of improved asphalt) and so on.

For these objectives, the Research team visited related ministries, road authorities, local governments and donors for the following surveys.

- To assess the present status of the road sector via questionnaires and interviews of stakeholders (including the private sector).
- To comprehend the policies and strategies of major donors regarding road sector development in the target country.
- To collect project data and conduct road condition surveys on actual road development projects completed by both Japan and other donors in order to compare construction costs, contract conditions, design specifications and so on.

Note: Among many research items, the following are particularly focused;

- Standard applicable to pavement structure design and design parameters such as reliability,
- Countermeasures for flow rutting of asphalt pavement from following viewpoints of:
    - over loading prevention (specific actions) ,
    - asphalt mix design with use of refusal density and Superpave (use of Gyratory compactor) , etc,
    - combination use of mechanical test such as creep test, wheel trucking test and LCPC test etc
    - change of pavement materials such as modified asphalt binder, cement concrete, and semi-flexible pavement, etc
    - revision of pavement design standard or specification
- Standards applicable to drainage design and countermeasure for climate change (torrential rain)
- Countermeasures applicable to problem soil such as expansive soils and dispersive soils, etc.
- Determination method of defect after completion (such as flow Rutting).

1.3 Target Countries

The following three countries have been selected as the focus of the Research, as these countries are major recipient countries in the road sector from Japan and other donors:

Federal Democratic Republic of Ethiopia
Republic of Ghana
United Republic of Tanzania

Towards the above goal, the Research team will visit various organizations in both public and private sector in target countries.

1.4 Site Survey Schedule

1) 1st Site Survey Schedule

TANZANIA

No. of Day	Date	Research Items
1	5/10 (Thu)	Leave for Tanzania
2	5/11 (Fri)	Arrival at Tanzania
3	5/12 (Sat)	Survey for city roads (urban rods)
4	5/13 (Sun)	Survey for city roads (urban rods)
5	5/14 (Mon)	AM: Meeting with JICA Office PM: Hearing to TANROADS
6	5/15(Tue)	Hearing to EU, DANIDA, WB
7	5/16(Wed)	Hearing to local consultant and contractor
8	5/17(Thu)	Hearing to Dar es Salaam University Hearing to Central Laboratory
9	5/18(Fri)	Hearing to Japan's ODA Project
10	5/19(Sat)	Hearing to Asphalt Plant
11	5/20(Sun)	Data Collection
12	5/21(Mon)	Reporting
13	5/22(Tue)	Report to JICA Office and TANROADS

GHANA

No. of Day	Date	Research Items
14	5/23(Wed)	Arrival at Ghana
15	5/24(Thu)	AM: Meeting with JICA Office PM: Hearing to GHA
16	5/25(Fri)	Survey for Japan's ODA Project (R1)
17	5/26(Sat)	Hearing to Japan's ODA Project (R8)
18	5/27(Sun)	Survey for regional roads
19	5/28(Mon)	Survey for city roads (urban rods)
20	5/29(Tue)	Hearing to EU, WB, ADB
21	5/30(Wed)	Hearing to local consultant and contractor Hearing to Asphalt Plant
22	5/31(Thu)	Data Collection and Reporting
23	6/1(Fri)	Report to JICA Office and GHA
24	6/2(Sat)	Reporting

ETHIOPIA

No. of Day	Date	Research Items
25	6/3(Sun)	Arrival at Ethiopia
26	6/4(Mon)	AM: Meeting with JICA Office, EOJ, JICA Expert PM:ERA HQ, ERA Central Region Office
27	6/5(Tue)	Survey for Japan's ODA Project (Phase 1,2,3,4)
28	6/6(Wed)	Survey for Trunk Road (after Phase 4 by WB, Chinese Contractor) Hearing to Japan's ODA Project (Kajima)
29	6/7(Thu)	AM: Hearing to EU Hearing to local consultant and contractor PM: Survey for Trunk Road (Mojo-Awash by EU)
30	6/8(Fri)	AM: Hearing to AACRA (Addis Ababa City Road Authority) Hearing to ERA (Axle Load Department) PM: Survey for Trunk Road (Addiss – Tamabel by GOE)

		*As pavement and countermeasure for BCS)
31	6/9(Sat)	Survey for city roads (urban rods)
32	6/10(Sun)	Reporting
33	6/11(Mon)	AM: Hearing to WB, ADB PM: Hearing to Asphalt Plant
34	6/12(Tue)	Hearing to Japan's ODA Project (Awash Bridge)
35	6/13(Wed)	Data Collection
36	6/14(Thu)	Data Collection & Reporting
37	6/15(Fri)	Report to JICA Office and ERA
38	6/16(Sat)	Leave for Japan
39	6/17(Sun)	Arrival at Japan

2） <u>2nd Site Survey Schedule</u>

TANZANIA

No. of Day	Date	Research Items
1	8/19(Sun)	Leave for Tanzania
2	8/20(Mon)	Arrive at Tanzania
3	8/21(Tue)	AM: Hearing to TANROADS PM: Hearing and discussion with Local Consultant
4	8/22(Wed)	AM: Data collection from TANROADS PM: Hearing to the contractor for New Bagamoyo Road
5	8/23(Thu)	AM: Survey for Kilwa Road PM: Survey for New Bagamoyo Road PM: Discussion with JICA
6	8/24(Fri)	Survey for Chalinze-Tanga Road (DANIDA Project)
7	8/2(Sat)	AM: Hearing and discussion with project manager for Chalinze-TangaProject

ETHIOPIA

No. of Day	Date	Research Items
8	8/26(Sun)	Arrive at Ethiopia
9	8/27(Mon)	AM: Discussion with JICA PM: Hearing and discussion with Local Consultant
10	8/28(Tue)	Survey for NR No.3 (Phase I, II, III by Japan's ODA)
11	8/29(Wed)	Survey for NR No.3 (Phase I, II, III, IV by Japan's ODA)
12	8/30(Thu)	AM: Hearing to AACRA PM: Hearing and discussion with ERA PM: Reporting to EOJ
13	8/31(Fri)	AM: Survey for Addis-Adama Highway PM: Data collection from ERA
14	9/1(Sat)	Reporting

GHANA

No. of Day	Date	Research Items
15	9/2(Sun)	Arrive at Ghana
16	9/3(Mon)	AM: Discussion with JICA PM: Data collection and hearing to Local Consultant
17	9/4(Tue)	AM: Data collection and hearing to GHA PM: Data collection and hearing to Local Consultant
18	9/5(Wed)	Survey for city roads (e.g. George Bush HW)
19	9/6(Thu)	AM: Reporting PM: Leave for Japan
20	9/7(Fri)	Transit
21	9/8(Sat)	Arrive at Japan

2. Pavement Technology in Japan

2.1 Types and Applicable Conditions of Pavement

(1) Types of Pavement

It is difficult to uniformly categorize types of pavement because descriptions and terms differ according to the surface course materials, construction methods, functions and locations. In practical terms, pavement can be broadly divided into asphalt pavement and concrete pavement.

Asphalt pavement refers to cases where the surface course is composed of asphalt mixture, while concrete pavement refers to cases where the surface course is composed of cement concrete.

These two types differ in terms of not only the surface course but also thinking on load propagation. In the case of asphalt pavement, each course bears the stress and successively dissipates the load, whereas in the case of cement concrete pavement, concrete plates on the surface course bear the load, while the ground underneath the plates mainly serves to uniformly support the surface course and secure easier execution. Due to these features, cement concrete pavement is described as rigid pavement, while asphalt pavement is called flexible pavement.

Photograph2-1 Asphalt pavement (left) and concrete pavement (right)

Pavement is also divided into various types according to the blend, construction method and anticipated functions. Table 2-1 shows types of pavement classified according to the surface course materials, blend and construction method and function.

In terms of surface course materials, pavement is divided into the above-mentioned asphalt pavement and cement concrete pavement as well other types. These can be classified according to the type of binder used to bind the aggregate, and they are the most recognizable and common category judging from surface observation too.

Classifications based on blend and construction method are also deeply related to pavement categories that have special functions and structures, and classifications are made according to the type of asphalt, method of blending, method of load dissipation and existence or not of reinforcing bars in concrete and so on.

Categories of asphalt pavement are as follows. Recycled asphalt pavement, which is made from modified straight asphalt, and modified asphalt pavement, etc. differ according to the type of asphalt. Rolled asphalt pavement and porous asphalt pavement are classified according to the blend. Meanwhile, full-depth asphalt pavement and composite pavement are classified according to structure. Semi-flexible pavement is an intermediate type of pavement that utilizes the flexibility of asphalt mixture and the rigidity of cement concrete, however, because the base material is asphalt mixture, it is classed as asphalt pavement.

Turning to cement concrete pavement, this is classified according to whether or not the concrete plates contain iron or reinforcing bars, etc. Compacted concrete pavement is a category based on the construction method, while composite pavement is a category of cement concrete pavement based on structural characteristics, although the differences are not always clear.

In terms of functional classification, pavement is classified mainly according to the functions that are required but categories do not indicate specific pavement types. Examples of functional categories include pavement that is resistant to flow rutting, which is the biggest problem on trunk roads, pavement that resists the abrasion that accompanies use of slip prevention measures such as spiked tires and chains, etc. during the winter, drainage pavement that is designed to quickly remove rain water and also reduce noise (as a secondary function), and light-colored pavement, which is intended to improve visibility in driving.

Table2-1. The kind of pavement and a classification

<table>
<tr><th>Classification of surface course</th><th>Work of pavement</th><th>Classification of function</th></tr>
<tr><td rowspan="2">Asphalt pavement</td><td>Recycle asphalt pavement
Modified asphalt pavement
Porous asphalt pavement
Rolled asphalt pavement
Full depth asphalt pavement</td><td rowspan="5">Plastic flow resistant pavement
Wear resistance pavement
Low noise pavement
Drainage asphalt pavement
Permeable pavement
Bright color pavement
Semi－flexible pavement
Colored pavement
Safeguard pavement</td></tr>
<tr><td rowspan="2">Composite pavement</td></tr>
<tr><td rowspan="2">Cement concrete pavement</td></tr>
<tr><td>Unreinforced concrete pavement
Reinforced concrete pavement
Continuously reinforced concrete pavement（CRCP)
Roller compacted concrete pavement(RCCP)
Precast concrete pavement</td></tr>
<tr><td>Others</td><td>Neat pavement
Plastic wastes pavement
Blocks pavement</td></tr>
</table>

Source: Based on Journal of Pavement Engineering (Japan Society of Civil Engineering, 1995)

(2) Main Functions and Applications of Concrete Pavement

Concrete pavement has cement concrete pavement plates for the surface course and is more rigid than asphalt mixture course. Accordingly, it is referred to as rigid pavement as opposed to asphalt pavement, which is called flexible pavement. The features of concrete pavement are as follows:

- Initial construction cost is expensive because large machinery and curing are required; however, because the pavement lasts a long time and entails low maintenance costs, its total cost over the long term is low.
- Noise and vibration are more likely to occur due to the rough face finishing and joints for preventing slips.
- Since there is no permanent deformation of the road surface or degradation of materials, the road life is long.
- Repairs are relatively complicated and take a long time (days).

Source: Fundamentals of Pavement Engineering (Japan Society of Civil Engineers)

In Japan, car ownership mushroomed and road construction was rapidly promoted from the 1960s. As a result, asphalt pavement (including basic pavement), which incurs low construction costs and allows roads to be quickly opened to traffic, was increasingly adopted, while the share of concrete pavement decreased. Moreover, use of concrete pavement was increasingly avoided due to the issues mentioned above.

Table 2-2 indicates the outline contents and applications of the main types of concrete pavement.

Table 2-2 Summary and application of concrete pavement

Type of concrete pavement	Summary of Structure	Applocation for japan
Reinforced concrete pavement	Put a joint appropriate distance. And put a dowel bar and thai bar in the joint and connect each concrete slub. The most common concrete pavement	It is generally applied at a general road, the pavement in the tunnel, yard pavement.
Continuously reinforced pavement	Instead of putting a transverse joint, It scattered cracking by the rebar that setted a vertical direction, and keep continuity as the pavement. Characteristic. • Run characteristics • Abbreviation of the maintenance work of the joint	There are the application results in some sections of the Japanese Expressway .
Roller compacted concrete pavement(RCCP)	Constructs a concrete of dry consistency with a little unit weight of water by the same machine of normal asphalt pavement. Characteristic • Construction speed is fast • Curing time is short. • Early traffic opening and Term of works shortening.	It is applied partly on a local container yard, a tank way. There are extremely few applications on the general road.
Precast concrete pavement	Produces a concrete slab by factory beforehand and the joining, unification at site.	There are the results in some sections of MLIT, but there is extremely few it
Composite pavement	Surface course or base course is an asphalt mixture. It puts a cement slab under the asphalt mixture. Life period is longer than normal asphalt pavement	There are the application results in some sections of Second Tomei Expressway, Chugoku Expressway.

Sorce : Creat by study team

(3) Main Functions and Applications of Asphalt Pavement

Asphalt pavement is generally constructed by carrying heated asphalt mixture manufactured in an asphalt mixture plant to the work site by dump truck, and leveling and compacting it by using machinery. The features of asphalt pavement are as follows:

- Because the construction machinery is compact and conducts rapid work with no need for curing, road can be opened to traffic at an early point. Accordingly, the construction cost is relatively cheap.
- Because forming is simple, good road flatness can be achieved and noise is also relatively small.
- Because the asphalt mixture tends to deform in high temperatures, it soon becomes rutted and loses its flatness, so its service life is short. It is not suited to airport aprons or freight yards and so on where heavy loads are left static for extended periods.
- Because the pavement can be repaired using simple methods, it is suited to places that have underground structures.

Source: Fundamentals of Pavement Engineering (Japan Society of Civil Engineers）

1) Asphalt mixture

Table 2-3 shows categories of asphalt pavement. The "Pavement Construction Handbook (2006)" prescribes the following types of asphalt mixture as standard according to the area of use.

Table 2-3. Type of asphalt mixture

Area	General area	Area with severe winters
Base course	①Coarse graded asphalt mixture （20）	
Surface course	②Dense graded mixture（20mm,13mm） ③Fine graded asphalt mixture （13mm） ④Dense and gap-graded asphalt mixture （13mm） ⑨Coarse graded mixture（13mm）	⑤Dense graded mixture（20mmF,13mmF） ⑥Fine and gap graded asphalt mixture (13mmF) ⑦Fine graded asphalt mixture （13mmF） ⑧Dense and gap-graded asphalt mixture （13mmF）
	⑩Porous asphalt mixture （20,13）	

Note1 :( ) Maximum size
Note2:"F" uses a lot of fillers
Note3: Gap-graded asphalt is the thing that a particle size is discontinuous.

Sorce : Pavement construction manual（Japan Road Association,2006）

Also, Table 2-4 shows the main types, characteristics and areas of use of surface course mixture.

Table 2-4. The type of surface course mixture and characteristic and main use point

Asphalt mixture	Characterstic					Mainuse point		
	Plastic flow resistant	Wear resistance	Skid resistance	Water resistance, crazing-resistant	Permeable	General area	Area with severe winters	Steep grade slope
②Dense graded mixture（20mm,13mm）						＊		＊
③Fine graded asphalt mixture　（13mm）	△			○		＊		
④Dense and gap-graded asphalt mixture（13mm）			○			＊		＊
⑤Dense graded mixture（20mmF,13mmF）	△	○					＊	
⑥Fine and gap graded asphalt mixture　（13mmF）	△	○		○			＊	
⑦Fine graded asphalt mixture　（13mmF）	△	○		○			＊	
⑧Dense and gap-graded asphalt mixture （13mmF）	△	○	○				＊	＊
⑨Coarse graded mixture（13mm）		△	○		○	＊		
⑩Porous asphalt mixture　（20mm,13mm）	○	△	○		○	＊	＊	

Note1: The ○ mark of the characteristic column shows that it is superior to ②dense graded mixture.
The no mark shows the equal ,△ mark is inferior.
Note2: △ The mark may use modified asphalt to improve a characteristic.
Note3: The steep grade is considered to be 9% of vertical section.

Sorce：Pavement construction manual（Japan Road Association,2006）

The following sections show commentaries and photographs of dense graded mixture and coarse graded mixture.

Photograph2-2.　Dense graded mixture

Photograph2-3.　Porous asphalt mixture

＜Dense graded mixture ＞

Dense graded mixture is most commonly used as a heated asphalt mixture for surface course. Out of the heated asphalt mixture types, this indicates asphalt in which 35~50% of composite particles can pass through a 2.36 mm sieve.

＜Coarse graded mixture ＞

In heated asphalt mixture, which is composed of coarse aggregate, fine aggregate, filler and asphalt, mixture that contains large porosity is generically referred to as coarse graded mixture. In a narrow sense, coarse graded mixture refers to asphalt in which 15~30% of composite particles can pass through a 2.36 mm sieve and the mix design has been set based on the Marshall stability test.

＜Porous asphalt mixture ＞

Porous asphalt mixture is a type of the aforementioned coarse graded mixture. This is used as the surface and binder course of drainage pavement and roadway permeable pavement.

(4) Functions and Applications of Semi-flexible Pavement

Semi-flexible pavement consists of loose graded semi-flexible pavement asphalt mixture with high porosity, permeated with permeable cement milk, and it has flow-resistance, light coloring and oil-resistance, etc. Its features and applications are as follows.

- Semi-flexible pavement is a durable type of pavement that combines the flexibility of asphalt pavement with the rigidity of concrete pavement.
- Semi-flexible pavement can be applied to locations such as intersections, bus terminals and toll booths, etc. where performance is required in terms of flow-resistance, oil-resistance, light coloring and landscape. It is also applicable to locations such as factories and gasoline stations where oil-resistance and fireproof performance is required.

Photograph2-4. Construction example of the Semi-flexible pavement

2.2 Transitions in Pavement Design Methods in Japan

(1) From specification code to performance code

Before June 2011: specification code

There was no unified standard any higher than the level of notification, and design and site pavement works were implemented based on the Asphalt Pavement Guidelines (Japan Road Association).

- Pavement design: Design based on the T_A method (pavement thickness, pavement composition)
- Pavement works: The client orders pavement upon stipulating the specifications (pavement section, materials, etc.)

June 2011 onwards: performance code

Meanwhile, revisions effected under the performance code were as follows. According to the standard in the case where performance code is fully introduced (corresponding to performance code (3) in Table 2-5) since the design method is not limited, any design method can be used so long as it guarantees performance.

- **Introduction of performance code (not limiting the design method):** Through prescribing only performance indicators (fatigue failure wheels, etc.), a degree of freedom was imparted to the design method that was conventionally conducted by the T_A[1] method, enabling cost cutting and new technology to be introduced.

- **Introduction of lifecycle cost thinking in the design period (not limiting the design period):** The design period is currently basically designed as 10 years, however, by setting this while giving overall consideration to in-service management costs and impacts on road traffic and roadside areas during construction, improvement of durability and cost cutting are promoted and congestion can be addressed.

- **Setting of pavement performance indicators:** In order to secure the safe and smooth traffic of vehicles, the performance index (fatigue failure wheels, plastic deformation, flatness, amount of permeating water) that the roadway and side belt need to possess is designed.

Table 2-5. Concept of performance code

<table>
<tr><th></th><th>Specification code</th><th>Performance code(1)</th><th>Performance code(2)</th><th>Performance code(3)</th></tr>
<tr><td>performance code</td><td>-</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Result form Quality</td><td>Rule</td><td>Rule</td><td rowspan="2">decided beforehand partially</td><td>not limiting</td></tr>
<tr><td>Construction method</td><td>Rule</td><td>Rule</td><td>not limiting</td></tr>
<tr><td>Design method</td><td>T_A method</td><td>T_A method</td><td>not limiting</td><td>not limiting</td></tr>
</table>

Performance code(1): It prescribes the pavement of the previous specifications code with the performance.
Performance code(2): It prescribes the performance of the completed pavement, but a design method and the construction method do not limit it
Performance code(3): It prescribes only performance of the completed pavement, but does not prescribe result form and quality of each layer.

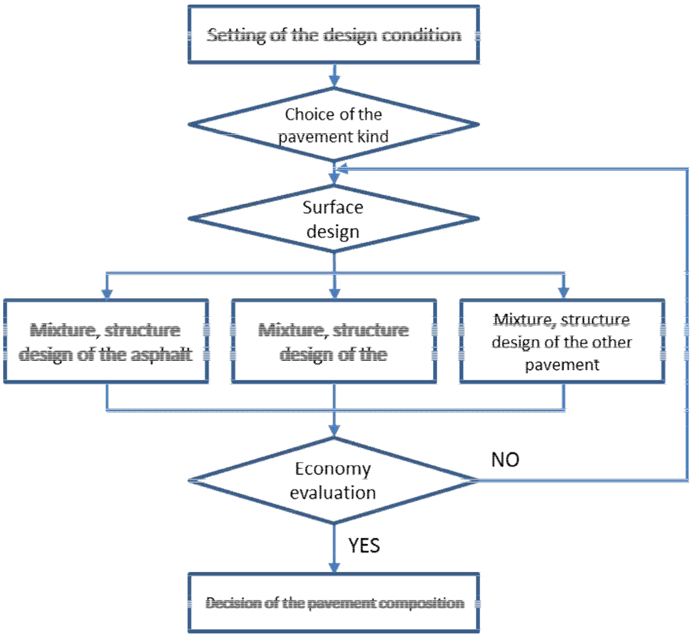
Sorce : Creat by study team

It is scheduled to successively move from performance code (1) to (3), but currently performance code (1) is the mainstream.

[1] T_A method: From the roadbed design CBR and design traffic volume, the equivalent converted thickness of asphalt pavement is determined and, even if the materials used in each course are different, the asphalt pavement is designed so that the target converted thickness is not undercut. This method was established as a unique pavement technical standard of Japan in reference to AASHTO. (See the attached materials).

(2) Flow of pavement design

The flow of pavement design indicated in the pavement design manual is as follows.



Source: Study team creat it based on Pavement design manual

Figure 2-1. Flow of the pavement design

Within the flow up to deciding the pavement composition, it is necessary to set design conditions and consider "performance indicators" in the road design stage. The pavement design categories, pavement performance and design outputs are indicated in the following table.

Table 2-6. Output of performance and the design of the pavement

Classification	Example of the performance of the pavement		Output of design
Conducting Road Design	Performance of surface course	Plastic deformation resistance Flatness,Permeability, Drainage characteristics, Noise reduction Sliding resistance	①Specifications materials of surface course ②Thickness of surface course ③Use materials of the base course ④Thickness of the base course ⑤Construction method
Structural Design	Performance of pavement structure	Fatigue Fracture Resistance Permeability Others	Pavement composition ①Number of a layer compositing pavement ②Materials of each layer ③Thickness of each layer ④Strength for concrete

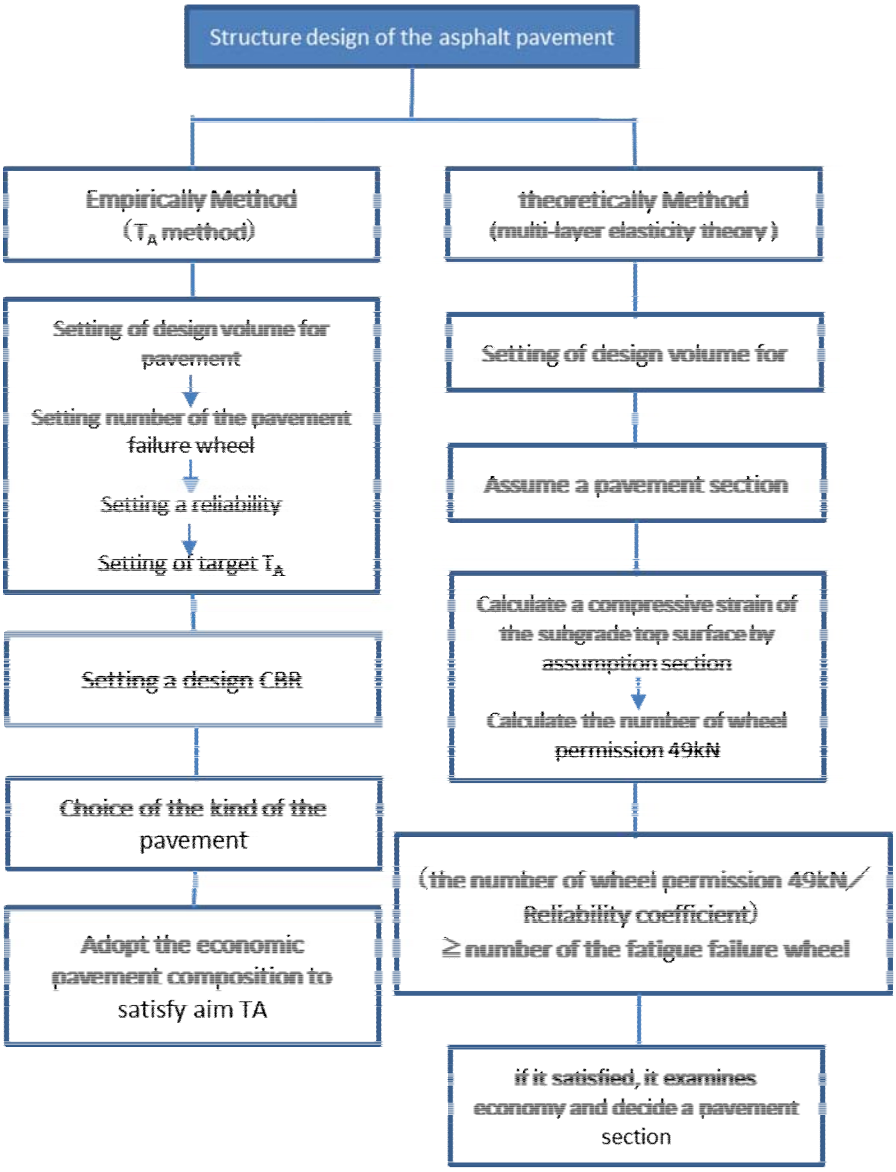
Source：Manual for Design and Construction of Pavement （Japan Road Association,2006）

In conducting road design, since the used materials greatly impact performance, it is necessary to select materials that enable the set performance indicator values to be obtained. Accordingly, consultants in design work in Japan generally use the standard pavement composition prescribed by the ordering party according to the design CBR and traffic volume categories.

2.3 Structural Design of Asphalt Pavement

(1) Structural design method

Structural design can be performed either empirically or theoretically. In the empirical design method, the target T_A is set according to the design traffic volume, and the pavement structure is set in order to satisfy this. In contrast, the theoretical design method entails using wheel load and number of wheel passes to calculate the compressed warp and 49 kN converted number of wheel passes and set the pavement structure that satisfies the fatigue failure number of wheel passes.



Source:Creat by study team based on pavement design manual

Figure2-2. Structure design of asphalt pavement

As was mentioned previously, through switching to the performance code, any design method can be used so long as performance is guaranteed. However, in terms of actual operation, design based on the T_A method is still the mainstream when provisional applications are also included. Reasons for this are as follows:

- The T_A method has been devised in consideration of numerous cases and actual performance in Japan, and it is stable and easy to understand.
- There is no method whereby the ordering party can check cross sections designed based on the multi-layer elasticity theory in the design stage (there is not enough actual experience). Providing that it is after completion, reverse analysis can be conducted by FWD (Falling Weight Deflectometer) test, etc.
- The scope for setting material conditions (elastic modulus and Poisson's ratio) used in the multi-layer elasticity theory is broad, so the validity cannot be confirmed. According to the actual pavement design execution guidelines too, it "is important to conduct follow-up survey of post-construction serviceability concerning the permissible scope and width of these settings."

Table 2-7. Example of the elastic modulus and
Poissons ratio of materials to use for each pavement layer

Material	Elastic modulus（MPa）	Poissons ratio
Asphalt mixture	600 ～ 12,000	0.25 ～ 0.45
Concrete for pavement	25,000 ～ 35,000	0.15 ～ 0.25
Stabilization with cement	1,000 ～ 15,000 Estimate from compressive strength	0.10 ～ 0.20 0.15 can use as representative value
Gravel material	100 ～ 600 Estimate from other dynamic test results	0.25 ～ 0.45 0.35 can use as representative value
Subgrade*	10 x CBR	0.35

*：Reference RR91/243 Department of Transport （South Africa）

Source:Creat by study team based on pavement design manual

Since the T_A method also includes a lot of empirical elements, in spite of its drawbacks in that it cannot be immediately applied to new materials (pavement sheet, etc.) and new methods (composite, etc.), it is likely to remain the mainstream method in Japan for the forseeable future until enough experience of applying design using multi-layer elasticity theory has been accumulated.

3. Applicable Standards in the Target Countries

3.1 Applicable Design Standards in the Target Countries

(1) Geometric Structural Standard

Geometric structural standard is a standard for designing roads so that traffic safety and comfort or the configured service level are satisfied while paying attention to economy. In Japan, the government order on road design standards prescribes the most important road structure geometric standards such as road width, building clearance, alignment, visual distance, intersections and connections, etc. together with the road standard. Moreover, in the target countries of the study too, the following geometric structural standards, which are similar to those in the government order on road design standards, exist.

Table 3-1. Geometric structural standard

Target country	Japan	Ethiopia	Ghana	Tanzania
Design standard	・Road Structure Ordinance (government ordinance based on the road law) ・A commentary and use Road Structure Ordinance	Geometric Design Manual	Road Design Guide	Draft Road Manual
Origin of publication	・The above is a government ordinance. ・"A commentary and the use" are Japan Road Association.	Ethiopian Roads Authority	Ghana Highway Authority	Ministry of Communications and works
the year of publication	revision 2004	2002	1991	1989

(2) Pavement design standard

The following table indicates the pavement design standards that are used in the target countries. Concerning Ethiopia and Tanzania, where the specification design method is applied, because the specifications of used materials are stipulated, it is necessary to confirm by materials survey that the prescribed materials can be acquired.

Table 3-2. The pavement design method of survey target countries

Target countries	Japan	Ethiopia	Ghana	Tanzania
Design standard	Pavement Design Manual （2006,Feb）	Pavement Design Manual 2002	Pavement Design Manual 1998	Pavement and Material Design Manual 1999
Application limit （Cumulation axle load）	—	30 x 10^6	—	50 x 10^6
Design method	Performance design method	Specification design method	Experiential design method（AASHTO）	Specification design method
Remarks	If it satisfy required performance, it use what kind of design method. For reference, the experiential design method (TA method), the theoretical design method (Multi layer elastic Analysis) are listed.	During the revision of the standard that out of an application limit to corresponding with the evolution of the pavement technology for the change of social conditions, expansion of the road maintenance, increase of the traffic volume. (Going to publish it as an edition in 2011. Draft version is completed now.)	There is the revision plan of the standard, for new pavment material (modified asphalt) and test method (Superpave,WT examination). It is going to be decided formally by the end of this year	Does not correspond to rigid pavement of the concrete pavement.

(3) Drainage design standards

Pavement drainage is an extremely important factor in pavement design. Because lack of drainage facilities is one cause of pavement failure, it is important for roads (pavement) to install appropriate drainage facilities. The following table shows the drainage design standards that are used in each country.

Table 3-3. Drainage method of survey target countries

Target countries	Japan	Ethiopia	Ghana	Tanzania
Design standard	Drainage works Manual 1987(Japan Road Association)	Drainage Design Manual 2002 (Currently revising)	Highway Drainage Manual (Second Edition)	—
Calculation method of run-off	① Rational method	① Rational method ② SCS Synthetic Unit Hydrograph	① Rational method ② The Natural Resources and Conservation Service Methods	① Rational method ② The TRRL East African Flood Model
Application of catchment area	Reference of note	① $< 0.5\text{km}^2$ ② $> 0.5\text{km}^2$	① $< 25.0\text{km}^2$ ② $> 25.0\text{km}^2$	① $< 1.0\text{km}^2$ 1.0km2＜② $< 200\text{km}^2$
Intensity of Rainfall	Drainage works Manual 2-1-2	Short time rainfall of area is shown by a graph in a manual according to the probability year.	Short time rainfall of area(14 area) is shown by a graph in a manual .	About around Dar es Salaam, we can obtain it from the weather station of the Dar es Salaam Airport.
Note	Application of Catchment area is less than about 40km2 . A surface layer condition and the rain condition of the catchment area are available to the same condition, 200 km2 degree.(Technical Criteria for River Works: Practical Guide for Planning) When we use it in the area over 200 km2, it is necessary to be careful.	The rainfall uses a Log PearsonIII type. It is recommended that I calculate rainfall of each probability year. However, it is limited when rain data more than ten years.	Short time reinfall I was shown in "Maximum Rainfall Intensity-Duration Frequencies in Ghana" (1974), and the it were made for about 40 years ago.	East African Flood Model is an effective method in the inland of the East Africa, but there is the opinion that it is not suitable for the use in the coast place with much rainfall.

3.2 Related Survey Standards in the Target Countries

(1) Traffic volume survey

① Ethiopia

The pavement design manual in Ethiopia stipulates that traffic volume survey and axle load survey be implemented for each project. It stipulates that surveys are conducted seven days running and that at a 24-hour survey be conducted on at least one day. Moreover, in Ethiopia, because the traffic volume fluctuates greatly, it is recommended that traffic survey be implemented a number of times per year. Concerning the axle load survey too, the manual recommends that it be implemented under the same conditions as the traffic volume survey.

Table 3-4. Standard of the traffic volume survey in Ethiopia

Traffic volume survey	Traffic volume survey of continuation seven days (at least one day 24 hours) and Axle load survey are carried out several times in a year. It is decided by discussion about the application of axle load of an investigated overloading vehicle.

② Ghana

The pavement design manual in Ghana stipulates that traffic volume survey be implemented for each project, and that the survey be implemented on a total of three days (12 hours), specifically two weekdays and one holiday. It has no stipulation concerning axle load survey, although it requires that the standard car model-separate axle load coefficients indicated in the design manual are used.

Table 3-5. Standard of the traffic volume survey in Ghana

Traffic volume survey	Traffic volume survey of continuation seven days and Axle load survey of 4 days are carried out. (The seasonal variation uses data of GHA.) It is decided by discussion about the application of axle load of an investigated overloading vehicle.

③ Tanzania

The Field Testing Manual 2003 in Tanzania stipulates that axle load survey and OD survey be implemented for each project. It requires that the surveys as a rule are implemented 24 hours a day for seven consecutive days. However, it states no contents concerning seasonal fluctuations. Concerning the axle load used in design, the manual stipulates that consideration also be given to overloaded vehicles.

Table 3-6. Standard of the traffic volume survey in Tanzania

Traffic volume survey	Traffic volume survey of continuation seven days(24 hour) are carried out. It prescribes that reflect for a design of axle load of an investigated overloading vehicle
Note	When the ratios of the large-sized vehicle(accumulation axle load over 13t) are more than 50%, It will consider a traffic class separately.

(2) Roadbed survey

Concerning survey of roadbed strength too, the standards according to each country's survey system are prescribed as follows.

Table 3-7. Subgrade surveyof target survey countries

Turget survey countries	Standard of subgrade strength survey
Ethiopia	CBR of laboratory：1 sample/km Soil test：500m pitch Contents of soil tesr：Consistency limit, grade etc
Ghana	New construction road Laboratory test：4 sample/km (trunk road) It is reduced the number of the samples in the collector or feeder road Existing road FWD test：Max50m pitch（with DCP）

Tanzania	CBR of laboratory：2sample/km（trunk road）、1sample/km（other）、1sample/2km（gravel road） Soil test：4sample/km（trunk road）、2sample/km（other）、2 sample/km（gravel road）

3.3 Asphalt Mix Design

(1) Blend design method for asphalt composite

The target countries use the Marshall test, which is widely used throughout the world, as well as the following asphalt composite blend design methods.

Table 3-8. Mix design method for asphalt composite

Turget survey countries	Blend design method
Ethiopia	− Refusal Density
Ghana	− Superpave
Tanzania	− Refusal Density − Superpave

① Ethiopia

According to the findings of the ERA hearing, use of "Refusal Density" is prescribed according to categories of traffic volume within the road design standards. The conditions for applying the "Refusal Density" according to the road design standards are as follows:

− The area concerned is subject to high temperatures.
− The section concerned is used by heavy vehicles.
− Traffic on the section is continuous.
− Heavy vehicles stop and drive slowly on the section.

The following table shows the concrete traffic volume classes for using the refusal density.

Table 3-9. Application condition of Refusal Density（Ethiopia）

Design Traffic (10^6 ESA)	< 1.5	1.5 - 10.0	> 10.0	Severe Sites
Traffic classes	Tl,T2,T3	T4,T5,T6	T7,T8	-
Minimum stability (kN at 600C)	3.5	6.0	7.0	9.0
Minimum flow (mm)	2-4	2-4	2-4	2-4
Compaction level (Number of blows)	2 x 50	2 x 75	To refusal	To refusal

出典：ERA Pavement design manual 2002

However, on checking the actual conditions of use with local consultants, they suggested that asphalt blending based on refusal density has so far not been actually implemented. Concerning the reason why, they suggested that because there is no stipulation in the standard works specification, although it is necessary to make a statement in particular specifications, nobody until now has compiled particular specifications taking that into consideration.

② Ghana

According to the GHA (Ghana Highway Authority), until now only blend design based on the Marshall test has been implemented, however, "Superpave" has been used in the recent Konongo-Kumasi Road rehabilitation project and Route 1 Project (George Bush Highway). Moreover, the GHA test facility has introduced a gyratory compacter for use with Superpave, and it has established a setup whereby the GHA itself can conduct tests. At the current time, there are no clear stipulations concerning the adoption of Marshall test and Superpave, however, these items will be reflected in revisions of the pavement design standards that are scheduled in future.

Moreover, in order to confirm the flow-resistance of asphalt, the GHA plans to purchase a wheel tracking test machine.

③ Tanzania

According to the Central Material Laboratory (CML) of Tanzania, which is a component organization of TANROADS, blend design based on the Marshall test is common, while the "Pavement Design Standards" stipulate blend design that uses "Refusal Density" for the following kinds of roads:

- Uphill roads where the vertical gradient is more than 6%
- Sections where vertical gradient of 4% or more continues for at least 1 km
- Approaches to large intersections
- Routes in all major cities
- Sections of continuous traffic, and areas where vehicles run at low speeds for reasons other than those stated above

Moreover, Superpave is used in DANIDA projects.

4. Conditions and Causes of Pavement Failure

4.1 Failure Conditions

In hot and humid areas in Africa and Asia, forms of pavement failure that are no longer seen in Japan are frequently observed on roads that have been constructed under Japanese ODA. Have such problems been conventionally attributed to improper maintenance, or are there numerous ways in which design and execution can be improved?

Concerning why such failures do not occur in Japan, the following explanation can be given. First, on the types of arterial roads on which large size trucks run in Japan, thickness of the asphalt course including asphalt stabilization reaches 20~30 cm, the roads structurally have ample durability, modified asphalt is used when the need arises, and maintenance is also carried out in an organized manner. Meanwhile, in developing countries, the asphalt course is no thicker than 10 cm, use of modified asphalt is limited, and roads are frequently designed and constructed without giving adequate consideration to the subbase drainage.

Typical forms of failure in such regions include rutting caused by fluidization of the surface course, subbase failure caused by the impact of groundwater, and structural failure arising from insufficient bearing force. (See Photographs 4-1, 4-2 and 4-3).

Photograph 4-1.
Groundwater flowing down from the mountain side becomes the pavement failure of the mountain side carriage way.
Improvement of the drainage by upsizing of the gutter or the Calvert setting is necessary.

Photograph 4-2.
Water in base course is mainly saturated in the sag part of the vertical section, becomes the pavement failure.
Damage is seen in both sides across the bridge.

Photograph 4-3.
For example rutting caused by fluidization of the surface course. Rrutting is remarkable partly in the steep gradiant section, because run speed becomes the super low speed.

4.2 Projected Causes of Failure

(1) Classification of causes of pavement failure

The causes of pavement failure are often complex in nature and it is extremely difficult to limit failure to just one cause. For example, rutting can be caused by both internal factors and external factors. Internal factors are inherent factors in the asphalt mixture itself and include the quality and quantity of asphalt, type of aggregate, grading and porosity, etc., while external factors comprise traffic volume, traffic load, temperature, pavement structure and so on. The following table, which shows the causes of pavement failure, has been compiled in reference to site surveys, domestic tests and existing literature, etc., although caution is required because it does not represent all the causes.

Table 4-1. Failure cause of the asphalt pavement (assumption)

Type of failure	Main phenomenon (damage)	Main origin
Rutting by fluidization	Lateral move of the asphalt mixture	・Excessive traffic volume and traffic load ・Low speed heavy vehicles ・Long-term high temperature ・Mixture defects* ・Construction defects **
Rutting by settlement	Settlement of trace（with Crack）	・Excessive traffic volume and traffic load ・Low speed heavy vehicles ・Bearing capacity shortage of subbase（Problematic soil） ・Influence of the groundwater（Drainage）
Crack	Crack of Hexagonal pattern	・Excessive traffic volume and traffic load ・Bearing capacity shortage of subbase and base course（Drainage） ・Fatigue　of the pavement(life) ・Influence of the groundwater（Drainage）
Stripping	Stripping of the pavement	・Construction defects ** ・Tack coat defects ・Long-term high temperature ・Thin surfacing ・Influence of excessive external force as hitting the brakes
Corrugation	Ruggedness of such as the wave	・Low speed heavy vehicles ・Mixture defects* ・Construction defects **
Level difference	Across the structure	・Construction defects **
Other	The loss of a pothole and the pavement	・Bearing capacity shortage of subbase and base course（Drainage） ・Surface water and groundwater (drainage) ・Behavior of the vehicle

* Mixture defects：Excessive quantity of asphalt,Viscous lack,It is excessive for fine grain,Lack of air void etc.

**Construction defects：Poor quality control of the As mixture,Lack of compaction of each pavement layer,Temperature management,Adhesion failure etc.

(2) Excessive traffic load (overloading)

In the target countries of the study, vehicle limit values are prescribed under the respective road traffic laws. Vehicles that go over the load limits are subject to control as overloaded vehicles. The running of overloaded vehicles is deeply related to failure of paved roads. Figure 4-1 shows the results of aggregating data on overloading obtained from Tema observation point (National Highway 1) in Ghana. According to this, the ratio of overloaded vehicles in Ghana is around 30% on average.

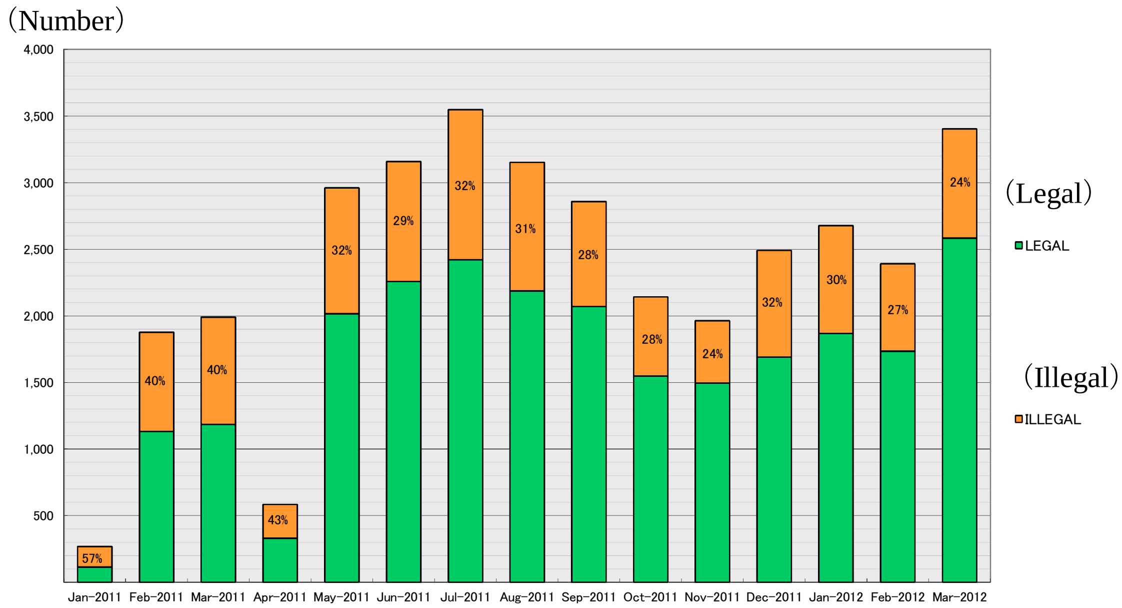


Figure 4-1. The overloaded actual situation in the TEMA observatory

Photograph 4-4. The truck which it is fully loaded with charcoal, and goes to the capital(Ghana)

Photograph 4-5. Dump to be fully loaded with limestone, and to run(Ethiopia)

(3) Excessive traffic volume (sudden increase in traffic volume)

Comparison of the results of recent traffic volume survey and the traffic volumes that were predicted at the time of survey is indicated below for Kilwa Road in Tanzania and Highway 3 in Ethiopia. Traffic volume on Highway 3 in Ethiopia is based on the results of survey implemented during the detailed design in the fourth trunk road rehabilitation project (Japanese grant aid).

Table 4-2. National highway traffic volume of Ethiopia

Unit：Number／Day・both direction

Year	Car	Mini bus	Large bus	Truck	Truck Trailer	Total(Large)	Remark
1994	105	87	47	181	30	258	actual value(ERA)
2000	111	92	50	191	32	273	predictive value
2004			48	191	47	286	actual value(ERA)
2005			51	204	50	306	predictive value
2006			55	219	54	327	predictive value
2007			59	234	58	350	predictive value
2008			63	250	62	375	predictive value
2009	243	146	114	274	73	461	actual value(ERA)
2010	259	159	124	297	79	500	predictive value
2011	250	276	129	478	129	736	actual value(JICA)

On both of these roads, measured traffic volume after the roads have gone into service is far higher than the volume projected during the design stage. The reasons for this are that not enough consideration was given to the volume of traffic transferring from other roads and the increase in traffic volume arising from economic growth and so on.

(4) Impact of low speed heavy vehicles

In the site surveys, numerous slow-moving large-size vehicles were observed (see Photographs 4-6 and 4-7). It was confirmed that these vehicles run at speeds of no higher than 20 km/h, and that this sometimes falls as low as 10 km/h or less on steep inclines. It is estimated that such vehicles impart greater damage to pavement than vehicles running at normal speeds of 40 km/h or more. Low speed heavy vehicles are not very conspicuous in Japan, however, they are commonly seen in developing countries.

Accordingly, we conducted wheel tracking tests in Japan in order to ascertain the impact of low speed heavy vehicles.

Table 4-3. Results of WT test

As (%)	Type	Surface load		Running speed* (回/分)	Dynamic Stability (回/mm)	Coefficient variation (%)	Deformation (mm/min)
		Examination wheel load (KN)	Ground pressure(MPa)				
5.3	Standard	686	0.63	42	492	18.4	0.085
	Heavy	980** (About 1.4times)	0.90	42	348	17.7	0.121 (About 1.4times)
	Low speed	686	0.63	21 (0.5 times)	294	6.8	0.143 (About 1.7times)

* Running speed: The loading running speed is prescribed to run the same speed which of 22cm central part of sample test piece.
42+-1 times/m are the standard values.
This value applies an examination standard of British RRL(Road Research Laboratory).
(Not clear of the assumption of the running speed.)
* * Limit value of the testing equipment

According to the test findings: ① when running speed is reduced to half (161.0 mm/sec→80.5 mm/sec), the test wheel load time is multiplied by two (0.14sec→0.27sec) and the deformation rate (RD) increases by approximately 1.7 times (0.085 mm/min→0.143

mm/min); and ② when the load is increased by 1.4 times (0.63 Mpa→0.90 Mpa), the deformation rate (RD) increases by approximately 1.4 times (0.085 mm/min→0.121 mm/min), and it is thought that the deformation rate is proportional to the load. Therefore, it is guessed that asphalt pavement deformation is greatly influenced not only by the vehicle weight but also by the running speed.

Photograph 4-6.
The speed is less than 10km/h because it is the small section of a vertical gradient is around 7%, and small curve radius.

Photograph 4-7.
The speed is less than 5km/h. This is because it is fully loaded with crushed stone and vertical gradient is around 10% .Asphalt begins to flow on a passage line of the right tire.

(5) Pavement temperature issues

Observation of the pavement surface temperature was carried out in the target countries, and the results are indicated below. The measurements were conducted three times at the same time of day.

Table 4-4. Measurement result of the surface of the pavement temperature

Measurement point: Site 1 of rural trunk road (Ethiopia)
Assay date: 2012/8/28
Assay time: 14:30～16:30 Weather: Rain to cloudy

Time		14:30	14:35	14:40	15:10	15:30	15:40	16:00	16:10	16:30
Distance from Start point		700m	1200m	3200m	4900m	10500m	12000m	14000m	17800m	19500m
Elevation		2410m	2375m	2253m	2135m	1760m	1636m	1493m	1177m	1070m
Measurement	1	25.6	25.4	43	48.7	48.4	48.6	48.6	48.4	44.6
	2	25.2	25.2	43.9	49.1	48.6	48.8	48.4	48.4	44.8
	3	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

Measurement point: Site 2 of rural trunk road (Ethiopia)
Assay date: 2012/8/29
Assay time: 11:00～12:30 Cloudy to fine

Time		11:15	11:30	11:40	11:45	11:52	12:10	12:20	12:25	12:30
Distance from Start point		39600m	38000m	34000m	32000m	29100m	25300m	22000m	21550m	20000m
Elevation		2445m	2407m	2120m	1997m	1823m	1513m	1261m	1215m	1070m
Measurement	1	36.9	38.1	37.2	48.6	51.1	54.5	58.9	57	61.6
	2	37.1	38.2	36.9	48.4	51.6	54.3	57.8	57.2	59.8
	3	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

As a result of the measurements, road surface temperatures in excess of 60℃ were observed in Ethiopia. In Japan, pavement temperatures in excess of 60℃ are basically not projected. (Even the wheel tracking test is conducted at 60℃, while temperature in the test machine cannot be raised to 60℃ or over).

Concerning the relationship between pavement temperature and strength (DS value) of asphalt pavement (using straight asphalt), the following relational expression has been obtained based on wheel tracking tests:

$$\mathrm{Log}_{10}\,(DS) = 8.656 - 0.07095T - 0.2285P$$

DS: Dynamic stability (times/mm)
T : Temperature (℃)
P : Contact pressure (kgf/cm_2)

Source: Q&A on Pavement Technology (Volume 7, top)

A graphic representation on this relational expression is shown in Figure 4-2. According to this, as opposed to the DS value of 864 times/mm in the regular test temperature (60℃), strength drops to 382 times/mm (44%) and 382 times/mm (20%) in temperatures of 65℃ and 70℃ respectively. This indicates that asphalt pavement becomes more prone to rutting when there are consecutive days of high temperatures.

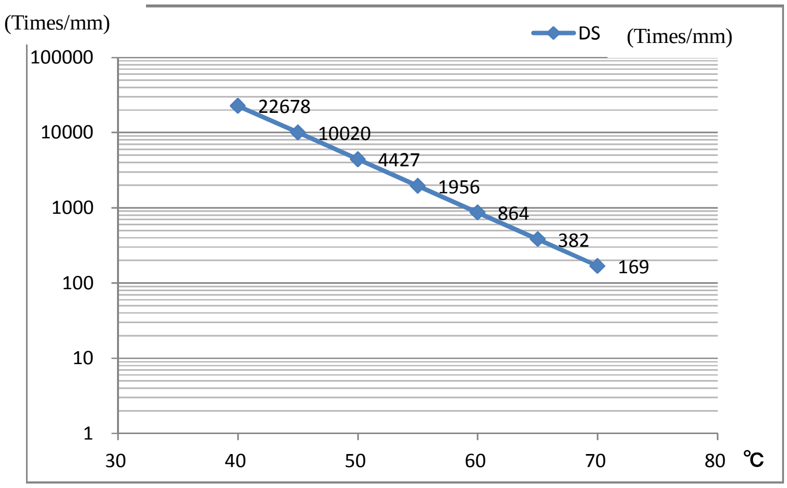


Figure 4-2. Relations of pavement temperature and the dynamic stability

(6) Grading distribution of aggregate

Trunk road Rehabilitation Project (both grant aid projects of the Japan), unexpectedly early failure of pavement (mainly flow rutting) was observed. Accordingly, core sampling was implemented and comparison was carried out on the properties of the asphalt mixture.

The following sections show the grading test results and Superpave control points on both roads. According to the results, the filler part of both roads (fine particles that pass through a 0.075 mm sieve) shows a fine particle distribution close to the upper value of the control point. Even in Japan, the amount of aggregate passing through a 2.5 mm sieve is known to have an impact on flow rutting, and it is generally recognized that rutting can be controlled the smaller this figure becomes. In cases of aggregate composed of grading of 2.5 mm or more, it has also been reported that the rutting depth becomes smaller the more that crushed stones of 5~13 mm are used. In the Ethiopia Trunk Road Rehabilitation Project indicated in Figure 4-4, data on sections that are in good condition after going into service are stated for comparison, and it can be seen that the sections in poor condition have a fine grading distribution. It is guessed that such asphalt mixture is inferior in terms of flow resistance particularly in the local environment that is characterized by low speed heavy traffic and high road surface temperatures.

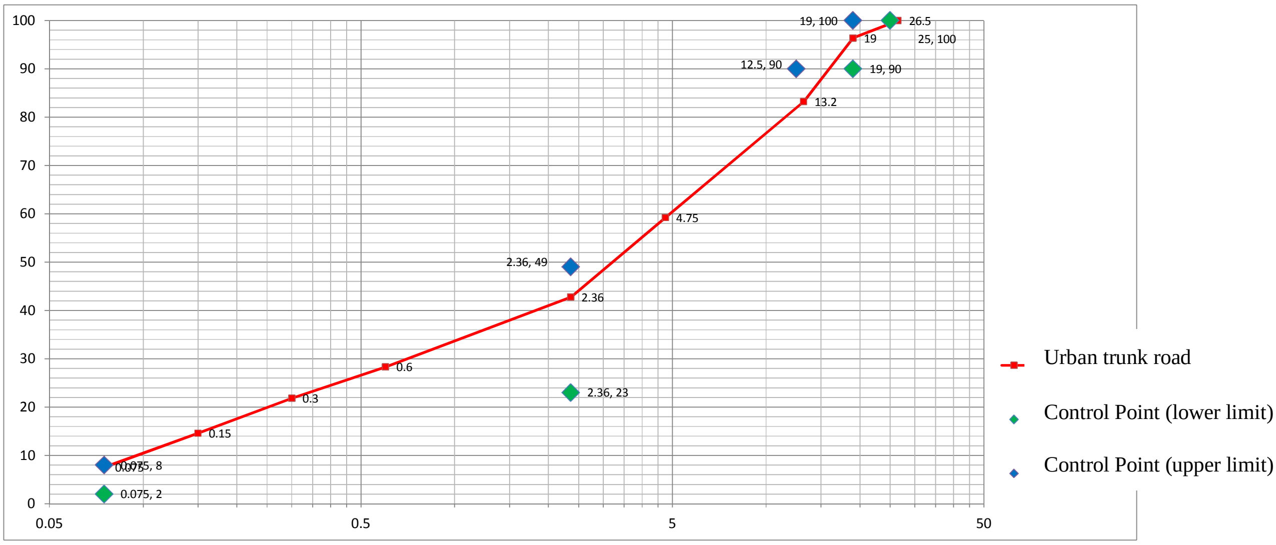


Figure 4-3.　Tanzania:Trunk road test results（AC-20）

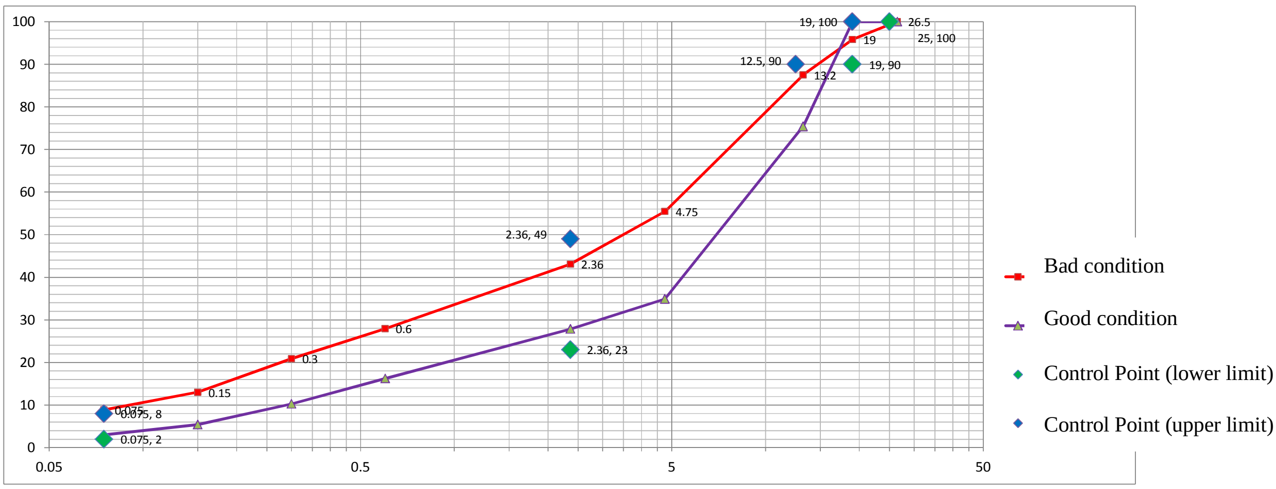


Figure 4-4.　Ethiopia:Trunk road testresults（AC-20）

(7) Structural failure

The photographs indicated below show pavement suffering from structural failure. The cases shown in Photographs 4-8~10 are caused by poor drainage, those shown in 4-11~12 are caused by problematic soil (black cotton soil), and that shown in 4-13 is thought to be caused by poor cohesion between pavement courses.

Photograph4-8. Etiopia:Rural trunk road
Pavement was failure because bearing capacity is down by influence of the water at sag point.

Photograph4-9. Etiopia:Rural trunk road
Pavement was failure because bearing capacity is down by influence of the groundwater from mountain side.

Photograph4-10. Ghana：Rural trunk road(2007)
Intensive section of the surface water

Photograph4-11. Ethiopia：Urban trunk road
Under the influence of black cotton soil, Rutting occurred on the surface.

Photograph4-12. Ethiopia：Rural trunk road
Typical early case of the pavement failure by black cotton soil（Vertical rutting of pavement edge）

Photograph4-13. Tanzania：Rural trunk road
Tack coat defects. Pavement exfoliates for heavy vehicle load

Road drainage is broadly divided into surface drainage and underground drainage. In this study, as a typical form of pavement failure arising from water, failure caused by groundwater in cutting sections and around sags was observed in numerous locations. Such failures can be predicted in advance, and they can be addressed by taking the kind of measures described later upon conducting economic examination. In addition, another cause of failure is weakening of the subbase and roadbed arising from surface water flows and inundation in low-lying areas. Figure 4-15 shows the water flows that have the potential to impact road pavement.

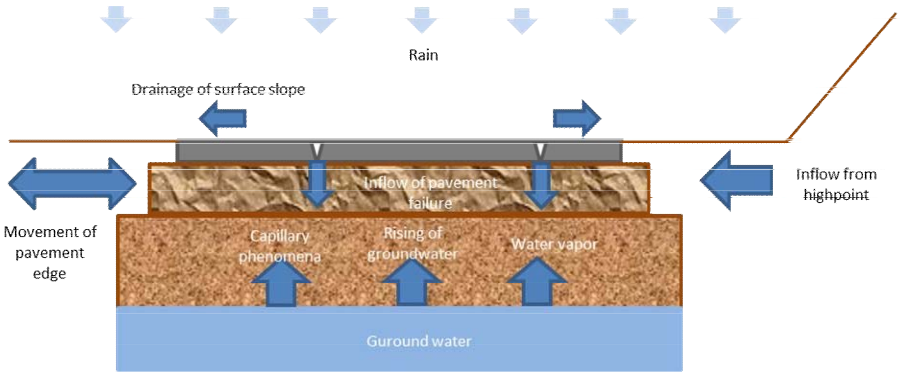


Figure 4-5. Flow of water affecting the pavement

Specifically, there are cases where insufficient depth of side ditches with respect to groundwater on the highland side causes the groundwater to infiltrate the subbase and weaken it, cases where rising groundwater level during the rainy season and water flowing inside the subbase rises in sag sections and thus weakens the subbase, and so forth (see Figure 4-16).

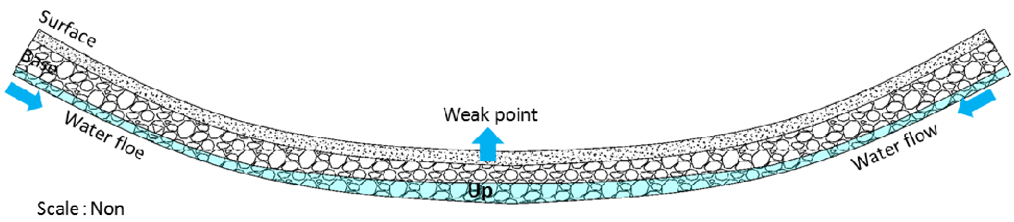


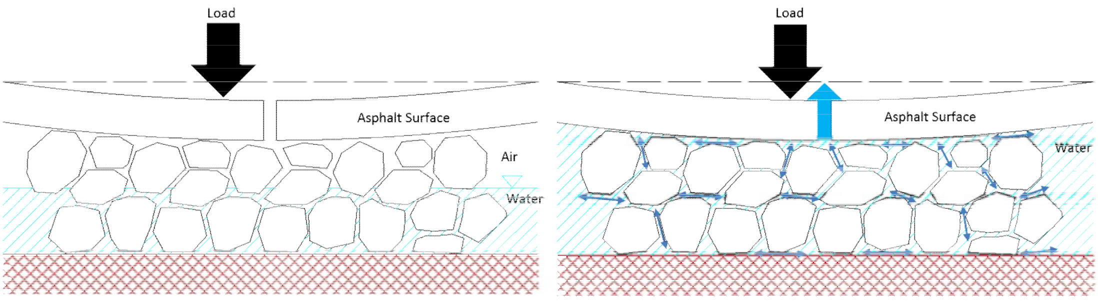
Figure 4-6. Flow of the water at Sag point(Mechanism of the pavement failure)

In the case of subbase, in particular the crusher run, the coefficient of permeability is around 10^{-3}, and if rainwater or groundwater flows into the subbase from outside, it is estimated that the said water will reach saturation point in a single rainy season[1]. Because water-saturated subbases bound by layers with extremely low coefficient of permeability, i.e. asphalt on the top and roadbed on the bottom, even the smallest amount of deformation caused by surface load will give rise to a pumping phenomenon whereby the saturated water inside the subbase moves while dragging particles along. Once small cracks appear on the surface, the pressurized water

[1] Assuming that water flows into sags in the road longitudinal direction, in the case of a 5% gradient and coefficient of permeability of 10^{-3} (cm/sec), it is possible that the subbase will become saturated over up to 100 m, although this will also depend on the porosity of the base course.

gushes out and rapidly causes critical failure (see Photograph 4-14 and Figure 4-17).

Photograph4-14.
The asphalt pavement that muddy water eructs by pumping from base course.



Condition of dry season (unsaturation)   Condition of wet season (saturation)

Figure 4-7. The pumping phenomenon

(8) Problematic soil (black cotton soil)

Black cotton soil is black-grey colored swollen soil that is widely found over East Africa. In the dry state, this soil is hard and has good bearing capacity, however, when its water content increases, it becomes clayey and swells and thus totally loses the strength it had during the dry season. When the soil dries from the wet state, contraction cracks appear, making this an extremely troublesome material for road construction. In terms of the AASHTO soil classifications, black cotton soil is classed as A-7-6. Moreover, numerous research studies have so far been conducted, yielding know-how such as that described below. Soil that is especially prone to swelling has been known to undergo volumetric transformation of more than 30%.

Table 4-6. Possibility of a plasticity index (PI) and the expansion

Possibility of expansion	Plasticity index（PI）
Low	0-15
Middle	10-35
High	20-55
Very high	>35

Sorce：Trunk road rport of Ethiopia

Table 4-7. Plasticity index (PI) and shrinkage limit and expansion degree

Plasticity index（PI）	Shrinkage limit	Rate of changeof the volume (%)Load：1psi	Expansion degree
>35	<11	>30	Very high
25-41	7-12	20-30	Hign
15-28	10-16	10-30	Middle
<18	>15	<10	Low

Sorce：Trunk road report of Ethiopia

Moreover, the form of road failure caused by black cotton soil shows a distinct pattern: first, vertical cracks appear on the pavement edges and from there the pavement failure spreads.

Photograph4-15. Black cotton soil in Ethiopia

Photograph4-16. Black cotton soil（Dry）

Photograph4-17. A test specimen of 20mm of the black cotton soil expands to 35mm 96 hours later(Condition is before immersion in water)

Photograph4-18. Typical early case of the pavement failure by black cotton soil（initial stage）

Photograph4-19. Highway section of the same area as photograph(2010 photography)

(9) Shoulder pavement failure

Failure of shoulder pavement frequently occurs on sections where low-cost pavement is used for dust control. Particularly in urban and suburban areas where the traffic volume is heavy, pavement is often damaged when cars try overtaking on the shoulder or enter the road from the roadside.

Photograph4-20.
Parking and stopping of the large car in the shoulder

Photograph4-21.
The passing vehicle which running a shoulder.

(10) Knowledge obtained from other site surveys (pavement failure)

Other opinions concerning pavement failure that were obtained in the site survey hearings are as follows.

- In light of experience of the early failure of surface course, there is thought to be a problem with tack coat. In areas of high temperatures, melting of tack coat must be taken into account.
- Failure is sometimes caused by inadequate geological survey. Particularly in Dar es Salaam, since it is possible that valley sections were previously used as waste dumps, it is important to confirm strength by boring survey in addition to CBR survey.
- Using good quality materials is the way to ensure the quality of pavement. Specifically,

a lot of failure is caused by using materials with high PI (plasticity index). (The plasticity index (PI) is an important element in determining the quality of subbase materials, etc. Generally speaking, deterioration of strength caused by water absorption is more extreme the higher the plasticity index becomes).

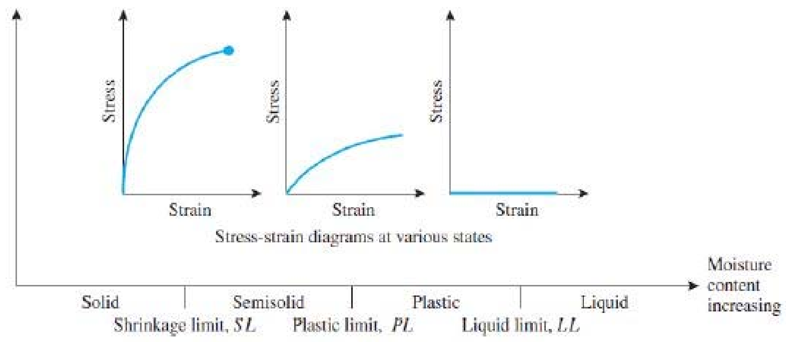


Figure 4-8 Condition of the soil and consistency limit

- In asphalt mixture, the grading distribution of aggregate often determines the quality of the mixture.
- It is important to consider weather conditions when selecting asphalt binder. In areas of high temperature, consideration should be given to using binder with higher viscosity (60/70 or 35/50). Also, use of modified asphalt with added polymer should be considered.(See Table 4-10)
- In Ghana, GHA (the client) didn't grant permission to use asphalt binder imported from a French affiliated petroleum company, citing poor product quality as the reason. This company also exports asphalt binder to Tanzania.
- In consultant works supervision, similar to project managers, it is important to assign experienced materials engineers throughout all processes. Moreover, it is important to implement stringent process control.

4.3 Implemented Pavement Failure Countermeasures

(1) Overloading countermeasures

All the target countries are striving to crack down on overloading, which imparts a lot of damage to pavement. In the background to this, many donors that conduct assistance in the road sector are requesting it, and there are even cases where loans are made conditional on taking measures to address the overloading issue. The following table shows each country's measures to deal with overloading.

Table 4-8. The control situation of the overloading vehicle

Ethiopia	Ghana	Tanzania
It is set up nine places of axle load observation station by the trunk road. The observation is carried out for 24 hours. They are planning three places of enlargement and carrying out the investigation by the consultant now. They carry out a round-table conference regularly and aim at the overloaded vehicle reduction.	In Ghana, management of axle load is carried out by GHA. There is axle load observation station of 14 places now. It is going to be added sequentially in future. The observation is carried out for 24 hours. They are introducing mobile axle loadmeasurement vehicle corresponding to a new system by support of WB now.	In Tanzania, They carry out the overloaded control at axle load observation station of 20 places. The observation is carried out for 3 change 24 hours.

Photograph4-22. Mozyo axle load observation station

Photograph4-23. Tema axle load observation station (Ghana)

(2) Failure countermeasures based on pavement type and blend design method

As a result of the site surveys, it was found that modified asphalt (plant mix type) and concrete pavement are used on important traffic sections in order to boost the fluidity resistance of asphalt in the target countries.

Table 4-9. Use example of such as the modified asphalt in survey target country

Country	Type of pavement	Note
Ethiopia	Reinforced concrete pavement － Bus stop（Japanese grant aid） － Power station access road (China) Semi－flexible pavement － Parking and stopping area（Japanese grant aid） Modified Asphalt － National route 1 project (China) － Awash Bridge（Japanese grant aid）	The expensive concrete pavement has not been adopted until recently because supply of the cement had a problem. However, three places of cement factories were built by Chinese fund. Therefore, supply of the cement was stable, and an amount of money fell greatly more. The adoption of the concrete pavement is pushed forward from now.
Ghana	Reinforced concrete pavement － Akura-Tema Road（1964） － Bus stop on the trunk road Interlocking pavement － Point that a large car runs at low speed (Tollgates) Modified Asphalt － George Bush HW（MCA） － Other trunk road	Modified asphalt is used on the main national highway. On the George Bush HW (MCA) of , Modified asphalt with beads is used. A major oil company is going to begin supply of the modified asphalt, and supply does not have the problem.
Tanzania	Roller compacted concrete pavement(RCCP) － Tanzam HW（Japanese grant aid） Modified Asphalt － Chalinze-Tanga Road（DANIDA） － Nelson Mandela Road（EU） － Kilwa Road（Japanese grant aid）	Becausea specialtechniqueis necessary forrepairas for the concrete pavement according tothe hearing toTANROAD, it is difficultto adoptit. In addition, supply has a problem even if they adopt concrete pavement because there is little fee for use of the cement. (Now building rush, cement is given priority to big building of the cement fee for use.)

Photograph4-24. Trunk road （Reinforced concrete pavement） （Ghana）

Photograph4-25. Trunk road：Roller compacted concrete pavement(RCCP)（Tanzania）

Modified asphalt is asphalt in which properties have been improved through adding polymer, rubber and other modifiers to regular straight asphalt, and using such asphalt makes it possible to reduce rutting of roads.

RCCP pavement is a type of concrete pavement. Ultra-hard mixed concrete is laid with an asphalt finisher and compacted by roller compaction. Because reinforcing bars are not used in this method, work can be executed faster and roads can be opened to traffic quicker than in the case of regular concrete pavement.

In addition to the above methods for reducing pavement failure based on pavement materials, there are cases where performance standards are set based on the dynamic stability (DS) (see Figure 4-10), while there are examples such as Superpave and Refusal Density where measures are taken based on the blend design. Refusal Density has already been applied in a number of funded assistance projects.

Table 4-10. The dynamic stability that was used by an expressway project in Ethiopia

<table>
<tr><td>Pavement composition;（Main line）</td><td colspan="3">Surface corse 4cm : AC-13（50# (40/60)、Modified material for fluidity resistance）
Base corse 6cm : AC-20 (50# (40/60)、Modified material for fluidity resistance（Steep gradient section*）
Base : 16cm-17cm：HMAM**-25 (50# (40/60)
Sub-base 32cm：Crushed stone for mechanical stabilization
*Maximum gradient5%
**HMAM: High Module Asphalt Macadam
Use cement concrete pavement at the tollgate.</td></tr>
<tr><td>Method of Mixture design</td><td colspan="3">Marshall test</td></tr>
<tr><td rowspan="2">The dynamics examination standard value（Dynamic stability）
Unit：times／mm</td><td>Surface corse（AC-14）</td><td>Base corse（AC-20）</td><td>Base（HMAM）</td></tr>
<tr><td>≧2800</td><td>≧2800（Modified）
≧1000（Not modified）</td><td>≧2800</td></tr>
</table>

(3) Rutting countermeasures

A common example of failure is rutting caused by fluidization. Assuming areas of high temperatures, rutting arises from the fluidization of asphalt mixture. Even under the same temperature and traffic conditions, rutting sometimes occurs in certain areas but not in adjoining areas for the reasons described below. The recommended countermeasures for such problems are also described. Out of these factors, the Study Team considers ① and ② to be the most important.

① Inappropriate grading distribution of aggregate … Cases that mainly arise out of quality control are due to excessive fine particles (2.35 mm or less).
⇒ (Countermeasure) Tightening of quality control

② Amount of asphalt, amount of air …This is a design issue. The optimum amount of asphalt according to the Marshall Law is larger than values obtained from Superpave and Refusal Density.
⇒ (Countermeasure) In the case of asphalt based on the Marshall method, examine the adoption of Refusal Density. Doing so makes it possible to mesh the aggregate.
The surest way to adjudicate the effects of such measures is to confirm the dynamic stability (DS) by means of wheel tracking test. In Japan, DS of 3,000 times/mm is adopted on important traffic routes. In cases where reference values are not satisfied by this test, if possible it is effective to use plant-type modifier in order to secure the strength of asphalt.

③ Aggregate particle shape issue … There are cases where the round shape of natural sand aggregate particles is a cause of fluidization.⇒ (Countermeasure) Check the shape of sand particles.

④ Asphalt needle penetration … In areas where the surface temperature is high, if procurement is possible, it is desirable to adopt low-penetration asphalt upon confirming the feasibility of execution.

(4) Structural failure countermeasures

In the target countries of the Study, concerning structural failure of pavement, failure caused by insufficient bearing force due to water inside the subbase was found to be common. In order to prevent such failure, it is important to prevent rainwater and groundwater from flowing into the subbase and to expedite the drainage of any water that does flow in. The following paragraphs describe countermeasures focusing primarily on subbase water drainage. Also, steps concerning the distinctive black cotton soil of this area are described in section (5).

Generally speaking, groundwater drainage aimed at reducing the groundwater level is installed in order to prevent weakening of road body, roadbed and subbase. However, in order to examine underground drainage measures, it is essential to implement groundwater survey at least two times, once in the rainy season and once in the dry season. According to the results of hearings with consultants concerning underground drainage facilities in Ethiopia, the following steps are taken in order to grasp groundwater flows.

- Information is obtained from local residents and local office employees concerning the flow trends of rainwater, etc. Also, hydrological engineers conduct site confirmations. Also, test pits are excavated and boring is conducted if necessary.

Concerning road drainage issues, the concept of subbase drainage is widespread in Western countries. This method entails using highly permeable subbase materials and using the subbase as a drainage layer for draining water to the roadside. This subbase drainage method is referred to as TPB (Treated Permeable Base) and a similar approach is also indicated in the SATCC and Road Note 31.

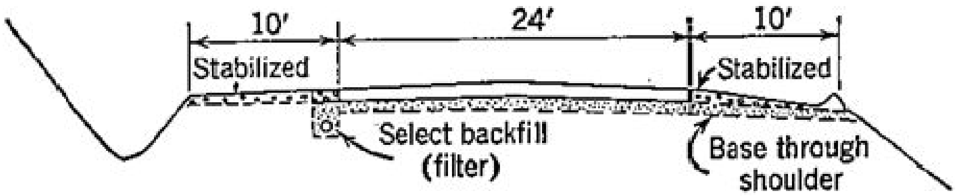


Figure 4-9. Design example of the base course drainage in the United States[2]

In the project (Japanese grant aid) currently being implemented in the target country , permeable subbase is extended to the road shoulder with a view to improving the horizontal drainage efficiency.

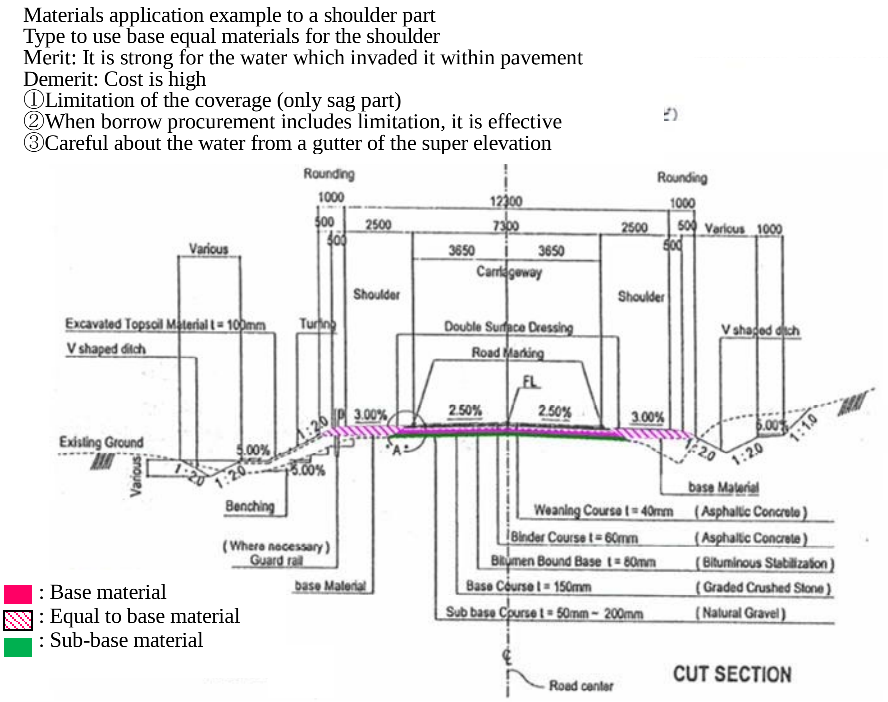


Figure 4-10. Change standard typical cross section

2 This is a common practice in the United States. Drainage sewers are installed in cuttings on the mountain side, and banking on the valley side is made by laying subbase materials through the shoulder. (However, in cases where the shoulder is wide or it is desired to achieve certain drainage, sewers are installed in the longitudinal direction on the mountain side too. Incidentally, stabilization of the shoulder materials includes graded crushed stone). In order to effectively facilitate subbase drainage, it is necessary to secure permeable materials such as crusher run or gravel for the base course (usually the lower base course), while drainage to the sides should be installed especially along the longitudinal gradient base (although it is not necessary in all sections). Similar contents are also stated in Japanese road earth and drainage works guidelines.

However, in the surveys conducted in both the rainy season and dry season, it was extremely difficult to fully grasp the actual groundwater conditions, so it is considered more valid to implement monitoring during the works period while examining countermeasure works.

(5) Countermeasures to problematic soil (black cotton soil) in the target countries

In Ethiopia, black cotton soil is distributed over almost the entire country and is a major hindrance to road construction. Accordingly, the ERA manual proposes the following countermeasures: ① alignment improvement (avoiding areas of black cotton soil), ② excavation/soil replacement (replacing black cotton soil with good quality materials along the road route), ③ limestone stabilization (stabilizing by mixing lime into the black cotton), and ④ minimization of water content changes (implementing measures to prevent water infiltration). Out of these, ② excavation/soil replacement is the most effective method, and it is recommended that this is applied as much as possible. Table 4-11 shows the black cotton countermeasures that have been adopted in recently completed projects and projects currently being implemented.

Table 4-11. Black cotton soil measures example in Ethiopia

Road	Control strategy
National road A	Replasement 800mm
National road B	Replasement 500 – 1500mm Setting of the wall with the low density polyethylene sheet.
National road C	Replasement 1000 – 3000mm Reinforcement of the wall with the sheet for block of water.
National road D	Replasement 800 – 1500mm
Standard of ERA	Replasement of 1,000mm by high quality materials.(more than CBR5) Black cotton soil remained in the lower layer, it take a measures what does not have to change a moisture content.

In Tanzania too, black cotton soil is distributed all over the country and it frequently becomes a problem in road construction works. Accordingly, black cotton countermeasures are stipulated in the TANROADS pavement design manual. In the said manual, black cotton soil is classified according to the coefficient of expansion, and countermeasures are proposed accordingly.

Table 4-12 shows the countermeasure standards for black cotton soil in different countries.

Table 4-12. Countermeasure standards for black cotton soil in different countries

Target country	Recommended measures plan
Zimbabwe	Replacement 700mm
Kenya	Replacement 1000mm
Case study in India	Replacement 1000mm
SATCC	Replacement 1000mm
United States of America	Replacement1500mm(Max)

(6) Shoulder pavement measures

Concerning the composition of pavement on road shoulders, the optimum pavement structure needs to be selected upon considering the transit area (suburban, etc.), the volume of pedestrian (bicycles) and vehicle traffic, vehicle behavior (shoulder driving or not), and road access from the roadside and so on. In Ghana, where the study was implemented, an internal notice recommends that asphalt concrete is used as the shoulder pavement on trunk roads. Meanwhile, in Tanzania, use of crushed stone shoulder is not recommended on paved roads for the following reasons:

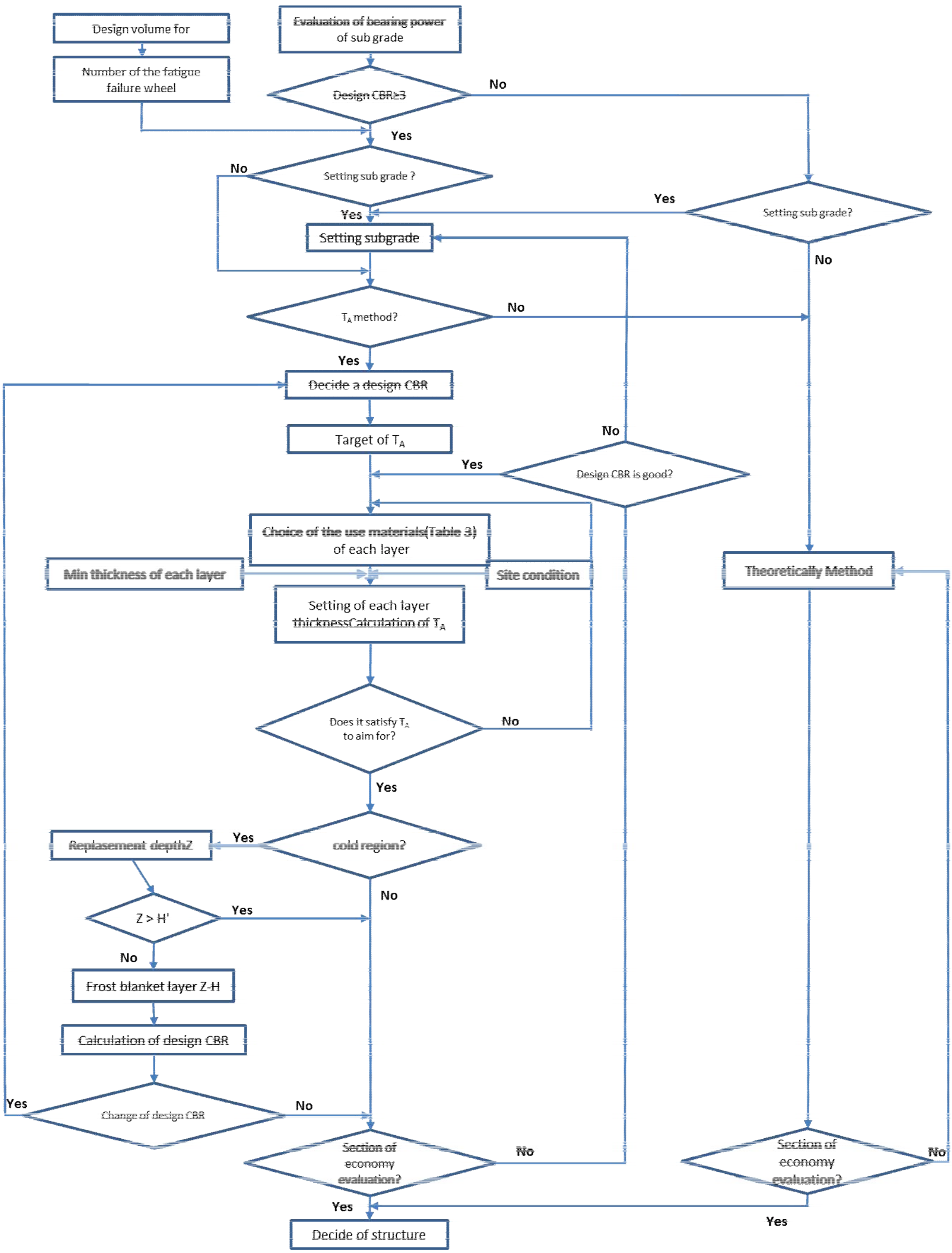
- In order to maintain appropriate performance of roads, excessive maintenance is required.
- There is greater risk of water flowing into the pavement structure.
- Unpaved shoulders compromise traffic safety.
- Height differences between the paved main road and crushed stone shoulders cause additional risk.

Pavement Design Method in Japan (T_A method)

This asphalt pavement design method entails stipulating the equivalent converted thickness of asphalt pavement and ensuring that the converted thickness doesn't drop below the target even if the materials used in each course are different. This method has been established as a unique pavement technology standard in Japan.

This design method was introduced in the Asphalt Pavement Manual that was issued in 1961. It entails seeking the total thickness of pavement from the daily vehicle traffic volume and design CBR, and it was developed by Professor Harumi Takeshita when he reworked the CBR design curve of the American military Corps of Engineers. In 1962, following 10 years of hard work and massive investment, the AASHO road test results were published. This design method entails seeking the equivalent converted thickness (T_A) from the design CBR and wheel load, and professor Takeshita reworked the relational expression according to actual conditions in Japan. When the guidelines were revised in 1967, a design method for seeking the equivalent converted thickness (T_A) from the design wheel load and design CBR was introduced and, because the conventional method for seeking the total pavement thickness was experiencing no particular problems, this was retained for checking the total pavement thickness. As a result, the T_A-CBR method, which is the core pillar of pavement design in Japan, was established and it was used up to revision of the guidelines in 1992.

In the guidelines revision of 1992, through prescribing the minimum thickness in each subbase layer, assuming that balanced pavement composition is adopted, the 4/5H provision (requiring that at least 4/5 of the calculated value is satisfied in the total pavement thickness) was removed, and the currently used design method based on T_A only was adopted. Figure 1 shows the design flow.



Source:Creat by study team based on pavement design manual

Figure-1. Concrete procedure of the structure design by the T_A method

1) Number of wheel passes causing fatigue failure

Fatigue failure refers to pavement damage resulting from cracking caused by repeated load, and the number of wheel passes causing fatigue failure refers to the "number of times required for pavement cracks to appear when wheel load of 49 kN is repeatedly exerted on the road surface). Standards figures for the number of number of wheel passes causing fatigue failure are specified as follows according to the pavement design traffic volume.

Table-1. The number of wheel passes pavement failure

Classification	Design daily Volume for pavement* （unit／day・direction）	Number of wheel passes causing fatigue failure （times／10 year）
N7	Over 3,000	35,000,000
N6	1,000～3,000	7,000,000
N5	250～1,000	1,000,000
N4	100～250	150,000
N3	40～100	30,000
N2	15～40	7,000
N1	Under 15	1,500

* : Average traffic of the heavy vehicles in the design period of the pavement
Source : Manual for Design and Construction of Pavement （Japan Road Association,2006）

Moreover, in cases where the traffic volume and wheel load during the design period are separately configured, the cumulative 49 kN converted wheel passes are sought using the following expression:

$$N_{49} = \sum_{j=1}^{m} \left[\left(\frac{p_j}{49} \right)^4 \times N_j \right]_i \qquad N = \sum_{i=1}^{n} (N_{49} \times 365 \times a_i)$$

N_{49} : 49 kN converted wheel passes per direction per day

P_j : Representative value of wheel load in the scope of wheel load at point J

m : Number of the scope of wheel load (j = 1～m)

N_j : Passing number at Pj

N : Cumulative 49 kN converted wheel passes in the design period, and necessary number of wheel passes causing fatigue failure

n : Design period

a_i : Rate of increase in wheel load passes after "i" years with respect to N_{49} (i = 1～n)

2) Design in consideration of reliability

With respect to the degree of reliability configured by the road manager, the required equivalent converted thickness T_A is sought from the roadbed design CBR and number of wheel passes causing fatigue failure using the following expression. T_A indicates the required thickness when pavement is designed as the surface course and binder course heat asphalt mixture. Reliability is differentiated according to the status of each road within the network and the importance of each road.

When reliability is 90%: $T_A=3.84N^{0.16}/CBR^{0.3}$

When reliability is 75%: $T_A=3.43N^{0.16}/CBR^{0.3}$

When reliability is 50%: $T_A=3.07N^{0.16}/CBR^{0.3}$

T_A : Required equivalent converted thickness

N : Number of wheel passes causing fatigue failure

CBR: Roadbed design CBR

Table -2. Reliability and traffic conversion

Reliability	50%	75%	90%
Mean	Causing fatigue failure term is more than 50% of design period.	Causing fatigue failure term is more than 75% of design period.	Causing fatigue failure term is more than 90% of design period.
Traffic conversion	1 time	2 times	4 times
Term to fatigue failure	The pavement that the fatigue failure does not happen through a design period if it is not change of the design condition	The pavement that fatigue failure does not happen through a design period even if a design condition has some changes. Or the pavement that fatigue failure does not happen even if it exceed design periods a little if it is not change of the design condition	The pavement that fatigue failure does not happen through a design period even if a design condition has a big change. Or the pavement that fatigue failure does not happen even if it largely exceed a design period if it is not change of the design condition

Source : Manual for Design and Construction of Pavement （Japan Road Association,2006）

3) Thickness setting of each course

The thickness of each course is determined in a manner so that the required equivalent converted thickness T_A is not undercut.

Required equivalent converted thickness (T_A’) < Required equivalent converted thickness (T_A)

$$T_A' = \sum_{i=1}^{n} a_i \cdot h_i$$

T_A’ : Required equivalent converted thickness (cm)

ai : Equivalent conversion coefficient of materials and methods used in each pavement course (value indicating 1cm of a pavement course in terms of how many centimeters of surface course and binder course heated asphalt mixture it corresponds to)

hi : Thickness of each course (cm)

Table -3. Coefficient of relative strength

<table>
<tr><th>Layer</th><th>Material/Method</th><th>Quality standard</th><th>Coefficient of relative strength</th></tr>
<tr><td>Surface coarse
Base coarse</td><td>Hot asphalt mixture</td><td>Use of straight asphalt</td><td>1.00</td></tr>
<tr><td rowspan="8">Base</td><td rowspan="2">Bituminous stabilization</td><td>Hot mixing: Stability≧ 3.43kN</td><td>0.80</td></tr>
<tr><td>Cold mixing: Stability≧2.45kN</td><td>0.55</td></tr>
<tr><td>Cement and bituminous stabilization</td><td>Unconfined compression strength 1.5～2.9MPa
Quantity of primary displacement 5～30(1/100cm)
Residual strength ≧65%</td><td>0.65</td></tr>
<tr><td>Cement stabilization</td><td>Unconfined compression strength [7days] 2.9MPa</td><td>0.55</td></tr>
<tr><td>Lime stabilization</td><td>Unconfined compression strength [10days] 0.98MPa</td><td>0.45</td></tr>
<tr><td>Crushed stone for mechanical stabilization
Iron and steel slag for mechanical stabilization</td><td>Modified CBR ≧80</td><td>0.35</td></tr>
<tr><td>Mechanical property of hydraulic, graded iron and steel slag</td><td>Modified CBR ≧80
Unconfined compression strength [14days] 1.2MPa</td><td>0.55</td></tr>
<tr style="display:none"><td></td></tr>
<tr><td rowspan="4">Sub-base</td><td rowspan="2">Crush stone
Iron and steel slag
Sand</td><td>Modified CBR>≧30</td><td>0.25</td></tr>
<tr><td>20≦Modified CBR<30</td><td>0.20</td></tr>
<tr><td>Cement stabilization</td><td>Unconfined compression strength [7days] 0.98MPa</td><td>0.25</td></tr>
<tr><td>Lime stabilization</td><td>Unconfined compression strength [10days] 0.7MPa</td><td>0.25</td></tr>
</table>

Source : Manual for Design and Construction of Pavement （Japan Road Association,2006）

The equivalent conversion coefficients shown in Table 3 represent only those values that are currently clarified. Concerning other new materials and construction methods, the T_A method can be applied so long as the road manager configures the equivalent conversion coefficient according to the strength of materials. However, in actual operation, because the test pavement used to determine the equivalent conversion coefficient incurs a lot of time and cost, a method that entails estimating the value based on indoor test results (elastic coefficient, etc.) is used. However, since such estimate values are only provisional, it is still necessary to confirm serviceability by means of test pavement. Accordingly, a figure of 1.0 is used as the equivalent conversion coefficient of modified asphalt and semi-flexible pavement, etc.

When determining the thickness of each course, the minimum thicknesses indicated in Tables 4~6 must be satisfied.

Table-4. The minimum thickness that added the surface coarse and base coarse.

Classification of traffic	Design daily Volume for pavement (unit/day)	The minimum thickness that added the surface coarse and base coarse. (cm)
N7	V≧3,000	20 (15)※1
N6	1,000≦V<3,000	15 (10)※1
N5	250≦V<1,000	10 (5)※1
N4	100≦V<250	5
N3	40≦V<100	5
N2, N1	V<4	4 (3)※2

※1：（ ）Show a minimum thickness when they use a bitumen stabilization method and cement, a bitumen stabilization method of base.

※2：Minimum thickness is 3cm without depending on bitumen stabilization method and cement, the bitumen stabilization method .

Table-5. Minimum thickness of each base layer
（Design daily Volume for pavement more than 40unit／day・direction）

Material/Method	Minimum thickness of a layer
Bituminous stabilization（Hot mixing）	Twice of Max particle size and 5 cm
Other	3 times of Max particle size and 10 cm

Table -6. Minimum thickness of each base layer
（Design daily Volume for pavement less than 40unit／day・direction）

Material/Method	Minimum thickness of a layer
Crushed stone for mechanical stabilization Crush stone	7cm
Bituminous stabilization（Cold mixing）	7cm
Bituminous stabilization（Hot mixing）	5cm
Cement and bituminous stabilization	7cm
Cement stabilization	12cm
Lime stabilization	10cm