Basic Research on Preventive Countermeasures to Cope with Disasters on Roadside Slopes (QCBS)

HANDBOOK I:
SURVEY/DESIGN IN ODA GRANTS FOR ROADS IN MOUNTAINOUS AREAS
(ROCK FALL AND SLOPE FAILURE)

February 2023

Japan International Cooperation Agency (JICA)

Oriental Consultants Global Co., Ltd.
Japan Conservation Engineers Co., Ltd.
Eight-Japan Engineering Consultants Inc.

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List of Abbreviations and Acronyms

Abbreviation / Acronyms	Meaning
AASHTO	American Association of State Highway and Transportation Officials
ADB	Asian Development Bank
ALOS	Advanced Land Observing Satellite
ASTM	American Society for Testing and Materials
AW3D	Advanced World 3D map
B/A	Bank arrangements
BOQ	Bill of Quantity
BOT	Build, Operate and Transfer
BS	British Standard
CBR	California Bearing Ratio
Ch.	Chainage
CHF	Swiss Franc
C/S	Construction Supervision
DB	Design Build
DCP	Dynamic Cone Penetration test
D/D	Detailed Design
DEM	Digital Elevation Model
DGPS	Differential GPS
DLP	Defect Liability Period
DNP	Defect Notification Period
DOD	Draft Outline Design
DoR	Department of Road
DPRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
E/N	Exchange of Note
EIA	Environmental Impact Assessment
EL	Elevation
EOT	Extension of Time
EPC	Engineering, Procurement and Construction
EPS	Expanded Poly-Styrene
FCB	Foamed Cement Banking
FIDIC	Fédération Internationale Des Ingénieurs-Conseils / International Federation of Consulting Engineers
F/S	Feasibility Study
Fs	Factor of Safety / Safety Factor
G/A	Grant Agreement
GCC	General Condition of Contract
GCP	Grand Control Point
GDP	Gross Domestic Product
GIS	Geographic Information System
GL	Ground Level
GNP	Gross National Product
GoJ	Government of Japan
GPS	Global Positioning System
GSI	Geological Strength Index
H.W.L.	High Water Level
ICB	International Competitive Bidding
IEE	Initial Environmental Examination
In-SAR	SAR Interferometry
JAXA	Japan Aerospace Exploration Agency

Abbreviation / Acronyms	Meaning
JGS	Japanese Geotechnical Society
JICA	Japan International Cooperation Agency
JIS	Japanese Industrial Standards
JPY	Japanese Yen
L/A	Loan Agreement
L/A	Land Acquisition
LCB	Local Competitive Bidding
L/D	Liquidated Damage
LiDAR	Light Detection And Ranging
M/D	Minute of Discussion
MDB	Multilateral Development Bank
MLIT	Ministry of Land Infrastructure, and Transport
MoRTH	Ministry of Road Transport, and Highway
MoFA	Ministry of Foreign Affairs
MVS	Multi-View Stereo
Mw	Momentum Magnitude
NEXCO	Nippon EXpressway COmpany Limited
NOC	No Objection Certificate
OD	Origin Destination
ODA	Official Development Assistance
O&M	Operation and Maintenance
PC	Pre-stressed Concrete
PFI	Private Finance Initiative
PMU	Project Management Unit
PPP	Public Private Partnership
PQ	Pre-Qualification
PRISM	Pico-satellite for Remote-sensing and Innovative Space Missions
P/S	Preparatory Survey
R/D	Record of Discussion
RFP	Request for Proposal
RMR	Rock Mass Rating
ROW	Right of Way
RQD	Rock Quality Designation
SAR	Synthetic Aperture Radar
SfM	Structure from Motion
SMR	Slope Mass Rating
SOW	Scope of Work
SPT	Standard Penetration Test
T/C	Technical Cooperation
TOR	Terms of Reference
TS	Technical Specification
TTB	Telegraphic Transfer Buying
TTS	Telegraphic Transfer Selling
UAV	Unmanned Aerial Vehicle
UNESCO	United Nations Educational, Scientific and Cultural Organization
USD	US Dollar
USGS	United States Geological Survey
VAT	Value Added Tax
V/O	Variation Order
WB	World Bank

Preface

< What is the Handbook in ODA Grants for Roads in Mountainous Areas? >

Based on the developing countries' request ODA Grants are to be prepared by a Japanese consultant through the JICA's Preparatory Survey and Detailed Design survey with a consultation of the Partner Country and diplomatic agreements between the two countries. There must be compromises such as limits of available time for project preparation and total project cost. Those compromises should be negotiated without affecting any negative influences especially against safety and quality issues of roads in mountainous areas to be planned.

The Handbook in ODA Grants for Roads in Mountainous Areas consists of, "Handbook I: Survey/Design in ODA Grants for Roads in Mountainous Areas", "Handbook II: Construction Supervision and Quality Control in ODA Grants for Roads in Mountainous Areas", and "Handbook III: Reference for Landslide Countermeasures in ODA Grants".

<Scope of this Handbook>

Category	Content
Target user of this Handbook	(Main) Engineers of consultants and construction companies engaged in ODA Grants (Secondary) JICA staff (Secondary) Counterpart engineers in the Partner Country (Technically important parts only extracted from Japanese original version of the handbook)
Target project of this Handbook	- ODA Grants related to road development (including bridge) in hilly areas and mountainous areas (hereinafter referred to as "mountainous areas") This Handbook is applicable to highways, high standard roads such as toll highways/ expressways and local roads as well.
Target slope disaster of this Handbook	(1) Slope failure (2) Rock fall Note) Landslides other than slope failures and debris flows are not subject to detailed surveys or design of countermeasures. However, These are added to the risk assessment of slope disaster for considering road alignment. Slope failure of road embankment and ground subsidence on flat ground/plain are not included.

<Basic policy of the handbook>

(1) As a handbook, contents are selected and compactly presented to provide the critical essences of the topics. For further understanding and explanation, it is recommended to study the technical books and guidelines mentioned in each section (most of which are available only in Japanese).

(2) Contents published in existing materials, such as Japan's highway earthwork manuals and steep slope failure prevention construction technical guidelines, would not be detailed in the handbook. This Handbook indicates the citations and encourages referrals to those citations (published materials) for more information.

(3) Following the contents of this Handbook, it shall be understood an add-on for the slope protection survey. In other words, there are additional activities and requirements to the JICA's Preparatory Survey for areas other than mountainous areas.

< Slope disaster risk management>

Road construction in mountainous areas frequently faces the risk of slope disasters by earthwork. It is necessary to minimize disaster risk at each stage of JICA's Preparatory Survey, detailed design, construction, and maintenance/operation. It is also important to clarify concerns (risks) that could not be resolved at each stage and ensure that they are communicated to the later stages.

Part 1 of this handbook, Survey and Design, describes risk reduction at the JICA's Preparatory Survey stage and risk reduction at the detailed design stage. The disaster risks that remains even at construction stages after appropriate JICA's Preparatory Survey and detailed designs is described in Part 2, Construction Supervision and Management, as disaster risk reduction at the construction stage. Regarding the disaster risk that remains after construction, disaster risk management is required at the maintenance/operation stage. In ODA Grants, although maintenance/operation is assigned to the Partner Country, the risk management in this stage is described in Part 2 as an important matter for technical transfer of maintenance/management. For reference, it is noted that geological and ground risk management in civil engineering projects is detailed in the "Guidelines for geological and geotechnical risk management in civil engineering projects (Ministry of Land, Infrastructure, Transport and Tourism, etc., 2022)".

CHAPTER 1 Introduction of Handbook Part1

1.1 Consideration in Survey/Design in ODA Grants for Roads in Mountainous Areas

In ODA Grants for roads in mountainous areas, the following points must be fully considered: 1) the differences between road development in Japan and ODA grant target countries, especially the awareness of survey/design procedures and the importance of JICA's Preparatory Survey; 2) survey of the roadside slopes and the disaster risk assessment in mountainous road development; 3) route selection of with less topography changes; 4) understanding topography and geology in a wide area containing the planned route; 5) design of road earthwork structures suitable to the geological / metrological conditions in the Partner Country; and 6) selection of the countermeasures considering sustainable maintenance in the Partner Country.

(Description)

ODA Grants preparation usually consists of 1) Preparatory Survey and 2) Detailed Design Survey. During the limited period of JICA's Preparatory Survey in ODA Grants, it is required to estimate the project costs (including temporary works and safety measures) as accurately as possible. Therefore, it is critical to conduct surveys to minimize the risk of occurrence of slope disasters associated with road construction in mountainous areas thus minimize the design change that leads to cost increase and extension of the construction period.

Even though the main purpose of the Detailed Design stage is to prepare the Tender Documents including Specs, Drawings, Cost estimation, the complementary detailed surveys that are not able to be conducted in JICA's Preparatory Survey shall also be included.

The following points should be emphasized in ODA Grants for roads in mountainous areas.

(A) Differences from Road Development Procedures in Japan, and Recognition of Differences in Survey and Design Procedures and Relative Importance of JICA's Preparatory Survey

The general flow of surveys in road development in Japan is as follows: 1) basic survey; 2) preliminary survey (survey for preliminary design of road); 3) detailed survey (survey for detailed design) and 4) Additional survey. Based on the results obtained from each of the surveys, detailed design and construction cost estimation of each earthwork structures will be carried out.

In JICA's Preparatory Survey for ODA Grants, the outline design of roads and earthwork structures is carried out based on the survey results corresponding to 1) and 2) in the survey/design flow of road development in Japan. The construction cost estimation using the outline design including temporary construction costs and safety measures costs is required as accurately as possible. Therefore, necessary investigations are required. If the JICA's Preparatory Survey results are not sufficient due to unavoidable circumstances, it is critical to indicate the details of the additional surveys required at the stage of detailed design, including roadside slope surveys.

(B) Survey of Roadside Slopes and the Disaster Risk Assessment Road Development in Mountainous Regions

Projects in mountainous areas (such as bridge construction, road widening, improvement of alignment, etc.) which do not explicitly include countermeasures for disasters on roadside slopes tend not to contain sufficient roadside slope surveys and the risk assessments. The risk of slope failures and disasters accompanied with earthwork must be always considered adequately. The necessity of identification of the problem areas and conduct of topographical and geotechnical survey in the JICA's Preparatory Survey stage for the outline design of countermeasures shall be well recognized. The further description with regard to those surveys in a wide area is mentioned in (D) below.

(C) Route Selection with the Preference to Less Topography Changes

A route with the less terrain change is the best way to minimize the risk of disasters that may be caused by the earthworks for highways in mountainous areas. Therefore, the consideration of different routes with the preference to less topographical changes shall be made for final route selection. This is especially important in countries and regions where slope disasters occur frequently. Also, from the viewpoint of landscape conservation in mountainous areas, less topography changes are better because the scale of cutting works becomes small.

(D) Understanding Topography and Geology in a Wide Area including the Planned Route

For example, a large landslide may exceed 3 km in width and length. The disaster risks on roadside slopes in mountainous areas cannot be fully evaluated by topographic/geological maps which cover only the limited narrow area around the planned route. This point should be considered. It is important to have the macroscale evaluation, as is the case for road development of Japan, where the following photographs/maps are used: wide-area aerial photographs (1/40,000 to 8,000); topographic maps (1/25,000 to 1/5,000); and geological maps (1/200,000 to 50,000).

The stability of cutting work and natural slopes is often dominated by natural morphologic evolution processes. The soil and rocks newly exposed by the cutting work are affected by complex factors such as geological/soil conditions of the ground, loosening due to stress release, effects of weathering process, etc. Therefore, the fully awareness of the deterioration progression over time is necessary, even if no deformations is observed immediately after construction (Japan Road Association, 2009a).

If aerial photos, topographic maps with sufficient accuracy do not exist in the Partner Country, the consideration for producing aerial photos and topographic maps shall be required. Aerial photos and 3D models provided by publicly opened, easily and freely available online maps (e.g. Google Maps) are widely used in mountainous road development projects. However, the accurate level of these services is inadequate and insufficient for understanding the topographical and geological conditions in a wide area including the planned route. These points should be fully recognized.

(E) Design of Earthwork Structures appropriate to the Geological/ Meteorological Conditions of the Partner Country

The cutting work is one of the basis of earthwork on roads in mountainous areas. A Japanese index for slope cutting such as gradient, height, etc. was made for keeping the stability under the following natural conditions in Japan.

- The complex distribution of geological conditions generated by orogenic movement;
- Location on the Pacific Ring of Fire, causing many big earthquakes,
- Weather conditions vary greatly by the region. Especially annual average rainfall spreads from 700 to 4,500mm (Japan’s national average is about 1,700mm)

The index of cut slope gradient for soft rock (Japan Road Association, 2009b) has a wide range of 1V: 0.5 H to 1 V: 1.2 H. Hence, the determination of the cut slope based on only this index value is difficult.

The appropriate cut slope is naturally different between Japan and Partner Countries, because of geological structure stability of the orogenic movement, annual rainfall amount (e.g. less than 500mm, more than 2,000mm).

In addition, it is noted that the classification of hard rock and soft rock adopted in the Japanese index of cut slope has been uniquely developed to judge the workability of earthwork with heavy machinery.

When considering the cut slope, the first step is the collection of various technical indexes established in the Partner Country, the on-site confirmation of the actual application of each index value (gradient of cut slope) written in their technical indexes. Japanese indexes may not always be appropriate in Partner Country Therefore, the confirmation of the various indexes on the actual slope of the specific site is necessary. If the index cannot be used for the ODA Grants site or the index is judged as unreasonable from technical viewpoint, the Japan's index should not be adhered.

If there is no available index in Partner Country but Japanese index as reference, it is required to fully understand the background mentioned above regarding the conditions of the Japanese cut slope standard (Section 3.3 and Japan Road Association, 2009b), and thoughtfully study to apply it to the Projects.

In general, the scale of the ODA Grants such as bridge construction is not large and often limited to short extensions. Under this situation, simple and stereotyped application of the cut slope index of Japan should be avoided for the stability of the cut slope constructed at the project site. A well-experienced professional engineer[1] should fully check and examine the geological conditions of the cut slope, weathering, cracks, rock quality, and examine each slope individually.

(F) Selection of the Countermeasures from the Viewpoint of the Sustainable Maintenance in the Partner Country

In ODA grant projects, adoption of countermeasures without special maintenance is desirable, but if such countermeasures are not found or are revealed inadequate, countermeasures that require special maintenance will be adopted. For example, ground anchor work and rock fall countermeasure work, which are used widely in Japan, need special maintenance during the service period. Ground anchor work requires special materials and equipment for maintenance such as lift-off test equipment. Rock fall countermeasure works require replacement and supply of maintenance materials timely after having been damaged. Or Horizontal drainage systems also require regular cleaning of the drainage pipes.

When adopting these slope protection works, the consideration of maintenance capacity of the Partner Country shall be kept in mind. From this consideration, it is necessary to take into account the proper assistance so that the Partner Country can continue to maintain and manage the countermeasure works regardless of the slope protection methods whether with or without special maintenance is required. This includes, wherever necessary, the supply of maintenance equipment and spare parts, the incorporation of maintenance manuals into the project, and trainings and through such soft components to establish maintenance capabilities in the Partner Country.

On the other hand, if countermeasure works only intend to protect and prevent erosion of the surface layer and do not expect to fulfil the requirements of resistance force, the consideration of the adaptability of the maintenance technology owned by the Partner Country is necessary to eliminate the above-mentioned maintenance-relating problems.

Source:
Japan Road Association (2009a): Road Construction Guidelines
Japan Road Association (2009b): Highway Earthwork- Guidelines for Cut Slope and Stabilization

[1] A "well-experienced professional engineer" is an engineer with sufficient experience both in Japan and overseas (25 years or more of experience), who holds qualification of Professional Engineer, and who continues to work. As a guideline, "well-experienced professional engineer "must have sufficient Japanese and English proficiency and are engaged in work related to slope disasters and civil engineering and geology. From viewpoint of scope of work, the engineer would be assigned with a grade of 3 or higher. Due to the importance of the work, it is not desirable to work concurrently with the survey of natural conditions.

1.2 Importance of Surveys to Minimize the Non-exposed[2] Disasters Risk on Roadside Slopes

> Even if slope disasters have not exposed at the time of the start of the project (at the start of the JICA's Preparatory Survey), the following considerations are required in developing roads in mountainous areas: 1) importance of disaster risk assessment on roadside slopes within the road development project. The risk assessment by the specialists on geological disaster and countermeasures is especially important; 2) necessity of minimum required surveys for disasters on roadside slopes in JICA's Preparatory Survey; and 3) importance of coordination between JICA's Preparatory Survey and detailed survey.

(Description)

"Exposure" means that the occurrence of disasters on roadside slopes such as landslides and collapses has already been confirmed and the necessity for the countermeasures to stabilize those slopes is identified in the Request for Proposal. And those slopes which are unstable or need countermeasures to stabilize are identified. If a project includes the countermeasures for an exposed slope, the survey items for consideration of appropriate countermeasures are often described in the Request for Proposal at the stage of the JICA's Preparatory Survey. However, even if countermeasures for disasters on roadside slopes are not included in the scope of work, in other words, the slope disasters have not exposed yet, the following considerations are necessary for road development projects in mountainous areas.

(A) Importance of Risk Assessment of Disasters on Roadside Slopes by the Road Development Project which especially Containing Cutting Works

Road development in mountainous areas often accompanies cutting work. The slope cutting works generally has the risk of destabilizing slopes which was in equilibrium before cutting works, then it is a factor of the disasters on roadside slopes. There are cases due to the cutting works, the reactivation of an old landslide or the induction of a new landslide in the case of geological structures. For example, when cutting the foot of an unstable rock mass that contains weak structures such as cracks、 it may induce a rock failure. Besides, various problems would be exposed such as occurrence of road failure in rainy season which has been constructed during dry season, and rock fall caused by huge boulders scattered on the upper part of slope for to-be-constructed access roads of bridge. It is necessary to clarify these potential of disaster risks as much as possible in the JICA's Preparatory Survey. Inadequate risk assessment will also increase the risks of non-exposed disasters by road construction. This can lead to additions or variations in construction details, expansion of project work volume, and extension of the construction period.

(B) Necessity of Minimum Required Surveys for Disasters on Roadside Slopes in JICA's Preparatory Survey

The quality of JICA's Preparatory Survey has a large impact on project scope of work and costs in ODA Grants. Therefore, even when disasters on roadside slopes have not exposed yet, it is necessary to establish the minimum required slope survey items to assess the disaster risks which cannot be grasped only by field reconnaissance (including existing condition and geological structure reconnaissance) for roads in mountainous areas.

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[2] The term "non-exposed disaster" in this handbook is used in the same sense as "Unforeseeable Physical Condition", which is often used in overseas civil engineering contracts. Unforeseeable physical conditions are defined in civil works contracts as "exceeding those conditions that an experienced contractor could foresee". Phenomena of this condition are treated as "unforeseeable". The costs for this shall be borne by the client. This is covered from the E/N amount in Grant Aid project. The meaning of the phrase "experienced con-tractor predictable" is ambiguous and often a source of dispute. On the other hand, if the design documents and data given to the contractor at the time of bidding indicate the risk of slope disasters, they are not treated as "un-foreseeable." However, the E/N amount must include the costs required for the countermeasures. Japanese consultants involved in JICA's Preparatory Survey for Grant Aid Project are required to propose necessary surveys, keeping in mind the minimization of "unforeseeable physical conditions", in this sense.

Table 1-1 shows the minimum necessary survey items for roadside slopes. The geophysical logging and seismic surveys in this table are supplementary when the local contractor is incapable of collecting high-quality drilling cores.

Table 1-1 Required Survey Items for Road Development Projects including Mountainous Areas in JICA's Preparatory Survey

Source: JICA study team

Survey Item	Qty.	Remarks
Analysis of topography and geology	1 set	The main purpose is to extract problem areas. It includes interpretation of topographic map, geological map and aerial photo.
Boring survey (boring cores/standard penetration test)	1 to 2 BHs / slope	To grasp the geological features of slopes which is assumed to have the long cut slope, height approx. 15m or more. It also includes RQD (Rock Quality Designation), crack information and others.
Physical logging (P and S wave velocity logging, borehole lateral loading test, etc.)*	1 to 2 tests / slope	To grasp the physical properties of the geotechnical conditions when the good quality boring cores cannot be obtained for core determination or laboratory test.
Elastic wave exploration*	1 cross section / slope	It is used as information to supplement core determination and physical logging on slopes which are assumed to have the long cut slope with height approx. 15m or more.
Soil test/Rock test	1 to 3 points / borehole	To grasp the ground strength and slaking characteristics at the slope body deeper than the cut surface.
Slope monitoring	1 to 2 locations / slope	When there exists a concern about the occurrence of a re-sliding by such as topographical analysis, including simple monitoring such as batter board observation.

* Physical logging and elastic wave exploration are supplementary when the collection of high-quality boring cores by locally subcontracted drilling companies is difficult.

The survey items listed in Table 1-1 should be planned and supervised by well-experienced technical experts. In particular, analysis of topography and geology requires sufficient experience in the fields of civil engineering i.e. engineering geology and slope disasters, and the analysis shall be carried out directly by well-experienced engineers.

(C) Importance of Risk Assessments by Specialists in Disaster Geologists and Countermeasure

Geological experts are divided into pure geological experts, resource geologists, engineering geologists, and disaster geologists. Only specialists in civil engineering geology and disaster geology can fully evaluate the risk of disasters on roadside slopes. Experts who have many years of experience in countermeasure works in Japan's road projects and Sabo projects are also suitable for the risk assessment. The evaluation of data obtained from field surveys and various observations between these experts and others such as pure geologists and resource geologists varies a lot, and the results of the risk assessment are distinctly different. In addition, the proposals for the necessary study are clearly different. Risk assessment by these appropriate experts is important in JICA's Preparatory Survey and detailed design's surveys.

(D) Importance of Coordination between JICA's Preparatory Survey and Detailed Survey

In road development projects where slope disasters have not exposed before the start of the project, the Slope Survey items and their scope of works tend to be insufficient in the JICA's Preparatory Survey. For example, slope monitoring, which requires the installation of measuring equipment, is rarely included in the JICA's Preparatory Survey items. In such cases, at least the necessary items and contents of additional surveys in the detailed design stage should be clarified in the JICA's Preparatory Survey stage. Cooperation between the two stages is important so that the detailed slope survey can be carried out without fail. Furthermore, it is necessary to clarify concerns (risks) that could not be resolved in the JICA's Preparatory Survey Stage, as well as to ensure they are taken over to the Detailed Survey. If the need for slope monitoring becomes clear during the JICA's Preparatory Survey, without waiting for the detailed design, the monitoring starting from the JICA's Preparatory Survey should be proposed to JICA. In that case, the handover and education to implementing agencies during the period until the detailed survey are necessary to ensure the implementation of the monitoring. Sufficient attention should be paid to this point.

1.3 Investigation and Design Flow for Exposed Disasters on Roadside Slopes

Surveys and designs in the JICA's Preparatory Survey which include exposed disasters on roadside slopes at the start of the JICA's Preparatory Survey are generally carried out by the following flow: 1) Desk Research in Japan; 2) First Field Survey; 3) Second Field Survey (detailed survey of natural conditions 1); 4) Third Field Survey (detailed survey of natural conditions 2); 5) Establishment of basic policy for planning and design; 6) design of countermeasures for disasters on roadside slopes; and 7) verification. The flow of investigation and design in detailed design is almost the same. However, it is still necessary to acquire additional appropriate information of design conditions for countermeasure design (topographical/geotechnical information, various design parameters including temporary work, and cost estimation) in the detailed design stage.

(Description)

In the JICA's Preparatory Survey which includes planning of countermeasures against exposed disasters on roadside, it is divided into two cases: 1) locations of countermeasure are already specified; and 2) locations of countermeasure are identified by setting priorities within the target areas. Figure 1-1 shows the flow of survey and design in JICA's Preparatory Survey for actualized slope disasters

1) Desk Research in Japan
(1) Study of similar projects: project overview, topographical and geological, meteorological conditions, construction period, and actual slope conditions of slope disasters
(2) Collection and analysis of topography and geology: local situation and regulations of preparing topographical and geological map, legal regulations related to aerial survey and local performance, procedure and methods for aerial survey to create topographic maps
(3) Collection and analysis of factors of slope disasters: amount of annual rainfall, maximum daily rainfall, maximum hourly rainfall, frequency of earthquakes, temperature (possibility of freezing and thawing)

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2) First Field Survey (preliminary survey of natural conditions)
(1) Acquisition or creation of topographic and geological maps: procurement or creation of topographic maps (1/25,000 to 1/5,000), acquisition of geological maps (1/200,000 to 50,000), comprehensive understanding of geology, topographic interpretation,
(2) Collection and analysis of available technical standard information related to slope countermeasures and disaster history in the target area: standard cut slope gradient and their practical application; standard cut slope gradient and their practical application for special geological features; technical standards for slope countermeasures; and disaster history in the surrounding area.
(3) Interpretation of aerial photographs: acquisition of aerial photographs (1/40,000 to 8,000) or stereo images of satellite images, interpretation of aerial photographs, risk assessment of landslide distribution and slope disasters, assessment of expansion possibility of landslide area
(4) Site reconnaissance: reconnaissance of the current situation, geological reconnaissance, preparation of detailed geological maps of the target area, preparation of the plan view of the target site
(5) Comprehensive analysis 1: extraction and evaluation of problem areas; and selection of areas to apply countermeasures and formulation of survey plans

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3) Second Field Survey (detailed survey of natural conditions 1)
(1) Detailed topographical survey of selected locations: plane survey, longitudinal and cross-sectional survey, creation of topographic maps (1/1,000 to 1/500), creation of initial surveyed cross-sections
(2) Sounding survey/boring survey/physical logging: simplified dynamic penetration test (simple penetration test, etc.), cone penetration test, boring core collection and evaluation, physical logging, and groundwater logging.
(3) Laboratory test: soil test, rock test
(4) Slope monitoring survey/groundwater survey: installation of monitoring equipment (groundwater level gauge, ground extensometer, underground extensometer, borehole inclinometer, pipe strain gauge, etc.), and carrying out the monitoring.
(5) Comprehensive analysis 2: analysis of factors for disasters on roadside slopes, evaluation of suitability of the current route, zoning of countermeasure implementation locations (disaster risk assessment and disaster type estimation), and setting the block priorities for countermeasure implementation

⇩

4) Third Field Survey (detailed survey of natural conditions 2)
(1) Slope monitoring survey/groundwater survey: collection and analysis of monitoring data,
(2) Site reconnaissance: reconnaissance of the current situation, understanding of changes in the local situation since the First Field Survey
(3) Geophysical prospecting (in combination with sounding surveys and boring surveys when the underground structure cannot be fully understood): elastic wave prospecting, simple elastic wave prospecting, electrical prospecting
(4) Comprehensive analysis 3: analysis of survey results and slope disaster mechanism, suitability evaluation of current routes, zoning of countermeasure implementation locations (disaster risk and disaster type), and priority setting of countermeasure implementation blocks
(5) Preparation of plans for necessary detailed surveys in the detailed design stage

⇩

5) Establishment of basic policy for planning and design ⇨ **6) Design of countermeasures** ⇨ **7) Verification**

Figure 1-1 Flow of Survey/Design for Disasters on Roadside Slopes in JICA's Preparatory Survey for Exposed Slope Disaster

Source: JICA Study Team

Based on the results of JICA's Preparatory Survey, the estimated project cost is decided. Therefore it is required that the cost including the temporary construction costs, construction costs for detour, and safety measures costs shall be accurate. When the unstable moving mass soil on the slope exists, such as a deep-seated landslide along the road, the accuracy of the survey results such as cores from boring surveys, slope monitoring of underground deformation using inclinometer in boreholes, etc. is very important, because the accuracy of estimating the depth of the slip surface affects the success or failure of countermeasure work.

In the desk research in Japan, the results of the JICA's Preparatory Survey for the project (report, topographic map, geological map, survey plan, and design drawing of landslide countermeasure work) are collected and analyzed. And, it is essential to plan the necessary surveys after grasping the insufficiency of documents such as topographical, geological maps or inadequate field surveys. In particular, additional slope monitoring such as the utilization of the borehole inclinometers to observe the underground deformation to improve the estimation of failure slip surface and other surveys to estimate design parameters for countermeasures are important.

1.4 Cut Slope and Embankment in Mountain Road Design

Careful judgment should be made on the basis of sufficient study regarding the method of constructing new roads or widening roads in mountainous areas.

(Description)

When constructing or widening a road in mountainous areas where only narrow flat land can be seen and sloping land is prominent, the comparison and judgement for the selection of the following options is important in road design, namely; (1) road construction/widening by cutting on the mountain side; (2) new road construction/widening by embankment on the valley side; (3) half cut, half fill considering both options the above. This judgment is also a choice of taking risks between (1) rock falls, slope failures and landslides induced by cutting; and (2) landslides, difficulties in embankment construction on steep slopes, or erosion and scouring of embankments along rivers; or even both of these risks.

Cut Slope tends to be used frequently for road projects in mountainous area by ODA Grants. On the other hand, it is necessary to choose appropriate engineering methods for Cut Slope according to the topographical and geological characteristics of the natural slope. This HB mainly focuses on rock fall and slope failure. Therefore, many descriptions related to cut slope are contained. This does not mean that JICA recommends cut slope. Judgement and proposal of cut slope, embankment, or half cut half fill, adoption of structures should be done by the engineer based on the considerations of natural conditions including topography and geology, design requirements for roads and bridges, and various conditions of the project in consultation with the client.

The notable differences between cut slope and embankment are followings; the cut slope is mainly intended for natural ground that is inhomogeneous and has many uncertainties; the embankment is composed of quality controllable homogeneous materials with predictable behavior, except for the foundation ground. European countries, especially France, tend to emphasize that it is easier to control works of embankment than cut slope. And it is observed the idea of using reinforced embankment rather than stabilizing the cut slope. With this background, various advanced earthwork technologies have been developed and put into practical use.

On the other hand, in Japan at least three types of light-weight embankments have been developed and put into practical use. Light-weight embankments are used in Japan for the development and widening of roads in mountainous areas, as well as the restoration of roads damaged by runoff. They are also used for the reduction of long cut slope. Although not an example of an embankment, road construction technology using overhanging steel piers from slopes is also used for road development and widening in mountainous areas and disaster recovery in Japan. All of these are technologies for constructing and widening roads mainly on the valley side. In addition, multiple construction methods of reinforced embankment are used in Japan, and there are many achievements as countermeasures against slope disasters. For example, there are the following cases: 1) Reinforcement embankment work is used to restore a collapsed road; and 2) An example of combination of roadbed restoration and embankment to prevent road slope collapse. It is also effective as a landslide countermeasure technology that reduces the magnitude of the change of slope.

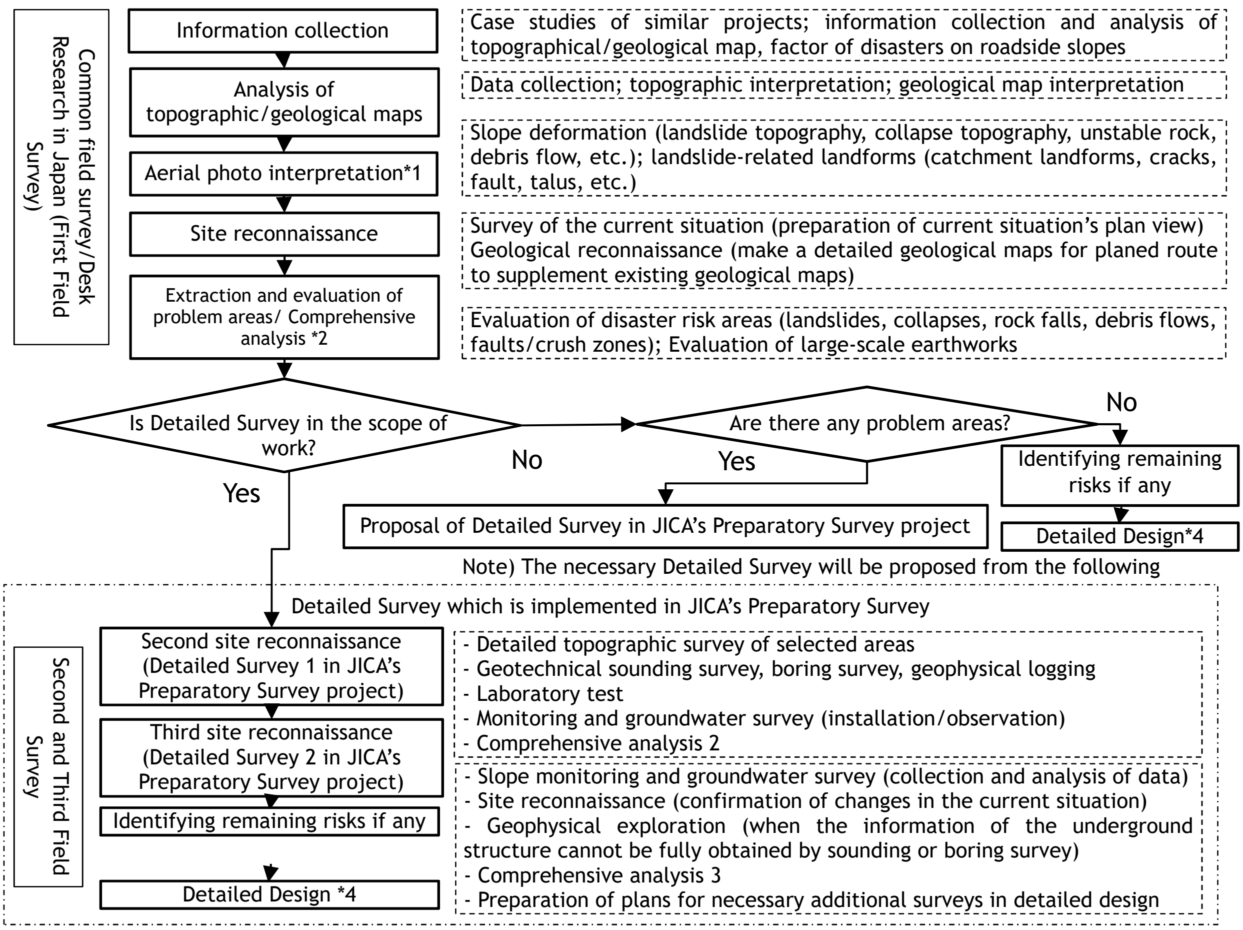
When constructing or widening a road on the valley side, special attention should be paid to the following points; erosion and scouring of embankment slopes and structure foundations by rivers; confirm and secure foundation ground for embankments and structures. In particular, there are cases that the erosion and scouring by rivers occurs when the flooding level exceeded the scale assumed at the design stage and causes serious damage to roads built on the valley side. Thus, careful consideration is required.

There are also cases when the bedrocks and soils used as the foundation for the embankment on steep slopes loosen, and for this type of damages, necessary reinforcement with the ground anchor mentioned in this HB can be considered.

For general matters concerning embankment research and design, please refer to the Japan Road Association's Highway Earthwork- embankment work guideline (2010 edition).

CHAPTER 2 Survey Methodology (Procedure, Disaster Record, Geology, Groundwater, Meteorological condition and others)

Figure 2-1 shows an ideal flow for surveys in the JICA's Preparatory Survey project for road development in mountainous areas including cases that have not yet encountered the actualization of slope disaster. Inclusion of common field survey items (First Field Survey) in the Instructions or Particular Specifications is necessary, even if the disasters on roadside slopes are not exposed when the JICA's Preparatory Survey starts. When problems are identified during the First Field Survey, it is necessary to conduct detailed surveys (Second Field Survey – Third Field Survey) and it is required to propose to JICA the appropriate survey items and contents. The contents of each survey are described in detail in the Highway Earthwork Guidelines (Japan Road Association, 2009a, 2009b) and others as applicable standards. The "common field survey" in the figure is a field survey that is always carried out in JICA's Preparatory Survey related to road development in mountainous areas, regardless of whether slope disasters have actualized or not. Second and third site reconnaissance is a field survey conducted when detailed survey is required in JICA's Preparatory Survey.



*1: Consider using satellite images or UAV images if the aerial photos are not available. In case, all these are not available, topographic analysis using topographic maps will be used with minimum required scale of 1/25,000 or larger (with contour lines within 10m).
*2: Conditions for selecting problem areas are specified in Table 3-1.
*3: In this figure, the "Common field survey" means First Field Survey.
*4: Detailed Design here is intended to hand over the survey results to the next stage after the JICA's Preparatory Survey.

Figure 2-1 Ideal Flow of a JICA's Preparatory Survey for Road Development in Mountainous Areas

Source: JICA study team, adapted from Japan Road Association (2009b)

Source:
Japan Road Association (2009a): Road Construction Guidelines
Japan Road Association (2009b): Highway Earthwork- Guidelines for Cutting and Slope Stabilization

2.1 Information Collection

In order to proceed with the field survey efficiently, conducting the following desk research in Japan is necessary: 1) case studies of similar projects; 2) collection and analysis of topographical and geological information; and 3) information collection of factors of roadside slope disasters.

(Description)

In order to proceed with the field survey efficiently, grasping the situation in the target country in advance is necessary. In case it is difficult to obtain such information and data in Japan, the consideration of other methods to obtain them shall be required. The main contents of the desk research in Japan are as follows.

(A) Case study of Similar Projects

It is desirable to obtain the documents of similar projects in the Partner Country such as roads, bridges and countermeasures of roadside slope disasters in each stage from Preparatory study to Detained Design and Construction Supervision. The experience in other infrastructure projects such as railway, irrigation, power supply and others is also useful. From such documents, study the following points: topographical and geological information (problematic geological features); meteorological conditions; construction period (rainy season/dry season); and actual conditions of disasters on roadside slopes (conditions of surrounding areas and problem areas during the construction period, disaster-related geological information).

(B) Information Collection and Analysis of Topography and Geology

Study the situation of topographic/geological map development and laws/regulations for its use/making in the Partner Country. There are such cases that obtaining accurate topographic maps required for surveys may be not possible due to military regulations, depending on the Partner Country. If the obtaining topographic maps with the required accuracy is difficult, it is required to prepare them by aerial surveys or satellite images. In addition to this, it is also necessary to investigate in advance the laws/regulations, local experience, survey arrangements related to aerial surveys, as well as methods of obtaining satellite images for making topographic maps, and others. The knowledge of the JICA local office regarding local laws/regulations related to the making topographic maps is appropriate and helpful.

(C) Information Collection and Analysis of Factors of Roadside Slope Disasters

The information of precipitation amount as a triggering factor of roadside slope disasters in the target area (amount of annual precipitation, maximum daily rainfall, and maximum hourly rainfall), presence or absence of rainy and dry seasons, frequency of earthquakes, temperature (freeze-thaw potential), snow thickness, etc., shall be collected so that the appropriate timing of field survey, points to note in designing countermeasures and appropriate construction duration can be considered appropriately.

2.2 Common Field Survey (First Field Survey)

The First Field Survey here is a Common Field Survey in Figure 2-1. The contents of the Common Field Survey for ODA Grants related to road development in mountainous areas are as follows: 1) acquisition / preparation and analysis of topographic and geological maps; 2) information collection and analysis of technical standards related to countermeasures for disasters on roadside slopes; 3) information collection and analysis of disaster records/characteristics of the area surrounding the target area; 4) interpretation of aerial photographs of wide areas including roads; 5) site reconnaissance of slopes around the road; 6) proposal for further investigation; and 7) extraction and evaluation of problem areas to assess the overall stability considering the degree of impact on the planned route.

(Description)

Even if no exposed disasters on roadside slopes exists, extraction of problem areas in the project area for road development in mountainous areas is important. As a common field survey for road development-related projects in mountainous areas, surveys of the following items are necessary.

(A) Acquisition/ Preparation and Analysis of Topographic/Geological Maps

By obtain topographic maps on the scale of 1/25,000 to 1/5,000 and geological maps on the scale of 1/200,000 to 1/50,000, along with the analysis of topographic conditions, the topography in wide area and geological conditions shall be macroscopically grasped. In particular, topographic maps are essential to extract problem areas exposed with a high risk of slope disasters with the help of the results of aerial photograph interpretation. If sufficient scale topographic maps are not available, it is necessary to make them from aerial photos or satellite images. The results of topographic interpretation from the topographic map are summarized as a micro-topographic map (landform classification map).

(B) Information Collection and Analysis of Technical Standards related to Measures for Disasters on Roadside Slopes

Since the road development in mountainous areas accompanies with earthworks, standard cut slope gradient values and their practical application in the Partner Country shall be collected as basic information and analyzed. But, even the technical standards developed in recent years are sometimes not applied to actual work in the Partner Country. Therefore, interviews should be conducted towards local consultants/contractors regarding the actual use of the standards and check whether the standards has problem or not. On the other hand, there are some countries that do not have standards for gradient of cut slopes. Local consultants and contractors often apply some values based on their experiences depending on the geological conditions.

In addition, collect and analyze other values in the technical standards for landslide countermeasures, if available in the Partner Country such as indexes related to designed safety factors for countermeasure design. Also, they may have standards for the countermeasures using vegetation suitable for their geology and climate. The standards would be a reference when considering slope protection work on the target site.

Furthermore, the special attentions shall be paid for the unique geological features affecting slope stability. Collect and analyze those information such as soil properties with its distribution, as well as appropriate cut slope and countermeasure construction methods.

(C) Information Collection and Analysis of Disaster Records/Characteristics Surrounding the Target Area

Investigate the disaster records of roadside slopes and debris flow in the area surrounding the target area, and use them as reference for extracting problem areas. Since there are countries that do not have the disaster record information, it is useful to carry out interviews with C/P's regional offices or local companies/residents to obtain those information. Internet map services which are providing the archives of the aerial photos can be utilized as needed.

(D) Interpretation of Aerial Photographs of Wide Areas including Roads

The aerial photos interpretation is the most important survey method for identifying problem areas in a wide area. Interpretation of aerial photos is performed using stereoscopic aerial photographs (scale 1/40,000 to 8,000) that are taken during topographic map making. Moreover, it shall be noted that aerial photographs interpretation cannot be done by using a single photograph such as ortho-photo.

Interpretation of aerial photos improves the accuracy of identifying problem areas by evaluating them in combination with topographical analysis results and geological maps. The results of the aerial photo interpretation should be organized as an aerial photo interpretation map on the topographic map.

If appropriate scale (1/40,000-8,000) aerial photos are not available, the interpretation shall be conducted by using the obtained stereoscopic satellite images or the contour lines on topographic map in the above (A). Aerial photos taken in developing countries may have the following problems compared to those taken by the Geospatial Information Authority of Japan: low resolution, high cloud coverage, fingerprints on the photo. If the aerial photo interpretation is not possible, use the satellite images and contour lines on topographic maps and others as complementary.

(E) Site Reconnaissance of Slopes around the Road

Site reconnaissance is divided into a current state reconnaissance related to the extraction of problem areas and a geological reconnaissance to make a detailed geological map of the problem areas by complementing the wide-area geological map. By confirming problem areas extracted by topographic analysis and aerial photo interpretation by close visual observation and simple measurements such as strike and dip (measurement convention used to describe the orientation, or attitude, of a planar geologic feature), the extraction accuracy of problem areas is greatly improved. In case aerial photos are impossible to obtain and substituted by (only) photographic analysis by topographic maps, it is required to enhance the site reconnaissance's content so that the same level of results shall be achieved as that obtained with aerial photos' interpretation.

Field surveys should be conducted by experienced and knowledgeable experts in civil engineering geology or disaster geology with the assistance of local engineers. Local engineers, especially geotechnical engineers, often have information on problematic geology and characteristic of disasters on roadside slopes in their country. Furthermore, there are cases the geological classification[3] in the Partner Country differs from that used in Japan, therefore, the assistance of local engineers is indispensable. Even in this case, the suitable experts are engineering geologists or disaster geologists, followed by engineers engaged in road maintenance.

(F) Proposal for Further Investigation

It is important to propose revisions of the survey results as necessary in the first field survey (which is common field survey). Consultation with JICA staff is required.

In particular, when large-scale earthwork[4] is unavoidable in route selection and when the results of ground surface surveys such as geological reconnaissance is not sufficient for risk

[3] Granite is a plutonic rock in Japan. But, metamorphic granite also exists in areas where produce a lot of metamorphic rocks. And it has a different appearance from Granite in Japan.

[4] For reference, the definitions of long cut slope and high embankment are shown below.
The long cut slope is about 15m or more in height. If accurate determination of the slope height is difficult, based on existing efforts, setting as a "cut slope higher than 3 small steps" is acceptable. Similarly, a high embankment is generally 10m or more in height. "An embankment that is higher than the two small steps" is also can be used. (Ministry of Land, Infrastructure, Transport and Tourism, Road Bureau (2018): Inspection Guidelines for Highway Earthwork Structures)

assessment, the survey borings, soil/rock tests, seismic exploration and physical logging shall be conducted.

In the case of a long cut slope, the additional boring survey of three boreholes/slope for creating a geological cross section is desirable. If the high quality cores is difficult to obtain by local subcontracted survey companies, seismic exploration and physical logging shall be carried out to grasp the strength characteristic values of the ground necessary for evaluating the stability of the cut slope.

(G) Extraction and Evaluation of Problem Areas

Evaluate the whole area and the overall stability by comprehensive judgment based on the above survey results. The problem areas that need to be extracted and their further evaluation conditions are shown below.

Table 2-1 Problem Areas that need to be extracted and their Conditions

Source Excerpt from "Japan Road Association (2009): Highway Earthwork - Guidelines for cutting and slope stabilization", partially revised

Phenomenon	Main conditions for extraction
Slope failure /rock fall/rock failure	1) Slopes already have distribution of landslides and adjacent slopes 2) Slopes that have been shattered entirely due to the effects of fault fracture zones and others 3) Slopes with a thick distribution of topsoil and talus, steep slopes, and slopes with transition lines 4) Slopes with poor vegetation 5) Strongly weathered slopes 6) Steep and cracked slopes 7) Long and cracked bedrock slope 8) Bedrock slopes that are long and weathered relatively quickly 9) Slopes with significant river erosion at the foot 10) The general stability is determined by referring to the "Guideline for stability evaluation of surface collapse and rock fall" in the rock fall countermeasure manual (Japan Road Association, 2017). 11) Geological features that frequently cause slope disasters due to cut slope in the area 12) Geology susceptible to deformation such as swelling and slaking due to stress release and exposure
Re-sliding landslide	1) Area where exposed the landslide topography 2) Slopes with many landslides in surrounding area 3) Slopes with significant river erosion at the foot
Debris flow	1) Streams with unstable soil deposited on the riverbed with a gradient of over 15 degree or more 2) Streams where debris flows occurred in the past 3) Existing embankment which is made by construction/industrial waste on the upper side slope of the project road of the project road.
Large-scale earthworks	1) Geological composition and structure where re-sliding landslides and collapses are expected after cutting slope 2) Slope having concern about the impact on the slope behind the target slope after cutting work
Embankment failure	1) Embankment made by removing excavated soil, collapsed soil around the road 2) Existing embankment made of construction debris and industrial waste on the upper side slope of the project road of the road and around the project road

Source:
Japan Road Association (2009a): Road Construction Guidelines
Japan Road Association (2009b): Highway Earthwork- Guidelines for Cutting and Slope Stabilization
Japan Road Association (2017): Handbook for countermeasures against falling rocks
Road Bureau, Ministry of Land, Infrastructure, Transport and Tourism (2018): Inspection Guidelines for Highway Earthwork Structures

2.3 Surveying Natural Conditions to Minimize the Risk of Non-exposed Disasters on Roadside Slopes

> In ODA Grants including road and bridge development project in mountainous areas where disasters on roadside slopes have not exposed, it is crucial to conduct a slope survey in the natural condition survey during the First Field Survey in order to minimize the risk of non-exposed disasters. Among them, the aerial photo interpretation and field reconnaissance (i.e. the current state reconnaissance and geological reconnaissance) are important and should to be fulfilled.
>
> The above is related to the Information collection, Analysis of topographic/geological maps, and site reconnaissance in Figure 2-1.

(Description)

This section explains points necessary to keep in mind regarding the aerial photo interpretation and field surveys. They are particularly important in First Field Surveys for ODA Grant projects in which the disasters on roadside slopes have not exposed. The field reconnaissance is divided into the following two: the reconnaissance survey of the current state of the slopes; and a reconnaissance survey of the geological conditions and geological structure of the target area to produce a detailed geological map that supplements the wide-area geological map.

(A) Points to Note in Interpreting Aerial Photographs to Extract Problem Areas Related to Disasters on Roadside Slopes

A reflective stereoscopic mirror is basically used in aerial photograph interpretation. If stereoscopic aerial photographs are not available, alternative measures described in Section 2.2(D) will be considered. As another alternative measure is that, when aerial laser survey data is available in the target country, interpretation can be carried out using contour topographic maps made by those data. If the above alternative measures are not possible, topographic interpretation would be implemented by contour topographic maps made by ALOS World 3D – 30m (AW3D30) which is an open source DEM (Digital Elevation Model) provided by JAXA (Japan Aerospace Exploration Agency) for the whole world. When using such ALOS (Advanced Land Observing Satellite) images and aerial laser data, specialized knowledge is required, such as their respective characteristics, application range, and accuracy confirmation in the case of the aerial laser. In case, those information is not possible to obtain, the topographic analysis by topographic maps as an alternative can be utilized, however, to conduct the analysis efficiently, the scale of topographic maps shall be 1/25,000 or larger (contour interval less than 10m).

Table 2-2 lists examples of topography and others which should be included in the aerial photo interpretation map.

Interpretation results will be verified by field reconnaissance. Any questions or problems that arise during interpretation will be reviewed and supplemented through field surveys.

Table 2-2 Examples of Information to be included in Aerial Photo Interpretation Map

Source: excerpt from "Japan Road Association (2009b): Highway Earthwork - Guidelines for cutting and slope stabilization", partially revised

Category	Extracted topographical features	Major Characteristics
Slope change	Collapsed topography	Collapsed areas can be easily identified because there is no vegetation compared to the surrounding area.
	Landslide topography	It has a unique topography. Gentle slope surrounded by multiple knick lines (line that connects points where the slope becomes steep) and gentle lines.
	Debris flow topography	Fan-shaped soil deposition is observed near the outlet of the stream into the flat plain. Debris flows are usually deposited with gradients of 2 to 10 degrees.

Category	Extracted topographical features	Major Characteristics
Related to the slope change	Gentle slope of upper part	Understanding the distribution of talus deposits, residual collapsed soil, landslide masses, etc.
	Cracks on upper slope	This is a possibility of precursor phenomena of slope failure and landslide.
	Linear pattern, fault topography, lineament	Landforms, color tones and others are linearly continuous.
	Slope change line	Knick line. In particular, knick lines (line that connects points where the slope becomes steep) are prone to collapses and landslides.
	Talus cone	A semi-conical shape with a slope of about 30 to 40 degrees that is slightly convex upwards, or a combination of these features.
	Exposed rock	Exposed rock generally forms steep cliffs in many cases, and is a potential area for rock fall and rock failure.
	Catchment area	Catchment landforms called zero-order basin or mountain folds tend to collect water, so they are prone to debris flows and sediment runoff due to mountainside collapses.
	Double ridges, small cliffs, linear depressions	Precursor landforms of large-scale failures and landslides
	Vegetation	Confirm the type (forest, grassland, bare land, etc.), density, and growth status. Depending on the vegetation conditions, it may be possible to estimate the geological, soil, and groundwater conditions.
	Embankment shape around the road	The following are likely to cause collapses and debris flows: existing road embankments that have been constructed using the soil excavated from around the project roads, collapsed soil and others; construction waste materials on slopes upstream of roads and around the project roads; and existing embankments made from industrial waste and others.

Details of aerial photo interpretation are described in "Chapter 3 Survey" of the Japan Road Association (2009b).

(B) Points to Note in Field Reconnaissance (Reconnaissance of Existing Conditions, Geological Reconnaissance) to Identify Problem Areas Related to Disasters on Roadside Slopes

Table 2-3 shows the items to be noted in the field reconnaissance. In the field reconnaissance, not only the natural conditions but also the condition of the existing cut slope (geology, presence or absence of abnormality in the current cut slope, types and effects of slope protection works and surface water drainage works and their conditions, vegetation conditions, etc.) can be obtained. These are important basic information for various works such as road earthwork that shall be implemented in the project.

Table 2-3 Items to be noted in the Field Reconnaissance

Source: excerpt from "Japan Road Association (2009b): Highway Earthwork - Guidelines for cutting and slope stabilization", partially revised

Category	Item	Contents of observations
Topography	Abnormal topography	Closely confirm the situation of overhangs, rocks, and knick line.
	Slope conditions of valley's head part	Condition of spring water and the steep slope behind valley's head
	Collapsed topography	Length, width, depth, geology/soil, cracks, weathering/alteration, gradient of slip surface, spring water, vegetation, cracks on slope, level difference, scarp, remaining/accumulation form of collapsed sediment, rock fall/collapse possibility of recurrence/expansion, existing disaster prevention facilities
	Landslide topography	Overall topography, slope, position of transition line, ground surface deformation (presence of cliffs, wetlands, shape of cracks, presence of upheaval/extrusion, spring water conditions, abnormal growth pattern of trees, etc.), structural changes
	Debris flow topography	Status of the source, status of the downstream part, status of the sedimentary part
Geology	Geology/soil	Confirmation of geological type, check of rock and soil
	Geological structure	The nature and distribution of geological discontinuities (bedding, schistosity, joints, unconformity, etc.) (strike/dip, continuity, interval, etc.), fold structures, igneous rock intrusions, faults and shatter zones , status of alteration zone
	weathering condition	Looseness of bedrock (crack spacing and degree of opening), weathering alteration status
surface information	Distribution of collapsed rock, expected falling rock	Size and shape, hardness, stability, distribution
	spring water and surface water	Location and amount of spring water, hydration condition of the surface, freeze-thaw conditions in winter
	Vegetation situation	Confirm the type (forest, grassland, bare land, etc.), density, and growth status. It is possible to estimate to some extent the conditions of geology, soil, groundwater, etc. from the vegetation conditions.
Information on existing structures	Cut slope	Appropriateness of geology and cut slope, actual conditions of slope protection works and surface water drainage works, growth of vegetation
	Slope protection work *1	Deformation of various landslide countermeasure facilities
	River facility	Deformation of revetments, dikes, sluice gates, sluice pipes, irrigation facilities, etc.
	Road facilities	Deformation of pavements, bridges, drainage works, etc.
	Agricultural land above the slope	Farmland usage (there is a risk that water in the farmland will destabilize the slopes)
	Embankment around the road	Situation of embankment slope protection work (including drainage), deformation of embankment boundary, deformation of embankment slope.
	Others	Deformation of buildings such as houses, railway facilities, etc.

*1) Developing countries sometimes have structures that cannot be seen in Japan. In some cases, such structures can be adopted as landslide countermeasures, but even in such cases, understanding their effects and deformation is necessary.

Details of field reconnaissance are described in "Chapter 3 Survey" of the Japan Road Association (2009b).

Source:
Japan Road Association (2009a): Road Construction Guidelines
Japan Road Association (2009b): Highway Earthwork- Guidelines for Cutting and Slope Stabilization

2.4 Surveying Natural Conditions for Exposed Disasters on Roadside Slopes in Detailed Survey Stage

The following points should be noted in the natural conditions survey (detailed survey) for disasters on roadside slopes that have exposed in the JICA's Preparatory Survey stage: 1) coordination with the First Field Survey results; 2) survey plan relating to the zoning of countermeasures; 3) implementation of monitoring relating to meteorological conditions such as rainy/dry season; 4) importance of to understand the distribution of unstable soil layers; 5) decision to implement geophysical survey; 6) field reconnaissance in detailed survey; 7) points to note for comprehensive analysis; and 8) proposal for additional surveys.

The above is related to the Information collection, Analysis of topographic/geological maps, and site reconnaissance in Figure 2-1.

(Description)

Points to note in the natural condition survey (detailed survey) for the exposed disasters on roadside slopes are shown below.

(A) Coordination with First Field Survey Results

Draft a detailed survey plan using the results of the First Field Survey.

(B) Survey Plan Considering Zoning of Countermeasures

In order to plan and design landslide countermeasures, it is necessary to zone (or classify) the target slopes into each type of disasters which is likely to occur. For example, the following zones can be considered; zones where re-sliding of colluvium is a concern; zones where rock fall is concerned on slopes with many cracks; zones where megaliths are scattered; zones where mix of them can be assumed and others. Classify the target slopes including the moving soil mass of the surrounding slopes. Since the countermeasures shall be considered for each zone, the extent of each zone shall also be considered based on the effectiveness and constructability of the countermeasures.

When preparing survey plan for all natural condition surveys, keep in mind that its result shall become the judgment materials for planning and designing the countermeasures for each zone.

(C) Implementation of Monitoring Relating to Meteorological Conditions such as Rainy/Dry Season

In countries with heavy rainfall period such as the rainy season, monitoring the changes of the rain intensity before and after that period is important. When making the survey plan, it is necessary to consider the number of days required for drilling boreholes. Borehole-drilling. Drilled boreholes are used for monitoring of soil mass movement such as groundwater fluctuation, pipe strain gauges, etc.

(D) Importance of Understanding Distribution of Unstable Soil Layers

Boring and sounding surveys are very important to investigate the distribution of unstable mass and its strength in the target slope.

The survey will basically conducted by a with core sampling (with a standard penetration test (SPT) for soil sections). In principle, the drilling survey will be attended by Japanese engineers or trained or experienced local engineers. On-site management can be done by the local engineers mentioned above, but the Japanese engineers of the study team will be present at least at key points, observe the state of drilling core extraction, and strive to accurately grasp underground information.

Dynamic Penetration Testing (DCP) without boring is widely used in many countries, but in this case it is impossible to obtain the cores. Therefore, DCP should be considered as a supplementary method, for exemplum, for grasping the distribution of unstable soil masses.

In Japan, drilling core sampling technology is particularly advanced. When using Japanese operators and boring machines/tools, it is expected that taking high-quality core samples, and soil tests using high-quality cores are possible. However, in the countries of the ODA Grants, boring surveys of the same quality as in Japan cannot be expected. This point should be fully understood.

It is necessary to assign the well-experienced specialists who has high techniques enough for exact core-collecting from crude cores. For example, the necessary information should be obtained even from cores with a low rate of core sampling. Even if the core has poor quality, it is possible to predict the condition of the core sections that are washed out, based on the results of surrounding site reconnaissance and observation in detail of the shape of the successfully extracted cores. In 2000s, Japan's core sampling technology developed rapidly. Before that, the situation was not much different from that of the core sampling in developing countries. Considering that the survey works were conducted even in that situation, the danger of relying completely on a high core sampling rate can be understood. It is noted that the high core sampling ratio itself does not guarantee high reliability on the results of the core sample observation. Even so, the fact that no cores are collected is itself valuable information, and the core collection rate is a reflection of geological and lithological conditions. Valuable information can also be obtained by listening to the operator about the collection status of the core outflow section and by observing the slime in the non-core section. In this sense, the information obtained from accurate and detailed daily drilling reports is as valuable as or more valuable than core samples. When selecting a local subcontractor, as will be described later, ensuring the details of the working record in the daily drilling report in their past experience is necessary.

Engineers engaged in ODA, not just Grant Aid, are expected to use their wisdom and ingenuity according to the situation so that they can achieve their objectives even in the above-mentioned difficult situations. In this sense as well, the placement of well-experienced specialists is essential.

Since the boring survey will usually be conducted by a local subcontractor, appropriate assessment of the ability of the contractor to be invited to the bidding, and their quotations in the market as well, is required in advance.

Even if we select the best local subcontractors in the Partner Country, core sampling of the same quality as in Japan cannot be expected. Therefore, making the investigation plan on the premise with regard to core outflow and core disturbance is necessary. In extreme cases, the core extraction rate at 0% is not uncommon. In the worst case, making the investigation plan that does not rely on core observation or core sampling is also necessary. In that case, it is necessary to grasp the soil strength characteristics of the target ground by combining sounding, geophysical logging, and seismic survey results. Slope stability evaluation is sometimes necessary without information on the strength characteristics of the ground lacks reliability and effectiveness.

Even if core collection is not possible, observing the water level inside the borehole is often possible. A lot of information can be obtained by the observation of the borehole water level before and after drilling, the casing depth of the day, and the drilling water head chart made by these records.

For local subcontracting of drilling, technical specifications that clearly define the following points must be used as bidding materials, and quality assurance must be ensured from the stage of selecting a local subcontractor: 1) collect cores of the highest quality possible; 2) place the cores correctly in the core box, and take photo of the cores that can withstand detailed observations; 3) obtain reliable location information (elevation and coordinates); 4) record the water level before and after work on all working days; 5) accurately record the daily drilling report describing the rotation speed, supply pressure, water supply pressure, water supply amount, water loss amount, casing depth, boring bit, core tube type for each core tube insertion; 6) make a columnar map recording the type of geological soil, hardness, consistency, grain size, water content, color tone, degree of weathering, core shape, crack interval, crack properties, and degree of alteration and 7) when providing samples for indoor soil and rock tests, use an appropriate sampler and handle the samples appropriately.

(E) Decision to Implement Geophysical Survey

Seismic exploration and electrical prospecting can grasp the two-dimensional underground structure. However, what is obtained is the distribution of elastic wave velocity and resistivity. Therefore, checking the results of boring surveys (core determination) and the results of various physical logging using boreholes is necessary. Then, elastic wave velocity and resistivity distribution are interpreted. Therefore, making a research plan that can analyze the geological structure by collating these is necessary.

On the other hand, if high-quality core sampling by subcontracted survey boring cannot be expected, geophysical exploration and geophysical logging may be used to ascertain the strength characteristics of the ground.

However, the number of companies capable of conducting geophysical surveys is limited in the Partner Country. Moreover, their capabilities may not be equivalent to those of Japan. The importance of verification of survey results is higher than in Japan. This point should be noted.

(F) Field Reconnaissance in Detailed Survey

The field reconnaissance in the detailed survey is to conduct a detailed reconnaissance of the extracted target locations (problem locations). The focus is on grasping the geological structure and physical properties of the cut slope part, as well as weak points that can become slip surfaces. In addition, confirm the changes in the current situation from the time of the field survey conducted in the First Field Survey, and use it as a basis for determining the slope zoning to consider countermeasures.

(G) Points to Note for Comprehensive Analysis

Analyze all survey results, clarify the mechanism analysis of slope disasters, evaluate the suitability of the current route, and prepare zoning based on the estimation of disaster risk and disaster type for each zone where will be implemented landslide countermeasures. Then, the priority of countermeasure blocks is set.

(H) Proposal for Additional Surveys

If additional surveys are necessary due to non-exposed facts, such as when the target slope disaster has expanded beyond the range assumed in advance, additional surveys must be conducted through the prescribed procedures.

2.5 Topographic Survey

Detailed topographic maps are the basis for detailed surveys, road earthwork and countermeasure design, construction planning, and cost estimation. In order to improve the accuracy of construction planning and estimation of countermeasures for disasters on roadside slopes, paying attention to the following points is necessary: 1) management of local subcontracting of the topographic survey; and 2) the extent of topographic survey.

The above is related to the information collection, analysis of topographic/geological maps, aerial photo interpretation, and site reconnaissance in Figure 2-1.

(Description)

A detailed topographic map (1/1,000 to 1/500) is the basis for making a survey plan and creating a survey plan view on the topographic map that summarizes the survey results when conducting a detailed survey. In addition, topographic maps and vertical and cross sectional views are indispensable for the design, construction planning and estimation of road earthworks and landslide countermeasures.

Quality control and progress management are important when topographic survey is to be subcontracted locally.

Topographical survey for countermeasures should include not only the planned area along the route and road earthworks, but also the problem areas (collapse topography and landslide topography) of the target area and slope behind the target slope that are expected to be affected by the collapse and landslide of the target areas. In this respect, making predictions by interpreting aerial photos and topographic maps in the First Field Survey is important.

2.6 Preparation of Detailed Survey Plan for Detailed Design

Points to note in the detailed survey plan prepared as part of the JICA's Preparatory Survey results are as follows: 1) quantity of survey borings and performance of drilling equipment based on the assumed disasters on roadside slopes; 2) determining the need for geophysical exploration; and 3) determining the necessity of monitoring. However, from the viewpoint of ensuring the accuracy of the estimated E/N amount, there are the cases where it is required to conduct the necessary survey in the JICA's Preparatory Survey

(Description)

Coordination between the JICA's Preparatory Survey and detailed design is important in ODA Grants which has the limitation of the survey period/frequency comparing the road projects in Japan. If there are any deficiencies in the JICA's Preparatory Survey for cooperation, prepare a detailed survey plan to ensure survey implementation during detailed design.

Quantity of Survey Borings and Performance of Drilling Equipment Based On the Assumed Disasters on Roadside Slopes

It is necessary to roughly determine the number of required survey borings and the total excavation length based on the assumption of the target disasters on roadside slopes, because the period required for boring survey differs depending on the number of survey borings and the length of excavation. In case that it is difficult to obtain the appropriate quality boring cores by the boring equipment in the Partner Country by ordinary specification used for the bidding, it is required to clearly specify the necessary specifications of the boring equipment.

(A) Determining Supplements by Geophysical Exploration

If the Engineer evaluates that the survey boring alone is insufficient to grasp the underground structure, and even if good quality boring cores are available, it is necessary to prepare a detailed survey plan that includes the geophysical exploration and geophysical logging inside the borings to analyze adequately the underground structure.

On the other hand, if obtaining high-quality cores by subcontracting boring survey is difficult due to local technical level, conduct geophysical exploration and geophysical logging to grasp the strength characteristic values for slope stability evaluation.

(B) Determining Necessity of Monitoring of Chronological Change of Slope

The monitoring requires a long period of time from installation to observation and data collection. Various monitoring surveys such as observation of ground surface movement, underground soil movement, groundwater level and others exist. Judge the necessity of the monitoring and reflect it in the detailed survey plan according to the type of the assumed disasters on roadside.

(C) Survey to Determine Design Parameters for Countermeasures

If ground anchor or soil nailing are selected in the preliminary design of the JICA's Preparatory Survey, investigation of the skin friction resistance of the target site ground at the time of detailed design is necessary. Therefore, a basic survey test (pull-out test) should be included in the detailed plan. When using an independent loading plate for ground anchor work, conducting field test to determine the coefficient of subgrade reaction on the ground surface is necessary. If deep landslides are expected, incorporating various types of surveys into the detailed plan to investigate the depth of the slip surface is necessary.

Similarly, in the detailed design stage, it is desirable to confirm the geological condition by boring survey at two outermost lines of deterrence piles or ground anchors which locate far from the main survey line.

CHAPTER 3 Design Methods (Procedure and Others) and their Points to Note

In this HB, the design carried out during the JICA's Preparatory Survey is expressed as "Outline Design". This Outline Design is especially important for the ODA Grants. This chapter can be applied in case of the following assumptions: necessary detailed survey for the design has been conducted in JICA's Preparatory Survey for against exposed disasters shown in the work flow in Figure 2-1; and a minimum detailed survey shown in Table 1-1 has been conducted. If Detailed Surveys are not implemented, Outline Design will be difficult to improve the accuracy of project volume estimates. In addition, this chapter also corresponds to the design of landslide countermeasures in Detailed Design.

In the ODA Grants, Detailed Design is implemented after the conclusion of EN. However, as mentioned above, the estimated project cost, which is the basis for the EN amount, must be more accurate. For this reason, the selection and design of landslide countermeasure works in this chapter may be carried out in JICA's Preparatory Survey to the extent that the above conditions are met. This point should be kept in mind.

The selection flow for the countermeasure works differs between the selection flow for cutting work and the selection flow for natural slopes which have risk of collapse. The selection flow associated with the former cutting work is described in "Highway Earthwork- Guidelines for Cutting and Slope Stabilization (Japan Road Association, 2009)". The selection flow for natural slopes can be found in the "Technical Guideline for Steep Slope Collapse Prevention Construction (National Flood Control and Sabo Association, 2019)". In addition, the flow for selecting rock fall countermeasures is included in the "Rock fall Countermeasure Handbook (Japan Road Association, 2017)".

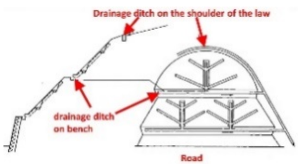
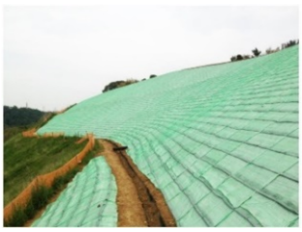
The above is a selection flow as a general theory made based on past disaster cases and damage cases in Japan's environment. Special characteristics are not considered such as the geological and meteorological conditions of each target area where the ODA Grants is implemented and the examples of damage. The following points are particularly important in selecting countermeasures. First, Consider the Topographic and geological features including geological structure of the target site, meteorological conditions, frequency of earthquakes, vegetation conditions, and, if there are landslide countermeasure structures in the vicinity, their soundness and others. Second, assume disaster scenarios at the target locations. Third, after conducting a risk assessment for each disaster scenario, select countermeasures that can respond to that disaster scenario. In slope protection projects in Japan, it is often required to specify the main factors that serves as the basis for selecting slope protection works. Although it is likely considered to be important to follow the flow of selection of countermeasures described in Public technical guidelines, refrain from as a matter of course using those flows in target countries where the situation is different from that of Japan. While referring to the Japanese selection flow as a basis for selecting countermeasures, the situation of the target site mentioned above must be carefully examined and the optimum countermeasures must be selected.

In addition, the above Japanese guidelines do not include a selection flow for preventive works such as the ground anchor/soil nailing method. Consideration of the deterrent function of each work, the extent of application, and the construction cost for the selection is necessary.

The purpose and function of major countermeasures and the selection method are shown below in Table 3.1 and following sections. It is worth noting that all methods listed in the table can be used for all types of roads from municipal roads to higher level roads.

Table 3-1 Objectives and Functions of Principal Countermeasures and Selection Method (1)

Source: Japan Flood Control and Sabo Association (2019): Technical Guidelines for Countermeasures of Steep Slope

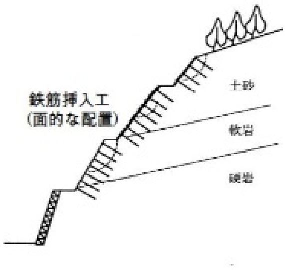
Type of Works	Objective/Function	Selection Method
Slope drainage 	Collects surface water and drains it outside the slope. Prevention of surface water inflow into the slope.	Slope drainage is used in most construction works when there is a possibility of slope erosion. The construction cost is cheap and the effect is great. Slope drainage is rarely used alone and is used in combination with other countermeasures. <Selection based on natural conditions, and required performance> If the slope surface is bedrock, or if the maximum annual rainfall in recent years is less than 500 mm and there is no rainy season, this method is not used. <Points to note regarding the capabilities of local contractors> Reinforced concrete U-shaped ditches are desirable because cracks are likely to occur in canals with masonry structures. An experienced contractor of constructing U-shaped ditches on slopes is desirable. <Notes on long-term maintenance> Removing the accumulated soil from the waterway and repairing leaks by cracks is necessary.
Groundwater drainage 	It drains the groundwater in the slope and lowers the pore water pressure to stabilize the slope.	Groundwater drainage is used in places where landslide failure is expected and on slopes with a lot of groundwater. This type of work is rarely used alone and is used in combination with other countermeasures. <Selection based on natural conditions, and required performance> It is not used for hard rock slopes. <Points to note regarding the capabilities of local contractors> In the case of high-place work, it is preferable to use a contractor with experience in temporary scaffolding. <Notes on long-term maintenance> Depending on the groundwater water quality, slime will occur early and the drainage function will deteriorate. Maintenance equipment such as high-pressure cleaners and borehole cameras inspection are required.
Vegetation 	Prevention of rainwater erosion, easing of ground surface temperature, prevention of soil freezing, beautification effect by vegetation	If the risk of collapse is low and slope protection by vegetation is deemed appropriate, there exists many methods such as a method using vegetation sheets, turfing, and vegetation base spraying Continuous long fiber reinforcement earthwork is also a kind of vegetation base spraying. The construction method will be selected according to the vegetation work selection flow. <Selection based on natural conditions, and required performance> The type of vegetation works varies depending on temperature, altitude, soil chemistry, and other factors. Select plant which grow under the local condition. <Points to note regarding the capabilities of local contractors> None (technical guidance may be required) <Notes on long-term maintenance>None

Type of Works	Objective/Function	Selection Method
Shotcrete / mortar spraying 	Prevention of erosion of slopes, weathering, and reduction of the ground strength.	Select a bedrock with no spring water, small cracks, and no major collapses. This method is selected when the stability of the slope can be maintained only by this method, mainly for the purpose of preventing weathering of the bedrock slope (no problem with shotcrete / mortar spraying alone without using combination of other types of works). The consideration of scenery is also a condition for the selection. <Selection based on natural conditions, and required performance> Shotcrete / mortar spraying is not used in extremely cold regions because the damage caused by freezing and thawing is remarkable. In recent years, Shotcrete / mortar spraying would not be selected due to scenic considerations. Shotcrete / mortar spraying is also unsuitable for slopes with many springs. <Points to note regarding the capabilities of local contractors> Nozzle man's skills have a significant impact on quality, so construction experience at high slopes is required. If there is no construction experience, technical guidance from a Japanese specialist is required. <Notes on long-term maintenance> Frequent repairs will be required at sites with lot of shallow groundwater, back cavities, cracks, and where delamination are likely to occur.
Concrete crib 	Prevent weathering and erosion of the slope. It is also used as a pressure-receiving structure for rebar / anchor work.	Select this method in case the stability of the slope cannot be achieved by shotcrete, or when concrete crib is used as a foundation of vegetation. If the slope is gentler than 1V:1.0H, use precast type. If the height is high or if the slope is uneven, shotcrete is suitable. <Selection based on natural conditions, and required performance> When used together with preventive works such as soil nailing/ ground anchor works, secure the design standard strength of mortar or concrete. But concrete crib is not suitable for winter construction in cold regions. <Points to note regarding the capabilities of local contractors> When the spraying method is used, the skill of the nozzle man has a significant impact on the quality. If experiences of construction in high places on slopes and construction experience do not exist in the Partner Country, technical guidance from a Japanese specialist is required. <Notes on long-term maintenance> Underground opening (crack/cavity) on the back of the structure is likely to occur at the point where there is a lot of shallow groundwater. Therefore, frequent repairs are required.

Table 3-2 Objectives and Functions of Principal Countermeasures and Selection Method (2)

Source: Japan Flood Control and Sabo Association (2019): Technical Guidelines for Countermeasures of Steep Slope

Type of Works	Objective/Function	Selection Method
Cutting work (Photo omitted)	Used in case of widening the road Removal of unstable soil, or improvement of slope shape	The most basic construction method for road landslide countermeasures. Select when securing road width or slope shaping is required. Since the cutting itself will lower the stability of the slope than before, structures such as retaining walls (earth pressure resistance structures) may be required. <Selection based on natural conditions, and required performance> None <Points to note regarding the capabilities of local contractors> None <Notes on long-term maintenance> Considering geological and meteorological conditions, it is necessary to use necessary slope protection works such as drainage and/or vegetation together.
Retaining wall 	Prevents small to medium collapses by fixing the foot. By securing a steep slope at the retaining wall, the slope of the upper part can be gentle. Foundation work such as rock fall protection fences.	When a collapse is a scale that can be prevented by a retaining wall can be expected. When making the lower part of the slope steeper in order to secure the road width is necessary. When the gradient of the top part of slope needs to be gentle. When foundation work for the countermeasures such as a rock fall protection fence is required. It should be noted that in some countries, local governments often adopt retaining wall -shape structures However in many cases, this kind of structures have no or little earth pressure resistance. <Selection based on natural conditions, and required performance> None <Points to note regarding the capabilities of local contractors> None <Notes on long-term maintenance> None
Anchoring 	The tensile force of the anchor artificially gives the pressure force to the surface soil of the slope and prevents it from collapsing.	When a large collapse is expected, the slope length is long, and other construction methods are not stable enough. The aptitude of the anchorage ground is also necessary. In some countries, anchor work using steel rods is common, like the old type anchor work in Japan. <Selection based on natural conditions, and required performance> None <Points to note regarding the capabilities of local contractors> The quality of this type of work is greatly influenced by the contractor's ability, such as drilling-hole cleaning, grout quality control/filling control, and quality confirmation testing. Construction experience at high slopes is required. There are wedge-type method and nut-type method for head fixing, and the final finishing method after inserting the tendon is different each other, so construction experience with each head fixing method is also required. <Points to note regarding the capabilities of local contractors> Adopt a head structure that the local contractor can perform maintenance works such as re-tensioning and

Type of Works	Objective/Function	Selection Method
		unloading. The tension load is constantly changing, such as its increase in tension load due to slope fluctuation, or its decrease in tension load due to plastic deformation of the ground near the pressure plate, and relaxation of the PC steel wire. In addition, the head is easily damaged by falling rocks and corroded by rainwater or groundwater. Regular maintenance is essential to maintain the function for a long period.
Earth reinforcement,(soil nailing)  	Slope failure is suppressed by the tensile strength of the reinforcing material.	When a relatively small collapse with a depth of about 3-4m or spalling of bedrock is expected. When the slope length is long. When the prevention works of whole area is required. <Selection based on natural conditions, and required performance> Not suitable for large and profound collapses. In the case of leaky ground, consider using a seamless packer together. <Points to note regarding the capabilities of local contractors> The quality is greatly influenced by the contractor's ability, such as cleaning the inside of the hole after drilling, quality control of grout, and filling management. Construction experience at high slopes is required. In some countries, there are contractors who do not grout the outer circumference of reinforcing bars even if they have construction experience, so checking the equipment used for grouting is necessary. <Notes on long-term maintenance> None
Rock fall prevention work (rope covering work) 	Reduce or eliminate the causes of falling rocks (countermeasures for the origin of risk).	Easy to take countermeasures at its (their) original position and the cost is low. <Selection based on natural conditions, and required performance> None <Points to note regarding the capabilities of local contractors> Contractor with construction experiences. Provide technical guidance by Japanese specialists as necessary. A contractor who has the equipment necessary for grouting anchor bolts. <Notes on long-term maintenance> Periodic inspection and repair for corrosion and for damage of steel materials are required.

Type of Works	Objective/Function	Selection Method
Rock fall protection work (rock fall protection fence work, pocket type rock fall protection net, etc.) 	Protect the target road from damage caused by falling rocks (roadside countermeasures).	When rock fall damage cannot be prevented only by countermeasures at the origin of risk such as rock fall prevention works. <Selection based on natural conditions, and required performance> Positions to install pillars and anchor bolts must have a low risk of small collapses or rock collapses. If the risk is high, framing work and spraying work will be used together. <Points to note regarding the capabilities of local contractors> Contractor with construction track record. Provide technical guidance by Japanese specialists as necessary. <Notes on long-term maintenance> Periodic inspection and repair or replace of damaged and corroded parts are required. Removal of soil and rock masses caught by the fence or net.

3.1 The Difference between Outline Design (Design at the JICA's Preparatory Survey) and Detailed Design in ODA Grants

Outline design and detailed design for ODA Grants should be carried out with the following points in mind: 1) estimation of project volume and accuracy of technical specifications; 2) differences in the amount of information on various physical properties required for design; and 3) importance of comparing outline design and detailed design

(Description)

Points to note regarding the difference between outline design and detailed design in ODA Grants are described below.

(A) Estimation of Work Volume and Accuracy of Technical Specifications

The outline design carried out at the stage of the JICA's Preparatory Survey is important because the outline design is directly linked to the project scope of works. Keep in mind the necessity and sufficiency of the design, assuming that the parameters required for the design may change due to the detailed investigation conducted at the detailed design.

If the slip surface depth of the assumed slope failure is deep, examine the thickness of the unstable mass by boring survey, and then consider the amount and arrangement of necessary countermeasures.

When designing ground anchor work, the length of the anchor material required and the excavation length differ depending on the depth of anchorage ground and the physical properties at that point (peripheral friction resistance, etc.). If boring survey in the JICA's Preparatory Survey is not possible or not sufficient, the depth and physical property values cannot be obtained. In this case, therefore, setting the depth on the safe side within the assumed range is necessary.

On the other hand, detailed design is for determining the technical specifications for ordering construction work. Therefore, the accuracy of technical specifications is important. In this sense, a detailed investigation is required to obtain the necessary design parameters and its coordination with the results of the JICA's Preparatory Survey is essential.

(B) Differences in Amount of Information on Physical Property Values Required for Design

When designing ground anchor work and soil nailing work, the peripheral frictional resistance of the anchorage ground is necessary. The basic investigation test (pull-out test) and others are required to measure it. When using an independent pressure bearing plate for ground anchor work, a field test to determine the coefficient of ground reaction on the ground surface is also required. In addition, investigation of the slip surface depth by various underground surveys is necessary, when the survey is targeting unstable soil masses on slopes caused by deep-seated landslides. These surveys to determine the parameters necessary for design are rarely conducted at the stage of the outline design.

(C) Importance of Comparing Contents of Outline Design and Detailed Design

In order to achieve appropriate outputs in the ODA Grants, coordination of the JICA's Preparatory Survey results and the detailed design is important. Compare the outline design of the JICA's Preparatory Survey with the detailed design before the detailed survey, and check whether there are any items that have not been considered yet.

3.2 Slope Stability Analysis

Slope stability analysis used for design should be conducted with the following points kept in mind: 1) conditions for slope stability analysis; 2) appropriate use of forward analysis and back analysis; 3) points to note when conducting forward analysis 4) considerations for selection of slope stability analysis formula; 5) limitation in Japanese practice of determining cohesion from depths of slip surface.

(Description)

Points to consider in slope stability analysis used for design are described below.

(A) Conditions for Slope Stability Analysis

There exist different methods of slope stability analysis depending on the target slope deformation phenomenon. In the case of rock fall, locations that require countermeasures are selected based on stability evaluations such as boulders. But, publicly admitted stability analysis for design does not exist. Nevertheless, there exist stability analysis methods (Ryunoshin Yoshinaka and Yuzo Onishi, 1992) that correspond to the failure mode, such as wedge failure, for bedrock collapse of fissured rock. In order to apply this, grasping the distribution of cracks inside the slope is necessary.

In general, stability analysis for cutting/filling work is targeted for failures due to circular slips or non-circular slips. In this section, points to note about this method are explained. In this stability analysis, plane slips along bedding planes can also be considered. In order to conduct a meaningful stability analysis for plane slip, grasp the distribution of the target bedding plane with necessary accuracy.

Stability analysis for the design of cut slopes is generally not conducted in Japan, excluding cutting at landslide and/or collapse sites (Japan Road Association, 2009a). The natural ground in Japan has a very complex and heterogeneous structure because the ground includes geological discontinuities and weathered/altered areas. Therefore, obtaining highly accurate distribution of parameters of the slopes to evaluate and conducting a meaningful stable analysis are not practical. However, if the slopes in the Partner Country are composed of relatively uniform geology as shown below, meaningful stability analysis may be practical.

1) When surface collapse of the topsoil is assumed
2) When almost homogeneous geology such as sand layer, talus layer, colluvium, gravel, volcanic soil, etc. is deposited thickly, and large-scale or landslide failure is assumed inside the layer
3) When the targeted ground is almost homogeneous in terms of civil engineering geology, and
4) When there is no geological characteristics which affect the stability due to geological structures and crack distributions that can be weak points such as bedding planes and joint planes.

In Japan, stability analysis is usually conducted for the following cases: examination of the road facilities including cut/fill slopes which have been deformed during construction or after construction (Japan Road Association, 2009a); occurrence of collapses on natural slopes along roads and, facing these incidents, when stabilization measures for moving soil mass are required. In that case, refer to the next item (B).

(B) Appropriate Use of Forward Analysis and Back Analysis

In the project of steep slope collapse prevention of Japan, the minimum safety factor is set from the iterative calculations and the slip surface shape of neighboring failure cases. After that, the soil strength parameter is adjusted so that the current safety factor F becomes F=1.0. This is called back analysis. The precondition of the back analysis is that the collapsed target slope requires some landslide countermeasures. The stability analysis is also applied to re-design the countermeasures and to investigate the restoration of original measures that have been deformed during or after cut slopes fall.

On the other hand, if the need to implement landslide countermeasures is not clear, for example there seems no apparent failure on target slope, forward analysis will be conducted.

Forward analysis is generally conducted to assess slope stability for existing situation and after completion of countermeasure. Back analysis is used to evaluate the relative increase in slope safety factor due to slope protection works, that means the absolute safety factor of the slope itself is not focused, and to determine the placement and quantity of slope protection measures to achieve the planned safety factor.

(C) Points to Note When Conducting Forward Analysis, and How to Obtain Soil Parameters

Understand the following limitations as a precondition: stability analysis formula of the limit equilibrium method assumes that the moving soil mass is a rigid body, in other words, no deformation; all local safety factors in the moving rigid body are equal; assumptions different from the actual soil properties are adopted; and the true safety factor of the slope cannot be evaluated. Despite the above limitations, stability analysis using the limit equilibrium method is widely used, including in Japan, to evaluate the relative increase of the value of the safety factor of countermeasures (Japan River Association, 2005).

(Tendency of formula)

The Fellenius formula and the modified Fellenius formula have the possibility to generate, according to the geological situation, a smaller safety factor than other stability analysis formulas such as the simplified Bishop formula. We should note that, when applying the Fellenius formula or modified Fellenius formula in forward analysis, depending on situation of sites, slight chance remains that such formula might evaluate stable slopes as unstable.

In addition, soil parameters should be carefully selected for forward analysis. The value of soil parameters to be adopted, including unit volume weight, should be based on estimated values using soil test results or sounding results. (See for details of the stability analysis formula, Geotechnical Society (2006): Introduction to Slope Stability and Deformation Analysis - From Basics to Actual Examples).

Nevertheless, unlike design for embankments where engineers can control materials and method of construction, the characteristics of natural slopes in hilly and mountainous regions are usually erratic. Thus, it is essential to obtain representative soil parameters taking into account its distribution of the value in the slope.

(D) Considerations for Selection of Slope Stability Analysis Formula

Based on the aforementioned points, proper formula should be selected depending on site situation and purpose of design.

The ODA Grants will be implemented by a Japanese contractor. Therefore, Japanese contractors will often use Japanese technology, which is highly reliable in terms of quality control and process control. Therefore, the modified Fellenius formula which is used in standard road earthwork stability analysis and Japanese design software may become the slope stability analysis formula.

On the other hand, software such as SLOPE/W (Geo-SLOPE) and Slide2 (Rocscience) from Canada and Slope (GeoStru) from Italy are often used in the design of countermeasures overseas. These software support many stability analysis formulas such as Spencer's method, simplified Bishop's method, and simplified Janbu method. However, those software do not support the modified Fellenius formula.

Engineers on the Counterpart side and local consultants may tend to use the above Western design software. When introducing Japanese technology and using Japanese stability analysis methods in ODA grants under such circumstances, understanding of Counterparts on the usefulness of the modified Fellenius formula (long-term achievements in Japan) is required. On the other hand, if a design using Western design software is adopted, confirmation of the feasibility of Japanese consultants and contractors to handle them is necessary. If the Japanese consultant or contractor has no experience with this design method or with the construction method designed through these software, hiring third country's company through subcontracting as sub-consultant or sub-contractor may be possible. In this case as well, though, in order to avoid the so-called "pass the buck", the subcontracting management ability of the Japanese consultant and contractor is required.

(E) Unique Method in Japanese Practice of Determining Cohesion from Slip Surface Depth

In Japan, for re-sliding landslides, a method to determine cohesion of slip surface from the maximum and/or average depths of slip surfaces of landslides are sometimes used. The cohesion obtained from the said method is often used to obtain internal friction angle φ through back analysis. This is a method unique to Japan in estimating soil strength parameters for existing slip surface clay. Not so many academic bases in terms of soil mechanics or geotechnical engineering support this method, however.

The soil parameters calculated in back analysis contains error values (noises) due to the difference between the current safety factor and the true slope safety factor and those due to essential problems of the stability analysis formula shown in (c) above. Thus the bias from the true value of the parameter becomes large. It is necessary to appropriately determine the internal friction angle φ, which greatly affects the estimation of the effects of groundwater drainage work, anchor work, rebar insertion work, etc., from soil tests or other conditions on site such as slope gradients at head scarp or slip surface exposed on site, etc. Then, cohesion can be obtained through back analysis. This method can more appropriately evaluate the effects of countermeasures (see "Landslide Society Tohoku Branch, 2001", etc.).

On the other hand, for initial failures on steep slopes as well as cut slope failures, it is necessary to evaluate the risk of slips (collapses) based on the peak strength of the ground. The method of determining cohesion from depths of slip surface cannot be applied for this case, either.

Source:

Japan Road Association (2009a): Highway Earthwork- Guidelines for Cutting and Slope Stabilization, p153.

Japan River Association (2005): River Sabo Technical Standards Commentary and Plan, Ministry of Land, Infrastructure, Transport and Tourism, p.189.

Geotechnical Society (2006): Introduction to Slope Stability and Deformation Analysis - From Basics to Examples, pp.29-43.

Yoshinaka, Tatsunoshin and Onishi, Yuzo (1992): Block theory and its application to rock engineering, doboku-kogakusha, 359p.

Landslide Society Tohoku Branch (2001): Strength Determination Method for Landslide Stability Analysis -Aiming for New Developments in Practice-

3.3 Cutting Works and Points to Note

Paying attention to the following for the design of cutting work is necessary: 1) basic concept of cutting work; 2) assumption of disaster scenario in stability evaluation of cutting; 3) stable slope and stability evaluation of cutting; 4) conditions to particularly pay attention to stability assessment; and 5) design of simple slope protection and drainage

(Description)

The main considerations in the design of excavation works are shown below. For details on the basic concept of cutting work, points to note, design conditions and others are described in "Japan Road Association (2009a): Highway Earthwork- Cutting and Slope Stabilization Guidelines" and "Hokuriku Regional Development Bureau (2020): Design Guidelines - Road Edition".

(A) Basic Concept of Cutting Works

"Basic Concept of Cutting Work" in "Japan Road Association (2009a): Highway Earthwork- Guidelines for Cutting and Slope Stabilization" says "Judgment of the stability of the design related to the stability of the slope through a detailed investigation is desirable. However, if no particular problems at the First Field Survey stage is confirmed, referring the standard slope gradient based on experience and the condition of the existing cut slope in the surrounding area is possible." Japan's standard of cut slope is an empirical value based on the premise of Japan's weather and geological conditions, and cannot be easily applied overseas. (Details are described in Chapter1.1(E))

In principle, the cut slope in the Partner Country should be individually evaluated for stability by an experienced professional engineer. However, the conditions which can be evaluated by stability calculation are limited, as explained in "3.2 Slope Stability Analysis". Expert engineers should evaluate the stability based on the physical property information of the ground (including core sampling), topographical conditions, and weather conditions obtained by detailed surveys.

(B) Assumption of Disaster Scenario in Stability Evaluation of Cutting Works

In order to evaluate the stability of cutting, an assumption on what kind of slope disaster may occur on the slope of the target cutting is necessary. If multiple types of slope disasters may occur on one cut slope, evaluation of the stability for each type of disasters is needed.

(C) Stable Slope and Stability Evaluation of Cutting Works

Soil and rocks newly exposed by excavation work are complexly affected by predisposing factors such as the soil conditions of the ground, the loosening due to stress release, and the weathering. Even if no de-formation immediately after construction exists, fully considering the deterioration progresses over time is necessary (Japan Road Association, 2009a).

The stability of the cut slope varies depending on the geology of the target site as well as the amount of rainfall and the frequency of earthquakes. In countries and regions with the same geology as Japan but with clearly lower rainfall than Japan, even steeper cut slopes are stable. The standard cutting gradient for road earthwork for soft rock in Japan also has a wide range of 1:0.5 to 1:1.2. The cut slope cannot be determined only by this reference value. The cut slope is determined by examining the presence and degree of deformation of the cut slope in similar geological features in neighboring areas.

When considering the stability of the cutting slope in the Partner Country, and in the case of complex ground conditions that are difficult to use the stability calculations, the consideration would rely on the stability evaluation by experts who have experiences in Japan and overseas. But, the information on physical property (including core judgment) necessary for the evaluation is necessary for the stability evaluation in the state of the natural slope before cutting. In addition, the method of rock mass classification using elastic wave velocity and workability of heavy machinery in road earthwork in Japan (highway earthwork-soil survey guideline, 1986) can be used as a guideline in overseas countries. In addition, the actual gradient of existing cut slopes around the target site and the condition of them (existence or non-existence of the deterioration) will also serve as criteria for evaluating stability. In order to understand the effects of loosening and weathering of the soil, observation of the slope immediately after construction is desirable. If possible, observing the cut slope after a long period of construction is necessary to understand the long term effects of the passage of time on the slope.

If securing the stable gradient of slope is not possible due to land restrictions and other reasons, the consideration is required for the combined use of other restraint works.

(D) Conditions Requiring Special Attention to Stability Assessment

Natural ground is highly heterogeneous. Its strength depends on the degree of weathering and cracking, stratification bedding, existence of void and moisture content. Therefore, it is necessary to consider the local situation, to investigate the existing slope conditions, and to evaluate the stability comprehensively. In particular, Japan's guideline says that the standard cutting slope may not be applicable to the special cutting conditions as shown in Table 3-3. Slope gradient and its height, effective slope protection method and slope drainage are determined after carrying out geological and soil surveys, and considering as reference the "Highway Earthwork- cutting earth work / reinforced earthworks guideline (2009 edition)".

Table 3-3 Cutting Conditions Requiring Special Attention in Stability Evaluation

Source: excerpt from "Japan Road Association (2009b): Highway Earthwork- Cutting/Slope Stabilization Guidelines"

Category	Conditions of Cutting
Regional / ground condition	1) In the case of a re-slide type landslide. 2) In the case of talus, colluvium, and strongly weathered slopes. 3) Sandy soil, etc., especially in the case of soil that is vulnerable to erosion. 4) In case of rocks which weather quickly such as mudstone, tuff and serpentinite. 5) In the case of rocks with many cracks. 6) When the crack becomes a sink. 7) When there is a lot of groundwater. 8) In snowy and cold regions (when peeling due to avalanche, snowmelt water, and freezing and thawing are likely to occur). 9) If the ground is susceptible to be damaged caused by earthquake.
Conditions for cutting	1) When the slope becomes a long slope (when the cutting height exceeds the height shown in footnote 4). 2) When there are restrictions from the site/land acquisition, etc.
Effects by collapse of cut slope	1) When collapse causes serious damage to adjacent area. 2) If it is collapsed, it will take a long time to recover, and the road function will be significantly obstructed. (e.g. cut slope where no alternative roads in mountainous area)

(E) Design of Simple Slope Protection and Drainage Works

In Japan, the minimum slope protection works such as vegetation work to prevent erosion are implemented on cut slopes with soft geology, even where a stable slope is secured. This reflects the fragility of Japan's geology and the amount of rainfall (including the frequency of heavy rainfall). Thus, this can contribute to secure the safety driving in rainy weather.

Cut slopes with soil/sand and strongly weathered rocks naturally require slope protection and drainage in the area where the average annual rainfall is about the same as or higher than that of Japan. However, following cases can be considered depending on the Partner Country: "post-disaster response after the disaster occurrence" system is assumed as a rule; the necessity and importance of minimum slope protection works for prevention are not understood.

Determine the need for minimal slope protection and drainage to prevent erosion based on the consideration of the deformation of existing cut slopes in the surrounding area, the presence/absence of the rainy season, the annual average rainfall, and the maximum daily rainfall records, even if the amount of rainfall is not too much.

In countries and regions with low rainfall, such as annual average rainfall of 500 mm or less, slope protection works for cut slope is thought not be necessary if a stable slope is secured. However, even if the annual rainfall is low, slope protection works may be necessary because of the existence of short-term/ high-intensity rainfall. Checking the rainfall situation and slope conditions on site and making a careful decision is necessary.

Source:
Hokuriku Regional Development Bureau (2020): Design Guidelines - Roads
Japan Road Association (1967): Road Construction Guidelines
Japan Road Association (1986): Highway Earthwork- Soil investigation guideline
Japan Road Association (2009a): Road Construction Guidelines
Japan Road Association (2009b): Highway Earthwork- Guidelines for Cutting and Slope Stabilization
Geotechnical Society (1974): Engineering properties of rocks and their application to design and construction, pp.361-378.
Adachi, Y. (1984): Rock Classification from the Perspective of Excavation Workability - Especially Classification of Soil, Soft Rock, and Hard Rock, Applied Geology Special Issue, pp.119-131.

3.4 Concrete Crib Works

Spray crib works by shotcrete is a countermeasure unique to Japan. Spray crib work has many slope protection functions and functions to assist other construction methods, therefore it is also effective overseas. Cast-in-place concrete crib work is a construction method similar to spray crib work, and expected functions are almost the same. However, cast-in-place concrete crib work is suitable for large cross-section of concrete crib work at a flat slope surface with a low slope height. Consider the conditions for avoiding use of the concrete crib work, because there are more restrictions on construction than spray crib work

(Description)

Spray crib work is a countermeasure unique to Japan, and not widely used overseas. Spray crib work is widely used because it has many slope protection functions. Cast-in-place concrete crib work is similar to spray crib work, and expected functionality is almost the same, but has more construction restrictions. This construction method is suitable when the mortar/concrete spraying machine is not available. The main design considerations are described below. The details of the design method are described in detail in "the concrete crib work design and construction guideline," National Specified Slope Protection Association, 2013".

(A) Expected Functions

Slope Surface Protection

Spray concrete crib work mainly prevents rock spalling and surface collapse by itself. Spray crib work is often used for rock slopes with many cracks and slopes that need emergency protection. These slope protection functions are superior to other construction methods such as the method of covering the ground surface with a steel net. The basic function is the same as the cast-in-place method, but it has better workability and can be applied even on uneven slopes. Spray crib work can be used for a wide range of gradient from steep slopes to gentle slopes. Spray crib work also has superior corrosion resistance and long-term durability compared to steel products such as steel nets in areas where there are concerns about high temperature, high humidity, and salt corrosion.

Function as Greening Foundation Works

Spray crib work is possible to implement vegetation work and vegetation base spraying work within the concrete crib work.

Function of Preventive Works as a Bearing Structure

Spray crib work is used as a bearing structure for soil nailing and ground anchor work on slopes.

(B) Conditions to Avoid

1) Slopes with a Large Amount of Surface Water Flowing during Rainfall and Spring Water Confirmed

Back surface of the concrete crib work may have underground openings (cracks, cavities, etc.) due to scouring.

2) Slope with a Thick Soil Layer on Slope Surface

Back surface of (beneath) the concrete crib work may generate underground openings due to scouring of rainwater and surface water. If the soil layer on the surface of the slope is thin, elimination it by slope surface shaping is desirable. On the other hand, removing a thick soil layer on the surface of the slope has the possibility to lead to destabilization of the slope. This point should be noted.

3) High Slopes with a Height Exceeding Lift Capacity of Mortar/concrete Spraying Machine (Spray Crib Works)

The stable pumping distance and lifting capacity differ depending on the model of the mortar/concrete spraying machine. At present (as of 2021), the capacity of maximum vertical height of the wet spraying machine is about 130m (pumping distance within 250m). But, the stable pumping distance is generally about 100m or less and the lifting height is about 45m or less. High slope designs that exceed the capabilities of the spray machines used in the Partner Country should be avoided.

4) Slope with Unevenness (Cast in-situ Concrete Crib Works)

If the slope has large unevenness, the formwork cannot be installed due to the unevenness.

5) High Slopes to Cast Mortar and Concrete (Cast in-situ Concrete Crib Works)

Flat slope surface with a large cross section and low height is suitable comparing with the cast-in-place crib work, because in this method a formwork is set up and concrete is placed on site and the transportation of completed large crib work is not necessary.

(C) Points of Consideration in Design

1) Concrete Design Standard Strength

The standard design strength in Japan is 18 N/mm2 thanks to the improvements in the performance of shotcrete equipment at present, 2022. But, until around 2006, 15 N/mm2 was used. (National Specified Slope Protection Association, 2006). Examine the design standard strength in consideration of the performance of the shotcrete equipment used in the Partner Country (including consideration of dry or wet classification).

2) Strength of Available Reinforcing Bar / Standards for Reinforcing Bar and Design Standard Strength

Reinforcing bars of various standards are available in Japan. But, the standards **of** available rebar in the Partner Country may be different. Consider whether to use Japanese standards or standards in the Partner Country. JIS and ISO differ in the type, shape and dimensions of standard strength (yield point strength) of reinforcing bars (deformed steel bars). The standards adopted in the partner countries may also differ from those of Japanese products in terms of standard strength, diameter, cross-sectional area, etc. This point should be noted.

3) Clarification of Structural Details

In Japan, structural details such as the required minimum cover and minimum spacing between reinforcing bars are stipulated in the standard specifications for concrete, but, overseas structural details may differ from those in Japan. Therefore, specify the structural details necessary to obtain the performance of reinforced concrete. In addition, specify clearly the structural details on the as-built drawings which is also serve for the later maintenance and management of constructed countermeasure works.

Source:
Japan Road Association (2009): Highway Earthwork- Guidelines for Cutting and Slope Stabilization, p.280-284.
National Specified Slope Protection Association (2006): Guidelines for design and construction of glue frames (revised version), November 2006.
National Specified Slope Protection Association (2013): Guidelines for Design and Construction of Glue Frame Work (Revised Edition 3rd Edition), October 2013

3.5 Ground Anchor Works

Anchor work has an excellent preventive function as preventive work for the stabilization of slopes, and is suitable for construction on steep roadside slopes. On the other hand, when the anchor work is damaged, the degree of influence on a third party is large. Maintenance of all countermeasures during the service period of the roads is needed. Design after evaluating suitability for the site, including maintainability is necessary.

(Description)

Design considerations are described below. The details of the design method are described in the following materials: Ground Anchor Design and Construction Standards, Commentary (Geotechnical Society, 2012) and Design Guidelines - Roads (Hokuriku Regional Development Bureau, 2020); Design Guidelines 2nd Collection (Hokkaido Development Bureau, 2021); and Ground Anchor Design and Construction Manual (Japan Anchor Association, 2013)

(A) Expected Functions

1) Prevention of Slope Failure

Ground Anchor Works can be used when risk of collapse or failure due to joints or cracks in the bedrock on a slope is expected, or when risk of collapse on a cutting slope or natural slope with relatively compact soil is expected. Secure a free stress length of 4m or more for the anchor material. Ground Anchor Works is generally used when the layer thickness of the unstable soil mass exceeds about 3m. If the layer thickness of the unstable mass is less than 3m, the use of soil nailing work should be considered.

2) Functions as Support for Structures (Such as Retaining Walls)

Ground Anchor Works can be used as a shoring of retaining walls installed to stabilize the slope foot.

(B) Conditions to Avoid

1) Soft Soil, Soil with Mainly Sand and Gravel, Slope of Special Soil

When the geology near the ground surface is soft, the anchor tension force causes large plastic displacement of bearing structures such as loading plates, resulting in a drastic decrease in the anchor tension load. If the anchorage ground is soft geology, the friction type anchor may not be able to support the designed anchor force. Consider using a bearing type support method.

If the geology near the ground surface is mainly sand and gravel, the anchor tension load cannot be maintained due to the outflow of soil and the occurrence of small collapses near the loading plate. If the anchorage ground consists mainly of gravel, consideration of countermeasures against grout leakage during construction is necessary. For the same reason of the former, if the geology near the ground surface consists of special soil (geology with high swelling properties, special soil that is prone to collapse, etc.), avoiding the use of Ground Anchor Works would be better.

2) Concerns about Head Corrosion Due to Acidic Soil and Salt Corrosion

The main cause of anchor deterioration is the corrosion and the deterioration of the head. If acid soil or salt corrosion is of a concern, use a corrosion-resistant anchor body.

3) Risk of Small Collapse Directly under Independent Loading Plate

If a small collapse occurs directly under the independent loading plate, the loading plate will be damaged, and the anchor tension load cannot be maintained. Consider measures to prevent small collapses and erosion of the ground beneath the loading plate.

(C) Points of Consideration in Design

1) Condition for Anchor Type

Ground Anchor Works should be designed considering the suitability of the support method at the anchorage and the head anchorage method. The differences and the suitability are explained in the table below. Especially when working overseas, select an anchor material that can be used even if the required length of the anchor material changes significantly due to changes in the anchorage ground.

Table 3-4 Differences and Suitability of Support Methods for Anchor Force

Source: JICA Study Team

Support Method	Content and Suitability for Countermeasure
Tension type	1) Anchor material and grout are combined over the entire length of the anchor fixing part. It is a conventional support method that exerts support mainly on the upper part of the anchor body. 2) It can be anchored even in unsuitable ground for anchoring layers such as hard and soft alternation of strata. 3) At the upper part of the anchor fixing part, the bond between the anchor material and the grout will be broken. Therefore, if re-tensioning is repeated for maintenance and management purpose, free length of the tendon gradually increases and the breakage of adhesion progresses.

Support Method	Content and Suitability for Countermeasure
Compression type	1) Anchor material and grout are combined only at the tip of the anchor fixing part. A support system that exerts support mainly at the tip of the anchor body. 2) If the ground near the tip of the anchor fixing part is poor, the risk of pulling out increases. Therefore, this method is not suitable for anchoring ground such as hard-and-soft-alternating layers. 3) Anchor material and grout are less likely to break off. Therefore, even if re-tensioning is repeated for maintenance, breakage of adhesion does not progress.
Bearing pressure type	1) A support method in which the diameter of the anchor body is expanded and, by this, the bearing force of the anchor body exerts the supporting force. 2) Suitable when anchoring ground is soft and anchor force cannot be supported by circumferential friction alone.

Table 3-5 Difference in head fixing method and suitability

Source: JICA Study Team

Head fixation method	Content and Suitability for Countermeasure
Wedge	1) The length of the anchor material can be easily cut to shorten its length at the construction site. Therefore, it can be used when the anchorage depth is uncertain. It is suitable when it is not easy to order additional or alternative anchor materials to fit the anchor length to anchorage depth at the site. 2) Fine adjustment of fixing load is difficult. 3) Re-tensioning is possible even if the tension is greatly reduced due to the influence of deflection of the anchor material at the grouting, etc. 4) When unloading and re-tensioning in the event of excessive tension, the portion of the anchor material pressed by the old wedge may cause the anchor material to break.
Combination of wedge and nut	It has the advantages of both the wedge type and the nut type, and can be used in many conditions.
Nut	1) If the support method is friction (compression), the limit value for adjusting the length of the anchor material is small. Therefore, it is difficult to respond on the site when the depth of the anchorage ground is deeper or shallower than expected. 2) If the support method is a friction (tension) anchor material, there are products that allow large length adjustment at the tip of the anchor material. 3) Fine adjustment of fixing load is easy 4) If the tension force is significantly reduced due to the clearance of the anchor material, etc., the nut cannot be re-tensioned beyond the adjustment range. 5) Even if the tension becomes excessive, the load can be easily released within the adjustment range of the nut.

Setting Bond Strength

Standard values for shaft friction used in Japan’s outline designs are for Japan's unique geological classifications of the ground. Japan classifies the rock into hard rock and soft rock for the design of anchor works, which is the same as the geological classification in the standard cut slope. This is a geological classification that emphasizes workability with heavy machinery, and its contents are described in Chapter1.1(E). When applying this method to target countries having different geological conditions, examine the similarities between the local geology and the geological divisions of Japan. As a general rule, the result of the on-site basic investigation test (pull-out test) should be used in order to decide the surface friction resistance used in the detailed design.

Designation of Initial Tension (at Fixation)

Ground Anchor Work on steep slopes is basically designed in consideration of the tightening effect. In this case, the initial (fixed) tension is set to 100% of the design load. It is possible to set the load to 80-90% of the design load to avoid excessive tension due to temperature changes. But if the initial tension is set as small as 50% of the design load, shear deformation occurs in the anchor due to the intersection between the slip surface and the anchor before the tension reaches 100% during the progressive deformation of the slope which is assumed in the design. Then, the sheath or the like that protects the anchor material may be damaged because these protection materials cannot follow the extension of the anchor body.

Ensuring Coverage of Fixing Part From Sliding Surface (Fixing Base Surface)

In order to reliably transmit the anchor force to the anchorage, secure a cover (covering distance) of at least 1m from the slip surface even if the anchorage has suitable geology (see the picture on the right). If the geology near the slip surface is fractured, secure a cover of at least 1m from the anchorage basement surface of the anchorage stratum rather than referencing the slip surface (see the picture on the left).

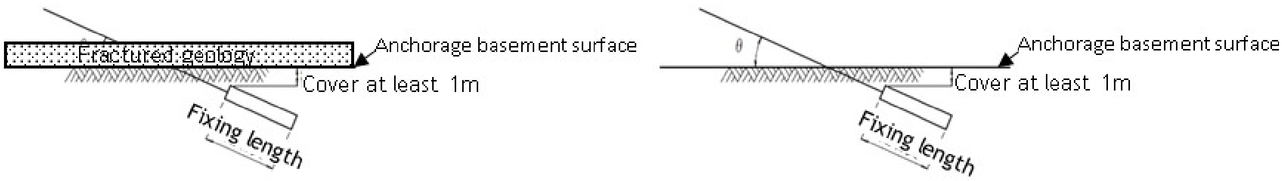


Figure 3-1 Cover of Fixing Part

Excerpt from "Hokkaido Development Bureau (2021): Road Design Guidelines Volume 2 Roadside Facilities"

Avoidance of Single Line Placement

In the case that the independent loading plate is used, if the Ground Anchoring Work is placed on a single line, the rotational movement (forward rolling movement) caused by sliding of the moving body and toppling may occur. In that situation, the predetermined prevention force cannot be exerted. Ground Anchor Work on the road slope should be placed in double lines or more. If single line placement is unavoidable, place the anchors in houndstooth style instead of in single linear line (Hokuriku Regional Development Bureau, 2020).

Recognition of Differences in Design Methods (Design Software) in Japan and Europe as well as U.S.

Well-known European and American design software for landslide countermeasures include Canada's SLOPE/W (Geo-SLOPE) and Slide2 (Rocscience), and Italy's Slope (GeoStru). These design software are used worldwide, including in Central America and Africa. Therefore, counterparts and consultants in the Partner Country may use those software. These design software adopts a different design method from that of Japan for the design of anchor work and other deterrent soil nailing work as well (See 3.6). Moreover, the design method differs depending on each design software even among Western software. Therefore, even if the anchor work has the same standard and specifications, the estimated result of the countermeasure work effect will differ depending on which design software is used, and then the required quantity of countermeasure work will be also different. The countermeasures in ODA Grants basically use Japanese slope technology. Therefore, Japanese design software will be used in order to carry out the project which uses Japanese technology. However, when applying Western-specific landslide countermeasure technology, it is necessary to use Western software suitable. When the European and American design software is used, recognition of difference of the design method between that of Japan and that of Western countries (and among the Western software) is necessary. When using Japanese slope technology, avoid the thoughtless use of the Partner Country's design method because there are various reasons for this. However, even if the use is unavoidable, fully consider the effects of differences in design methods. On the other hand, when using the countermeasure technology of the Partner Country or those of Europe and the United States, their suitable software for design shall be used.

When Japanese technology and Western technology are used in mixture, it is necessary to take appropriate measures to confirm each other's consistency (i.e. the function of one measure is not disturbed by another measure) or to obtain best mix (i.e. the function of one measure is strengthened or complemented by another measures) after carefully considering the conditions of each slope.

Source:
Geotechnical Society (2012): Ground Anchor Design and Construction Standards, Commentary
Hokuriku Regional Development Bureau (2020): Design Guidelines - Road Chapter 7 Ground Anchor
Hokkaido Development Bureau (2021): Road Design Guidelines Volume 2 Roadside Facilities Chapter 3 Ground Anchor Work
Japan Road Association (2009): Highway Earthwork- Guidelines for Cutting and Slope Stabilization, p.288.
Hokkaido Development Bureau (2021): Road Design Guidelines Volume 1 Road
Japan Anchor Association (2013): Ground Anchor Design and Construction Manual

3.6 Rock Bolt / Soil Nailing

Soil Nailing and head wire connection type soil nailing work are popular landslide countermeasures in Japan. The expected functions and design methods are different from those of overseas soil nailing. In the design of rock bolt / soil nailing with Japanese technology, adopt Japanese design methods, which Japanese engineers are familiar with. On the other hand, when using overseas Soil Nailing method, the respective design method of Soil Nailing should be used.

(Description)

Design considerations are described below. The details of the design method are described in detail in "NEXCO (2007): Design and Construction Guidelines for Cutting Reinforcement Earthwork Method" and "Japan Geotechnical Society (2011): Design and Construction Manual for Earth Reinforcement Earthwork Method".

(A) Expected Functions

1) Prevention of Slope Failure

Reinforcing material inserted into the ground enhances the stability of the slope surface and the entire slope. It is used for relatively small-scale collapse prevention, for steep slope reinforcement measures, and for temporary slope reinforcement measures such as excavation for structures placement, and others. Generally, it is used when the layer thickness of the unstable soil mass is less than 3m. If the layer thickness of the unstable soil mass exceeds that, the use of anchor work should be considered.

Some overseas soil nailing have rebar lengths over 30m, but it should be kept in mind that the expected functions and design methods are different from those in Japan.

The reason why Japanese soil nailing is limited to relatively shallow collapses is based on the long-term experience in its use in Japan. Since soil nailing is a method that does not apply prestress, the deterrent force is zero immediately after its installation, and the deterrent force gradually increases in parallel to the amount of deformation of the ground. Even long soil nails is used in the case of deep landslides so that the total length of the nail reaches the stable slope ground, the deterrent force of soil nailing can reach theoretically the design value when the in parallel to the ground deformations, however, the target ground may collapse before the soil nailing reaches the design value. This is the concept of soil nailing works in Japan. From this knowledge, it is thought that even applying long soil nails, this is the method of Western countries, under the same conditions as in Japan, this long soil nails may not be able to fully demonstrate the designed collapse prevention function against deep collapses. With this in mind, when applying long soil nails, confirm the design method of soil nailing and evaluate whether the target ground and metrological conditions are suitable for long soil nailing. The difference in design methods of soil nailing shall also be referred to Section 3.5(C) 0.

2) Minimization of Environmental Impact by Cutting

Because this method relies on the slope stabilizing effect of the natural soil reinforcing, the soil nailing minimizes the environmental impact otherwise caused by simple cutting. The gradient of cut slope reinforced by the nailing materials can also be slightly steeper than the normal stable slope.

3) Combination of Active Conservation for Natural Vegetation and Slope Failure Prevention (Head Wire Connection Type)

By using the head wire connection type, it is feasible to prevent the slope failure while keeping trees in addition to vegetation on the slope as much as possible.

(B) Conditions to Avoid

1) When Layer Thickness of Unstable Soil Mass Exceeds 3m (When Applying Japanese Design Method)

Japanese design methods limit the soil layer depth suitable for prevention to within about 3m. The rock bolt / soil nailing has no preventive force immediately after installation, and is a passive prevention work that exerts prevention force as the moving object (road side slope) deforms. If the moving layer is thick and the length of the nail material is very long in order to cover whole depth of moving layer, as mentioned above, the theoretically calculated amount of deformation until when 100% of the design value of prevention force of nailing is exerted shall become very large. That means collapse due to plastic deformation of the moving soil mass may occur during the process before the design value of nailing force reaches its 100%.

2) When Length of Reinforcing Material Exceeds 5m (When Applying Japanese Design Method)

The Japanese design method limits the length of the reinforcing material to maximum 5m. If the length exceeds this limit, the introduction of anchor work should be considered.

3) When Moving Mass of Soil May Not Keep Its Integrity and Part of Mass Hollowed Out, Such as Sandy or Loose Material

The deterrent force immediately after construction of the rock bolt / soil nailing is zero, namely the anchor is put into the ground without tension force same as rebar in reinforced concrete. The rock bolt / soil nailing is a passive deterrent that exerts a deterrent force as the moving object deforms. Therefore, if the moving mass does not have a binding property as a binding mass, the rock bolt / soil nailing is unsuitable because the soil adjacent the inserted anchor will be detached from the soil adhered to the anchor.

(C) Points of Consideration in Design

1) Setting Circumferential Frictional Resistance (Bond Strength)

Standard values for shaft friction used in Japanese outline designs are for Japan's unique geological classifications. Japan has a classification of hard rock and soft rock, which is the same as the geological classification in the standard cut slope. This is a geological classification that emphasizes workability with heavy machinery, and its contents are described in Chapter 1.1(E). When applying to the partner countries with different geological conditions, examine the similarities between the local geology and the geological divisions of Japan. As a general rule, the result of the on-site basic investigation test (pull-out test) should be used as a parameter for the shaft friction resistance used in the detailed design.

2) Consideration of Weight of Bearing Structure

In Japan it is not clearly decided whether or not the self-weight of the framework of the structure such as shotcrete/concrete crib works should be taken into account in the slope stability analysis, when using the framework as the bearing structure on the ground surface. Nevertheless, it is desirable to consider its own weight in accordance with the “Technical Guidelines for Steep Slope Collapse Prevention Construction (National Flood Control and Sabo Association, 2019)” and the “Manual for Design and Construction of Ground Reinforcing Earthwork Method (Geotechnical Society, 2011)”.

3) Layout of Soil Nailing on Slope Surface and Verification of Minimum Safety Factor after Layout

Rock bolt / soil nailing is a construction method that the nailing is placed as a network on a slope surface. But, check whether the extent of the layout is appropriate and whether there is any slip surface left behind that does not reach the planned safety factor assumed in the design.

4) Recognition of Differences in Design Methods (Design Software) in European Countries

Pay attention same as described in Chapter 3.5(C) 0.

3.7 Mortar Spraying Works

> In recent years, to apply the mortar spraying has become less and less common in Japan because of the lack of consideration for the landscape and environment, and the long-term stability is also concerned. If introducing other countermeasures such as concrete crib works overseas is difficult due to cost, and the main purpose is to prevent solely weathering and erosion of slopes, use of mortar spraying works can be considered.

(Description)

Points to consider in the design of mortar spraying are described below.

(A) Expected Functions

1) Prevention of Weathering and Erosion of Slopes

Prevent weathering and erosion by covering slopes with mortar or concrete.

2) Prevention of Rock Fall

If unstable rock masses such as floating stones are scattered on the slope, cover them with mortar or concrete to prevent them from falling.

(B) Conditions to Avoid

1) When Consideration for Landscape or Environment Is Required

Slopes with concrete sprayed all over spoil the scenery and the harmony with the surrounding environment. Avoid using this method in places where it is highly needed to consider the scenery and environment e.g. in the nature preservation area.

2) When Small Collapses Are Expected on Slope

If collapse is expected, consider other countermeasure works because the mortar spraying does not have function to prevent even small collapses.

3) Slopes with a Large Amount of Surface Water Flowing during Rainfall and Spring Water Confirmed

Under such conditions, the full effectiveness of groundwater drainage from the back of the mortar spraying work such as horizontal drainage cannot be achieved. Underground opening may occur due to scouring on the back of the mortar spraying.

4) Slope Mainly Composed of Soil

Underground opening may occur due to scouring on the back of the mortar spraying.

5) Regions Affected by Freezing and Thawing

Separation between the mortar spraying and the ground may occur, and groundwater, etc. may enter the space, causing deterioration or collapse of the mortar spraying.

(C) Points of Consideration in Design

1) Decision to Apply

Design calculation is not conducted because resistant function from external force such as movement of the detached rocks is not assumed. Visual judgment of the target slope is important for the judgement of the suitability of this method.

2) Difference in Structure Due to Temperature

In places that are not cold, mortar or concrete is sprayed after the lath wire mesh is placed. But, in areas with concern about the effects of freezing and thawing, reinforcing bars are additionally arranged and mortar or concrete is sprayed to increase the resistance to freezing and thawing as a reinforced concrete structure. Generally the mortar spraying is not used in areas where freeze-thaw effects are more severe.

3) Consideration for Drainage of Groundwater from Back of Spraying Works

Deformation such as peeling and scouring of the back surface is likely to occur due to shallow water and groundwater on the back surface. Therefore, consider the drainage on the back, such as the placement of drain pipes.

3.8 Rock Fall Barrier

> Rock fall barrier is one of the typical rock fall barrier works. They can be broadly classified into conventional type and high energy absorption type. Multiple products for each exist, and the details of the structure differ for each product. The design method must conform to the design manual of each product.

(Description)

Design considerations are described below. The details of the design method are described in detail in "Japan Road Association (2017): Rock fall Countermeasure Handbook".

(A) Expected Functions

1. Capturing rocks falling to the road to protect the road at roadside.
2. Capturing falling rocks at halfway up the slope

(B) Conditions to Avoid

1. When rock fall is expected to exceed the allowable rock fall energy

2. When the site does not have a ground where anchor bolt can be installed (in case of rock fall barrier installed halfway up the slope)

(C) Points of Consideration in Design

1) Estimation of Falling Rock Energy

Calculation of the impact energy at the time of **the crash of** the assumed rock **into the fence** is necessary.

2) Estimating Trajectory of Falling Rocks to Assure Height of Protective Fences

Conduct a rock fall simulation using the Monte Carlo method, estimate the trajectory of the rock fall, and check whether the planned location and the height of the protective fence are appropriate so that the falling rock does not jump over the fence and reach the road.

3) Necessity of Consideration during Earthquakes

In Japan, the design is carried out considering the effects of earthquakes, but confirm in advance whether such consideration is necessary in the Partner Country.

Source:
Japan Road Association (2017): Handbook for countermeasures against falling rocks

3.9 Rock Fall Prevention Net

The Rock fall Prevention Net Work is available in two types, pocket type and cover type. The former is classified as rock fall protection work, and the latter as rock fall prevention work. Both are protected by placing vertical and horizontal wire ropes at regular intervals and combining them with wire netting. There exist multiple conventional types and high energy absorption types of wire net for each pocket and cover type, The details of the structure differ for each product. The design method must conform to the design manual of each product

(Description)

Design considerations are described below. The details of the design method are described in detail in "Japan Road Association (2017): Rock fall Countermeasure Handbook".

(A) Expected Functions

1. Capturing fallen rocks from above the slope (pocket type)
2. Absorption of falling rock energy (pocket type)
3. Guiding rocks to fall into the space between the wire mesh and the natural ground (pocket type)
4. Covering the entire slope which has a risk of rock fall to prevent the occurrence of rock fall (covered type)

(B) Conditions to Avoid

1. When rock fall is expected to exceed the allowable rock fall energy (pocket type)
2. When the rocks and boulders at the source are huge and the movement of which cannot be restrained by this method (covered type)
3. When early corrosion of wires due to acid soil or salt damage is expected (especially covered type)
4. When the site does not have a ground where anchors can be installed (pocket type, covered type)

5. Slopes with many small-scale collapses at the position where the posts are installed (damage to the post due to the collapse of the upper slope may become issues in operation (temporary restriction of road traffic) and maintenance).
6. When the snow load will lead to deformation of the facility especially in heavy snowfall area.

(C) Points of Consideration in Design

1) Estimation of Falling Rock Energy (Pocket Type)

The calculation of the energy at the time of the assumed rock fall impact against the net is necessary

2) Estimating Trajectory of Falling Rocks to Assure Height of Protective Fences

Conduct a rock fall simulation using the Monte Carlo method, estimate the trajectory of the rock fall, and check whether the planned location and the height of the pocket are appropriate so that the falling rock does not jump over the pocket net.

3) Necessity of Consideration during Earthquakes (Pocket Type)

In case of pocket type, the design is carried out considering the effects of earthquakes in Japan, but confirm in advance whether such consideration is necessary in the Partner Country.

4) Evaluation of Risk of Slope Deformation at Upper Slope of Posts and Anchor Bolts

In particular, in the case of the pocket type, if a small collapse occurs at the post position or anchor bolt position, the function of the rock fall prevention net will be deteriorated or failed. Therefore, evaluate the risk of slope deformation. If the target site has concern about small collapses and others, consideration of other measures is necessary (see (B) 5) above).

Source:
Japan Road Association (2017): Handbook for countermeasures against falling rocks

3.10 Rope Covering Works

Rope covering works are representative methods of rock fall prevention works.

(Description)

Design considerations are described below. The details of the design method are described in detail in "Japan Road Association (2017): Rock fall Countermeasure Handbook".

(A) Expected Functions

1. Fix at its original position the floating stones and boulders scattered on the slope so that they do not start to move.
2. By making closer the wire spacing, fixing relatively small floating stones and boulders becomes possible.
3. When floating rocks or boulders are too huge when impossible to break it down into small size in order to bring them down, or when the target must be fixed on the slope due to land restrictions, etc.

(B) Conditions to Avoid

1. When the site does not have a ground where anchor bolt of the wire for fixing the rock can be installed
2. When targeting huge floating rocks or boulders that exceed the allowable mechanical capacity (tension strength) of wires and anchor bolt
3. The use of this method should also be avoided when a huge bedrock collapse is assumed.
4. When the target site has a large risk about early wire corrosion due to acid soil or salt

(C) Points of consideration in design

1) Boulders Getting Out of Wire Ropes

Checking information such as the size and shape of loose rocks and boulders at the site is necessary and set the wire spacing so that boulders do not slip out of the gaps.

2) Anchor Bolt Shape and Dimensions

Appropriate shape and dimensions should be selected according to the geological conditions.

Source:
Japan Road Association (2017): Handbook for countermeasures against falling rocks

3.11 Counterweight Fill Works and Works of Head Part Soil Removal

This section describes the design and considerations of foot part's counterweight fill works and works of head part soil removal, which are often used as countermeasures when slope failure occurs during or after construction on the cut slope as well as the protection of natural slopes

(Description)

This section explains design considerations for foot part's counterweight fill works and works of head part soil removal when collapsible slippage occurs **mainly** during or after construction on the cut slope.

(A) Expected Functions

1. Slope stabilization by stabilizing the foot part of the slope and increasing resistance against sliding (counterweight fill works)
2. Slope stabilization by reducing sliding force (works of head part soil removal)
3. Reduction of necessary prevention force when accompanying other preventive works (works of head part soil removal)

(B) Conditions to Avoid

1) Head Part Soil Removal when Main Slip Surface Shape Is Flat

When the main slip surface shape is planar, such as slipping on an inclined bedding surface, almost no effect of head removal is expected because remaining lower part has an independent risk for sliding. But, when accompanying other prevention works, the effect of reducing the necessary prevention force to be borne by the other prevention works can be expected by reducing the sliding force of the moving soil mass.

2) Head Part Soil Removal when Slope Behind Target Slope Is Landslide Topography

When the head part soil removal method is used, the influence of this top soil removal on the stability of the slope behind the target slope which has the landslide topography should be examined. It means, that the top soil removal, in turn, becomes a foot part soil removal from the viewpoint of the slope behind the target slope.

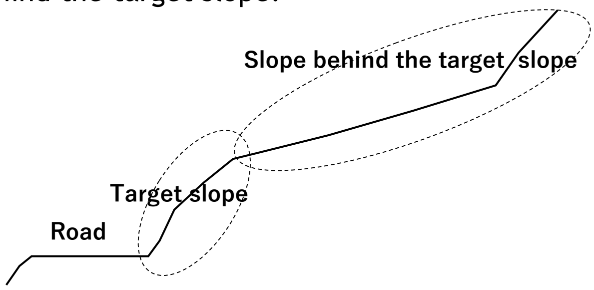


Figure 3-2 Slope Behind Target Slope

3) Head Part Soil Removal When There Is Relatively New Stepped Topography on Slope behind Target Slope

Along with the investigation of the distribution and continuity of the observed stepped terrain, estimate its position on the cross section, and estimate the influence area of the head part soil removal on the cross-sectional view, and finally evaluate the risk of occurrence of new slips starting from the observed topographical step due to earth removal works.

(C) Points of Consideration in Design

1) Understanding Geological Structure as Factor of Disasters on Roadside Slopes

It is suggested that the triggers for slope failure during or after construction are the decrease in ground strength due to the stress release and the excessive supply of groundwater caused by heavy rain. On the other hand, grasping the geological structure as a factor of disasters on roadside slopes in the design is important.

For example, the sliding along the boundary of different bedding planes and the toppling[5] on steep bedding planes and the joint planes require different calculation methods for the effect of counterweight fill works and works of head part soil removal. As shown in Figure 3-3 (a), arc-type slip is not controlled by geological structure, the collapse is occurred when the balance between sliding force and shear resistance of the soil mass is lost due to cutting. In this case, a large effect can be expected for both the foot part counterweight fill by adding sliding resistance and the head part soil removal by reducing the sliding force. As shown in Figure 3-3 (b), counterweight fill works that add resistance are effective when sliding along the bedding plane. But, the head part soil removal that aims at reducing the sliding force is not expected to have a great effect because the remaining part still has the risk of sliding. When there is a toppling risk due to stress release associated with cutting as shown in Figure 3-3 (c), counterweight fill works at the bottom of the slope or of the toppling part are effective, but the effect of head part soil removal is not large from the similar reason as mentioned above for Figure 3-3(b).

[5] Toppling is a slope deformation phenomenon in which the bedrock separates at weak surfaces such as joint surfaces and collapses downward.

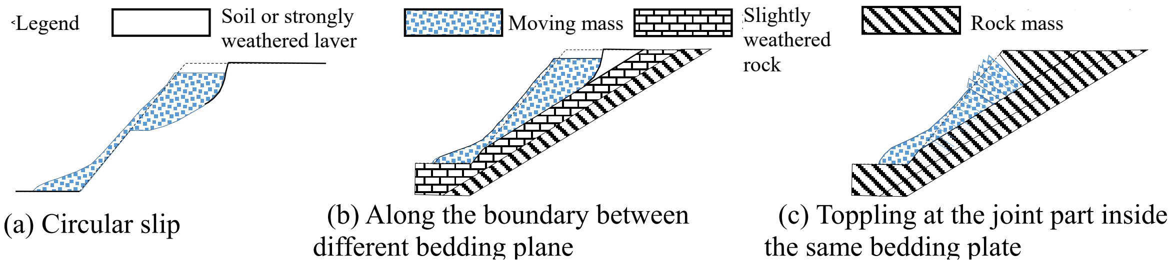


Figure 3-3 Difference in Failure Mechanism due to Difference in Geological Structure

Source: JICA Study Team

2) Study of Stability of Slope behind Target Slope after Head Part Soil Removal

Regardless of the presence or absence of landslide topography and step cracks on the slope behind the target slope, evaluate the stability of the slope behind the target slope after head part soil removal.

3) Consideration of Permanent Countermeasures after Counterweight Filling

Counterweight Fill Works are often implemented as an emergency measure to ensure short-term stability. When this is implemented as a permanent measure, it is necessary to add the use of earth retaining work and/or the retaining wall work to stabilize the toe of the slope is necessary.

3.12 Considerations in Road Alignment Design (if re-sliding landslides are assumed)

If landslide topography or re-sliding landslides exist, the road alignment should be designed to avoid them. If unavoidable, consider road alignments that minimize the impact of road development on landslides and minimize the impact of landslide on roads

(Description)

Items that need to be considered in road alignment design are shown below.

(A) Consideration for Landslide Topography (Dormant Re-sliding Landslide)

There exist many cases both in Japan and overseas of dormant landslide topography that started to re-slide as a result of the excavation near the end of the landslide topography due to road development. Large-scale landslide topography with both length and width of 1km or more may resume activity by excavating a little at the end. The fundamental consideration is to shift the horizontal and the vertical alignment as much as possible to avoid landslide topography, but if it is unavoidable to avoid the landslide topography, the following considerations are necessary.

1. The best alignment of the road is to cross the central area, which has less impact on landslide activity. See (C) of this section for details.
2. When planning a road on the head of a landslide, minimize the load on the head of the landslide by adopting a lightweight embankment, and examine the degree of impact on the landslide using a slope stability analysis formula.
3. In some cases, such as the impact of a landslide on a road is small, countermeasures against slope failures described in this handbook can be used.

(B) Consideration for Active Landslide

Since countermeasures to physically prevent re-sliding landslides require high costs, same as (A), the consideration of road alignments that avoid landslides in action is fundamental. In the road alignment design, consideration of detours including bridges and tunnels is necessary.

In the case of small-scale active re-sliding landslides, consideration should be given to select a reasonable method used for the slope protection by comparing the cost of deterring the landslide to that of detours.

(C) Consideration When Putting Road on Active Landslide Is Required

When a large-scale active landslide site cannot be avoided, consider the road alignment that has the least impact of both landslide activity and the impact of road development on landslides.

If the planned alignment passes through the head part of a landslide like “Route A” in Figure 3-4, the ground subsidence due to landslide activity will be large, and the stepped cracks on the road will gradually expand, making it impossible to maintain the prescribed road structure. Placing the alignment at the edge of the landslide like Route C increases the probability of the landslide activation caused by road construction.

If avoiding the active landslide is not possible, arrange a road alignment such as Route B that crosses the central part of the landslide. Of course even this alignment causes the road to slip due to landslide activity, which requires regular maintenance. But, compared to “Route A” and Route C, relatively fewer steps may become obstacles for vehicle traffic.

But even if “Route B” is selected, the displacement of landslides must be within the permissible range for road maintenance. If the amount of movement exceeds that, measures for the landslide with groundwater drainage works such as drainage wells will be necessary.

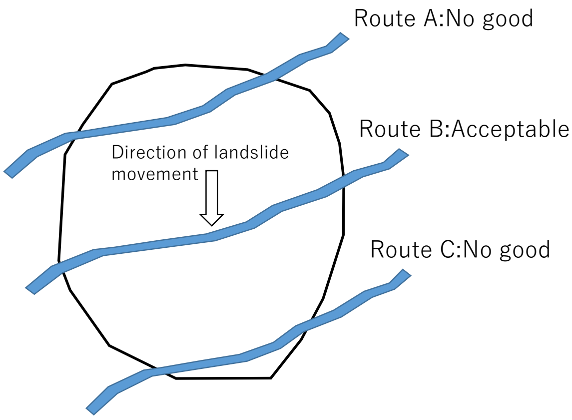


Figure 3-4 Appropriateness of Road Alignment in a Large-Scale Active Landslide

Source: JICA Study Team

3.13 Consideration of Life Cycle Costs

This section describes the maintenance and management of countermeasure works and the necessary equipment. In the JICA’s Preparatory Survey, the planner should select appropriate countermeasure construction method after confirming the possibility of maintenance by the Partner Country’s technology/equipment However, when locally procured maintenance equipment does not show sufficient required performance to cope with the specialty of local topography and geological conditions, development of simple manuals and conduct training to implement maintenance would be required. In such cases, state the requirements and specifications at the time of bidding, and procure them within the framework of the project. And, propose a soft component for training to JICA as technology transfer.

(A) Maintenance of Slope Protection Works and Necessary Equipment

The contents of maintenance and management of countermeasure works and necessary equipment are shown below. In particular, the increase or decrease of the tension force of ground anchors after construction and fractured anchor head due to over-tension may become a life-threatening disaster risk for road users. Therefore, regular maintenance is required.

Table 3-6 Main Contents of Maintenance and Management of Countermeasure Works

Source: JICA Study Team

No	Countermeasure Works	Details of maintenance and necessary equipment
1	Groundwater drainage works (drainage boring, etc.)	- Clogging of water collection pipes is likely to occur due to the generation of slime and algae caused by iron bacteria in the groundwater. Cleaning the inside of the hole using a high-pressure cleaning device about once every few years is necessary. - Special equipment is required for cleaning the inside of the hole. (e.g. special nozzle, high pressure hose, high pressure washer)
2	Vegetation works	- If problem with the growth of the introduced vegetation exists, maintenance such as changing to a different vegetation is required.
3	Mortar spraying/shotcrete works	- Periodically check for cracks and cavities on the back. In case of any abnormality, repair or reinforce it. - Special equipment is required to focus on the back cavity and repair cracks. E.g. equipment for fillers such as cement and mortar (ready mixed concrete trucks, feed pumps, pressure hoses, flow meters, generators and others)
4	Concrete crib works	- Periodically check for cracks and cavities on the back. In case of abnormality, repair or reinforce it. - Special equipment is required to focus on the back cavity and repair cracks. E.g. equipment for fillers such as cement and mortar (ready mixed concrete trucks, feed pumps, pressure hoses, flow meters, generators and others)
5	Ground Anchor works	- Periodically check the head as it is a type of construction that is prone to corrosion. Refill with anti-corrosion oil. - Periodically check the tension load as it is easy to cause a decrease in the tension load or excessive tension. Implement the lift -off test to confirm the current tension load if necessary. Maintenance such as re-tensioning is necessary. Risk of an accident in which the head of the anchor pops out due to excessive tension is expected. - Special equipment is required for refilling antirust oil, lift-off test, and re-tensioning. E.g. lift-off test jack, magnetic stand, measuring instrument, hydraulic unit, pressure transducer
6	Rock bolt / soil Nailing	- Inspection of the head for corrosion and deformation is necessary. The wire-connected type requires inspection for wire corrosion, etc.
7	Rope covering works	- Inspection of wire corrosion, soundness of anchor bolts, etc. is required.
8	Rock fall barrier works	- Inspection of steel materials for corrosion and deformation, etc. is necessary, and if soil is deposited on the back, periodic soil removal is necessary.
9	Rock fall prevention net works	- Inspection of the corrosion and deformation of steel materials, the soundness of anchor bolts, etc. is necessary. Periodic soil removal is also necessary if soil is deposited on the back.

(B) Selection of Countermeasure Works and Materials Considering Natural Environment

Multiple types of products for the countermeasures exist, because even the products are for the same type of work, the materials and structures are different each other. For example, there exist products that use the resin (do not use steel or cement-based grout) in order to cope with acidic soil in ground anchor construction. If the target site has an environment that adversely affects the countermeasures, such as acidic soil or salt corrosion, select a product that is suitable for that environment (such as materials with high corrosion resistance).

(C) Selection of Countermeasure Works Considering Maintenance Capacity of Related Industries in Partner Country

In order to maintain and manage slope protection works on a continuous basis, find not only contractors who conduct each work of maintenance and management, but also suppliers who maintain the equipment for maintenance and management.

At the JICA's Preparatory Survey stage, investigate whether the Partner Country has the necessary maintenance technology, and investigate whether the Partner Country's government or the implementing agency has the ability and willingness to provide the necessary budgetary arrangement for maintenance, and then reflect the results in the selection of countermeasures.

Table 3-7 Related Industries Necessary for Maintenance of Slope Protection Works

Source: JICA Study Team

No	Countermeasure works	Details of maintenance and necessary equipment
1	Groundwater drainage works (drainage boring, etc.)	Consultants for inspections and detailed investigations, contractors for high-pressure washing, maintenance contractors for high-pressure washing equipment
2	Mortar spraying/shotcrete works	Consultants for inspections and detailed surveys, contractors to repair and reinforce deteriorated parts in high places
3	Concrete crib works	Consultants for inspections and detailed surveys, contractors to repair and reinforce deteriorated parts in high places
4	Ground Anchor works	Consultant for inspection and detailed investigation, contractor for re-tensioning and lift-off test, maintenance contractor for equipment used for re-tensioning and lift-off test
5	Rock bolt / soil nailing	Consultants for inspections and detailed investigations, contractors for replacement of corroded and deteriorated parts of the head
6	Rope covering works	Consultants for inspections and detailed surveys, contractors to repair and reinforce deteriorated parts in high places
7	Rock fall barrier works	Consultants for inspections and detailed surveys, contractors to repair and reinforce deteriorated parts in high places
8	Rock fall prevention net works	Consultants for inspections and detailed surveys, contractors to repair and reinforce deteriorated parts in high places

Note) Depending on the type of work, special techniques such as high-place work, removal of members, loading work, and hammering inspection may be required for inspection and detailed investigation. In addition, evaluate whether the deformation of the landslide countermeasure work is simply due to the deterioration of the members or the influence of the slope change. For these reasons, inspections and detailed surveys should preferably be carried out by experts such as consultants. It is assumed that daily inspections such as patrols are carried out in normal road facility management.

3.14 Construction Method That Can Be Used as Supplementary Measure against Disasters on Roadside Slopes

> Supplementary landslide countermeasures should be selected in consideration of not only the initial cost, but also the maintenance cost, ability, and renewal cycle.

(Description)

The following are examples of construction methods that can be used as countermeasures against disasters on roadside slopes, although they are not principal countermeasures.

Table 3-8 Examples of Construction Methods as Supplementary Measures

Source: JICA Study Team

Name or works	Description	Examples of how to use
Lightweight embankment works	This works makes artificial lightweight materials and is often used as a road embankment. A method using foamed concrete and a method using foamed plastic such as urethane foam or polystyrene foam exists. Aerated concrete, which is locally produced from lightweight materials, is suitable for overseas.	Lightweight embankment works can be used for road repair when there is an unstable mass of soil on the lower slope of the road, as it can be used to cope with collapse of the road surface.
Reinforced soil works	Various types of construction methods for embankments with reinforcing materials placed inside exist. In addition to the function of securing the strength of the embankment itself, the reinforced soil works also has the function of stabilizing the slope with a retaining wall-like effect.	Reinforced soil works is possible to realize slope stabilization by anticipating the retaining wall effect of reinforced embankment in response to road collapse.
Pile of preventive work which is layout in a row	A construction method in which a line of connected large-diameter steel pipe piles are installed, while using the installed pipe right before as the scaffolding for next (adjacent) pile installation.	If installation of large-scale temporary facilities or bring in heavy machinery is difficult, this works is possible to quickly construct deterrent piles against the disasters.