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

HANDBOOK III:
REFERENCE FOR LANDSLIDE COUNTERMEASURES IN ODA GRANTS AND FAQ (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

CHAPTER 1 Technical Terms

1.1 Terminologies of Survey and Design

(A) Double Tube Core Barrel

Double Tube Core Barrel is a core sampler consisted of a double pipe system. Circulating water flows outside the inner core tube so that the circulating water during boring does not come into direct contact with the boring core. It is suitable for collecting cores such as heterogeneous geology with many cracks and/or soft layers.

(B) ROW

ROW is abbreviation of Right of Way. In the sense of road construction site, ROW is also understood as the extent of land acquisition. On the other hand, it is necessary to pay attention to the ROW in landslide countermeasure projects, because the project may be implemented beyond the determined ROW.

(C) Daily Drilling Report

Daily Drilling Report contains the following information: daily used machine, drilling depth, casing depth, water level in borehole, soil/rock name, color tone, standard penetration test (SPT) result, core length, auger bit information (hole diameter, type, number of revolutions, load), pump information (water supply volume, water supply pressure, drainage volume), other typical features, etc. The Daily Drilling Report is a detailed record of the drilling works.

(D) Underground Water Level Graph

The Underground Water Level Graph is a graph showing changes in the water level in the borehole during survey boring. Changes over time in the water level before and after boring works provide important information for understanding the status of groundwater reserves.

(E) Water Level Before and After Work

Changes over time in the water level before and after work are important information for grasping the status of groundwater reserves. Water Level Before and After work can be organized in a Underground Water Level Graph, etc., and are used to analyze the presence of groundwater such as pressurized groundwater, permeable layers, and leaky layers, etc.

(F) LiDAR

LiDAR is an abbreviation for Light Detection and Ranging. LiDAR is a remote sensing method that uses laser light, visible light, and ultraviolet light to irradiate an object with light, and the reflected light is captured by an optical sensor to measure the distance. Aircrafts and drones equipped with LiDAR device are used to obtain the detailed terrain information. A similar device that uses radio waves is commonly known as radar.

(G) Disaster Scenario

Disaster Scenario is an assumption of the type and scale of disasters that may occur due to the devastation of the site, ground surface deformation such as cracks, topographical and geological conditions, weather conditions, and seismic motion. Regarding slope disasters, it is necessary to estimate the types of disasters that can occur due to each type of trigger factor, such as heavy rain, strong winds, earthquakes, and earthworks, and to predict the rough scale and extent of occurrence for each trigger.

(H) Slaking

Slaking is a phenomenon in which sedimentary rocks undergo repeated cycles of drying and wetting, resulting in grain disintegration in a short period of time. It is common in Neogene mudstone and tuff. Immediately after cutting, even slope of fresh rocks can be disintegrated due to slaking, which causes slope failures. There is a rock slaking test (JGS2124) etc. to check the slaking characteristics. Slaking or similar fragmentation in rocks occurs in the European Alps, the Italian Apennines, and the Himalayas of Bhutan and India.

(I) Lift-Off Test

Lift-Off Test is a repeated tensile test to examine the residual tensile strength of an existing anchor.

1.2 Terminologies of Construction Supervision and Management

(A) Rotary Percussion Boring Machine

Rotary percussion boring machine is one type of borehole drilling machines that uses a combination of rotational and percussive force to drill. Also used for anchor driving.

The double-tube rotary percussion boring machine performs excavation and casing insertion simultaneously and is characterized by its ability to prevent collapse of the borehole wall by casing. Anchor works, soil nailing works and horizontal drainage works require the prevention of borehole wall collapse before material insertion and grouting, and the double-tube rotary percussion boring machine plays an important role in the construction of slope disaster prevention technology in Japan.

(B) Down-the-Hole Drilling Method

Down-the-hole drilling method is a rock excavation method which uses air from a compressor to reciprocate a hammer piston, which strikes the ground with a hammer bit.

(C) Slope Stake

Slope stake is a guide used when embankment and/or cuttings are made. Generally, it consists of horizontal and diagonal boards attached on evenly spaced wooden stakes.

(D) Fall-Prevention Harness

Fall-prevention harness is a protective equipment to prevent occupational accidents such as falling when working at height. Usually a combination of a belt and safety string (e.g. rope) to prevent a person from falling.

(E) Nozzle Man / Gunman.

Nozzle man is an operator who holds the end of the hose for shotcrete or concrete. Gunman is an operator who operates special machines (shotcrete machines) to pump the material to be sprayed.

(F) Slime

Slime is the sludge generated during borehole drilling. If not discharged, the in-hole testing and construction of anchors etc. cannot be carried out properly.

(G) Workability

It is the ease of constructing fresh concrete (e.g., transport, casting, compaction, finishing). It influences the viscosity, flowability, and resistance to material separation, etc.

(H) Slump

Slump is an indicator of the softness of concrete before it has hardened. The concrete is filled into a hollow steel cone with a 10 cm upper inner diameter, 20 cm lower inner diameter and 30 cm height. Slump is the difference height of concrete after the cone is pulled out.

(I) Laitance

A muddy substance that forms in a thin layer on the surface after concrete cast due to cement or sand. Because of the bleeding, internal fine particles rise to the surface and form it on the concrete surface.

(J) Gabion

Gabion is a generic name for stone-packed baskets, known in Japan as 'jakago'. It is widely used as temporary earth retaining structures.

CHAPTER 2 Comparison of Technical Standards in Japan and Overseas

This chapter summaries the major differences of official manuals and technical standards, etc., between Japan, European countries/United States (France, Switzerland, Italy and California/USA) and developing countries (Sri Lanka, Nepal, Ethiopia, Indonesia, Philippines, Honduras and Bhutan).

2.1 Comparison of Technical Standards and Others Related to Survey

This section compares the contents of the main items in the survey for countermeasures of landslide among Japan, Europe, the United States, and developing countries.

Table 2-1 Differences between Japan and other Countries in Terms of Technical Standards for Surveys

Source: JICA study team

Item	Japan	Europe/USA	Developing Countries
Utilization of topographic and geological maps	Attention points of topographic interpretation and geological maps in road development are described in detail in road construction guidelines (Japan Road Association, 2009a, 2009b).	There are manuals detailing the relationship between Landslide and topographical/geological features, and how to create geological maps. However, no documents detailing how to utilize existing topographic and geological maps in road development projects have been identified.	The use of topographic maps and geological maps is often described in official manuals, but there are few that detail attention points for topographic interpretation and geological map as in Japanese technical standards.
Aerial photograph interpretation	Attention points regarding interpretation of aerial photographs in road development are described in detail in road construction guidelines (Japan Road Association, 2009a, 2009b).	Some countries have guidelines for interpreting landslide topography using aerial photographs. However, there are some countries that only list it as one of the necessary surveys, or that there is no description of aerial photograph interpretation in official standards. In addition, there is no description of attention points regarding aerial photo interpretation specifically to road projects. TRB (1996), which is world-famous on landslide investigation and countermeasures, has a substantial description on interpretation of landslide topography using aerial photographs.	There are few manuals that refer to aerial photograph interpretation. Although there are cases where the use of remote sensing is described in manuals, there are no manuals that detail the points of attention for interpretation as in Japan.

Item	Japan	Europe/USA	Developing Countries
Survey boring/core sampling	The main points for various ground surveys such as borings and sampling in road development, implementation intervals, location of cross sections at cut sections, etc. are described in Highway Earthworks guidelines (Japan Road Association, 2009a, 2009b).	Some countries list the borings/core sampling in the necessary surveys, but no technical standards have been identified that describe the important points and layout of borings in road development project.	The purpose and necessity of boring surveys and core sampling are often described in official manuals. However, in many countries there is no description of implementation intervals. And in some other countries, the layout of cross-sections at cut slopes is described.
Laboratory test /in situ test	The key points of laboratory tests and in-situ tests necessary for road development are described in road construction guidelines (Japan Road Association, 2009a, 2009b).	Some countries list laboratory test/ in-situ test in the necessary surveys, but no technical standards have been confirmed that describe key points in road development.	The types of soil tests and in situ tests required are often described in official manuals.

Source:
Japan Road Association (2009a): Road Construction Guidelines Japan Road Association (2009b): Highway Earthworks - Guidelines for Cutting and Slope Stabilization
TRB (1996): Landslides - Investigation and mitigation, Transportation Research Board, special report 247.

2.2 Comparison of Technical Standards for Design

This section compares the major items related to the design of landslide countermeasures for roads among Japan, Europe, the United States, and developing countries.

Table 2-2 Differences between Japan and Overseas in Terms of Technical Standards for Design, etc.

Source: JICA study team

Item	Japan	Europe/USA	Developing Countries
Standard gradient of cut slope	Standard gradients according to Japan's unique rock classification are listed in road construction guidelines (Japan Road Association, 2009, Hokuriku Regional Development Bureau, 2020).	There is no technical standard describing the standard gradient as in Japan. It is assumed that each cut slope will be individually evaluated by the engineer for stability.	Most countries have standard gradient of cut slope for road development projects. In some countries, there is only one cut slope gradient. Also, some countries do not define standard gradients on the premise that all cut slopes will be evaluated for stability.
Specifying Stability Analysis Formulas	The Highway Earthworks - Guidelines for Cutting and Slope Stabilization (Japan Road Association, 2009) indicates several stability analysis formulas can be used for landslide countermeasures. However, the Modified Fellenius method is considered as the basic formula. For anchor works, only the Modified Fellenius formula is considered as an effective calculation.	In the United States, various stability analysis formulas that are commonly used such as in design software are specified in official manuals. In Europe, although the official standards do not specify any specific formulas, but various stability analysis formulas are used.	Technical manuals prepared by JICA projects sometimes show the selection flowchart of the stability analysis formulas, but it is not confirmed by the country's technical standards.

Item	Japan	Europe/USA	Developing Countries
Slope greening and drainage works (basic slope protection works)	The Highway Earthworks Guideline (Japan Road Association, 2009) describes in detail the types and selections of slope greening methods. It also details the design and construction of slope drainage.	In Europe, some countries and regions have developed guidelines of bioengineering method and recommend to use vegetation method for prevention of slope failures.	In some cases, outlines are explained in the list of landslide countermeasure works, but there are many countries where there is no description in the technical standards. Bioengineering manuals have been developed in some countries under the initiative of Europe. The technical manual prepared by JICA introduces the types and applications of slope greening, and details the functions and layout of slope drainage.
Specifying the Designed Safety Factor	The designed safety factor in the case of embankment slope stability is described in the Highway Earthworks guideline. However, for landslide countermeasures and cutting works, it is not specified.	In the United States, each state specifies a designed safety factor for slopes. In Europe, it has not been confirmed the designed safety factor in the official standards. (Set separately).	Many countries specify the designed safety factor in their official standards. Countries that do not conduct slope stability analysis do not set a planned safety factor.
Design methods of counterme asures	The main points of design methods for various countermeasures are described in detail in Highway Earthworks guidelines, rock fall countermeasure handbooks, and technical guidelines of prevention steep slope collapse.	There is a description of the outline of the landslide countermeasure works, etc., and the design method is also shown.	A number of countries have confirmed the types and outlines of countermeasures in their technical standards. However, no country has been identified that indicated the design method. Even the technical manual prepared by the JICA project only covers up to the design theory.

Source:
Japan Road Association (2009): Highway Earthworks - Guidelines for Cutting and Slope Stabilization
Japan Road Association (2010): Highway Earthworks - Guideline for Embankment
Japan Road Association (2017): Handbook for countermeasures against rock falls
Hokuriku Regional Development Bureau (2020): Design Guidelines - Roads
Japan Flood Control and Sabo Association (2019): Design and Examples of New Slope Failure Prevention Works - Technical Guideline for Steep Slope Failure Prevention Works

2.3 Comparison of Technical Standards for Construction

This section compares the major items related to the construction of landslide countermeasures for roads among Japan, Europe, the United States, and developing countries.

Table 2-3 Differences between Japan and Overseas in Terms of Technical Standards for Construction, etc.

Source: JICA study team

Item	Japan	Europe/USA	Developing Countries
Construction Supervision	As the construction supervision is carried out by the client, implementation guidelines and manuals on construction supervision are developed by the client, namely central government, prefectural government, etc.	Construction supervision is carried out by consultants in many countries. In the USA, a manual on construction management for federal high-standard roads is in place.	In many countries, construction supervision is carried out by consultants, and technical standards for construction supervision have not been developed.
Quantity Measurement	As the final quantity measurement is carried out by the client, there are implementation guidelines and manuals for quantity measurement by the client, namely central government, prefectural government, etc.	In many countries, quantity measurement is carried out by consultants, and no technical standards for quantity measurement have been identified.	In many countries, quantity measurement is carried out by consultants, and technical standards for quantity measurement are not in place.
Quality Inspection	As the final quality control is carried out by the client, there are implementation guidelines and manuals on quality control by the client, namely central government, prefectural government, etc.	European quality control regulations for each type of construction and the US ASSHTO quality control standards are used.	In some countries, there is a description of quality control in the technical specifications for slope protection works specified by ministerial ordinance. Some countries have adopted the ASSHTO quality control standards.

2.4 Comparison of Technical Standards for Products

This section compares the major items related to the products of landslide countermeasures for roads between Japan, Europe, the United States, and developing countries.

Table 2-4 Differences between Japan and Overseas in Terms of Technical Standards for Products, etc.

Source: JICA study team

Item	Japan	Europe/USA	Developing Countries
Products of landslide countermeasures	Major countermeasure works that use specific products, such as ground anchor and rock fall countermeasure are certified by the Japan Construction Information Center Foundation (JACIC), JIS (Japanese Industrial Standards), JGS (Japanese Geotechnical Society). Countermeasures registered in the New Technology Information System (NETIS) of the Ministry of Land,	Each country has standards such as ASTM and BS. The standards of the EU member countries are optimized for each country by detailed regulations in accordance with the EU standards.	In some countries where roadside landslide countermeasures are actively introduced, technical specifications for ground anchor works and soil nailing works etc. are stipulated in ministerial ordinances. These technical specifications act as an indirect product designation.

Item	Japan	Europe/USA	Developing Countries
	Infrastructure, Transport and Tourism are also used.		
Materials for landslide countermeasures	General-purpose materials certified by JIS standard or listed in the monthly magazine "Kensetsu Bukka" are used for landslide countermeasures.	Same as above	In some countries where roadside landslide countermeasures are actively introduced, technical specifications of materials for ground anchor works and soil nails etc. are stipulated in ministerial ordinances.
Technical specification for landslide countermeasures	The technical specifications are defined for the products of JACIC certified and/or NETIS/JIS/JGS registered.	General structures are specified in standard specifications. For supplier-initiated works, the supplier provides draft technical specifications.	Technical specifications for landslide countermeasures may be stipulated in ministerial ordinances in countries where roadside landslide countermeasures are actively introduced.

CHAPTER 3 Points of Design Calculation and Verification of Japanese Slope Protection Works

This chapter describes points of design calculation and verification, considering both outline design and detailed design.

3.1 Spray Crib Works

(A) Verification of Validity of Crib Works Arrangements for Spray Crib Works

The crib works arrangements is very important to know the quantity of materials used for concrete crib at the time of construction. The validity is verified by the following method.

(1) Confirm whether the plan view, longitudinal view, and cross-sectional view (longitudinal section and cross section in the road project) used to create the crib works arrangements are consistent with the actual topography.
(2) Calculate the slope length from the distance and the elevation difference from the reference point on the cross section, and check the consistency with the slope length at the cross section position on the crib works arrangements.
(3) From the total length of the horizontal beam and the elevation at each horizontal beam position, examine the consistency with the length of the contour line at the relevant elevation on the plan view.
(4) Check the consistency of the crib works arrangements and the plain view.

In addition, there are differences by engineer in how to develop the crib works arrangements and how to calculate slope length. It is desirable to develop the crib works arrangements from the center of the slope. In addition, the shape of the slope changes to some extent during the construction concrete crib works, so, it is usual for the contractor to redo the allocation of the framing. Therefore, the inconsistency between the crib works arrangements at the time of design and after construction is not a problem.

(B) Verification of Handling of Self-Weight of Concrete Frame, etc. In the Design Calculation

When performing numerical slope stability analysis, check whether the weight of the frame and filling material is taken into account. In particular, there are cases in which the self-weight of the slope is not taken into account when restraining works such as anchor works and soil nailing works are used together. 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 Earthworks Method (Geotechnical Society, 2011)” specify that the self-weight of the slope frame should be considered in calculations.

(C) Verification of Minimum Cover of Reinforcing Bars

Cover thickness of reinforcing bar is an important item for maintaining the quality of framing over the long term. It is necessary to check whether the thickness value is higher than the value derived from the calculation formula (using the standard strength of mortar National Specified Slope Protection Association, 2013). Also, in a corrosive environment, the cover thickness must be set larger than the minimum value calculated by the formula. Alternatively, engineers must use a reinforcing bar that has undergone rust prevention treatment such as epoxy coating or plating. It is also necessary to verify which one is adopted.

(D) Inspection of Main Reinforcing Bars

For example, if the frame size is 300mm, there are cases where D13 is used and cases where D16 is used. Check if the design calculations and standard drawings are consistent. It is also necessary to confirm that the specified rebar specifications (including reference strength) are available in the country concerned.

(E) Verification of Frame Size when Prevention Works Are Used Together with Spray Crib Works

When prevention works are used together, it is necessary to secure insertion holes at the intersections of the frames. Therefore, for example, when using anchor works together, a frame size of 400 mm or more is required.

(F) Review of Temporary Construction Method

Confirm what kind of temporary construction method is assumed and evaluate the possibility of construction.

Source:
National Specified Slope Protection Association (2013): Guidelines for Design and Construction of Glue Frame Works
Japan Flood Control and Sabo Association (2019): Design and Examples of New Slope Failure Prevention Works - Technical Guideline for Steep Slope Failure Prevention Works
Geotechnical Society (2011): Design and Construction Manual for Ground Reinforcing Earthworks Method

3.2 Anchor Works

(A) Basis for Estimating Distribution of Anchorage Ground in Direction of Anchor Installation

The anchor excavation length at each location is set based on the estimation result of the three-dimensional distribution of the anchorage ground. It is necessary to verify the validity of its distribution from the results of the detailed investigation.

(B) Appropriate Anchor Placement

Check the adequacy of anchor placement from the following points.

(1) Is the number of construction rows two or more? In the case of single-row arrangement, is a staggered arrangement adopted?
(2) Are the number of anchors on each stage the same? If the number of anchors for each row is different, are the reason and attention points regarding design and construction noted?
(3) Are there any isolated anchors or construction steps? Anchor works is necessary to be arranged with at least two to three rows as one set in the area.
(4) When constructing with the crib works, it is necessary to avoid the construction at the crib edge because it causes a shortage of the bearing area.

(C) Verification of Free Length and Fixed Anchor Length

A free length of 4 m or more is required to control the anchoring load and to function as an anchor. In addition, the fixed anchor length of general peripheral friction anchors must be more than 3m and less than 10m. If the fixed anchor length is about 10m, the long-term stability is a concern, so it is desirable to reduce the length to less than 7m and increase the borehole diameter.

(D) Verification of Adequacy of Anchorage Ground

The following types of ground are unsuitable for anchorage ground for anchor works.

(1) Ground where the N-value is extremely small (less than 10) and no peripheral friction force can be expected. In this case, consider adopting the expanded hole bearing type.
(2) Ground with many open cracks and voids, where there is concern that a large amount of grout may flow out. In this case, consider using a seamless packer together.
(3) Ground with strong weathered tuff, etc., where creep deformation increases after the introduction of stress.
(4) Gravel ground, etc., where there is a risk of grout flowing out due to groundwater self-eruption or water loss.
(5) Corrosion becomes severe when pH becomes 4.0 or less. General anchoring cannot be applied to strongly acidic ground with less than 2.0.

(E) Validation of Circumferential Friction Resistance (Bond Strength)

The standard values in the Highway Earthworks Guideline (Japan Road Association) are empirical values in Japan according to the geotechnical/geological classification by the workability of earthworks with heavy machinery. This standard values have a wide range for one rock type. It cannot be applied overseas as it is. As in Japan, in principle, it is necessary to conduct a pull-out test in the target area to get the circumferential frictional resistance.

(F) Verification of Soil Cover from Anchorage Ground

For the anchor body at each construction stage, confirm that the soil cover of good quality ground that will serve as the anchorage ground for the anchor is 1 m or more.

(G) Verification of Sliding Over the Piles

There is a risk that the pressure plate of the uppermost anchor (especially the central anchor plate) may cause overriding slippage. Check whether the safety of the over-slide has been verified.

(H) Verification in Case of Combining with Crib Works

The following verifications are required if the cribs is used as a bearing structure.

(1) Verification of the handling of the self-weight of the slope frame, etc. in the design calculation (see Section 3.1 (b)).
(2) It is necessary to avoid construction at the edge of the slope, as this will lead to a shortage of pressure-receiving area.

(I) Review of Temporary Construction Method

Confirm what temporary works are used and evaluate the feasibility of construction.

Source:
Japan Road Association (2009): Highway Earthworks - Guidelines for Cutting and Slope Stabilization

3.3 Earth Reinforcement (Rock Bolt / Soil Nailing)

(A) Basis for Anchorage Distribution and Calculation of Reinforcing Bar Length

The reinforcing bar length of each location is set based on the estimation results of the three-dimensional distribution of the anchorage ground. It is necessary to verify the validity of its distribution from the results of the detailed survey.

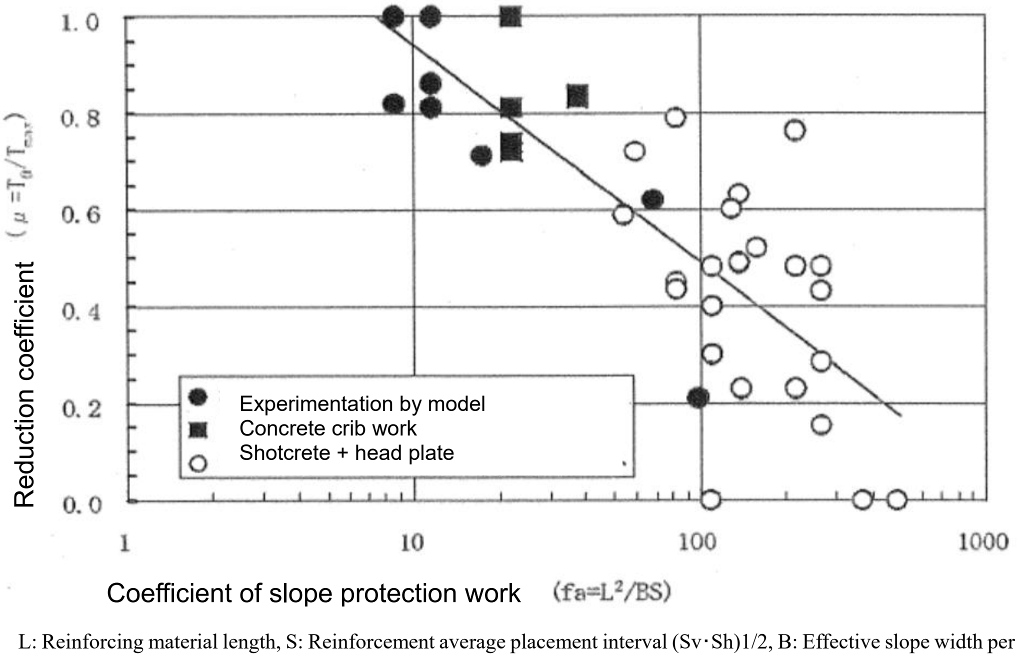
(B) Verification the Reduction Coefficient μ

The design reduction factor is an important parameter that directly affects the effectiveness of soil nailing. Table 3.1 shows the common range of the reduction coefficient. However, if the design prevention force is large, it is necessary to verify the coefficient μ based on Fig. 3-1. When soil nailing is used together with shotcrete, the coefficient differs depending on the size of the head plate. Attention must be paid to this point. This “reduction coefficient” is a concept unique to Japan. There is a similar idea in US soil nails. However, the coefficient calculation method is different, and it is not confirmed in Europe.

Table 3-1 Standards for the “Reduction Coefficient” for Typical Slope Protection Works

Source: NEXCO, 2007

Slope protection works	μ	Remarks
Slope vegetation	0	
Shotcrete	0.2～0.6	
Concrete crib works	0.7～1.0	
Retaining walls	1.0	Continuous board type slope protection works



L: Reinforcing material length, S: Reinforcement average placement interval (Sv･Sh)1/2, B: Effective slope width per reinforcing material (A1/2), T0: Effective on slope work Tmax: Maximum reinforcement tensile force, Sv, Sh: Vertical and horizontal placement intervals of reinforcement, A: Pressure-receiving area of slope work per reinforcement
Note) In the case of shotcrete, B is the width of the head plate.

Figure 3-1 Relationship between Slope Protection Coefficient and Reduction Coefficient μ

(C) Validation of Circumferential Friction Resistance (Bond Strength)

The circumferential friction resistance generally used in Japan (NEXCO, 2007) refers to the values using for the anchor works according to the ground classification, which is classified according to the workability of earthworks with heavy machinery. This value is a reference value that adopts 80% of the minimum value of the peripheral friction resistance for the ground classification. This “80% comes from long term experience but is not set on scientific basis. As in Japan, in principle, it is necessary to conduct a pull-out test in the target area to set the circumferential frictional resistance.

(D) Verification of Failure Slip by Minimum Safety Factor after Soil Nailing

Soil nailing must be placed on the target slope and the planned safety factor must be satisfied anywhere on the target slope. It is necessary to check whether or not the safety factor F of the minimum safety factor after soil nailing exceeds the planned safety factor Fp.

(E) Verification of Combined Use with Concrete Crib Works

The following verifications are required if the landslide countermeasure is used as a bearing structure.

(1) Verification of the handling of the self-weight of the concrete crib work’s frame, etc. in the design calculation (see Section 3.1 (b)).

(F) Verification of Temporary Construction Method

Confirm what temporary construction method is used and evaluate the feasibility of construction.

Source:

NEXCO (2007): Design and construction guidelines for cutting reinforcement earthworks method

3.4 Rock Fall Prevention Works (Common Points for Design Calculation and Verification)

(A) Consistency between Survey Results and Design Conditions

In the survey, individual features (size, slope angle, etc.) of boulders and unstable rock masses on the target slope are investigated. However, some of the rock fall countermeasures are designed using features such as individual boulders. Therefore, it is necessary to confirm whether the features of boulders, etc. to be designed match the design conditions.

(B) Validity of Jumping Height of Falling Rocks

Confirm that the standard value (2m or less) is sufficient for the jumping height of falling rocks. In addition, confirm whether there are topographical conditions that require a rock fall simulation (such as the upper part of the slope being loose, the lower part of the slope being steep, and falling rocks from the upper part of the slope making a large jump). Then, verify the validity of their treatment in the design.

(C) Validity of Design Parameters Used for Rock Fall Kinetic Energy

Confirm that the adopted equivalent coefficient of friction and drop height (maximum value of 40m) are appropriate.

(D) Appropriateness of Technical Specifications corresponding to Ground Conditions at Installation Position of Post/Pillar for Rock Fall Prevention Works, etc.

Confirm that the types and lengths of ropes and anchors used to fix posts are determined based on the existing ground conditions. In addition, it is necessary to verify the validity of how the ground of the installation position is assumed.

(E) Verification of Consistency between Design Calculations and Drawings

Many rock fall countermeasures consist of various materials. Check whether the size of countermeasure works such as fence height and the standard of members are consistent between the design calculation sheet and the drawing.

3.5 Rock Fall Protection Fence (Typical type)

(A) Validity of Fence Height

Make sure that the fence height is determined based on the assumed rock fall jumping height.

(B) Adequacy of Standards of Products Adopted

Check whether the standard can absorb the falling rock energy. In the case of a heavy snowfall area, it should be confirmed whether it is a snow weight resistant type.

(C) Confirmation of Foundation Design Method

Confirm whether foundation works is being considered at all times and during falling rocks (in the case of retaining wall foundations, it is necessary to consider earthquakes as well).

(D) Appropriateness of Foundation Ground Conditions

When a gravity retaining wall is used together, the adequacy of the ground conditions used as design parameters such as soil strength parameters, unit volume weight, slope inclination angle, etc. of the supporting ground is verified.

(E) Confirmation of Workability of Foundation Works

The followings should be checked:

(1) Is it possible to cast concrete for foundation works?
(2) Is the necessary extra excavation (0.4 to 0.5m) secured when installing the formwork for the foundation works?
(3) Is the penetration of the foundation works sufficient? A depth of 0.5m and a horizontal overburden of 1m should be used as a guideline.

(F) Consistency between Calculated Cross Section (Design Cross Section) and End Cross Section

Falling rock protection fencing may extend in the longitudinal direction of the road. If the topography of the design cross section used in the design calculation and the end cross section are significantly different, it is necessary to verify the validity of the design results for the design cross section.

3.6 Rock Fall Protection Fence (High Energy Absorption Type)

(A) Checking Stability of Ground at Installation Location

High-energy-absorbing rock fall protection fences are often installed in the middle of slopes. It is not suitable that the ground with a high risk of slope failure is used as an installation position.

(B) Verification of Planning Policy

Even with a high-energy absorption type, there is a limit relating to the rock fall kinetic energy that can be absorbed for each product. Therefore, it is necessary to first consider whether it is possible to deal with large boulders, etc., by removing stones or by installing countermeasures at the source. In addition, it is necessary to confirm the validity of the conclusion that the high-energy-absorbing rock fall protective fence construction is optimal.

(C) Verification of Planning Location and Height of Fence

If the terrain requires a rock fall simulation (see Section 3.4 (b)), confirm that the planned location and fence height correspond to the results.

(D) Confirmation of Capacity to Accept Falling Rock Kinetic Energy

Check the design calculations and drawings to confirm whether the rock fall protection fence construction standards correspond to the assumed rock fall kinetic energy.

(E) Verification of Extension of Fence Assuming Spread Range of Falling Rocks

According to the Rock Fall Handbook (Japan Road Association, 2017), the maximum lateral side spread of the rock fall route from the rock fall source is about 45 degrees. Make sure that the extension of the rock fall protection fence takes into consideration the planar spread (±45°) of all the target boulders/rock fall.

(F) Verification of Elevation Difference at Installation Position in Fence Extension

The fence is often installed halfway up the slope. If the elevation difference is large, special parts are required. In addition, there are cases where it is necessary to treat gaps due to unevenness. Confirm that the installation position in the extension of the fence is almost at the same altitude and that there is few unevenness.

(G) Confirmation of Construction Conditions

When installing in the middle of a slope, it is necessary to confirm the following construction conditions.

(1) Are temporary works and temporary plans appropriate?
(2) How to transport drilling machines, etc. (crane, monorail, etc.).
(3) Does the width of the scaffolding for temporary works conform to the machine used?

(H) Arrangement of Materials Required for Maintenance

High-energy-absorbing rock fall protection fences have specific components that need to be replaced after receiving a large rock fall, which differs for each product. Check whether the replacement parts for the adopted product are organized.

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

3.7 Covered Rock FALL Protection Net

(A) Confirmation of Vertical and Horizontal Rope Standards and Intervals

Since it is the most important member of the covered rock fall protection net, check the consistency between the design calculation sheet and the drawing.

(B) Verification of Design Conditions

Validity of the following design conditions is confirmed.

(1) Is the weight of the wire mesh taken into account in the design calculations?
(2) Is the coefficient of friction between the ground and falling rocks appropriate (usually 0.5)?
(3) Is the safety factor for the breaking load of vertical and horizontal ropes appropriate (safety factor is 2.0)?

(C) Verification of Area Calculation and Crib Works Arrangements

After confirming whether the plan and cross-sectional views used in the design are consistent with the local topography, calculate the slope length at each cross-section and check the consistency with the area calculation and crib works arrangements.

(D) Confirmation of Construction Conditions

It is necessary to confirm the following construction conditions.

(1) Are temporary works and temporary plans appropriate?
(2) How to transport materials and drilling machines (crane, simple cable crane, monorail, etc.).

3.8 Pocket Type Rock Fall Protection Net

(A) Verification of Topographical Conditions at Planned Location

Check if the planned location meets the topographical conditions (location of the kink line) where the pocket type can be applied.

(B) Confirmation of Stability of Ground at Installation Location

In the case of the pocket type, there is a possibility that the function will be lost due to slope failure at the position of the pocket strut or pipe anchor on the head. It is not suitable, if the installation position is on the ground where the risk of slope failure is high.

(C) Confirmation of Vertical and Horizontal Rope Standards and Spacing

Since it is an important member, check the consistency between the design calculation sheet and the drawing.

(D) Confirmation of Conformity of Component Standards

Confirm the consistency between the design calculation sheet and the drawing for the following members.

(1) Diameter and spacing of vertical and horizontal ropes.
(2) Length of horizontal rope, height of post, and length of suspension rope.
(3) Cross-sectional area of strut

(E) Confirmation of Conformity of Component Standards

Confirm whether the plan and cross-section used for the design are consistent with the actual topography. After that, calculate the rope length at each section and check that the rope length and net area cover the range of interest.

(F) Verification of Net Extension (Construction Range) Assuming Spread Range of Falling Rocks

According to the Rock Fall Handbook (Japan Road Association, 2017), the maximum spread of the rock fall route from the source is about 45 degrees. Make sure that the extension (construction area) of the rock fall protection net takes into account the planar spread (±45°) of all the target boulders at the time of rock fall.

(G) Confirmation of Construction Conditions

It is necessary to confirm the following construction conditions.
(1) Are temporary works and temporary plans appropriate?
(2) How to transport materials and drilling machines (crane, simple cable crane, monorail, etc.).

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

CHAPTER 4 Characteristics of Japanese Survey and Design Methods - Their Background and Design Concept

4.1 Basic Concept of Landslide Countermeasures in Highway Earthworks - Concept from Survey to Maintenance

In Japan, there are highway earthworks guidelines and higher standards such as technical standards for highway earthworks structures. This section summarizes the important points that are often overlooked from among the basic ideas regarding roadside landslide countermeasures in these standards, and also important contents for ODA Grants.

(A) Phased Responses to Large Uncertainties

Highway earthworks structures are characterized by large uncertainties that occur at actual sites with respect to the setting of conditions that are prerequisites for planning and design. Therefore, in order to ensure the performance of highway earthworks structures, it is important to gradually reduce uncertainties in survey, design and construction. Taking the foundation ground of a highway earthworks structure as an example, there is a natural limit to conducting detailed surveys such as boring at the survey stage, and there is no choice but to leave a certain amount of uncertainty. On the other hand, since the foundation ground is exposed by excavation during the construction stage, it becomes possible to grasp more clearly the distribution of phenomena and the actual condition of the foundation ground, which could not be grasped in advance surveys. Uncertainty can be reduced by changing design and construction methods as necessary. Moreover, it is difficult to eliminate all uncertainties even at that time when the construction is completed and the service is started. Therefore, it is important to gradually reduce uncertainty while maintaining performance through appropriate inspections and repairs during service (Technical Standards and Commentaries for Highway Earthworks Structures (Japan Road Association, 2017, P.16).

(B) Application of Empirical Engineering Judgment and its Limitations

Since the level of certainty of the quantitative evaluation of the stability of highway earthworks structures based on the results of surveys, tests, and consequent engineering calculations is not high, in many cases, it is necessary to make a comprehensive judgment in light of past achievements and experiences. Therefore, empirical techniques are emphasized in the design of earthworks structures. An example is the standard cutting gradient of the embankment/cut slope. The standard cutting gradient is premised on application limits, proper placement of drainage, and proper construction. And the standard cutting gradient is set in light of past achievements in order to avoid damage that would greatly hinder traffic in Japan's natural environment. The application of such empirical techniques is still possible. However, in cases such as high embankments that exceed the applicable limit, large cuts, or when there are important facilities in close proximity, it is necessary to consider the application of various analyses, information-aided construction, etc. (Road construction guidelines (Japan Road Association, 2009a), p.14)

(C) Mutual Complementation of Highway Earthworks Structures

A highway earthworks structure includes several structures, such as a retaining wall, a shotcrete, a ground anchor, etc., and combines their functions with respect to one assumed disaster source. As a result, it has the characteristics of ensuring road safety (Technical Standards for Highway Earthworks Structures and Commentaries (Japan Road Association, 2017), p.17).

(D) Dealing with Uncertainties Including Disaster Triggers

Events assumed to act on highway earthworks structures contain many uncertainties. Therefore, it is unrealistic to try to secure safe and smooth traffic only with existing road earthworks under any conditions. For example, among the effects of rainfall, it is premised on ensuring safety by implementing appropriate road traffic regulations against localized heavy rain. In addition, it is also necessary to set the effects of rainfall that are taken into account in the design of highway earthworks structures (Technical Standards for Highway Earthworks Structures and Commentaries (Japan Road Association, 2017), p.17).

(E) Consideration for Slope Disasters during Construction

No matter how meticulously researched, planned and designed, unpredictable situations may occur during construction, leading to the collapse of highway earthworks structures. Therefore, in design and construction, it is important to limit the impact of collapses on road structures, by the adequate design considerations and construction of countermeasures, etc. (Technical Standards and Commentaries for Highway Earthworks Structures (Japan Road Association, 2017), p.17).

Source:
Japan Road Association (2017): Technical Standards and Commentaries for Highway Earthworks Structures
Japan Road Association (2009a): Road Construction Guidelines
Japan Road Association (2009b): Highway Earthworks - Guidelines for Cutting and Slope Stabilization

4.2 Mutual Complement between Various Surveys

The ground on natural slopes often has a complex geological structure and, it is rarely uniform. Fractures and weathering further complicate the engineering characteristics of soil structure. In addition, the ground hydrological conditions are also often complex. There are various kinds of surveys such as geophysical exploration, geophysical logging, survey boring, underground dynamics observation, and so on. It is difficult to accurately grasp ground information including three-dimensional anisotropy with one survey type. In addition, there are measurement errors and limits of investigation/measurement for one research type. Therefore, in ground surveys, it is important to obtain more accurate ground information by mutually complementing the results of multiple types of surveys.

CHAPTER 5 Examples of Countermeasures with Japanese Technology in Overseas

5.1 Examples of Countermeasures in Sri Lanka

Figure 5-1 shows a pocket-type rock fall protection net and a rope hanging works along National Highway A026 in Kandy West. It was constructed between 2014 and 2016 under the World Bank's Climate Resilience Improvement Project (CRIP). The actual design was carried out by the manufacturer, Tokyo Steel, and the construction was handled by Nittoku Construction and local contractor ELS. In this section, various rock fall countermeasures were implemented on multiple slopes several tens of meters apart.

Figure 5-1 Japan's Rock Fall Countermeasures Constructed by the World Bank's Project

Fig. 5-2 shows spray crib works (left) and anchor works (right) combined with soil nailing for the Diyagala landslide along national highway A07, which was implemented by the Landslide Disaster Protection Project (LDPP) of Japan's ODA Loan Project. It was constructed between 2017 and 2020. Vegetation is invading the frame and transitioning to a natural forest state.

Figure 5-2 Concrete Crib Works Using Both Soil Nailing and Anchor Works by LDPP

Figure 5-3 shows the anchor works and light embankment works for the Nawalapitiya landslide along National Road AB013, also by LDPP. It is in a stable state without the deformation. The construction period for this is also from 2017 to 2020.

Figure 5-3 Anchor Works and Light Embankment Works by LDPP

5.2 Examples of Countermeasures in Philippines

Fig. 5-4 shows the pocket-type rock fall protection net constructed around 2018 as a pilot project of JICA's Project on Improvement of Quality management for Highway and Bridge Construction and Maintenance Phase 3 (TCP-III). At the time of confirmation in May 2022, a 10m wide and 20m long collapse that occurred at the top of this slope had damaged one of the pillars of the head, causing it to hang in the air. According to a local engineer of Tokyo Rope, the manufacturer of this countermeasure, there is no action plan for repair at the time of interview.

Figure 5-4 Pocket-Type Rock Fall Protection Net Constructed under a JICA Project

Figure 5-5 is a rock shed along the Aspirus-Parisp is Highway (Route 208, formerly the Marcos Highway) west of Baguio. JICA's ROSARIO-PUGO-BAGUIO Road Restoration Project (1993-2001) was implemented as a road restoration project for the former Marcos Highway, which was damaged by the 1990 earthquake. Figure 5-6 shows the rock fall protection fence constructed on the adjacent slope in the same project.

Figure 5-5 Rock Shed on Rosario-Pugo-Baguio Road

Figure 5-6 Rock Fall Protection Fence on Rosario-Pugo-Baguio Road

5.3 Examples of Countermeasures in Honduras

Figure 5-7 shows the landslide countermeasure works (Sta.14.7km) along National Highway No. 6 constructed with Japan's ODA from 2018. There was no deformation of the anchor head, and it is presumed that countermeasures were appropriate based on visual confirmation.

Figure 5-7 Landslide Countermeasure along National Highway No. 6 (Sta.14.7km)

Figure 5-8 shows the situation as of August 2021 of the landslide countermeasure works (Sta.22km) along National Route 6 constructed by Japan's ODA in 2019. Steel pipe piles are being constructed on this unpaved area as a landslide prevention works. Since no deformation was observed on the ground surface at the unpaved site and no deformation was observed on the road surface of the paved section, it is considered that the steel pipe piling works are functioning well. Figure 5-9 shows the situation at the time of construction in 2019.

Figure 5-8 Landslide Countermeasure along National Highway No. 6 (Sta.22km)

(Source: INSEP)

Figure 5-9　Construction of Steel Pipe Piling in 2019

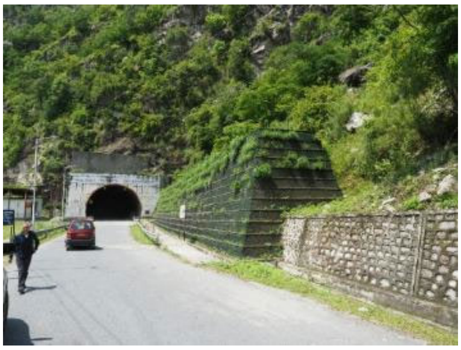
5.4　Examples of Countermeasures in Bhutan

Landslide countermeasures (2 sites) of implemented by Protech Engineering Co., Ltd based on JICA's SME support scheme were confirmed. One is the macro net construction method on National Route 1, and the other is a rock fall protection embankment installed at the north entrance of the tunnel on National Route 5.

Macro net construction method signboard

Macro net works

Figure 5-10　Macro Net Works (National Route 1)



Rock fall protection embankment in front of the tunnel entrance

Rock slope behind rock fall protection embankment

Figure 5-11 Macro Net Works (National Route 1)

The test construction site of non-frame implemented by Design Division and O&M Division of Department of Public Works and Highways, Kyoto University, and Nippon Steel Metal Products was also confirmed on National Route 1.

The test construction site of non-frame

Test construction signboard

Figure 5-12 Test Construction Site of Non-Frame Works (National Route 1)

Source:
The photographs in this chapter were taken by the JICA study team unless otherwise noted.

CHAPTER 6 Expected Questions and Answers from Counterpart of Partner Country

This chapter assumes questions about Japanese technology from counterparts and engineers of partner countries, which are likely to be encountered frequently in the field of ODA, and describes a draft answer. Whether or not this answer is correct should be decided by each engineer after understanding the content of the question and answer.

6.1 Assumed Questions and Answers about Survey and Design

(A) Q1: Which type of contract should be used for countermeasures of roadside slopes?

Landslide countermeasures and landslide countermeasures are expected to change in quantity because invisible underground conditions restrict construction. Therefore, it is better to use a unit price system[1] that can easily respond to changes in quantity.

(B) Q2: Do we have to acquire the land for countermeasure? (Including space for temporary road/facility)

In many cases, the land for project will be outside the existing ROW. It will be necessary to occupy the space during the construction period. However, the countermeasure benefits the land owners of the slopes adjacent to the road. Therefore, it seems that it will be sufficient to negotiate for free rental during the construction period and access permission for maintenance.

Also, in some countries, the countermeasure is the responsibility of landowners. However, in most cases, landowners do not have the capacity to implement countermeasures. Therefore, the national government and administrative agencies will carry out the countermeasure instead. Even in that case. Access permits for free rental and maintenance during construction would need to be agreed.

(C) Q3: RocScience's Slide2, etc. have a sensitivity analysis function for input parameters, and can also specify a slip surface. Using these functions, it is possible to do something similar to back analysis, but can we use Slide2 to design slope measures and landslide measures?

It is necessary to perform an appropriate stability analysis using appropriate parameters. It is not necessary to stick deeply to any analysis method. However, the effect calculation formula for prevention works such as anchor works and soil nailing differs for each software on the market. Attention must be paid to this point. As a result, the design results (the number and arrangement of necessary countermeasures) differ for each software. Naturally, the formula for calculating the effect of deterrence works is different from that of design software on the market in Japan.

(D) Q4: Where can we get the back analysis software?

RocScience's Slide2, etc. It also supports sensitivity analysis when material parameters are changed, and operations similar to back analysis are possible.

The software provided by Japanese companies[2] is compatible with back analysis.

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[1] It is often called BOQ (Bill of Quantity) contract or Item Rate contract. A design-built contract is a contract in which a contractor performs design and construction, and payments are made in a lump sum. In this case, the change in the construction quantity does not directly lead to the change in the payment amount.

[2] E.g. COSTANA of Fujitsu, https://www.fujitsu.com/jp/group/fjj/solutions/industry/construction/plan/costana/

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

6.2 Assumed Questions and Answers about Construction

(A) Q1: Is it require special machines that are not used in general earthworks for landslide countermeasure works? Why should the machined be used?

General heavy machinery can be used to slope cutting and vegetation works.

Boring machines are required to insert/inject materials and grout using boreholes that are drilled slightly above or below such as rock bolts and soil nailing, ground anchor works (tension anchor works), and drainage horizontal boring works.

Rotary percussion boring machines are often used for efficient and effective boring. Furthermore, in the countermeasures described above, it is necessary to properly protect the borehole walls from collapsing, because if the borehole wall collapses before the material or grout is inserted/injected, the function of countermeasure works cannot be properly exhibited due to poor construction. Double-tube rotary percussion boring machines were developed to prevent collapse of the borehole wall. They are used in most slope protection works in Japan.

<Details related to Q1 are described in Sections 5.4, 5.5 and 5.10 of Handbook II.>

(B) Q2 : Is scaffolding necessary for construction? Can't it be done by using a crane to hoist a machine and a person like soil nailing works?

Scaffolding is not necessary if the rebar insertion of the soil nailing and the grouting are properly carried out by lifting the machine and the person or by fixing the machine and the person to the slope with a wire. Self-drilling rock bolts and soil nailing are often constructed by the above construction methods. Proper grouting is more of an issue than rebar insertion, however. In addition, since the above method does not secure a foothold, it is inferior in terms of safety measures.

The advantage of scaffolding is that the safety of work is ensured, and heavy equipment can be installed. The double-tube rotary percussion boring machine described in (1) requires scaffolding.

Rock bolts and soil nailing can also be constructed by self-drilling. However, since self-drilling is difficult for ground anchor works and drainage horizontal boring works, it is necessary to use a double-tube rotary percussion boring machine. Thus, scaffolding is required.

<Details related to Q2 are described in Sections 7.3, 7.4 and 7.5 of Handbook II.>

(C) Q3: Is there a better way to transport material up the slope?

Temporary monorails and cableways are used in Japan. Small crawler is also utilized. There is also a method using a winch and a sled in general, but as with the cableway, attention must be paid to safety.

If budget permits, transportation by helicopter is also considered. Alternatively, it is worth considering reducing the load by adopting construction methods that use light materials and construction equipment.

<Details related to Q3 are described in Sections 7.2 of Handbook II.>

(D) Q4: Is there a safe way to use heavy equipment on steep slopes?

Unmanned excavators are used by hanging them above slopes in Japan.[3]

<Details related to Q4 are described in Sections 5.2 and 7.2 of Handbook II.>

6.3 Assumed Questions and Answers about Maintenance

(A) Q1: The ground anchor (active anchor) requires tension control. Drainage borings need cleaning. Those are noted. Do other countermeasure works require no maintenance?

Basically, all slope protection works require maintenance. For example, shotcrete is prone to surface cracking and back cavity. They must be checked regularly. If there is an abnormality, repair or reinforcement is required. The same goes for concrete crib works. Rock fall prevention works requires routine work to remove sediment and fallen rocks that have accumulated on the back. Rock fall prevention works with braking systems may need replacement after falling rocks. In addition, when members such as posts and wires are damaged due to falling rocks, etc., they must be replaced. The challenges are to establish a system and secure a budget for continuous inspection and maintenance, as well as to develop private companies.

<Details related to Q1 are described in Sections 9.2 of Handbook II.>

(B) Q2: What should be done for maintenance of ground anchor (active anchor) works? What equipment do we need?

In the maintenance of ground anchor works, it is important to periodically check the deformation of the head and manage the tension. Close visual inspection is sufficient to confirm the deformation of the head. However, tension management requires special tests such as lift-off tests. The lift-off test requires a load-measuring device as well as a special hydraulic jack to re-tension the anchor. It is recommended that these measuring devices and equipment be procured at the time of construction.

<Details related to Q2 are described in Section 4.6 of Handbook I and Section 9.2 of Handbook II.>

(C) Q3: What is the ground anchor maintenance schedule? How many times a year should we check the tension? What is the inspection frequency?

When the ground anchor works is damaged, the degree of impact on third parties is high. Therefore, it is desirable that regular inspections (visual inspection from the road) by staff members, etc. be done about once a month or once every six months. If any abnormality is found in the regular inspection, detailed inspection such as close visual inspection should be carried out. Anchor works is a type of works that often causes head deformation and damage. Deep inspections (confirmation of the condition of the rust preventive agent inside the anchor cap and the condition of the anchor material in the head, etc.) are to be conducted about once a year immediately after installation, and at least once every five years after five years have passed. Confirmation of residual tension is often carried out when close visual inspection reveals deformation of the head that may cause a decrease in load or excessive tension.
<Details related to Q3 are described in Section 4.6 of Handbook I and Section 9.1 of Handbook II.>

[3] Links for reference (in Japanese)
https://www.jice.or.jp/award/detail/211
http://www.kumagaigumi-aso.com/mujin.html
http://www.kenmukyou.gr.jp/

(D) Q4: There is a ground anchor that has lost its head cap. Do we need to take action? (A case was confirmed in Honduras where the loss of an anchor cap was neglected.)

It is the head that is most frequently damaged in anchor works. The head cap is an important member to prevent corrosion of the head of the anchor material, and it is desirable to replace it immediately if it is found to be damaged or lost.
<Details related to Q4 are described in Section 4.6 of Handbook I and Section 9.2 of Handbook II.>

(E) Q5: Concrete caps are used for the head caps of anchor works, but do they need to be replaced?

Before 1990, many concrete caps were used in Japan. However, it has not been used since 199 because its waterproof performance deteriorates over time, leading to corrosion of the head, and because it is difficult to inspect and repair the head. Since around 2015, Japanese expressways have been working to update old-type anchors using concrete caps (old-type anchors are left in place and new-type anchors are added nearby). If there are anchors using concrete caps in the country concerned, it is better to consider replacing them with steel anchor caps. If it is not possible to update only the anchor caps, it will be necessary to update them in the same way as for highways in Japan.
<Details related to Q5 are described in Section 4.6 of Handbook I and Section 9.2 of Handbook II.>

(F) Q6: What should be done for maintenance and management of drainage boring works construction? What equipment do we need?

Regularly check the clogging status of the pore mouth once a year as a guide. If the pipe is clogged with slime, etc., it is necessary to wash the inside of the hole with a high-pressure washer used for cleaning water pipes in buildings.

In areas with a lot of limestone, such as Europe, the limestone in groundwater may solidify and clog, and there are cases where acid is used for cleaning, but it is necessary to pay attention to the impact on the environment.
<Details related to Q6 are described in Sections 9.2 and 9.3 of Handbook II.>

(G) Q7: Since the water did not come out, we cleaned the drainage boring, but the water did not come out. What should we do?

Even if a large amount of groundwater flows out immediately after installation of a drainage bore, the outflow decreases over time, and there are many cases in which there is no outflow when there is no rainfall. This means that the groundwater existing in the groundwater zone of the corresponding ground location has been removed. If the groundwater zone is connected to other groundwater zones, groundwater outflow may be confirmed immediately after a heavy rain. It is important to keep the condition as it is because the function as a drain boring works is maintained.

If no outflow of groundwater is confirmed even immediately after a heavy rain, it is necessary to dig a new drain hole near the existing drain hole.
<Details related to Q7 are described in Sections 9.2 and 9.3 of Handbook II.>

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