Corrigendum-I

Name of Work: Consultancy Services for Preparation of Detailed Project Report for Slope Protection work of section of Km. 25.60 to Km 26.1 (Bagrakot -Kafer) of NH-717A in the state of West Bengal

NIT No. & Date: NHIDCL/Bagrakot-Kafer/Slope Protection/NH-717A/West Bengal Dated 11.02.2020

Tender ID: 2020_NHIDC_543712_1

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<tr><td>2</td><td>TOR Cl. 1.4.1, 32</td><td>1.4.1 For expert advice the matter was referred to the Japan International Cooperation Agency (JICA). Their experts carried out site visits and their site visit reports are enclosed as Appendix-XI for reference and incorporation of suitable measures to take care of the specific issues brought out in their site report in this RFP. The JICA experts also provide Draft Guidelines regarding planning, slope stability, bridge and tunnel are enclosed for perusal and incorporation of suitable measures in this RFP (Appendix-XII). To understand gravity deformation, the draft slope stability guideline should be well studied. In addition the JICA expert also provides TOR for Topographical Survey and Drilling as well as requirements of surveys, including topographic mapping, drilling survey, geophysical exploration, and landslide monitoring, and the same have also been part of this RFP.</td><td>1.4.1 For expert advice the matter was referred to the Japan International Cooperation Agency (JICA). Their experts carried out site visits for reference and incorporation of suitable measures to take care of the specific issues brought out in this RFP. The JICA experts also provide Draft Guidelines regarding planning, slope stability, bridge and tunnel are enclosed for perusal and incorporation of suitable measures in this RFP (Appendix-XI). To understand gravity deformation, the draft slope stability guideline should be well studied. In addition the JICA expert also provides TOR for Topographical Survey and Drilling as well as requirements of surveys, including topographic mapping, drilling survey, geophysical exploration, and landslide monitoring, and the same have also been part of this RFP. ToR for Draft Slope Guideline is attached herein.</td></tr>
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(Y C Srivastava)
General Manager (Tech.)

Appendix-XI

ToR for Draft Slope Guideline

Ministry of Road Transport and Highways
India

Japan International Cooperation Agency (JICA)

Capacity Development Project on Highways in Mountainous Regions

GUIDELINE FOR SLOPE PROTECTION AND EMBANKMENT WITH ADVANCED TECHNOLOGY

DRAFT

August 2019

Oriental Consultants Global Co., Ltd.
Kokusai Kogyo Co., Ltd.
East Nippon Expressway Co., Ltd.
Japan Conservation Engineers Co., Ltd.

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List of Abbreviations and Acronyms

BRO	Border Roads Organization
C/P	Counterpart
C/R	Completion Report
EPC	Engineering, Procurement and Construction contract
GNSS	Global Navigation Satellite System
GoI	Government of India
IAHE	Indian Academy for Highway Engineer
JCC	Joint Coordination Committee
JICA	Japan International Cooperation Agency
MoRTH	Ministry of Road Transport and Highways
MS	Monitoring Sheet
NHDP	National Highways Development Project
NHIDCL	National Highways and Infrastructure Development Corporation Ltd.
OJT	On-the-Job Training
OSV	On Site Visualization system
PDM	Project Design Matrix
PO	Plan of Operation
PPP	Public Private Partnership
PWD	Public Works Department
R/D	Record of Discussion
TG	Technical Group
TOT	Training of Trainers
WP	Work Plan

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CHAPTER 1 INVESTIGATION

1.1 Investigation of Hill Slope Condition

1.1.1 General

For hill road construction as well as operation and maintenance, stability of slope is one of the most important concerns for the governments and road administrators. Stability of slopes shall be evaluated for the existing slopes as well as the slopes after construction / improvement. For such purpose, investigation of hill slope condition shall be properly planned and executed.

In addition, in planning, design, and sometimes maintenance of hill roads, engineers shall pay their careful attentions to stability of slopes not only along hill roads but located at a distance, because rock fall, debris flow, and deep-seated landslide occurring at a distance may cause damage to hill roads over such distance with its moving mass. Precursors of such disasters, therefore, shall be carefully studied even though those are distantly located from hill roads.

In this section, investigations required for construction and maintenance of hill roads are explained, especially focusing on stability of slopes. In addition, based on results of such investigations, through a sequence of disaster scenario, methods to examine possibility of a disaster and estimation of subsequent damage are proposed.

1.1.2 Summary of Investigation Method for Topographic and Geological Study

A hill road project usually has the following stages and proper surveys and investigations for stability of slopes shall be conducted in each stage.

1) Outline Design Stage
2) Detailed Design Stage
3) Construction Stage
4) Operation and Maintenance Stage

Basically the area to be surveyed is wider in the earlier stages whereas surveys and investigations shall be in detail in the later stages.

In the outline design stage, where alignment of road is examined and preliminary design is carried out, investigations called “preliminary investigation” are conducted. In the preliminary investigation, along with collections of existing study results, disaster records, and other relevant data and information, field surveys are conducted in the aim of finding disaster prone slope and then establishing a disaster scenario for each disaster prone site. The disaster scenario is a basis of proposing necessary surveys and investigations in the detailed design stage.

In the detailed design stage, where design documents for procurement are prepared, along with basic requirements for road construction, countermeasures against supposed landslides envisaged in the disaster scenarios shall be designed and relating documents shall be prepared. Before such design, necessary surveys and investigations for such design shall be conducted.

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Along the route proposed in the outline design, for basic requirements for road construction as well as comprehensive understanding of geological conditions, geological field survey, geophysical exploration, sounding, drilling with core sampling, in-situ tests, and laboratory tests shall be carried out. At this stage, surveys and investigations shall also be conducted for the areas where special considerations are required, such as tunnels, bridges, and landslides.

During the construction stage, investigations for quality control shall be conducted. Surveys and investigations for unforeseeable conditions shall also be conducted, if required.

During the operation and maintenance stage, while roads are in service, surveys and investigations for maintenance may be conducted to keep the roads in good condition and to repair damaged sections.

Table 1-1 Target of each stage of road construction

Stages of Road Works	*Targeted Area*	*Time scale*
Outline Design Stage	Wide area enclosing alternative routes	Recorded disaster in the area, traces of disaster implied by topographic anomalies. Foreseeable disasters in the area based on the disaster records and anomalies as well as influence by human activities, including artificial cutting and filling as well as other possible construction works.
Detailed Design Stage	Narrow area along the proposed route	Investigation for the largest disaster in the service period foreseeable in the design stage.
Construction Stage	Required sections which are under construction	Data collection according to construction phases and detected unforeseeable conditions.
Operation & Maintenance Stage	All section under service where necessity arises.	Periodical inspections under service period as well as occasional ones after disasters.

Source: JICA Project Team

The surveys and investigations in the outline design stage, where disaster scenarios are established, and the detail design stage, where countermeasures are designed, are outlined in the following sections.

For the existing technologies in India elaborated in IRC codes, this guideline only provides additional information. For the surveys and investigations for planning and operation & maintenance, the corresponding guidelines shall be referred.

(1) Preliminary Investigation (in outline design stage)

Preliminary investigation includes compilation of existing data, aerial photo reading, and geological field survey. Through this stage, basic site information along the alignments, such as topographic, geological, geotechnical, and hydro-geological conditions shall be understood.

For the areas where special considerations are required in alignment study or basic design of road structure or where supposed site conditions may drastically affect construction cost, such as rock fall / slope failure prone area, landslide prone area, soft soil section, high and long cut section, tunnel section, bridge section, and groundwater depletion anticipated section, additional investigation, including geophysical

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explorations, soundings, and drilling with core sampling, should be conducted as much as possible.

(i) Collection and Organization of Existing Information

Basically, existing information such as listed below shall be collected and organized:

- Design drawings from any previous structure at the site.
- Site investigation reports including borehole logs and results of in-situ and laboratory tests
- Construction records.
- Geological maps, survey data and records.
- Hydrological data.
- Aerial photographs.
- Regional seismicity data.
- Disaster records

The collected information should be organized and plotted into large scaled maps of about 1/5000. Topographic, geological, and geotechnical conditions, hydrological and hydrogeological conditions, distribution of landslides along the planned route are to be examined. Ground conditions of the sites should also be examined where important structures are planned, such as high and long cuttings, high embankments, bridges, and tunnels.

Aerial photo reading provides valuable information for topographic interpretation, such as photo lineament, gradient of slopes along with nick / concave nick lines, degree and pattern of erosion, elevation of peneplain and flat terrace, traces of collapse, and landform unique to landslide. Through such topographic interpretation, unfavorable ground conditions against construction and operation & maintenance of hill roads are effectively detected, including fractured / sheared zones, faults, steep slope, and landslides.

Aerial photo reading is, however, manually conducted by skilled engineers. Thus individual difference in the results of photo reading is inevitable and training of such engineers takes long time and experience. In addition, for the areas where thick vegetation covers the surfaces, detailed topographic information is not effectively obtained with aerial photographs. For such cases, air borne laser scanning (ALS) or generally LIDAR (light detection and ranging) is effective. ALS is based on the principle of the analysis of laser pulses which are emitted from an aircraft borne equipment, moving at a certain distance from the targeted object. By using ALS technology, Digital Elevation Model (DEM) of high quality can be interpolated with spatial resolution of about 1 m and height accuracy of 0.1 to 0.20 m in elevation.

On the other hand, wide variety of satellite images are available recent days and some of them are distributed free of charge. Digital Surface Model (DSM) can be generated with such satellite images with a help of GIS software. With such DSM, topographic analysis and interpretation of a certain area can be executed effectively and provide valuable information for hill road planning as well as landslide investigation.

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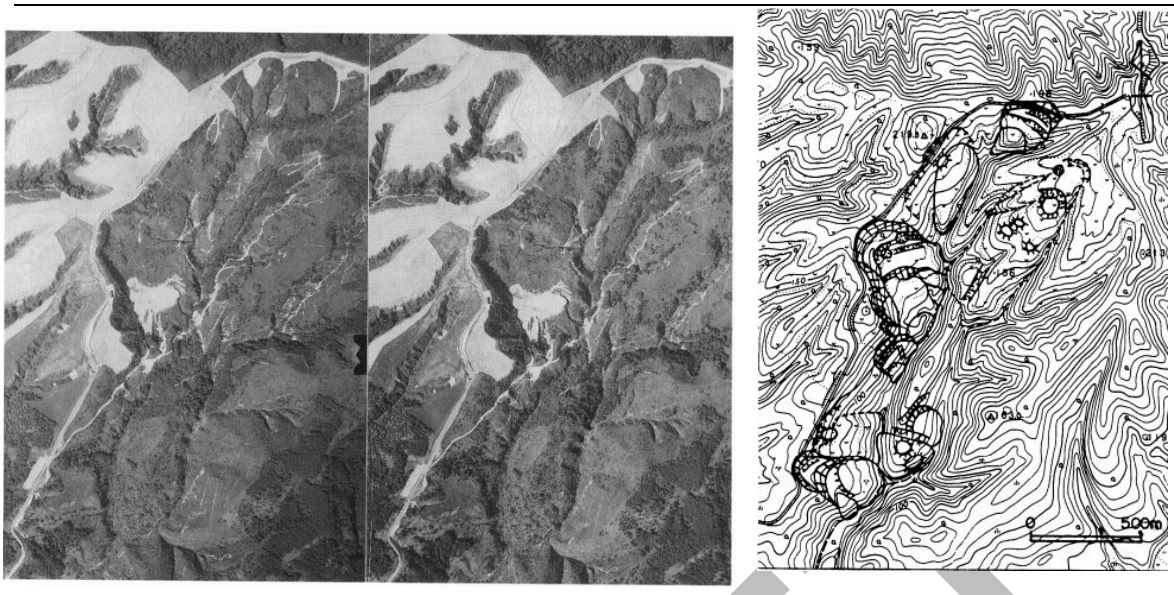


Figure 1-1 Example of Aerial Photos for Stereoscopy (left) and Landform Classification map (right) Produced with Aerial photo Reading

[1]

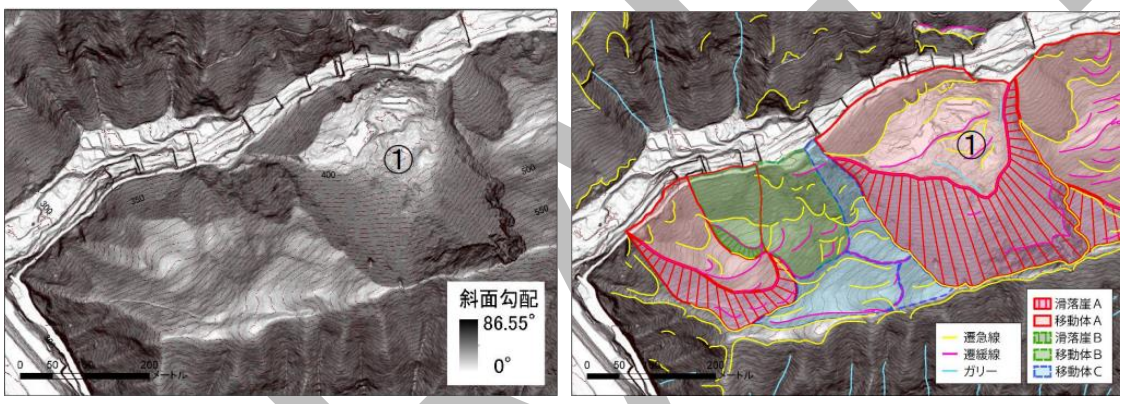


Figure 1-2 Example of Topographical Expression Created with Aviation Laser Survey (ALS)

[2]

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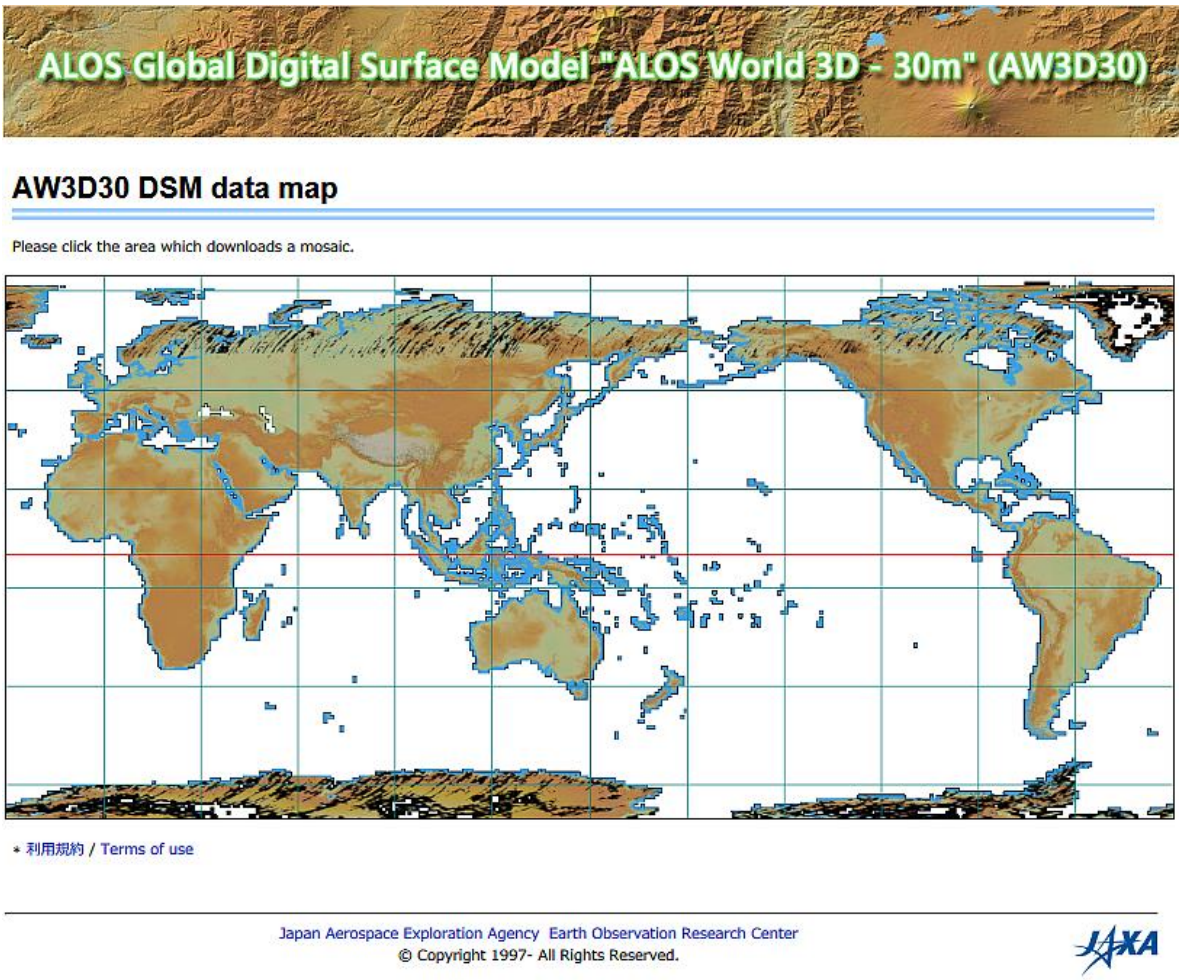


Figure 1-3 ALOS Global Digital Surface Model "ALOS World 3D-30m"(AW3D30)

[3]

The Himalayas are active orogenic belt lying along the northern border of India. With its active tectonic movements, the mountain ranges in and along the Himalayas have specific topographic and geological setting; steep and high rocky slope composed of the hard rock of the Greater and Lesser Himalaya Geological Zones. This setting, steep and high slope composed of hard rock, is one of the main factors of gravity deformation, which may cause periodical subsidence of hill road and occasionally lead to much devastating deep seated landslides. Gravity deformation shows specific micro topographic features along and within the deformed areas. Thus by detecting such specific micro topographic features, locations of gravity deformation can be understood and such information can be a basis of a disaster scenario, alignment study, and design of countermeasures, if required.

(ii) Field Survey

The field survey shall confirm the information collected through the previous step, including photo reading and topographic interpretation. For the areas where landslide is expected, possible mechanism and disaster scenario of landslide shall be well studied through the field survey, including areas to be affected by the landslide.

Interviews with residents, especially old ones, and local authorities provide valuable information. If possible, outcrops at cliffs, quarries, and borrow pits shall be checked carefully and samples shall be obtained for laboratory tests, if necessary.

The file survey will provide basic information for planning of investigation in the following stage. Thus the survey shall be conducted by well-experience engineers / engineering geologists to obtain accurate information as possible.

(iii) Geophysical Exploration

By utilizing physical characteristics of seismic waves, electric resistivity, and electromagnetic waves, geophysical exploration provides tow dimensional (2D) image of ground condition along predetermined survey lines.

For the sites where important structures such as high and long cuts, tunnels, and bridges are planned or for the section where unfavorable conditions are anticipated, geophysical exploration in preliminary investigation stage is worth considering because it provides 2D information of geological conditions along the planned route, which may support decisions in alignment study and location and scale of structures that may substantially affect project cost.

Seismic exploration provides 2D distribution of seismic velocity of the ground, by which hardness / soundness of the ground are assumed. Since seismic velocity of the ground is basic information for efficiency of excavation, stability of cut slope, and excavation and supporting for tunneling, Seismic exploration is useful for planning of tunnel and high and long cuts.

Resistivity survey provides 2D distribution of resistivity of the ground, by which hydrogeological conditions are assumed. Geological conditions such as clay rich part or fissures filled with groundwater are also assumed with resistivity survey.

Aeromagnetic survey enables magnetic surveys for large areas within a very short time periods with airborne magnetometers. Aeromagnetic survey provides 2D distribution of resistivity of the ground in steep mountain ranges, by which relaxed zones in bedrocks, which may suggest gravitational deformation, are detected.

========== Technical notes

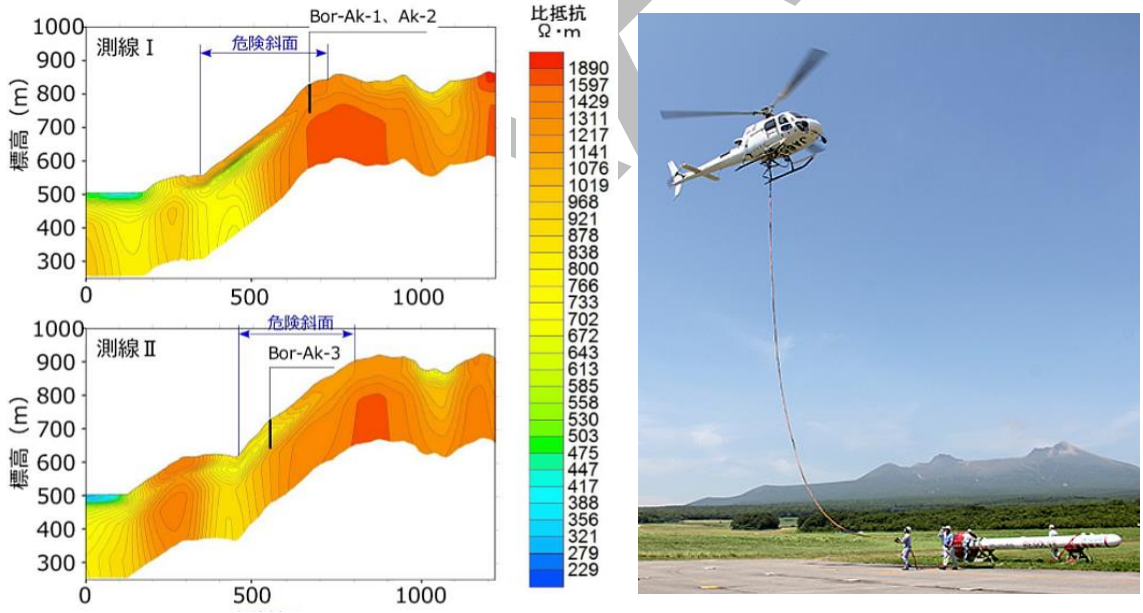


Figure 1-4 Example of Aeromagnetic Survey (Left: Results, Right: Site Work)

Left [4], Right [5]

(iv) Sounding

Sounding is carried out to measure the resistance against penetration of sampling spoon, cone or other shaped tools under dynamic or static loading. For road construction projects, sounding is used for exploration of soil profiles with depths of

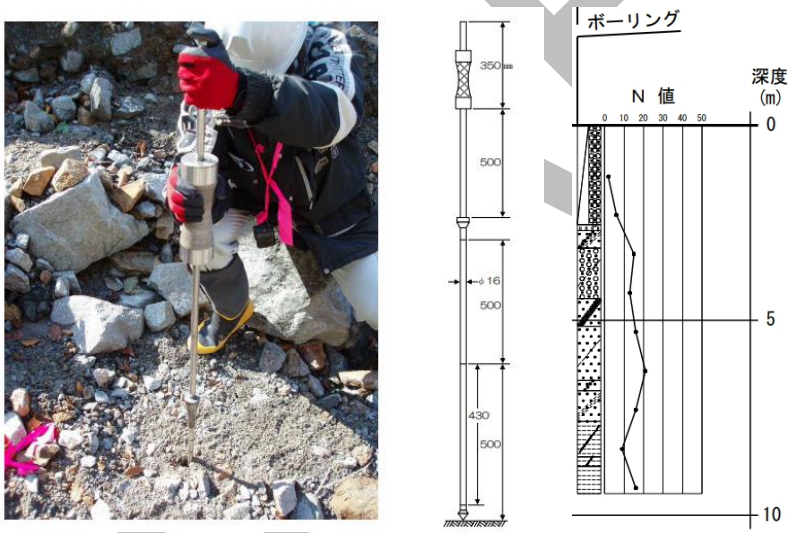
bedrock along with soil properties including strength of soil. Sounding includes standard penetration test (SPT) for normal ground, and cone penetration test (or Dutch cone test) and Swedish weight sounding for soft ground. .

Standard penetration test (SPT) is often planned with drilling investigation with a borehole diameter of between 55 and 150mm, in the aim of obtaining N-value, a versatile property for design of structures. SPT shall be carried out every 1 meter (in JIS) or every 1.5 meters (in BS). Disturbed samples obtained in SPT shall be packed properly in air tight bags to be used for laboratory tests. SPT shall be executed until bedrock or bearing layers are confirmed with consecutive 4 or 6 N-values with more than predetermined thresholds, such as 30 or 50 blows.

The ground with N-values of not more than 4 blows shall be considered as soft grounds, which require special attention for trafficability as well as settlement and stabilization of embankment.

In case shallow landslides with a depth of slip surface is around 3 meters are targeted, SPT shall be supplemented by Dynamic Cone Penetrometer Tests (DCP). Survey lines of DCPs shall be planned to cover the entire areas of shallow landslide so that depths of bed rock can be understood in detail, which are basis for setting slip surface or design of countermeasures.

========== Technical notes



Portable Dynamic Cone Penetrometer Test N-value Profile

Figure 1-5 Portable Dynamic Cone Penetration Test (Left: Site Work, Right: Profile)

Left [6], Right [7]

(v) Drilling with Core Sampling

Even in preliminary investigation, for the locations where geological conditions affect alignment study and cost estimation, such as high and long cut section, landslide or section where stability of slope is questioned, bridge location, portal of tunnel, and soft ground section, drilling investigation shall be planned for at least one borehole at each of such locations. Basically, for rock part, drilling shall be done with core sampling (coring) whereas for soil part, SPT shall be executed. With core samples and disturbed samples from SPT, drilling logs shall be prepared through visual inspection of samples as well as groundwater conditions understood through the drilling. Laboratory tests may supplement description of visual inspection. Drilling logs shall have description of progress and apparatus used for drilling.

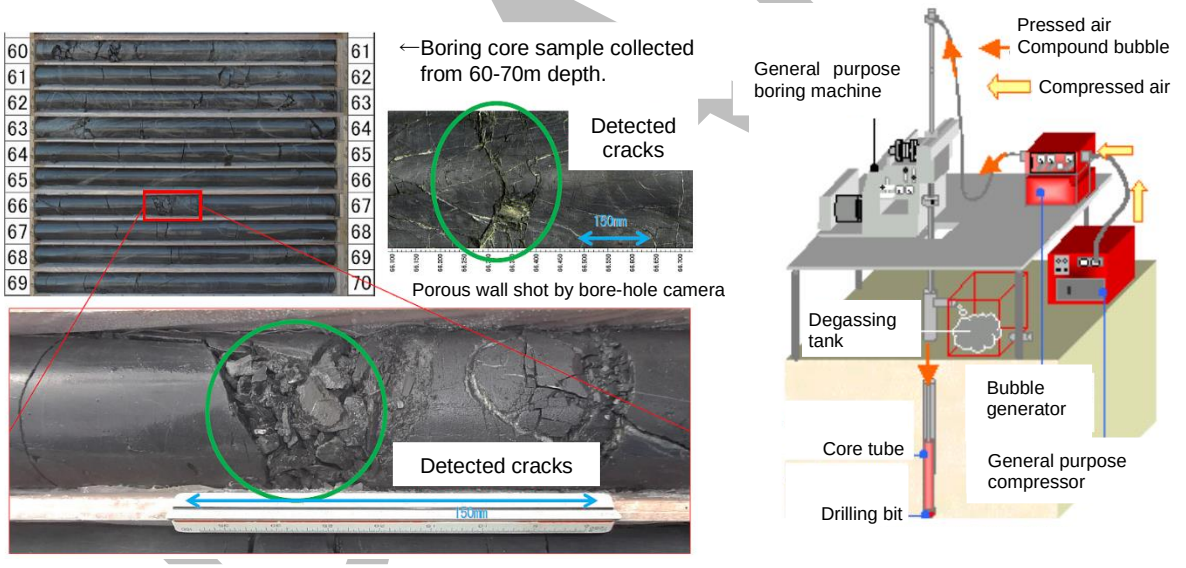
Basically, drilling shall be executed until a depth where bearing layers are confirmed for 5 meters or more. At the sections where cutting is planned, drilling shall reach a depth 2 meters deeper than the planned formation level. For the sections where a landslide is expected, drilling shall be done up to a depth whichever deeper among the followings:

- 5 meters deeper than a slip surface, if there are multiple slip surfaces, 5 meters deeper than the deepest
- 5 meters deeper than the planned formation level
- For structures, drilling shall confirm bearing layers up to a sufficient depth where engineers require.

In Japan, coring methods have been improved in recent years and high quality core samples are available, which exhibit actual conditions underground, including landslide clay and filling materials within cracks and fissures, both of which are fairly difficult to be sampled with conventional coring methods. and Figure 1-7 illustrate examples of high quality core sampling. With such coring methods, undisturbed samples of landslide clay can be obtained and, with such samples, depths and shearing properties of slip surfaces are understood with certain extent of accuracy.

In preliminary investigation stage, due to its scarce density of drilling investigations, high quality coring will provide valuable information for outline design and planning of investigations for detail design stage.

========== Technical notes

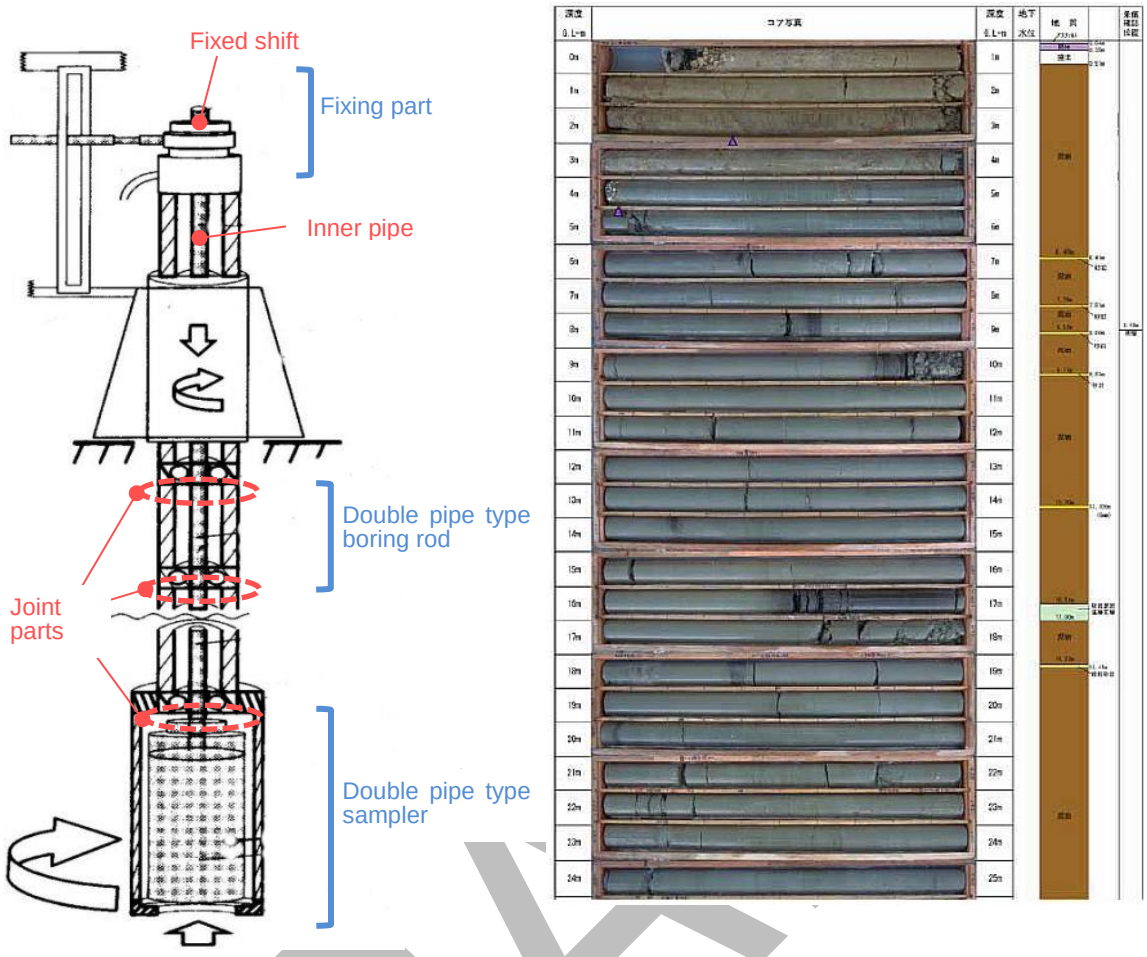


Core Samples Collected by High Quality Boring System

Basic Procedure of High Quality Boring System

Figure 1-6 Example of High Quality Bubble Boring

[8]



Double Pipe Type
Fixed Direction Sampling Method

Example of collected core samples

Figure 1-7 High Quality Sampling Method (Double Pipe Type Fixed Direction Method)

Source: JICA Project Team

(2) Detail Investigation (in Detailed Design Stage) for Cutting

Detail investigation shall be done for and prior to detail design. Detail investigation shall be so planned that underground conditions along the planed hill roads should be comprehensively understood, especially in the sections where problems in construction and operation are anticipated.

In this guideline, detail investigations for cutting slope and filling embankment are explained. In this section, investigations for cutting, which may be applied for quarry and borrow pits, are explained. In the following chapter, investigations for filling are explained.

Detailed investigation for cutting slope shall be done for the following purposes:

- To study stability of cutting slopes, including upper natural slope above artificial cutting slope
- To select adequate methods and equipment for cutting
- To assume conditions of road beds after cutting at subgrade level
- To understand properties of materials to be used in the construction, some of

which may be produced by cutting
- To forecast change of groundwater condition induced by cutting
- To grasp geological, geotechnical, hydrogeological conditions underground in the aim of understanding the above listed items

For the aforementioned purposes, investigations listed below shall be planned and executed:
- Geological field survey
- Geophysical exploration
- Sounding
- Drilling investigation
- Sampling
- Laboratory tests

(i) Geological Field survey

Geological field survey shall be carried out at the first step of detail investigation.

Through geological field survey, especially for long and high cut sections, possibility of slope failures or landslides triggered by construction should be well considered.

In case where micro topographic features suggesting landslides were detected through aerial photo readings or topographic interpretation in the preceding preliminary investigation, geological field survey shall be carefully done in the aim of improving the disaster scenario, including factor and trigger of landslide, activity, possibility of future activity, and estimation of extent of damage, if landslide is activated.

Even in case micro topographic features were not detected in the preliminary investigation, a disaster scenario shall be set up for primary landslides, when:
- Geological conditions are considered unfavorable against hill road construction
- Property and direction of geological strata suggest unfavorable conditions
- Weak part such as faults and sheared / fractured zones are confirmed

========== Technical notes

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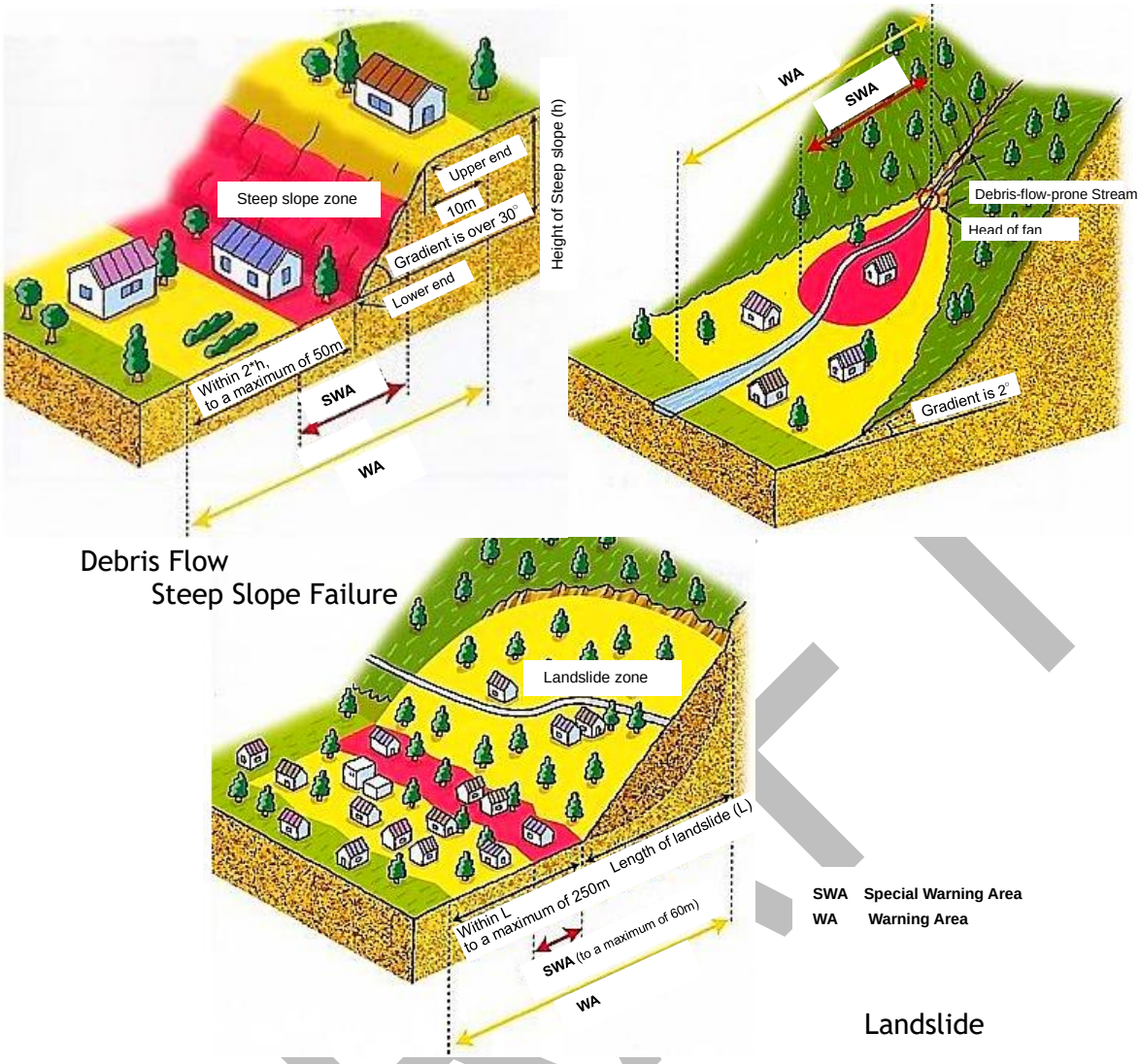


Figure 1-8 Delineation of Hazards (Steep slope, debris flow and landslide)

(ii) Seismic Exploration

Seismic exploration shall be done at the sections where high and long cuts are planned as well as necessity arises. Seismic exploration provides valuable information for selecting adequate methods and equipment for cutting and evaluating stability of slope.

Basically, explorations shall be conducted along a main survey line parallel to a center line of a planned road and a couple of sub survey lines crossing perpendicular to the main survey line.

In case information of shallower part is required, such as for shallow landslide or rock fall, portable methods with hammering can be done.

(iii) Sounding

Standard Penetration Test (SPT) is a basic sounding method for hill road construction. SPT shall be done along with drilling investigation where soil or highly weathered parts of rock are encountered in a drilling. N-value measured in SPT is basic information for stability analysis and detail design. Disturbed samples obtained through SPT shall be used for laboratory tests in order to obtain soil properties.

Among other sounding methods, Dynamic Cone Penetration Test (DCP) may supplement N-values of SPT. DCP shall be planned along survey lines of seismic exploration or between drilling points.

(iv) Drilling with Core Sampling

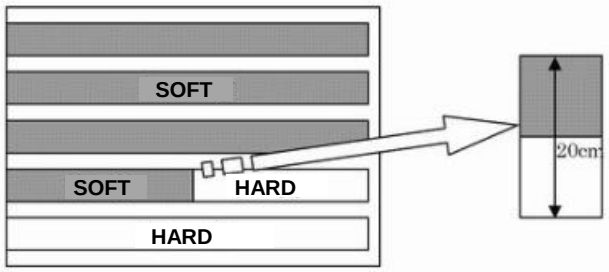
Drilling with core sampling shall be done on center lines of planned hill roads and in areas of cutting. At least one drilling shall be executed in an area of cutting basically on the center line. For the section of high and long cut, several drilling shall be planned and executed on the center line as well as areas of cutting.

Planned depths of drillings shall follow the requirements for the aforementioned preliminary investigation.

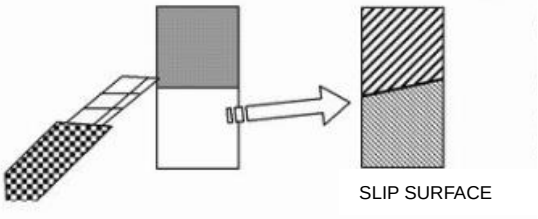
By utilizing boreholes of drilling investigations, monitoring well may be installed for obtaining variation of groundwater level, which is essential information for design of landslide countermeasures.

========== Technical notes

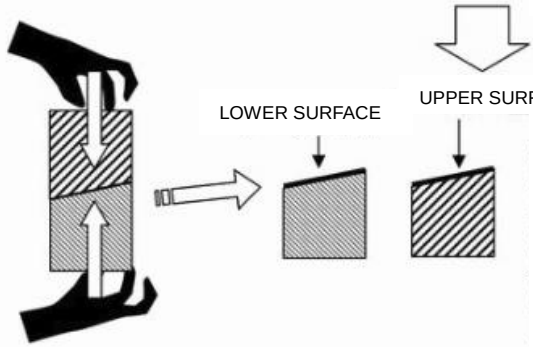
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Find clayey layers that may include a sliding surface. Cut 10cm above and below the clayey layers and make a short cylindrical shape.



Carefully remove mud-cake, which adhered to core surface during drilling, with a knife. Then, thin clayey layer and structure of base rock become clear. Sliding surface direction will be detected from dip and strike of the base rock.



When separating the sliding surface, as shown in the left figure, hold the upper and lower ends of the core with both hands and move horizontally the upper or lower core in the direction of sliding surface with a strength not causing buckle of the core

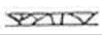
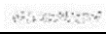
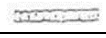


Slip surface of tuff

Figure 1-9 Identification of Slip Surface on Core Samples

[9]

Items to Describe by Visual Inspection of Core Samples1/2

<table>
<tr><td>Items</td><td>Classification criteria / Items to be discribed</td></tr>
<tr><td>①Material, Rock/ Soil Type</td><td>Ex. Andesite, mudstone, sandy soil, sand with gravel, cleyey sand, etc.</td></tr>
<tr><td>②Colour</td><td>Colors as well as shades should be recorded. (ex. Dark brown, pale green, etc.)</td></tr>
<tr><td>③Hardness</td><td>Hardness Classification criteria
<table>
<tr><td>Class</td><td>Definition☐</td></tr>
<tr><td>A</td><td>Sound. Extremely hard. Too hard to crack by hit with hammer.</td></tr>
<tr><td>B</td><td>Hard. Sound clearly and metallicly when hit with hammer</td></tr>
<tr><td>C</td><td>Moderately hard. Easily cracked when hit with hammer.</td></tr>
<tr><td>D</td><td>Soft. Broken in peaces when hit with hammer</td></tr>
<tr><td>E</td><td>Very soft. Decomposed to Sandy or clayey soil</td></tr>
</table></td></tr>
<tr><td>④Shape</td><td>Shape Classification criteria ☐
<table>
<tr><td>Class</td><td>Definition☐</td><td></td></tr>
<tr><td>1</td><td>  </td><td>Cylindrical core sample (more than 50cm)</td></tr>
<tr><td>2</td><td>  </td><td>Cylindrical core sample (between 15 and 50cm)</td></tr>
<tr><td>3</td><td>  </td><td>Cyylindrical core sample (between 5 and 15)</td></tr>
<tr><td>4</td><td></td><td>Cylindrical or flake core sample (less than 5cm) and outer peripheral surface of the core is barely recognized</td></tr>
<tr><td>5</td><td>  </td><td>Brecciated</td></tr>
<tr><td>6</td><td>  </td><td>Sandy</td></tr>
<tr><td>7</td><td>  </td><td>Clayish</td></tr>
<tr><td>8</td><td></td><td>No sample obtained or only slime or sludge or cut off obtained.</td></tr>
</table></td></tr>
<tr><td>⑤Type of crack</td><td>Crack Classification criteria ☐
<table>
<tr><td>Class</td><td>Definition☐</td></tr>
<tr><td>a</td><td>Tightly closed or, if separeted, surface of crack is not weathered or altered</td></tr>
<tr><td>b</td><td>Surface and peripheral of crack is weathered or altered. But body is not affected</td></tr>
<tr><td>c</td><td>Rock body along cracks is wearthered or altered and softened..</td></tr>
<tr><td>d</td><td>Not recognized as crack in sandy or brecciated cores..</td></tr>
</table></td></tr>
<tr><td>⑥Weathering</td><td>Weathering Classification criteria ☐
<table>
<tr><td>Class</td><td>Definition☐</td></tr>
<tr><td>a</td><td>Extremely fresh. No alternaton of minerals</td></tr>
<tr><td>b</td><td>Fresh. Feldspar is not altered. Reddish browning around colored minerals</td></tr>
<tr><td>c</td><td>Slightly weathered. Oxidation of colored minerals and partial whitening of feldspar.</td></tr>
<tr><td>d</td><td>Weathered. Colored minerals show golden color and its surrounding becomes brownich clay. Most of feldspar is altered.</td></tr>
<tr><td>e</td><td>Highly weathered. Most of minerals are altered excluding quartz and some type of feldspar. Texture of mother rock is not recognized.</td></tr>
</table></td></tr>
</table>

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Items to Describe by Visual Inspection of Core Samples 2/2

<table>
<tr><td>Items</td><td>Classification criteria / Items to be discribed</td></tr>
<tr><td>⑦Alteration</td><td>Alteration Classification criteria □
<table>
<tr><td>Class</td><td>Classification</td><td>State</td></tr>
<tr><td>1</td><td>No alteration</td><td>Altered minerals is not recongnized by visual observation.</td></tr>
<tr><td>2</td><td>Weak alteration</td><td>Texture of mother rock is visually observed and degree of alteration (decoloration) is low or yet altered part is dominant (more than 50%)</td></tr>
<tr><td>3</td><td>Middle alteration</td><td>Alteration is visually observed but texture of mother rock is clearly recognized and identified. Or yet altered part remains or reticulatedly altered.</td></tr>
<tr><td>4</td><td>Strong alteration</td><td>Altered minerals are dominant and texture of mother rock is not recognized.</td></tr>
</table></td></tr>
<tr><td>⑧Sampling rate (%)</td><td>Core recovery rate in certain consecutive section or 1 meter long section of drilling.</td></tr>
<tr><td>⑨Maximum Length (cm)</td><td>Maximum length of core sample within consecutive section of the same rock type</td></tr>
<tr><td>⑩RQD(%)
(Rock Quality Designation)</td><td>Sum of length of core samples longer than 10cm in a 1meter long section</td></tr>
<tr><td>⑪Evaluation</td><td>Classify rock quality depending on hardness, shape, crack condition, weathering, and alternation.</td></tr>
</table>

Figure 1-10 Criteria for Borehole Logging

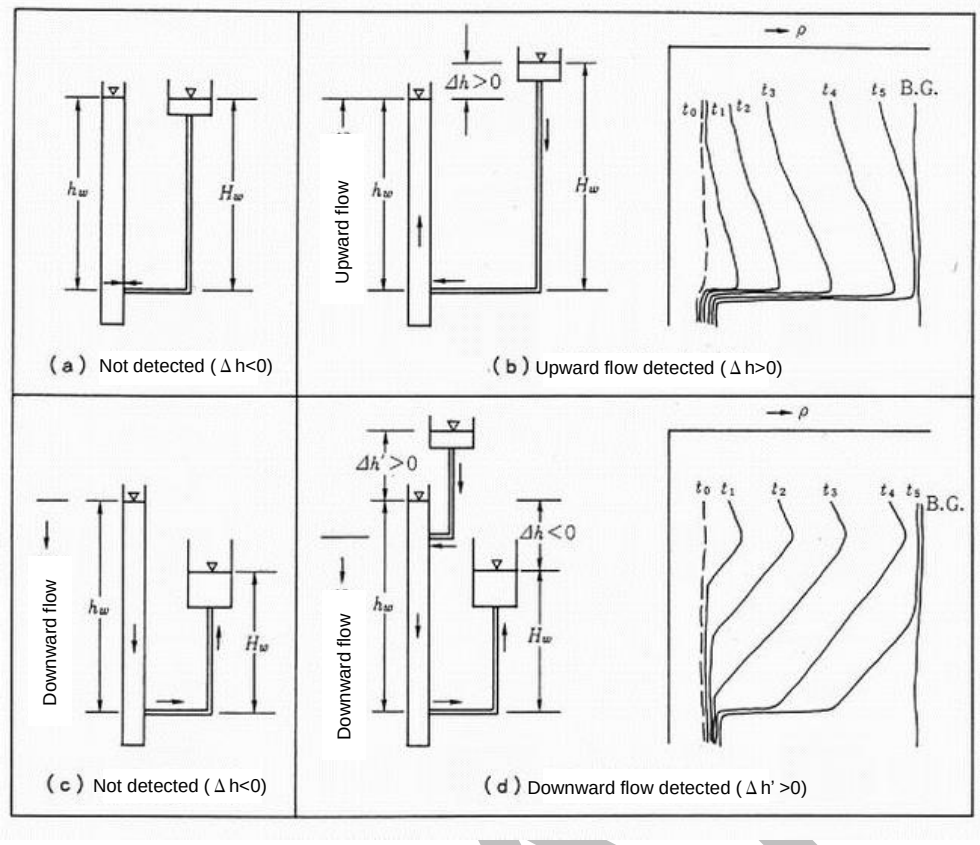
[9]

Ground water level in boreholes shall be measured every morning and evening, before and after the work. Variation of groundwater levels during drilling shall be organized with progress of drilling and depth of casing for each day during the work.

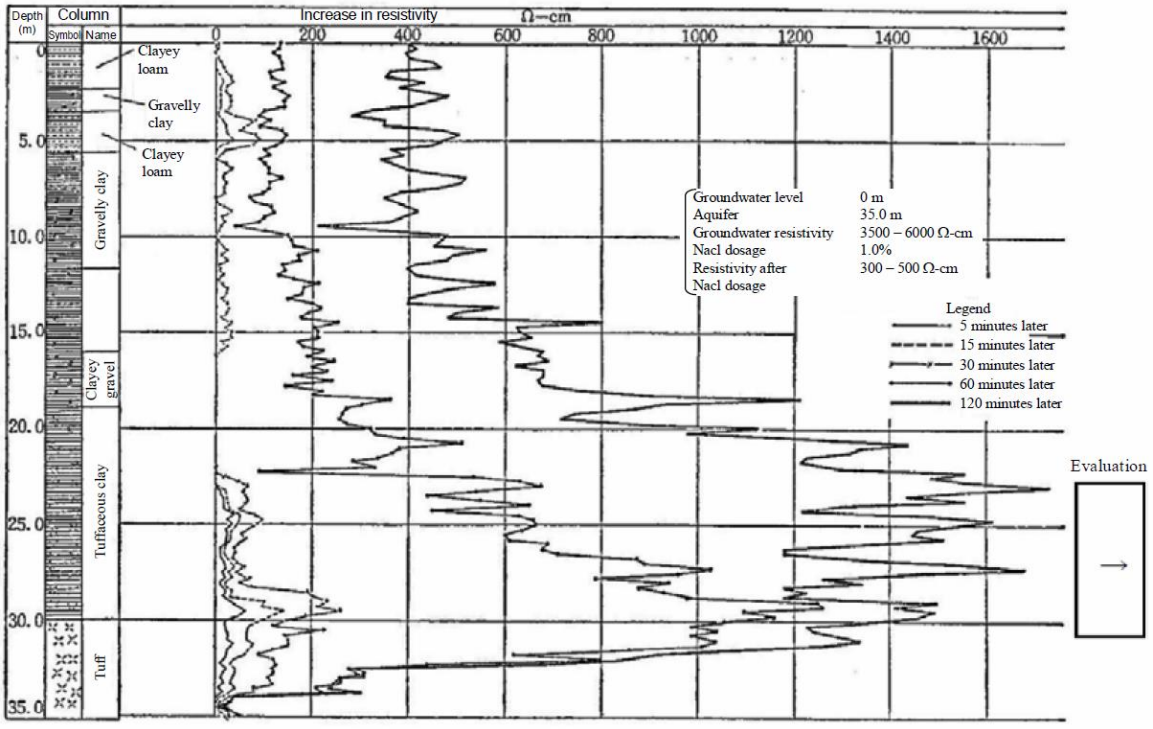
In case pressured groundwater is encountered during drilling, groundwater logging shall be executed to grasp pressure head of such groundwater.

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Basic Principle of Groundwater Logging



Result of Groundwater Logging

Figure 1-11 Example of Groundwater Logging

[10]

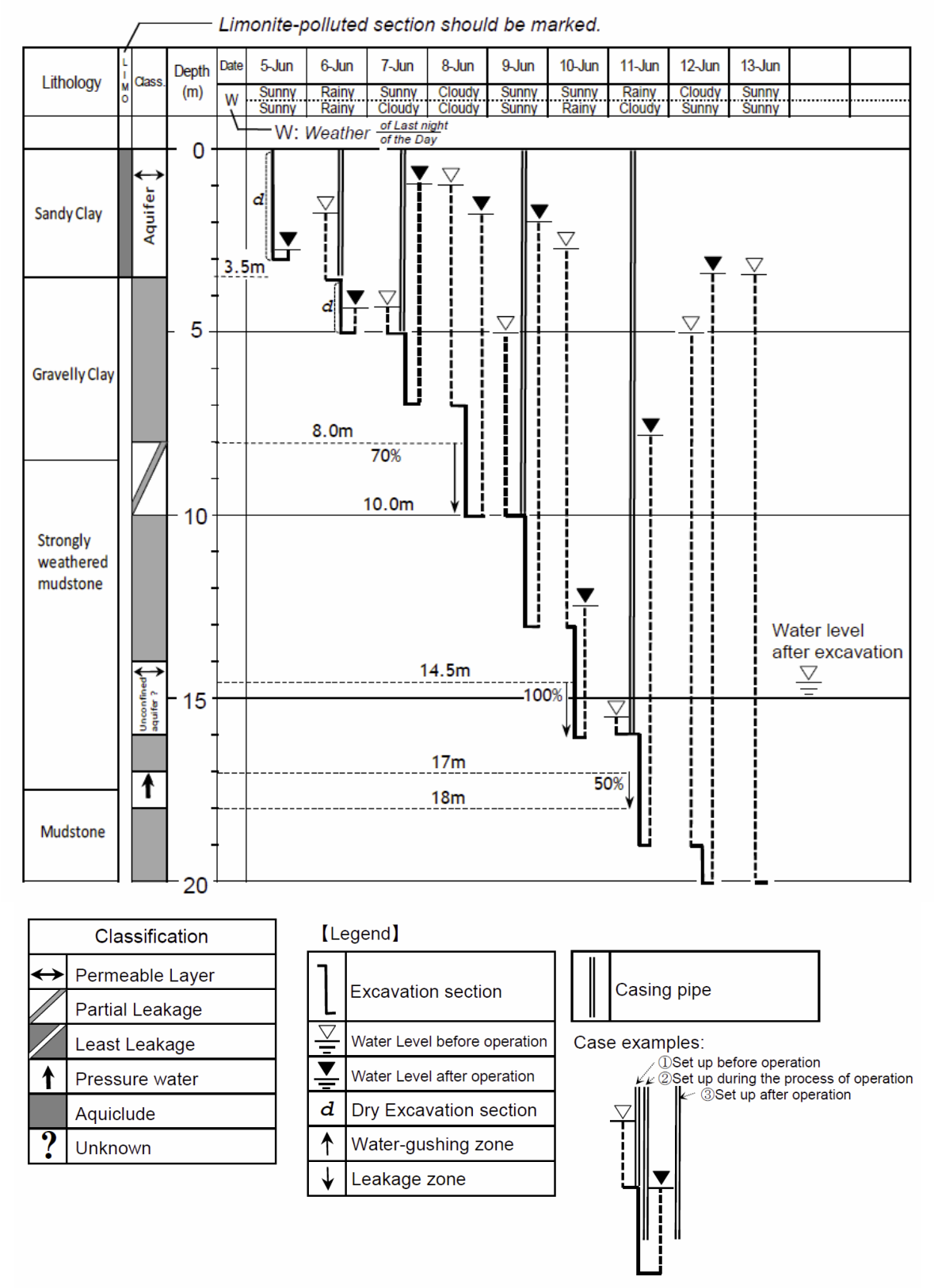


Figure 1-12 Example of Groundwater Variation Analysis Based on Daily Report

[11]

(v) Sampling

Disturbed samples are obtained to determine soil type and classification, particle size distribution, water content, density, consistency, contaminants, stratification, and other information through laboratory tests as well as visual observation. Disturbed samples may be obtained by hand excavating methods by picks and shovels, or by truck-mounted augers and other rotary drilling techniques. SPT also provides small amount of disturbed samples with split barrel sampler used in the test.

Undisturbed samples of soil may also be obtained by means of 100mm diameter sampling tubes with a sharp cutting edge on its end. Thin-walled tube sampler is representative sampling method for the soil in soft ground. Undisturbed samples are used to determine strength, compressibility (settlement), natural moisture content, unit weight, and permeability of soil. Discontinuities, fractures and fissures of rock are well understood with samples obtained through high quality coring explained in the previous section. Undisturbed samples obtained through high quality coring may be used for obtaining physical and mechanical properties of landslide clay, if available.

In the section where large cutting are planned as well as quarries and borrow pits, materials for filling shall be obtained from test pits for each representative stratum and laboratory material tests shall be done with such samples. Volume and weight of samples shall be measured under in-situ, after excavation, and after compaction in the aim of obtaining bulking factor of soil.

========== Technical notes

TYPES	L	C	1／C	L／C
Gravel soil	1.20	0.90	1.11	1.33
Sand and sandy soil	1.20	0.90	1.11	1.33
Cohesive soil	1.25	0.90	1.11	1.39
Soil with cobble stones, rock	1.20	1.00	1.00	1.20
Soft rock (I)	1.30	1.15	0.87	1.13
Soft rock (II)	1.50	1.20	0.83	1.25
Medium-hard rock	1.60	1.25	0.80	1.28
Hard rock	1.65	1.40	0.71	1.18

Bank volume is to be cut. Loose volume is to be hauled and compacted volume is to be filled.

L: Loose volume / Bank volume
C: Compacted volume / Bank volume
1/C is used for converting compacted value to bank volume.
L/C is used for converting compacted value to loose volume.

Figure 1-13 Indicative Bulking Factor of Soil in Japan

[12]

(vi) Laboratory Tests

Laboratory tests for material shall follow prevailing and effective guidelines and standards in India.

Laboratory tests for soil shall cover the following items:
(With disturbed samples)

- Classification
- Specific gravity of soil
- Particle size distribution analysis (hydrometer and sieve analysis)
- Moisture contents of soil
- Atterberg limits

(With undisturbed samples, if required and available)

- Direct shear strength
- Unconfined strength (UCS)
- Tri-axial strength
- Consolidation tests

Tests for strength and consolidation properties of soil shall be planned and executed where consolidation settlement of soft ground and stability of embankment are concerned.

Depending on the requirements, laboratory tests for rock shall be planned and executed. Laboratory tests which may provide valuable information for hill road design and construction are listed below:

- Classification
- Bulk density
- Water absorption, porosity and density
- Hardness (Mohs' scale)
- Point load strength
- Direct shear strength
- Unconfined strength (UCS)
- Tri-axial strength
- Laboratory determination of pulse velocities and ultrasonic elastic constants
- Slaking durability (if slaking is anticipated)
- Swelling property (if swelling is anticipated)
- X ray test for clayey minerals (if swelling is anticipated)

For landslides, in Japan, special laboratory tests are carried out with undisturbed samples of landslide clay obtained at slip surfaces. With the following tests, residual strengths of landslide clay are measured:

- Ring shear test
- Cyclic direct shear strength test

For gravity deformation, creep strength of rock shall be measured. Samples of creep zones shall be obtained and tested.

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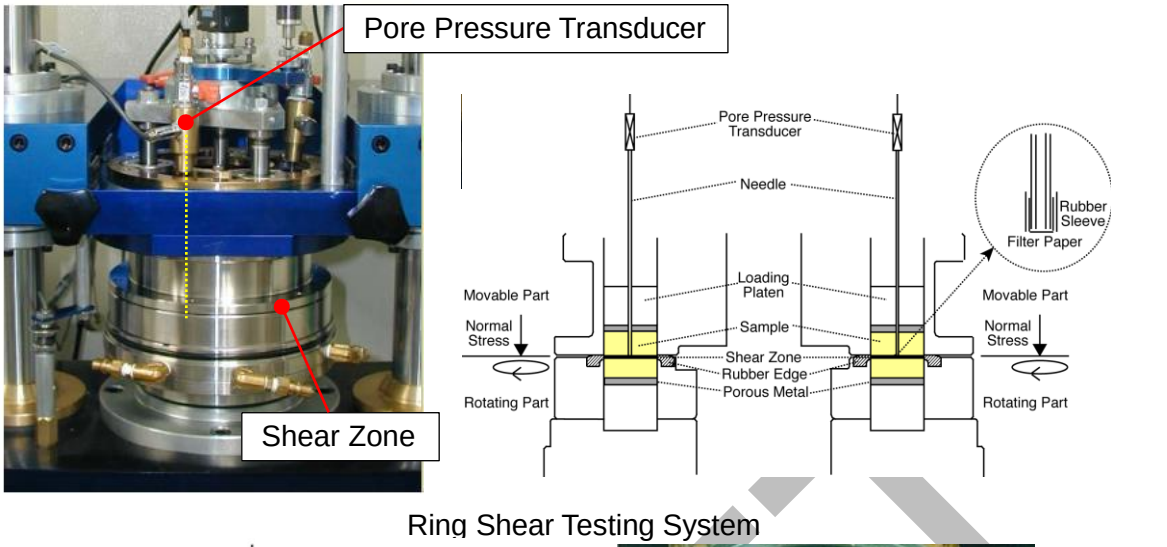
Table 1-2 Methods of Soil and Rock Test (Shear test)

The coverage of the survey	Purpose	Measurement item	Test method
Gravitational deformation	To determine angle of shear resistance for stability analysis	Creep strength	Simple shear test Test to measure creep strength of shear band. Shear box should be flexible.
	Determine cohesion for stability analysis	Uniaxial compressive strength	Uniaxial compression test Mechanical test measuring maximum of compressive strength. (ex. ASTM D2487).
Landslide	Determination of shear strength parameter for stability analysis	Residual shear strength	Improved direct shear test to give long shear displacement. Ring shear test This test apparatus gives rotational displacement to donut shaped specimen. Cyclic direct shear test This test apparatus gives reciprocating shear displacement.
Surface failure	Evaluating stability of unstable sediments in landslide area	Fully softened shear strength	Direct shear test Consolidated and drained conditions. Can be done on site. Tri-axial compression test Unconsolidated and undrained conditions. In general, the soil material which was sheared once turns into normal consolidation state and thus shall be tested with direct shear test in order to obtain fully softened shear strength. On the other hand, for the stability analysis under total stress condition, specimens shall be tested with tri-axial compression test, by which strict drainage control is available.
	Considering subsequent expanding in area of landslides	Peak shear strength	
Deep-seated landslide	Evaluating stability of unstable sediments in landslide area.	Fully softened shear strength	
	Considering subsequent expanding in area of landslides	Peak shear strength	

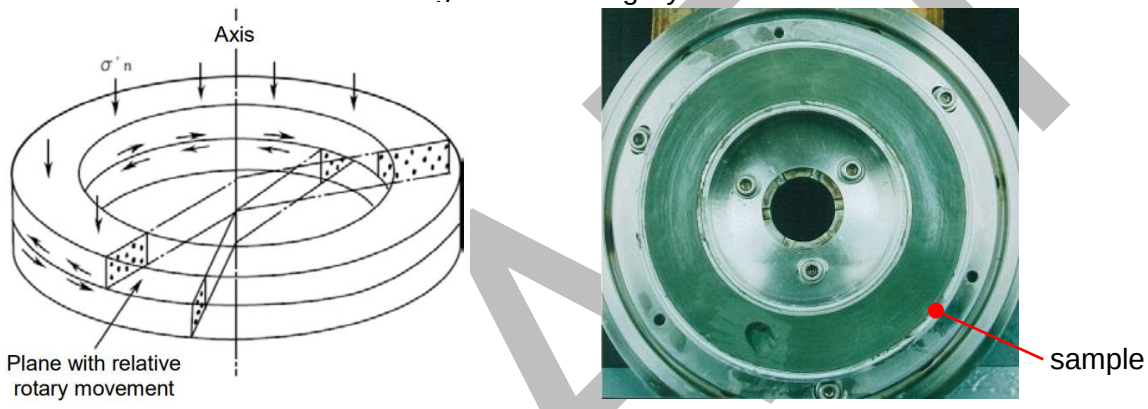
Source: JICA Project Team

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Ring Shear Testing System



Basic Principle of Ring Shear Test Donut Shaped Circular Shear Box

Figure 1-14 Ring Shear Test Apparatus to Measure Drained Residual Strength

Top [13], Bottom Left [14], Bottom Right [15]

(3) Detail Investigation (in Detailed Design Stage) for Filling

Investigation for foundation of embankment shall be planned and executed.

Filling embankment on valley and colluvial slopes may induce destabilization of slope and/or potential landslides. Investigation for filling shall, therefore, be done for not only study for foundation of embankment but possible destabilization of slope and landslides to be induced by the planned filling, and shall include slope stability analysis. Especially, for the slope where micro topographic features which suggests potential disasters, detailed investigation shall be carefully planned and executed so that embankment on slope shall be stabilized.

In addition, even along hill roads, soft ground may lie along the route, especially in flat terrain surrounded by mountains. In such terrain called “drowned valley”, soft ground composed of organic clay or silt may lie with certain thickness.

(i) Sounding

Standard Penetration Test (SPT) is a basic sounding method for study of embankment as well and shall be done along with drilling investigation where soil or highly weathered parts of rock are encountered in a drilling. N-value measured in SPT is

basic information for stability analysis and detail design. Disturbed samples obtained through SPT shall be used for laboratory tests in order to obtain soil properties.

Other than SPT, the following sounding method can be applied:

- Dutch cone penetration test
- Swedish weight sounding
- Dynamic cone penetration test

The above listed soundings shall be planned among drilling locations to supplement the results of drilling. Soundings shall be done up to the depths where adjacent SPT is done. In case simple stratification is expected based on the preliminary study or drilling can provide sufficient information, the above listed soundings can be omitted.

(ii) Boring

Drilling with core sampling shall be done on center lines of planned hill roads and in areas of filling, if considered necessary. At least one drilling shall be executed in an area of filling basically on the center line and additional drilling shall be appropriately planned inconsideration of the input data for slope stability analysis. For the section of high embankment, several drilling shall be planned and executed on the center line as well as areas of filling. For the long embankment sections, at least one drilling shall be done for each section with similar topographic and geological properties.

Planned depths of drillings shall follow the requirements for the aforementioned preliminary investigation. Basically, a drilling shall confirm bearing layers with thickness of not less than 5 meters.

For the clayey layers which may negatively affect embankment in terms of consolidation settlement and bearing capacity, soil properties shall be properly understood and for such purpose, undisturbed sampling shall be done. Since SPT is also executed every one meter with drilling, additional borehole for undisturbed sampling may be planned and drilled.

In case landslide clay interbedded in rock strata is required to be tested, sampling shall be done with high quality coring. The sample obtained in the high quality coring shall be properly packed in the aim of keeping moisture content of the samples.

In case fixed direction coring is employed, direction of core samples shall be clearly indicated on the side of core samples.

By utilizing boreholes of drilling investigations, monitoring well may be installed for obtaining variation of groundwater level, which is essential information for slope stability analysis and consolidation settlement calculation as well as design of embankment and soft soil treatment.

(iii) Laboratory Tests

For foundation of embankment, stability of slope, bearing capacity and consolidation settlement shall be calculated with results from laboratory tests.

With undisturbed samples obtained from test pits or drilling, direct shear test, unconfined compression strength test, tri-axial compression strength test, and consolidation tests shall be done.

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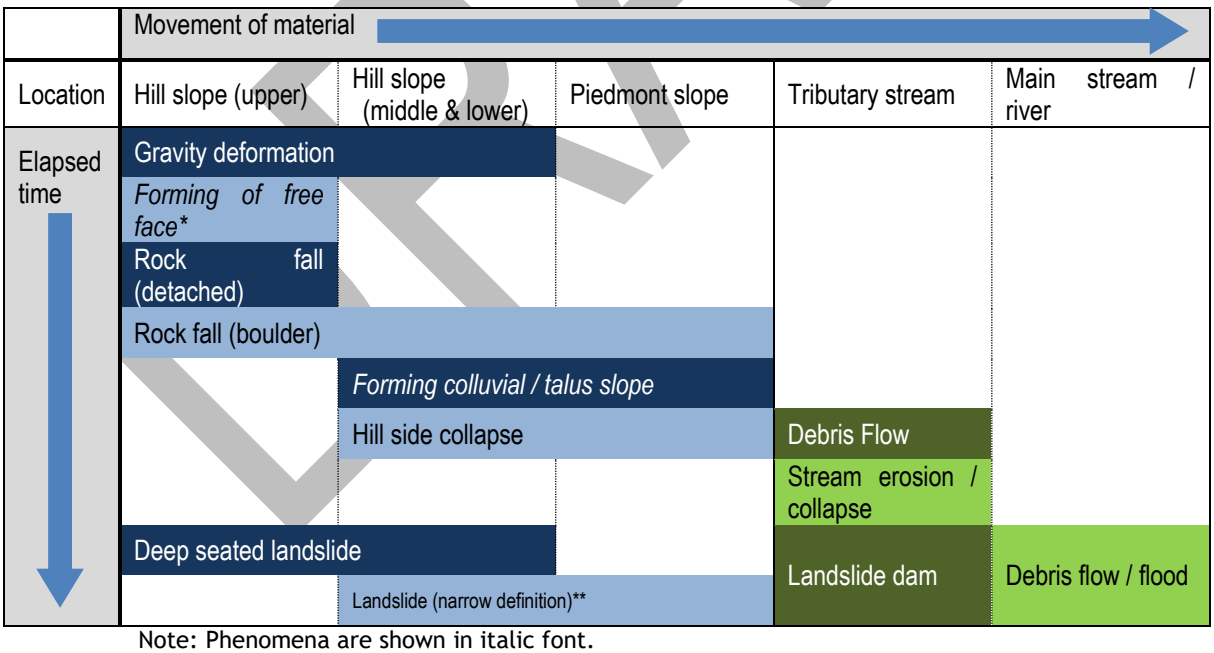
1.1.3 Topographic Conditions Relating to Hazards

In the hill road project, starting from investigation and design to construction and operation & maintenance, the most serious disaster which should be paid attention is landslide (in wide definition).

Landslide involves downward movement and accumulation of material as well as deformation and decomposition of base rock. In other word, landslides degrade and transform hill slope toward gentler form as well as transport material downward and create gentler slope with the transported material at piedmont slope. Those processes entail various types of landslide and river related disasters. Based on the location and elapsed time, landslides (wide definition) can be classified as shown in Figure 1-15.

It is important to understand that landslide and river related disasters in Figure 1-15 occur interrelatedly; a disaster is caused as a result of another disaster but may cause one another disaster. For example, when a collapse occurs at a hill slope which is located at toe of a gravity deformation, the gravity deformation may decrease its stability. Only by the collapse or with other triggers, such as a rise of groundwater level, the gravity deformation may lose its stability and transform to a deep seated landslide, which cause devastative destruction to wide area of hill slope. The debris derived from the deep seated landslide may flow into a tributary and cause extensive stream erosion and related collapse. Involving river floor sediments and the existing debris along the river cause as well as newly produced debris from stream collapse, the debris from the deep seated landslide then cause a devastating debris flow and attack villages downward.

When a disaster is assumed along a planned hill road, therefore, establishing a disaster scenario, which estimates interrelation of relating landslides, is important for hill road project.



Note: Phenomena are shown in italic font.
*: Free face means protruding hill slope which are affected freely by gravity.
**: Landslide (narrow definition) is explained in Table 1-3.

Figure 1-15 Degradation of Hill Slope and Types of Landslides Related to Degradation

Source: JICA Project Team

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(1) Definition of Landslide Disaster

Landslide disasters which should be paid attention in hill road projects are listed in Table 1-3 along with its definition.

Table 1-3 Classification and Definition of Landslide Disaster

Landslide Disaster	Material	Factor / Trigger	Definition	Location / Features
Gravity deformation	Bedrock	Factor: gravity and weight of rock protruding from steep hill slopes	Long-term deformation of bedrock by the action of gravity	At slopes of a gradient of not less than 40 degrees. Often entailed with small collapse.
Landslide (narrow definition)	Fresh / weathered rock, colluvium, debris, sediments.	Factor: Formation of slip surface, which often consists of landslide clay. Sometimes fractured zone is involved. Trigger: increase of pore water pressure (often called "rise of ground water")	Recurrent and downward movement of material on slope. Landslide mass (moving material) moves on slip surfaces. Slip surfaces show circular or planer shape or composite of them.	Often occurs at gentler slope of a gradient of not more than 30 degrees. Between 3 and 20 degrees in Neogene sedimentary rock.
Rock Fall (Detached)	Detached rock	Factor: unstable part of outcrop formed by gravity deformation, weathering, decomposition, and other degradation. Triger: rainfall, freezing and thawing, earthquake, and shakes by other reasons.	Detached with cracks, fissures, joints, and other discontinuities, and by unloading, relaxation, deformation, and other phenomena including human activity.	At cliffs or escarpments formed by gravity deformation, landslide, collapse, and faults, as well as human activity, such as road construction and land formation.
Rock Fall (Boulder)	Boulder, including fallen detached rock	Factor: boulders on steep slopes Trigger: rainfall, freezing and thawing, and erosion of the surrounding ground	Boulders and fallen detached rocks on steep slope fallen down by the triggers on the left column.	At lower slope of cliff where rock fall (detached) occurs. At heavily eroded colluvial / talus / terrace slope
Slope failure / Collapse	Any material on slope.	Factor: weak or heavily cracked material on slope Trigger: increase of pore water pressure, erosion, and earthquake	Materials on slope slide down or collapse with a thickness of a several meters. Often entails slip surface.	Often occurs at slopes in catchment area. Also occurs at artificial slopes.
Deep seated landslide	Bed rock along with overlying strata	Factor: gravity deformation of bed rock Trigger: increase of pore water pressure and collapse at toe.	Massive downward movement involving bedrock and overlying strata	At entire or a part of slopes deformed by gravity deformation
Debris flow	Debris and water from rainfall and stream	Factor: Landslide prone slopes along streams Trigger: heavy rain fall and landslides at hill slope	Debris and water together flow downward along stream or river with high speed.	Source: landslides at hill slopes Often accumulated on flat terrain forming fan shape after passing the mouth of valley.

Source: JICA Project Team

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(2) Topographic Features of Landslides

Along with geological conditions, topography has a very close relationship with occurrence and distributions of landslides.

Basically steeper slope is more unstable. But the story is not so simple. The gradient of slope which makes slope unstable varies depending on various parameters, such as shape of slope, direction and properties of geological strata, relative density / stiffness of soil, hardness of rock, direction and density as well as location and

properties of weak layers or discontinuities, and strength properties of materials, which ranges drastically in relation with weathering and decomposition conditions as well as water contents and earth pressure.

On the other hand, there are certain topographic features relating to specific types of landslides because a landslide leaves particular traces on terrain depending on its type and movement. Understanding such topographic features will help engineers locate hazardous areas of landslides. Especially when cutting slope is planned along the alignment, such features imply potential landslides which may negatively affect the cutting and thus require careful treatment in design. Table 1-4 summarizes such topographic features.

Gradient of natural slope also suggests types of landslides. Gravity deformation and landslide in rock slope may show similar topographic features. There are, however, significant differences in gradient of slope. Gravity deformation is formed by creep deformation of rock material which occurs in relaxed zones of base rock. The internal friction angle of creep deformation usually exceeds 45 degrees even in case of jointed rock mass. On the other hand, landslide clay never shows internal friction angle of more than 45 degrees. Such property of landslide clay affects gradient of slip surface as well as natural slope formed by such landslides. The average gradient of natural slope with landslide in rock slope shows 30 degrees or less, whereas the average gradient of slope of gravity deformation exceeds 45 degrees.

Table 1-4 Topographic Features of Landslide Disasters

Landslide	Locations	Topographic features
Gravity deformation	Extends throughout hill slope from ridge (shoulder) to piedmont (toe). Usually developed in the hilly areas where geological strata of Paleozoic and Mesozoic Erathem or Paleogene System appear. Often confirmed in the hills of hard rock which is partially fractured or layered or densely cracked/jointed up to deeper zones	Linear depression (multiple ridges) developed parallel with ridge line Pediments (gentler terrain on hill slope) Up-hill facing scarplets (small cliffs) Sagging (landform formed by bedrock creep, with toppling on the head and steep slopes with buckling at the toe) Small collapse in and around deformation Steep slopes with a gradient of 40 degrees or more
Landslide (narrow definition)	Occurs in dip slope structure, colluvial slope, and terrace formed slope. Also occurs in the areas of Neogene System and metamorphic zone of low temperature-high pressure type which yields crystalline schist. In Neogene System, swelling clay, such as smectite or montmorillonite, is often found in slip surface	Horseshoe-shaped head scarp Gentle slope with rugged and disturbed surface, which is composed of moving landslide mass (landslide block). Clear contrast between head scarp (small cliff) and gentle surface Subsidence at the head (upper slope) Uplifts at the foot or toe (lower slope) with flank walls Landforms produced by compression at foot and toe. Gentle slope with a gradient of not more than 30 degrees
Rock Fall (Detached)	Occurs at free face of the upper slopes of gravity deformation	Steep slopes and cliffs developed parallel with ridge line
	At existing landslides At trace of collapse	Head scarps and steep slopes of flanks Steep slopes at traces of collapse
	At terrace scarp	Eroded scarp of river terrace
Rock Fall (Boulder)	At lower slope under cliffs and scarps where rock fall (detached) occurs.	Fan-shaped slope at the foot of cliffs and scarps
Slope failure / Collapse	Occurs at steep rock slopes often with plunging structure. At unstable soil block in existing landslides and its boundaries At artificial cut/fill slope At steep slopes at catchment areas At shoulder of slope (vulnerable when an earthquake occurs)	Horseshoe-shaped steep slope around zero-order stream or knick line Often left unclear traces due to shallow depth of slip surface

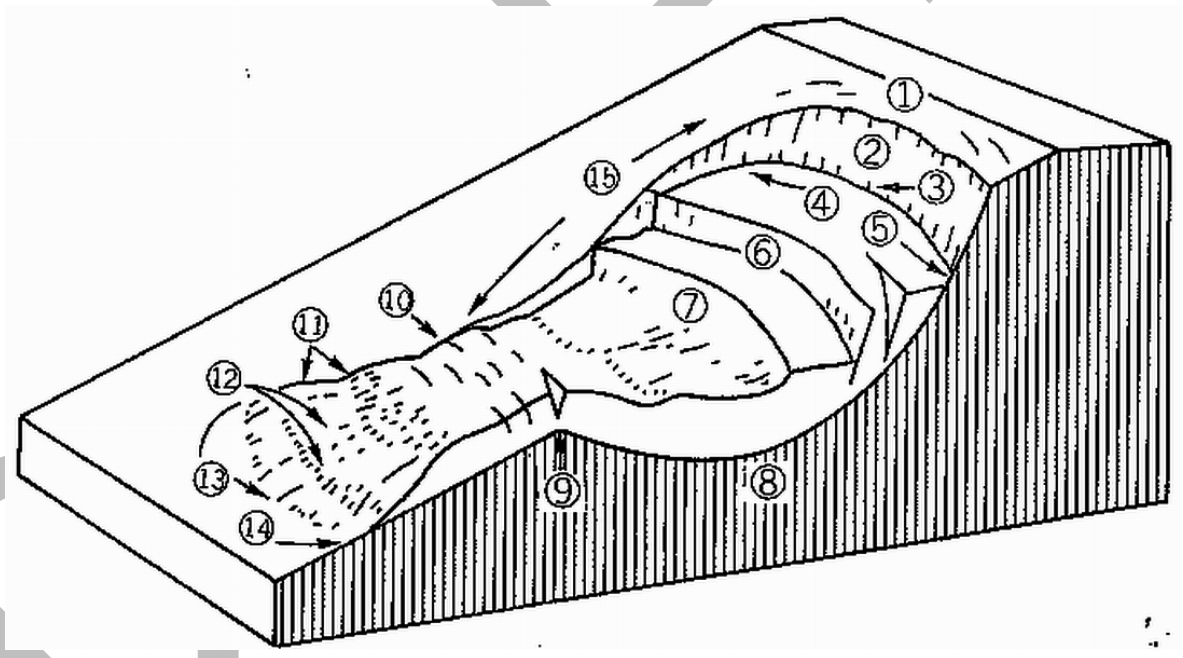
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Landslide	Locations	Topographic features
Deep seated landslide	Occurs at a part of or entire slope of gravity deformation In case triggered by heavy rains, occurs at slopes hydro-geologically connected with upper catchment areas with fissures and cracks which convey groundwater to the slope and increase its pressure.	Planner shaped steep slope or cliff (slip surface of deep seated landslide) Landslide dam (or trace of it) at the toe of steep slope. Large scale head scarp
Debris flow	Occurs at rivers and streams which have hazards of landslide, deep seated landslide, and hill slope collapse along its main course as well as its tributary. At river and stream, the gradient of river bed exceeds 20 degrees.	Fan shaped terrain at valley mouth. Debris flows occur recurrently. Thus along the river bed, strata of old debris flows are formed. Generally transportation by a debris flow starts turning to accumulation at a gradient of river bed of less than 8 degrees. At less than 3 degrees, debris flow dissociates into water and debris and ceases.

Source: JICA Project Team

(3) Technical Terms for Landslide

Figure 1-16 shows typical topographic features of landslide, with the commonly accepted terminology, based on the original source by D .J. Varnes



① Crown
② Main Scarp / Head Scarp
③ Top : The highest point of contact between the displaced material and the main scarp.
④ Head : The upper parts of the landslide in contact with the main/head scarp
⑤ Transverse Crack (Tension Crack/Open Crack)
⑥ Minor Scarp : Landslide Area is divided into two blocks (upper and lower) by minor scarp.
⑦ Longitudinal Fault Zone : Landslide blocks can be subdivided by this fault zones
⑧ Surface of Rupture / Slip Surface: Slip surface is commonly used
⑨ Foot : The line where the surface of rupture and the original ground surface intersect and might be buried

⑩ Transverse cracks (Compression Crack)
⑪ Transverse Ridge (bump)
⑫ Radial Cracks (extrusion)
⑬ Tip：The pointed end of the toe
⑭ Toe
⑮ Right Flank: Opposite side is Left Flank, seen from the upper side of landslide)

Figure 1-16 Technical Terms for Landslide

[16]

(4) Gravity Deformation and Relating Micro-topographic Landform

Detecting landforms specific to gravity deformation helps engineers locate hazardous areas of deep seated landslides as well as sinking zone of hill roads. The landform specific to gravity deformation is indicated by particular types of micro-topographic landform on the hill. The micro-topographic landform relating to gravity deformation is explained in Figure 1-17 and Figure 1-18.

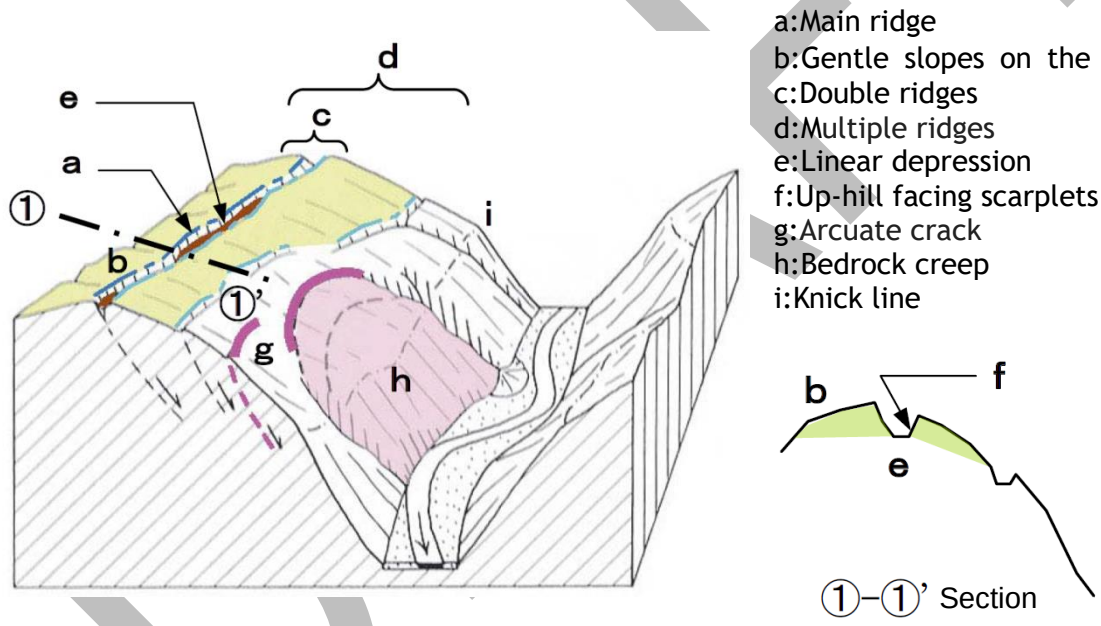


Figure 1-17 Microtopographic Landform Related to Gravity Deformation

[17]

(i) Gentle slope on the ridge

Close to ridges, gentle slopes of almost flat terrain are often recognized. These slopes are called “gentle slope on the ridge” or simply “peneplain”. Peneplain is flattened by long-lasted erosion. Uplifted peneplain is formed by following uplift (usually by orogeny) and dissection by rivers, and remains along ridges.

(ii) Double ridge, linear depression, up-hill facing scarplets

Scarplets (small scarps) aligned parallel to main ridge are often observed. Along with main ridge, this micro-topographic landform is called “double ridge”. In the case multiple alignments of scarples are found, they are called “multiple ridges” (Figure 1-17 c, d). Narrow concaves between double (multiple) ridges are called “linear

depression" (Figure 1-17 e). "up-hill facing scarplets" are aligned at the opposite side of main ridge (Figure 1-17 f). These micro-topographic features are formed as a result of the "bedrock creep" or gravitational deformation.

(iii) Arcuate crack

Arcuate cracks show groove shapes and run parallel with contour lines (Figure 1-17 g). Arcuate cracks are observed at the shoulder of the slopes where bedrock creep or large scale landslide is progressing and regarded as a precursor of such movements of land mass.

(iv) Bedrock creep

Bedrock creep itself shows slight corrugation on the surface, which does not harmonize with the surrounding hill slopes. Such corrugation is, however, not so clearly recognized in aerial photo reading with stereoscopy, compared with topographic features of landslides explained in Figure 1-16. Bedrock creep may be detected by finding particular micro-topographic landform often seen adjacent to bedrock creep, such as double (multiple) ridges and up-hill facing scarplets, which are recognized through aerial photo reading (Figure 1-18 and Figure 1-17 h).

At the slope of bedrock creep, distinct slip surface is not formed between creeping and stable parts and downward deforming proceeds more slowly compared with other landslides. Thus bedrock creep does not show distinctive landform on its surface.

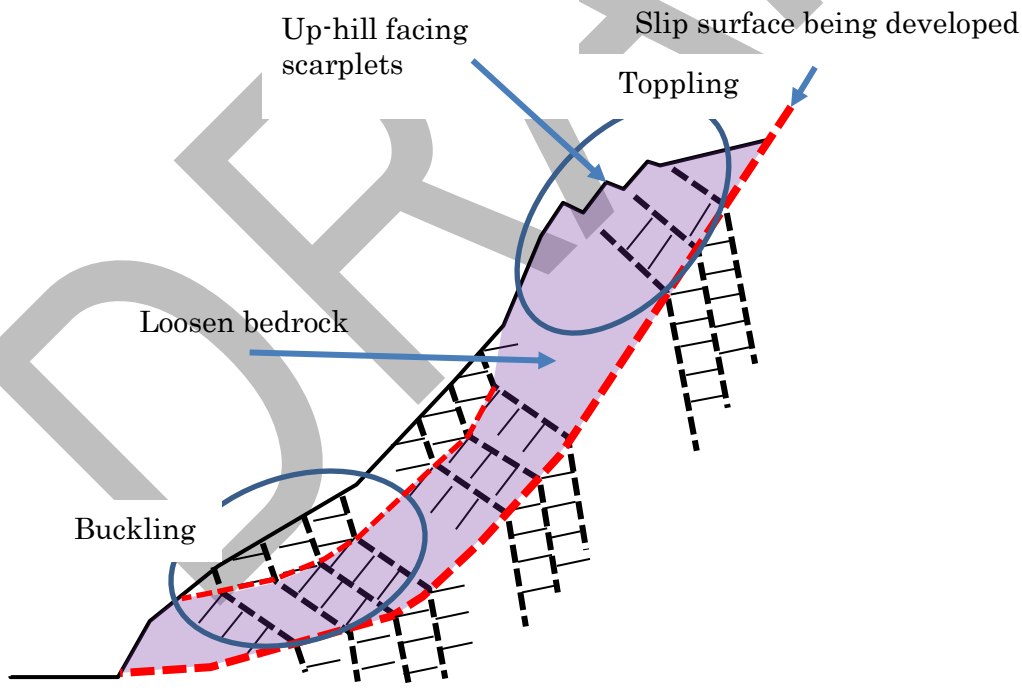


Figure 1-18 Gravity Deformation and Bedrock Creep

Source: JICA Project Team

1.1.4 Geological Conditions Relating to Hazards

Similar to topographic conditions, geological conditions substantially govern design, construction, and operation & maintenance of hill roads. Understanding of

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geological conditions along planed / existing hill roads, therefore, has significant meaning for road administrators.

(1) Geological Conditions and Its Impacts on Hill Road

The geological conditions supposed to appear along hill roads in India are summarized in Table 1-5, Table 1-6, and Table 1-7, along with its impacts and supposed countermeasures / mitigation methods.

Table 1-5 Geological Conditions and Its Impacts (Soil)

Geological Condition	Impacts	Countermeasures / Mitigation
Overburden	(Cut slope) (Especially in sandy matrix) Erosion then collapse	Stable gradient of slope Drainage system Vegetation for anti-erosion Rounding on shoulder Prevention measures (anchors / nailing)
	Rock fall of boulders	Rock fall net / barrier Removing at source of rack fall
	Spring erosion then collapse	Treatment of spring (connection to drainage)
	(Fill slope) (Depends on condition) Insufficient bearing capacity / (Rare) Settlement	Soil improvement Light weight material for filling
Debris / Talus Deposit / Colluvium / River deposit (sandy & gravelly)	(Cut slope) Collapse (Especially in sandy matrix) Erosion then collapse Landslide	Stable gradient of slope Drainage system Vegetation for anti-erosion Rounding on shoulder Horizontal drainage boring Prevention measures (anchors / nailing / piles)
	Rock fall of boulders	Rock fall net / barrier Removing at source of rack fall
	Spring erosion then collapse	Treatment of spring (connection to drainage) Horizontal drainage boring
	(Fill slope) (Depending on condition) Insufficient bearing capacity / (Rare) Settlement	Soil improvement Light weight material for filling
Marsh / Lake / Wetland Deposit / Terrace Deposit / River deposit (clayey)	(Cut slope, not recommended) Collapse Erosion then collapse Landslide	Stable gradient of slope Drainage system Vegetation for anti-erosion Horizontal drainage boring Prevention measures (anchors / nailing / piles)
	(Rare) Rock fall of boulders	Rock fall net / barrier Removing at source of rack fall
	Spring erosion then collapse	Treatment of spring (connection to drainage)
	(Fill slope) Insufficient bearing capacity / Settlement	Soil improvement Light weight material for filling

Source: JICA Project Team

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Table 1-6 Geological Conditions and Its Impacts (Rock)

Geological Condition	Impacts	Countermeasures / Mitigation
Hard Rock (densely jointed)	(Cut slope) Collapse in relaxed zone (plunging slope) Wedge failure	Stable gradient of slope (related to direction of joints) Prevention measures (anchors / nailing + concrete crib work) Drainage system Rounding on shoulder Horizontal drainage boring
	Rock fall of unstable part	Rock fall net / barrier Removing at source of rack fall
Hard Rock (dip slope condition, with bedding, joints, and foliation)	(Cut slope) Collapse in relaxed zone Rock slide	Stable gradient of slope (related to direction of joints, bedding, and foliation) Prevention measures (anchors / nailing + concrete crib work) Drainage system Rounding on shoulder Horizontal drainage boring
Hard Rock (with vertical joints / bedding / foliation)	(Cut slope) Toppling failure Gravity deformation	Prevention measures (anchors / nailing) Unloading of weight from the upper part of deformation.
	Rock fall of unstable part	Rock fall net / barrier Removing at source of rack fall
Hard Rock (massive)	(Cut slope) (with discontinuities) Collapse in relaxed zone (plunging slope) Wedge failure Toppling failure Gravity deformation	Prevention measures (anchors / nailing) Unloading of weight from the upper part of deformation. Drainage system Rounding on shoulder Horizontal drainage boring
	Rock fall of unstable part	Rock fall net / barrier Removing at source of rack fall
Soft Rock (Tertiary sedimentary rock, Volcanic soft rock)	(Cut slope) (Due to weak resistance against weathering or erosion,) Collapse in relaxed zone Landslide	Stable gradient of slope Prevention measures (anchors / nailing + concrete crib work) Shotcrete for anti-erosion Vegetation for anti-erosion Drainage system Rounding on shoulder Horizontal drainage boring
Weathered Rock (various conditions)	(Cut slope) Similar hazards to the fresh rocks *Depending on weathering status, strength of rock deteriorates. Thus landslides occur more often than in fresh rocks.*	Stable gradient of slope Prevention measures (anchors / nailing + concrete crib work) Shotcrete for anti-erosion Vegetation for anti-erosion Drainage system Rounding on shoulder Horizontal drainage boring

Source: JICA Project Team

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Table 1-7 Geological Conditions and Its Impacts (Unfavorable Condition)

Geological Condition	Impacts	Countermeasures / Mitigation
Faults / fractured zones / sheared zones	(Cut slope) (Due to weak strength of fractured / sheared zone) (sometimes due to groundwater pressure sealed by clayey fractured zone) Landslide Collapse	Stable gradient of slope Prevention measures (anchors / nailing + concrete crib work) Horizontal drainage boring Unloading of head of landslide Buttress fill (counterweight embankment at toe) Drainage system Horizontal drainage boring
	Rock fall of unstable part detached by fractured zones	Rock fall net / barrier Removing at source of rack fall
Rock with time-dependent deterioration	(Cut slope) (Due to swelling of rock caused by unloading) Landslide Collapse	Stable gradient of slope Avoiding cutting slope (cancel unloading) (In case swelling is not so severe) shotcrete right after cutting. (In case swelling layer is thin) removal of swelling layers Lime stabilization. Prevention measures (anchors / nailing + shotcrete + concrete crib work) Horizontal drainage boring Unloading of head of landslide Buttress fill (counterweight embankment at toe) Drainage system
	(Cut slope) (Due to slaking of rock caused by unloading and cycle of dry and wet conditions) Collapse	Stable gradient of slope Shotcrete right after cutting. Vegetation Prevention measures (anchors / nailing + shotcrete + concrete crib work) Horizontal drainage boring Drainage system

Source: JICA Project Team

As explained in the above tables, along with topographic and groundwater conditions, geological conditions along hill roads govern stability of slopes of the hill roads. Understanding geological conditions, therefore, has significant meaning in securing stability of slopes. By providing appropriate design of slopes, including setting adequate gradient of slopes as well as slope countermeasures, instability of slopes along hill roads are minimized and safe and constant service of hill roads are achieved.

(2) Geological Conditions Understood from Topographic Map and Aerial Photos

Geological conditions are controlling factors of topographic situation, such as:

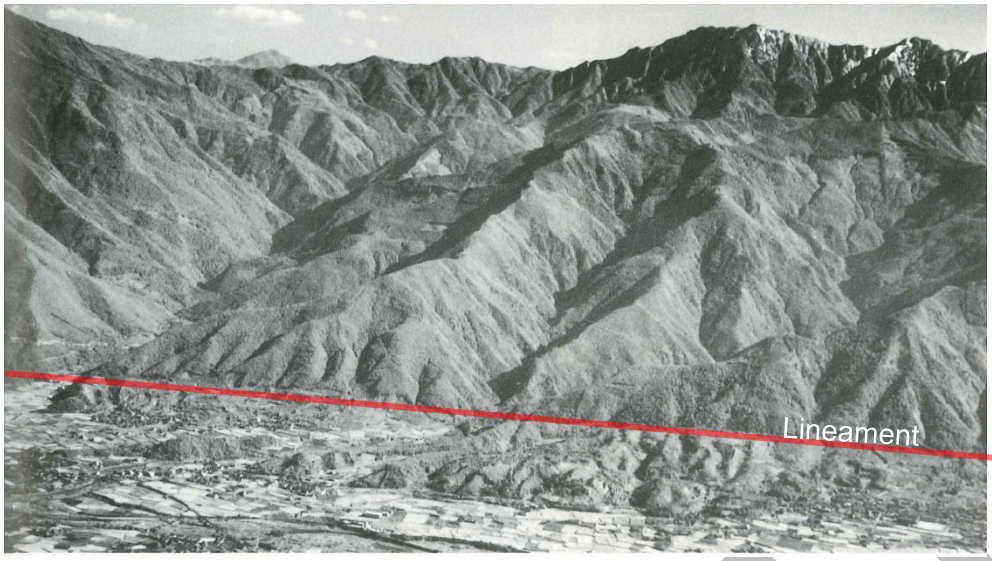
- Hard rocks constitute steep slope whereas soft rocks form gentle slope,
- Difference in permeability of material differentiates landform and riverine system,
- Faults form lineament; linear shaped landform read on aerial photos and topo maps,
- Landslide movement forms particular shape of landform specific to landslide,
- Terrace deposits form terrace landform along rivers,

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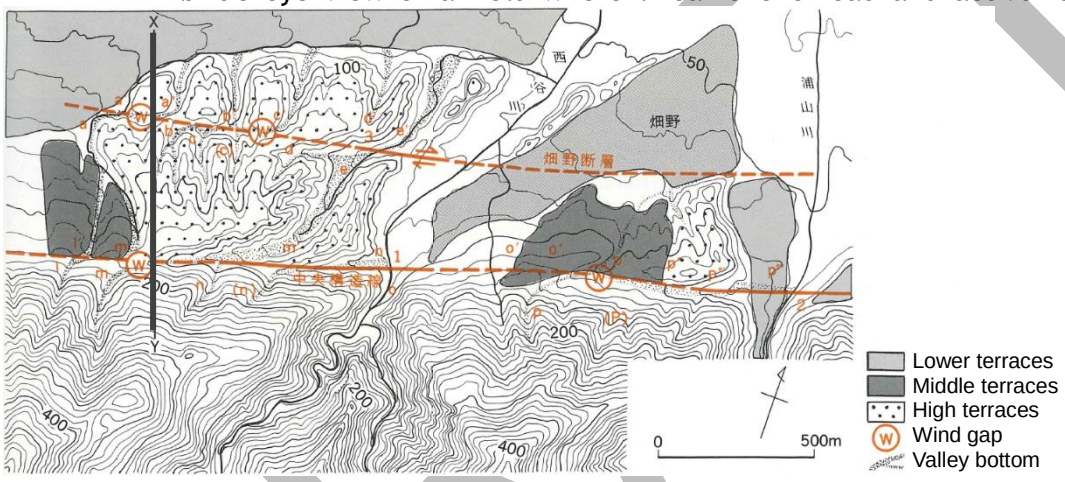
- Debris, colluvium, and talus form particular shape of slope for each geological condition,
- Gravity deformation and deep seated landslides constitute particular shape of slope, and
- Geological structures constitute landforms with its distinctive formation, for example, dip slope structure forms cuesta landform.

Reading aerial photographs as well as topographic maps provide valuable information for preliminary geological survey. Examples are explained in the figures below:

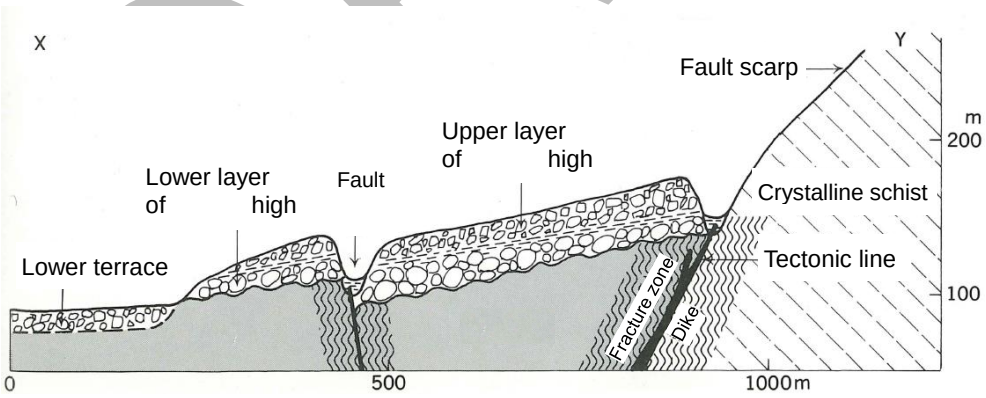
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A bird's eye view of a field where lineament is read and active faults are



Geomorphological map of the fields



Geological cross-sections (X-Y)

Figure 1-19 Lineament Implying Faults and Fractured Zones

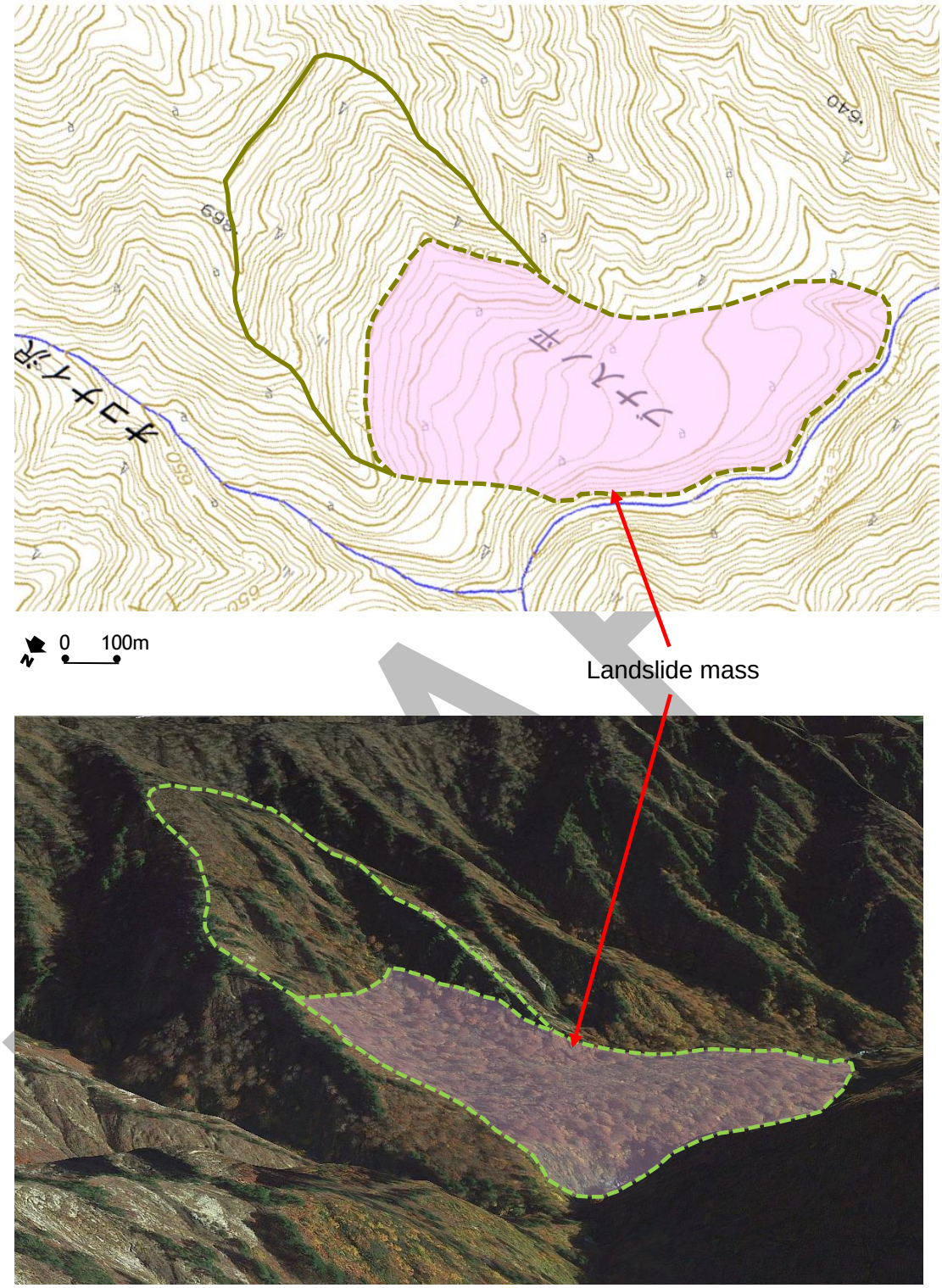


Figure 1-20 Landform Specific to Landslide

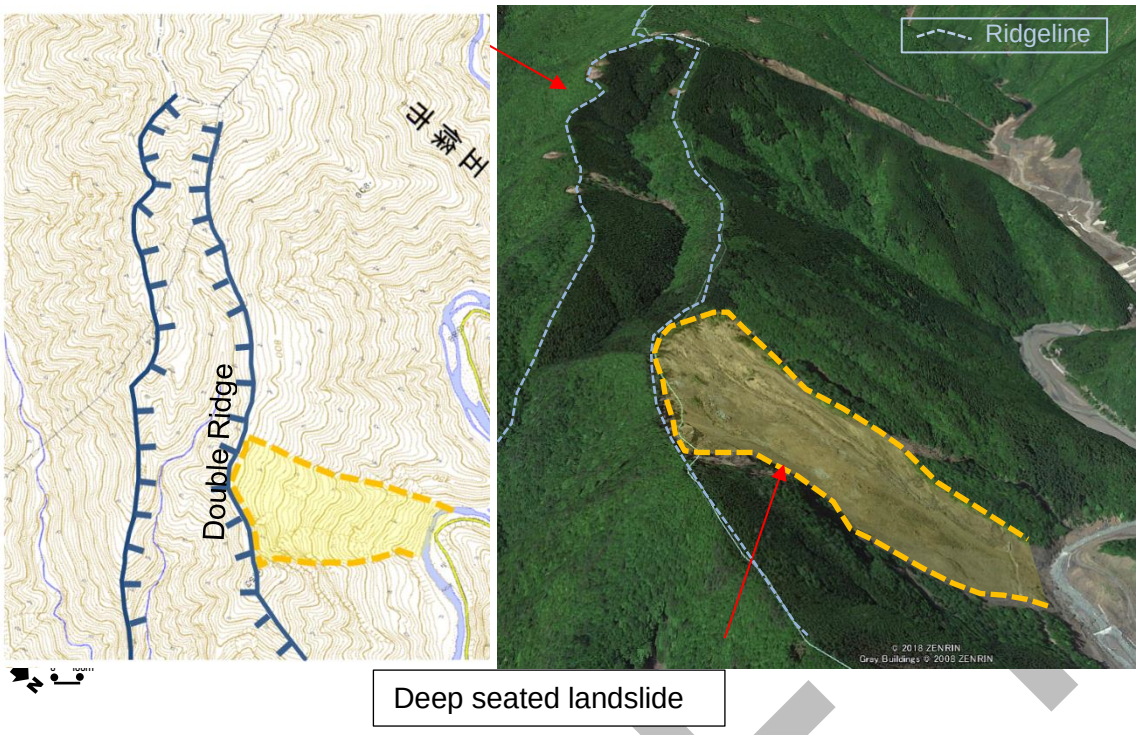


Figure 1-21 Landform Implying Gravity Deformation

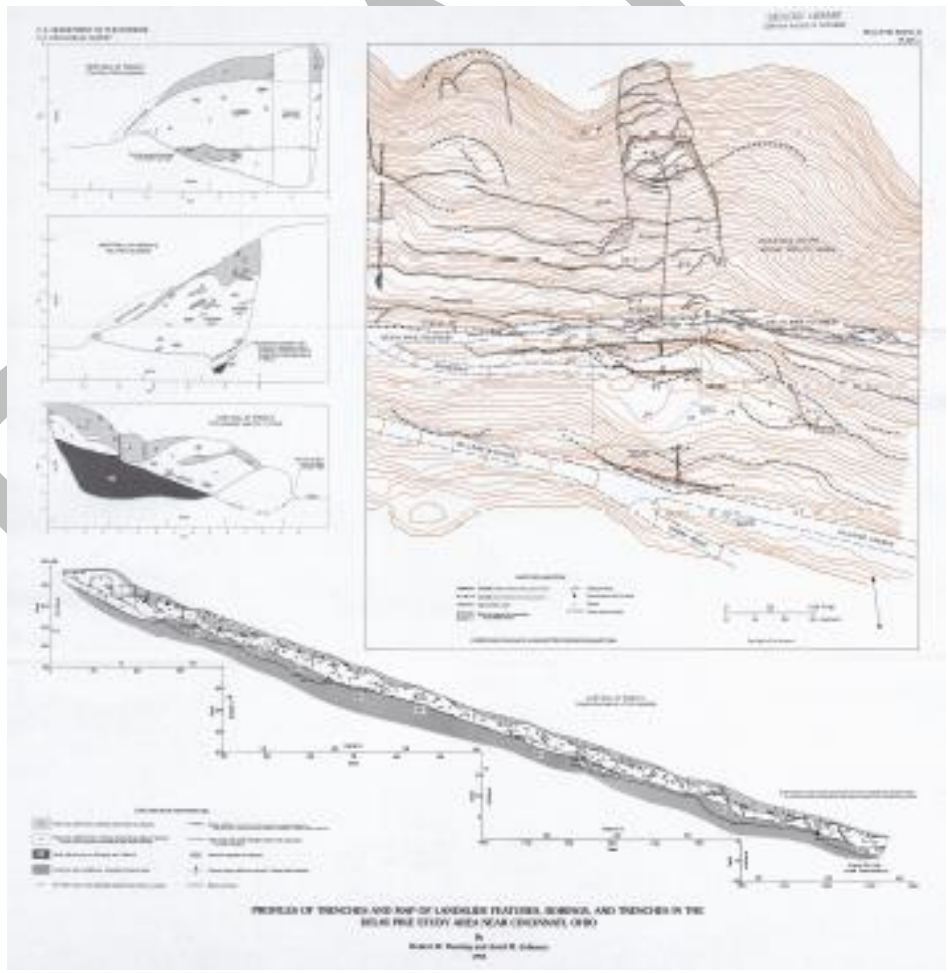
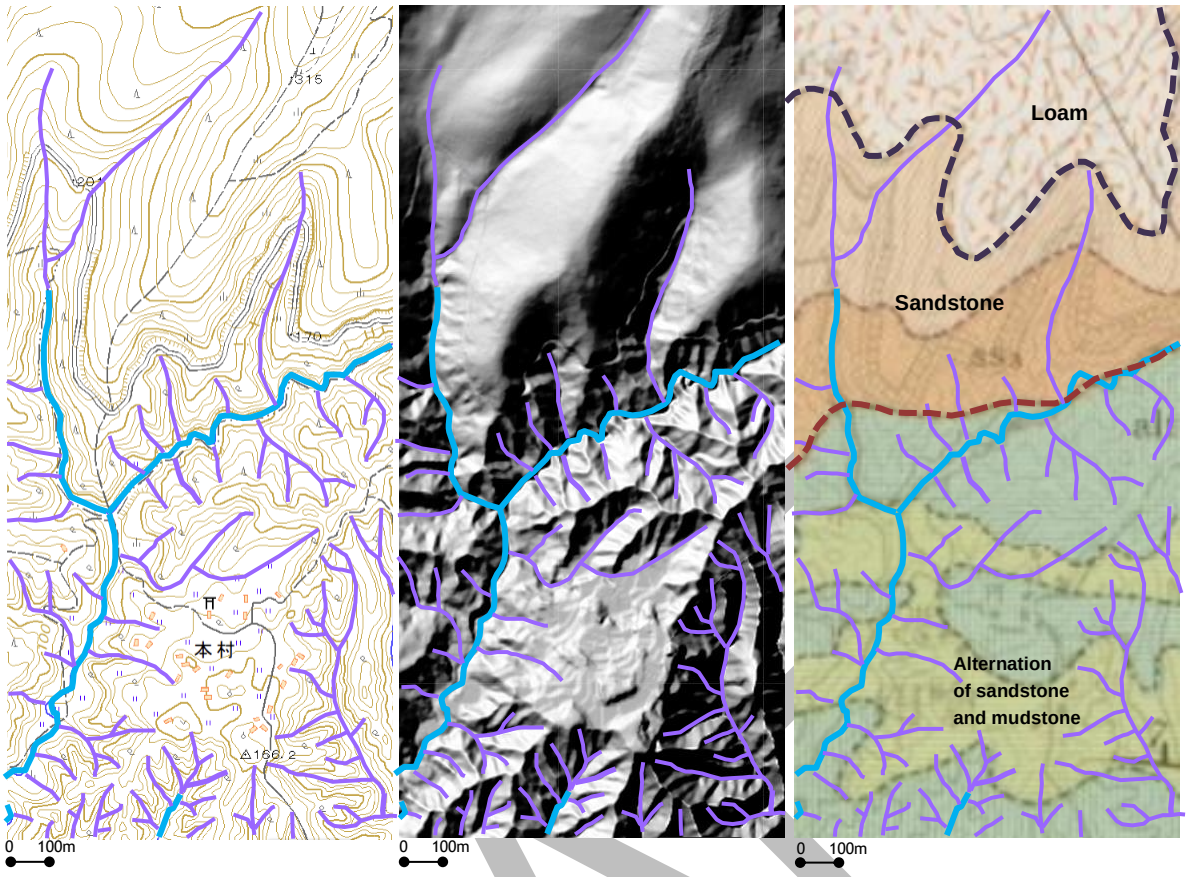


Figure 1-22 Landform of Colluvium and Landslide Occurred

[18]



A) Topographical map [19]

B) Shaded-relief map [19]

C) Geological map [20]

Drainage pattern depends on rock type and geological structure. Permeability affects resistance ability of rock and soil against erosion, which can cause differential erosion in topography. In the area above, dencity of draiange and valley system shows difference between the northern and southern areas. Valley system developes well in the south that consists of alternation of sandstone and mudstone, compared to the northern hill covered with loam and underlain by sandstone

Figure 1-23 Riverine System Governed by Geological Conditions

Left and Middle [19], Right [20]

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(3) Points to Understand in Field Survey and Drilling Investigation

Along with aerial photo and topographic map reading, field survey provides detailed and geological information for planning and design of hill roads. Table 1-8 outlines the items and points to confirm in a field survey for hill road projects.

Table 1-8 Items and Points to Check in Field Survey (Outline)

Category	Item	Points to Check
Topography	Shape of slope	Height, gradient, cross section, etc.
	Normal topography	Talus, terrace, hill, normal slope, etc
	Anomaly	Overhang, outcrop, knick line, etc.
	Landslide topography	Landslide, debris flow, collapse, etc.
Geology	Rock type	Geological strata, rock facies, hardness
	Discontinuities	Fault, fractured zone, joint, bedding, foliation
	Structure	Strike, dip, folding
	Weathering	Weathered/altered condition, strength
	Soil/deposit	Soil type, composites, thickness, density
Surface	Boulder/detached rock	Size, density, instability, etc.
	Vegetation	Type(forest, meadow, bare land, etc.), density, growth situation
	Spring	Location, quantity, deposition
Structure	Type	Hill slope protection, sabo structure, landslide countermeasures, road, structure, river structure
	Scale	Height, extent, condition of deposit
	Deformation	Crack, bulge, deformation, displacement

[21]

Following preliminary geological survey, detailed survey, including drilling and field survey, shall be conducted to obtain more detailed geological information at the surface and subsurface. Table 1-9 explains the items and points to check in a detailed survey. In a detailed survey, depending on the purpose of survey, additional surveys shall be conducted, such as geophysical exploration, landslide monitoring, rainfall observation, ground water level observation, and laboratory tests.

Table 1-9 Items and Points to Check in Field Survey (Detailed)

	Item	Points to Check
Topography	Slope Failure / Collapse	Property of collapse (length, width, and depth), geological conditions (rock and soil properties), crack, fissure, geological discontinuity*, weathering and alternation, gradient and material of slip surface, spring and seepage, vegetation, cracks on slope, displacement of slope, head scarp, conditions of debris (material and deposit conditions), possibility of reoccurrence or development of rock fall and collapse, and existing structure.
	Rock Fall	Slope with boulders, steep rock slope with densely developed joints, cracks, and fissures along with unstable or detached parts, slope with overhung, slope with collapse, slope with outcrop, slope with debris, talus, colluvium, and terrace sediments, slope with gully erosion, bald land, undulation of slope, detached ridge or valley, vegetation, and distribution of boulders
	Landslide	Anomaly of surface Location, alignment, shape, and scale of head scarps, swamps, ponds, and wetlands, subsiding at head of landslide, situation of middle of landslide, shape of cracks, raise and bulge at toe (pressure ridge), collapse at toe, spring, anomaly of trees, and rice paddy as well as farm land Anomaly of structure Deformation of building, retaining wall, road, railway, utility pole, tunnel, well,

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	Item	Points to Check
		masonry, and other structures.
	Debris Flow	At source Properties and conditions of collapse and landslide at the source, situation and condition of stream bank and bed, thickness, distribution, and gradient of highly weathered part of rock, colluvium, debris, talus, and river deposit. Transport section Bed slope, width of stream, situation of stream bank erosion, and vegetation Deposit section Thickness and distribution of debris at stream and stream mouth, diameter of detached rock, boulder, cobble, and gravel, rock type, vegetation
Geology	Rock and Soil Type	Rock Type of rock, hardness, notable minerals and void Soil Type of soil (residual soil or debris?), thickness, shape and diameter of gravel, property of matrix (particle size and inclusion of silt and clay), moisture condition, proportion of gravel and matrix, and degree of compaction (relative density)
	Geological Structure	Geological discontinuities* Properties of bedding, foliation, joint, and unconformity (tightness, roughness of plane, interval, and filling material and its properties), distribution of discontinuities (strike and dip, continuity, density, and angle with slope), folding, and others. Intrusive rock Strike and dip of contact surface, property of chilled margin, property of condition of contact metamorphism Fault and fractured zone Strike and dip, scale, width, and property (characteristics of fault surface and fractured part, development of slickenside, interbedded clay, degree of compaction (relative density), and spring and seepage) Alteration zone Type of mother rock, degree of alteration, distribution, softness, color, development of slip surface
	Weathering condition	Relaxation of rock mass, openness / interval of crack and fissure, conditions / degree of weathering, hardness of rock, void, material due to weathering (clay, residual soil, decomposed soil), and color.
	Core samples from drilling	(Rock) Rock type, hardness, shape, color, length of core sample, smoothness of core surface, interval, roughness, color, and filling of cracks, direction of discontinuities (bedding, foliation, and joints), weathering condition (color, softness, material due to weathering, and decomposition status), alteration condition, void, and RQD. (Soil) Soil type, color, contents, moisture condition, particle size of sand, clayey content, relative density/stiffness, consistency, size and shape of gravel, void, and included minerals.
	Groundwater	(Through drilling investigation or monitoring well) Groundwater level and its seasonal variation, permeability, conductivity, pH, chemical property, water quality, flow property, pressure status (free or artesian ground water), and quantity
Surface	Boulders and detached rock	Shape, hardness, stability distribution of boulders and detached / unstable rock
	Spring and Surface water	Position of spring, quality and quantity of spring water, moisture content of soil / rock, freezing / unfreezing during winter
	Vegetation	(often seen at unstable slope) Bald land, fallen tree, damage on tree trunk, bending of tree, and poor growth of

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	Item	Points to Check
		vegetation (often seen at landslide / failure sites) Bamboo, willow, and butterbur (often seen at thick overburden with well drained property) Well grown cedar trees (often seen at unstable slope such as failure / landslide sites) Silver grass, knotweed, kuzu, and plume poppy (often seen at sandy ground, talus, and alluvial fan) Fruit farm of orange, peer, and chestnuts (often seen at debris / colluvium or failure sites) Stark difference from the surroundings
Structure	Landslide / debris flow countermeasures,	Sabo dam, check dam, hill slope works, flow channel works, surface drainage, horizontal drainage boring, nailing, and ground anchors.
	River Structure	Revetment works, dike / embankment, water gate, water shoot, and irrigation facilities.
	Road Structure	Slope protection works, cut slope, embankment, bridge, and drainage.
	Others	Public building, treatment facilities and others.

*: discontinuity: a plane which detached rock mass, such as joint, bedding, foliation, and fault as well as fractured zone.

[21]

(4) Unfavorable Geological Condition for Hill Road

Certain types of rock and geological setting / structure often act unfavorably to hill road construction as well as operation and maintenance. In case engineer / road administrator notices such conditions along the planned hill road, engineer / road administrator shall avoid such conditions as much as possible and if such conditions are unavoidable, engineer / road administrator shall employ countermeasures in the aim of minimizing the influence from such conditions.

(i) Swelling

Certain rock type or rock with particular mineral cause time-dependent deterioration called “swelling”. Swelling is a phenomena caused by unloading and moisture absorption of certain clayey minerals called “smectite”. Montmorillonite is typical smectite clay. Smectite clay has particular mineral structure which can absorb abundant moisture in the air or surroundings and expand drastically.

Through the process of swelling, with drastic expansion, rock body containing smectite deteriorates and the strength of rock weakens. With the expansion, swelling causes damage to concrete / steel structures.

Swelling occasionally occurs in sedimentary soft rock and igneous rock, such as tuff, mudstone, serpentinite, and marl, depending on the contents of smectite clay. Smectite clay is also found in the bands of hydrothermal alteration. On the other hand, black cotton soil is famous expansive soil type for its distinctive expansive property. So is marly clay.

Observation of core sample from drilling investigation provides valuable clues for detecting swelling rock. Due to unloading by drilling and moisture content in the air, swelling rock obtained as core samples shows its expansive property after being recovered from the subsurface. Thus observation of core samples at different timings may provide information about swelling.

Once possibility of swelling is noticed, further testing is required, such as X-ray analysis, methylene blue test, and laboratory swelling tests measuring dimension or swelling pressure.

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(a) Muddy Tuff with Slicken Side (b) Damaged Invert by Swelling (c) Deformation of Advanced Tunnel

Figure 1-24 Swelling in Tunnel Construction

[22]

(ii) Slaking

Slaking is another time-dependent deterioration phenomenon. Slaking occurs when rock surface appears to the surface by excavation or landslide and then is exposed to repeated dry and wet cycle. By being exposed to dry and wet cycle repeatedly, binding among particles in the slaking rock weakens and then decomposition proceeds. Through the process of slaking, the strength of rock and resistance against weathering and erosion weaken. Thus, in the alternation with sound hard rock, slaking rock often exhibits differential erosion and forms overhung which may cause instability of slope.



Figure 1-25 Slaking along Highway in HP, India

Source: JICA Project Team

Slaking is often observed in sedimentary soft rock, such as sandstone, mudstone, marl, and tuff. In metamorphic rock or Mesozoic – Paleozoic rock, slaking is occasionally seen in the rock strata containing clayey minerals. Slaking is often observed at outcrops, such as shown in Figure 1-25. Slaking property is evaluated through slaking test, in which a specimen is exposed in 11 cycles of wet and dry conditions.

(iii) Layered rock strata

Rock strata with bedding and foliation are not unfavorable geological conditions. Since bedding and foliation are weak planes in rock strata, however, depending on the direction of such planes, landslide, collapse and rock fall often occur in such geological conditions.

In case an apparent dip of bedding or foliation shows such angles shown in (a) of Figure 1-26 and cutting works are planned as the red line, the cut slope shall be considered as unstable; the slope is controlled by dip slope structure. In case an apparent dip shows such angles in (c), the dip slope structure is deemed stable but, depending on development of cracks or gradient of slope surface, hazards like rock fall or gravity deformation may arise. The details of dip slope structure are explained in Chapter 2.1.2.

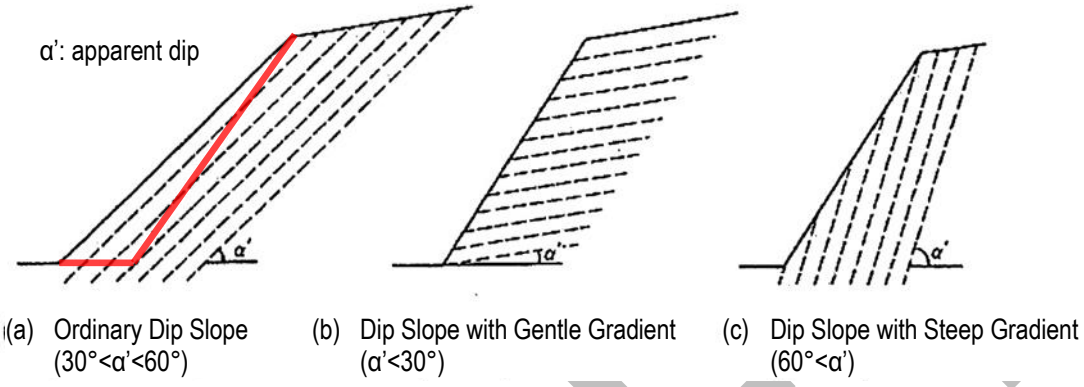


Figure 1-26 Dip Slope Structure

[21]

Beddings are observed in Cenozoic sedimentary soft rock and Mesozoic – Paleozoic sedimentary rock and formed parallel with the deposition plane. Foliation is seen in metamorphic rock and formed parallel with the flattened plane during metamorphic process.



Figure 1-27 Dip Slope Structure in India (Left: HP, Right MG)

Source: JICA Project Team

(iv) Rock with rich mica contents

Mica is a flat shaped mineral with slippery surface. Mica is often observed in igneous rock, such as granite and pegmatite, as well as metamorphic rock, such as certain types of schist and gneiss. When mica forms foliation planes, since mica is easily detached each other, the problems explained in the previous section may become more severe. The easily detached feature of mica facilitates decomposition of rock by the action of weathering as well as unloading.

Debris and colluvium including abundant mica contents, which are derived from decomposition of mica rich rock, show a distinctive feature of smaller internal friction angle than expected with the normal soil condition. Such weaker mechanical properties of debris make slope prone to landslide under the conditions of abundant rainfall or increase of groundwater level.



Figure 1-28 Metamorphic Rock and Debris Rich in Mica

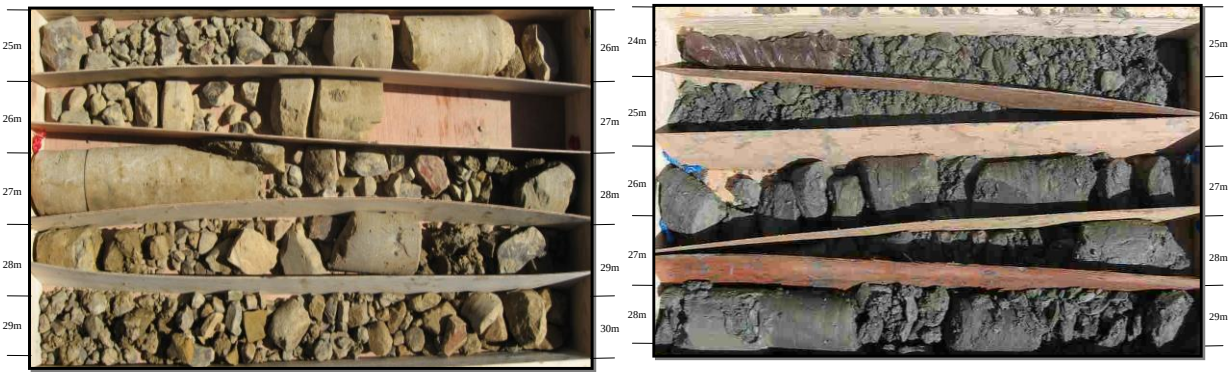
Source: JICA Project Team

(v) Faults and Fractured Zones

Fault is a major discontinuity with some extent of displacement. In many cases, along the faults, rock mass is detached, deformed, stretched, compressed, sheared, or fractured. Fractured zones are developed by the movement of faults and composed of the materials formed by strong compression and shear, most of which are clay and sand characteristically seen at fractured zones.

Fractured zones form weaker belts in rock mass and often cause problems in construction, such as tunnel construction and slope stabilization along hill roads. With its clayey contents, fractured zones often form natural impermeable walls and cause substantial difference of groundwater level between both sides of the zones, which cause sudden inflow of groundwater during tunnel construction.

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Core samples of Fractured Zones



A col formed by a fractured zone.

Figure 1-29 Fractured Zone

Source: JICA Project Team

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1.1.5 Surface water/groundwater condition relating to hazards

As explained in the previous sections, rainfall is one of the major triggers of landslides. Slope failure, collapse and debris flow occur during or right after substantial amount of rainfall. Even rock fall occurs during or after rain. On the other hand, some of landslides* start sliding a few days after a peak of rainfall; time lags exist between peak of rain and activation of landslide. This time lag suggests that activation of landslides is not so sharply related to rainfall, compared with other landslide disasters; more complicated mechanism works in activation of landslides.

In the process of activation of landslides, rainfall needs to travel from the surface through water passages in the ground including cracks, fissures, voids, and porous zones of rock/soil to the slip surface lying deep ground. On slip surface, infiltrated rainfall increases pore water pressure and then decreases shear strength of slip surface, which leads landslides destabilized. The time lag between peak of rain and activation of landslide means, therefore, the time necessary for rainfall to travel from the surface to slip plane.

*: The "landslide" in this section means that of narrow definition in Table 1-3.

This section explains relationship between landslide disaster and surface runoff /groundwater, highlighting pore water pressure which induces large-scale slope disasters.

Table 1-10 Surface Runoff and Groundwater as Trigger of Landslide

Form of Water	Landslide/damage	Mechanism
Surface water	Raindrop erosion	Due to physical collision between raindrop and the surface of soil/rock, particles detached from the ground are taken into surface runoff and washed away.
	Gully erosion	Erosion caused by surface runoff. Surface runoff emerges when an amount of rainfall exceeds infiltration capability of the ground. Surface runoff erodes the surface as it flows and forms v-shaped groove. The term "rill" is used for the similar but narrower erosion than gully.
Unconfined groundwater	Shallow slope failure	Unconfined groundwater is directly recharged by rainfall which infiltrates into the ground. On slopes, recharged groundwater changes its course when it encounters a constraining floor, such as bedrock, fresh rock, and aquiclude, from vertical to obliquely downward along the surface of the constraining floor. The groundwater flow then has seepage pressure which moves soil particles in shallower part and eventually causes shallow slope failure. The similar mechanism is assumed for cut slope failure, in which debris/colluvium on bedrock or weathered part on fresh rock collapses due to rainfall after cutting.
Pressured groundwater	Deep seated landslide	When fissures in deep bedrock, regardless of its cause, primary or due to gravity deformation, are saturated by groundwater infiltrated from the upper slope, the groundwater becomes pressured due to the difference in heads with that of the upper slope, and eventually destabilize the slope with much wider and deeper sliding body than ordinary failures.
	Cut slope failure of bedrock	The similar mechanism with deep seated landslide is assumed. In cut slope of bedrock, closed fissures in bedrock before cutting become open due to relaxation by stress release by cutting. When the opened fissures are saturated, the groundwater becomes pressured and then destabilizes the cut slope of bedrock..
	Landslide	Landslides (of narrow definition) are featured with landslide clay spread on its slip surfaces (slip planes). The groundwater infiltrated and reached to slip surface increases pore water pressure and decreases effective pressure on the slip surface. This process reduces

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Form of Water	Landslide/damage	Mechanism
		resistance force against sliding along the slip surface and triggers landslide movements. Among landslides and slope failures relating to debris and colluvium, landslides with landslide clay, which occur repeatedly, are caused by pressured ground water through the aforementioned mechanism.

Source: JICA Project Team

(1) Definition of Terms Related to Groundwater

Depending on the place where groundwater is stored, whether in strata or fissures of bedrock, such as fault, crack, and joint, groundwater is divided into two types; stratum water and fissure water.

Stratum water is stored in aquifers, which have porous parts to allow water to stay or flow through it. On the other hand, aquicludes do not allow water to stay or flow through it and thus confine groundwater below it. The groundwater confined by aquicludes is called “confined groundwater” and the groundwater in contact with the atmosphere through porous spaces of overlying strata is “unconfined groundwater”. Confined groundwater keeps the pressure where it is recharged.

Fissure water flows and stays in water passages or veins in bedrock. Based on its water head, fissure water is divided into 2 types: “non-pressured groundwater” and “pressured groundwater”. Non-pressured groundwater has its water head at the same level with the top of the fissure system where it stays or lower. Pressured groundwater has its head higher than the top of the fissure system where it stays, reflecting the height of other fissures the water travels through from where it is recharged.

Stratum Water	Unconfined Groundwater
	Confined Groundwater
Fissure Water	Non-Pressured Groundwater
	Pressured Groundwater

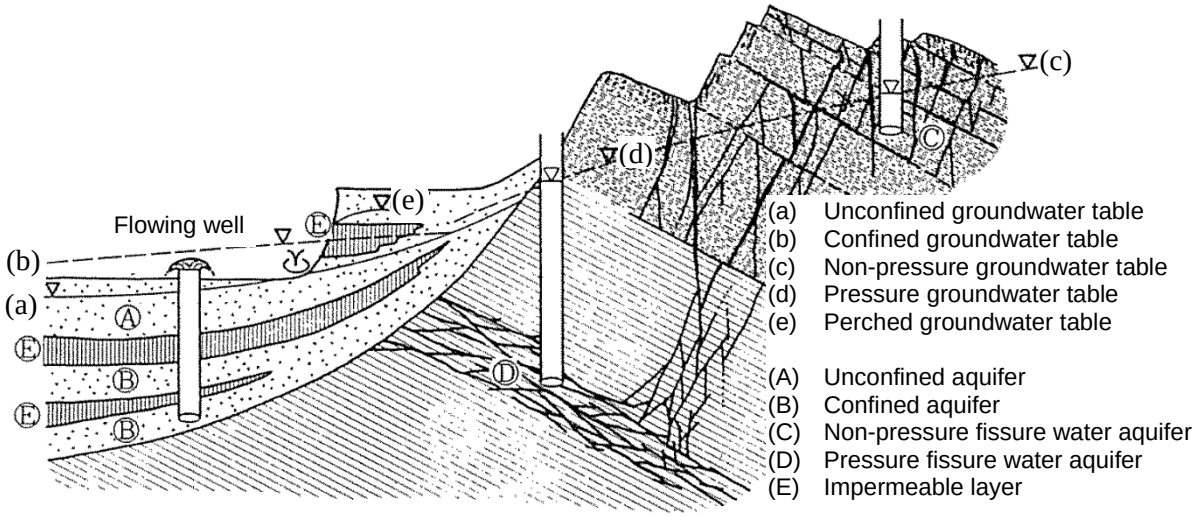


Figure 1-30 Stratum Water and Fissure Water

[1]

(2) Difference between Landslide and Slope Failure in Activation Mechanism

Both landslide and slope failure are triggered by so called "increase of groundwater level", but the mechanisms for their activation are different. Pressured water triggers landslides whereas unconfined groundwater causes slope failures. Such difference is due to properties of soil/rock of moving bodies.

Landslides have slip surfaces and due to increase of pore water pressure on the surface, landslides are activated. So where does increase of pore water pressure come? The followings are the features of landslides regarding slip surface, condition of landslide mass above slip surface, and conditions of groundwater summarized from the reports of investigations of landslides and construction of countermeasures including drainage wells (Shin, 1995).

(i) Most of core samples of rocks obtained though drilling from the upper parts of slip surfaces usually show cylindrical form. Such conditions of the core samples indicate intact state of rock mass which does not allow rainfall to infiltrate from the surface to the slip surface.
(ii) Even when the groundwater level is observed just below the ground surface, results of groundwater logging, which is initiated by lowering groundwater level in boreholes, indicate groundwater flowing into boreholes at very limited sections near slip surfaces.
(iii) Records of excavation of drainage wells report seepage water from the wall of wells at limited sections of loosened zone near the ground surface. And seepage water was rarely found at intact sections up to slip surfaces.
(iv) Observations of slip surface during excavation of drainage wells report particular sections on both sides of slip surfaces, the thickness of which are several to 10 centimeters or more, with numerous fractures of honeycomb shape. However, the rock mass above and below the fractured sections of slip surfaces is hard and intact.

The aforementioned (i) to (iv) lead the conclusions below:

- Rainfall and snow melting water are unlikely to infiltrates to the slip surfaces through the less porous layers of landslide mass.
- The groundwater which increases pore water pressure on the slip surfaces is provided through honeycomb shaped fractures lying on both sides of slip surfaces, from deep groundwater aquifer and/or groundwater passage, both of which may bear pressured groundwater.

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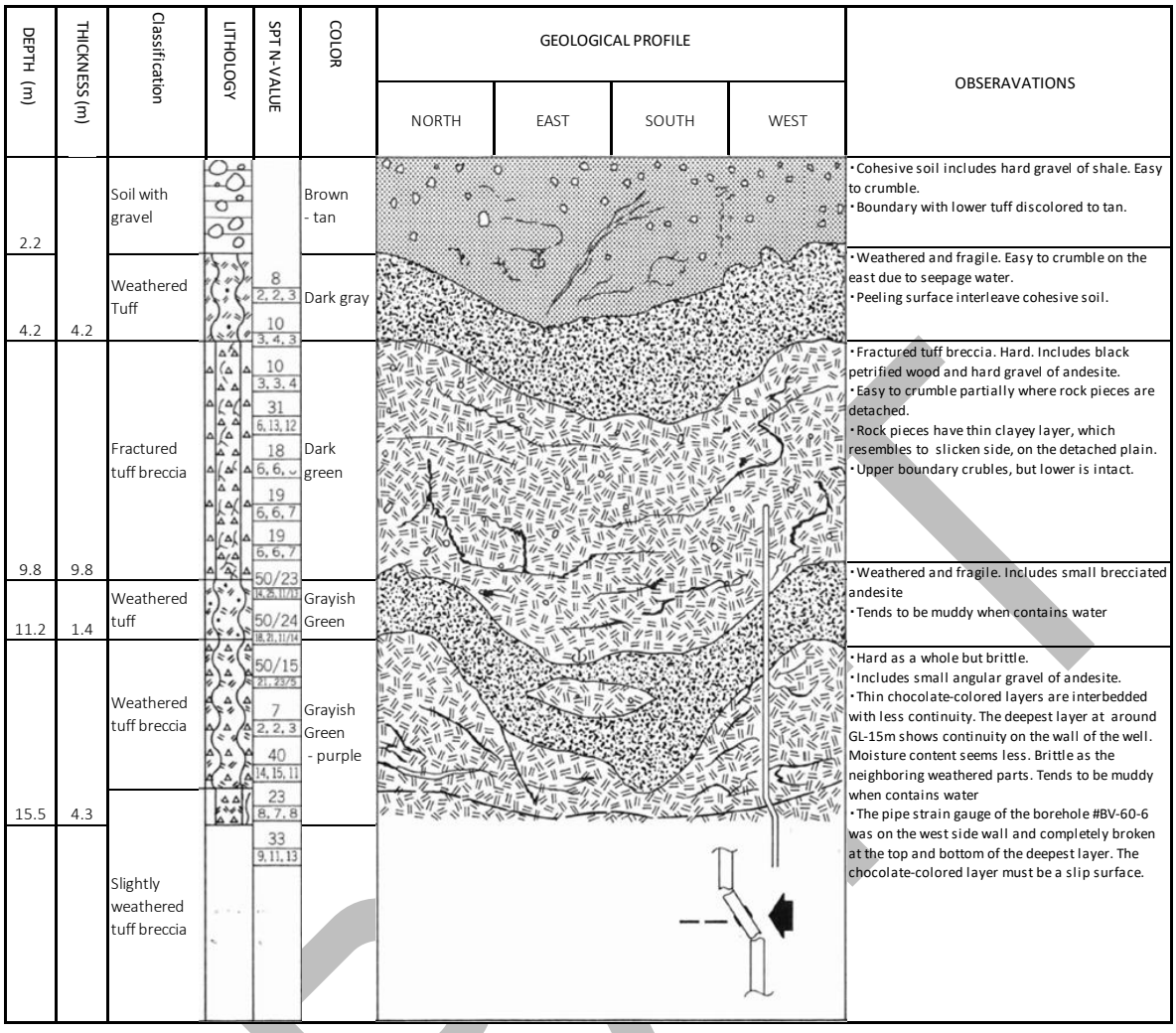


Figure 1-31 Geological Profile of Drainage Well at the Landslide Site [1]

[1]

On the other hand, slope failure involves loose soil which allows rainfall or snow melting water to infiltrate vertically to the ground. The infiltrated groundwater forms unconfined groundwater and changes its flow course when it encounters a constraining floor, such as bedrock, fresh rock, and impermeable aquiclude, from vertical to obliquely downward along the constraining floor. The groundwater flows through narrow void space among soil particles and then has seepage pressure which affects soil particles. Along with the sliding force derived from the component force along the constraining floor of the submerged weight of the soil, the seepage pressure destabilizes the soil above the constraining floor. Slope failure occurs in such mechanism, which is totally different from that of landslide. (*)

As explained in the previous section, groundwater supplied through infiltration of surface water, such as rainfall or snow melting water, is called unconfined groundwater. Groundwater supplied through fissures is fissure water and fissure water with pressure is called pressured groundwater.

Using these terms, slope sliding phenomena caused by unconfined groundwater can be defined as slope failure or collapse, and those caused by pressured groundwater can be defined as landslide.

When we adopt these definitions, scale and speed of moving mass are not essential for classification. Both landslide and slope failure have various speed and size of moving mass and this interpretation does not contradict the fact we observe on site.

*: Landslides composed of debris are activated by pressured groundwater in case it moves repeatedly and forms landslide clay along slip surface under sliding mass.

(3) Unconfined Groundwater and Pressured Groundwater

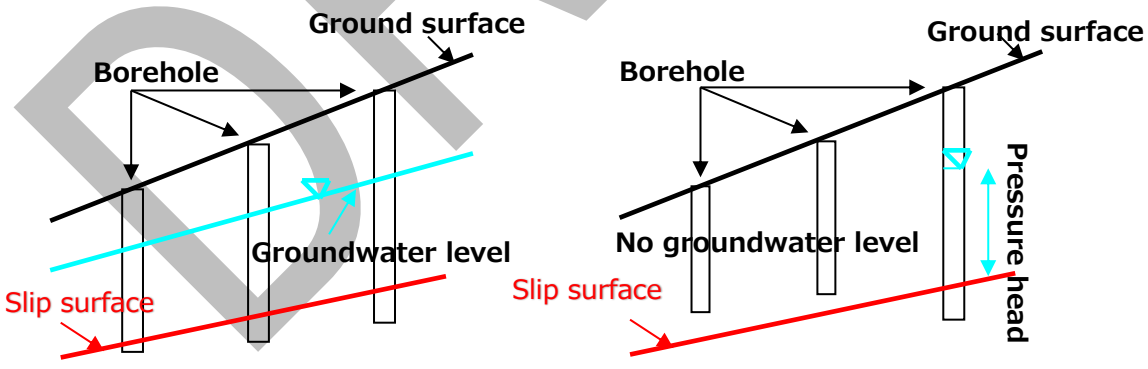
Figure 1-32 explains distribution of water table of unconfined and pressured groundwater.

Unconfined groundwater forms groundwater level in all boreholes (a, b and c) in Figure 1-32. Unconfined groundwater is stratum water and thus, when groundwater logging is carried out in the boreholes, flow of groundwater through strata should be observed below groundwater level.

On the other hand, pressured groundwater forms groundwater level only at borehole c in Figure 1-32. Only when a borehole reaches the slip surface, pressured groundwater shows its head. At boreholes a and b, pressured groundwater borne on the slip surface does not show its head.

For stratum water, ground water level implies the quantity of groundwater borne in an aquifer. On the other hand, since it is fissure water, heads of pressured water, which may be observed in piezometers or dedicated monitoring wells, does not suggest quantity of groundwater.

This understanding has critical meanings in design and construction of groundwater drainage works including horizontal drainage boring, which is one of the essential control works in landslide countermeasures. Horizontal drainage boring aims to prevent increase of pore water pressure acting on a slip surface and thus targets pressured groundwater. It aims to release pressure of groundwater, not groundwater itself. So the quantity of drained water from outlets of horizontal drainage does not have significant meanings on the success of the works. Drainage boring will be in success when it properly penetrates the slip surface.



(a) Unconfined groundwater (b) Confined

Figure 1-32 Concept of Groundwater Level

Source: JICA Project Team

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1.1.6 Evaluation / Assessment of Slope Stability

Stability analysis is defined as "analytical method to quantitatively evaluate the degree of stability of artificial or natural slope". In detailed design stage, stability of cut / filling slope shall be evaluated with slope stability analysis. In case instability is anticipated, stability analysis of natural slope may be done. As a result of slope stability analysis, in case a slope is evaluated as instable, countermeasures to increase stability shall be planned and designed. Thus investigation for countermeasures shall be done simultaneously to clarify appropriate position, scale, and quantity of countermeasures. And slope stability analysis is basis of detail design and shall be carried out properly.

There are six essential matters for conducting proper stability analysis, which are described in this section.

(1) Identification of Landslide Blocks (Essential Matter 1)

In general, landslide rarely exists independently; landslides often coexist in a form of landslide blocks which move interrelatedly. In order to decide proper location of countermeasures, each block should be delineated and its stability should be evaluated.

In case specific landslide block is treated, due attention should be paid to both the target landslide as well as neighboring ones. For example, in case an earth removal work is planned at the upper part of the target landslide, the cutting work for soil removal may trigger another landslide at the upper slope. Similar case may occur for counterweight embankment (buttress fill). Such cases should be avoided.

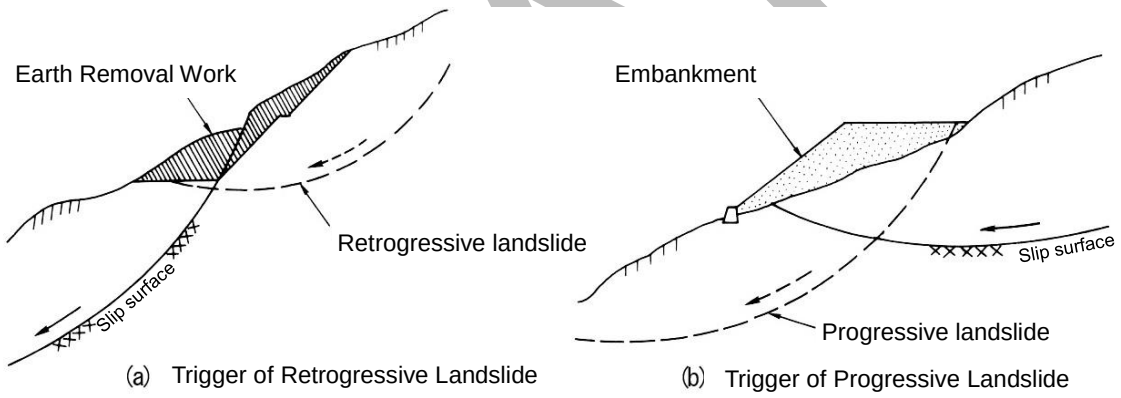


Figure 1-33 Earth Removal and Embankment That May Cause Landslides

(2) Alignment of Survey Lines (Essential Matter 2)

Survey lines should be set in a manner properly obtaining shape of landslide blocks and slip surface, as listed below.

I. Direction of longitudinal survey lines (lines for landslide profiles) should follow the direction of landslide movement.
II. Landslides often have asymmetrical form of slip surface in the direction perpendicular to its movement. In case magnitude of a landslide considered as large, additional survey lines for profiles and cross sections should be planned to cover the area of landslide. Multiple survey lines enable pseudo 3D analysis as shown in Figure 1-36.

Figure 1-34 shows an interesting example of arrangements of survey lines for landslide investigation. The contour lines of Figure 1-34, which show elevation of the terrain, imply the movement of the landslide from the top to bottom of the figure. But

the actual survey lines were arranged as the straight lines of A to F. Figure 1-35 shows the counter map of slip surface, bottom of the landslide mass, of the same landslide. The slip surface is controlled by strike and dip of a coal bearing layer interbedded in Neogene sedimentary rock formation and thus forms the flat plane with the maximum dip inclining from left to right. In the actual scene, the landslide moved to the direction composed of the maximum dips of the terrain and the slip surface and the survey lines follows such direction. If the survey lines had been decided only with the tendency of the terrain on the topographic map, such lines must have been useless. The survey line for profiles and cross sections should be decided considering actual movement of landslides.

Since this landslide was considered as large and the shape of the slip surface varies among the profiles, pseudo 3D analysis was employed as shown in Figure 1-36.

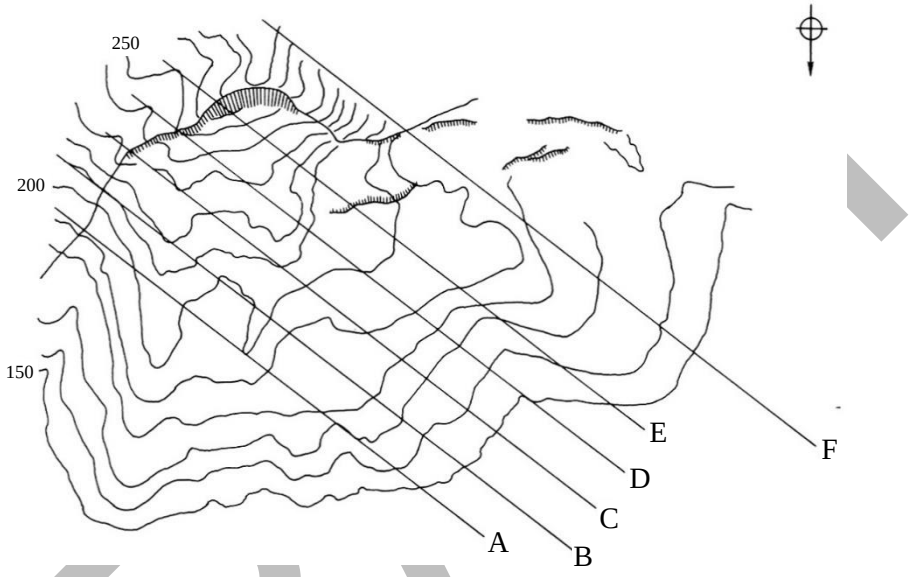


Figure 1-34 Example of Survey Lines for Profile in a Landslide Site

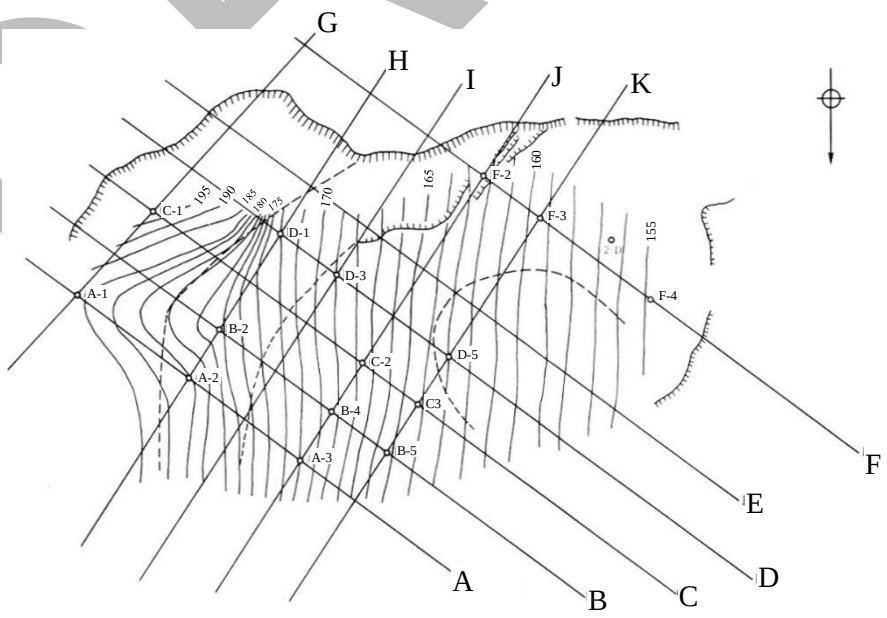
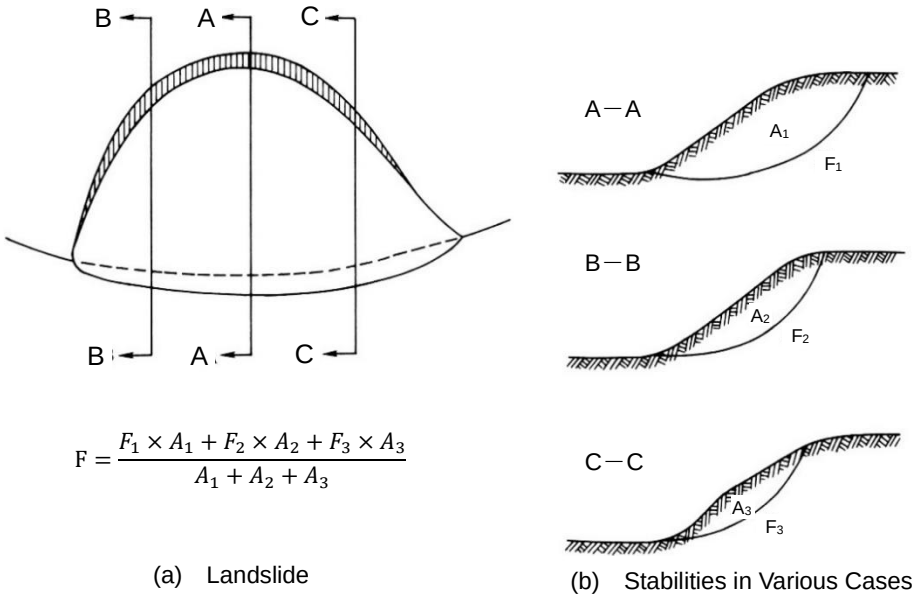


Figure 1-35 Contour Map of Slip Surface of Landslide



$$F = \frac{F_1 \times A_1 + F_2 \times A_2 + F_3 \times A_3}{A_1 + A_2 + A_3}$$

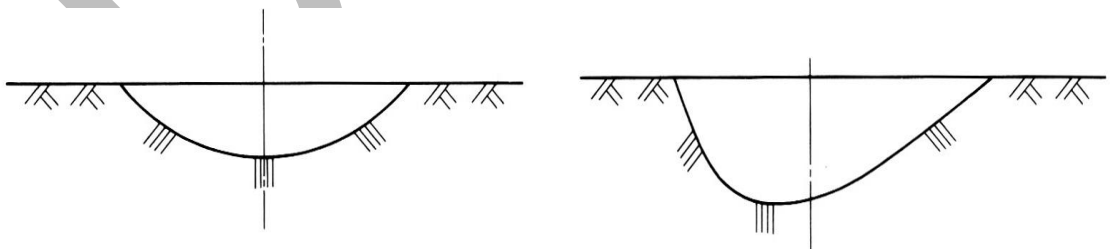
(a) Landslide

(b) Stabilities in Various Cases

Figure 1-36 Pseudo 3D Analysis Model by Lambe and Whitman

In case stability of small landslide is evaluated through 2D analysis only on a main profile, location of the survey line for the main profile is crucially important. The survey line for the profile should be placed where a slip surface runs the deepest position on a cross section such as shown in the left of Figure 1-37 because the deepest slip surface leads the lowest stability and thus requires the largest countermeasures. In other words, if the main profile is set apart from the deepest section such as shown in the right of Figure 1-37, the stability analysis on such profile provides higher safety factor than the actual and thus leads insufficient countermeasures to be designed through it.

Basically, a stability analysis on a profile set close to flanks of landslides provides higher safety factor. Thus an actual safety factor for entire landslide must be higher to some extent than that of examined on the profile of the deepest slip surface. If a design based on the stability analysis on the deepest slip surface is considered too large, true 3D or pseudo 3D analysis should be employed, both of which require more detailed investigation than 2D analysis.



Main profile
(Analyzing cross section)

Main profile
(Analyzing cross section)

Figure 1-37 Setting Main Profile for Analysis

(3) Careful Preparation of Landslide Profile and Close Examination of Slip Surface (Essential Matter 3)

Shape and depth of a slip surface shown in a landslide profile are the basic input for stability analysis and the following design. In other words, design of countermeasures depends on slip surface and landslide profile. If a design of countermeasure is made based on an incorrectly prepared landslide profile or falsely interpreted slip surface, design and the following construction of countermeasures would be ruined. Landslide profile should therefore be carefully prepared along with closely examined slip surface based on results of landslide investigations which are carefully planned and conducted with sufficient details.

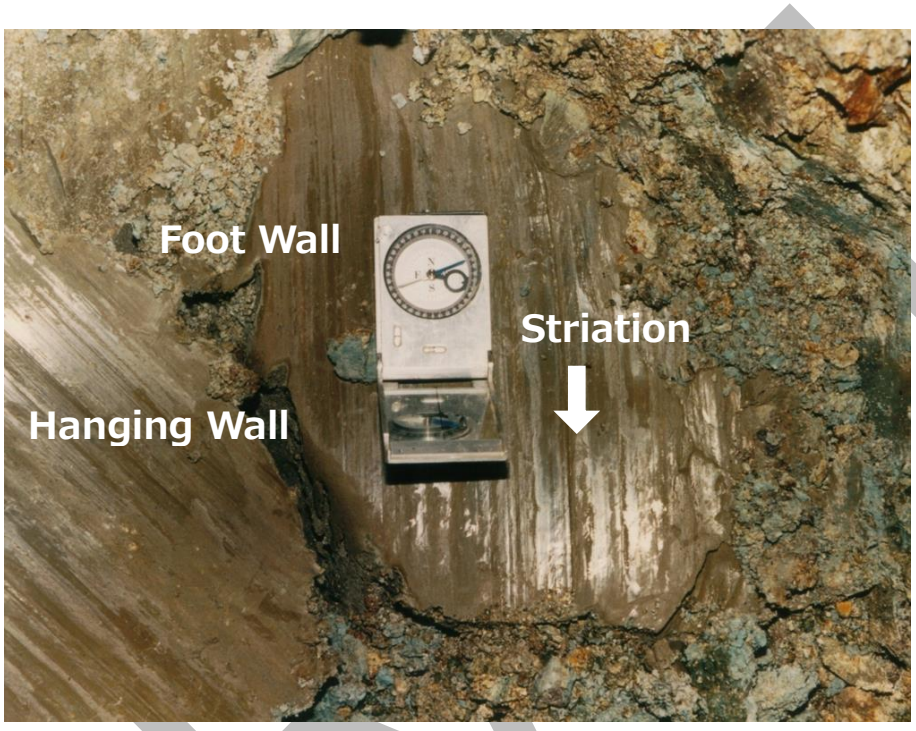


Figure 1-38 Slip Surface on Landslide Clay Observed in Drainage Well Construction

(4) Distribution of Pore Water Pressure (essential matter 4)

Groundwater is obviously one of the most important triggers to activate landslides. When groundwater level varies, pore water pressure on slip surface also varies. Pore water pressure on slip surface controls landslide movement; when pore water pressure rises, safety factor decreases, and vice versa.

Accordingly, for the design of groundwater control works, distribution of pore water pressure should be precisely understood as much as possible. For such purpose, dedicated monitoring well for pressured groundwater with automated water level meter should be employed. A dedicated monitoring well has upper and lower packer to limit targeted pressured groundwater just above slip surface or landslide clay for precise monitoring of pore water pressure acting on slip surface. On the other hand, non-dedicated well, with perforated pipes for entire length of well, is not suitable for the purpose of design of landslide countermeasure.

Figure 1-40 shows comparison between dedicated and non-dedicated monitoring well of variation of groundwater level. Non-dedicated monitoring well collects groundwater from all sections from the surface to the bottom of the well, including unconfined shallow groundwater as well as pressured groundwater just above the slip surface or landslide clay. The water level observed in non-dedicated well is

resultant of such groundwater and responds sensitively to rainfalls with more amplified variation. On the other hand, water level in dedicated well simply indicates pore water pressure acting on slip surface. The ground water level to be used for analysis and design should be that from dedicated well. The ground water level from non-dedicated well leads improper design with insufficient effects of countermeasures because, with such amplified groundwater level, shear resistance of slip surface is over estimated and thus the design of countermeasure should be less effective.

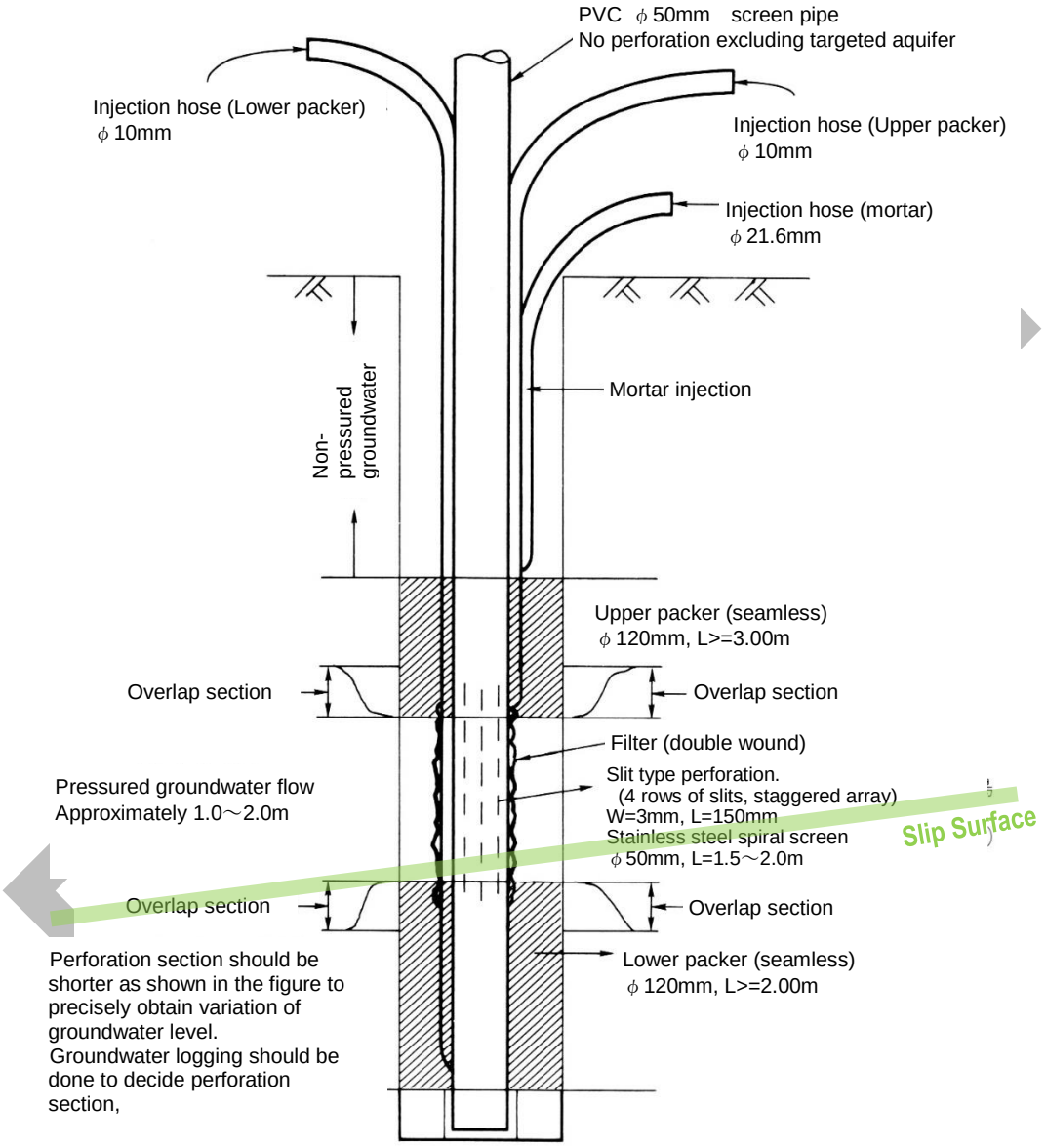


Figure 1-39 Dedicated Grownwater Monitoring Well

Source: JICA Project Team

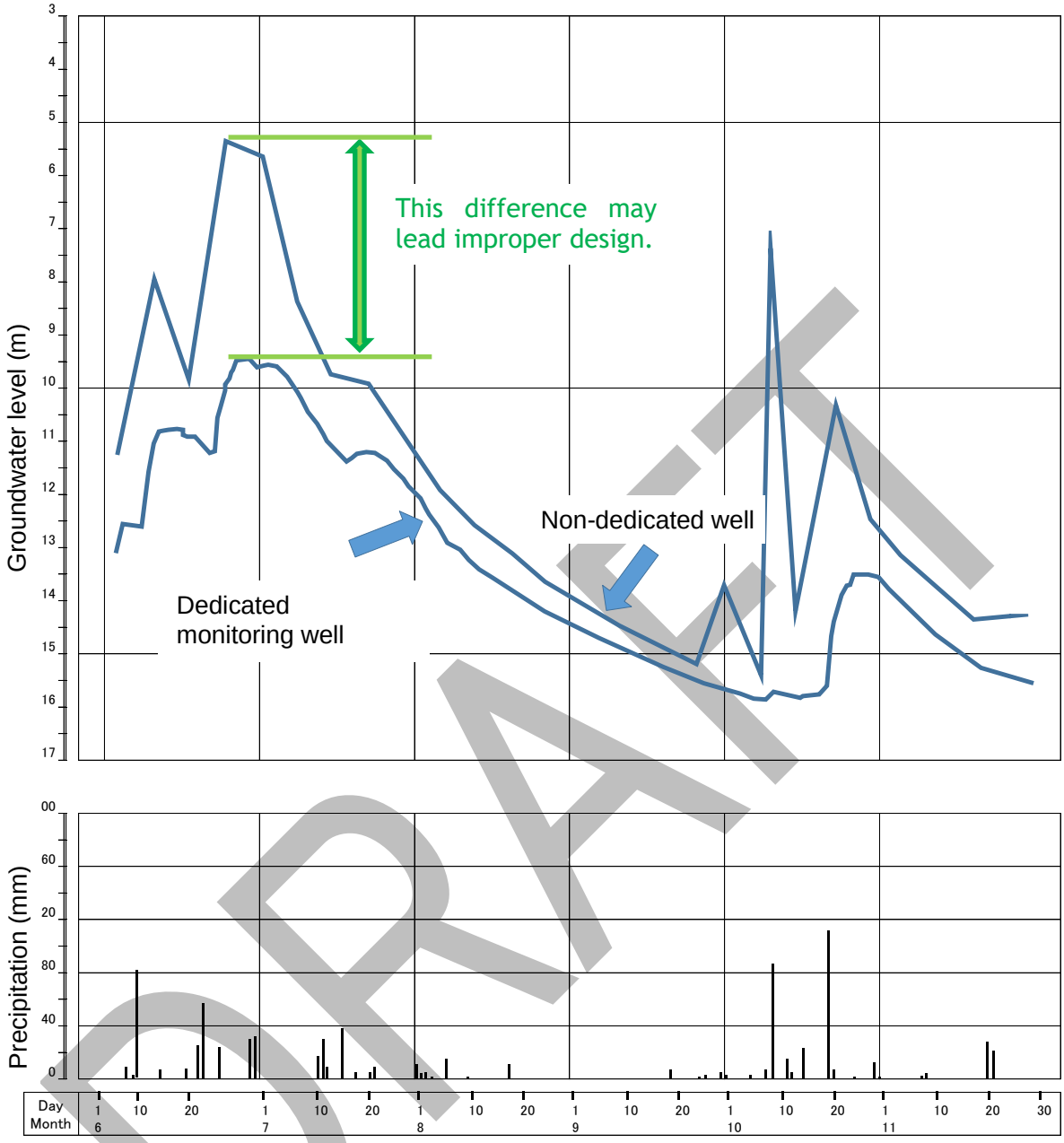


Figure 1-40 Variation of Ground Water Level Observed in Dedicated and Non-dedicated Monitoring Well

Source: JICA Project Team

(5) Determination of the Strength Parameters (Essential Matter 5)

In addition to pore water pressure acting on slip surface, soil parameters essential for stability analysis are as follows:

I. Cohesion of slip surface: c'
   Angle of shear resistance of slip surface: ϕ'
II. Unit weight of sliding mass above slip surface: γ

For long time, it has been considered difficult to determine shear strength of slip surface with laboratory tests using samples directly taken from slip surface. Thus, in

Japan, back analysis has been used to estimate a set of c' and φ′ by assuming either of them, with a linear expression of average value of c' and tan φ′ along slip surface obtained through back analysis. In recent days, thanks to advanced technologies in the sphere of land slide investigation especially methods of sampling and laboratory testing, laboratory shear test on slip surface and ring shear tests provides abundant test results of landslide clay, which are organized into empirical values of representative geological units that often cause landslides. In stability analysis of landslide, it is preferable to use the shear strengths of slip surface or landslide clay obtained through such advanced methods for sampling and laboratory tests.

As for unit weight γ, obtaining core samples with 100% core recovery ratio with the advanced drilling methods such as explained in 1.1.2, measuring weight of core boxes will provide unit weight γ.

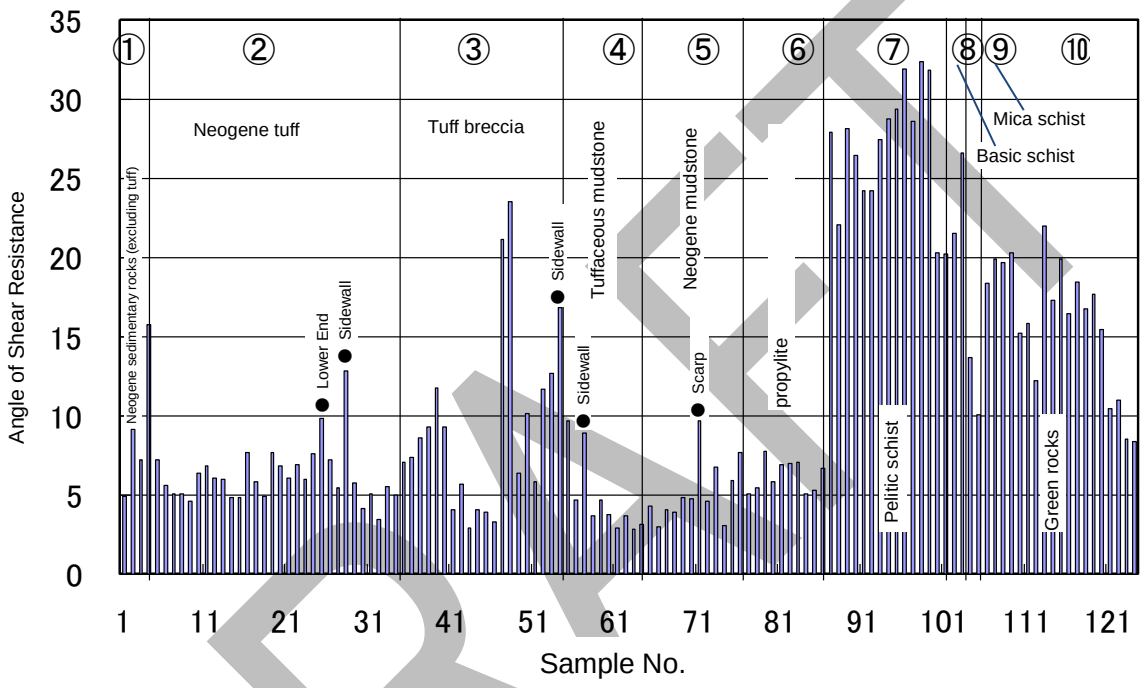


Figure 1-41 Results of Shear Tests of Slip Surface (in Japan)

Table 1-11 Results of Shear Tests of Slip Surfaces by Geology (in Japan)

Geological Unit		Angle of Shear Resistance (Residual Strength) φr'	
		min ～ max	Average
①	Neogene sedimentary rocks (excluding tuff)	5 ～ 16	9
②	Neogene tuff	4 ～ 13	6
③	Tuff breccia	3 ～ 24	9
④ ⑤	Neogene tuffaceous mudstone / mudstone	3 ～ 10	5
⑥	propylite	5 ～ 8	6
⑦	Pelitic schist	20 ～ 32	27
⑧	Basic schist	22 ～ 27	24
⑨	Mica schist	10 ～ 14	12
⑩	Green rocks	8 ～ 22	16

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(6) Adequate formula for stability analysis (Essential Matter 6)

Fellenius method (also known as slice method or Swedish Circle Method) had been developed by Fellenius for the stability analysis of circular slip in 1927. Since the formula is simple, it has been widely used for stability analysis of slopes.

There are two types of analyses principals; one is to calculate safety factor along circular arcs from balance of moments around centers of arcs and Fellenious method is the simplest of this category. Another is to use balance of horizontal forces (ΣH=0), vertical forces (ΣV=0) and moments (ΣM=0) along non-circular slip surface. Depending on shape of slip surface, adequate formulas for stability analysis should be selected.

Table 1-12 Stability Analysis Methods Appropriate for the Shape of Slip Surface

Type	Appropriate methods
Circular slip	Fellenius method (simplified method) Modified Fellenius method. Bishop method
Noncircular slip	Janbu method (including simplified method) Morgenstern and Price method Spencer method

Source: JICA Project Team

The stability analysis methods for landslides usually assume pressured groundwater, which acts on slip surface of ordinary landslides. In such methods, the water pressure acting vertically on slip surface is considered in the analysis and unit weight of soil for the analysis should be wet unit weight without considering buoyancy by groundwater because, unlike in flat lands, formation water is not usually assumed on hill slope where landslide or slope surface often occurs. Pressured groundwater which provides pore water pressure to slip surface exists as a form of fissure water or in groundwater passage heterogeneously distributed underground and thus is unable to provide buoyance to the soil of landslide mass.

Contrary, unconfined groundwater having its head in contact with the atmosphere through voids of soil acts on slip surface of failures relating to embankment on flat land or in the porous ground which allows air to flow. For such case, analysis method that assumes unconfined groundwater, which entails seepage pressure, should be employed. In such method, unit weight of soil below the ground water level should consider buoyancy by groundwater because formation water is assumed in such settings.

1.1.7 Identification of Landslide Prone Area

On the course of hill road planning, an alignment of hill road may be planned unintentionally through vulnerable areas against landslide or landslide prone areas including hazardous area of deep seated landslide. If a deep seated landslide occurs, volume of debris may exceed100,000 m3, entailing large-scale debris flow and landslide dam, both of which cause serious damage to downstream. . In order to prevent or mitigate such disasters, identification of landslide prone areas in planning stage is essentially important in order to shift alignment of hill road to avoid such disaster prone areas.

Gravity deformation is widely recognized as a precursor of devastative deep seated landslide. By locating areas of gravity deformation, vulnerable areas against deep seated landslide are identified and thus an alignment of hill road may be planed avoiding such areas. At the same time, as gravity deformation emerges as a precursor

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of landslide, rock fall/slide, and slope failure as well, detecting gravity deformation on hill slope provides valuable information in planning and designing as well as operation & maintenance of hill roads.

In this section, the following items are described in the aim of extracting gravity deformation and hazardous slopes of deep seated landslide.

- Traces on topography of deep seated landslide in the past
- Topographical and geological properties of gravity deformation
- Method of extracting deep seated landslide based on quantitative geomorphometric data calculated from digital maps.

(1) Purpose and Target

Deep seated landslide, described in this section, are "the massive landslides of which slip surface runs deeper portion of slope than ordinal slope failure or landslide and of which landslide mass includes not only debris, overburden and weathered part of rock but relatively fresh part of rock which lies deeper portion of slope".

Characteristics of deep seated landslide are explained as follows and in Figure 1-42.

(i) Landslide mass (debris) moves at high speed.
(ii) Most of the landslide mass (debris) moves downward to outside of area of origin, such as B-1 and B-2 in Figure 1-42.
(iii) The mass moves downward while being broken into separated debris or keeping original shape at the beginning of slide then being detached.

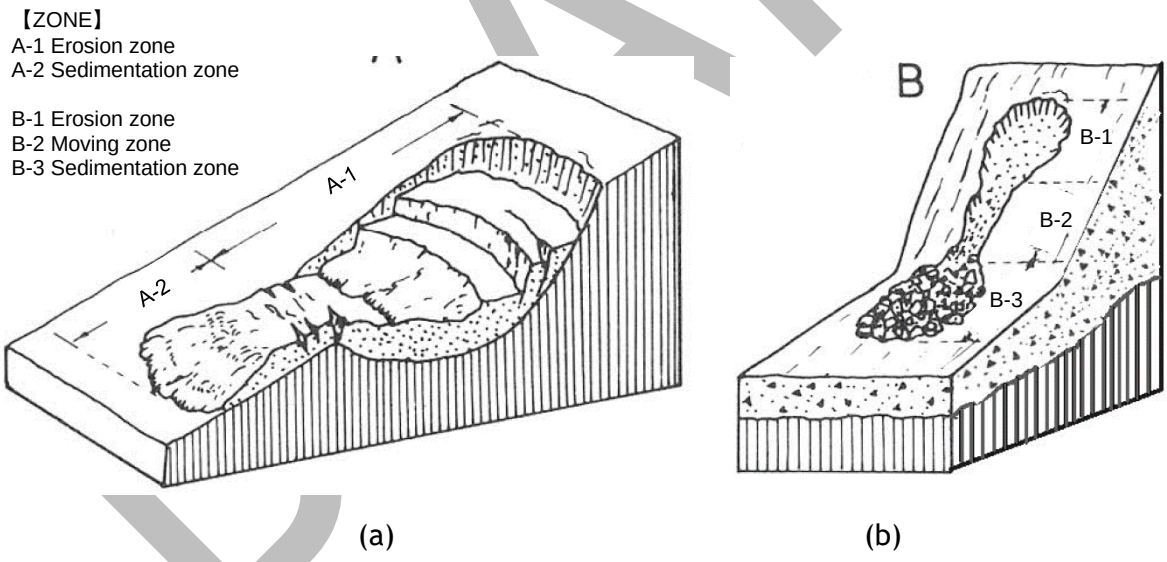


Figure 1-42 Topographic Features Made by Landslide (A) and Deep Seated Landslide (B)

Left [2], Right

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(2) Method of Identifying Slopes with Potential Deep Seated Landslide

The following methods help identify slopes with potential deep seated landslides:

(i) Traces of deep seated landslides

A deep seated landslide often occurs in the vicinity of existing sites of deep seated landslides. Finding traces of existing deep seated landslides on hill slop, therefore, helps identify slopes with potential hazards of deep seated landslide.

(ii) Geological conditions

Certain types of geological condition are considered as a factor of deep seated landslide, such as hard rock strata which experienced stress under tectonic movement or flood basalt with columnar joints, especially including folded or fractured parts or with open cracks.

(iii) Micro-topographic landform of gravity deformation

Gravity deformation is considered as a precursor of deep seated landslide. Micro-topographic landforms of gravity deformation, such as slopes with rock creep and linear depressions along ridges are therefore keys to identify hazardous slopes.

(iv) Quantitative geomorphometric data derived from digital maps

Topography has a significant influence on deep seated landslides, some of which can be understood through analysis of quantitative geomorphometric data.

- The more gradient of the slope increases, the more stability of slope decreases and probability of deep seated landslide increases.
- The more a catchment area spreads, the more groundwater converges and probability of deep seated landslide increases.

(3) Procedure of Identifying Slopes with Potential Deep Seated Landslide

First of all, the areas where traces of deep seated landslides are often found should be selected as target areas and indexed by density of existing ones (index of density). Next, in such target areas, relations between deep seated landslide and geological structure or micro-topographic landform should be studied comprehensively and indexed (index of geology). Then the relation between deep seated landslide and quantitative geomorphometric data should be studied and indexed (index of geomorphology).

Based on indices of density, geology and geomorphology, slopes with potential hazards of deep seated landslides are identified.

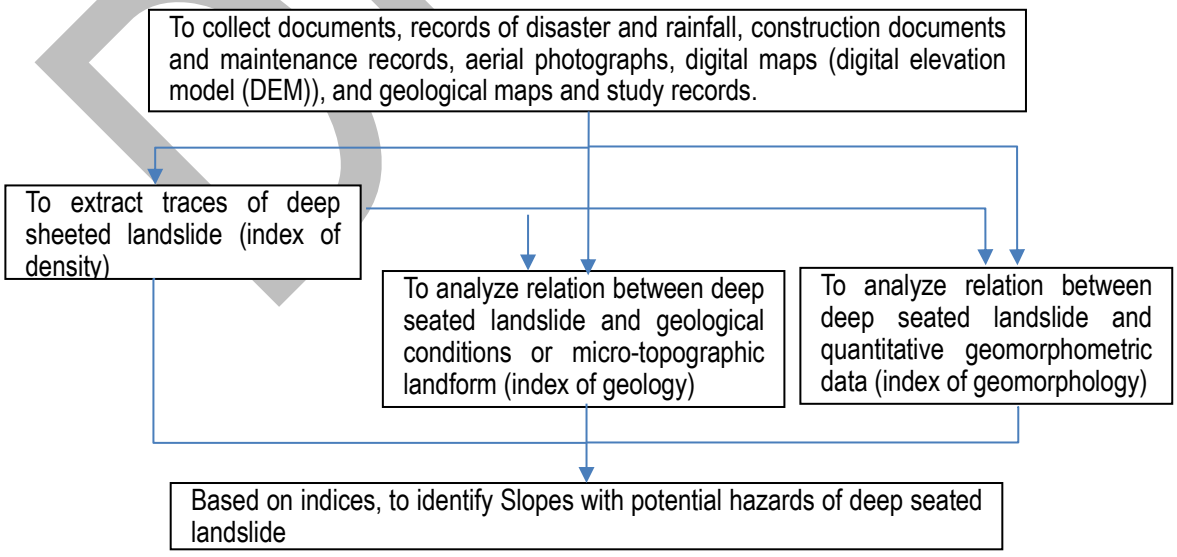


Figure 1-43 Procedure of Diagnosing Streams with Potential Deep Seated Failure

Source: JICA Project Team

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1.1.8 Topographic Map Production with Advanced Technology Utilizing Satellite Data for Hazards Detection

Digitization of geographical information has progressed along with development and commoditization of GIS, Geographical Information System. On the other hand, satellite imagery, which can shoot fur much wider areas at once than conventional aerial photogrammetry, has become more popular and affordable to private and public sectors for civil works. Rapid development of such information technologies make spatial digital information rapidly used in various fields of engineering. In addition, some spatial digital data are available at low cost or even practically no cost.

In this section, utilizing spatial data obtained from satellites for practically no cost and open source GIS software, procedure for producing topographical map with a personal computer is introduced. With this procedure, easy and quick preparation of topographic maps of any areas in India is available and thus identification of landslide prone areas with topographic map reading would be easily utilized in many hill road projects. Through such process, therefore, avoiding landslide prone slopes in planning stage of hill roads may be realized and detecting hazardous slopes during construction as well as operation & maintenance stages would be done effectively and quickly.

(1) Satellite Data

Currently, digital data from two satellites, AW3D30 and Sentinel-2, are available for this purpose. In this section, the digital data from AW3D30 are used for explanation as examples.

AW3D30（ALOS Global Digital Surface Model "ALOS World 3D - 30m "）: Japan Aerospace Exploration Agency (JAXA) is providing global digital surface model (DSM) dataset open to public with a horizontal resolution of approx. 30-meter mesh (1 arc-sec) free of charge.

Sentinel-2： Sentinels are a fleet of satellites designed specifically to deliver wealth of data and imagery that are central to the European Commission's Copernicus program.

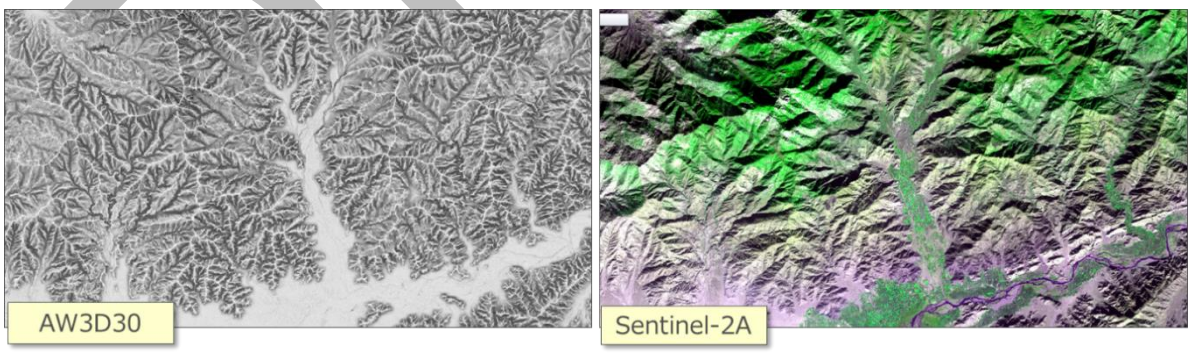
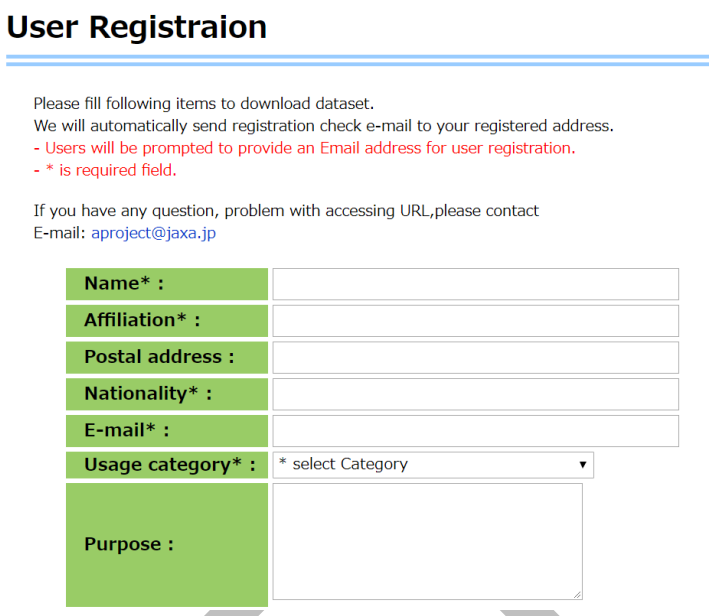


Figure 1-44 Global Digital Surface Model (DSM) Datasets

Source: JICA Project Team

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AW3D30 dataset for the entire world can be downloaded from the website of JAXA. Registration and login are prerequisite before downloading. AW3D30 dataset is open to public for free of charge but requires citing credit of JAXA. It must be required to read the terms of use before using.



User Registraion

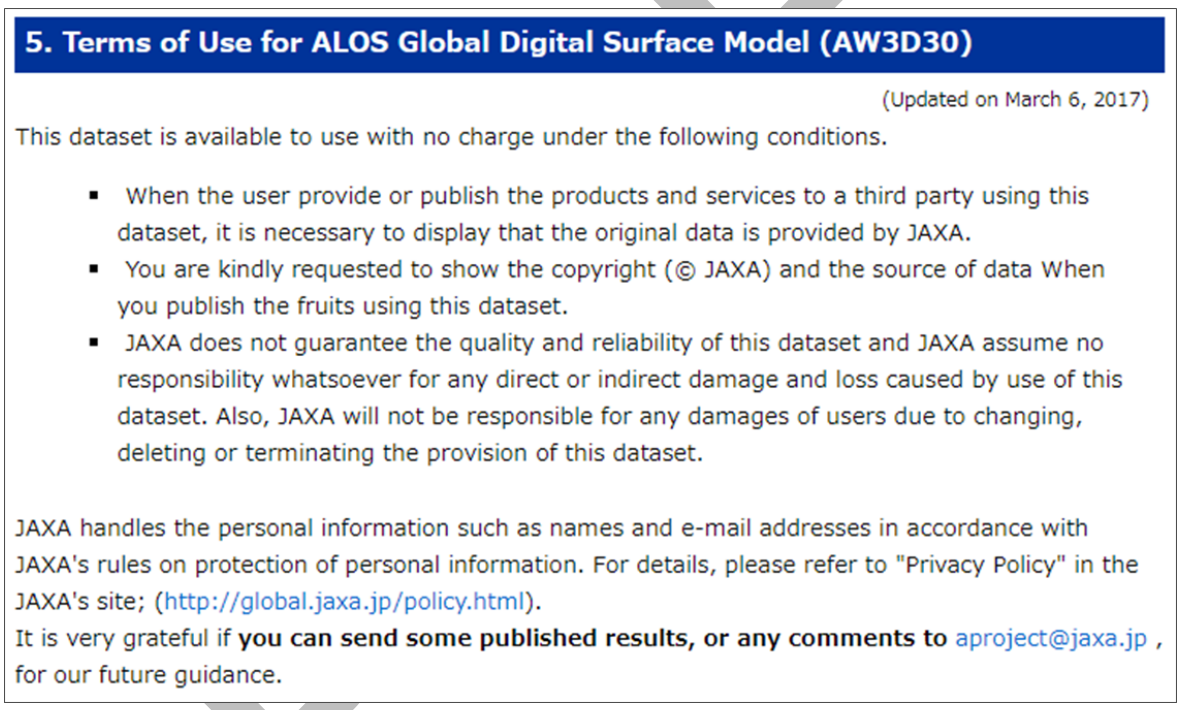
Please fill following items to download dataset.
We will automatically send registration check e-mail to your registered address.
- Users will be prompted to provide an Email address for user registration.
- * is required field.

If you have any question, problem with accessing URL,please contact
E-mail: aproject@jaxa.jp

Name* :	
Affiliation* :	
Postal address :	
Nationality* :	
E-mail* :	
Usage category* :	* select Category
Purpose :	

Figure 1-45 User Registration Form of AW3D30

[3]



5. Terms of Use for ALOS Global Digital Surface Model (AW3D30)

(Updated on March 6, 2017)

This dataset is available to use with no charge under the following conditions.

- When the user provide or publish the products and services to a third party using this dataset, it is necessary to display that the original data is provided by JAXA.
- You are kindly requested to show the copyright (© JAXA) and the source of data When you publish the fruits using this dataset.
- JAXA does not guarantee the quality and reliability of this dataset and JAXA assume no responsibility whatsoever for any direct or indirect damage and loss caused by use of this dataset. Also, JAXA will not be responsible for any damages of users due to changing, deleting or terminating the provision of this dataset.

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It is very grateful if **you can send some published results, or any comments to** aproject@jaxa.jp , for our future guidance.

Figure 1-46 Terms of Use for ALOS Global Digital Surface Model (AW3D30)

[4]

(2) Introduction of QGIS

Development of QGIS started in 2004. Programmers from around the world have joined for the development. The latest updated version is 3.0（as of 2018 May）. It is called "QGIS" since V2.0（before that, it was called Quantum GIS). QGIS is open source program and installing and using QGIS program costs you practically no rupees. The details are given at https://www.qgis.org/en/site/.

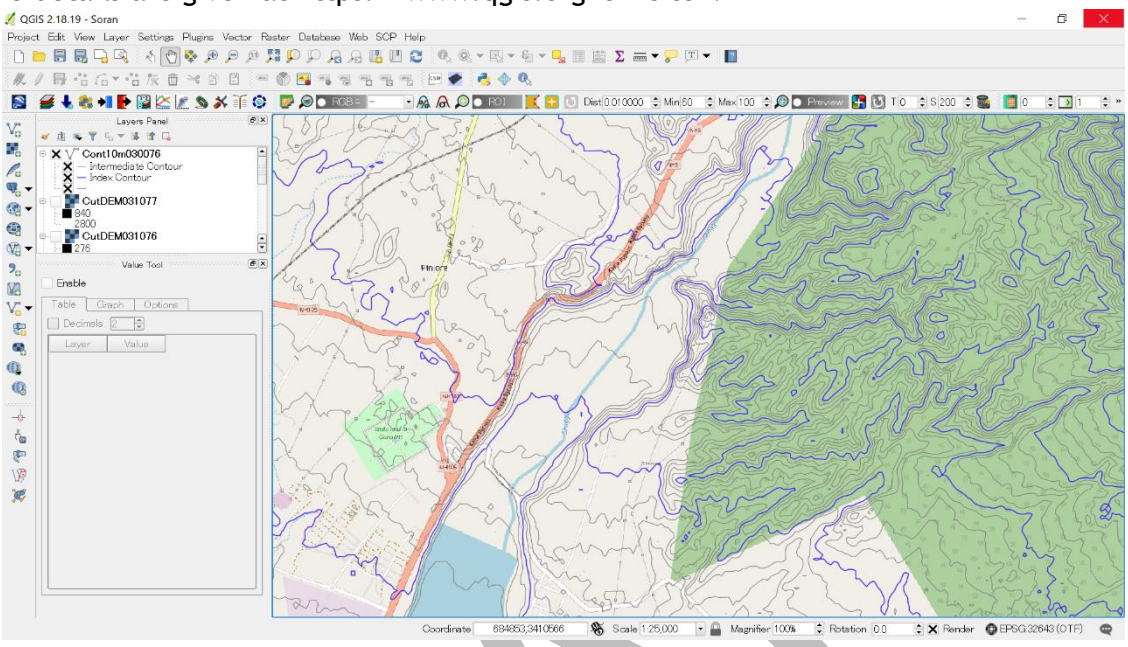


Figure 1-47 Screen of QGIS Immediately after Startup

Source: JICA Project Team

(3) Procedure of Creating Contour

In order to identify the area for map production on QGIS, an available map should be arranged as a background. Then the area for production should be delineated by a rectangle shaped polygon with which DSM or DEM is clipped. Using clipped DSM or DEM, QGIS produced contour lines as designated. Without clipping digital map, contour production would require long hours to process and produced contour maps would be too heavy to be handled with ordinary PCs.

Through arranging direction and scale of map as well as properties of intermediate and index contour lines and contour interval, a topographic map with sufficient resolution for map reading and interpretation would be prepared.

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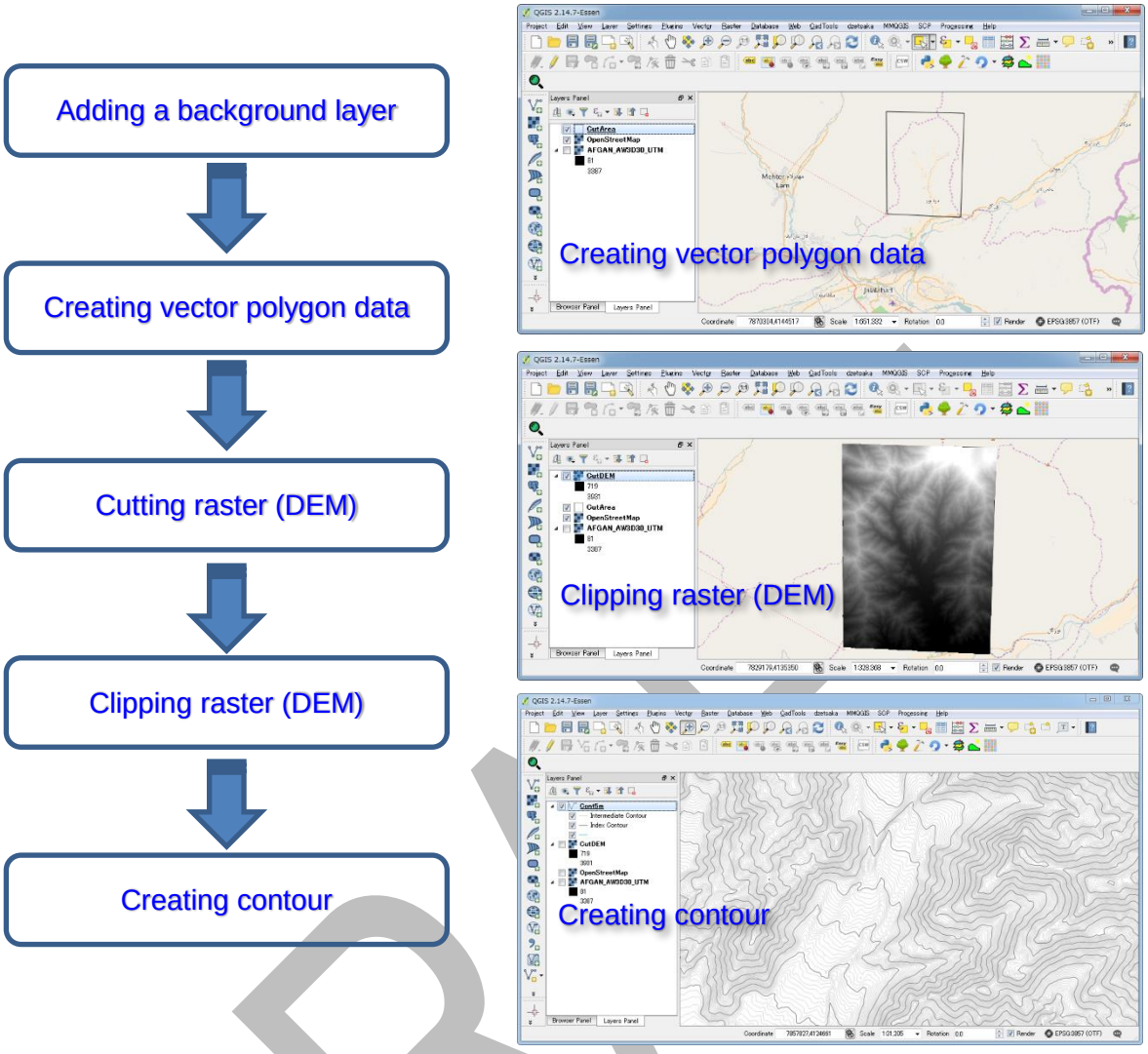


Figure 1-48 Procedure of Contour Creating

Source: JICA Project Team

[1] Shin, Y.S., Jisuberi Kogaku (Landslide Engineering), Sankaido, 1989.

[2] Varnes, D.J., "Slope Movement Types and Processes, in Schuster, R.L., and Krizek, R.J., eds., Landslides. Analysis and Control," *Transportation Research Board Special Report 176*, p. p. 11.23., 1978.

[3] Japan Aerospace Exploration Agency, "User Registraion," [Online]. Available: http://www.eorc.jaxa.jp/ALOS/en/aw3d30/registration.htm.

[4] Japan Aerospace Exploration Agency, "ALOS Global Digital Surface Model "ALOS World 3D - 30m (AW3D30)"," [Online]. Available: http://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm.

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1.2 Landslides/hazards affecting the hill road in service

1.2.1 General

In the Chapter 1.2 ~ 1.5, landslides along hill roads in service as well as in construction are described. Each section focuses one of important phases in hill road projects as listed below:

Phase1（1.2）: (for roads in service) interpretation of damage which affects road structure
Phase2（1.3）: (for roads in service) disaster scenario for the places where damage does not appear but implication or precursor of damage is observed.
Phase3（1.4）: (for road widening) evaluation of impact to slopes by road widening
Phase4（1.5）: (for new road construction) potential disaster which may be triggered by new road construction

1.2.2 Hazards

In this section, typical damage often observed on hill roads in service is explained with actual examples in India and Japan.

(1) Subsidence and Lateral Displacement of Road Surface

Subsidence of road surface is caused by two reasons; landslide and improper practice of construction.

The subsidence and lateral displacement caused by improper construction often gradually cease unless external force to facilitate deformation is added. On the other hand, the subsidence and lateral displacement that may cause landslide tend to gradually destabilize slopes and eventually lead to fatal destruction of slopes and roads.

For the sections where repeated repair is required due to deformation, to make proper decisions on road maintenance, the engineers should investigate whether it is going to stabilize or destabilize.

For making proper decisions, as typical cases, three examples of subsidence and lateral displacement are explained below. One example of differential subsidence involving embankments is also highlighted.

(i) Deformation of Road Surface Caused by Gravity Deformation

As described in the previous sections, gravity deformation is long-term deformation of bedrock slope by the action of gravity due to the weight of bedrock slope itself. The slowly but steadily deformation of rock is called “creep”. Gravity deformation often occurs in the slopes of relatively hard bedrock, such as gneiss, phyllite, and crystalline schist, with deeply developed fractured zones. In such bedrock slope, creep deformation proceeds in loosened fractured zones which lies deep underground with certain thickness.

Topographic features of gravity deformation resemble those of landslide, with head scarp at the top and bulging at the bottom. But gradient of slope is totally different. Gravity deformation is considered as initial form of slope deformation and, compared with landslides, the gradients of deformed slope and fracture zone behind it are definitely steep.

Gravity deformation progresses under simple shear stress. With less deformed moving rock mass above and stable ground below, fractured zone of several meters in thickness deforms as a form of creep. The boundary between the fractured zone and the

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lower stable ground is called lower surface, and that with the upper moving mass is called upper surface. Both surfaces are considered as main displacement shear surfaces. These two boundary surfaces extend to both flanks of a gravity deformation and exhibit double or multiple displacement, a set of adjacent two or more traces of subsidence with lateral displacement, on the road structures traversing at each flank of the deformation. The mechanism of gravity deformation with double displacement is explained in Figure 1-49 and Figure 1-50. At the same time, Figure 1-50 shows an actual example of gravity deformation observed at Paglajhora on NH55 between Siliguri and Darjeeling in the state of West Bengal. The gravity deformation at Paglajhora has three layered fractured zones, which exhibit 3 sets of double displacement on the road surface and structures of NH55.

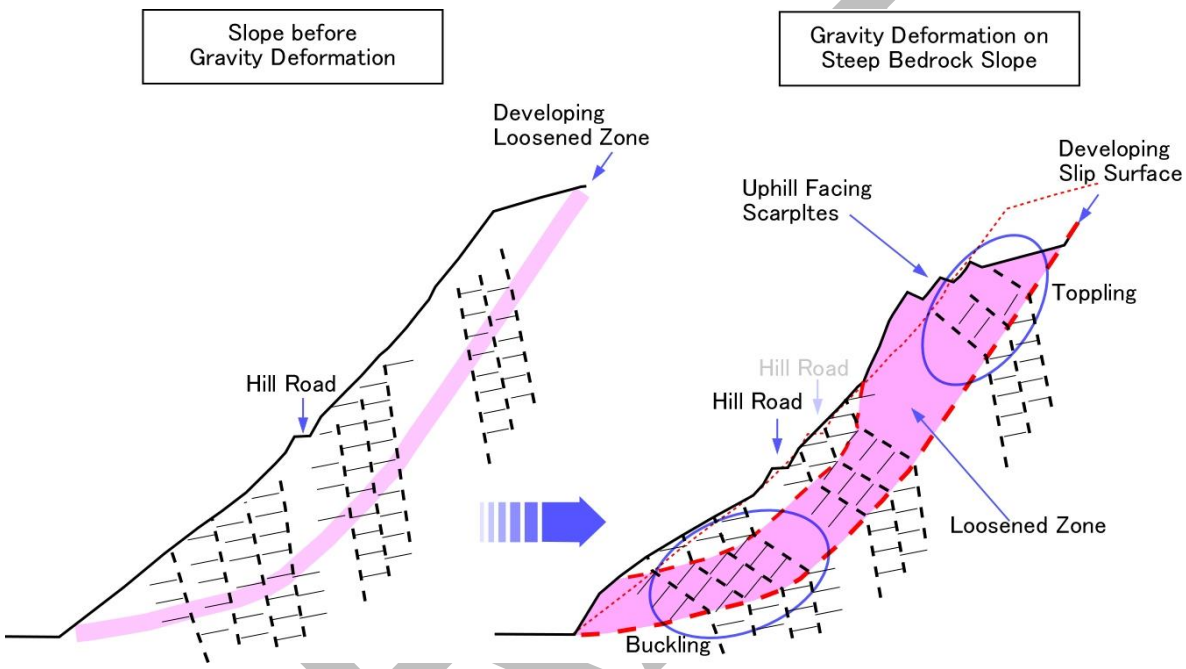


Figure 1-49 Mechanism of Gravity Deformation

Source: JICA Project Team

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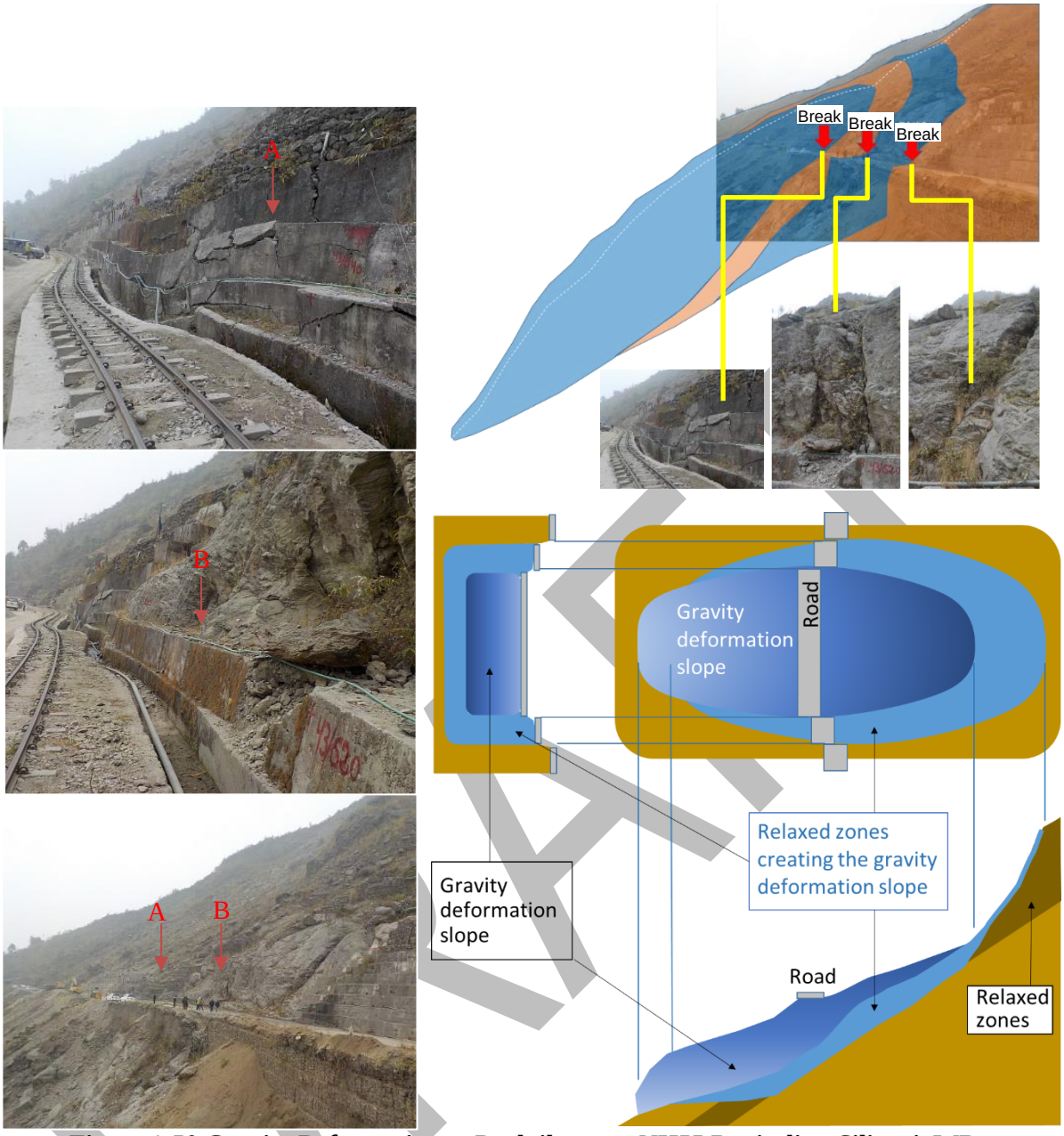


Figure 1-50 Gravity Deformation at Paglajhora on NH55 Darjeeling-Siliguri, WB

Source: JICA Project Team

(ii) Deformation on Road Surface Caused by Landslide with Low Angle Slip Surface

The landslide with low angle slip surface is the landslide of narrow definition in Table 1-3, which has landslide clay on its slip surface. Since the slip surface is gentler, the driving force of such landslide is theoretically smaller than that of gravity deformation. So such landslides should be less active compared with gravity deformation. But such landslides move repeatedly with relatively small triggers. Another factor other than gradient of slip surface may govern the movement of landslides and gravity deformation.

Shear strength of fractured rock acts as resistance force of gravity deformation whereas that of landslide clay acts as resistance of such landslides, the expected strength of which must be much weaker than that of fractured rock. In addition, residual shear strength of landslide clay, which is the weakest among the shear strength of clay, governs the resistance force. This is the reason why landslides

chronically repeats slide and stop movements, even though driving force is far much smaller than that of gravity deformation.

Similar to the fractured zone of gravity deformation, slip surfaces of such landslides have main displacement shear surfaces on both upper and lower sides of landslide clay. Between the two main shear surfaces lies landslide clay, in which sheared zone is formed with complicatedly developed subsidiary shear surfaces. The thickness of such sheared zone is usually several ten centimeters or less, however. Thus, unlike gravity deformation, double displacement is rarely observed at flanks of landslides with low angle slip surface. Subsidence of road surface with lateral displacement is observed at one location on each flank of such landslides.



Figure 1-51 Subsidence with lateral displacement at Flank of Landslide (Japan)

Source: JICA Project Team

(iii) Gravity Deformation Facilitated by River Bank Erosion and Submerging Slope of Dams

In general excessive river bank erosion at undercut slope along a river may deteriorate the roads running above the slope in a form of collapse of shoulder and cracks on pavements due to relaxation of slope as well as slide away of road beds when river bank slope collapses. Submerging slope due to flooding or impounding of dam may cause accumulating subsidence of road surface caused by wash away of soil particles inside slope when water level decreases. Thus river bank protection and wash away protection behind river structures are important for roads along rivers.

Gravity deformation may be expedited by the similar triggers. River bank erosion facilitates gravity deformation by removing support at the toe of deformation.

Washing away of soil from the fractured zone (creeping zone) of gravity deformation weaken the strength of the zone and facilitate the deformation.



Figure 1-52 Damage on NH10 Siliguri-Gangtok in WB, Left: river bank erosion and revetment as a countermeasure, Right: subsidence of road by washing away of soil

Source: JICA Project Team

Figure 1-53 shows actual examples of gravity deformation observed at sections on NH10 in the state of West Bengal. Riverbank erosion and collapse of submerging slope facilitate gravity deformation by removing supports and loads at the toe of the slope. In most of such cases, the gradients of the slope as well as creeping zones are supposed to exceed 45 degrees. On road structures, subsidence of the road surface and bulging of the slope are dominating.

Double displacement on the road surface, featuring gravity deformation, was observed on both flanks of deformations. Seepage on the slopes was often confirmed at flanks of deformation, where loosened fractured zone is exposed.



Figure 1-53 Gravity Deformation on NH10 in WB, Left: partially collapsed slope of gravity deformation, Upper Middle: subsidence of road, Lower Middle: seepage from loosened zone, Right: top of partial collapse of gravity deformation

Source: JICA Project Team

(iv) Damage at Boundary between Cut and Fill

Combination of cut and fill is often employed in hill road construction in the aim of minimizing the risk of cut slope failure and utilizing materials form cutting. After

entering service period, however, the following damage often emerges at sections of cut and fill: open cracks with subsidence along center lines and turtle back shaped cracks on the pavement of filling areas. Such damage is caused by the difference of hardness, compaction, and stability between cut and fill areas. Cut areas often exhibits high bearing capacity whereas artificial filling is sometimes compacted due to the traffic loads after entering service. At the same time, fill slope is often damaged by ill-prepared drainage and slope protection which may erode or destabilize the slope. To avoid such damage, proper selection of filling material and adequate control of compaction are essential, along with well-prepared drainage system and fill slope protection.

If filling is put on heads of landslides, the landslide is activated during rainy seasons and causes damage to the road. Careful investigation is essential to avoid such damage.

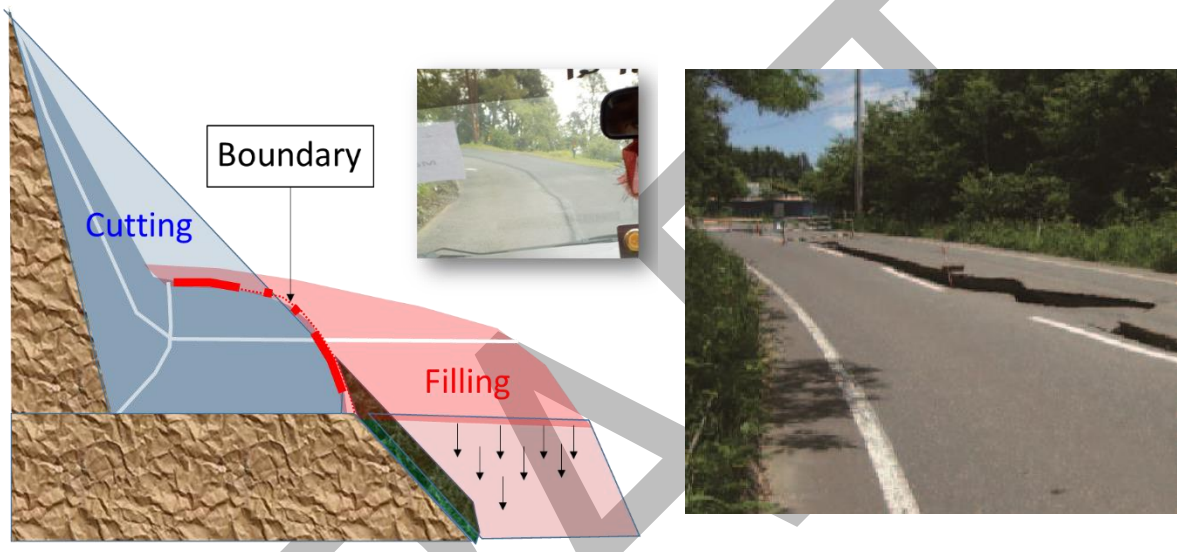


Figure 1-54 Cracks along Boundary of Cut and Fill

Source: JICA Project Team

(2) Damage by Debris or Deposits from Upper Slope

Various causes are assumed for the damage by debris or deposition provided from the upper slopes; rock fall/slide from natural/artificial slopes, debris from slope failure of upper slopes, debris and boulders which travel long distance from free face* of mountain slopes which is located quite far from the road, and debris flow at valleys.

To counteract such damage on roads by debris, locating the source of debris is essential by checking properties of debris, deposits, and boulders on not only roads but lower slope and stream bed, for rock type, shape of boulders and gravels, and structure of deposits.

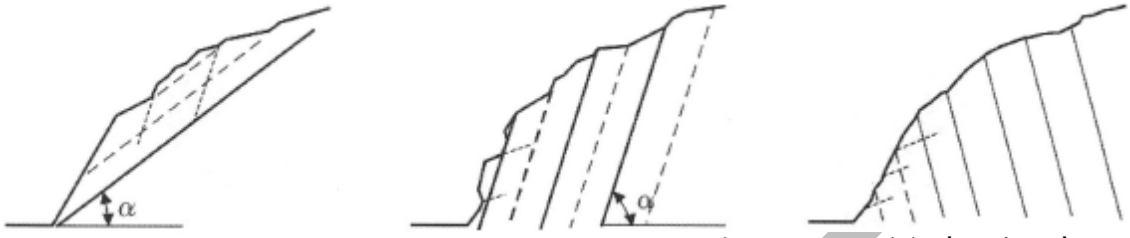
Examples of deposits and debris along hill roads in India from various sources are explained in this section.

(*) “free face” means unsupported slope by others. Protruding slopes or slopes at ridges have free faces.

(i) Supply of Debris from Cut Slope along Hill Road

Due to changes in intersection between road alignment and geological structures or topographic condition as well as variations in weathering/alternation conditions of slopes, condition of outcrop observed on cut slopes along hill road may vary significantly even among adjacent or neighboring slopes. Understanding conditions

of cut slopes, such as material and geological structures of slopes including dip and plunging slope, is essential for risk evaluation of hill road. Table **1-13** shows other check items for cut slopes, including evaluations on weathering, erosion, rock fall, and slope failures.



(a) dip slope α=30~50° Slope failure with sliding

(b) dip slope α>50° Rock fall

(c) plunging slope Toppling, rock fall

Figure 1-55 Dip and Plunging Slope

[1]



Figure 1-56 Neighboring Slopes Showing Variations in Slope Conditions along NH310A Gangtok-Lachung in Sikkim, Left: slope of soil, Center: Slope of soil with boulders, Right: rock slope failure

Source: JICA Project Team

Type property of cut slopes supplying debris governs selection of countermeasures against landslide.

The slopes mainly composed of soil require reshaping with proper gradient, which depends on strength of soil and the height of slopes between berms, and structures against weathering and erosion, which duly pay attentions against wash away of soil and seepage of groundwater. The slopes where earth pressure may affect partially or entirely require retaining structures. The soil slopes with boulders require removal of unstable boulders in addition to the aforementioned works for soil slopes.

For the slopes of rock, depending on relaxation conditions, applying shotcrete, rock fall net / fence, concrete crib work, concrete crib work + rock bolts, and concrete crib work + ground anchors are considered for countermeasures.

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Table 1-13 **Check Items for Risk Assessment of Cut Slopes**

Items	Soil and lithology		Soil incl. HW Rock	Soil with Gravel & Boulder	Weathered Rock	Rock
Property	Topography	Height	✔	✔	✔	✔
		Gradient	✔	✔	✔	✔
	Geology	Strike and dip	-	-	✔	✔
		Slaking	(✔)	-	✔	✔
		Contraction / Swelling	(✔)	-	✔	✔
Weathering	Topography	Catchment Topography	✔	✔	✔	✔
		Direction of Slope (Facing Sun or not)	✔	✔	✔	✔
Erosion	Topography	Catchment Slope	✔	✔	✔	(✔)
		Development of Gully	✔	✔	(✔)	-
	Vegetation	Vegetation Cover	✔	✔	(✔)	-
Rock Fall	Types	Detached	-	-	✔	✔
		Boulder	-	✔	-	-
	Energy	Location	-	✔	✔	✔
		Movement	-	✔	✔	✔
Slope Failure (Collapse)	Risk of Failure	Cracks	✔	✔	✔	✔
		Relaxation	✔	✔	✔	✔
		Restricted surface	✔	✔	✔	✔
		Soil pipes	✔	✔	✔	✔
		Spring / seepage	✔	✔	✔	✔

Source: JICA Project Team

(ii) Supply of Debris from Free Face on Upper Slope located Far from Hill Road

In the hilly regions in India close to the Himalayas, abundant debris is often observed depositing on and around hill roads. Such debris seems to have traveled from outcrops of very steep free face located far and high from the hill roads, after being detached from the outcrops as a form of rock fall or rock slide. Free face slope is often formed by gravity deformation, which entails fractured zones or relaxed cracks.

Figure 1-57 shows devastating debris deposition observed at Syanachatti Village along NH94 in the State of Uttarkhand, which occurred in the rainy season of 2017. The debris was apparently provided from the upper slope which shows features of free face. The latest trace of failure or slide, which shows brighter colors in the photos, has a dimension of 100 meters in slant length and 60 meters in width, and a distance from the hill road of 520 meters in slant distance and 370 meters in height. The geology of the source of the debris is hard and rigid gneiss with plunging structure at the face, with cracks and fractured zones which partially developed at the outcrop. Obviously, weathering front remains in the shallower depth from the face of unloading.

The structure of debris suggests multiple depositions in the past as forms of rock slide then debris avalanche. The boulders in the debris are mainly gneiss, the maximum diameter of which reaches 3 meters. In the rock slide of 2017, the amount of debris was not such large to form a landslide dam. This is probably because the sliding mass in 2017 was relatively small; frequent rock slides in rainy seasons minimize the relaxed parts of free face which may develop after unloading occurs at the face.

If debris along a road seems to be provided from the source located far from the road, recording shape and size of fallen rocks of debris is important, by which

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impact force at given locations is assumed. The impact force is one of major factor to consider proper countermeasures. In addition, debris often forms talus slopes with angle of repose, on which boulders may move again by triggers, such as rainfall, erosion, and earthquake. Such reactivation of rock fall or slide should also be considered.



Figure 1-57 Debris Deposit (Talus) Provided from Upper Free Face (NH94, Syanachatti), Left: full view, Top Right: collapsed slope and talus, Bottom Right: Talus at lower part.

Source: JICA Project Team

(iii) Debris Flow Deposit

In the Himalayas, due to orogenic activities which entail densely developed thrusts running parallel to the mountain range, steep mountain slopes were formed along with fractured zones in bedrock, both of which are factors of gravity deformation. Under such conditions, various types of landslides, including deep sheeted landslide, rock slide, and debris avalanche, of wide range in size frequently occur and produce numerous amounts of debris, which facilitate frequent debris flows along streams in the mountains. On the steep slopes in the Himalayas, hill roads inevitably cross mountain streams where devastating debris flows frequently occur.

To counteract debris flow, the following procedure is recommended:

(a) To study history / records of debris flow for all mountain streams crossing hill roads,
(b) Based on the study of debris flow occurrence, among the crossing streams, to designate dangerous streams as “debris flow prone streams”,
(c) (For debris flow prone streams) to plan and install a series of groundsill (drop works) and check dams (sabo dams) on the mountain streams in the aim of stabilizing riverbeds and preventing production of debris, and
(d) (For debris flow prone streams) to plan and install impermeable type check dams and channel works along hill roads where it cross mountain streams.

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Figure 1-58 Damage by Debris Flows along NH310A, Gangtok-Lachung Sikkim, Left: damage on NH310A, Top Center: collapse (source of debris flow), Bottom Center: debris flow deposit under NH310A, Upper Right: erosion of debris flow deposit, Lower Right: debris flow joining main stream

Source: JICA Project Team

(3) Deformation on Embankment

As long as properly designed and constructed, embankment may not cause serious problems to hill roads. Several causes may lead deformation on embankment as follows:

(a) Improper material
(b) Insufficient compaction of material
(c) Improper treatment of bearing layer
(d) Erosion of embankment slopes
(e) Improper treatment of toe of slopes
(f) Improper treatment of drainage system (surface, crossing, and slope)
(g) Improper treatment against consolidation settlement

The causes of (a) and (b) may develop differential settlement and cracks on the road surface which may lead infiltration of surface water into embankment. Such infiltration causes internal erosion and then leads pipe flow within embankment, which may cause failure of embankment. The embankment with such defect may show tilting or bulging of retaining walls along the toe of embankment.

The cause (c) may lead a failure of embankment, especially when the embankment is put on a head of a landslide.

The causes of (d), (e), and (f) destabilize embankment slopes. Among them, erosion or wash away of toe of embankment directly cause failure of embankment.

The cause of (g) may not be eye catching along hill roads but where soft soil lies below the alignment, consolidation settlement causes long life problems of differential settlement at the boundary with structures. Along hill roads, submerged valleys, back marsh, traces of ponds / lakes, and marsh lands formed by landslide dams may have soft soil layer underground.

A shoulder of embankment collapsed by foot erosion is shown in Figure 1-59. Gully erosion at lower slope led collapse of the lower slope and affected the foot of the embankment possibly located on the middle of the slope.

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Figure 1-59 Damage Due to Embankment Collapse (NH707A, Dehradun－Uttarakhand, UK)

Source: JICA Project Team

1.2.3 Slope inventory (Disaster Record)

In this section, points to check at site for preparing slope inventories (or disaster records) are explained for each landslide type described in the previous section. The landslide types to be explained are as follows:

- Gravity Deformation
- Landslide
- Rock fall
- Slope failure (collapse)
- Deep-seated landslide
- Debris flow

Depending on the landslide types, the points to check on site are different. The following four points are, however, common among the six landslide types.

Important point 1 : Understanding origin or source of landslide including topography (length, width, and depth) and location.
Important point 2 : Understanding moving property of landslide including distance, direction, velocity, mode, and continuity of movement
Important point 3 : Understanding mechanism of landslide (factor and trigger) and evaluating probability of expansion
Important point 4 : Confirming facilities to protect against and assessing impact to the surroundings by landslide

In Table 1-14 ~ Table 1-19, individual points to check on site are summarized for each landslide type. Besides such tables, results of drilling investigation and landslide monitoring should be collected if available. Such results are useful in understanding geological and hydrogeological conditions as well as activities of landslides in relation to variation of rainfall and groundwater level. Drawings, layout, and specifications of existing structures are also essential.

(1) Gravity Deformation

Gravity deformation is a less-developed form of more devastating deep seated landslide. Thus, when damage by gravity deformation is found on hill roads, possibility of developing to deep seated landslide should be carefully evaluated. A deep

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seated landslide is triggered by an earthquake or heavy rainfalls and often led by precursors such as frequent occurrence of rock fall and small collapse at the toe of gravity deformation.

The supposed mechanism of rock fall and small collapse as the precursor is explained below and in Figure 1-60:

1. At the bottom of steep loosened (and sometimes fractured) zone accumulates the maximum effect by the gravity.
2. Progressive failure starts from the bottom of steep loosened zone toward the toe.
3. Compressive failure at the toe occurs due to the progressive failure. As compressive failure proceeds, irreversible deformation at toe is accelerated, which may initiate deep seated landslide of entire slope.

In other words, rock fall and small failure at the toe of gravity deformation suggest the loosened zone is extended by the progressive failure to the surface. At the same time, such small failures leads gradual unloading at the toe, which facilitates destabilization of entire slope. Slope failures at the toe sometimes clogs groundwater springs and then saturates the loosened zone, which produces pressured groundwater easily at the toe. Such conditions with pressured groundwater in the loosened zone drastically increase danger of deep seated landslide when exceptional heavy rain pounds.

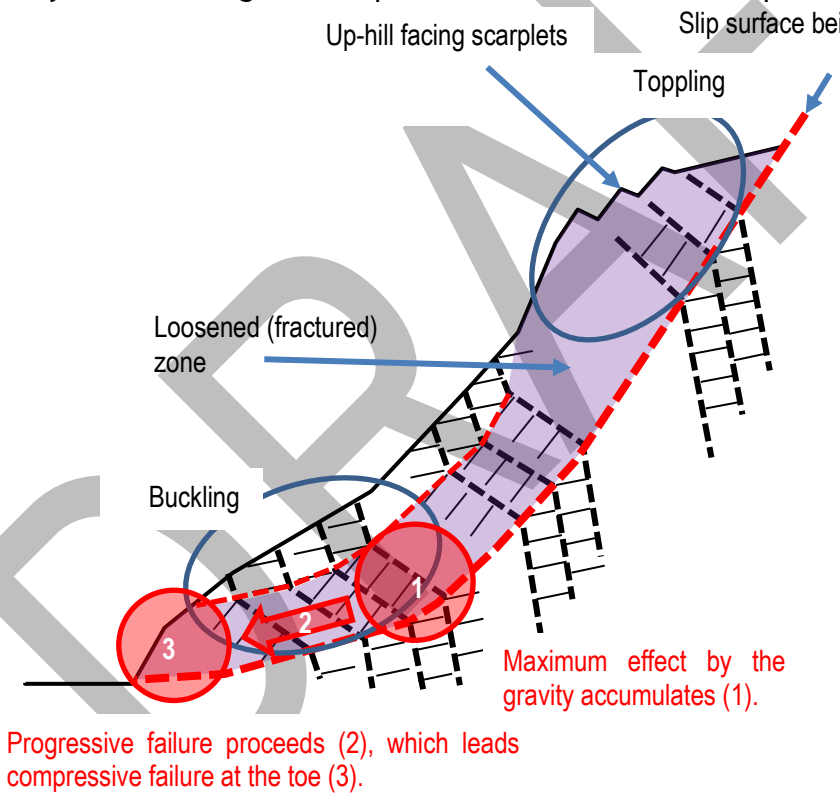


Figure 1-60 Gravity Deformation Develops to Deep Sheeted Landslide

Source: JICA Project Team

Besides deep seated landslides, subsidence of hill roads is another major problem caused by gravity deformation in operation and maintenance of hill roads. Understanding location and extent of damage and characteristics of subsidence may help considerations for countermeasures. Unloading is an effective countermeasure against gravity deformation so possibility of unloading should be evaluated along with delineating extent of gravity deformation.

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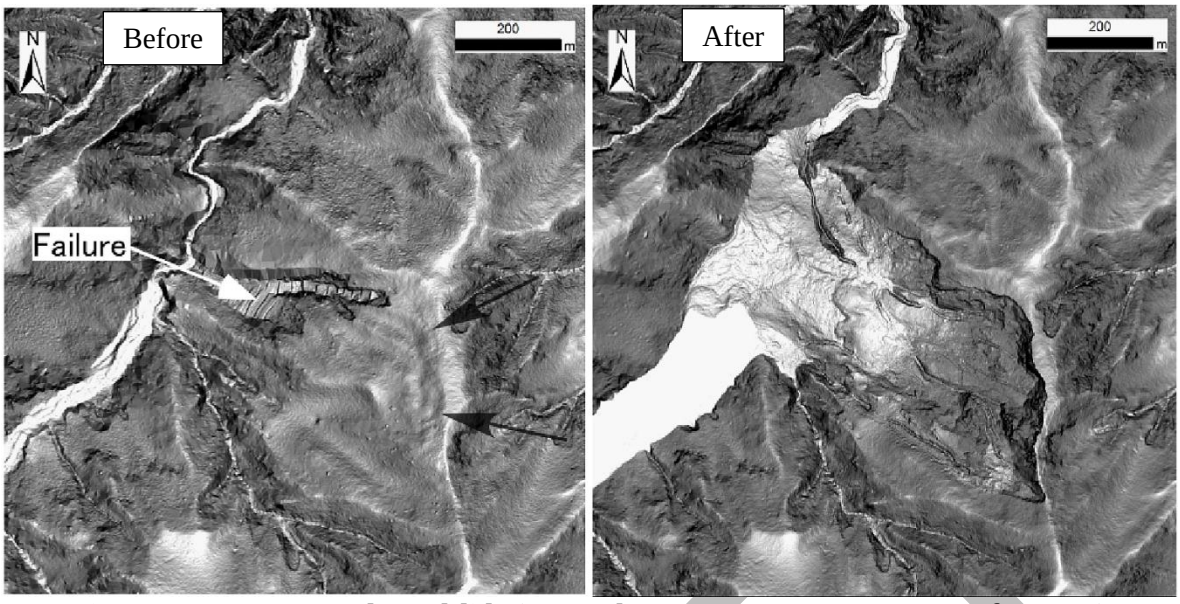


Figure 1-61 Deep-seated Landslide (September 2011, Nagatono, Nara Pref., Japan)

[2]

Table 1-14 Onsite Checklist (Gravity Deformation)

Type	Category	Details
Gravity Deformation	Shape and Location	To locate gravity deformation through map reading and the following confirmation on site. To measure length, width, and gradient of slope of gravity deformation. To record damage on road structures, such as location, pattern, and continuity of cracks on pavement as well as displacement along the cracks. To grasp details of deformation at both flanks, including subsidence, uplift, and displacement as well as degree of deformation.
	Movement	To grasp sense of shear and direction of cleavage of cracks on structures. To collect history of subsidence of road surface, including timing and displacement of subsidence. To collect record of repair/maintenance of structures. To collect disaster records, including interviewing with residence / witness. To check conditions of tilted and fallen trees
	Mechanism	To understand geological conditions, such as lithology, geological structure, fault, and fractured zone. To understand topographic conditions, such as lineament, alignment of kerncol and kernbut, and bending of valley system. To check micro-topographic features of gravity deformation, such as double ridges, up-hill facing scarplets, and traces of deep seated landslides. To check development of toppling and buckling on outcrop as well as bulging on middle to lower slope. To check collapse at toe of slope (risk assessment of deep seated landslide) To check back slopes which may work as catchment areas To understand hydrological conditions of groundwater, such as location of spring and seepage as well as quantity, quality including pH and ion distribution, and temperature of spring water. To understand hydrogeological conditions, such as fissures to contain groundwater and constraining floor to control groundwater. To study feasibility of unloading, removal from head, as countermeasures against subsidence.
	Facilities to Protect	To check facilities, including underground ones, within the area of gravity deformation. To check facilities adjacent to the area of gravity deformation.

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Type	Category	Details
		To forecast runout distance of debris (landslide mass) of deep seated landslide if it occurs, and to check the facilities to protect within the depositional area of debris To evaluate possibility of forming a landslide dam (natural dam) if deep seated landslide occurs, and to estimate the damage due to washout of the landslide dam.

Source: JICA Project Team

(2) Landslide

The essential step in landslide investigation is to delineate landslide blocks from moving mass of landslide as accurate as possible and to confirm direction of movement of each block through aerial photo / map reading followed by field surveys and drilling investigation. This step is essential for slope stability analysis and design of countermeasures against landslides because the shape and extent as well as moving direction of landslide blocks govern results of analysis and design.

Besides shape and direction of landslide block, mode of failure is another essential factor in stability analysis and design. Depending on the material and controlling discontinuities, such as cracks, joints, and bedding plane, mode of failure entails particular shape of slip surface such as follows:

(a) Moving mass of soil, without rock, often shows circular slip surface.
(b) Rock slide in rock strata, which move on a single major plane, shows rectangle (or planner) slip surface.
(c) Wedge failure, which is controlled by two conjugate planes, shows line of intersects.

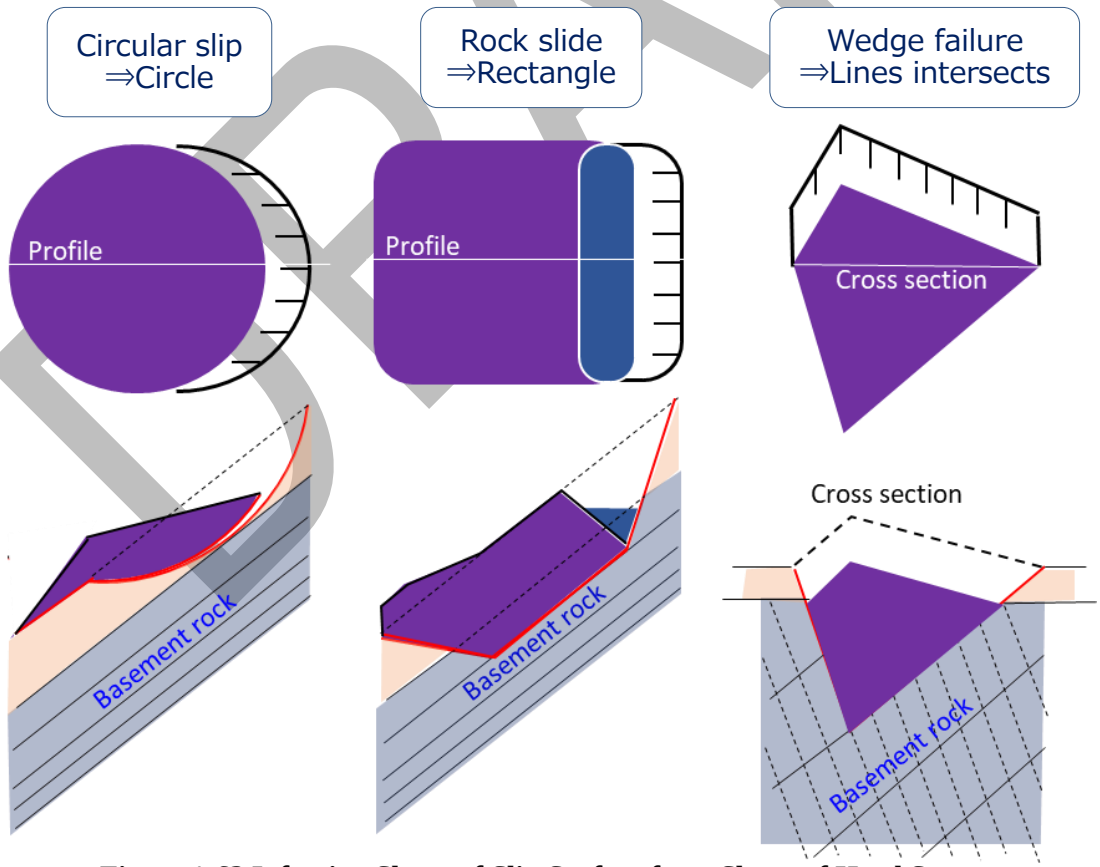


Figure 1-62 Inferring Shape of Slip Surface from Shape of Head Scarp

Source: JICA Project Team

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Each mode of failure entails particular shape of head scarp (or crown) as shown in Figure 1-62.

In wedge failure, line of intersects is the deepest in slip surface and crosses head scarp at bend. In circular slip and rock slide, the shape of head scarp implies the deepest section of landslide. Slope stability analysis and design of countermeasure should be examined on the prolife on the deepest slip surface, deciding the location of the main survey line is important and shapes of head scarp provide valuable suggestions for such purpose.

Landslide movement often leaves traces on trees. Since trees tend to grow vertically, when trees are tilted by movement of landslides, bending of trees, which indicates direction of landslide movements, is observed in such areas and called “tree bending”. Even after being logged, tree bending leaves deviation of tree ring, by which direction of landslide movement is also indicated.

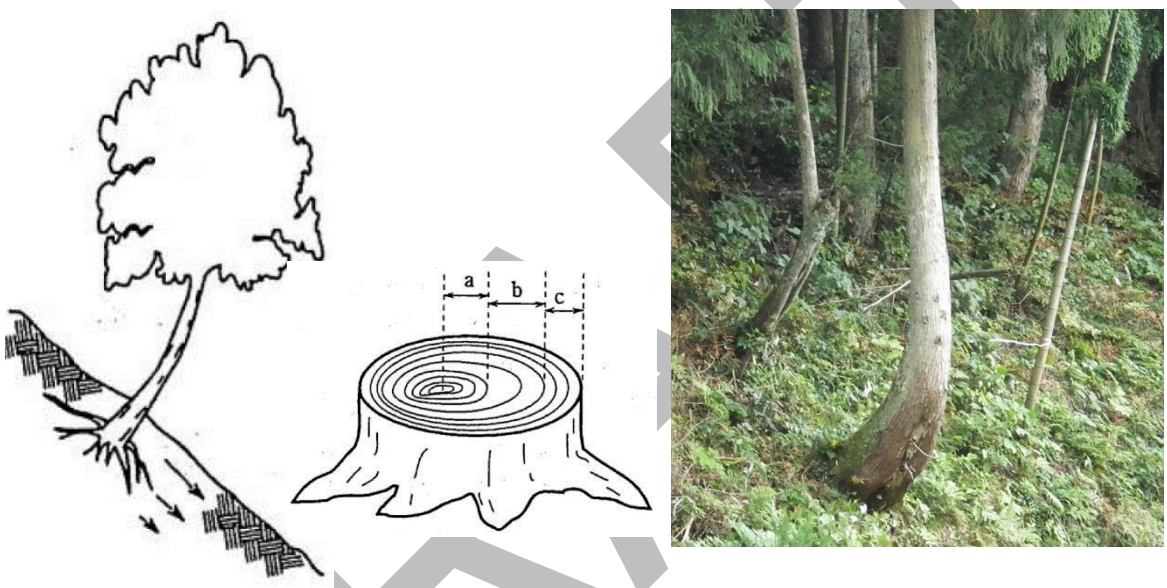


Figure 1-63Tree Bending in Landslide Area, Left：Cause of Tree Bending, Center：Deviation of Tree Ring, Right：Photo in Landslide Area

[3]

Table 1-15 Onsite Checklist (Landslide)

Type	Category	Details
Landslide	Shape and Location	To locate landslide through map reading and the following confirmation on site. To measure length, width, and gradient of slope of landslide. To evaluate shape of head scarp (or crown); circle, rectangle, and wedge. To record damage on road structures, such as location, pattern, and continuity of cracks on pavement as well as displacement along the cracks. To grasp details of deformation at both flanks, including subsidence, uplift, and displacement as well as degree of deformation. To check development of subdivided blocks
	Movement	To grasp sense of shear and direction of cleavage of cracks on structures. To collect history of subsidence of road surface, including timing and displacement of subsidence. To collect record of repair/maintenance of structures. To collect disaster records, including interviewing with residence / witness. To check tree bending.

Type	Category	Details
	Mechanism	To understand geological conditions, such as lithology, geological structure, fault, and fractured zone. To understand topographic conditions, such as lineament, alignment of kerncol and kernbut, and bending of valley system. To check landslide clay at the toe of landslide. To understand hydrological conditions of groundwater, including location of spring and seepage as well as quantity, quality including pH and ion distribution, and temperature of spring water. To understand hydrogeological conditions, such as constraining floor to control groundwater. To evaluate possibility of expansion of landslide.
	Facilities to Protect	To check facilities, including underground ones, within the area of targeted landslide. To check facilities adjacent to the area of landslide. To forecast runout distance of landslide and to check the facilities to protect within the runout distance.

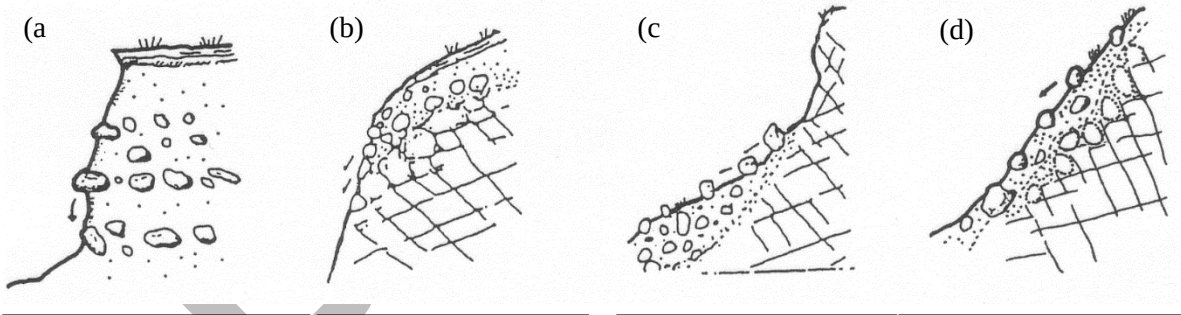
Source: JICA Project Team

(3) Rock Fall

Rock fall is divided into detached and boulder types by property of origin.

Figure 1-64 shows the typical forms of boulder type rock fall. Such rock fall starts with movement of boulders on or included in debris, or starts with collapse of debris itself including boulders. For the former case, boulders will move by triggers like earthquake, rainfall, freezing and melting of soil, trees blown by strong wind and contact with wild animals. In addition, erosion by rainfall, surface runoff, and groundwater flow erodes matrix of debris and eventually destabilize boulders within debris.

Generally the gradient of slope of case (a) is gentle, so boulders rarely jump after starting falling down. On the other hand, in the cases of (b), (c), and (d), generally boulders jump when it hit the ground after falling down.

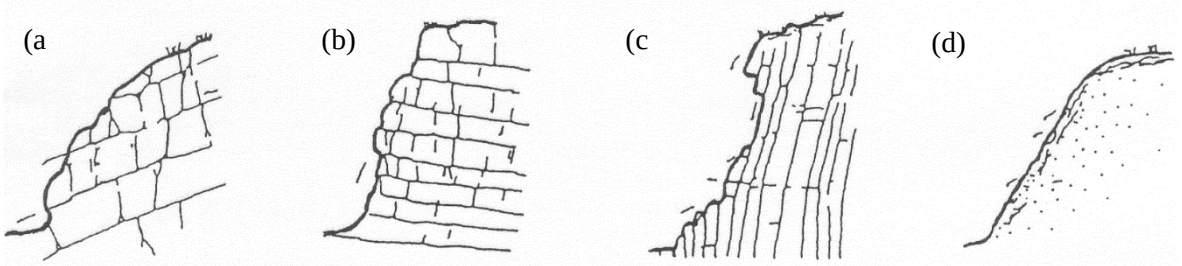


Conglomerate slope (terrace or volcanic sediments	Overburden and debris of at shoulder of slope	Slope composed of talus or debris.	Slope of soil, debris, or weathered part of rock

Figure 1-64 Forms of Rock Fall (Boulder)

[4]

Detached type rock fall, shown in Figure 1-65, mainly occurs on slope composed of rocks with discontinuities, such as cracks, joints, bedding, and foliation. Detached rock fall has similar mechanism of occurrence with failure of bedrock, triggered by rainfall, erosion, earthquake, freezing and melting of soil, trees blown by strong wind and contact with wild animals. Similar to gravity deformation, gravity facilitates formation of open cracks and loosened zone.



Dip slope structure	Plunging slope or horizontal discontinuities	Slopes with steep discontinuities	Slopes with no visible discontinuities

Figure 1-65 Forms of Rock Fall (Detached)

[4]

"Easiness of start moving" from the original position of rock fall should be evaluated in rock fall survey based on visual observation of open cracks with degree of aperture and filling material as well as possibility of move of boulders or unstable rock when external force is applied. Checking vibration characteristics of rock or boulder with simple strike of rubber hammer provides numerical data for evaluation.

In addition, estimation of runout distance of rock fall is another essential item to evaluate. If rock fall reaches to the road, possible damage by rock fall should be estimated.



Figure 1-66 Vibration Measuring by Hammering

Source: JICA Project Team

Figure 1-67 shows accumulation of rock fall under different conditions.

In the upper photos of Figure 1-67, the talus composed of rock fall derived from the head scarp accumulates in repose angle on bear land. On the slopes under such conditions, slope failure often occurs during rainfalls even with moderate precipitation.

In the lower photos, the head scarp which provides detached type rock falls is located at distance and the slope is covered by undergrowth. Under such conditions, small particles of debris settle at the upper slope but boulders of cubic shape with a diameter of 1 meter or more rebound repeatedly, scatter over the slope, and reach to and around the road.

For selecting appropriate countermeasure against rock fall, understanding the runout distance and extent of accumulation of rock fall as well as detailed accumulation structure including particle size distribution is an essential requirement in field survey for rock fall. In addition, categorizing the slope under investigation by topographic conditions shown in Figure 1-68 helps understandings of direction of rebounding and structure of accumulation of fallen rocks.

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Figure 1-67 Difference in Accumulation of Rock Fall, Upper : Barkot-Syanachatti on NH94 in Uttarkhand, Lower : Gangtok-Lachung on NH310A in Sikkim

Source: JICA Project Team

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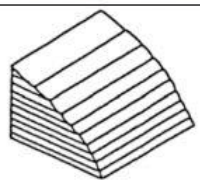
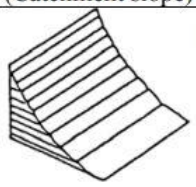
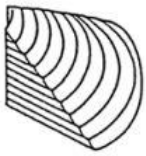
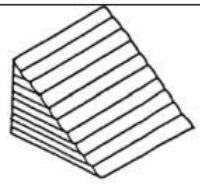
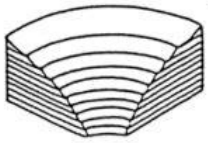
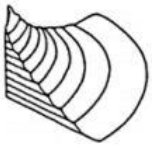
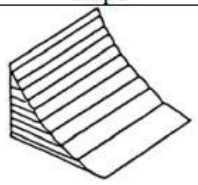
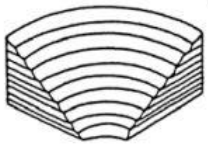
Viewpoint		State of change in the direction of the maximum gradient (water flow path)		
	Classification criteria	Classification of slope by the horizontal cross-sectional shape (planar shape of contour lines)		
	Classification	Ridge type slope (Sprinkling slope)	Straight line slope	Valley type slope (Catchment slope)
State of change in the magnitude of the maximum gradient (inclination)	Classification of slope by the vertical cross-sectional shape: Convex slope	 [1] Convex ridge type slope	 [4] Convex straight line slope	 [7] Convex valley type slope
	Straight line slope	 [2] Straight line ridge type slope	 [5] Straight line straight line slope	 [8] Straight line valley type slope
	Concave slope	 [3] Concave ridge type slope	 [6] Concave straight line slope	 [9] Concave valley type slope

Figure 1-68 Type of Slopes

[5]

Table 1-16 Onsite Checklist (Rock Fall)

Type	Sub type	Category	Details
Rock Fall	Detached	Shape and Location	To locate rock fall through map reading and the following confirmation on site. To measure width, height, and gradient of slope of the source of rock fall, such as steep cliff and head scarp. To grasp size and shape of fall rocks. To measure length and gradient of the slope where fallen rocks bound or slide, including knick and concave knick lines.
		Movement	To understand accumulation of fallen rocks on the slope where fallen rocks bound or slide, including distribution of fallen rocks and in relation to its size. To estimate direction of rock fall. To understand density of trees. To understand surface condition of the slope, soil or rock. To collect record of repair/maintenance of structures. To collect disaster records, including interviewing with residence / witness.
		Mechanism	To understand geological conditions, such as lithology, geological structure, fault, and fractured zone as well as crack/joint interval. To understand topographic conditions, such as lineament, alignment of kerncol and kernbut, and bending of valley system. To evaluate stability of rock fall at the source, including loosened condition and possibility of detachment, toppling, and sliding. To check development of toppling and buckling on outcrop (source of rock fall).

Type	Sub type	Category	Details
			To understand hydrological conditions of groundwater, such as location of spring and seepage as well as quantity, quality including pH and ion distribution, and temperature of spring water. To understand hydrogeological conditions, such as fissures to contain groundwater and constraining floor to control groundwater. To evaluate conditions of soil-binding by roots of trees (Evaluating risk of rock fall caused by windfall trees)
		Facilities to Protect	To forecast runout distance of rock fall and to check the facilities to protect within the runout distance. To estimate impact energy by fallen rocks to facilities to protect.
	Boulder	Shape and Location	To locate rock fall through map reading and the following confirmation on site. To measure distance between hill road and source of rock fall. To grasp size and shape of fall rocks. To measure length and gradient of the slope where fallen rocks bound or slide, including knick and concave knick lines.
		Movement	To understand accumulation of fallen rocks on the slope where fallen rocks bound or slide, including distribution of fallen rocks and in relation to its size. To estimate direction of rock fall. To understand density of trees. To understand surface condition of the slope, soil or rock. To collect record of repair/maintenance of structures. To collect disaster records, including interviewing with residence / witness.
		Mechanism	To evaluate stability of rock fall at the source, including embedded depth of boulders and erosion resistance of matrix of debris. To understand hydrological conditions of groundwater, such as location of spring and seepage as well as quantity, quality including pH and ion distribution, and temperature of spring water. To understand hydrogeological conditions, such as fissures to contain groundwater and constraining floor to control groundwater. To evaluate conditions of soil-binding by roots of trees (Evaluating risk of rock fall caused by windfall trees To understand development of gully erosion.
		Facilities to Protect	To forecast runout distance of rock fall and to check the facilities to protect within the runout distance. To estimate impact energy by fallen rocks to facilities to protect.

Source: JICA Project Team

(4) Slope Failure

Slope failure includes surface failure and rock slope failure.

Rock slope failure is similar to deep seated landslide but far much smaller in scale. Sometimes it is similar to detached rock fall as well.

Surface failure is defined as a phenomenon in which surface part of soil on bedrock with a thickness of several meters or less slides down. Since it occurs on the surface involving shallower part of soil, topographic conditions significantly affect the phenomena. In addition, it is strongly affected by weathering, vegetation, rainfall, gully erosion, shallow groundwater, wind, and artificial modification such as cutting and filling. Since various factors and triggers affect surface failure, identification of occurrence mechanism is essential for filed survey at site.

In addition, surface failure tends to occur simultaneously at the slopes with similar conditions. Thus in case multiple failures occur simultaneously along a valley system, even though size of each failure may be small, accumulated volumes of the failures may reach tremendous amount and cause devastative debris flow.

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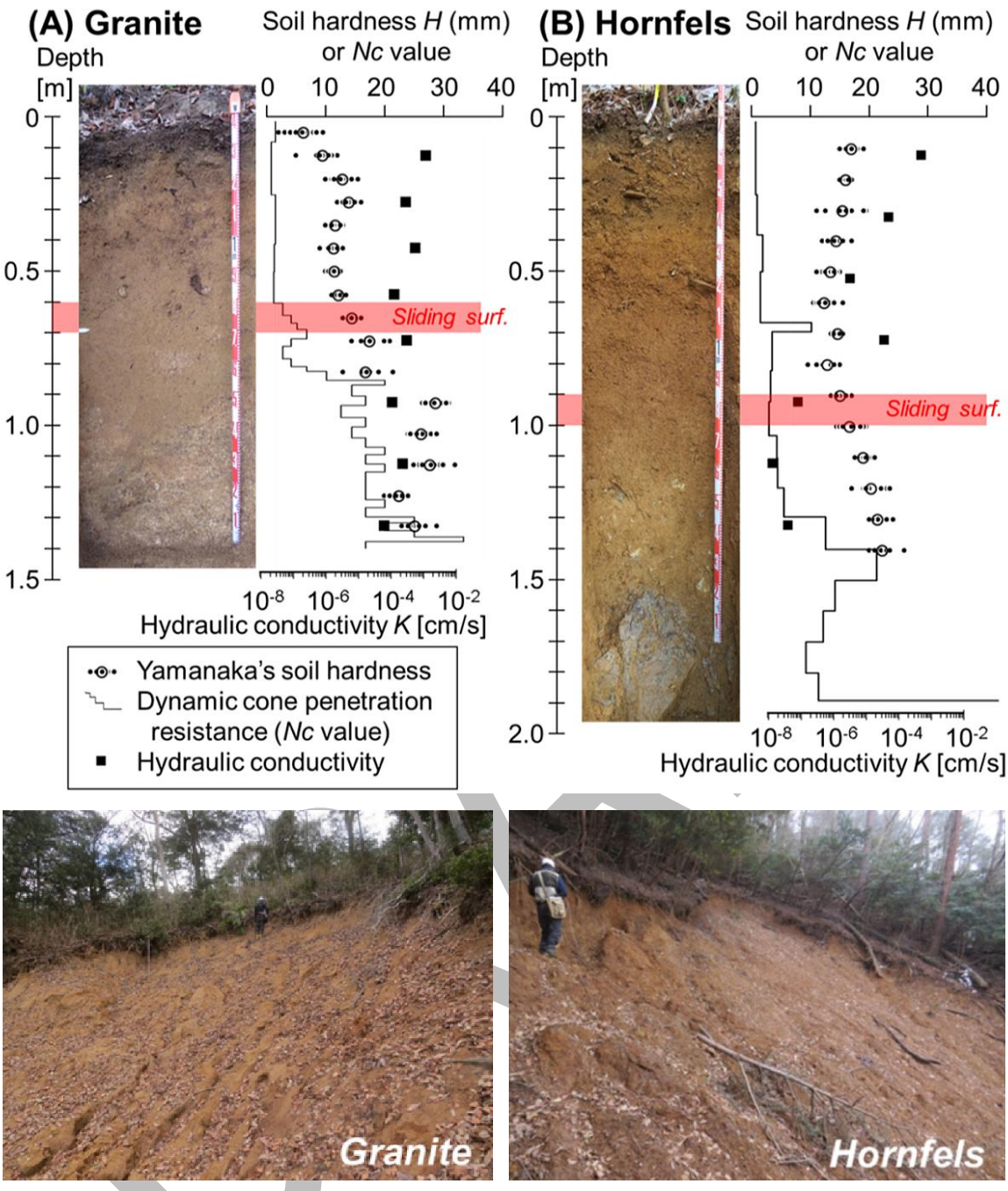


Figure 1-69 Soil Structures and Vertical Changes in Mechanical and Hydraulic Properties of Subsurface Material of Granite and Hornfels

[6]

Table 1-17 Onsite Checklist (Surface Failure)

Type	Category	Type
Surface failure	Shape and Location	To locate failure through map reading and the following confirmation on site. To measure length, width, area, depth and shape of failure, volume of debris, and gradient of slope of failure. To record the direction of slope and stream order. To grasp slopes with similar failures. To record damage on road structures, such as location, accumulated debris, wash away of roadbed.
	Movement	To measure travel distance of debris To understand situation and structure of debris deposition. To check tree bending To check Occurrence/nonoccurrence of debris flow To collect disaster records, including interviewing with residence / witness.
	Mechanism	To grasp catchment area, not only division by topographic conditions but by drainage structures of hill roads. To understand geological conditions such as weathering and rock quality. To understand permeability of weathering crust. To evaluate depths of bedrock (as a constraining floor). To understand forest cover, tree planting, bare land, and windfall trees. To evaluate increased instability caused by artificial cutting and filling. To evaluate instability of back slope caused by the failure. To grasp development of gully erosion. To understand development of soil pipes (number, depth and diameter) To understand hydrological conditions of groundwater, such as location of spring and seepage as well as quantity, quality including pH and ion distribution, and temperature of spring water.
	Facilities to Protect	To forecast runout distance of failure deposit including future expansion of the failure. To identify facilities inside the forecasted distance.

Source: JICA Project Team

(5) Deep-seated Landslide

Once it occurs, deep seated landslide requires immediate countermeasures against landslide dam. Landslide dam causes damage by flooding upstream and by massive debris flow downstream when it is breached. Thus immediate actions to discharge water from the landslide dam are necessary, while securing stability of the landslide dam.

In addition, due attention should be paid for stability of the slope where deep seated landslide occurred.. At head scarp, flanks, and surface of collapse, loosened condition of bedrock should be checked. Deposition of debris should also be investigated for its stability. Then unstable parts should be identified and monitored and direction of debris flow should be forecasted when loosened slope or unstable debris collapsed.

After deep-seated landslide occurs, unstable slopes show the following geological features:

- Steep bedrock slope with developed discontinuities, such as cracks, joints and bedding, where toppling, buckling and wedge failure are likely to occur
- Loosened zone at margin of head scarp, such as remaining rock creep and expansion of collapse.
- Debris rich in fine particles and easy to fluidize. If lower parts of debris have such property and are exposed, such parts are vulnerable to gully erosion which leads debris collapse.

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By finding out such parts of slope, estimating an amount of debris production is essential for planning countermeasures.

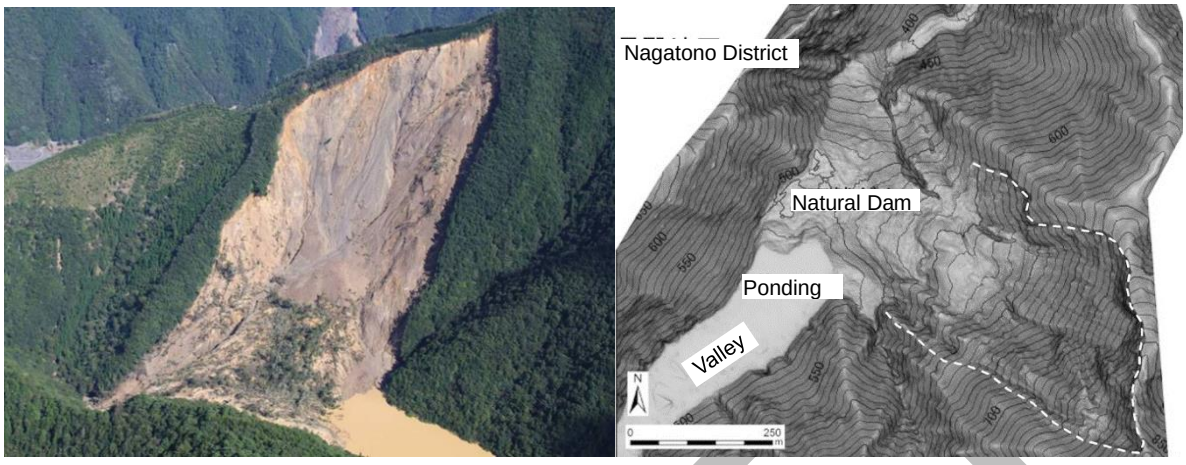


Figure 1-70 Landslide Dam Formed by Deep Seated Landslide (Nagatono, Wakayama, Japan) [7]

[7]

Table 1-18 Onsite Checklist (Deep-seated Landslide)

Type	Category	Details
Deep seated landslide	Shape and Location	To locate deep seated landslide through map reading and the following confirmation on site. To measure slope length, width, area, depth, shape, and volume of collapse and gradient of slope where collapse occurred. To grasp geological condition of the slope where collapse occurred. To locate similar deep seated landslides To estimate gradient of slope before the collapse occurred.
	Movement	To decide single or multiple failure. To measure travel distance of debris and deposit condition. To estimate the shape of landslide dam and volume of debris. To understand condition of debris flow occurrence. To collect disaster records, including interviewing with residence / witness, of date and time as well as situation of collapse and slope condition before collapse.
	Mechanism	To understand geological conditions, such as lithology, geological structure, fault, and fractured zone. To understand topographic conditions, such as lineament, alignment of kerncol and kernbut, and bending of valley system. To check micro-topographic features suggesting deep seated landslide before collapse, such as double ridges, up-hill facing scarplets, and traces of old deep seated landslides. To check development of toppling and buckling at head scarp and both sides of flanks. To check back slopes which may work as catchment areas To understand hydrological conditions of groundwater, such as location of spring and seepage as well as quantity, quality including pH and ion distribution, and temperature of spring water. To understand hydrogeological conditions, such as fissures to contain groundwater and constraining floor to control groundwater. To confirm traces of liquefaction of slip surface.
	Facilities to Protect	To confirm runout distance of debris of deep seated landslide and damage within the area of debris.

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Type	Category	Details
		To monitor water level of the pond behind landslide dam to evaluate the risk of collapse of landslide dam. To estimate damage by flooding of the pond behind landslide dam. To estimate damage by massive debris flow caused by collapse of landslide dam.

Source: JICA Project Team

(6) Debris Flow

Debris flow is caused by surface failures at valley head thus the condition of slope of the source of debris flow is same as that of surface failure.

Debris flows occur repeatedly on the same valley system. So the valley system prone to debris flow can be identified. Along such valley system, deposits of old debris flow remain on valley floor and bank, while keeping unstable conditions which enable movement downward. Such remaining deposits are widely eroded again when massive debris flow occurs. Measuring areas and cross sections of erosion where eroded by debris flow is essential for estimating debris production by an event of debris flow.



Figure 1-71 Large-scale Debris Flows (2011, Kanayamadani River, Wakayama, Japan), Left: Slope Failure at Head of Valley, Right: Erosion of Deposits of Past Debris-Flow

[8]

Damage by debris flow to hill roads should be discussed considering property of road structure crossing a valley.

In many cases, embankment with crossing culvert is placed where hill road crosses streams. At such locations, when a debris flow occurs at the stream, the embankment over the stream is often damaged or eroded due to overflow of debris flow caused by clogging of the crossing culvert, or washed away by impact of debris flow. Even though effective cross section of crossing culvert secures enough area to accommodate debris flow, driftwood transported by debris flow may reduce the effective cross section and then leads to damage of embankment.

In case the structures over valley system or mountain streams are damaged by debris flow, causes of the damage should be identified and countermeasures against the causes should be incorporated into the design of restoration.

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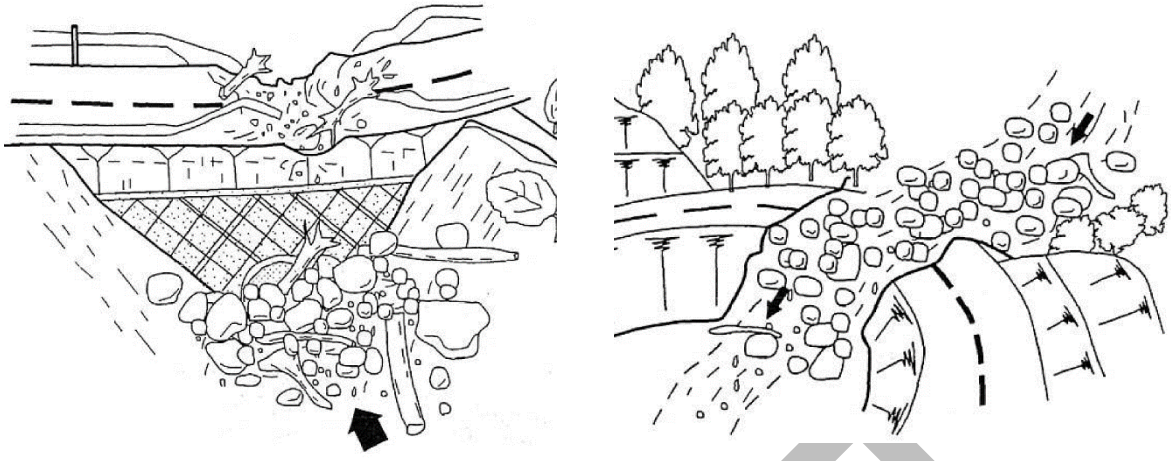


Figure 1-72 Damage by Debris Flow to Embankment on Stream, Left: crossing culvert is clogged by debris with driftwood, Right: embankment washed away by impact of debris flow

[3]

Table 1-19 Onsite Checklist (Debris Flow)

Type	Category	Details
Debris flow	Shape and Location	To locate debris flow through map reading and the following confirmation on site. To measure slope length, width, area, depth and shape of failure at valley head, volume of debris, and gradient of slope of failure. To measure existing deposits of old debris flow on valley bank and floor. To confirm starting point of flood (called as Reference Point). To confirm running distance of debris flow.
	Movement	To measure travel distance of debris from valley head failure. To understand situation and structure of debris deposition from valley head failure. To check conditions of driftwood production. To confirm erosion of valley bank and floor and to estimate production of debris by erosion. To confirm erosion of existing deposits of old debris flow. To collect disaster records, including interviewing with residence / witness.
	Mechanism	《In case source of debris is surface failure》 Refer the checklist of surface failure 《In case source of debris is deep seated landslide》 Refer the checklist of deep-seated landslide 《Areas of transportation and deposition of debris》 To check thickness and distribution of deposits derived from old debris flow.
	Facilities to Protect	To check situation of existing sabo dams (check dams), such as filling of deposition area behind dams and damage to dam body. To estimate runout distance of debris flow considering subsequent debris provision due to expansion of slope failures in back land and to locate facilities to protect within the estimated runout distance.

Source: JICA Project Team

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1.2.4 How to decide probable slip surface of existing landslide/slope failure

Up to the previous section, points to be observed during field surveys are explained. In this section, the methods to obtain underground information relating to slip surface are described, especially depth or position of slip surface.

Drilling investigation is the most reliable technique to obtain underground information. By using the high-quality drilling technique described in the section of 1.1.2, collecting almost undisturbed core samples is possible which keeping depth information and property of cracks at the original position including its direction. High-quality drilling can also obtain core samples of landslide clay, which is easy to be washed out and difficult to obtain with conventional drilling methods. Landslide clay is formed on slip surface of landslides with repeated movement. With proper understanding of property of landslide clay such as shown below, engineers may identify slip surface of landslide with core samples:

Feature1 : Slip surface lies within landslide clay, the thickness of which is several to several tens centimeters. Slip surface is composed of main displacement shear surfaces on both upper and lower sides of landslide clay and complicatedly developed subsidiary shear surfaces, which are called Riedel shear and thrust shear, between the main shear surfaces. Main shear surfaces lies closely to upper or lower limit of landslide clay, with slickenside and striation on its surface.

Feature2 : Landslide clay has higher clayey content than surrounding mass. And slip surface has much higher clayey content than landslide clay, with thin layer of slip surface clay of several millimeters thick. Slip surface clay often shows different color tone from that of landslide clay and colors pale yellow to brown.

Feature3 : Landslides in Neogene sedimentary rock, landslide clay often contains smectite. After forming shear surface under residual condition, thin layer of smectite covers shear surface. The strength of such slip surface is governed by residual shear strength of smectite (around $\phi r' = 5^\circ$)

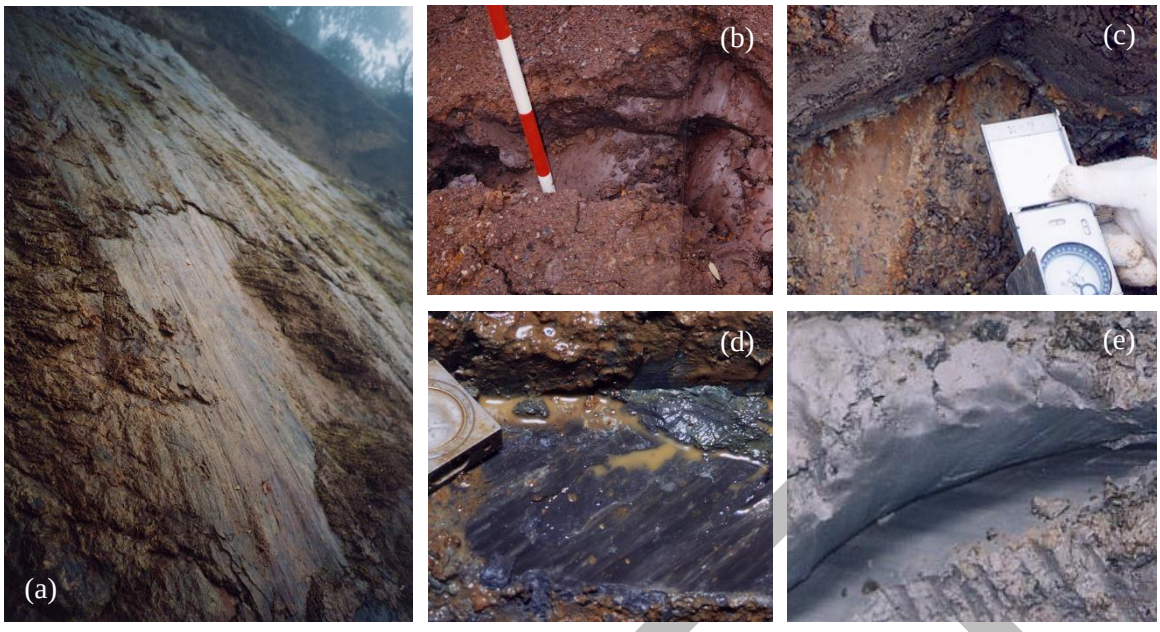
Feature4 : Coarse particles remaining around slip surface or undulation of bedrock marks striation on slip surface. Remarkable striation may increase shear strength of slip surface.

Feature5 : Natural moisture content of slip surface clay is often close to the plastic limit (liquidity index is 0.2 or less). In ground water logging, layer with dominant underground water inflow is usually detected just above landslide clay and rarely below it. It should be noted that slip surface clay obtained through drilling often shows high water content, due to water absorption by stress relaxation.

Feature6 : Slip surface is accompanied by underlying bedrock, which act as constraining floor for both landslide clay and groundwater distribution. Oxidized zone is, therefore, formed above slip surface and reduced zone is below it. As a result, clear deference in color may be observed in core samples between the two zones.

Note: landslide clay is in many cases thin and soft. With conventional drilling method, landslide clay is usually washed away by drilling water or burned by no water drilling. With high-quality drilling technique, or by a skilled operator with a capability of "water controlled drilling, drilling method to minimize drilling water, landslide clay can be obtained while keeping properties on site.

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(a) slip surface appears on head scarp, (b) slip surface on flank, (c & d) slip surface on Tuffaceous Mudstone, and (e) slip surface on metamorphic greenstones

Figure 1-73 Various Slip Surface

[9]



Figure 1-74 Slip Surface in Boring Cores

Source: JICA Project Team

Wakisaka et al. (2012) conducted detailed geological comparisons between landslide moving mass and fault fractured zone, through observations of outcrops and core samples obtained with high quality drilling. As a result, in fault fractured zone, planar structures were observed in fault breccia but, in landslide moving mass, no planer structured were recognized in breccia or fractured rock. Wakisaka et al. organized features of breccia or fractured rock of landslide moving mass as follows:

Feature1 : Vertically developed tension cracks show irregular shapes with serration (Figure 1-75(1)). Such vertical cracks are often filled with fine angular gravels (Figure 1-75(2)).

Feature2 : Breccia or fractured rock contains relatively coarse angular gravels and fine grain matrix. Such appearance resembles fault breccia, but planar structures are not recognized in landslide moving mass (Figure 1-76).

The difference between fault breccia having planar structures and the nonstructural breccia of landslide moving mass is due to the difference in confining pressure when each is formed; fault breccia is formed under high confining pressure and nonstructural breccia of landslide moving mass is formed under low confining pressure. To identify landslide moving mass, confirming the followings are important: degree of fragmentation, existence of planar structures within breccia or fractured rock, and position and frequency of appearance of nonstructural breccia.

By checking core samples, breccia or fractured rock of landslide moving mass can be identified by the following properties:

- No planar structures are recognized excluding slip surface clay (nonstructural breccia)
- Vertically developed tension cracks show irregular shapes with serration.
- Such vertical cracks are often filled with fine angular gravels.



Figure 1-75 (1) Serrated Crack in Landslide Moving Mass, (2) Crack Filled with Fine Granules, *Scale: 1cm

[10]

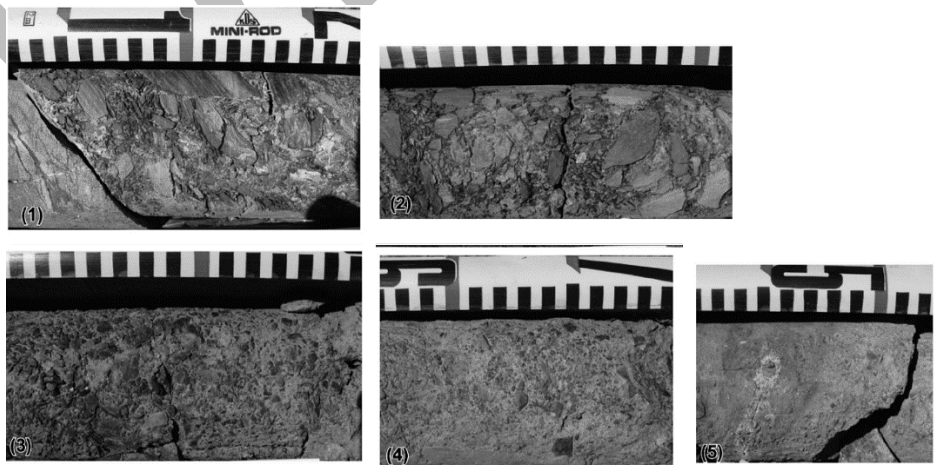


Figure 1-76 Various Fragmentation of Breccia in Landslide Moving Mass, *Scale: 1cm

[10]

As for monitoring methods for landslide movement to identify the depth of slip surface, various methods are available and the details are described in the existing IRC publications. So, in this section, comparison of monitoring methods is explained in Table 1-20.

The monitoring methods listed in Table 1-20 are effective only after the targeted landslide moves. So, such monitoring methods may be meaningless if any events which trigger landslide activity, such as rainfall or earthquake, do not occur during monitoring period, which is usually limited. In this sense, therefore, improving drilling skills to obtain high quality core samples and enhancing engineer's skills to detect slip surface from core samples are important.

To identify slip surface by landslide monitoring, position (depth) of slip surface and its displacement are essential. Table 1-20 shows features of various monitoring equipment used for detecting slip surface.

The column of "Interval" under "Slip Surface Depth" shows the minimum interval of measurement in depths and that of "range" shows the maximum depths to practically monitor landslide movement. The column of "Accuracy" under "Displacement" shows accuracy of measurement and that of "Range" shows the maximum displacement range to be measured. The shown values are typical ones and actual values depend on specification of equipment. In addition, accuracy and range are not the only factors to evaluate monitoring equipment. For investigation of slip surface, continuous measurement, easiness of installation, durability, and snow/rain proof are important function for monitoring equipment. Site condition and easiness of continuous observation should be considered in selecting monitoring equipment for a certain site.

Table 1-20 Function of Landslide Monitoring Equipment

	Measurement Items			
	Slip surface depth		Displacement (at slip surface)	
	Interval	Range	Accuracy	Range
Pipe strain gages.	1.0m	50m approx.	(able to measure indirectly)	
Borehole inclinometer	0.5m	50m approx.	1.0mm	10cm approx.
Vertical extensometer	Unmeasurable		-	200cm approx.
Multi-layer movement meter	1.0m	30m approx.	-	200cm approx.
Creep−well	0.1～0.5m	20m approx.	10.0mm	100cm approx.

Source: JICA Project Team

Statistical approach is also effective for rough estimation of depth of slip surface.

Relationships between width of landslide (W) and depth of slip surface (D) is shown on the left and those between depth of slip surface (D) and slope length of landslide (L) is shown on the right of Figure 1-77.

From the figure on the left, relation between D and W ranges from 4 to 10 in width to depth ratio (W/D). In particular, when W exceeds 120 meters, W/D falls in the range of 6 to 10. Type of landslide affects W/D ratio; W/D of debris landslide is relatively high, and those of rock and weathered rock landslide are low. In rock and weathered rock landslide, geological structures, such as faults and bedding, often control slip surface and shape of landslide. Due to such restrictions, width of landslide may be limited to narrower. On the contrary, moving mass of debris landslide is not controlled by geological structures. That is mostly controlled by topographic condition. The width of debris landslide can extend to the range of collapse, which is mainly

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controlled by valley and ridge system and usually wider than restriction by geological structures. Thus W/D ratio for debris landslide is relatively high.

From the figure on the right, relation between L and D ranges from 4 to 15 in length to depth ratio (L/D), wider than W/D. As a landslide develops, landslide mass tends to be divided into small blocks. Consequently profile of the landslide becomes more complex and extended and slope length of landslide is also extended. Such development of landslide makes ranges of L/D much wider than that of W/D.

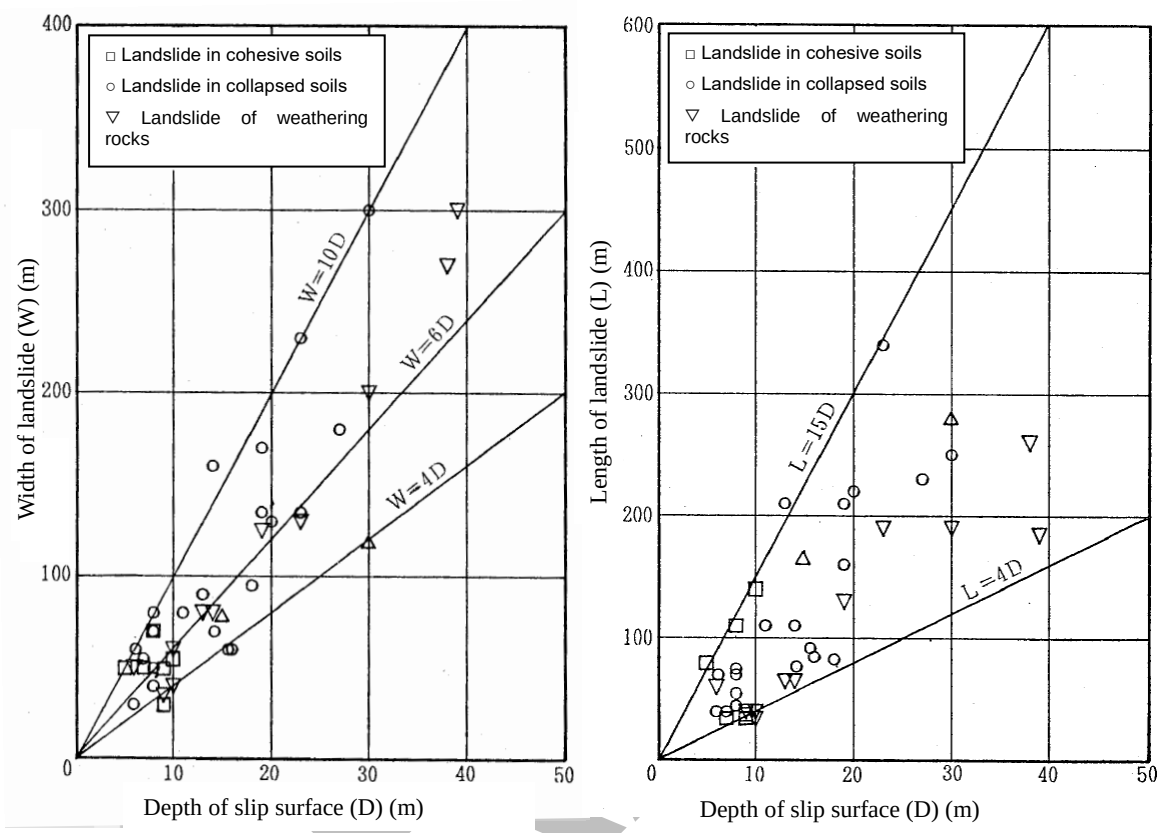


Figure 1-77 Relationship between Shape of Landslide and Depth of Slip Surface

[11]

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1.3 Landslides/hazards foreseen from current condition of hill road in service

1.3.1 General

In the preceding section, points of investigation are discussed for planning and designing of proper countermeasures against the damage which already affects road structures. In this section, points of investigation against potential hazards are described. Before potential hazards affect road structure with substantial damage, in most cases, slight deformation or precursor of landslide/collapse is often observed. So this section focuses such slight deformation or precursor in the aim of avoiding future damage to road structure by potential hazards.

In general, cut slopes are most stable immediately after cutting and stability decreases as time elapses, due to progression of loosening caused by unloading by cutting. Loosening of slope enables rainfall and/or surface runoff infiltrate into the ground and facilitates erosion within the ground as well as accumulation of fissure water. With abnormal rainfall, fissure water turns into pressured groundwater that triggers destabilization of slopes.

Such tendency of cut slope of gradual loosening after cutting requires periodical monitoring of roadside slopes in terms of observing relaxation of slopes.

On the other hand, after enduring the most unstable condition right after being established, with increased pore water pressure in the ground by loading, embankment gradually increases its stability due to gradual dispersion of the pore water pressure. Once surface runoff or rainfall gets into embankment body, however, embankment may destabilize and eventually collapse.

Thus, like cut slopes, periodical monitoring of embankment slope is also required in the aim of detecting infiltration of water into embankment body and taking proper countermeasures when negative effects by water are detected.

For operation and maintenance of new and existing hill roads, monitoring of slopes in relation to water infiltration to the ground is essential.

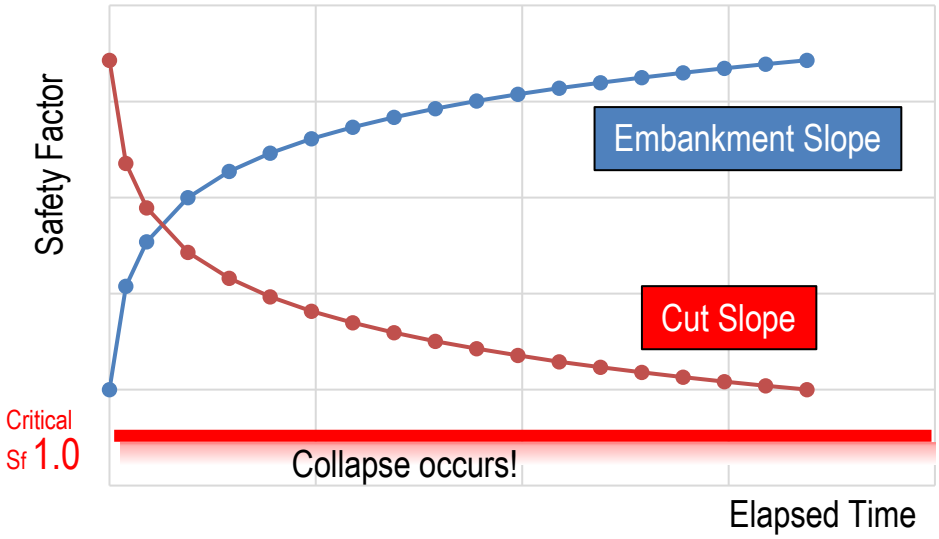


Figure 1-78 Change of Stability with Time for Cut and Embankment Slopes

Source: JICA Project Team

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1.3.2 Hazards

By showing some examples in India and Japan, the conditions of slopes that may cause disasters in future are explained below.

(1) Potential Hazards in Natural Slope

In the hilly regions of India along the Himalayas, in addition to artificial cut slopes, steep slopes of bedrock usually appear along hill roads. On such outcrops, stratified bedrock with extensive folding and fractured state are often observed. Among such bedrock slopes, due to relaxation of slope and loosening of cracks, clear open cracks are often observed, as shown in Figure 1-79.



Figure 1-79 Loosened Cracks in Cliff of Natural Slopes

Source: JICA Project Team

Under such geological conditions, gravity deformation tends to develop at many places on steep slopes, involving hill roads. In many cases, gravity deformation is accompanied by streams flowing on both flanks and the entire ridge between the streams is involved in the deformation. If a hill road crosses a deforming slope, subsidence and displacement of the road are observed at the flanks or the streams, as explained in Chapter 1.2.2 (1). At the same time, the ridge with gravity deformation shows topographic features of double (multiple) ridges and up-hill facing scarplets, such as described in Chapter 1.1.3.

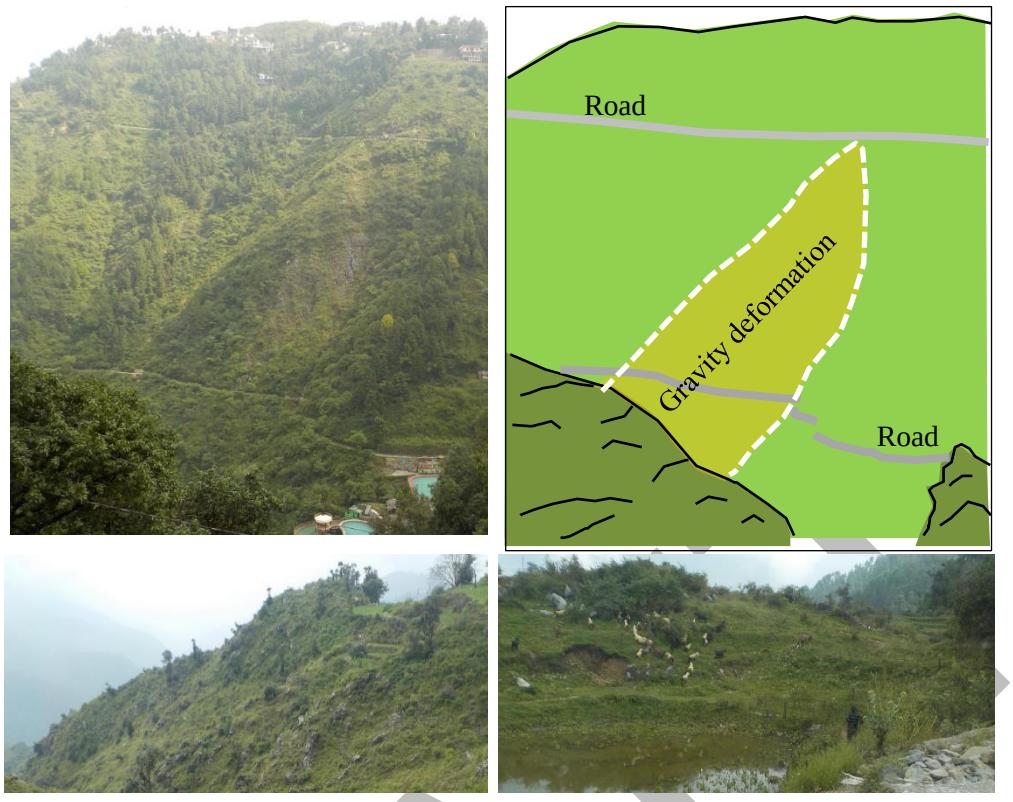


Figure 1-80 Specific Landform of Gravity Deformation, Upper: Slope with gravity deformation, Lower Left: Double ridges with gentle slope, Lower Right: Pond at concave on ridge line

Source: JICA Project Team

(2) Potential Hazards in Steep Cut-Slopes

Other than the natural slopes with gravity deformation in the previous section, long and steep slopes formed by cutting are observed at many places along the hill roads in India.

Figure 1-81 shows a case of cut slope with a size of 100 meters in length and 40 meters in height with average gradient of around 60 degrees from horizon. The slope faces southwest and consists of alternation of sandstone and shale, with a dip of 30 degrees toward southeast and a strike crossing the slope. Accordingly, the slope was unloaded by the cutting in a direction almost perpendicular to the strike. The sandstone, light brownish white in the picture, is of 5 to 10 m in thickness and weathered and fractured, with joints of 50 cm in spacing. On the contrary, the crack interval of the shale is around several centimeters. These geological conditions facilitate differential erosion, because of difference in strength of rocks; the shale is weaker and more fragile than sandstone. In addition, the shale works as an aquiclude with its less permeability than sandstone and acts as a constraining floor for groundwater flow. This means the surface of the shale works as a regulation surface of slope destabilization. Although such conditions lead instability of slope, since the cut slope is perpendicular to the direction of the strike and the apparent dip to the cut-slope is almost horizontal, the slope keeps stable at the time of observation.

The lower pictures of Figure 1-81 show bird's-eye views of the slope; oblique views from the starting point (left) and the ending point (right). Possibility of wedge failure is suggested in the 3D model from these angles.

The existing countermeasure at the corresponding slopes is only breast walls at the foot of the slope. Countermeasures against weathering and erosion are not

observed, however. At the time of observation, partial flaking was observed at several points. From the viewpoint of the maintenance, however, destabilization of slope is inevitable due to weathering and erosion in future. In addition, risk of sudden collapse of the slope by an intense rainfall remains.

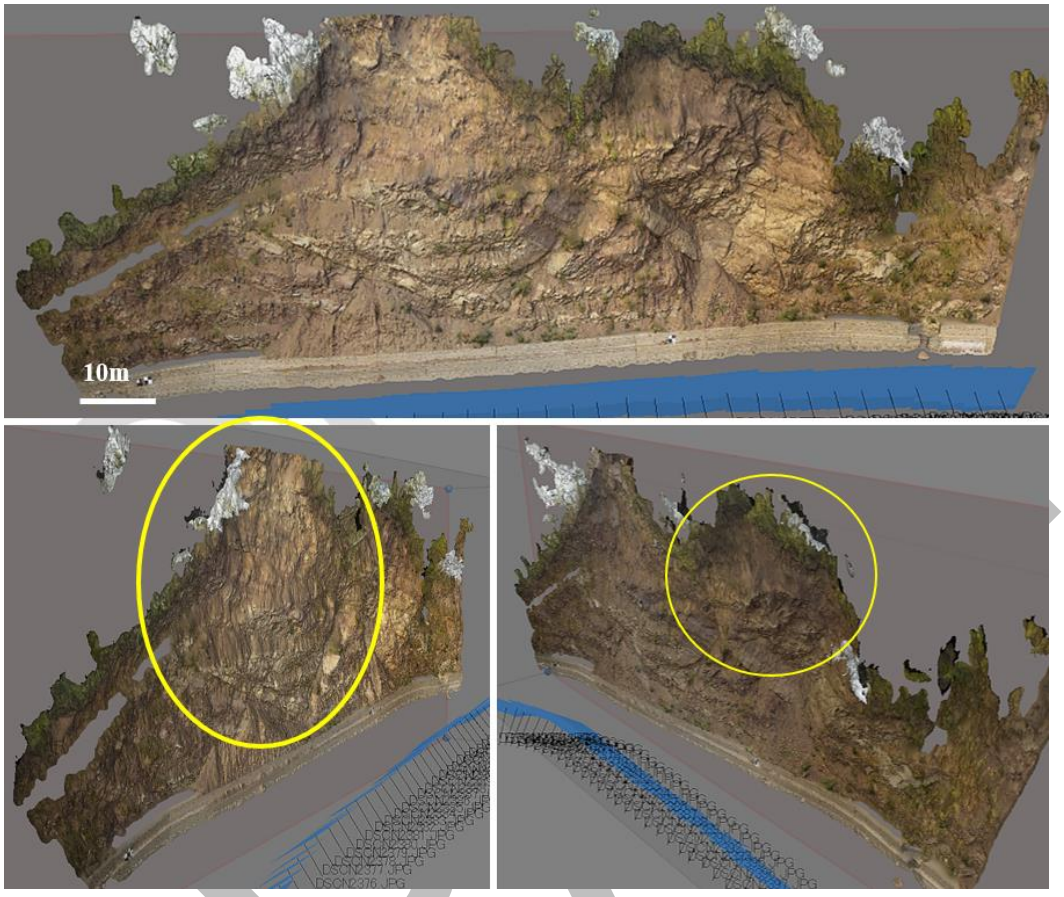


Figure 1-81 Example of Steep Cut Slope (3D topographic models), Upper: front view, Lower Left: Bird's-eye view from the starting point, Lower Right: Bird's-eye view from the ending point.

Source: JICA Project Team

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Figure 1-82 Example of Steep Cutting Slope（Parwanoo-Solan along《NH22》）Upper left: Fractured sandstone, Upper Right: Fractured shale, Lower: full view

Source: JICA Project Team

High and long cut slopes often involve deformation not only on cut-slope itself but on road surface under service.

In the example shown in Figure 1-83, the carriage way on the hill side (LHS) just below the toe of the cut-slope is partially subsiding. At the subsiding section, the surface of the carriage way is slightly tilting towards the shoulder more than that of normal camber. The overlaid pavement at the section suggests the deformation is on progress.

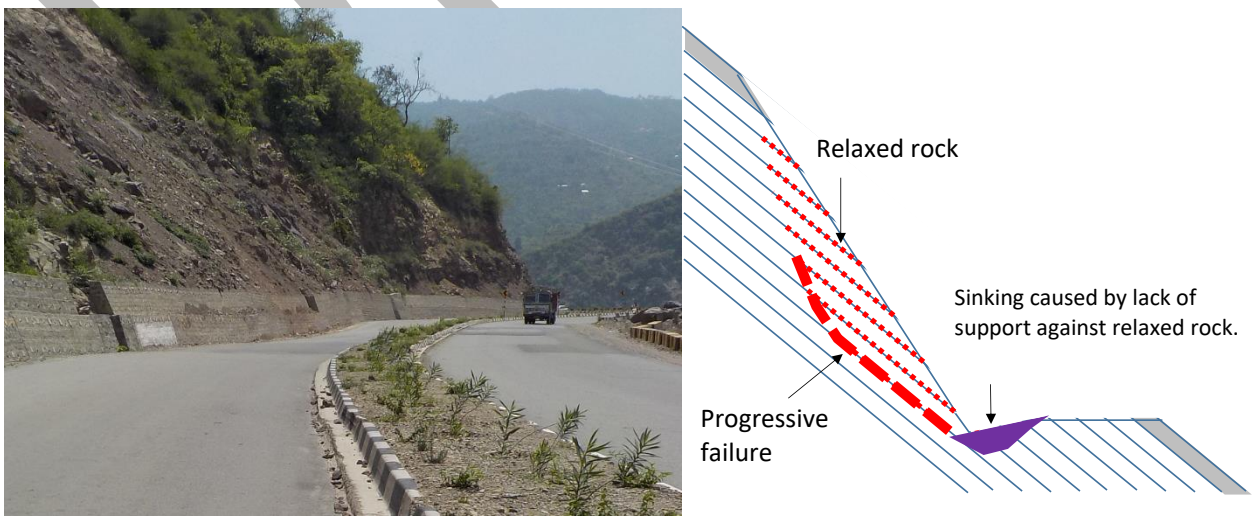


Figure 1-83 Sinking Found on Road in Service (Parwanoo-Salon along, NH22)

Source: JICA Project Team

Based on the situation of the photo, it is highly likely that the unloading by the cutting caused the deformation; the cutting unloaded the stress and the bedrock was then relaxed, and a progressive shear fracture surface was formed along the lower boundary of the relaxed zone. At the same time, by the cutting, the support for the relaxed zone was almost removed. Then the weight of the relaxed zone was loaded on the shoulder of the carriage way where the loading caused deformation.

(3) Displacement and Damage of Structure by Gravity Deformation and Landslide

Signs of damage by gravity deformation noticed on pavement or other road structures are usually small at the beginning. Usually the development of damage caused by gravity deformation is sluggish unless strong external forces, such as tremendous rainfall and strong earthquake, affect. Thus, in most of the cases, the damage is recognized as deterioration of structures by road users, residents, and even inspectors from road administration. Furthermore, periodic repairs cover and overlay the damage. The deformation that causes the damage, however, keeps expanding steadily but gradually and, in several years, emerges as subsidence and/or bulges much larger than those in the initial state. When displacement or damage is noticed on the structures of hill roads, careful and periodic observation and recording are important for earlier detection of gravity deformation.



Figure 1-84 Small Displacement Found on Structures, Upper: Expansion of gravity deformation in the upper slope behind Paglajhora on right side flank (Upper Left: repair of pavement, Upper Right: displacement at railway track of Darjeeling Himalayan Railway), Lower: Expansion of gravity deformation in the upper slope behind Paglajhora on left side flank (Lower Left: repair of pavement, Lower Right: crack on foundation of a house.)

Source: JICA Project Team

On the other hand, the damage and displacement by landslide on pavement or other road structures is similar to those by gravity deformation. Especially at the

initial stage of movement, the damage and displacement by landslide or gravity deformation are quite difficult to differentiate.

The gradients of slope as well as slip surface are, however, remarkably different between landslide and gravity deformation. Gravity deformation is simple shear (creep deformation) of the fractured rock. On the contrary, landslide is defined as single shear displacement on a single slip surface with landslide clay. Thus gradient of slopes where gravity deformation exists is often steep but those where landslide lies is generally gentle. By checking the gradient of hill slope where damage or deformation is noticed, differentiating gravity deformation and landslide on site is quite important.

(4) Deformation Caused by High Embankment

High embankments exceeding 20 meters in height are often observed as valley side structures of the hill roads in India. Gabion, retaining wall of stone masonry, and retaining wall of gabion with geotextile reinforcement are applied in accordance with site conditions.

Along the hill roads in India, embankments are often placed on steep hill slope. Accordingly the embankments on such steep slopes are often laid up from the foot of the slopes, consisting of high embankments. High embankments entail risk of failure involving bearing ground due to insufficient bearing capacity of the bearing ground as well as failure of embankment body itself sliding down on the steep slopes. If situation allows, such risk of high embankment failures should be minimized by adopting light weight embankment which enables lighter loads by embankment or ground anchors which enables foundation for embankment on steep slopes, on which smaller embankment can be constructed, compared to laying embankment from the foot of the slopes.



Figure 1-85 High Embankment with Gabion Retaining Wall Reinforced with Geotextile

Source: JICA Project Team

As mentioned in 1.3.1, embankment is considered as most unstable just after the completion of filling. It gradually gains stability as time elapses. This idea is based on the behavior of excess pore water pressure unavoidably occurring just after the loading and dispersing with time. Regarding high embankment, however, critical issues lie in bearing capacity of foundation in longer term; whether foundation as well as lower parts of embankment can support the load of high embankment or not.

Figure 1-86 explains an example of high embankment of several ten meters high with gabion retaining wall with geotextile reinforcement. Bulging and buckling of the gabions were confirmed from the foundation ground to the height of around 5 meters, with tension fractures of steel wire mesh consisting of gabions. Strips of geotextile laid in between the gabions were drawn inside of embankment possibly due to deformation of the gabions.

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In addition, deformations of the ground in front of the toe of the high embankment were confirmed. The deformation may be caused by proceeding passive destruction of the bearing ground, because of heavy weight of the high embankment. Due to such deformation, many compression cracks are observed on the vertical wall of the drainage ditches installed at the toe of the high embankment.

The site conditions suggest possible lack of counterbalance at the passive area and, in case the load of the passive area is reduced due to erosion or artificial soil removal/cutting, consequent collapse of the high embankment.



Figure 1-86 Various Signs of Degradation of Stability Seen at High Embankment

Source: JICA Project Team

(5) Adjacent Slope of Existing Collapse

In the surroundings of existing collapse, it should be noted that the similar factors which caused the existing collapse still lie. Once triggers of collapse come into effect, the lying factors may cause the similar collapse in the same way. Such factors include geology and lithology, strike and dip of strata and road side slopes as well as their relative directions, relative locations between slope and roads, and influence of fault and fractured zones.

The most critical locations around the existing collapse are the slopes of upper and both sides of the collapsed slope. For the upper slope of the collapse, the original slope before the collapse may have worked as a support to keep stability. By losing the support, the upper slope should have decreased stability and thus be considered as potentially unstable. Similar idea can be applied to the slopes of both flanks of the existing collapse. For such slopes, the original slope before the collapse may have provided resisting force against possible slides. By the existing collapse, the resistance disappears and the slope on both flanks decrease stability in some extent.

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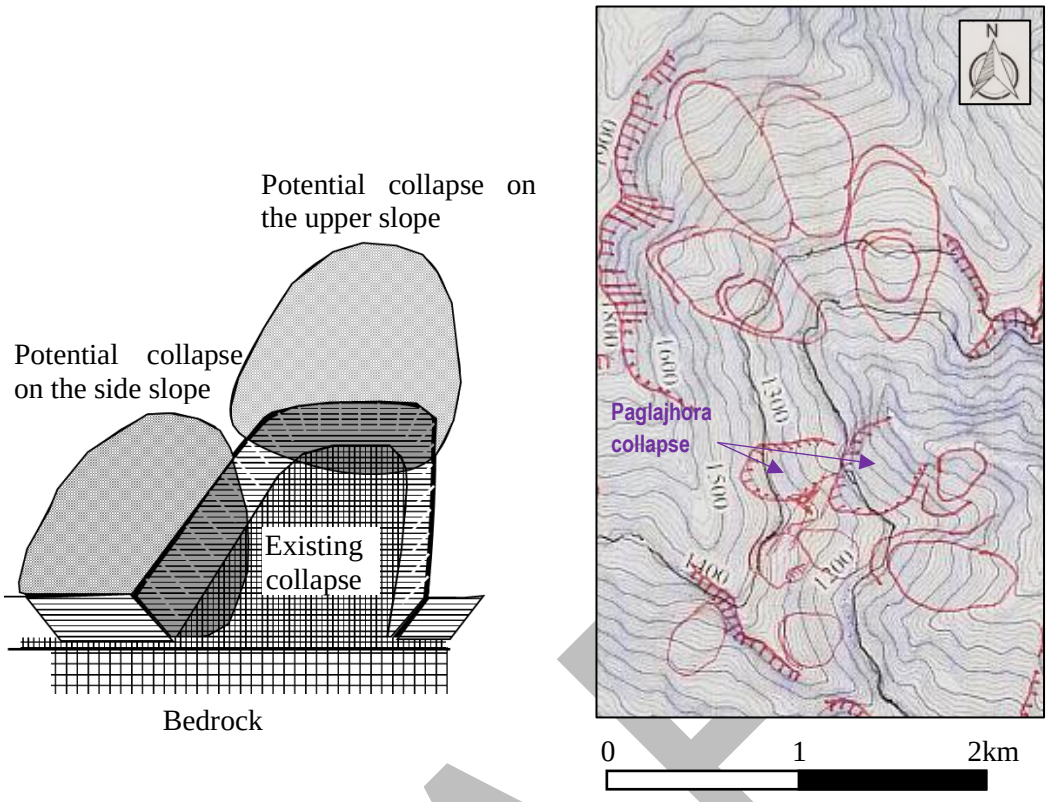


Figure 1-87 Risk of Further Collapse at Adjacent Slopes of Existing Collapse, Left: Mechanism of destabilization at adjacent slopes, Right: Map reading around Paglajhora collapse

Source: JICA Project Team

(6) Debris Flow Prone Stream

Debris flow is triggered by provision of debris to mountain stream from collapse of hill slope and stream bank due to heavy rain. A debris flow arises on a swollen stream or saturated riverbed when wet debris from collapse pours into the stream. Then mixture of water, debris, and riverbed sediments cascade down the stream and accumulates at gentle slope or flat land after the mouth of stream.

Debris flow plays an important role in carrying materials downstream, which are produced through various erosion activities on hill slopes. Thus, theoretically debris flow may occur in any mountain streams in hilly regions. Capacity of sediment production of watershed, which governs the magnitude of debris flow, is different by steams, however.

The mountain stream where debris is actively produced in its watershed has its beds covered by newly accumulated debris. On the other hand, the mountain stream with less debris production has its beds intruded by vegetation and filled with sediment rich in finer particles.

In addition, in such streams where sections of steeper stream beds lie in 15 degrees or more and valleys are formed with wide variation in widths and gradients of stream beds, debris flow may temporary reduce its speed, increase its thickness, and then enlarge its scale.

In the valleys where thick volcanic sediments including volcanic ash and lapilli lie, in general, risk of debris flow is considered high.

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Figure 1-88 Stream Bed of Debris Flow Prone Stream, with New Debris Accumulation

Source: JICA Project Team

(7) Meaning of Rich Groundwater and Densely Developed Valley System

In the area where valleys develop densely on hill slopes, bends of hill road alignment naturally increase. And this is very normal situation where hill roads in India run.

In the areas where valley system develops densely, dissection is actively proceeding. In such areas, instead of downward erosion at fixed rivers, erosion at multiple flow paths deepens the valleys while increasing the number of valleys.

In the areas where dissection easily proceeds, in general, vertical cracks densely develop and reach to deep ground. Such vertical cracks lead rainfall and surface runoff into deep ground and store them as groundwater for long period of time; densely developed vertical cracks works as recharge area and retain abundant groundwater within it.

On the other hand, risk of gravity deformation lies in the bedrock where hard rock strata are fractured in the deep ground. Such geological setting is similar to densely developed vertical cracks where abundant groundwater is stored.

This means where valley system develops densely and abundant groundwater is stored, which is recognized as groundwater spring/seepage and abundant flow of mountain streams, gravity deformation also lies in the slopes and thus high risk of deep seated landslide remains, which may be triggered by abnormally tremendous rain fall. Such slopes should be carefully checked and monitored through operation and maintenance activities for hill roads.



Figure 1-89 Signs of Abundant Groundwater, Left: abundant stream flow in dry season, Right: groundwater spring at flank of gravity deformation

Source: JICA Project Team

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1.3.3 Slope inventory including potential of hazards

To detect potential hazards described in the previous section, keeping slope inventory with proper information is essential. The theme of this section is to record conditions of roadside slopes which have potential risk or hazards, such as landslide, collapse, and rock fall, and to keep and update such information as slope inventories. Slope inventories should be established and updated, regardless of emergence of clear hazards. In most cases, the information should be collected without clear signs of hazards but from deformations which cause slight issues to the road in service and roadside slopes where any deformation on roads are not detected by visual inspection.

Slope inventories are essential information in assuming potential hazards and evaluating possible size of and damage by such hazards. Slope inventories are also important in considering countermeasures against such hazards. The main points to be checked on site for establishing and updating slope inventories are explained in this section.

The main points to be checked on site are organized as "Check Points" and possible disaster scenario assumed from the "Check Points" are summarized as "Judgement" for the following 4 slope types:

- Natural rock slope
- Cut-slope of rocks along hill roads in service or newly constructed
- Cut-slope of weathered rock along hill roads in service or newly constructed
- Embankment slope on inclined base rock

(1) Natural Rock Slope

For the natural slope where rocks are exposing along the target hill roads, since the slope has had no big collapse for a certain long period, the hazards to occur in short term period are not focused*. The point to evaluate is time dependent durability of bedrock in long-term period. For such conditions, gravity deformation is assumed as a disaster scenario and checking factors of triggering deep-seated landslide is also required.

*Note: In such slopes, check points for rock fall in Chapter 1.2.3 shall be checked accordingly.

Table 1-21 Potential Hazards of Natural Rock Slope

Check Points			【Judgement】
Category	Conditions	Classification	
Shape of slope	h>5m, α>30°	Rock Slope (natural slope without collapse in recent years)	・Gravity deformation influencing road structure may occur. ・As deformation advances, rock fall from the upper slope and rock mass failure (wedge failure) may occur. ・Deep-seated landslide may occur when abnormally heavy rain falls and faults form the conditions of damming up. ・Gravity deformation of the upper slope should be monitored, unless damage on road is noticed.
Damage on road	Cracks on pavement or road surface	Cracks crossing roads, tendency of slightly subsidence	
	Cracks on retaining wall	Cracks connecting to those on road surface	
	Drainage problems	Leakage, closure, and abnormal gradient and alignment of drainage.	
Property of rock slope	Stratified bedrock	Joints, bedding, and alternation of hard and soft strata	
	Folding and fractured zone	Congested cracks, weak strength, and high fissility (detachment).	
	Relaxation/loosening	Development of toppling and buckling	
	Faults	Plunging toward slope with high angle of dip forms condition of damming up of groundwater and pressured groundwater (trigger of deep-seated landslide)	
	Spring water	Spring/seepage at flanks and toe of slopes	

Source: JICA Project Team

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(a) Toppling (b) Buckling

Figure 1-90 Characteristic Deformation of Rock Slope where Gravity Deformation Occurred

Source: JICA Project Team & [1]

(2) Cut Slope of Rock

For the slope of fresh rock newly formed by cutting, relaxation of rock due to unloading starts and progresses inevitably. For the existing cut slope, relaxation continues to develop. Cutting may initiate relaxation in sound rock by unloading or facilitate relaxation of fractured zone by the same.

Under such conditions, relationship between strike and dip of strata or discontinuities such as crack, joints, and foliation and direction of slope governs the types of hazard which may occur. Plunging slopes may provide fields for gravity deformation. Dip slope with high angle of dip is a major factor for rock sliding. A set of two planar structures such as bedding and discontinuities forms wedge failure. And dip slope with low angle of dip provides fields for landslide*.

The hazards mentioned above have specific modes of activities. Gravity deformation is sort of rock creep and thus speed of deformation is generally gradual, even though it is accelerated by rainfall. On the other hand, rock slide and wedge failure suddenly occur and collapse immediately once it moves. Some rock slide and wedge failure occur after earthquakes as well as peaks of heavy rainfall but substantial numbers of them occur without rainfall. Landslide also shows slow movement but has closer relationship with rainfall than gravity deformation does. Relation between direction of strata as well as discontinuities and slope has such significant meaning in assuming possible hazards.

In addition, time dependent degradation of rock, such as slaking and swelling explained in Chapter 1.1.4, facilitates destabilization of cut slope of rock. Both slaking and swelling are caused by exposure to the air and unloading, or stress relief, by cutting.

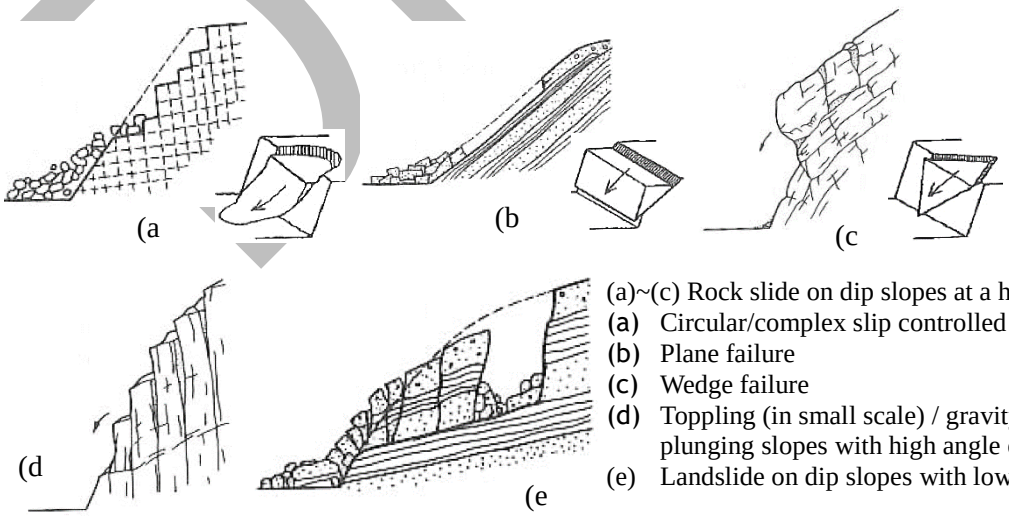
* Note: The “landslide” in this section means that of narrow definition in Table 1-3.

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Table 1-22 Potential Hazards of Cut-slope of Rock

Check Points			【Judgement】
Category	Conditions	Classification	
Shape of slope	h>5m, α>30°	Rock slope (by cutting)	・Cutting facilitates destabilization of slope ・Relationship between strike and dip of strata or discontinuities and direction of slope governs the types of hazard which may occur. ・Plunging slopes may provide fields for gravity deformation. ・Dip slope with high angle of dip is a major factor for rock sliding. ・A set of two planar structures forms wedge failure. ・Dip slope with low angle of dip provides fields for landslide. ・Slaking and swelling tend to facilitate destabilization of slope. ・Highly weathered part may cause surface failure. ・Existing countermeasure should be reviewed whether it provides sufficient function against assumed hazards. If insufficient, additional measures should be proposed.
Damage on road	Cracks on pavement of road surface	Cracks crossing roads, tendency of slightly subsidence	
	Cracks on retaining wall	Cracks connecting to those on road surface	
	Drainage problems	Leakage, closure, and abnormal gradient and alignment of drainage	
Rock slope	Stratified bedrock	Joints, bedding, and alternation of hard and soft strata	
	Fold and fractured zone	Congested cracks, weak strength, and high fissility (detachment)	
	Relaxation/loosening	Development of toppling and buckling	
	Strike and dip of planar surface and slope	Plunging slope -> Gravity deformation	
		Dip slope with high angle of dip -> Rock Sliding	
		Set of 2 planar surface -> Wedge Failure	
		Dip slope with low angle of dip -> Landslide	
	Slaking properties	Occurs in soft rock strata and may facilitate differential erosion and destabilization	
	Weathering	Highly weathered parts may cause surface failure.	
	Swelling properties	Caused by unloading. Facilitates destabilization by swelling pressure and reduced strength	
	Faults	Plunging toward slope with high angle of dip forms condition of damming up of groundwater and pressured groundwater. -> Deep-seated landslide	
		Dip slope with low angle of dip ->Landslide Faults may form head scarp.	
	Spring water	Spring/seepage at flanks and toes of slopes	
Facilities / structure	Breast Wall	Upper parts of slope remain untreated.	
	Rock fall protection	Insufficient against rock slide or retaining earth pressure.	

Source: JICA Project Team



(a)~(c) Rock slide on dip slopes at a high angle
(a) Circular/complex slip controlled by joints and bedding.
(b) Plane failure
(c) Wedge failure
(d) Toppling (in small scale) / gravity deformation on plunging slopes with high angle of dip (in large scale)
(e) Landslide on dip slopes with low angle of dip

Figure 1-91 Classification of Rock Slide/Failure/Landslide

[1]

(3) Cut Slope of Weathered Rock

When cut slope is composed of weathered rock, even though residual soil or decomposed rock appears on the surface, fresh or lightly weathered bedrock usually underlies such residual soil or decomposed rock at shallower depth. Regardless whether it is debris or residual soil/decomposed rock, thin layer of soil on the bedrock with inclined surface tends to slide down easily. Thus such type of soil should be considered as naturally prone to be instable. Under such condition, rainfall and surface water easily infiltrate the ground and reach to the constraining floor of bedrock as unconfined groundwater. As explained in the Chapter 1.1.5 (2), then unconfined groundwater flows along the inclined surface of bedrock with seepage pressure, which pushes soil particle and then destabilizes the slope.

On the other hand, smaller surface failure is more susceptible to the triggers, such as rainfall, earthquakes, and erosion. Thus collapse on the cut slope of weathered rock tends to slide down in shorter time period after a precursor, if any, is noticed. So if any precursors are observed, prompt actions should be taken.

In case range of failure or deformation of a slope is far much wider than those of assumed from possible depth of surface failure, development of gravity deformation should be considered due to unloading by the cutting. For such case, disaster scenario of gravity deformation and rock slope failure explained in Chapter 1.3.3(2) should be also examined.

Table 1-23 Potential Hazards of Cut-slope of Weathered Rock

Check points			
Category	Condition	Classification	【Judgement】
Shape of Slope	h>5m, α>30°	Weathered rock slope(by cutting)	・Slopes prone to surface failures have the following features: − Subsidence at upper part of slope and bulging at lower part. − Soil pipes just under the bulging. ・In case the gradient of constraining floor (surface of bedrock) is steeper than that of the slope surface, the risk of surface failure increases. *Note: soil pipe is made through internal erosion underground by seepage water. Soil pipe is a sign of possible destabilization of slope. On the other hand, soil pipe works as drainage favor for stabilization.
Damage on road	Cracks on pavement or road surface	Crack crossing roads, tendency of slightly subsidence	
	Cracks on retaining wall	Cracks connecting to those on road surface	
	Drainage problems	Leakage, closure, and abnormal gradient and alignment of drainage	
Property of weathered rock slope	Cracks	Open cracks with subsidence and bulging	
	Soil Pipes*	Traces of water pressure loaded on walls of pipes	
	Strike and dip of constraining floor	Dip slope at high angle of dip → Surface failure	
	Spring water	Spring from soil pipes and constraining floor	
	Vegetation removal	Rill or gully erosion develops and destabilizes the slope	
Facilities	Breast Wall	Upper parts of slope remain untreated.	
	Steel net for protection	Insufficient for surface failure and earth pressure	

Source: JICA Project Team

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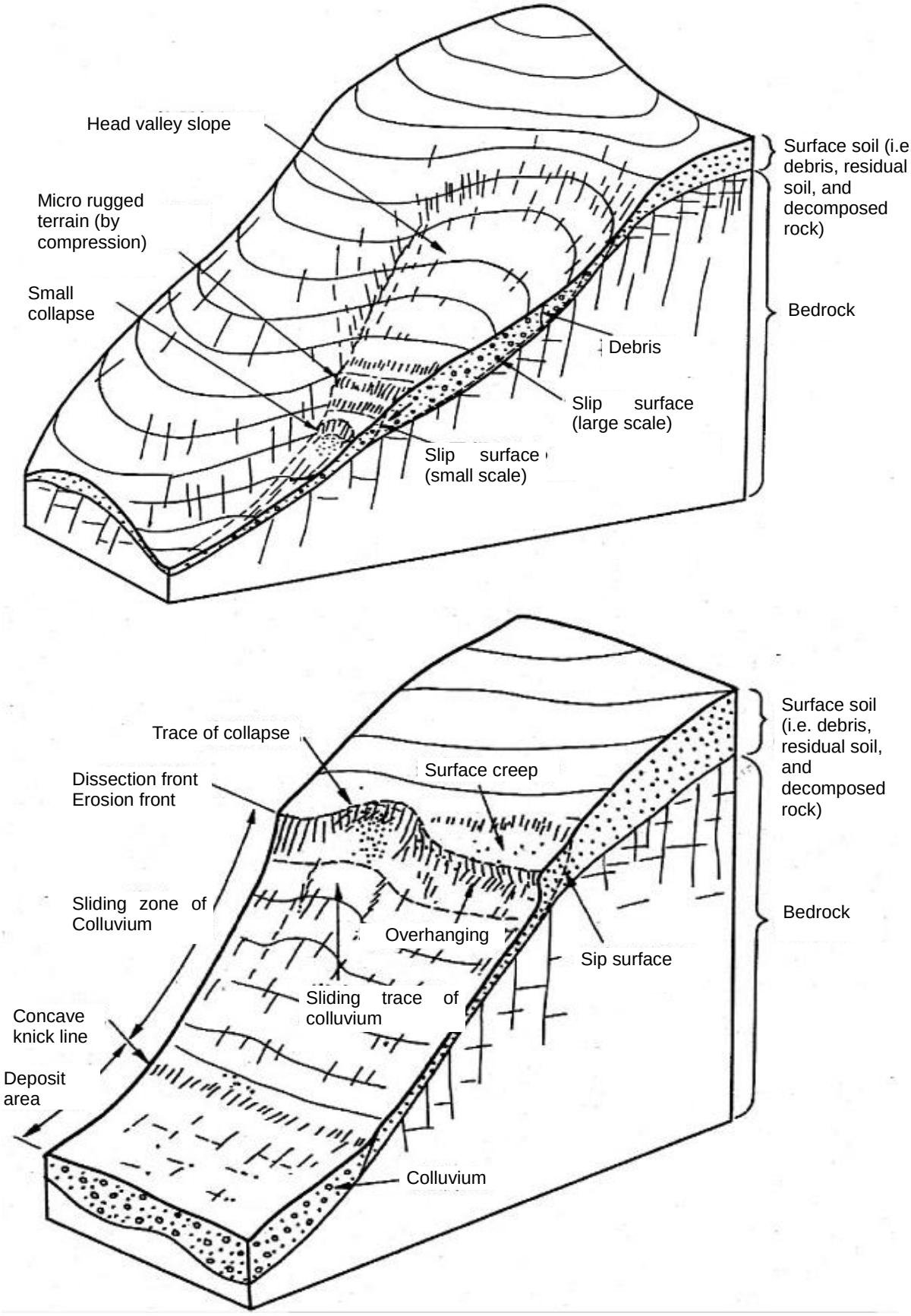
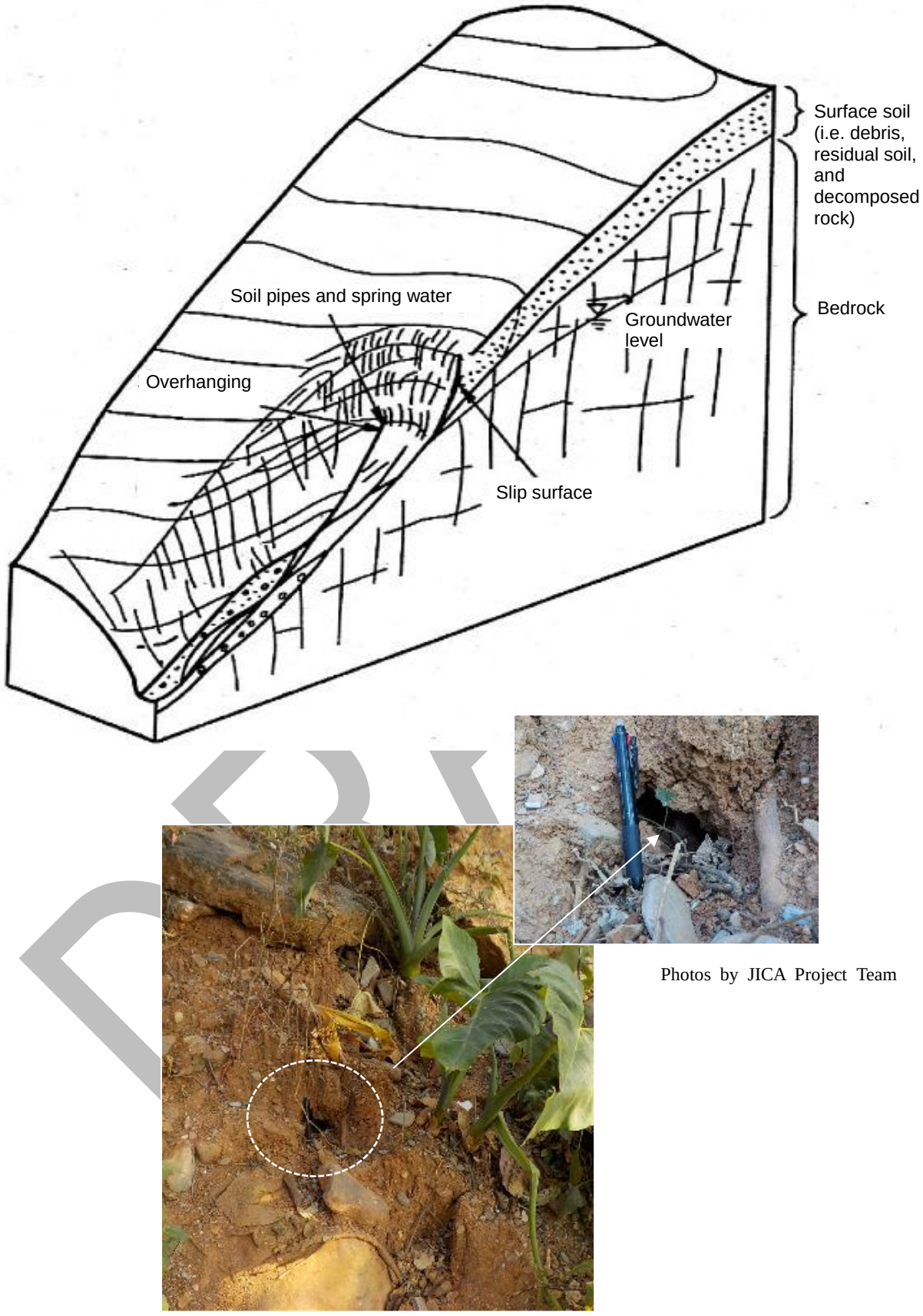


Figure 1-92 Surface Failures in Weathered Rock Slope

[1]



Photos by JICA Project Team

Figure 1-93 Surface Failure in Weathered Rock Slope and Soil Pipes (in Photo)

[1]

(4) Embankment Slope on Inclined Bedrock

Embankments along hill roads are often constructed on steep slopes where bearing ground for embankment is steeply inclined. Combination of cut and fill for new road construction as well as road widening also entails embankments on valley side. For both cases, embankments are constructed on the surface of slopes, on which two groups of materials with clear difference in physical properties contact each other; the slope surface works as an inclined boundary between materials with different characteristics.

Such difference in property and inclined boundary may cause differential settlement after being opened in service and facilitate differential erosion by infiltrated rain fall and destabilization by perched ground water.

For site inspection, structure of embankments should be checked first. Based on that information, locations where future deformation may occur should be selected for inspection.

Table 1-24 Potential Hazards of Embankment along Hill Roads

Check points			
Category	Condition	Classification	【Judgement】
Height of filling (with berms of 1.5 meters wide at each 5 meters in height)	Height <5m	Considered as unstable if steeper than 2H3W	・Standard gradients of slope are determined by material and height of embankment. ・The embankment that does not follow the standard gradients may suffer from deformation by its own weight and surface failure involving shoulder of slope. ・Insufficient bearing capacity of inclined ground as well as poor compaction of widening of embankment may collapse of entire embankment. ・Surface failure caused by perched groundwater and soil pipes may occur in valley filling or cut and fill embankment which allows rain fall to infiltrate into the boundary between cut and fill. ・Countermeasures should be so planned that the works meet requirements from the site conditions including disaster risk on site.
	5m< Height <10m	Considered as unstable if steeper than 5H9W	
	10m< Height	Considered as unstable if steeper than 5H9W, even with high quality materials	
Types	Cut and Fill	Deformation at boundary between cut and fill by infiltrated rain water	
	Widening	Collapse due to insufficient compaction	
	Valley filling.	Infiltration of stream water Destabilization by earthquake	
Bearing layer	Talus and alluvial lowland	Settlement and slide due to lack of bearing capacity	
	Soft ground		
	Landslide and fault zone	Deformation and destruction by external force	
Materials	Cohesive and organic soil	Consolidation settlement. Insufficient compaction	
	Containing fragile rocks	Destabilization of embankment structure	
	Low degree of compaction	Immediate settlement	
Slope	Crack	Open crack, subsidence, bulging	
		Small collapse	
	Spring water	Soil pipes	
		Gully erosion	
Facilities	Retaining wall	Upper parts of slope remain untreated	
	Drainage	Leakage due to deformation of embankment	

Source: JICA Project Team

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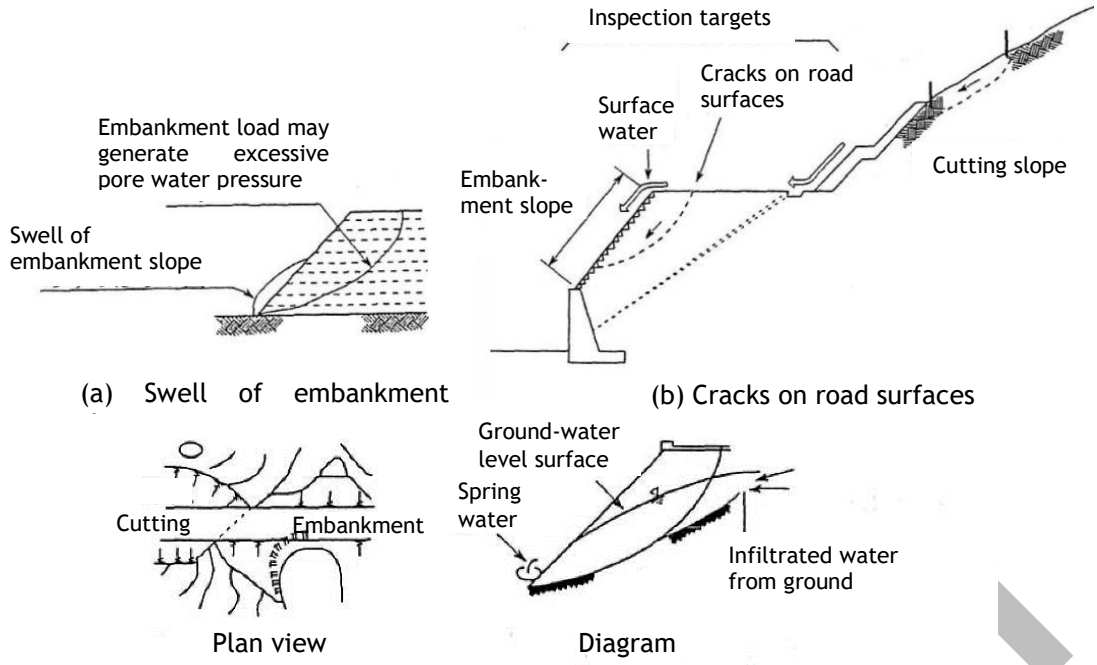


Figure 1-94 Possible Failure and Deformation at Embankments on Slope

[2]

1.3.4 How to decide possible slip surface of foreseen landslide/slope failure

In Chapter 1.3, potential landslides/hazards along hill roads foreseeable from the current condition are discussed. Such potential hazards silently develop underground without showing clear deformation or damage visible on the surface. For such potential hazards, detecting loosened zone of bedrock and slip surface of landslide deep underground is not so easy task for ordinary monitoring devices. But with high quality boring and sampling methods explained in Chapter 1.1.2, undisturbed core samples with depth information are obtained and necessary information to detect loosened zone or slip surface is available from the core samples. In case high quality core sampling is not available, by introducing bore-hole camera, images of borehole wall captured in situ are available for observation, including loosened zone of bedrock showing slight deformation.

The most important point to consider is the location of drilling (borehole) investigation. Drilling investigation for potential hazards should be so located as to obtain core samples which include loosened zones where rock creep develops. At natural unstable slope, cut slope, and embankment slope, scattered creep deformations precede development of wide and continuously spread sheared zone. At the time of scattered creep deformations, deciding appropriate locations for borehole investigation is quite difficult by visual inspection of the slope where steep slopes hamper the access to the sites.

For such cases, introducing spatial information technology is effective, such as laser scanning, terrestrial photogrammetry, and remote sensing including airborne electromagnetic survey as mentioned in Chapter 1.1.2.

(1) Terrestrial Laser Scanning (TLS or T-Lidar)

Ground based terrestrial laser scanning (or TLS or T-Lidar) has been frequently used since the late 2000s for topographic survey. The object to be measured by TLS is in the range of several meters to several kilometers, with high resolution of

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several millimeters to several meters and high accuracy of several millimeters to several tens of centimeters.

An example of measurement by TLS and time series analysis of a sea cliff is shown in Figure 1-95 (Rosser et al. (2005)). Steep cliffs like Figure 1-95 change it shape rapidly, so both erosion on the cliff and deposition at the foot are to be observed. Also, because of the nearly vertical slope, ground based TLS has more advantage in measurement than airborne TLS. Figure 1-95 is one of the pioneering studies of TLS measurement. The study targeted the changes by erosion of the sea cliff consisting of sedimentary rocks in eastern England and located the points of rock falls and collapse on the cliff, by measurements at several times in a period of one year and several months. The TLS used for this survey was intermediate range type with relatively slow speed of measurement of 250 points per second. But point clouds with mean intervals of 3 cm were obtained from the surface of the cliff.

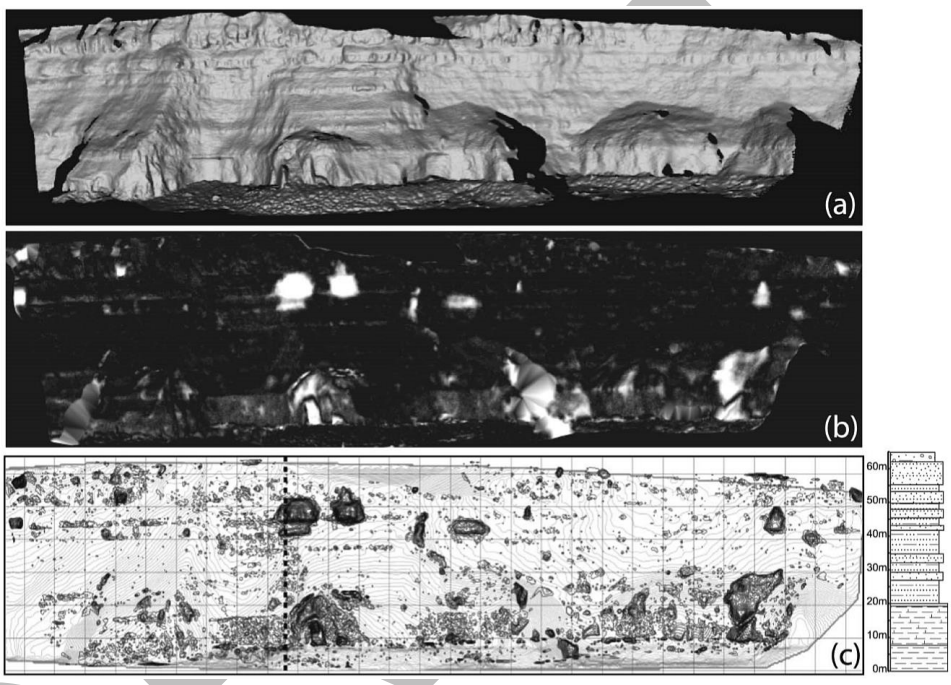


Figure 1-95 Coastal Cliff Measurement and Detecting Changes with TLS（Rosser et al., 2005, Fig. 5）Top: image of hill shade on vertical plane of cliff face（ca. 300 m×60 m）. Middle and Bottom: extracted locations with changes over 16 months and topographic contour lines.

[3]

(2) Drone and SfM-MVS technology

In recent years, Structure-from-Motion Multi-View Stereo Photogrammetry (hereinafter referred to as SfM-MVS) has been used in various fields. Using SfM-MVS, 3D shape data of an object can be obtained from many pairs of images which generate stereo images (hereinafter referred to as Stereo Pair Images). The process to reconstruct shooting positions of each image as well as three-dimensional shape of an object is called SfM, from several photographic images with multiple viewpoints. The process to model a more detailed three-dimensional shape of an object is called MVS, using the point clouds with coordinates calculated from SfM. Development of the high-precision GNSS (Global Navigation Satellite System) improves stability of drone to be used for SfM-MVS and the price of a drone is declining. So utilization of spatial information obtained from SfM-MVS is expanding.

Figure 1-96 and Figure 1-97 show comparisons of SfM-MVS obtained and analyzed from Stereo Pair Images obtained with drone at two different timings.

Difference analyses of 3D shape data provided areas of deformations of the terrain. In both figures, deformations that occurred in a part of the objects are clearly shown.

In general, if a mirror-less SLR camera equipped with an image sensor of APS size and attached with a lens of a focal length of 16mm, equivalent to 24mm in 35mm format, is mounted on a drone and images are captured at a height of 100 meters from the ground, the analyzed model processed with commercially available 3D modeling software has a RMSE, Root Mean Square Error, for accuracy of position of about 4 to 5 cm in horizontal and about 8 to 12 cm in vertical direction. If the technology is applied to topographical survey, the evaluation on the above accuracy may be limited. The differential analysis focusing on the relative positional relationship of point clouds is, however, effective for many needs for locating and monitoring areas of deformation.

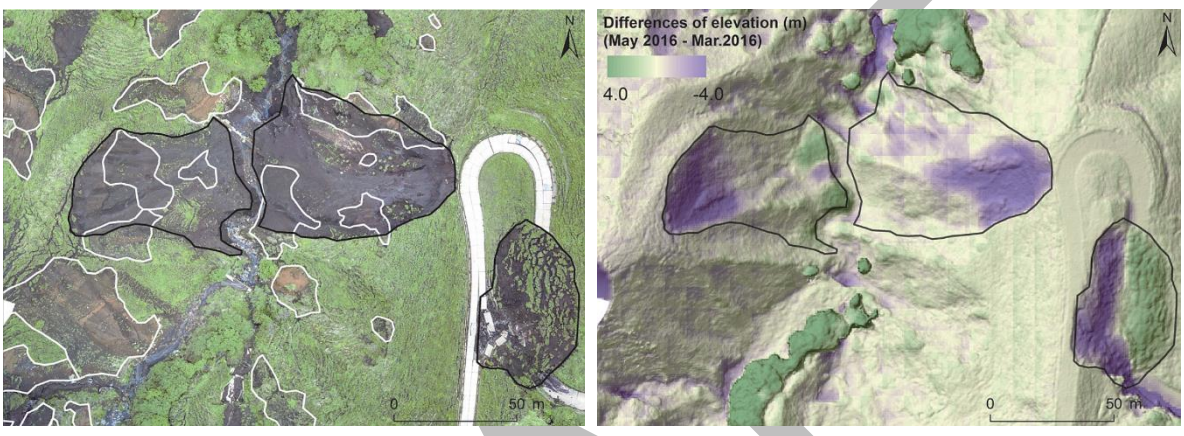


Figure 1-96 Use of Spatial Information (Sensuikyo, Kumamoto, Japan)Left: ortho images taken in May 2016 at 0.04m (spatial resolution) with collapsed areas due to the Kumamoto Earthquake (black-framed) and surface failure areas due to heavy rainfall in Northern Kyushu District in July 2012 (white-framed). Right: differences between DSMs in March 2016 and May 2015 (analyzed erosion areas in blue-shaded)

[4]

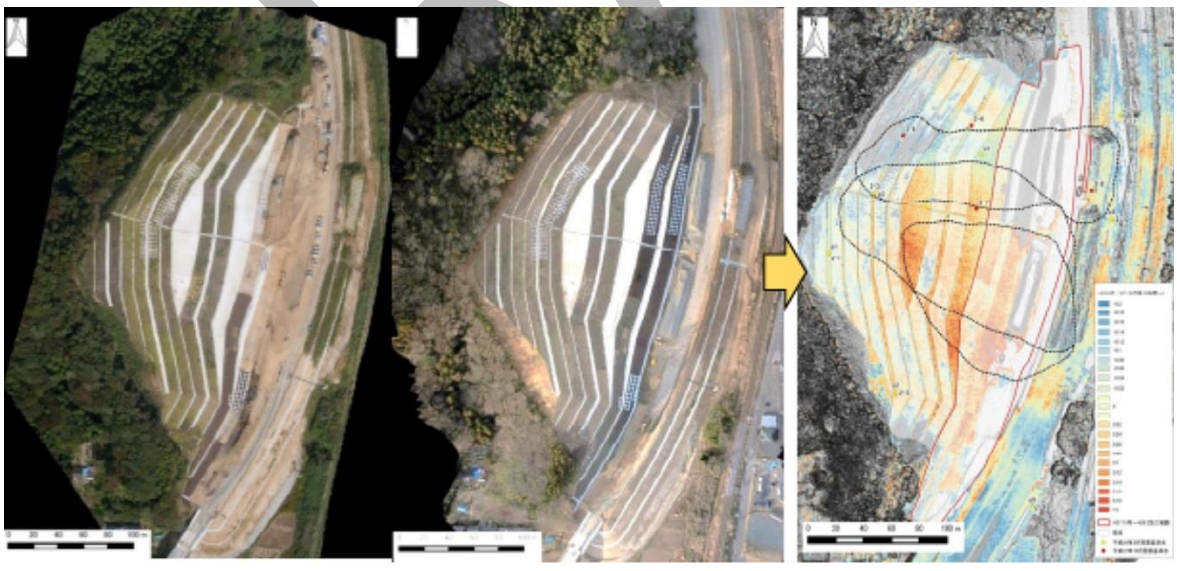


Figure 1-97 Use of Spatial Information for High and Long Cutting Slope

Source: JICA Project Team

(3) Airborne Electromagnetic Survey

Airborne electromagnetic survey is a kind of electrical prospecting method using the principle of electromagnetic induction action. It is often used for exploration of electric conductors (low resistivity anomaly) such as ore vein underground and survey of geological structure using the resistivity distribution of the ground. Unlike electrical prospecting carried out on the ground, installation of electrodes on the ground is not needed. So airborne electromagnetic survey is applied to inaccessible steep slopes and thus is an effective exploration method for obtaining resistivity distribution of wide mountainous areas.

Generally, in electrical prospecting and electromagnetic survey, loosened zones of bedrock are detected as high resistivity if it is dry. If the cracks of such zones are filled with groundwater, however, the loosened zones are detected as low resistivity. In other words, loosened zones of the bedrock show drastic change in resistivity distribution depending on the conditions of groundwater storage. By focusing on this feature, estimation of loosened zone is considered possible. If airborne electromagnetic survey is carried out in both dry and rainy seasons, the comparison between both seasons of resistivity distribution provides valuable information. Changes in resistivity distribution suggest the areas where storage of groundwater was changed. Accordingly, such portions along with connecting narrow high/low resistivity zones are considered as loosened zones of bedrock.

Not only loosened zones of bedrock, resistivity of some rock types is also high (* resistivity of igneous rocks is generally high). As common to geophysical prospecting, it should be noted that specific resistance value in electrical prospecting or elastic wave velocity of seismic prospecting are not decisive information that specify physical properties of the ground. For comprehensive interpretation, integrating information of geophysical prospecting with other data, such as borehole logs from drilling at the relevant site, is important.

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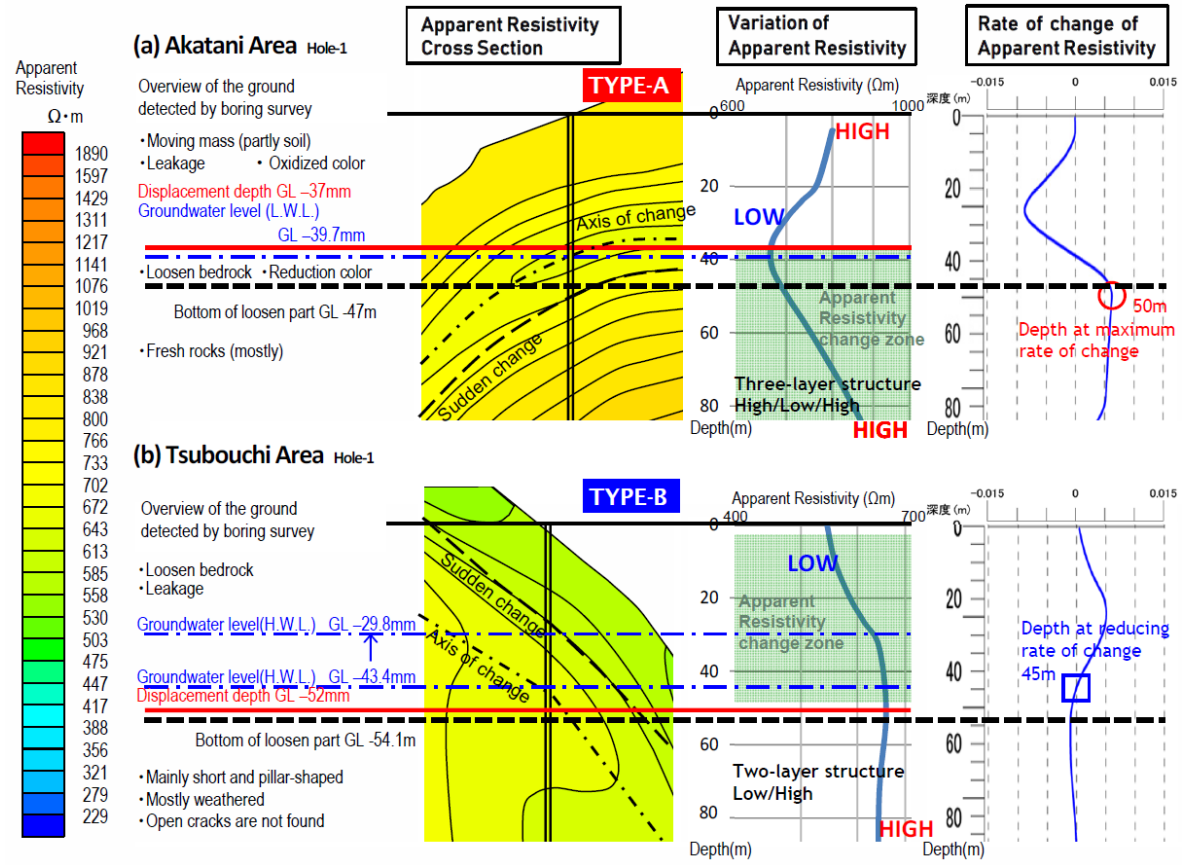


Figure 1-98 Comparison between Variation of Apparent Resistivity and Geological Structure, (a)Apparent Resistivity Structure Type-A [High-low-high], (b)Apparent Resistivity Structure Type-B [Low-high]

[5]

[1] Japan Road Association, Highway EarthWork Series- Manual for Slope Protection, Japan Road Association, 2009.

[2] Bureau of Public Roads, Ministry of Land, Infrastructure, Transport and Turism of Japan, Inspection Manual - Reference Material "Operations Guide for Reconfirmation of Hazard Points on Roads".

[3] Hayakawa Y.S. and Oguchi T, "Applications of Terrestrial Laser Scanning in Geomorphology," *Journal of Geography,*, vol. 125, no. 3, pp. pp.299-324, 2016.

[4] Saito H. et al., "High-definition Topography Applied to Slope Failure Due to The Kumamoto Earthquake in 2016," *Research Abstracts on Spatial Information Science, CSIS DAYS*, 2016.

[5] Hayashi K. et al., "Estimation Method for Failure Depth Using Airborne Electromagnetic Survey in Gravitational Deformation Slopes," *JSECE Publication No. 83 (Proceedings of Japan Society of Erosion Control Engineering)*, 2017.

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1.4 Landslides/hazards foreseen from road widening by cutting/filling

1.4.1 General

This section explains possible hazards relating to road widening. In addition to new road construction on green field alignment, road widening of the hill roads is in strong demand in India, pushed by strong economic growth. In general, road widening is realized by cutting of hill side or filling on valley side or combination of them. At the same time, road widening often triggers landslide / hazards along hill roads and some of which may be avoided if due attention is paid for slope conditions along the existing alignment.

If toe of landslide or gravity deformation is cut by road widening, unloading at the toe may cause destabilization of the landslide or acceleration of the gravity deformation. In case road widening is required within a limited width of land acquisition or Right of Way (ROW), gradient of cut slope is often steepened far more than standard gradient of cut slope. Such steep slopes often cause collapse and landslide unless properly treated with countermeasures.

In general, by the suction caused by rapid unloading, slopes right after cutting seem as if they were tightened. The bedrock is, however, gradually relaxed by stress release unless proper treatment is applied. Under such conditions, surface of the slope swells through absorption of moisture after rainfall and unstable zone expand to deep ground. The situation becomes worsened with time. Rainfall and surface runoff form gully erosion and excessive groundwater flow through soil pipe causes surface failure on the slope. Gully erosion and surface failure remarkably destabilize upper and neighboring parts of slope. Such process repeats and collapse continues unless proper treatment is applied or stable gradient is achieved.

If the slope is covered by debris or talus deposit and cutting is made at the toe of such slope, debris slides down to the road endlessly unless stable gradient is formed..

When implementing road widening of hill roads mainly with filling to reduce cutting, high embankments standing from the toe of slope would be added on steep and deep valley side slopes, unless advanced technologies are applied. For such high embankments, reinforcement to ensure internal stability against its own weight and proper drainage system to maintain drainage capacity are essential. In addition, in order to satisfy stability inspection against sliding of embankment, forming steps by cutting toe of slope is also required. This treatment requires safety consideration during construction.

In this section, actual cases of slope hazards relating to road widening are explained. Then, disaster scenarios to be assumed in cutting and filling of road widening are introduced.

1.4.2 Hazards to be triggered by cutting or filing

(1) Debris and Fractured and Weathered Rock Remained on Dip Slope

Depending on the geological and weathering conditions as well as shape of cut slope, debris and/or fractured and weathered part of bedrock may remain on dip slope structure. Structurally, dip slope itself facilitates sliding of unstable parts or debris on the planar plane of bedrock dipping downward. Dip slope of bedrock also acts as a constraining floor for groundwater of infiltrating rainfall and surface runoff. Such groundwater flows downward along the dip slope and generates seepage pressure that

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facilitates instability of debris and/or fractured and weathered parts of rock remaining on the dip slope and increases driving force of sliding.

In addition, such weak parts on slopes would slide down when an earthquake occurs, by being resonated with the shake of the earthquake.

When finishing cut-slopes, therefore, unstable parts, such as debris and fractured/weathered parts of rock should be removed from of the slope. Gradient of cut-slopes should not exceed standard gradient of slope unless reinforcement of slope which realize steeper gradient slopes are installed.



Figure 1-99 Unstable Debris and Fractured and Weathered Rock on Dip Slope

Source: JICA Project Team

(2) Risk of Cutting of Alternation of Sandstone and Shale

Alternation of sandstone and shale, which is often observed at some geological groups in Lesser Himalaya, has particular risks on cutting.

On the cut slopes where alternation of sandstone and shale is exposed, due to unloading and exposure to the air by cutting, slaking weakens strata of shale from the surface and differential erosion develops, which erodes shale preferentially and forms overhang of relatively hard sandstone. With the joints developing within it, overhang of sandstone gradually loses its stability and causes rock fall with detached parts of it.

Unloading by cutting develops relaxation of shale and loosens micro cracks and bedding planes within it. Unloading as well as repeated cycles of wet and dry conditions on the surface facilitate slaking of shale, which crumbles the surface of shale into fragments. Loosened cracks and planes in shale forms fissures, which enable shallow groundwater to flow through it. Such specific conditions of shale facilitate weathering and deteriorate the strength of shale, which eventually reduce stability of cut slopes. For such cut slopes, along with prevention of weathering, mitigation of slaking by hampering wet and dry cycles is important.

Also, alternation of sandstone and shale should be considered as alternation of hard and soft layers, in which cracks induced by unloading develop differently and units of collapse are easily formed. Accordingly, in addition to prevention of weathering and erosion, protection works with retaining function to some extent against earth pressure are recommended, such as retaining wall including concrete crib works.

Similar conditions are assumed for the slopes with alternation of sandstone and mudstone, which are expected in geological formations of sedimentary soft rock.

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Figure 1-100 Collapse at Cut Slope of Alternation of Sandstone and Shale (Parwanoo – Solan, along NH22)

Source: JICA Project Team

(3) Cut Slope with Too Steep Gradient due to Constraints from Land Acquisition

Figure 1-101 shows an example of cut-slope formed with a too steep gradient of 3H10V, as a result of constraints from land acquisition. The geological condition of the cut slope is terrace deposit, the assumed standard gradient of which is 1H1V if slope is less than 5 meters in vertical height and 6H5V if less than 10 meters, due to strength reduction by erosion and in saturated condition.

Without having erosion protection or reinforcement which assures stability, gully erosion would damage the slope and eventually the slope would collapse. And the building close to the shoulder of slope would be affected.



Figure 1-101 Unreasonably Steep Cutting Slope Due to Constraints of Land Acquisition (Parwanoo – Solan, along NH22)

Source: JICA Project Team

(4) Destabilization of Slope by Slaking

The slope in Figure 1-102 is composed of tuffaceous rock, which is prone to fragmentation and decomposition by slaking, compared to the rock strata exposed on the neighboring cut slopes. The cut slopes in Figure 1-102 suffer from middle sized collapse involving bedrock and bulging of entire slope, as a result of cutting steep slopes without applying proper treatment to the peculiar geological condition of time dependent deterioration of rock.

For the slopes where unusual geological conditions are expected, investigation including laboratory soil and rock tests should be done in preliminary study stage for evaluating risk of such conditions. Based on the evaluation, if slaking is predicted, appropriate countermeasures such as adopting gentle gradient of slope, protection against weathering and erosion, reinforcement of slopes, and countermeasures against earth pressure including concrete crib works should be installed



Figure 1-102 Cut Slope Damaged by Slaking (Parwanoo – Solan, along NH22)

Source: JICA Project Team

(5) Unstable Condition Due to Cutting of Toe of Landslide

An example of instability of landslide due to cutting of the toe for road widening is shown in Figure 1-103. Although the scale of the landslide is small with a slope length of 50 meters, width of 20 meters, and estimated depth of slip surface of less than 5 meters, based on the evidence of tree bends on the slope, the landslide is considered as active.

From the shape of bending trees, it is considered that landslide had already moved before road widening was executed and stability of the landslide was decreased by cutting. In addition to the road, railway line passes directly above the landslide block. Thus the landslide needs countermeasure to stop its movement as well as detailed investigation and continuous monitoring (24 hours).



Figure 1-103 Instability Caused by Cutting of Toe of Landslide for Road Widening (Parwanoo – Solan, along NH22)

Source: JICA Project Team

(6) Destabilization of High and Long Cut Slope Caused by Road Widening

The high and long cut slope of Figure 1-104 shows an example of destabilization by road widening. The steep bedrock slope of plunging Proterozoic phyllite was cut by road widening and the high and long cut slope was formed while increasing risks of instability of slope.

The toe of entire slope is located at undercut slope where erosion by river water actively progresses. In addition, the bedrock on the flank of the existing collapse exhibits progressing toppling of gravity deformation. Under such situation, risks of major collapse including expansion of the existing one still remain at the cut slope.

One of supposed countermeasures for the slope is a combination of various works. Firstly, after securing foundation on the valley side, possibly in the river with erosion protection, works for detour of the traffic should be prepared. One of the supposed methods is constructing steel jetty along the existing road. After securing detour, works of removing the relaxed parts of the rock and reshaping slope to gentle gradient follows. The removal includes the shoulder of the slope and the progressing toppling of gravity deformation and aims to mitigate gravity deformation. After the removal, slope drainage and weathering protection should be realized. Shotcreting of slope surface is one of the supposed methods for weathering protection. At the same time, protection against river erosion of the toe of the slope should be realized, such as revetment work at the toe and flow control works placed upstream including groyne.

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Figure 1-104 Destabilization of Cut Slope of Plunging Bedrock by Road Widening (Siliguri-Gangtok, along NH10)

Source: JICA Project Team

(7) Collapse of Slope due to Inappropriate Stability Analysis

Results of slope stability analysis govern design of cut and fill slope including countermeasures against landslide, if any.

The collapse shown in Figure 1-105 occurred at the cut slope for road widening protected by leaning type retaining wall. Leaning type retaining wall is applied to prevent collapse by active earth pressure behind it. The retaining wall in Figure 1-105 was severely deformed by the collapse of the cut-slope behind it caused by intense rainfall. The deformation was large at the top of the retaining wall but small at the toe. So it is considered that an active collapse of the cut slope behind the retaining wall pushed the leaning type retaining wall of piled concrete blocks, which toppled with its foot as the rotation center. Thus the deformation was considered due to inappropriate evaluation of stability of the cut-slope behind the retaining wall.

Figure 1-106 shows another example of collapse of steep cut-slope. For this site, no slope protection or countermeasure is installed to the cut slope other than the breast wall at the toe. The head of the collapse, which was caused by intense rainfall, was located at the upper slope behind the shoulder of the cut slope and the toe of collapse corresponded with the toe of the cut slope. Since the head of the moving mass showed inclination towards hill side, the collapse is considered as a rotational slide with a circular slip surface. Based on the observation above, the slip surface of the collapse should correspond to the circular slip surface of the minimum safety factor on the concerned cut slope. In other words, if slope stability analysis had been conducted properly, the scale of the collapse would have been specified and the countermeasures against the slide would have been realized.

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Figure 1-105 Tilted Retaining Wall Due to Active Collapse of Slope Behind (Parwanoo – Solan, along NH22)

Source: JICA Project Team



Figure 1-106 Rotational Slide Occurred on Untreated Cut Slope (Parwanoo – Solan, along NH22)

Source: JICA Project Team

1.4.3 How to decide possible slip surface of possible landslide/slope failure

In the previous section, the actual examples of hazards to be triggered by road widening are explained. In most of the cases, the artificial slopes look stable right after cutting/filling, but destabilization of the slope emerges as time elapses. After certain period of time elapsed, the slope with stability problem collapses. The reasons of the collapse in Chapter 1.4.2 are various, from too steep gradient of slope, peculiar geological condition and structure to inappropriate consideration of slope stability analysis. But there is one common factor among the cases; countermeasures against hazards are not sufficiently planned.

If the slopes along highway retain risks of collapse or slide, in most of the cases, placing breast wall is not sufficient to counteract the risks. If the slopes are cut or filled with stable gradients of slopes and without any risks of destabilization,

weathering/erosion protection would work. In case slopes are designed steeper than stable gradients of cut/fill slopes, such assumption should be accepted that collapse or slide must occurs on such slopes, and countermeasures should be designed against collapse/slide with the most appropriate slip surface. Even slopes are designed with stable gradients, if there are risks of destabilization, such as dip slope condition and time dependent degradation, countermeasures against collapse/slide should be designed in the same manner. For such purpose, setting the appropriate slip surface for design is essential.

In this section, for the new cut/filling slopes steeper than stable gradients or the slopes with stable gradients but with unstable condition, methods for setting appropriate slip surface of collapse/slide to be used for design of countermeasures are explained.

An appropriate slip surface is the slip surface on which probable collapse/slide moves. So if such surface is obvious from the site condition, adopting such surface for design is recommended. For cut slopes of bedrock with stratified geological structures, such as bedding, foliation, and joints, the slip surface of the probable slide can be assumed from the site conditions, including strike and dip of the dominant geological structure observed in a field survey as well as weathering conditions of rock and loosened conditions of cracks obtained from borehole logs. With helps from drilling (borehole) investigation and monitoring, the slip surface of the existing landslide can be identified and used for design of countermeasures.

The methods for setting appropriate slip surface to be explained in this section should be used for the case where appropriate slip surface cannot be set with available information or slip surface assumed from the available information should be verified.

(1) Definition of Safety Factor in the Slope Stability Analysis

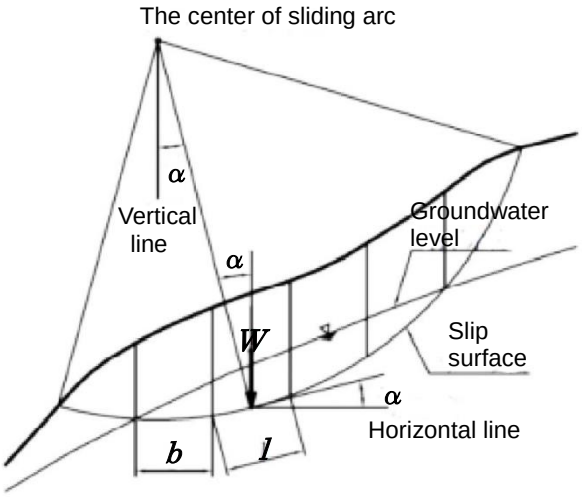
The 2D slope stability analysis is a method to evaluate stability of slope on two-dimensional slice section. The analysis compares the totals of shear stress (sliding force) acting on slip surface of each sliced section and frictional resistance force derived from Mohr-Coulomb yield criterion on each sliced section.

As an example, the definitional identity of "Modified Fellenius Method", which simplifies the relation between sliding and resistance force in slope stability analysis, is shown in Figure 1-107. The factor of safety (Fs) is defined as the ratio between sliding force (the denominators) and the frictional resistance force on the slip surface (the numerator). Accordingly, when Fs = 1.00, the slope is considered in a limit equilibrium state (a state in which stability is barely kept at a minimum limit).

Another important definitional identity relating to the factor of safety of slope stability is for calculating the required prevention force to be provided by the prevention works against landslide/collapse. This factor of safety is called "design factor of safety", which is defined as the factor of safety as of the time when the planned prevention works are completed. The definitional identity of design factor of safety is shown in Figure 1-108.

The formula in Figure 1-108 is derived from the formula of Modified Fellenius Method by adding prevention force from the planned countermeasures as “Pr” to the frictional resistance force (numerator). By setting a design factor of safety and then finding out the “Pr” which meets the design factor of safety, the necessary prevention force to be provided by the planned countermeasures is calculated.

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$$Fs = \frac{\sum \left(c \cdot l + \left(W - u \cdot b\right) \cos \alpha \cdot \tan \varphi\right)}{\sum W \cdot \sin \alpha}$$

Fs : Factor of safety
c : Cohesion
φ : Shear resistance angle (internal friction angle)
l : Arc length of slip surface of each sliced section(m)
u : Pore water pressure (kN/m^2)
b : Width of each divided piece (m)
W : Wight of each divided piece (m)
α : angle between 'the line connecting midpoint of slip surface of sliced sections and the center of sliding arc' and 'vertical line'

Figure 1-107 Definitional Identity of Safety Factor Based on Modified Fellenius' Method

[1]

$$F_{sp} = \frac{\sum \left(c \cdot l + \left(W - u \cdot b\right) \cos \alpha \cdot \tan \varphi\right) + P_r}{\sum W \cdot \sin \alpha}$$

F_{sp} : Design Factor of Safety
P_r : Required Prevention Force (kN/m)

Figure 1-108 Definitional Identity of Design Factor of Safety by Modified Fellenius' Method

[1]

(2) Outline of Circular Search Method

Circular search method is a practical method to search an appropriate slip surface of a probable landslide/collapse in a particular slope. Risk of landslide/collapse contains probability and selecting an appropriate slip surface from tremendous options of slip surface also inevitably entail probability. Thus the process with tangible evidences is required for selecting the most probable slip surface as an appropriate slip surface for design. The circular search method, in which slip surfaces along circular arcs are repeatedly calculated to find out the slip surface with the minimum factor of safety, by changing the center and radius of the arcs, are used for such process. Usually, the slip surface with the minimum factor of safety is considered the most probable. By changing shape of arc as well as soil parameters, circular search method is used for finding out the slip surface with the minimum factor of safety.

Definition: To find out the slip surface with the minimum factor of safety through the slope stability analysis made on two-dimensional cross section with slip surface of circular arc shape, by changing the center and radius of arcs. The results of circular search method are used for evaluation of stability of particular slopes as well as design of countermeasures against slide/collapse as external forces to the prevention works. (Figure 1-109)

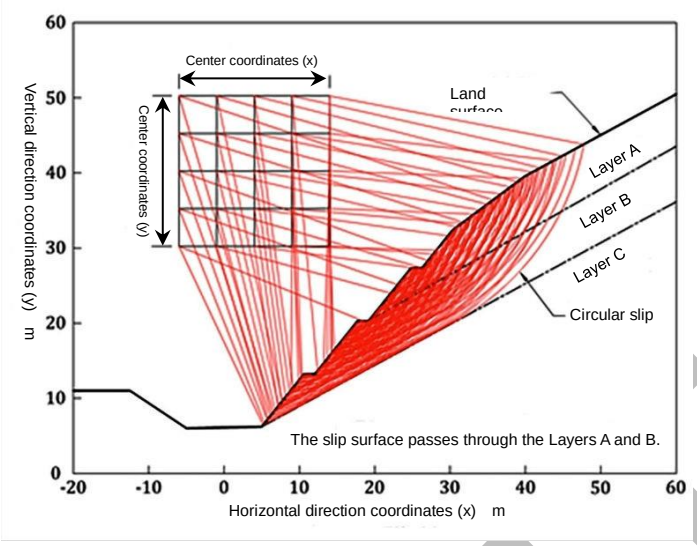


Figure 1-109 Circular Search Methods

[2]

(3) Slip Surfaces with Minimum Factor of Safety or Maximum Resistance Force

The slip surface having the minimum factor of safety is sometimes different from the slip surface which maximizes the resistance force to be provided by prevention measures, such as countermeasures against slide/collapse or reinforcement to the slope.

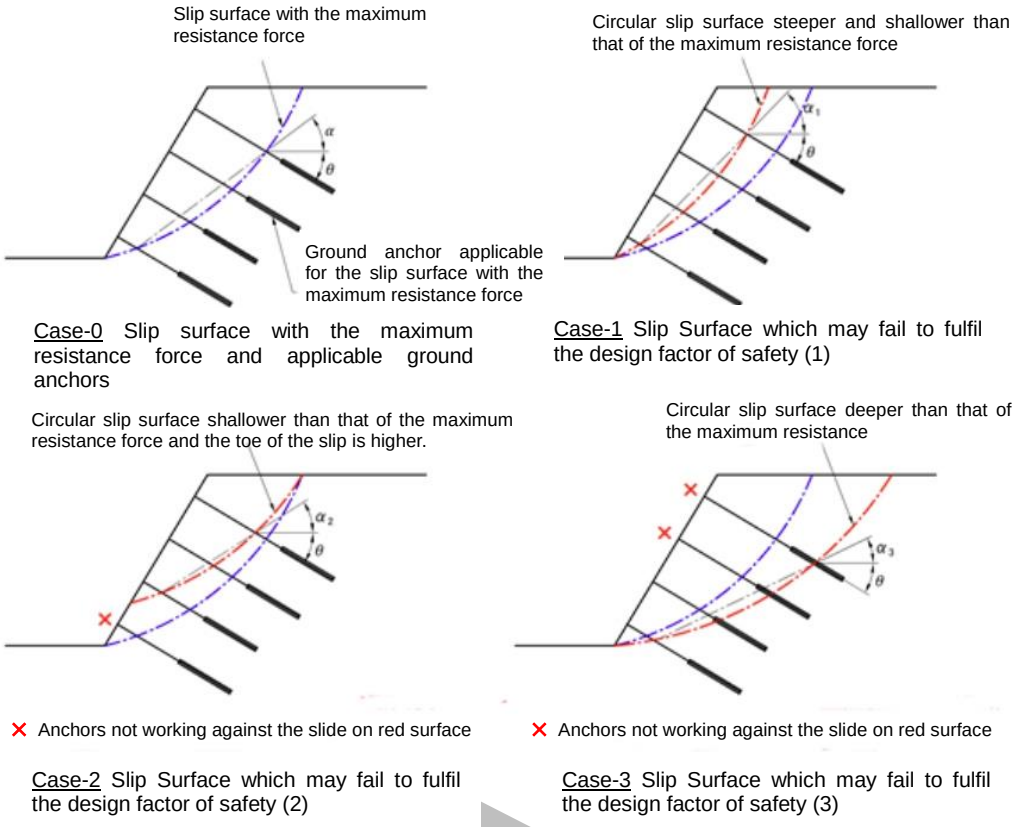
The slip surface with the minimum safety factor is extracted among a number of circular slip surfaces through circular search method with limit equilibrium state analysis. On the other hand, the slip surface with maximum resistance force requires the maximum resistance force calculated through circular search method under certain topographic and geological conditions with geotechnical parameters.

In the design, the maximum resistance force is considered as the external force which affects structures of prevention works, such as ground anchor works, soil nailing, rock bolts, and landslide piles and shafts. This theory assumes that, by stabilizing the slide on the slip surface with maximum resistance force, slides on other slip surfaces are also stabilized. For this point, due attention should be paid.

When the maximum resistance force calculated from circular search method is used for design, however, the internal and external stability of the slope including the prevention works itself should be sufficiently ensured. The cases to pay due attention are explained in Figure 1-110, in which positional relations among the following three factors are illustrated:

(a) The slip surface with the maximum resistance force (in blue)
(b) Anchor designed based on the slip surface with the maximum resisting force
(c) Circular slip surfaces which require prevention works other than those from the maximum resistance force (in red)

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[Case-0] The circular slip surface with the maximum resistance force (blue line) and the position of anchor applicable to the slip surface and the maximum resistance force

[Case-1] The circular slip surface running in the shallower part than the slip surface with the maximum resistance force. Compared with the slip surface of [Case-0], as the volume of landslide mass is smaller, the required resistance force is also smaller. Larger anchor force, however, may be required due to the steeper angle of the slip surface than that of [Case-0].

[Case-2] Similar to [Case-1] but the toe of the circular slip surface is higher than [Case-0]. The anchors at the bottom do not work against the slip surface. Thus provided anchor force becomes 3/4. Further evaluation is required to confirm the reduced anchor force is sufficient for the slide of [Case-2].

[Case-3] The circular slip surface running deeper than that of the maximum resistance force. The volume of landslide mass is bigger but the inclination of the slip surface is gentler than [Case-0]. For this case, the required resistance force is usually smaller than [Case-0]. The top and 2nd top of anchors are, however, not working against the slides on [Case-3]; the available anchor force becomes halved. Further evaluation is required to confirm the reduced anchor force is sufficient for the slide of [Case-3].

Figure 1-110 Anchor Works against Slip Surface of Maximum Resistance and Other Slip Surfaces Which Require Review of Effectiveness

[3]

The circular search method should be applied to the slopes where 1) no indication of landslide/collapse is observed, 2) no landslide/collapse yet occurred, and 3) shape and depth of slip surface is unable to assume. For such slopes, design of countermeasures against slides/collapse as well as reinforcement should be based on the slip surface with the maximum resistance and then such design should be reviewed through circular search method to confirm that the design factor of safety is assured with any other circular slips.

Note: For the slopes where slip surface is obvious, circular search method is not applicable.

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[1] Japan Road Association, Highway EarthWork Series- Manual for Slope Protection, Japan Road Association, 2009.

[2] RISE Slope Design Co.,Ltd., "Website Blog 21 Aug 2014 Factor3," [Online]. Available: http://riseslopedesign.com/2014/10/11/smallest_safety_factor_3/.

[3] RISE Slope Design Co.,Ltd., "Website Blog 21 Aug 2014 Factor4," [Online]. Available: http://riseslopedesign.com/2014/10/11/smallest_safety_factor_4/.

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1.5 Landslides/hazards foreseen from new road construction

1.5.1 General

From Chapter 1.2 to 1.4, by showing actual examples of landslides observed along hill roads, the characteristics, precursor, and mechanism of various types of landslide hazards are explained. Besides that, the investigation methods along with its points to be noted are explained for each hazard type and the techniques to understand each landslide hazard in three-dimensional perception are introduced. The hazard types explained in the previous sections are gravity deformation, rock falls/slides, slope (surface) failure, deep seated landslide, (normal) landslide, and debris flow.

In this section, based on the features of landslide hazards, a technique of map reading is highlighted. The map reading technique is to extract landslide hazards along a planned alignment of hilly highways from particular shapes of contour lines of topographic maps. Each landslide type leaves its traces or features on the terrain where it lies or occurred. Thus, by map reading, locations of landslides including its origins are identified, and records of activities of landslides along with its influenced zones are interpreted. Those areas should be considered as risky areas for highways in hilly areas. Such risky areas should be surveyed on site and risk of landslides should be evaluated. Through the aforementioned procedure, risks of landslides along a green field alignment can be identified and necessary countermeasures, including avoiding such risks by realignment, can be planned and executed.

1.5.2 Hazards to be triggered by road construction

The topic of this section, "hazards to be triggered by road construction", is not limited to landslides/collapse triggered by change of landform by road construction but includes the cases where a newly planned alignment of hill road approaches to and activates the existing hazards in a project area.

Along hill roads, numerous hazardous factors naturally exist. But alignment of newly planned hill road should avoid such hazardous factors as much as possible. On the course of alignment study as well as avoiding such hazards, adopting structures such as bridges and tunnels should be considered accordingly. Earthwork along the alignment should be so planned that cutting and filling would not trigger hazards like landslide and collapse. In case avoiding hazards by adjusting alignment is difficult, countermeasures against hazards should be planned including fixing/treating the source of hazards.

In case huge energy is estimated to be provided by the hazards along the planned alignment, countermeasures to reduce energy of hazards, such as check dam, rock fall prevention net, guide wall, and groyne, should be planned. Thus alignment study for hill roads should consider not only control points for alignment but avoiding or reducing the risks provided by the hazards along the alignment.

Figure 1-111 shows examples in the Sikkim Himalayas where metamorphic rocks of Greater and Lessor Himalaya lie. The metamorphic rock of the Sikkim Himalayas are usually hard and but sometime forms stratification with fractured zones.

The picture on the left shows a slope of gravity deformation. The scale of the deformation is very large with a height of more than 100 meters. The road passes through the foot of the deformation. Once the gravity deformation turns to a deep-seated landslide, the road would be completely destroyed. A deep seated landslide may form a natural dam and cause catastrophic damage downstream when the dam collapses. Gravity deformation alone causes continuous subsidence of the road and burdens the road administration with the maintenance cost.

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The picture on the right shows trace of avalanche or mud flow caused by snow melting. In the snow-covered regions, cautions and countermeasures against snow-related hazards should be exercised.



Figure 1-111 Hazardous Slopes in Sikkim Himalayas（Lachung-Yumthang State Road）
Source: JICA Project Team

An example of massive scale rock mass collapse and the following debris avalanche observed at Lachung in the State of Sikkim is shown in Figure 1-112. In May 2015, a part of the steep rock slope collapsed with slope length of about 800 meters and a width of about 300 meters. The collapse occurred in the rocky mountain slope which stands more than 1,600 meters high from the foot. The collapsed rock mass flowed down as a debris avalanche. The debris avalanche, containing large boulders of over 5 meters in diameter, divided its course into two flows and the upstream avalanche flowed about 1,000 meters toward the valley and stopped just before colliding with the mountain slope of opposite side of the valley. The debris avalanche consists of two layers. The upper layer consists of boulders, the gaps among which are filled with uniformly sized fine sand. The fine sand is considered to have blown out from the lower layer where fine sand is dominant, by the same mechanism with sand boiling by liquefaction during earthquakes.

Many of the trees on the lower part of the mountain slope of opposite side of the valley had been broken off from the trunk. The fallen trees uniformly tilted upslope. These conditions suggest that, at the time of the collapse, the debris avalanche was extremely huge and moved at very high speed, probably with high fluidity provided by the action of pore fluids of water or air among and under the boulders.

In other words, the rock mass collapse in Figure 1-112 is an example of the deep-seated landslide which was turned from gravity deformation. Many slopes with similar risk exist along the hill roads in the Himalayas. No road structures, however, can withstand the massive energy of deep-seated landslides and no countermeasures can prevent progress of large-scale gravity deformations. For such cases of gigantic landslides, identifying the locations of gravity deformation in advance and avoiding such locations are effective countermeasures in hill road planning.

Among the various types of considerations required for planning new highways in hilly regions, identifying landslide hazards along the alignment and selecting proper countermeasures against the hazards are one of the most important examinations during the project. If it fails, road administrators would bear tremendous amount of life cycle cost. The countermeasures effective against landslides in hill road construction are summarized in Table 1-25. By appropriately combining these technologies, hill roads with high efficiency and cost-performance will be realized.

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Table 1-25 Effective Countermeasures for Hill Road Construction

Tactics		Types	Specific measures
Attacking hazards	To prevent hazards	Countermeasures against hazards on site	Fixing source of rock fall on site, preventing movement of Landslide with anchors and piles, reinforcing slopes, soil removal at the head and buttress fill at the toe, and groundwater drainage works.
Avoiding hazards	To weaken hazards	Reducing energy	Small check dam, Rock fall prevention net (placed on the slope)
	To divert power of hazards	Changing direction of debris flow and avalanche	Guide Wall, Groyne
	To avoid hazards	Change of alignment with structure	Tunnel, Bridge
Defending from hazards	To counteract hazards	Reinforcement by structures	Erosion-control dam, rock shed, and rock fall catchment fence and embankment etc.

Source: JICA Project Team

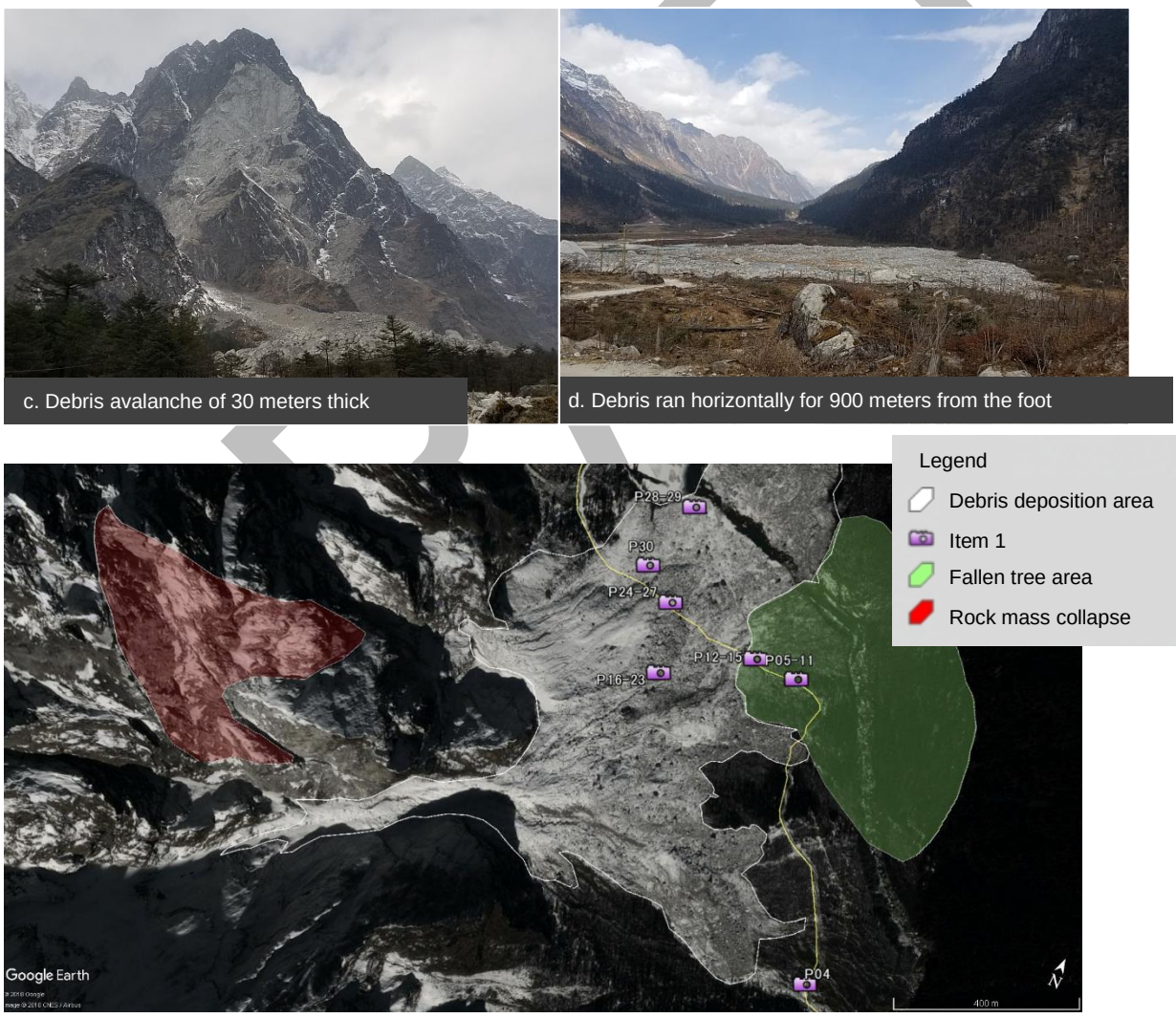


Figure 1-112 Lachung Debris Avalanche（Lachung-Yumthang State Road）

Source: JICA Project Team

1.5.3 How to decide possible landslide/slope failure along with possible slip surface

When studying alignment plan for a new highway in hilly region, identifying and evaluating hazards which spread over in wide areas are required, with uniform standard based on objective indicators. The technique of topographic interpretation, such as aerial photo and topographic map reading, is used for such purpose.

Topographic interpretation can be performed with aerial photographs or topographic maps with elevation counter lines of the targeted areas, by well experienced engineers. The quality of interpretation, however, heavily depends on the experience of the engineers who perform aerial photo/topographic map readings. Such technique cannot be acquired in a short time. Training an interpreter of photo/map readings requires good instructors/instruction books and repetitive practices for a long period. Through such training, interpretation skill of a trainee gradually rises to higher levels. Efforts by a trainee are important but arranging good environment for training is also required.

In recent years, techniques for almost automatically extracting slopes with hazards from interpretation of time series data, such as finite difference analysis of SAR images, are being developed. Although it is an epoch-making effort to eliminate individual differences among interpreters, substantial time is still required to improve such technique to utilize the result of automatic interpretation.

As of the time of writing this guideline, topographic interpretation is conducted manually by experienced engineers with helps of IT technologies and DEM production with satellites/air planes/drones.

(1) Aerial Photo and Topographic Map Reading

Topographic interpretation includes Aerial photo and topographic map readings.

Topographic map reading is defined as, "not only understanding explicit information on a topographic map but also preliminarily presuming the situation of an area on a map in the past, present, and future through interpreting implicit or hidden information on a topographic map."(Suzuki, 1997, 12p) It is also said that " (1) map reading itself is a basic investigation method of land conditions, and (2) map reading is a complementary technology indispensable for understanding the results of other related studies, surveys, and investigations" (Suzuki, 1997, 12p).

At the beginning of a project, all information obtained through topographic, geological, hydro-geological, and environmental field surveys and from the existing data collection is plotted on the relevant topographic maps of the targeted areas. In addition, results of aerial photo reading are plotted on the relating topographic maps as well. Thus reading/interpreting topographic map is an essential skill for an engineer to be involved in surveys and investigations.

Aerial photo reading is to interpret topographical information relating to civil works construction with helps from sense of exaggerated height provided from stereoscopy of aerial photographs with 60% overlap each other. Various types of information are interpreted from aerial photo reading, such as lineament, landslide, collapse, gravity deformation, double ridge, kerncol and kernbut, triangle shaped slope, bending of rivers and streams, inclination of terrains, river/coastal terrace, alluvial fan, talus cone, colluvial slope, natural levee, old river course, back marsh, dissection condition of terrain, landform classification, vegetation, and even moisture content of the surface. But the technique for such "interpretation" requires long training periods and intensive experience.

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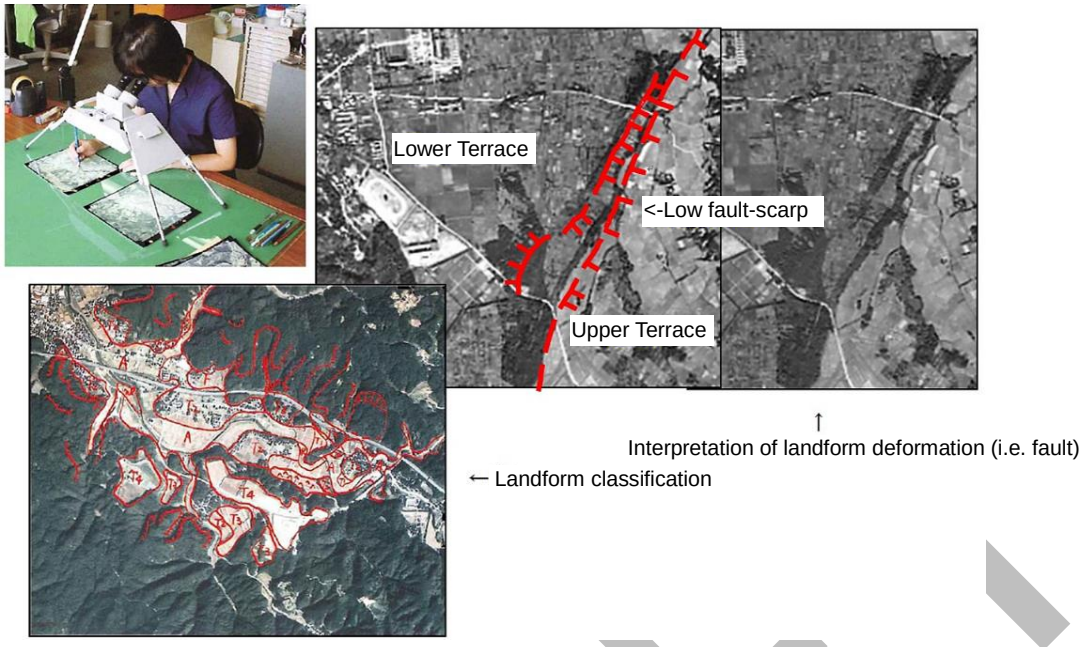


Figure 1-113 Aerial Photo Reading

[1]

In recent years, map reading aided by various terrain representations created from Digital Elevation Model (DEM) is highlighted. DEM is a type of digital topographic data and prepared from Digital Surface Model (DSM), which is obtained from airborne laser scanning or radar observation by satellites, by extracting elevation data.

Since DEM is numerical data, by adding magnification, emphasizing three dimensional effect of terrain is available. Furthermore, by utilizing logarithm of elevation, emphasizing roughness/asperity of flat land and, at the same time, suppressing height of terrace and mountain are possible so as to create effective terrain representation for interpretation of wider areas.

Compared to aerial photography, the biggest advantage of airborne laser scanning is that elevation of the ground under trees is directly measured without being hampered by leaves and branches. Other advantages are:

1) A wide range of terrain is observed seamlessly,
2) Topography can be observed after deleting buildings trees and emphasizing the roughness/asperity, and
3) Compilation of interpretation result is not necessary. Interpretation of aerial photo reading requires transcription to topographic maps but positional information of terrain representation from DEM can be added directly.

Regardless of aerial phot or map reading, topographic interpretation aims to understand the past and future events of the targeted area. This process involves presuming process of geomorphological development. The time scale of geomorphological development is considered as an order of 10^6 years, which is longer than the historical period (10^3 years order) but shorter than the geological time scale (10^9 years order). In order to interpret the geomorphological development in chronological order, identifying temporal order of formation of each terrain is required. The basic principles for identifying the temporal order of terrains in topographic interpretation are listed below:

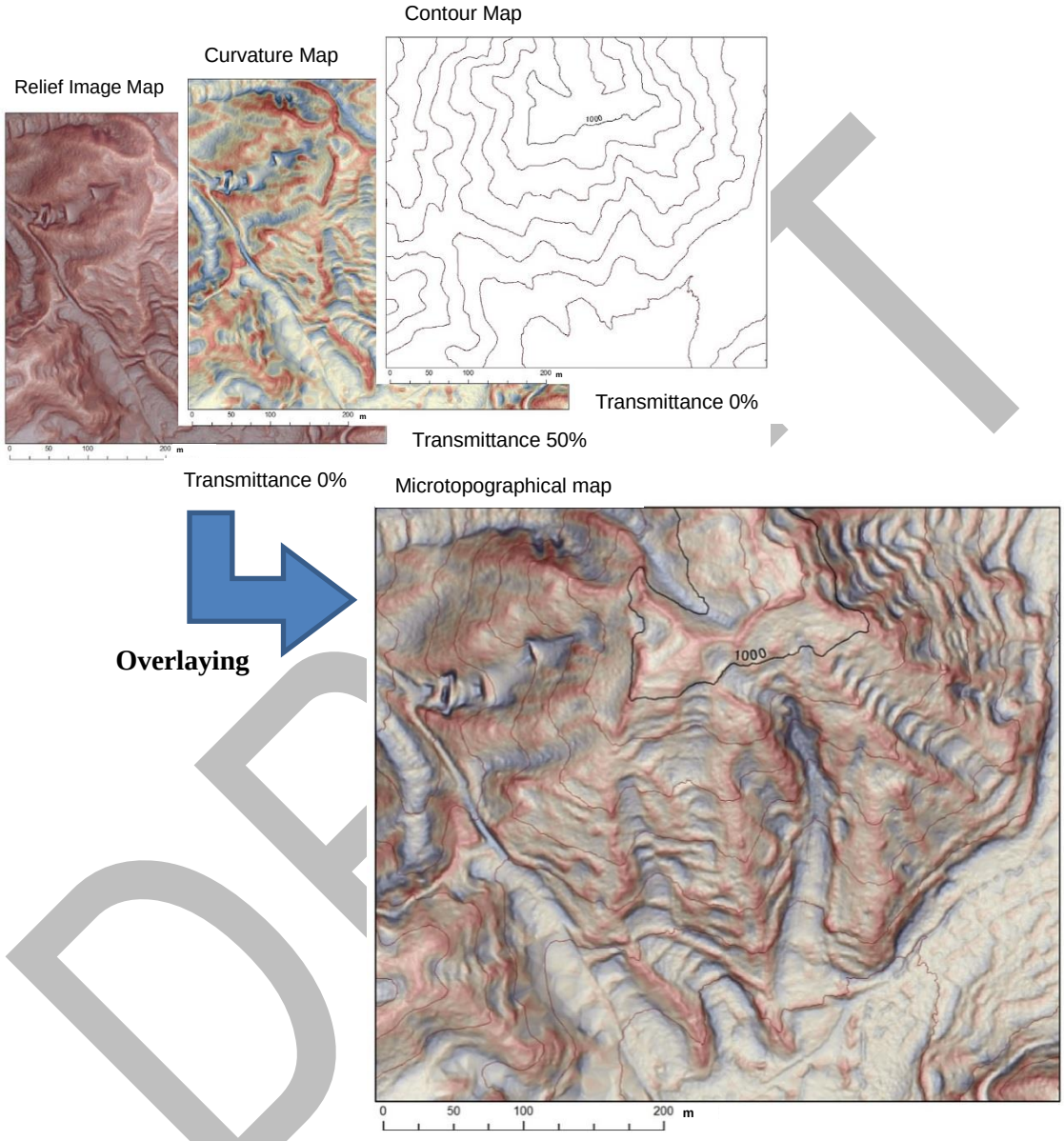
(i) Topographically contiguous terrain was formed at the same time,
(ii) The terrain formed by erosion is newer than the original terrain before

erosion,

(iii) The terrain overlying another terrain is newer than the underlying terrain,

(iv) The terrain formed by displacement or deformation is newer than the original terrain before such movements,

(v) If placed under the same environmental conditions, the terrain with denser traces of movements is older than the terrain with lessor traces.



数値地形データを用いた「微地形図」の作成方法
file:///C:/Users/jce/Desktop/bichikei.pdf ←要再確認

Figure 1-114 Preparation of Microtopographical Map with Digital Topographic Data

(2) Topographic Interpretation of Hills and Mountains

Through aerial photo reading of hilly and mountainous regions, it is often required to interpret geological strata and its distribution, geological structure including faults and fractured/sheared zones, and landslide and slope failure. In many cases,

extracting lineament is highlighted in photo reading, but, as general information, reading water system along with ridge lines of hills and mountains is essential.

Water systems mean that a series of flow paths from different water sources to a shared outlet, including a mainstream and its tributaries along with lakes and swamp connected to them. Watershed or catchment area means an area where precipitation flows into a water system and extents to the ridges surrounding the water system. Interpretation of water system on a topographic map follows the procedure below:

1) To extract peaks in the target area,
2) To connect tips of convex shaped contour lines seen from the peaks to draw ridge lines, and
3) To connect bottoms of concave shaped contour lines to trace flow paths/valley lines/water system.

In other words, connecting the paths of lower elevations makes flow paths/water system, and connecting paths of higher elevation makes ridge lines.

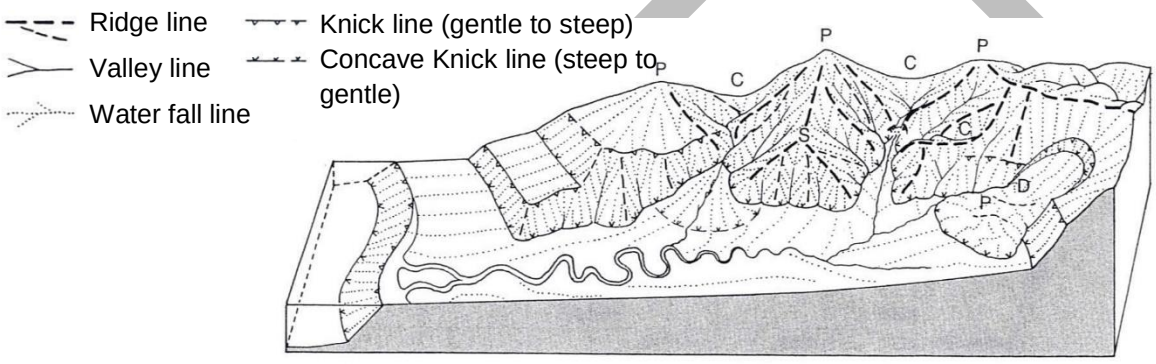


Figure 1-115 Illustrated Image of Water System and Catchment Area

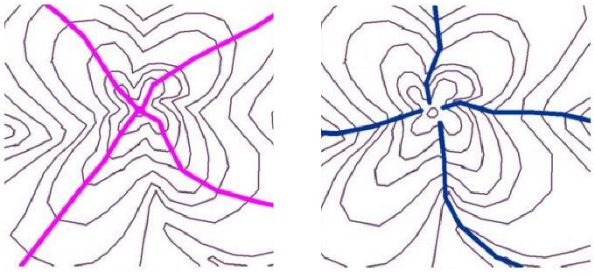


Figure 1-116 Difference between Ridge and Valley Lines

The topographic features refereed to for photo/map reading are detailed in Chapter 1.1.3 and 1.1.4. In this section, typical shapes of contour lines are illustrated, by which gravity deformation and series of hazardous terrains subsequently formed are interpreted by map reading.

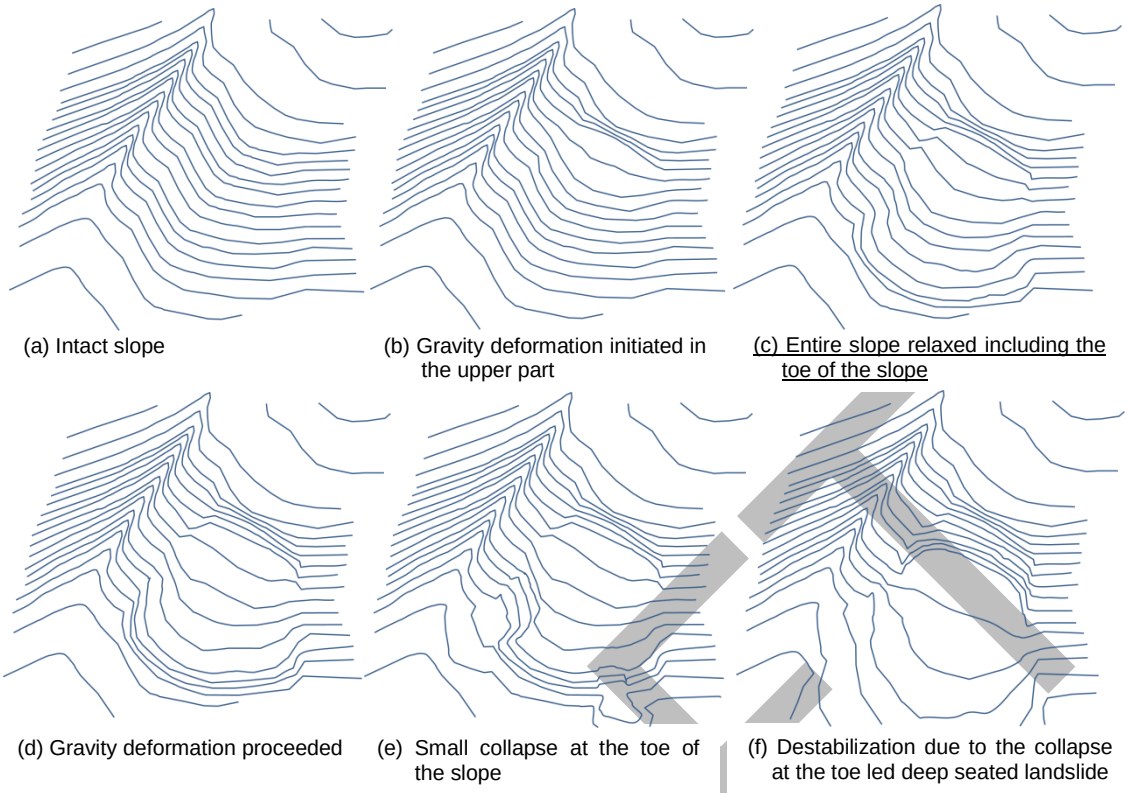


Figure 1-117 Typical Landform Change by Gravity Deformation Seen in Elevation Contours
Source: JICA Project Team

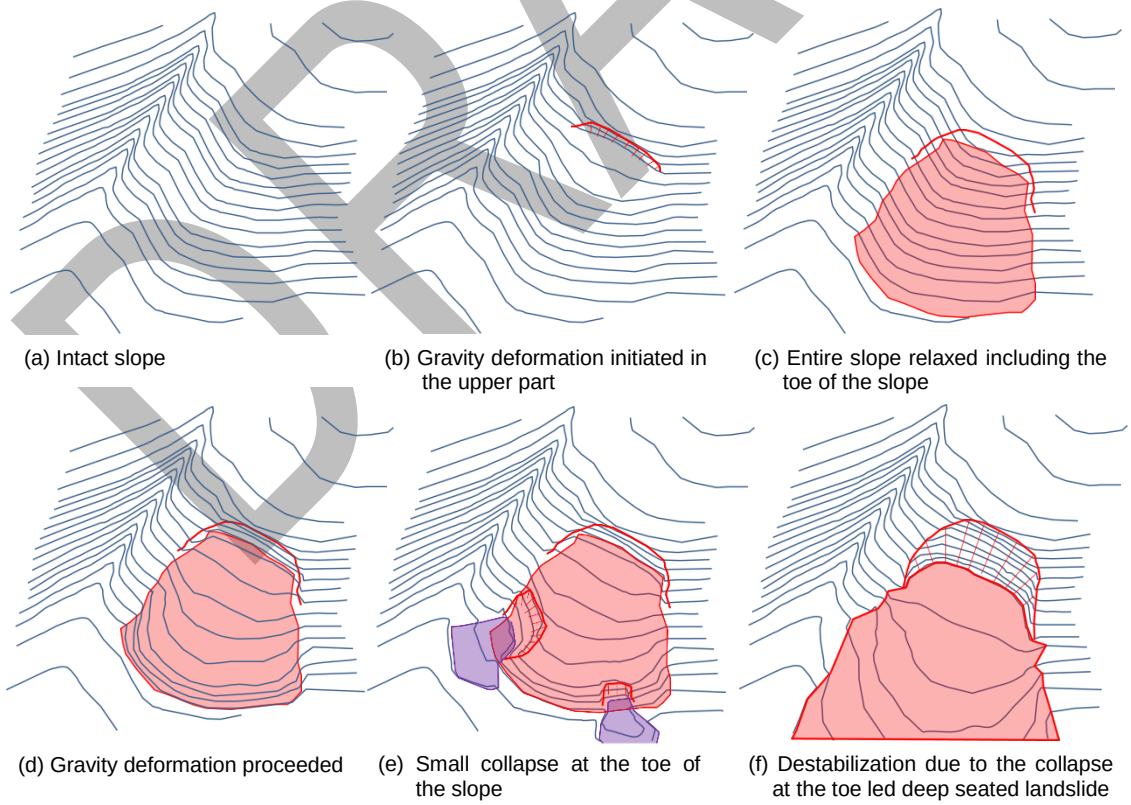


Figure 1-118 Map Reading Results Overlaid on Elevation Contours of Figure 1-117
Source: JICA Project Team

In Figure 1-118, the process of gravity deformation to deep seated landslide is illustrated by contour lines, in which an intact slope is gradually relaxed and deformed by gravity and then collapsed in a form of deep seated landslide triggered by small failures at the toe of the slope.

Generally, gravity deformation forms tensile zone in the upper part and compressed zone in the lower part of slopes. In the initial stage, the deformation is remarkable in the tensile zone. Thus toppling and up-hill facing scarplets are observed in the upper part of slope, especially at the gentle slope above the shoulder of slope.

As the deformation progresses, bulging at the lower part of the slope appears accompanied by buckling and loosening of bedrock. The bulging slope becomes steeper and small collapse occurs at the lower part, especially at the toe of the slope.

Such small failures often occur at the toe of the slopes where groundwater spring is constantly observed, implying development of water passages for fissure water in the loosened bedrock. This suggests such small failures are triggered by external factors such as heavy rainfall and earthquakes. When the fissure water in the water passages of the bedrock turns to pressured groundwater due to heavy rains or other factors, effective resistance force of the slope decreases. This leads rapid destabilization of the slope. For the slopes of gravity deformation, small collapse at the toe of the slope drastically destabilizes the entire slope. As a result, a deep seated landslide occurs at the slope.

In the process of development of gravity deformation from intact slope to deep seated landslide, the anomaly of elevation contours at the stage (c) in Figure 1-117 is easily detected by map reading. Detecting gravity deformation as early as possible is important for planning and maintenance of the hill roads; detection of gravity deformation in a planning stage of a hill road enable a new alignment to avoid such slopes with gravity deformation.

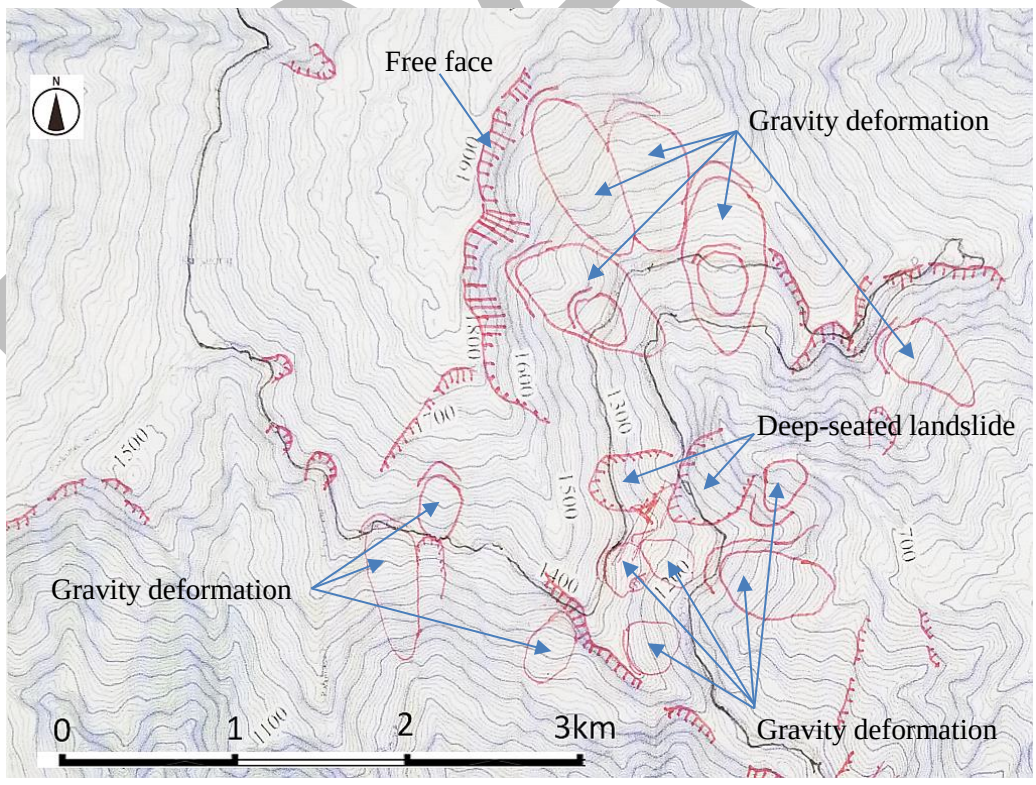


Figure 1-119 Gravity Deformation and Deep-seated Landslides Identified through Map Reading

Source: JICA Project Team

Figure 1-119 shows an example of topographic interpretation of gravity deformation and deep seated landslides along a hill road. A number of particular shapes of elevation contours suggesting gravity deformation, deep seated landslides, and steep cliffs with free face were observed along the hill road. A free face is a steep hill/mountain slope without supports by other slopes. The relationships between the hill road and the gravity deformation are categorized into 3 patterns as follow;

(i) The route traverses at the head of gravity deformation
(ii) The route traverses at the toe of gravity deformation
(iii) The route runs close to but does not touch the gravity deformation

The relationship between an alignment and gravity deformation should be clearly understood and reflected to plans for countermeasures as well as earthworks. Otherwise it may cause severe consequences.

For example, if cutting is carried out at the head of gravity deformation to satisfy a designed width, it may be favorable to slow down deformation by reducing the weight of the upper part of the deformation. On the other hand, if cutting is executed at the toe of gravity deformation for widening of a hill road, cutting may accelerate the gravity deformation and might lead to a deep seated landslide.

The topographic interpretation of aerial photo and topographic map reading can be performed by skilled and well experienced engineers with terrain information with enough accuracy, such as DEM, topographic maps, and aerial photos and, if properly practiced, it will provide valuable information with small cost for planning of a new alignment of a highway in hilly regions.

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[1] Junko IWAHASHI, Tadashi SATO, Koji UCHIKAWA, Yasushi ONO, Tsuneaki SHIMOJI and Minoru HOSHINO, “Investigation of Tectonic Landforms Using Anaglyphs Made from LiDAR DEMs,” *Journal of the Geospatial Information Authority of Japan (GSI)*, no. 121, pp. 143-155, 2011.

Ministry of Road Transport and Highways
India

Japan International Cooperation Agency (JICA)

Capacity Development Project on Highways in Mountainous Regions

GUIDELINE FOR SLOPE PROTECTION AND EMBANKMENT WITH ADVANCED TECHNOLOGY

DRAFT

August 2019

Oriental Consultants Global Co., Ltd.
Kokusai Kogyo Co., Ltd.
East Nippon Expressway Co., Ltd.
Japan Conservation Engineers Co., Ltd.

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List of Abbreviations and Acronyms

BRO	Border Roads Organization
C/P	Counterpart
C/R	Completion Report
EPC	Engineering, Procurement and Construction contract
GNSS	Global Navigation Satellite System
GoI	Government of India
IAHE	Indian Academy for Highway Engineer
JCC	Joint Coordination Committee
JICA	Japan International Cooperation Agency
MoRTH	Ministry of Road Transport and Highways
MS	Monitoring Sheet
NHDP	National Highways Development Project
NHIDCL	National Highways and Infrastructure Development Corporation Ltd.
OJT	On-the-Job Training
OSV	On Site Visualization system
PDM	Project Design Matrix
PO	Plan of Operation
PPP	Public Private Partnership
PWD	Public Works Department
R/D	Record of Discussion
TG	Technical Group
TOT	Training of Trainers
WP	Work Plan

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CHAPTER 2 DESIGN

2.1 Standard gradient of slope (application and limitation)

In addition to meet required specifications as road structure, hill roads should be so designed to assure safety as well as durability and to realize easy maintenance. Furthermore, prevention of slope related disaster should also be well considered.

Construction of hill roads often involves earthwork such as cutting and filling for securing necessary space for hill roads and very often plans to utilize excavated soil for filling material. It should be noted that the natural ground, which is the target for earthwork, is composed of various types of soil and rock, the structure and properties of which are often very complicated.

Earthwork for hill road construction is executed under natural weather conditions, so they are strongly affected by seasonal changes, such as climate, rain, flooding, and groundwater. In order to secure bearing capacity of foundation and roadbed as well as to maintain stability of slopes and to control subsidence of embankment, appropriate measures should be adopted for construction of not only ordinary road structures but earthwork such as cutting and filling as well as temporary structures.

Especially, soil and heavily weathered rock are prone to erosion by surface water. Strength of such material is remarkably lowered by infiltration of water. Proper control of surface runoff and groundwater is, therefore, essential.

In addition, subsidence of hill road and collapse of rock slope often disturb traffic of the existing hill roads in India. Many of such disturbances are caused by gravity deformation and appropriate countermeasures to mitigate gravity deformation are required.

2.1.1 General

If we want to strictly evaluate stability of cut slopes, geological/geotechnical surveys including drilling and geophysical exploration are required for each slope along hill roads. Performing such surveys for each slope is, however, not practical due to budgetary and time constraints. For design of hill roads, therefore, "standard gradient of slope" are used to decide appropriate gradients of cut slopes with minimum cost and time.

Standard gradient of slope is proposed for the types of rock and soil which may appear on the slopes along hill roads. Standard gradient of slope is often summarized in a table, showing the gradients of slope which are considered stable for each rock/soil type. Standard gradients of slope for rock often depend on weathering/altering condition and/or quality of rock. Standard gradients of slope are often proposed through empirical and statistical consideration of the existing stable slopes in the country. By applying standard gradient of slope, the height and gradient of each slope, which is considered stable without any treatment or with simple slope treatment, such as vegetation or rock fall prevention net, are easily determined, if there are no concerns about long-term stability of slope as discussed below.

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Application of standard gradient of slope should be carefully examined. In hilly and mountainous regions, many hill slopes should be in the critical equilibrium state; it may collapse anytime by actions of heavy rains or earthquakes as a trigger, with properties of the ground as factors. For such slopes, therefore, if construction of road cuts lower part of the slope, the safety factor of the cut slope decreases to less than 1.0; it means slope is unstable.

In addition, even though a slope is stable just after the completion, stability of the slope decreases with time due to progress of weathering, loosening by unloading, earthquakes, severe weather conditions, and other time dependent events.

In design of cut slope, based on the stability of the actual slope before cutting, application of standard gradient of slope should be carefully examined. In case gradients of slope steeper than the standard gradients are adopted due to constraints of topography or other reasons, application of slope protection and reinforcement should be considered. Even in case standard gradients of slope are adopted, if concerns for longer stability arise based on the geological or other natural conditions, application of slope protection and reinforcement should be considered as well.

(1) Standard Gradient of Cut Slope

The empirical values for standard gradient of cut slopes are shown in Table 2-1, excerpted from IRC SR15 State of the Art: Landslide Correction Techniques, 1995. The standard gradients of slope are the criteria to follow to secure stability of slopes, depending on the conditions of the slopes, such as height and material of slope. Applying standard gradients of slope should be considered mandatory in the design of hill roads and applying steeper gradients of slope than standard ones should be avoided.

On the other hand, disadvantages of applying a gentler gradient than standard one should be also understood. The cut slope with gentler gradient would have considerably wide areas of slope, which require more costs for land acquisition, construction of earthwork as well as slope protection, and maintenance of wider areas. In addition, in general, gentler slope is more vulnerable against erosion such as gullies and rills with widened surface of slope exposed to rainfall and surface runoff. For such slopes, therefore, weathering and erosion protection is additionally required.

Table 2-1 Slope Values for Bed Rock Excavations（After HRB･176, 1973）

	Rock Type	Range of Permissible Slope (Horizontal : Vertical)
(i)	Igneous	
	Granite, trap, basalt and lava	1/4:1 to 1/2:1
(ii)	Sedimentary	
	Massive sandstone and limestone	1/2:1 to 1/2:1
	Interbedded sandstones, shales and limestones	1/2:1 to 3/4:1
	Massive clay stone and silt stone	3/4:1 to 1:1
(iii)	Metamorphic	
	Gneiss, schist and marble	1/4:1 to 1/2:1
	Slate	1/2:1 to 3/4:1

As pointed out in the IRC standard (IRC SR 15 State of the Art: Landslide Correction Techniques, 1995, p. 153), the most important consideration in applying the table of the standard gradients of slope is to decide appropriate gradients through careful observation of conditions of slopes. It is not easy, however, to properly evaluate the conditions of slopes before cutting.

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Thus re-evaluating the conditions of slopes during construction is important, after the actual slope surface is exposed. For cut slope, in addition to stability of cut slopes with standard gradients right after cutting, future stability of cut slopes should be evaluated, considering the effects of loosening of bedrock to proceed gradually with time by the effects of unloading by cutting. Then, if unstable conditions in future are anticipated, appropriate countermeasures should be additionally installed, including reshaping the corresponding slope to gentler gradient.

(2) Shape of Cut Slope

As shown in Figure 2-1, in the design of cut slopes, gradients of slope are decided depending on the property of soil and rock and berms are generally placed at the boundaries of the gradients. If a slope shows similar ground conditions both horizontally and vertically, single gradient of slope may be applied. On the other hand, in case a slope shows complicatedly distributed various properties of rocks and soil, single gentler gradient suitable for the weakest property may be applied, even though it is less economical.

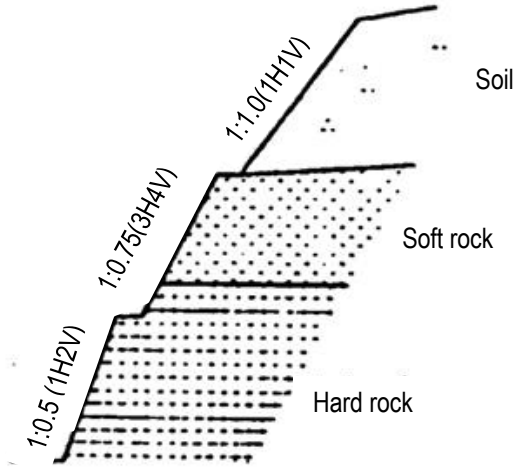


Figure 2-1 Applying Gradient of Slope in Accordance with Ground Conditions

[1]

(3) Berms

Excluding the case of the previous section, berms should be placed on a high cut slope at certain intervals. Such berms should have a width of around 2 meters unless it is used for inspection and maintenance, which requires a width of 3 meters.

(i) Purpose of Berms

At the lower part of the continuous high cut slopes, the volume and velocity of surface water increases, so that the slope is eroded. In such a case, it is possible to reduce the velocity by installing berms in the middle of the slope. In addition, the concentration of the surface water to the lower part of the slope is prevented by installing the drainage on the berms. The berms are also used as a scaffold for inspection and maintenance.

(ii) Cross Fall of Berms

Unless drainage facility is placed along it, berms should have a cross fall, or camber, from 5 to 10 % toward downslope so as to quickly drain water, as shown in

Figure 2-2 (a) and (b). In case the lower slope of a berm is considered easy to erode or fail or drainage ditch is placed along it, the berms should have a cross fall toward upslope, so as to discharge water to the drainage ditch, as shown in Figure 2-2 (c) and (d).

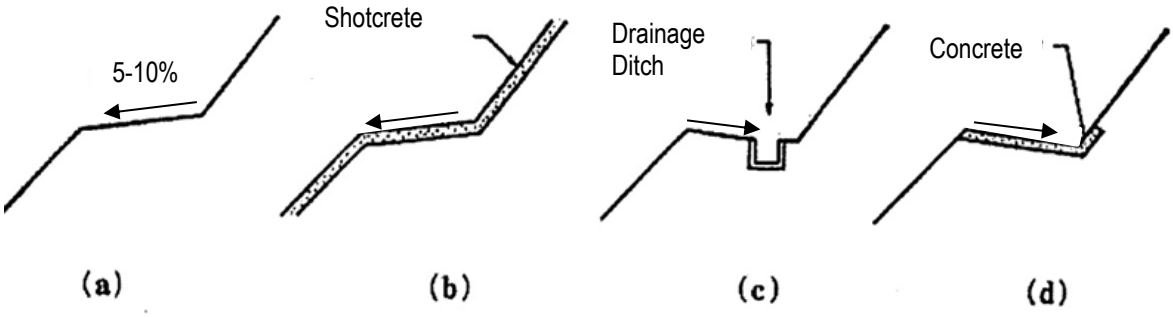


Figure 2-2 Cross Fall of Berms

[1]

(iii) Arrangements of Berms

Arrangements of berms should be planned in consideration of various conditions, such as difficulty of inspection and maintenance, gradient of slope, height of cut slope, property of soil and rock, and construction cost. On the cut slope, based on the properties of the ground and the scale of the slopes, berms with widths of 1 to 2 m are usually placed at every 5 to 10 meters. For high and long cut slopes or cut slopes with rock fall protection fence placed on berms, wider berms are recommended.

2.1.2 Limitations, such as unfavorable topographic, geological, geotechnical, and groundwater conditions

From topographic, geological, geotechnical, and hydro-geological points of view, when gradients of cut slope are decided, important points to consider are described below:

(1) Cut Slopes in Colluvium and Highly Weathered Rock

On the slopes of certain types of deposits or fragile soil, such as talus, colluvium, highly weathered rock, brittle clay, and volcanic mud flow, due to deterioration of fragile soil, which leads strength reduction, at the time of rainfall or earthquake, slope failures often occur even under normal natural conditions. Under such conditions, if excavation makes cut slope steeper than natural ones, the cut slope should be unstable and collapse may occur.

(i) Surface failure

As shown in Figure 2-3, a wide step at the surface of bedrock may hold debris or boulders from upper slope. The gradients of slope for colluvium and highly weathered rock should be as gentle as possible.

(ii) Large-scale failure and landslide

In this case, the following countermeasures are generally required:

- Earth removal works to make gentle gradient of 2V3H to 1V2H or gentler
- Groundwater drainage (e.g. horizontal drainage boring)

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- Landslide prevention works (e.g. landslide prevention pile)

Aforementioned countermeasures require considerable construction costs. So application of such countermeasures should be carefully examined.

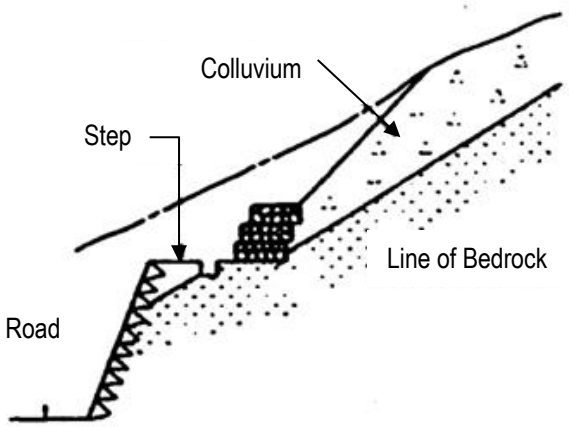


Figure 2-3 Countermeasure against Surface Failures

[1]

(2) Cut Slopes in the Ground Easy to Erode

The slope mainly composed of cohesionless soil, such as sand and sand with gravel, is easily eroded by surface runoff and rainfall, and frequently causes rock fall, small surface failure, and flow out of eroded soil or debris.

Instead of making slope gentler, against the erosion caused by surface runoff and rainfall, erosion protection and surface drainage system should be adopted as countermeasures. Surface runoff should be completely drained from the entire slope from the shoulder to the toe of the slope, by properly designed surface drainage system. Especially, infiltration of surface runoff form the shoulder should be prevented as much as possible.

In addition, securing some additional space at the toe of the slope as a pocket for debris is essential, to prevent debris from reaching directly to the road in the event of collapse.

(3) Cut Slopes in the Rocks Susceptible to Weathering

Certain types of rocks have particularly weak weathering resistance due to distinctive slaking and swelling properties. Tertiary mudstone, some types of shale, marl, and tuff, serpentinite, altered andesite, and some types of phyllite have such weak weathering resistance.

Due to unloading by cutting and being exposed to repeated dry and wet cycles on the surface, the cut slopes with the aforementioned rocks are gradually decomposed from the surface to cohesionless soil, which has less strength and erosion resistance than the mother rocks.

As the decomposition proceeds, the slopes are deteriorated by surface failures and gully erosion, which form overhung and foot erosion on the slopes by differential erosion. Such conditions induce toppling and surface failures involving remaining parts of slopes, facilitated by densely developed joints and cracks.

To avoid such failures, the following precautions should incorporated in the design of the cut slope:

(i) The gradients of slope should be so designed to secure stability even under the conditions where weathering of rock proceeds. Adopting berms is encouraged to limit the extent of slope failures.

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(ii) In order to mitigate weathering, the surface of the cut slopes should not be exposed. Protection works to cover the surface is essential unless groundwater seepage/spring is expected on the slope. The slopes with seepage/spring require special treatment to keep drainage and to cover the slope.

(4) Cut Slope in Intensely Jointed and Fractured Rocks

Fracture zones are frequently observed in Paleozoic and Mesozoic sedimentary and metamorphic rocks. Igneous rocks, such as basalt, andesite, rhyolite, and granite, have columnar or planner joints developed by shrinkage of lava and magma during cooling process.

Such jointed and/or fractured rocks often cause dip slope or wedge failures. The stability of the slopes with jointed and/or fractured rocks depends on the development of joints and fractured zones. Thus conditions of joints and fractured zones should be comprehensively evaluated through geological field survey, drilling and laboratory tests, seismic exploration, coefficient of fissures, and disaster records of neighboring slopes.

(5) Cut Slope in Dip Slope Structure

When planner discontinuities in particular direction are dominant in stratified rock and the apparent dip of the discontinuities faces downslope along the slope, this structure is called “dip slope”. When the apparent dip is toward slope, it is called “plunging slope”. Bedding of sedimentary rock, columnar and plane joints of igneous rock, and foliation of metamorphic rock usually form “dip slope” and “plunging slope” structures.

Usually, stability of a dip slope structure is evaluated by “apparent dip”. An apparent dip is an angle of a dip slope structure shown on a cross section of a slope and calculated with a formula shown in Figure 2-4.

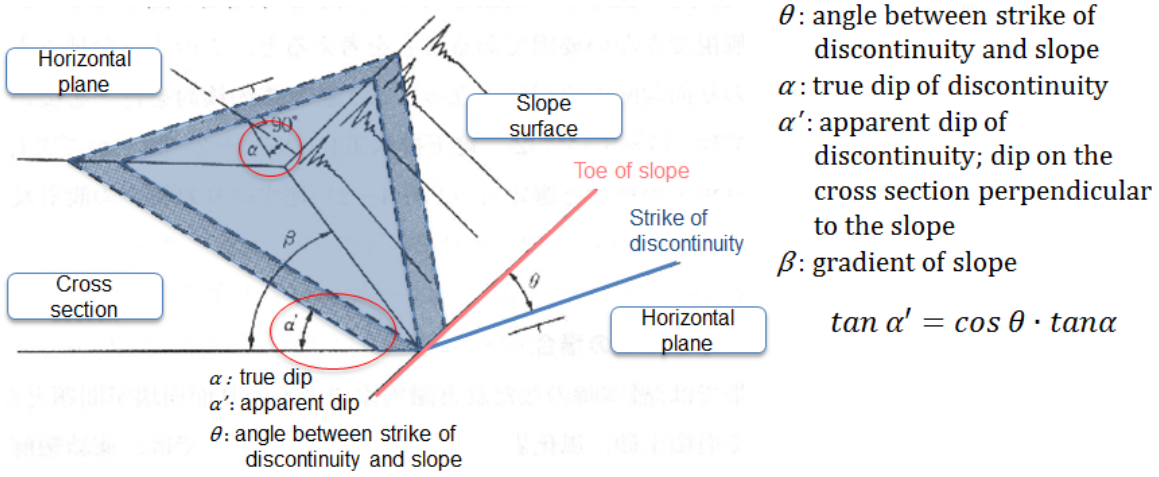


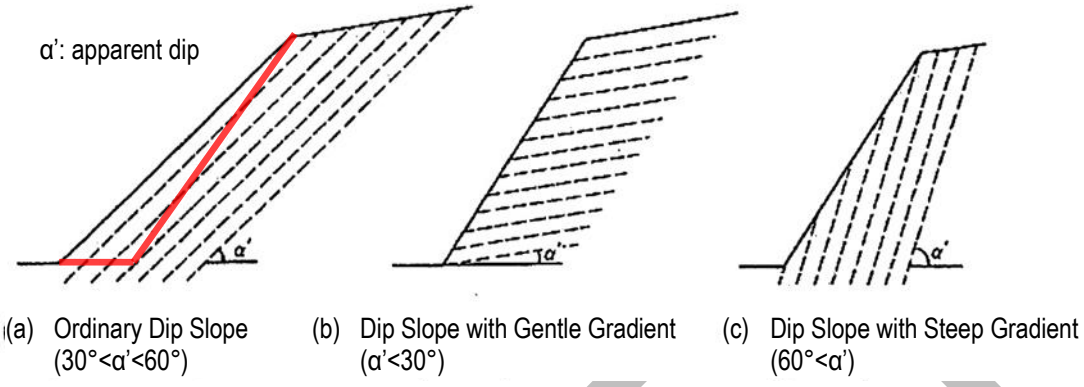
Figure 2-4 Relation among Slope and Apparent & True Dip of Discontinuity

[1]

Relation between apparent dips and gradient of slopes are explained in Figure 2-5. In general, the dip slope structure showing apparent dips from 30 to 50 degrees are considered dangerous, as shown in Figure 2-5 (a). A gradient of slope steeper than the apparent dip composes a dangerous slope as shown in red line of the

said figure. For such case, gradients of slope equal or gentler than the apparent dip are considered as stable.

Even in the case bedding or foliation is tightly closed, dip slope failure may occur in connection with joints which develop diagonally with bedding or foliation. Careful attention is, therefore, required



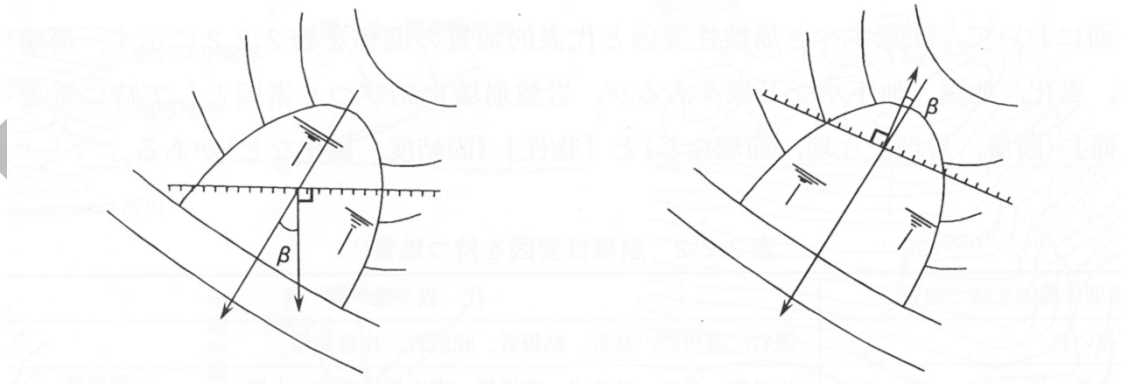
(a) Ordinary Dip Slope (30°<α'<60°) (b) Dip Slope with Gentle Gradient (α'<30°) (c) Dip Slope with Steep Gradient (60°<α')

Figure 2-5 Relationship between Slope and Apparent Dip

[1]

In case apparent dips is gentler than 30 degrees as shown in Figure 2-5 (b), unless the slope is in landslide areas, gradients of slope may be decided on other factors other than the apparent dips; a gradient of slope may be steeper than 9H5V, which corresponds to the apparent dip of 30 degrees.

On the other hand, in case apparent dips exceed 60 degrees as shown in Figure 2-5 (c), even the gradient of slope of 3H5V is not stable, which corresponds to the apparent dip of 60 degrees. For a slope with dip slop structure, if a total height of a slope exceeds 10 meters, gradients of slope should not be steeper than 4H5V.



(a) Dip Slope
β <= 30 degrees: dangerous dip slope failure
β <= 60 degrees: dip slope failure affects the road

(b) Plunging Slope
β <= 10 degrees: dangerous toppling failure
β <= 30 degrees: toppling failure affects the road

Figure 2-6 Relation between Slope and Strike of Discontinuities

[2]

Relation between slope direction and strike of discontinuities may give some hints on danger of dip slope failures. If the angle between the strike of a discontinuity

and the direction of dip of a slope is equal or smaller than 60 degrees, dip slope failure induced by the dip slope structure may affect the road, as shown in Figure 2-6.

(6) Sites with Abundant Groundwater

Slopes with groundwater springs providing substantial water or with high groundwater levels are often unstable. For the cut slope under such conditions should adopt gentler gradients of slope, regardless of geological conditions.

For the slopes where abundant groundwater is expected, adopting groundwater drainage works should be prioritized rather than making slope gentler.

(7) High and Long Cut Slope

The standard slope gradients of slope shown in Table 2-1 is for the cut slopes with a height of 12 meters or less limited by berms. For higher cut slopes, the gradients of slopes should be determined through deliberate consideration of the site conditions, especially for the followings.

(i) For the rocks containing substantial amounts of smectite or montmorillonite with swelling properties, gradients of slope should be determined to ensure stability even if weathering/swelling progresses.

(ii) When an alignment runs through a col or saddle of a mountain ridge, fractured zones should be paid attention. Fractured zones are formed by faults and found at cols or saddles of ridges. So if fractured zones are detected by drilling or seismic exploration, directions and extent of fractured zones along with degree of fracture should be carefully examined.

(iii) A cut slope planned at a steep natural slope often results in high and long cut slope, if the design for such slope simply follows standard gradients for each rock type/quality to be appeared.

For such cases, minimizing cut slopes by utilizing reinforcement by landslide prevention works, such as ground anchors and prevention piles/caissons, may be considered, for minimizing land acquisition costs and adverse aesthetic impacts to landscape.

It should be noted that minimizing by prevention works requires that the upper slope of the works be stable.

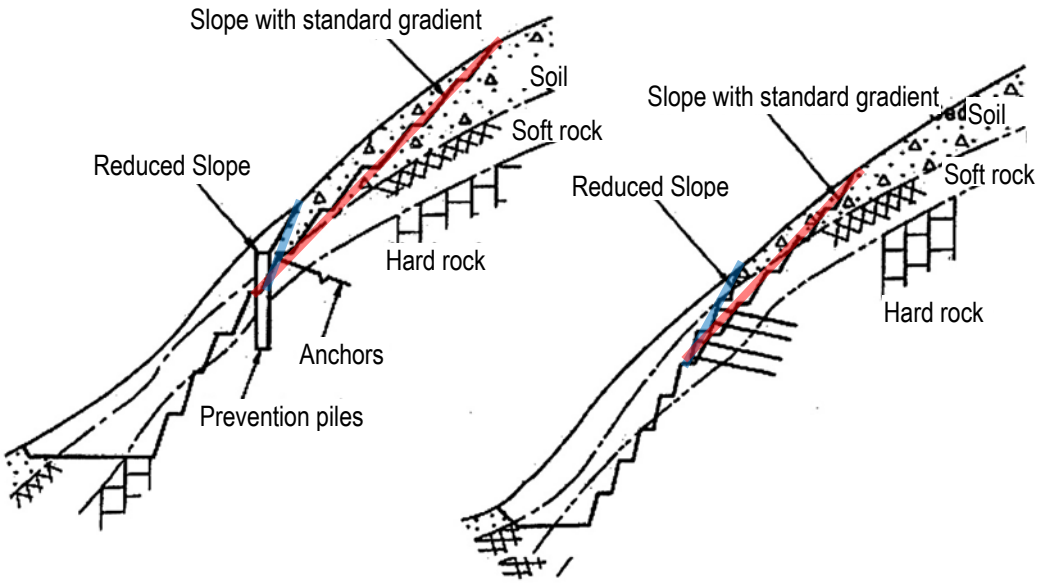


Figure 2-7 Minimizing High and Long Cut Slope with Prevention Works

[1]

(iv) For high and long cut slopes, in addition to normal berms, wider berms of a width of 3 meters should be placed at each 20 to 30 meters in height, for easier inspection and maintenance.

(8) Consideration of Earthquake Resistance of Cut Slope

In most cases, most parts of landslide countermeasures are fixed to the ground; unlike bridges or embankment, the works are combined with the ground during earthquakes, without being shaken independently. This is the same reason why a tunnel is naturally resistant against earthquakes.

When considering earthquake resistance of cut slope, effects by earthquakes should be incorporated in the consideration of moving force by landslides. Countermeasures are designed to prevent landslides by increasing resistance force to be more than moving force by landslides, which may be triggered by earthquakes.

Increase of groundwater pressure is another factor to be dealt with for earthquake resistance. Naturally, for most cases, landslide countermeasures include surface/underground drainage system, which disperses pressure of groundwater even it is raised by earthquakes.

For reference, based on the actual damage to the works caused by a series of severe earthquakes in Japan, simple evaluation of earthquake resistance of slope protections and landslide countermeasures are summarized below.

(i) Works with relatively high resistance against earthquakes
- Structures designed to retain earth pressure (e.g. retaining walls)
- Structures tightly fixed with the stable ground/bedrock
  The structures which are combined with the ground during earthquakes (e.g. cast-in-place concrete crib works)
- Flexible structure
  The structures which absorbs energy of earthquakes by flexible structure which allows slight deformation (e.g. gabion, retaining walls of boulders and stacking concrete frames)

(ii) Retaining walls of stone and concrete blocks masonry are also earthquake resistant. Among them, those damaged by earthquakes are dry masonry and retaining walls at steep slopes with very thin backfill concrete.

(iii) Shotcrete, rock fall protection net, rock fall protection fence are to some extent earthquake resistant. Their effects are considered as limited, however.

For the cut slopes where high earthquake resistance is required, slope protection and landslide countermeasures with high earthquake resistance are desirable.

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2.1.3 Importance of investigation, especially for unfavorable conditions

In nature, topographic, geological and hydrological conditions are not uniform the hills. Thus the conditions of the slopes to be cut vary from place to place. To deal with such complicated conditions in design and construction, appropriate surveys and investigations should be conducted in advance. Based on the results of such surveys and investigations, the conditions of each slope should be comprehensively analyzed and appropriate gradients of slope along with necessary slope protection and reinforcement should be designed.

Various surveys and investigations to decide appropriate gradients of slopes including adopting standard gradients are summarized in this section, along with the points to check in the results of surveys and investigations, through analyses and interpretation of them.

For design of cut slopes, in addition to the conditions of the ground surface, underground conditions should also be understood, such as degree of loosening due to unloading or cutting, fracture zones or weak layers, and groundwater conditions. For that purpose, drilling investigation with core sampling and/or geophysical surveys including seismic exploration and resistivity survey provide valuable and sometimes decisive information for design. Establishing a well-balanced survey plan, therefore, is important. A survey plan should assemble necessary surveys and investigation while fulfilling the requirements but considering time and cost.

The surveys and investigations to decide gradients of slopes along with slope protection and reinforcement are summarized in Table 2-2 for design stage and in Table 2-3 for revision in construction stage.

Table 2-2 Surveys to Decide Gradients of Slope during Design Stage

Type of survey	Information to Obtain	Items for Design of Slope
Aerial Photo / Map Reading	(To extract and classify) landform of gravity deformation & landslide	・ Distribution of relaxed / loosened zones in bedrocks (distribution on surface) ・ Degree of relaxation / loosening ・ Possibility of destabilization of upper slopes
	Lineament	
	Geomorphological processes	
	Catchment areas	・ Possibility of pressurization of fissure water
Collecting geological information	Subsurface geology	・ Vulnerability of bedrocks (density of cracks) ・ Durability against weathering and erosion ・ Dip slope structure
	Geological structure	
	Field survey data: strike & dip, type of soil / rock, hardness, weathering, etc.	
Collecting hydrological information	Location of springs	・ Quantity of groundwater storage ・ Distribution of constraining floor ・ Groundwater storage in dry seasons
	Head of gully erosion	
	Vegetation	
Seismic exploration	Seismic wave velocity	・ Vulnerability of bedrocks (density of cracks)
	Variation of seismic velocity	・ Distribution of relaxed / loosened zones in bedrocks (distribution in depth)
Resistivity survey (in both rainy and dry seasons)	Resistivity (specific resistance)	・ Geological and lithological evaluation
	Variation of resistivity	・ Groundwater storage areas
	Comparison between dry and rainy seasons	・ Groundwater storage areas (Distribution of relaxed zone in bedrocks)
Aeromagnetic survey (in both rainy and dry seasons)	Resistivity (specific resistance) in dray and rainy seasons	・ Geological and lithological evaluation
	Variation of resistivity	・ Groundwater storage areas
	Comparison between dry and rainy	・ Groundwater storage areas (Distribution of

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Type of survey	Information to Obtain	Items for Design of Slope
	seasons	relaxed zone in bedrocks)
Drilling with core sampling	Core sampling	・ Geology, lithology, structure, loosened zone, and slip surface
	Borehole Image Data (BHTV, FWS)	・ Distribution of cracks (distribution of relaxed / loosened zone in bedrock)
	Groundwater logging	・ Aquifer with groundwater flow, pressure head, discharging zone

Source:

Table 2-3 Surveys to Revise Gradients of Slope during Construction Stage

Investigation method	Obtained Information	Analyzed factor for design of slope gradient
Observation of slope surface	Geological structure	・ Geology, lithology, structure loosened zone, and slip surface ・ Distribution of relaxed / loosened zones in bedrock ・ Durability against weathering and erosion
	Field survey data: strike & dip, type of soil / rock, hardness, weathering, etc.	
	Condition of cracks	
	Condition of relaxation / loosening	・ Degree of relaxing / loosening
	Groundwater storage	・ Location of constraining floor
Soil test	Slaking durability	・ Durability against weathering and erosion
	Clay mineral (X-ray analysis)	・ Existence of swelling clay minerals
	Direct shear test (slip surface)	・ Shear strength for design
Landslide monitoring	Two-dimensional deformation measurement (Slope staking)	・ Observation of deformation at specific location
	Three-dimensional deformation measurement（3D-Laser, Ground SAR）	・ Observation of deformation in the whole targeted area
Stability analysis	Two-dimensional stability analysis (LEM,FEM)	・ Approximate stability of the target area
	Three-dimensional stability analysis (wedge, LEM, FEM)	・ Strict stability of the targeted slope

Source:

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2.2 Minimizing high and long cut and embankment with advanced technology

2.2.1 General

If the cut slopes along hill roads are left as it is after cutting without any treatments or protection implemented on it, large scale slope failures or landslides may occur due to various factors and triggers, such as weathering under severe climatic conditions, erosion by surface water, seepage water by torrential rain or snowmelt, increased pore pressure of fissures in rock mass, and earthquakes. These factors and triggers were caused or facilitated by degradation of stability of cut slopes with passage of time. As explained in Chapter 1.3.1, even if it appears to be stable immediately after the cutting, stability of cut slopes decreases with time faster than it is expected form the appearance.

Immediately after cutting, effects of unloading by cutting remain in the surface of the cutting. The larger the cutting is, the stronger the effects of unloading are. Regardless of the material composes a slope, whether it is soil or rock, a cut slope, from which cutting removes weight of material rapidly, causes slowly but steadily expansion of the volume of its surface. As show in Figure 2-8, in the process of the expansion, a cut slope becomes relaxed or loosened, and the risk of slope failures increases (see Figure 2-8).

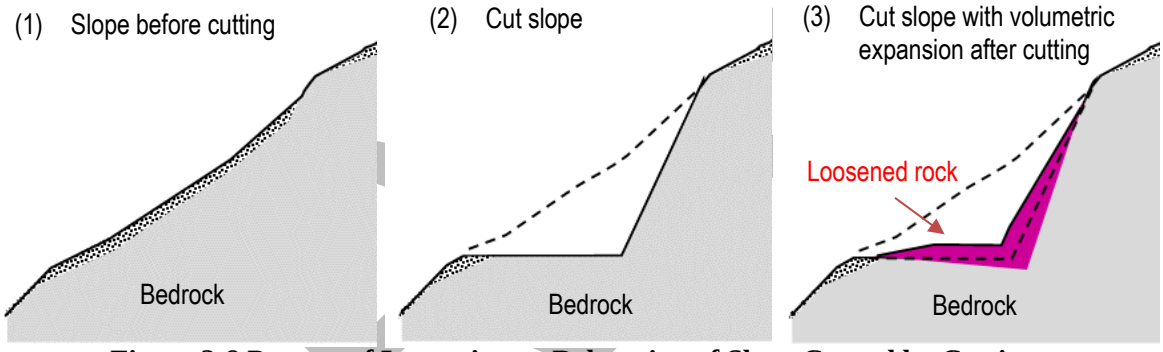


Figure 2-8 Process of Loosening or Relaxation of Slope Caused by Cutting

Source: JICA Project Team

Even if a slope is composed of intact bedrock, more or less, cutting affects stability of slopes by triggering relaxation or loosening. In case a block of gravity deformation lies in a slope, cutting the toe or middle of such slope facilitates deformation of the slope.

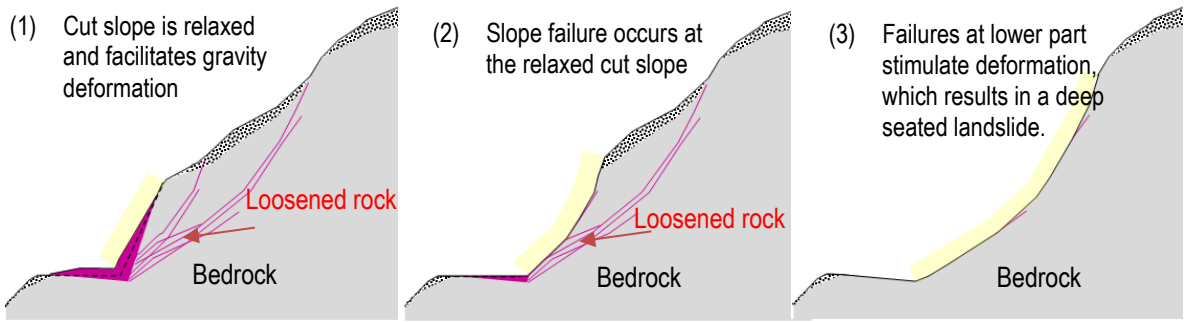


Figure 2-9 Gravity Deformation and Deep Seated Landslide Activated by Cutting

Source: JICA Project Team

As deformation precedes, the lower part of the slope, which corresponds to compression area, becomes steeper. Then, if cutting is made at the toe, the unloaded and relaxed cut slope firstly collapses. Such failures at the toe facilitate unloading at the toe of the deformation block and stimulate further development of gravity deformation, which may result in a massive deep-seated landslide. The aforementioned process is explained in Figure 2-9.

Figure 2-9 shows an example of cutting slope at the foot of existing gravity deformation. Even on a slope with no sign of gravity deformation, however, cutting may initiate a new block of gravity deformation.

As explained above, cutting slope for road construction often cause stability problem of slopes. Filling has similar problem as well. Without cutting and filling, however, hill road construction is almost impossible. Thus technologies minimizing cutting and filling slopes as much as possible are worth to consider for sustainable development of hill roads in India.

2.2.2 Minimizing high and long cut with slope stabilizing technology

In road construction in hilly areas, cutting or cutting and filling of slopes are effective method to secure required widths of hill roads while saving cost and time for construction.

If design of cut slope based on standard gradient of slope requires a high and long cut slope, minimizing such cut slope should be considered, utilizing slope stabilizing technology. Minimizing cut slope should involve slope stability analysis in its design process, and slope protection works should be employed for minimized cut slopes. In case stability of slope is in problem, adding resistance force against sliding with landslide prevention works should be considered, such as soil nailing / rock bolting, ground anchor, and pile works.

(1) Slope Protection Works

The purpose of slope protection works is to prevent erosion or weathering by covering slope surface with vegetation or structures, and to stabilize slopes with drainage works, retaining structures and landslide prevention works.

Table 2-4 summarizes slope protection works with its type and purposes. Slope protection works are divided into two groups; protection by vegetation and structures. To select appropriate slope protection, deliberate considerations should be made based on properties of soil and rock, pH, groundwater spring and surface runoff, weather conditions, and scale and gradient of slopes as well as construction cost, site conditions, natural and social consideration, conservation of landscape, and operation and maintenance of the works.

Table 2-4 Type and Purpose of Slope Protection Works

Grouping		Type of Works	Purpose
Vegetation	Seeding	• Seed spraying • Borrow material spraying • Vegetation base spraying • Planting sheet • Planting mat	Prevention of erosion and frost-heaving. Covering slopes with vegetation in a short period.
		• Terracing works with seeding or planting	Making narrow terrace of earth or stone on slope for planting or seeding vegetation. Prevention of erosion. Promoting rooting and growth of plants.
		• Vegetation sandbag	Promoting early growth of plants by placing base

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		• Planting base material injection	for vegetation. Thick base for vegetation are kept for a long period.
	Planting	• Sodding	Prevention of erosion and frost-heaving. Covering slopes with sodding in a short period.
		• Sodding step	Making narrow terrace of wood for sodding strip on slope surface. Prevention of erosion. Promoting rooting and growth of sod.
		• Planting	Establishment of preferable landscape
	Planting nursery stocks with vegetation base spraying		Covering slopes quickly with vegetation. Establishment of preferable landscape.
Structures		• Wire-mesh (lath net) works • Textile net works	Preservation of vegetation base and prevention of erosion slope surface by surface runoff.
		• Fence works • Gabion	Prevention of erosion and loss of soil by surface runoff and groundwater spring on slope surface
		• Precast concrete crib works	Prevention of erosion of slope and retaining of material within frames.
		• Mortar / shotcrete spraying • Stone pitching works • Concrete block pitching works	Prevention of weathering, erosion and infiltration of surface water.
		• Lean-type concrete retaining wall • Shotcrete spray crib works • Cast-in-place concrete crib works	Preventing collapse of slope surface, retaining slopes under some earth pressure, and preventing detached rock..
		• Stone masonry • Concrete block masonry • Gabion works • Lattice works • Concrete retaining wall • Geotextile reinforced earth method	Preventing collapse of slopes under substantial earth pressure.
		• Soil nailing / rock bolting • Ground anchor works • Pile works	**(Landslide Prevention Works)** Resisting driving force of landslides and preventing slope failures.

[3]

Vegetation works are to enhance thick growth of vegetation on the surface of slopes. By firmly binding soil on the surface with root system of plants, the surface of slope is stabilized and protected against erosion, while extreme temperature variation on slope surface is mitigated. And vegetation also provides a preferable landscape. In addition, vegetation works prevent erosion by rainwater as well as surface runoff and failure of slope surface by freeze heaving. As vegetation works are usually reasonable and frequently used where slope surface is suitable for growth of plants.

Vegetation is, however, not so versatile. Roots of plants for vegetation works usually develop only in relatively shallow zones from the surface of slopes. So they are not effective to mitigate slope failure or landslide.

Vegetation is not suitable for the areas where sunshine and rainwater are not sufficient, such as under bridges and viaducts, rock slope is covered by a thin layer of soil, and highly acidic soil is lies.

For the slopes with gradients steeper than 6H5V and gentler than 4H5V, depending on the property of soil on the surface, vegetation works alone may not be sufficient to prevent erosion or collapse of slope surface. For such slopes, slope protection by structures should be considered, while vegetation can be supplementary applied.

For the slope with gradients steeper than 4H5V, applying vegetation may not be an option.

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Slope protection with structure has a wide range of types and scales, from small scale structures to provide bases for vegetation or to stabilize filling slopes, to relatively large structures to prevent weathering, erosion, and collapse of the surface of slopes, and much larger structures to prevent or mitigate slope failures and landslides.

Limited types of the structures in Table 2-4 are expected to retain earth pressure or resist sliding. Retaining wall and concrete crib works are expected retain slopes against certain earth pressure. Soil nailing/ rock bolts, ground anchors, and landslide prevention piles are to provide resistance against sliding. Many types of structures in Table 2-4, however, do not have functions to retain unstable slopes against earth pressure. For the slopes where earth pressure is acting or may act in near future, therefore, appropriate structures should be applied to retain earth pressure.

In case groundwater springs appear on the slope, besides the slope protection works, surface water drainage is indispensable to prevent erosion or destabilization of the slope.

If properties of slope surface or conditions of groundwater are not constant by part of slope, suitable slope protection works for each property or condition should be selected.

(2) Countermeasures against Rock Fall

For the slopes with risk of rock fall, countermeasures against rock fall should be applied along with slope protection works. Countermeasures against rock fall include rock fall prevention works at source areas of fallen rock and rock fall protection works to reduce the damage caused by fallen rocks. Many types for the countermeasures against rock fall are developed so far but principles for the works are limited as follows.

- To prevent weathering and erosion which trigger or facilitate rock fall
- To prevent rock fall by fixing unstable boulders or part of rock outcrop at sources of fallen rocks
- To absorb energy of fallen rocks.
- To change direction of fallen rocks and lead them to a harmless place.
- To reduce energy of fallen rocks to stop movement of them.
- To double as prevention of fall of small detritus and avalanches.

Table 2-5 explains types and Figure 2-10 gives a guide of application of rock fall protection works.

Table 2-6 summarizes points of concerns regarding application of countermeasures against rock fall as well as general guidance for application of rock fall protection and rock fall prevention works.

Table 2-7 summarizes application of rock fall prevention works.

In selecting countermeasures against rock fall, applicable conditions of each type of works should be well considered. At the same time, the functions, durability, workability, economic efficiency and maintenance issues of each type of works should be carefully examined. And careful consideration should also be paid to the conditions of road and slope, and based on that, appropriate set of works should be selected.

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Table 2-5 Rock Fall Protection Works

Type of Works	Details
Rock Fall Protection Net 	Wire rope net type Conventional rock fall protection fence (Wire Rope net type), which absorbs energy of fallen rocks by plastic deformation of wire mesh, wire rope, and columns. Often installed with concrete foundation at the toe of slope.
	High energy absorption type (wire slide type) While using wire rope and wire mesh of conventional type, plastic deformation of mortar-filled steel pipe and slide of buffer bracket of wire rope absorb energy.
	High energy absorption type (ring type) Plastic deformation of wire mesh ring and brake system on fixed ropes absorbs energy of fallen rocks. Fixing of anchorage of stay rope needs careful attention.
Rock Fall Protection Shelf 	Used with rock sheds. Rock fall protection net is place at the end sections of rock sheds.
Rock Fall Protection Net 	Wire rope mesh type Covering type absorbs energy by friction between wire mesh and the ground. Pocket type traps fallen rocks by energy absorption by wire mesh.
	High energy absorption type Sliding of buffer clamps of wire ropes absorb energy of fallen rocks. The wire ropes should be anchored to the stable ground Catch type and pocket Type are available.
Rock Fall Protection Wall 	Concrete retailing wall Resistance of the ground against rotating of retaining wall as rigid structure absorbs energy of fallen rocks. Allowable amount of energy absorption depends on the ground property. Requires area for installation.
	Reinforced Soil Retaining Wall Deformation of retaining wall of reinforced soil with geotextile absorbs energy of fallen rocks.
Rock Shed 	Elastic design is based on impact force transmitted by shock absorbing materials placed on the roof. Sand and EPS are used as shock absorbing materials.
Rock Fall Protection Embankment and Trench	(If flat land is available at roadside) embankment or trench along road absorbs and disperse energy of fallen rocks.

[4]

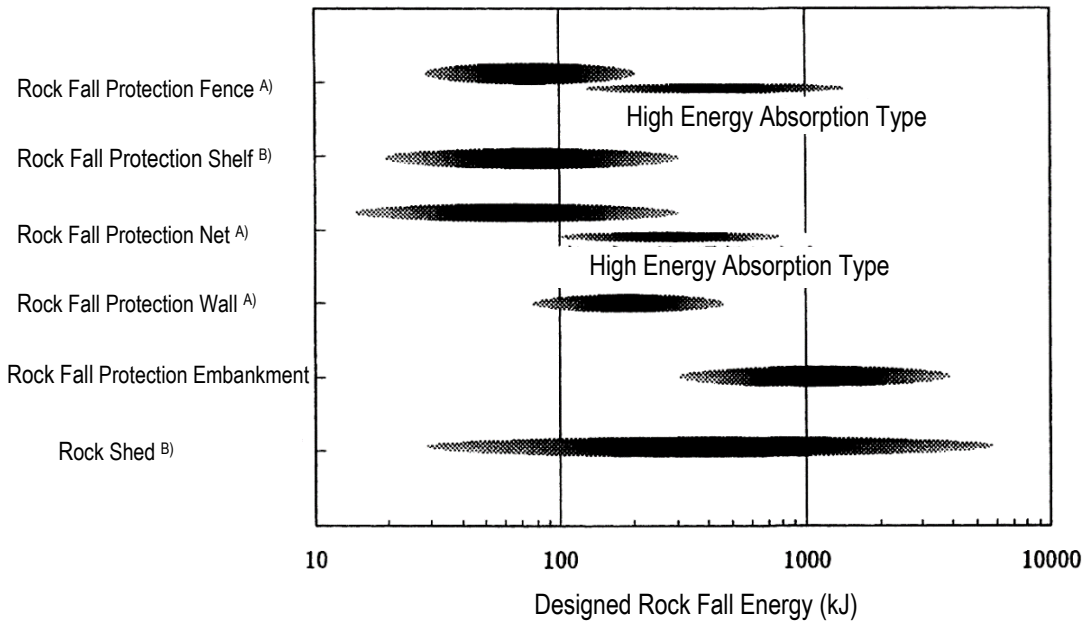
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Table 2-6 Application of Measures against Rock Fall

Category	Characteristics / Type of work	Effects of Works: Prevention of weathering and erosion	Prevention of rock fall	Change of direction of fallen rocks	Absorbing energy of fallen rocks	Resistance against shock	Durability	O & M	Construction	Reliability	Economic Efficiency
		+++ Very good ++ Good + Sometimes good					+++ Very Good ++ Good + Damaged by fallen rocks	+++ Less effort ++ Effort is required + Much effort	+++ Easy ++ Moderate + Difficult	+++ High ++ Middle + Low	+++ High ++ Middle + Low
Rock Fall Prevention Works	Cutting		+++				+++	++	+	+++	++
	Removal		+++				++	++	+	++	++
	Foot fixing		+++				+++	++	++	+++	++
	Bonding	++	++				+	++	+++	+	+
	Anchoring		+++				++	+++	++	+++	++
	Fix by wire rope		+++				++	++	+	++	+++
	Drainage	+++					++	++	++	++	+++
	Wicker works	++	++	+			++	++	+++	+	+++
	Vegetation	++	++				++	+++	+++	+	+++
	Shotcrete	+++	++				++	++	+++	++	+++
	Lean-type retaining wall	+++	+++				+++	+++	++	++	+++
	Concrete crib works	+++	+++				+++	+++	+++	+++	++
	Retaining Wall	+++	+++	+			+++	+++	++	+++	++
	Rock fall protection net with rock bolt		+++				++	++	+++	++	+++
	Shotcrete with rock bolt	+++	+++				++	++	++	+++	+++
	Lean-type retaining wall with rock bolt	+++	+++				+++	+++	++	+++	++
	Concrete crib works with rock bolting	+++	+++				+++	+++	++	+++	+++
	Concrete crib works with ground anchor	+++	+++				+++	+++	++	+++	+++
	Retaining wall with ground anchor	+++	+++				+++	+++	++	+++	+
Rock Fall Protection Works	Covering-type rock fall protection net		++	++	+++		++	++	+++	++	+++
	Pocket-type rock fall protection net			++	++	++	++	++	+++	++	+++
	rock fall protection fence			+++	++	+	++	++	+++	++	+++
	Multistage rock fall protection fence		+	+++	+++		++	++	+++	++	+++
	Rock fall protection Shelf			+++	+++	+++	+++	+++	++	++	++
	Rock fall protection Wall			+++	++	+	+++	++	+++	++	+++
	Rock Shed			+++	+++	+++	+++	+++	++	+++	++
	Rock fall Protection Embankment / Trench			+++	++	+	+++	++	+++	++	++

[1]

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A) Methods designed by energy calculation
B) Methods designed by static strength calculation

Figure 2-10 Guide of Scope of Rock Fall Protection

[1]

Table 2-7 Application of Prevention Works against Rock Falls with Scale and Type

Estimated Size of Each Falling Rock		Large Scale Size: Φ1m (Boulder) Weight: several tons		Middle Scale Size: Φ40cm Weight : several hundreds kilograms		Small Scale Weight: less than several tens kilograms	
Type of Rock Fall / Countermeasures for Specific Purposes		Peeling Type	Dropping Out Type	Peeling Type	Dropping Out Type	Peeling Type	Dropping Out Type
To remove detached rocks	Removing detached rocks, and cutting	++	++	++	++	++	++
To prevent weathering and erosion of filling materials in cracks and matrix of colluvium	Drainage	++	+++	++	+++	++	+++
	Shotcrete	+	Not suitable for earth and sand	++	Not suitable for earth and sand	+++	Not suitable for earth and sand
	Net hurdling	-	-	-	++	-	++
	Vegetation	-	-	-	++	-	++
To fix and stabilize detached rocks and boulders	Foot fixing	++	++	Rarely applied due to inefficiency			
	Bonding	++	+	++	++		
	Lean-type retaining wall	+	+	++	++	++	++
	Cast-in-place concrete Crib works	++	+	++	++	++	++
	Ground anchor and rock bolt;	Not applied alone. But often applied with shotcrete or cast-in-place concrete crib.					
		++	++	++	++	++	++
	Rock fall protection net	Often applied with rock bolts				++	++
		++	+	++	+		
	Fixing by wire rope	++	++	Often applied with covering-type rock fall protection net			
	Retaining Wall.	Adopted if source of fallen rocks is less than 8.0 meters in height from the road to protect.				-	-
		++	++	++	++		

Legend: +++ adopted very well, ++ adopted well, + may be adopted, - not adopted

[1]

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2.2.3 Embankment with advanced technology

The light-weight embankment utilizes light weight materials of a weight of about 3/4 to 1/100 of the common filling materials. With light weight materials, earth pressure and load on foundation are reduced.

Representative materials for light-weight embankment include EPS (Expanded polystyrene), FCB (Air-mixed cement or mortar soil), and urethane foam. The unit weights of each method are listed in Table 2-8.

Table 2-8 Unit Weight of Lightweight Banking Methods

Developed Year	Lightweight banking Material	Unit Weight (kN/m3)	Remarks
?	Volcanic Ash Soil	12～15	Ex) "Shirasu" in the southern part of Kyushu Island, Japan.
1961	FCB	5～12	
1985	EPS	0.12～0.3	
1986	Water Granulated Slag	10～15 approx.	
1987	Expanded Beads Mixed Lightweight Soil	7. or more	
1990	Urethane Foam	0.3～0.4	
1997	Waste Glass	4～14	Making foam from waste glass
2000	Tire Chips	—	Many examples are found in the United States.

Source: 和文最終形に記載なし

(1) Advantages of Light-weight Embankment

The advantages of adopting lightweight embankment are described below.

- Compared to the conventional embankment with normal earth material, light-weight embankment can reduce the additional loads by embankment and thus ease consolidation settlement of soft ground. It also mitigates landslides on slopes which may be triggered by filling, with the reduced loads of embankment.
- Since consolidation settlement is eased, light-weight embankment may reduce the cost for soft soil treatment and for maintenance of filling on soft soil.
- The materials with self-supporting property are available for this method, which is able to considerably reduce lateral pressure on side walls. Using such materials, filling embankment becomes possible with simple vertical wall structure similar to surface protection as side walls.
- Since large and heavy machinery is not required for this method, construction of light-weight embankment is possible on steep slopes or other difficult conditions, with temporary works of relatively light structure.
- Compared with conventional retaining walls, light-weight embankment requires narrower foundation. This advantage allows wider application to the sites on steep slopes. In addition, deformation of the natural slope may be reduced compared to the conventional retaining walls.

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(2) Introduction of Representative Lightweight Embankment

The outline of typical lightweight banking materials is introduced below.

(i) EPS Method

EPS stands for Expanded Poly-Styrene and means "foamed polystyrene". EPS method is to construct embankment by stacking large sized EPS blocks. The standard block size is 1.0 × 0.5 × 2.0 meters and its extremely light weight enables labors to carry it by hand. The blocks are fixed by binding metal fitting. Deck slabs of a thickness of 15 cm are placed at every 3.0 meters in height, to adjust unevenness, to disperse the loads, and to avoid infiltration of harmful substances.



Figure 2-11 Image of EPS Method

[5]

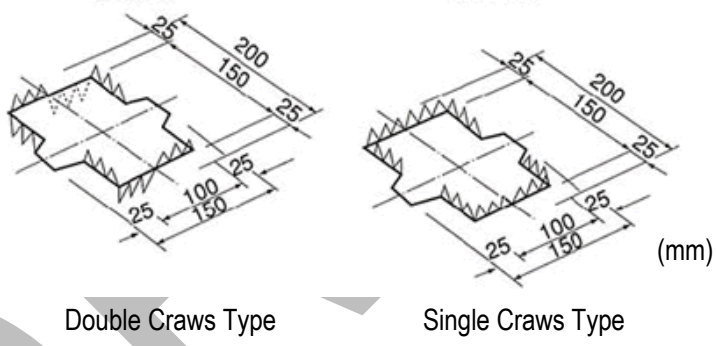


Figure 2-12 Binding Metal Fitting

[5]

When applying EPS Method, following points should be paid attention:

- It is soluble in organic solvents, such as gasoline and heavy oil.
- It is flame-retardant but not non-flammable. Precautions should be made against fire.
- Cutting of EPS blocks is required at the edge of filling where adjustment is required. EPS blocks should be cut with heating wire. The use of saws should be avoided due to cutting scraps created through cutting. .
- During temporary storage, attention should be paid that EPS blocks are not to be blown off by wind.
- If it is placed below high-water level (HWL), buoyancy will act on EPS blocks. Thus application at lowland or below HWL should be avoided otherwise use of Buoyancy-Resistant EDO-EPS Blocks should be considered.

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(ii) FCB Method

FCB is an acronym for Foamed Cement Banking, meaning "foamed cement embankment." FCB Method is to use air mixed cement or mortar to construct embankment.

As a general method, fine air bubbles are added in a cement slurry of raw material (sandy soil) and cement with water. Then the air-mixed cement or mortar is casted and cured in a manner not to crush the air bubbles with in it. In order to keep the air bubbles, casting per day should be limited up to 1 meter in height.

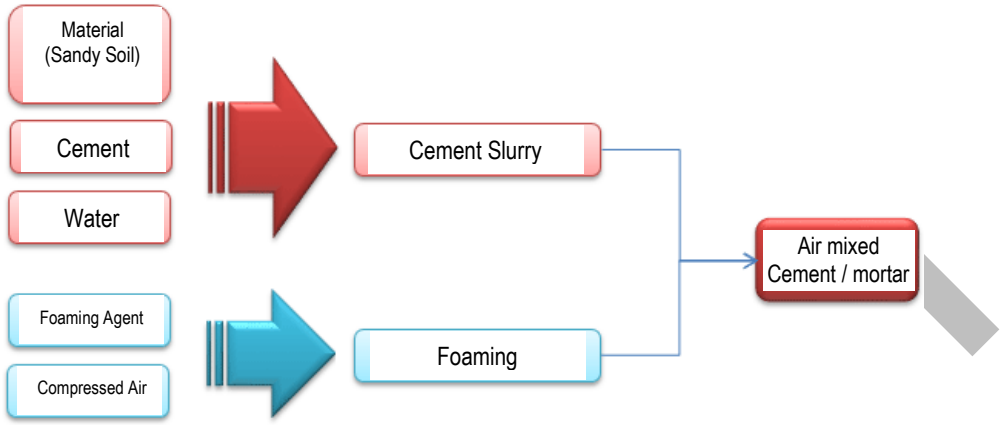


Figure 2-13 Production Process of Air-mixed Cement/Mortar

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When applying FCB Method, following points should be paid attention:

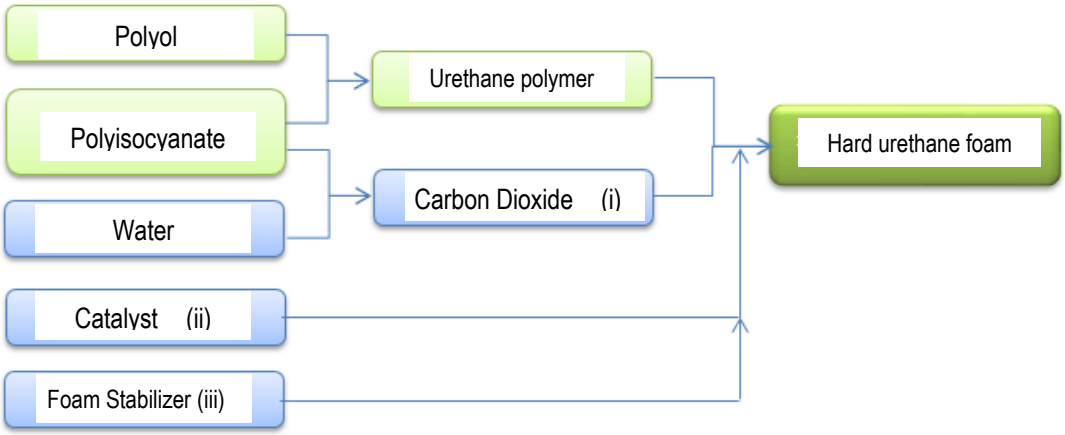
- A concrete batch plant should be prepared at site for on-site mixing. For small construction sites, an agitator vehicle may be used instead of a plant.
- During rain, casting air-mixed cement/mortar should be avoided because air bubbles may be vanished by rainwater.
- Since the casting per day is limited up to 1.0 meters in height in principle, longer period than other light-weight embankment method may be required.
- During winter, like conventional concrete, curing of air-mixed cement/mortar need longer period to obtain the required strength.
- If it is placed below high-water level (HWL), it is necessary to examine effect of buoyancy. With FCB Method, density of air-mixed cement/mortar can be changed by adjusting mixed proportion. In case air-mixed cement/mortar is placed below HWL, the density of it should be heavier than water.

(iii) Urethane Foam Method

Urethane Foam Method is to construct embankment of hard urethane foam which is produced on site by mixing two chemical solutions.

Urethane polymer is formed through chemical reaction of mixing liquid polyol and liquid polyisocyanate. By adding (i), (ii) and (iii) in Figure 2-14 and then treated through foaming process, urethane polymer turns into hard urethane foam in which fine closed cells are included.

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Figure 2-14 Production Process of Urethane Foam

For applying the urethane foam, following points should be paid attention.

- A construction yard for on-site production of urethane form is required.
- The construction yard and the site of spraying urethane form should be completely covered for the purpose of preventing emission and keeping stability of materials. The workers for the works should wear protective goggles, gas mask, gloves, and other necessary safety gears as required).
- As it is special construction works, skilled workers and strict quality control are required.
- As the raw materials are hazardous compounds, strict storage control is required.
- Fire is strictly prohibited for raw materials in liquid form. The hardened urethane foam is flame-retardant but not non-flammable. Precautions should be made against fire.
- If it is placed below high-water level (HWL), it is necessary to examine effect of buoyancy.

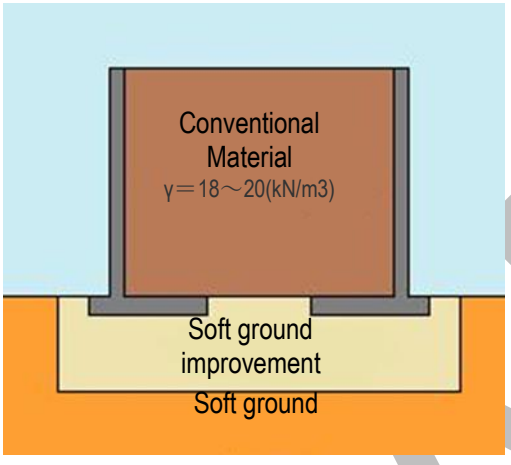
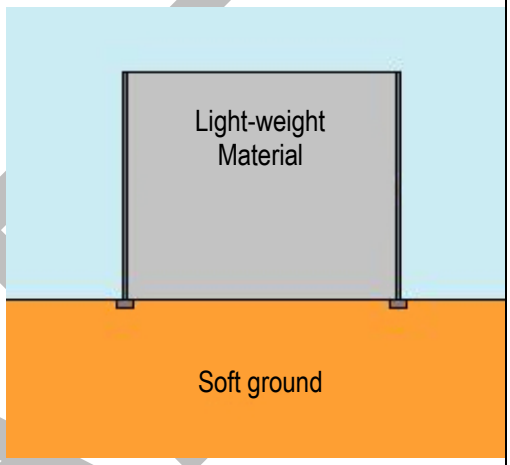
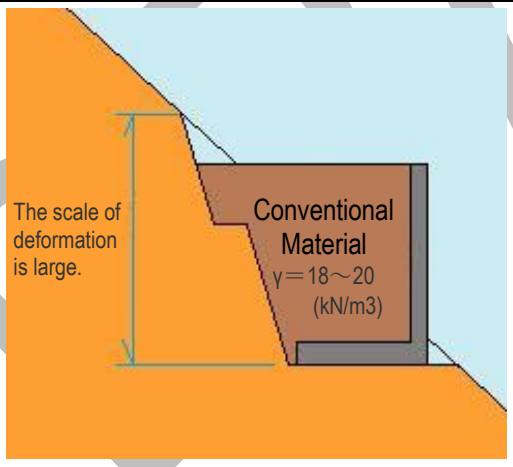
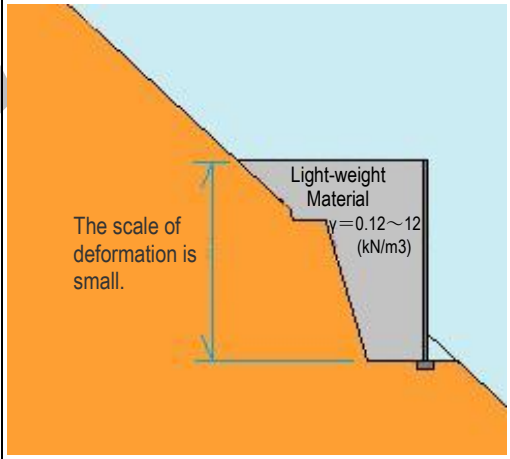
(3) Summary

The cost of light-weight embankment is often higher than conventional method. So engineers may be reluctant to adopt light-weight embankment. As light-weight embankment has valuable advantages in its light-weight and self-supporting property, however, it is particularly applicable to the rods on soft ground and hill slopes. By examining optimum application to the sites of hill slope, light-weight embankment may new extend possibilities of hill road construction as well as slope protection measures. Light-weight embankment is also useful when minimizing cut slopes is required.

- Due to its light-weight, when it is applied to soft ground, consolidation settlement due to embankment construction is expected to be reduced. Thus soft ground treatment may be minimized. Maintenance costs after completion is as well.
- Compared to adopting conventional retaining wall, the required width of the site is expected to be reduced. The scale of deformation of natural slope is as well.
- Since large and heavy machinery is not required, construction at narrow space or soft ground is possible.
- Compared to adopting conventional retaining wall, the scale of temporary works may be reduced.

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Table 2-9 Comparison between Conventional and Light-weight Embankment Method

Types	Conventional Method (Concrete Retaining Wall and back-filling with earth)	Light-weight Embankment Method
Wall	Leaning-type retaining wall. L-type retaining wall Reversed T-type retaining wall	Spraying mortar or shotcrete.
Material of Filling	Borrow material Locally available material γ＝18～20(kN/m3)	EPS、FCB、Urethane Foam γ＝0.1～12(kN/m3)
Workability	Large heavy machinery is required. Large-scale temporary works are also required.	Large heavy machinery is not required. Temporary works are small.
Soft Ground	 Measures such as pile foundation or soft soil treatment are required.	 Measures are not required or less scale measures are required. Maintenance costs may be reduced.
Hill Slopes	 The scale of deformation of natural slope is large.	 The scale of deformation of natural slope may be reduced.

[6] [7] [8] [9] [10] [11]

2.3 Selection Sequence for Slope Protection and Landslide Mitigation / Countermeasure Works

2.3.1 General

On the course of survey and design of hill roads, since possible landslides along hill roads have a wide range of varieties as explained in Chapter 1, appropriate countermeasures should be selected against the risks of landslide not only within Right of Way (ROW) but outside ROW. In particular, if a large scale landslide is detected during the survey along the planned route, which is difficult to prevent by mitigation or countermeasures and may pose serious social impacts if it occurs, avoiding such landslides by realignment of the planned route may be required. For this sense, detecting disaster-prone landform is important during preliminary survey stage, as explained in Chapter 1.

In order to provide reliable service of hill roads without being hampered by landslides, appropriate measures should be adopted in the aim of securing stability of roadside slopes of hill roads. And such measures should suite properties of such slopes.

Cut slopes generally suffer from time-dependent degradation due to relaxation by unloading and/or weathering of soil/rock exposed at the surface of cut slopes. The degradation of slope directly links to strength decrease of the slope.

Surface and groundwater significantly affects stability of slopes. In particular, erosion by surface water and degradation of strength by groundwater should be fully considered.

Construction of hill roads involves alteration of natural conditions, such as landform and vegetation. Even slope protection and countermeasures against landslides more or less affect surrounding natural environment and landscape. Design of slope protection and landslide countermeasures should consider protection of surrounding environment and landscape as much as possible as well as protection of slope and securing stability of slopes.

Planning of hill roads and design of slope protection and countermeasures should comprehensively consider aforementioned aspects as well as cost and construction periods.

2.3.2 Selection Sequence for Slope Protection and Landslide Countermeasures

(1) Basic Concept

(i) Information of Site Conditions for Design

When selecting slope protection and landslide countermeasures, the first priority should be given to long-term stability of the targeted slopes. Preservation of natural environment and landscapes should also be considered.

The following information regarding site conditions should be collected for the design:

- Properties of soil and rock:
  - Hardness
  - pH value
  - Properties of discontinuities such as cracks, bedding, joints, and foliation
  - Weathering and decomposition of rock, including resistance properties
  - Slaking and swelling properties
  - Matrix and boulder/gravel of colluvium/debris
- Topographic settings:
  - Gradient of slopes

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- ✧ Shape of slopes
- ✧ Knick lines and concave knick lines

- Geological settings:
  - ✧ Faults and fractured zones
  - ✧ Folds and sheared zones
- Surface/groundwater conditions:
  - ✧ Inflow of surface runoff
  - ✧ Groundwater spring
- Weather conditions:
  - ✧ Air temperature
  - ✧ Precipitation
  - ✧ Freezing and frost
- Natural Environment:
  - ✧ Vegetation
  - ✧ Rare species

(ii) Factors of Design

Design of slope protection and countermeasures should consider the following factors:

- Countermeasures:
  - ✧ Gradient of slope
  - ✧ Slope protection
  - ✧ Type, scale, and extent of countermeasures
  - ✧ Combination of countermeasures
- Temporary works and transport
- Construction method and required machinery
- Material and its availability
- Construction cost
- Workability and construction period
- Operation and maintenance

(iii) Cause of Landslide, Key Elements of Design

Selection sequence of slope protection / landslide countermeasure should start from a site of a landslide or a planned site of cut slope construction, where site situation and conditions should be understood as accurate as possible. In other words, phenomena of landslide or precursor of failure which may be triggered by cutting should be grasped by the engineers in charge.

Especially, unnatural and abnormal points on site should be paid attention. Abnormal points are particular features which are not observed at normal slopes; head/main scarp of landslide/slope failure, open cracks and slicken side and/or striation on the walls of scarp or flanks, flat or gentle terrain on slopes, concave slope and U-shaped gorge on slopes, displacement and subsidence of road surface and side ditches, cracks and deformation on pavement and side ditches, and groundwater spring and soil pipes. Once an abnormal point is detected at site, properties of an abnormality should be well investigated, such as shape, scale, possibility of expansion, spacial continuities, and succession of the abnormality.

If multiple abnormalities are found, the relations among abnormalities should be well considered. The relations among abnormalities should be endorsed by tangible evidence. In case one theory for explaining relations among abnormalities has discrepancy or contradiction with other theories, these theories should be verified again to eradicate discrepancy or contradiction. Such verification process should be repeated again and again among theories so that the theories could be proofed to conclusions.

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Through examining such verification process again and again, engineers become able to clearly understand what happened at the sites of landslides and will happen in future. These clear understanding of the situation and conditions of the site will give the engineers clear images of what the slope protection and landslide countermeasures should be. In order to reach much more reinforced conclusions, engineers should find abnormalities on site as much as possible, try to prove theories for explaining more relations among such abnormalities, and repeatedly verify the theories to eliminate discrepancy. The important point is not only finding abnormalities as much as possible but rigorously verifying theories repeatedly, though which engineers could reach clear images of necessary countermeasures.

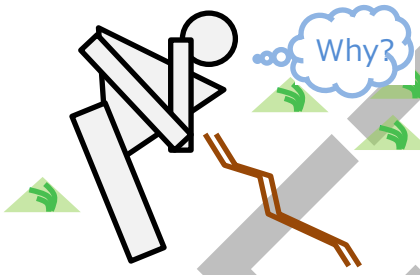


Figure 2-15 Thinking about Cause of Landslides, Key Elements of Design

Source: JICA Project Team

Focal Points of Design

Understanding of the site by engineer governs design of slope protection / landslide countermeasures. For example, if a section of hill road suffers from repeated sinking, the engineer should understand what causes the sinking.

As shown in Figure 2-16, in a block of gravity deformation, compared with landslides, slip surface of gravity deformation has steep gradients in most stretch. (More precisely, gravity deformation has loosened zone instead of slip surface. For easier understanding of design procedure, however, we use the term of "slip surface" for gravity deformation.)

On the other hand, a slip surface of a landslide consists of two sections; a short section with steep gradient continued from a head scarp and another long section with gentle gradient which occupies most of slip surface.

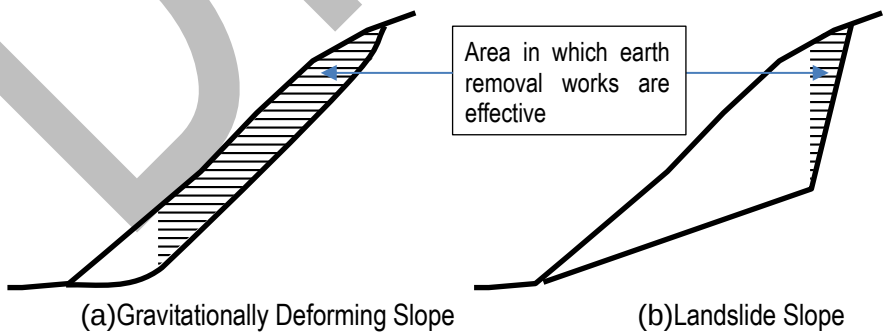


Figure 2-16 Effective Areas for Soil Removal Works of Gravitationally Deforming Slope and Landslide Slope

Source: JICA Project Team

If soil removal is planned as a countermeasure against the sinking, the area to be removed should be carefully considered. Soil removal should be done where slip

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surface has steep gradient and appropriate area of soil removal is different between gravity deformation and landslide. For gravity deformation, since the slip surface is steep at most stretch, the effect of soil removal is generally same at any part of the slope shown by hatching in Figure 2-16. For landslide, the appropriate area for soil removal is limited to the part with hatching in Figure 2-16.

If soil removal is carried out at any sections where the gradient of slip surface is gentler than that of the slope surface, block of landslide or gravity deformation is destabilized. For landslide, such section occupies most stretch of slip surface. Thus strict consideration is required for the location of soil removal for landslides. So identification of types of landslide as well as understanding causes of damage is important for design of slope protection and landslide countermeasures.

The aforementioned example explains how types and mechanism of landslide affect design of countermeasure. By understanding the mechanism of landslide, focal points of design of countermeasures become clear. Against rock fall and debris flows, analysis of impact force or “energy of movement” is required. Against collapse and landslide, the "force" with vectors such as earth pressure or driving force of landslide and the "strength" represented by shear strength should be considered. In other words, design of effective countermeasures requires proper understanding of phenomena and where and how the “force” acts and “strength” resists.

Pressured Groundwater and Deep-seated Landslide

The relation between groundwater and stability of slope is another interesting aspect in landslide engineering. As well understood, groundwater destabilizes slopes. But this does not mean any types of groundwater have to destabilize slope. Groundwater stagnated in an unsaturated condition does not destabilize slope. But saturated groundwater destabilizes slopes by generating "water pressure". Water pressure is the key of destabilization.

Figure 2-17 shows one of the possible explanations for generation of pressured groundwater which may cause destabilization of gravity deformation and lead to deep-seated landslide. At the initial stage, the fissure water stagnated in the upper slope, which is shown in gray hatching in Figure 2-17, is not connected to the fissure water stored in the loosened zone of gravity deformation in the lower slope. If heavy rainfall infiltrates into the ground and saturates fissures, the fissure water in the upper slope becomes connected to that of loosened zone and then extremely high pressure affects the fissure water in the loosened zone. It is turned to pressured groundwater and may destabilize the block of gravity deformation.

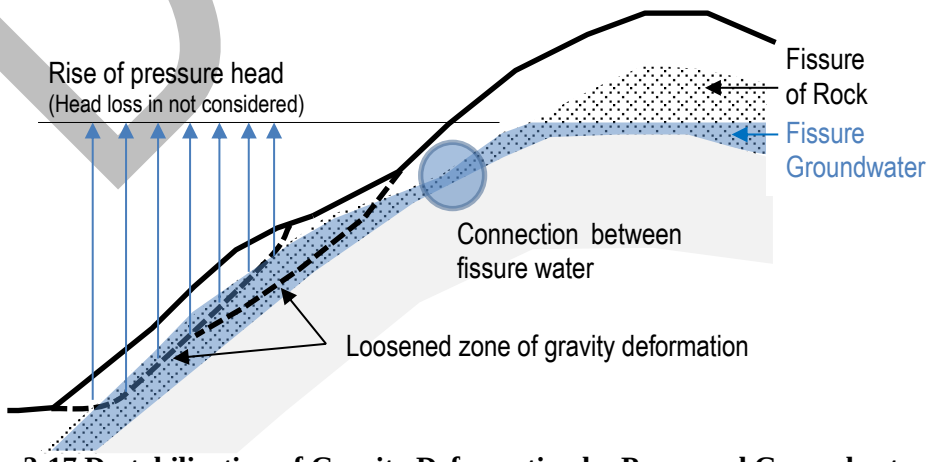


Figure 2-17 Destabilization of Gravity Deformation by Pressured Groundwater

Source: JICA Project Team

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The requirement for groundwater to generate high pressure head are that fissures are filled with groundwater. Factors related to the quantity of groundwater are not included. In other words, if enough amount groundwater is provided by rainfall to fully saturate fissures, the pressure head, which corresponds to the highest elevation of the continuous fissure water in the rock mass, will be generated at the lower part of the slope.

Uncertainty in Design and Adopting Multiple Countermeasures

As mentioned above, in the design of slope protection and countermeasures against landslide, engineers should properly understand the mechanism of landslides on the objective slope. Based on such understanding, engineers should predict the specific deformation or displacement to be generated in particular locations of slope. With all applicable technologies, countermeasures should be so designed to mitigate or prevent the predicted deformation or displacement.

In the design of countermeasures, “forces” such as earth pressure, driving force, and pore water pressure are invisible and thus uncertainties in setting parameters are inevitable.

Furthermore, the risk of destabilization due to pore water pressure depends on the amount of rainfall. So, for setting objectives of countermeasures, certain criteria are also required for the probability of occurrence of landslides.

Due to the aforementioned uncertainties, securing "absolute safety" in the design of slope protection and landslide countermeasures is difficult. Instead, "relative safety" is sought in the design; design policy to improve stability of slope at certain degree from the existing ones. Generally, the concept of "factor of safety" is introduced and, through multiple design steps, countermeasures are so designed to fulfill the “design factor of safety”, the required safety factor to stabilize the slope with countermeasures.

All steps of design include consideration process which induces design of safer side. Introducing multiple types of countermeasures, which means increase of design steps, facilitates safer side design by achieving higher factor of safety than the design. Such increase of factor of safety is to counteract the uncertainties inevitably involved in the design of countermeasures.

Introducing multiple types of countermeasures is recommended due to financial reasons. Introducing relatively cheaper control works, such as soil removal and groundwater drainage, reduces total construction cost while partially securing required design factor of safety.

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(2) Important Points in Selecting Slope Protection

In the previous section, basic concept of design is explained by referring to landslides and gravity deformation, which require considerations for entire stability of slope, or external factors for stability of slope. On the contrary, in this section, important points in selecting slope protection are discussed, while paying attentions to internal factors for stability of slope.

Slope protection can be categorized into three major groups; rock fall prevention and protection, vegetation, and structures.

As a general rule, the following points should be considered in the design of slope protection:

- Based on the topographic, geological, geotechnical, and meteorological survey results in and around the sites and the records of construction of similar works in the past, stability, durability, workability, environment, landscape, cost, and operation & maintenance should be comprehensively examined.
- Utmost attention should be focused on the purpose of slope protection; provision of safe service of the hill roads. Due consideration should be paid for the function of slope protection as well as preservation of the surroundings and securing functions of facilities such as drainage ditches and sidewalk.
- The process of selection should be: 1) rock fall prevention and protection, 2) vegetation, 3) combination of vegetation and structures, and 4) structures.

In selecting slope protection, the important points for grasping situation and condition of the targeted slope are explained below:

(i) Erosion-prone Slopes Consisting of Sandy Soil and Others

For the cut slope composed of the soil that is easily eroded even with a small amount of spring water, such as sandy soil, vegetation alone is generally adopted.

When prevention of erosion by surface water is required, however, crib works and net hurdling are added to vegetation. For the cut slope with a large amount of spring water, gabion or crib works filled with boulders or net hurdling is applied depending on the actual quantity of spring water. Installing shallow groundwater control works of French drain or conduit in dendroid pattern with additional covers of concrete blocks is effective to prevent scouring behind the slope protection works.

Regardless of existence of groundwater spring or amount of spring water, installing drainage ditches at each berm and the shoulder of slope is recommended.

(ii) Slopes with Large Amounts of Spring Water

For the slopes with a large amount of spring water, open-type slope protection works, such as crib works, gabion, and crib works filled with boulders, should be placed for protection and shallow groundwater control works and horizontal drainage boring should be installed for drainage purposes.

(iii) Slopes Prone to Rock fall (refer to Chapter 2.2.2(2))

Scale of rock falls governs the selection.

The slopes composed of soil with gravel, such as colluvium, debris, and talus and terrace deposit, and weathered soft rock generally produce relatively small size fallen rocks. For these slopes, in addition to vegetation, installation of rock fall

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protection net to trap fallen rocks and/or rock fall protection fence to prevent fallen rocks from causing damage to hill roads are required

For the slopes of well cracked soft rock without spring water, shotcrete or mortar spraying is appropriate.

For the slope of well cracked hard rock, where exfoliation and detachment frequently trigger fallen rocks, rock fall prevention at source of fallen rocks as well as rock fall protection works for trapping fallen rocks are recommended. Especially for steep cut slopes, combination of rock fall prevention and protection works is recommended.

(iv) Cut Slope Composed of Hard Rock and Hard Surface

Planting on the slopes composed of hard rocks should be carried out after cutting and applying borrow material to the area where surface conditions are not suitable for vegetation. For the slopes composed of high-density sandy soil (exceeding soil hardness of 27 mm), hard cohesive soil (exceeding soil hardness of 23mm), and soft rock or hard clay, sodding should be applied after base of borrow material was placed.

(v) Cut Slope Composed of Acidic Soil, Inadequate for Plant Growth

The slope composed of acidic soil, the pH of which is pH = 4 or lower, lime neutralization should be done before planting or applying vegetation. Some geological conditions, such as old lake sediment, rapidly show strong acidity after being exposed to the air. Careful attentions are required for such type of geology.

Under particular circumstances, acidic water derived from groundwater from certain types of bedrock shows acidity and negatively affects vegetation. If such conditions are assumed, drainage or water shielding works to avoid adverse effect from the acidic groundwater are recommended for sound growth of vegetation. Depends on the site condition, instead of vegetation, slope protection works with structures, such as concrete block pitching, are appropriate.

(vi) Cut Slope of uneven conditions of soil/rock properties and groundwater conditions

Even on a continuous cut slope, soil/rock properties and groundwater conditions may vary by locations. For such uneven conditions, appropriate slope protection should be selected for each condition on slopes.

For such slopes, groundwater /surface water control works should be installed prior to the construction of other slope protection works.

Detailed points of concerns for the design of vegetation and structures are described in the following section:

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(3) Design for Vegetation

(i) Basic Concept of Design for Vegetation

The main objectives of applying vegetation are "prevention of erosion", “harmonized scenery with the surroundings”, and "conservation of landscape”. Effects of prevention of collapse are not expected, however.

The following conditions are required when applying vegetation.

- The surface of slope to apply vegetation should be stable.
- The plants to apply should be suitable for the conditions of the targeted slope as well as the surrounding.
- Vegetation base should resist erosion and being washed away. Vegetation base should not inhibit sprouting and growing vegetation.

As vegetation utilizes living plants, due consideration should be paid to the design procedures and concepts, otherwise the results are considerably different from what initially intended. Design of vegetation should consider objectives of vegetation, period for curing, and operation & maintenance methods through deliberate consideration, such as shown in Table 2-10.

Table 2-10 Design Procedure of Vegetation

Order of Design	Design Contents	Points of Concern
1	Setting objective plant community and level of maintenance	Conditions of site, cost, landscape
2	Selection of plants suitable for objective plant communities	Plant community, local weather condition
3	Selection of vegetation works which enable to sprout and grow	Properties of plant, topographic and geological conditions, gradient of slope
4	Selection of vegetation foundation to stabilize vegetation base material	Rainfall intensity, geology, gradient
5	Selection of blend ratio and amount of seeding, or species and size of planted trees	Plant community, method and period of construction
6	Setting of vegetation materials according to plants and vegetation works	Components, species, characteristics of vegetation
7	Setting of construction period	Components, species, area of vegetation

[12]

(ii) Setting Objective of Vegetation

The objectives of the vegetation are divided into four main categories as shown in Table 2-11, depending on the physiognomy of plant community to be intended. When objective is decided, due consideration should be paid for variation with time of vegetation as well as operation & maintenance after construction.

(iii) Selection of Vegetation to plant

The types of vegetation to plant should be selected according to the decided greening objectives. For "grassland type", exotic and/or native herbaceous plants should be applied. For "shrub type", shrubs should be mainly planted along with herbaceous plants. For "high forest type", trees should be mainly planted, blended with shrubs and herbaceous plants. The forms of vegetation material to apply are seeds, nursery stocks, and adult trees, etc.

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Table 2-11 Vegetation Objectives and Types of Plant Communities

Objectives	High Forest Type	Shrub Type	Grassland Type	Special Type
Images				
Appearance	Plant community mainly composed of trees	Plant community mainly composed of shrub	Plant community mainly composed of herbaceous plants	Special or artificial plant community
Overview	Plant community similar to a natural forest where trees, lower trees, shrubby trees and herbaceous plants are mixed	Plant community mainly composed of low trees and shrubs. Disaster prevention functions against steep slopes or rocky slopes are excellent	Herbaceous plant community mainly composed of herbaceous plants. It is suitable for areas surrounded by farmland or pasture.	Artificial plant community composed of vines, flowering trees, fruit trees, etc., or endangered plants
Remarks	Plants community may lose stabilization on steep slope	If managed properly, trees may be introduced.	As it is easily altered to forest type, regular maintenance is required	Careful maintenance is required to prevent disasters.
Application	Areas in forests or natural park	Areas in forests or farmland	Areas in farmland or pasture	Area where careful attention is required.

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(4) Design for Structure

Slope protection with structure is to cover slopes with structure for the purpose of preventing weathering, erosion and collapse.

As the first step of design, based on survey results, the main factors of destabilization of the targeted slope should be identified. Then the structures to eliminate or mitigate the factors of destabilization or to prevent deformation due to the factors should be selected.

The important points in design of structure are as follows.

- Based on the results of preceding survey and investigation, factors of destabilization and areas to be affected should be deliberately examined.
- Utmost attention should be focused on the purpose of slope protection; provision of safe service of the hill roads. Due consideration should be paid for the function of slope protection as well as preservation of the surroundings and securing functions of facilities such as drainage ditches and sidewalk.
- During the selection of structures, in addition to the destabilized parts of the slope, overall conditions of the slope should be examined.
- The existing structures of slope protection at neighboring slopes should be well studied.

Various types of structures for slope protection are available for types and scales of destabilized slopes.

In this section, slope protection with structures is divided into two major categories; surface protection against shallow failure and prevention works against large failures.

Internal Stability

Surface protection works are to protect slope surface against surface failures, which deteriorates internal stability of slope with slip surfaces of 3 meters deep from the surface or shallower.

External Stability

Prevention works are to stabilize the slope against large failures and landslides, which have slip surfaces of more than 3 meters deep from the surface and require considerations for entire stability of slope, or external factors for stability of slope.

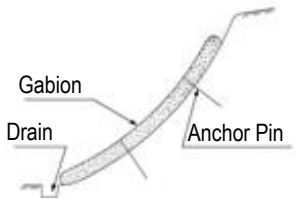
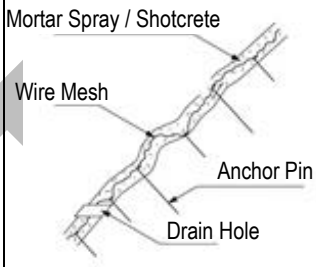
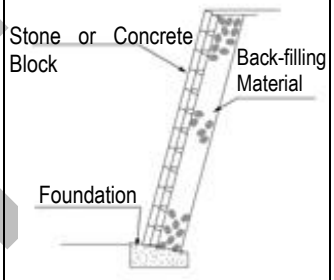
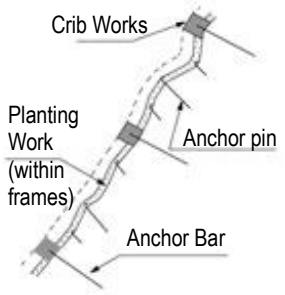
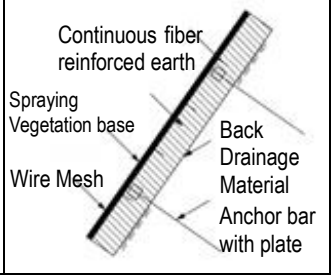
(i) Surface Protection Works

Table 2-12 shows representative types of surface protection works.

When applied to roadside slopes, due consideration should be paid for securing sights of drivers and sidewalk for pedestrians as well as preserving landscaping for aesthetic purpose.

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Table 2-12 Types and Features of Surface Protection Works

	Type of Works	Outline and Purpose	Remarks for Application	Features and Sketches
Surface protection works	Gabion	Placing gabions filled with boulders on the slope, to prevent erosion and washout of slope surface by rain fall, surface runoff and groundwater spring.	Effective for protection against groundwater spring, drainage of surface runoff and prevention of frost heaving.	
	Mortar spray Shotcrete	Spraying mortar or shotcrete on the slope with a thickness of about 5 to 10 cm, to prevent weathering and erosion. Mitigation of earth pressure by preventing infiltration of surface water is expected.	Applicable to large area of slope. Appearances may differ from natural slopes of the surrounding and thus discomfort may arise.	
	Stone pitching Concrete block pitching	Placing stone or concrete blocks on slope surface, to prevent weathering and erosion and to resist certain level of earth pressure. Mitigation of earth pressure by preventing infiltration of surface water is expected.	Applied at the toe of slopes. Not suitable where suitable foundation is not secured. For aesthetic purpose, stone or false rock block pitching may be applied.	
	Shotcrete crib works Cast-in-place concrete crib works	Grid shape frames on slopes are constructed by spraying, mortar or shotcrete or cast-in-place concrete, to prevent exfoliation of rock or surface failure and to resist certain level of earth pressure..	Applicable to large area of slopes. Appearances of crib works may differ from natural slopes of the surrounding. Mainly applied to the slope of 1H1V or steeper. Also applied as bearing members for ground anchors and rock bolts	
	Continuous fiber (geotextile) reinforced earth method	Covering slopes with reinforced soil materials of continuous fibers and sandy soil, to prevent erosion of the surface, exfoliation of rocks or surface failure. Vegetation is planted on the surface of the reinforced soil materials.	Applicable to large area of slopes. Since vegetation is applied to the surface, applicable to the slope of 1H2V or gentler..	

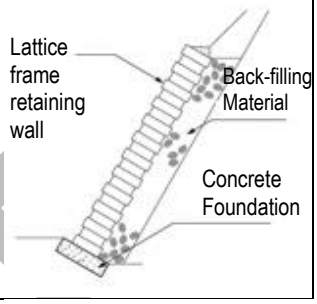
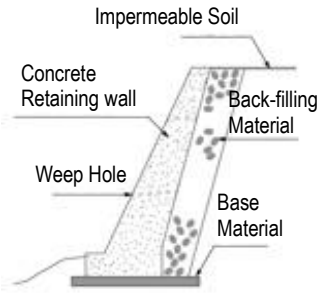
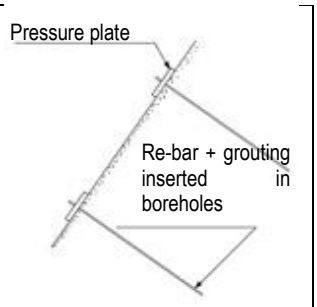
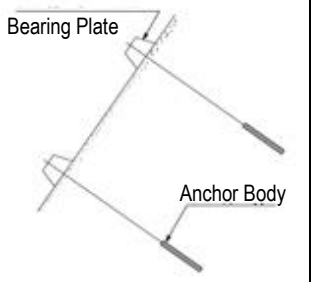
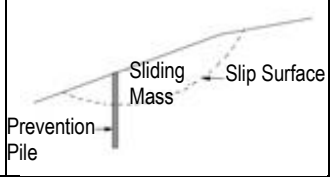
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(ii) Prevention Works

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Table 2-13 shows representative types of prevention works. Some of prevention works become large and costly. Thus properties of the targeted failures and/or landslides should be well studied before selection.

Table 2-13 Types and Features of Prevention Works

	Type of Works	Outline and Purpose	Remarks for Application	Features and Sketches
Prevention works	Gabion Lattice frame retaining wall	Stacking gabions or lattice-formed concrete frames filled with boulders at the toe of slopes.	Applied where large amount of spring and surface water exist and certain earth pressure acts, or for protection of the toe of slopes and reduction of earth pressure. Not suitable where stable foundation is not secured.	
	Concrete retaining wall Stone masonry retaining wall Concrete block retaining wall	Installing heavy structures composed of stones or concrete at the toe of slopes to resist earth pressure.	Applied at the toe of slopes. Not suitable where stable foundation is not secured. Appearances may differ from natural slopes of the surrounding. Also may be applied as bearing members for ground anchors and rock bolts.	
	Rock bolts	Installing reinforcing bars with grouting to slope surface, to increase resistance against slope failures and to prevent rock fall or failure of rock slope.	Applied to prevent exfoliation of rocks or to stabilize cut slopes. Application of rock bolts should be considered based on slope stability analysis.	
	Ground anchor	Giving pre-stress to anchor cable fixed to anchorage in bedrock and bearing plates on the surface to stabilize slope. Applied to increase resisting force against landslide, rock slides, and slope failures.	Applied as prevention works against landslide and failures. Also applied to reinforce pitching works, concrete crib works, and retaining walls. Application of ground anchor should be considered based on slope stability analysis.	
	Pile Works	Applied to large-scale landslide and failures which require strong resistance force to stabilize.	Pile works should be Installed at the position where the resisting strength is maximized. Application of pile works should be considered based on slope stability analysis.	

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(5) Standard Sequence of Selecting Slope Protection / Countermeasures

Figure 2-18 shows the standard selection sequence of slope protection works. The sequence is composed of two components; external and internal stability. Consideration of external stability comes first and then that for internal stability follows. The countermeasures for external stability may substantially change the landform at the site. After major modification of landform is fixed, consideration to ensure internal stability should be performed for each part of the targeted slope.

Landslide, gravity deformation, and large slope failure require external stability, to which slope stability analysis should be examined, based on the results of preceding surveys which provide profiles of slope and landslides as well as parameters for the analysis. For securing external stability, control works, such as soil removal, buttress fill, and groundwater drainage, and prevention works should be applied.

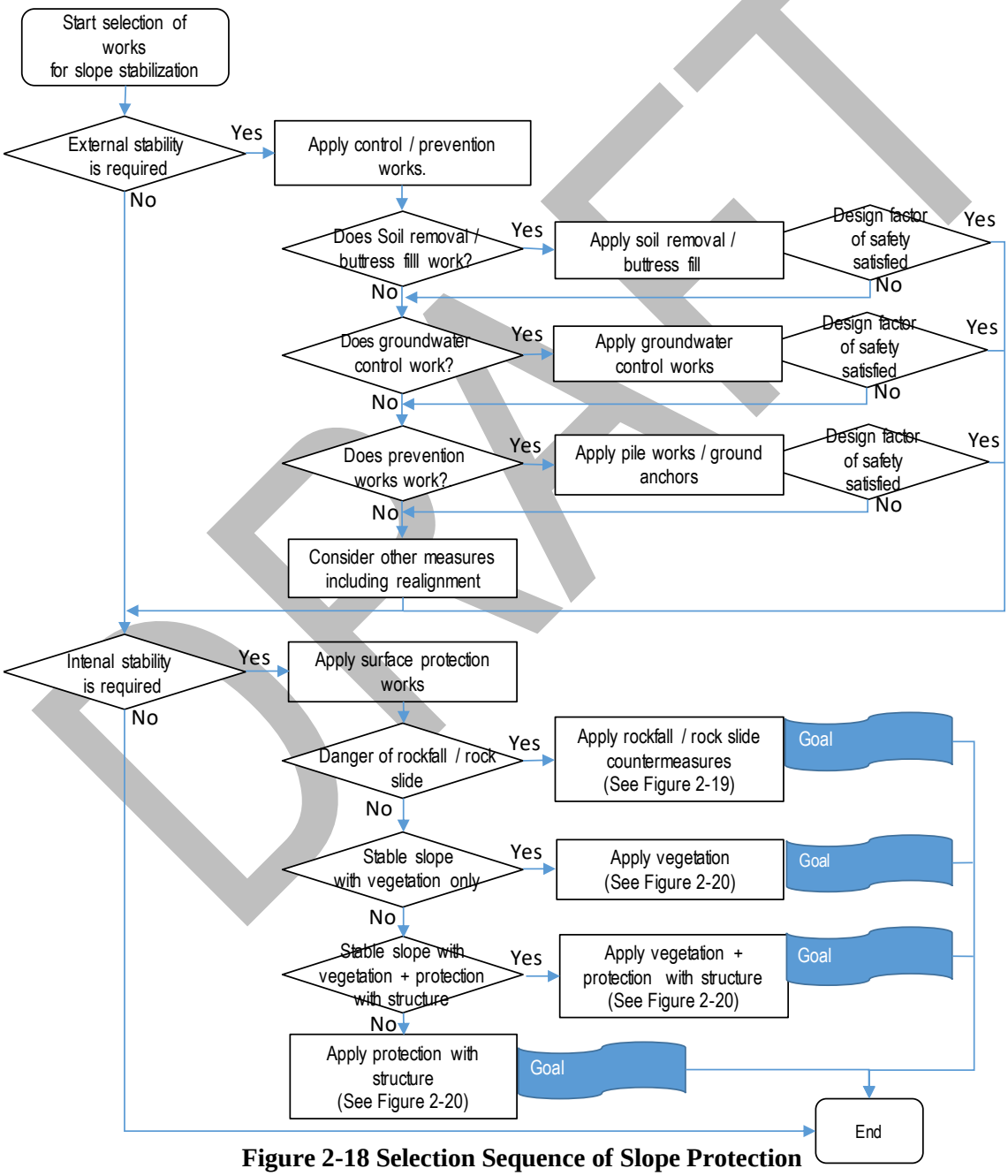
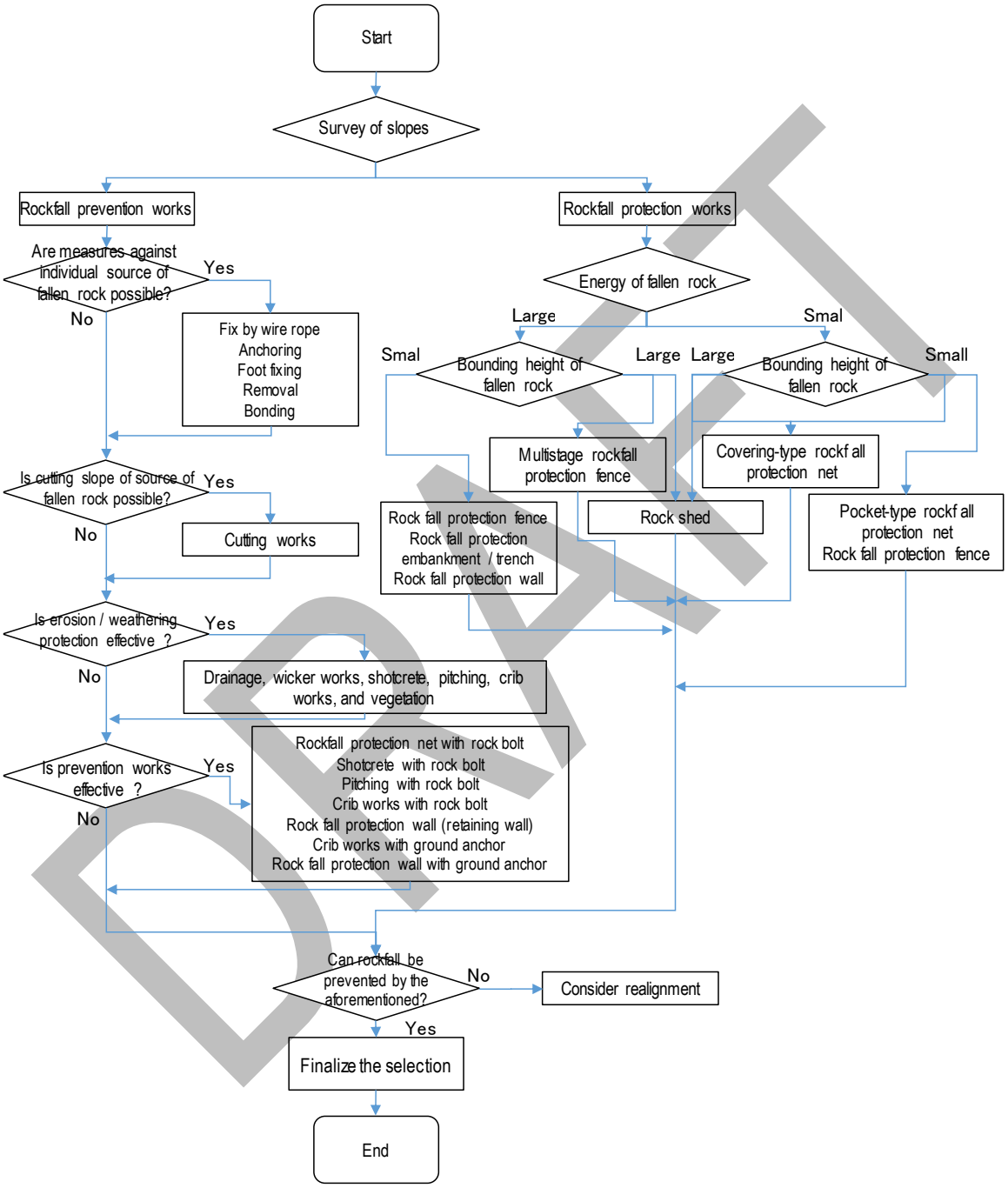


Figure 2-18 Selection Sequence of Slope Protection

Source: JICA Project Team

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For ensuring internal stability, measures against rock falls/slide, vegetation, and structures should be considered, Firstly, rock fall/slide prevention/protection should be considered for both natural and cut slopes including source of fallen rocks located at upper slopes. Then assuming stable gradient of slope is secured, from the viewpoints of long term stability, surface protection should be considered. In case stability of slope is not assured, for ensuring internal stability, prevention works should be selected.



Source: **JICA Project Team**

Figure 2-19 Selection Sequence of Rock Fall / Slide Protection/Prevention

Figure 2-19 shows selection sequence of rock fall/slide protection/prevention works and Figure 2-20 shows that for slope protection.

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Both rock fall protection and prevention works in Figure 2-19 should be considered in parallel while comparing each other. Combination of rock fall protection and prevention works are effective against large-scale rock fall and slope failures in wide area.

In Figure 2-20, separated sequences for selection of slope protection for the slopes of soil, soft rock, and hard rock are prepared. By focusing on its function, slope protection works are categorized as follows:

- If it is affected by spring water: open-type structure
- If erosion or weathering are assumed but vegetation is not required: Closed-type structure
- If erosion or weathering are assumed and vegetation is required: Structure with vegetation
- If neither of spring water, erosion nor weathering is assumed: Vegetation

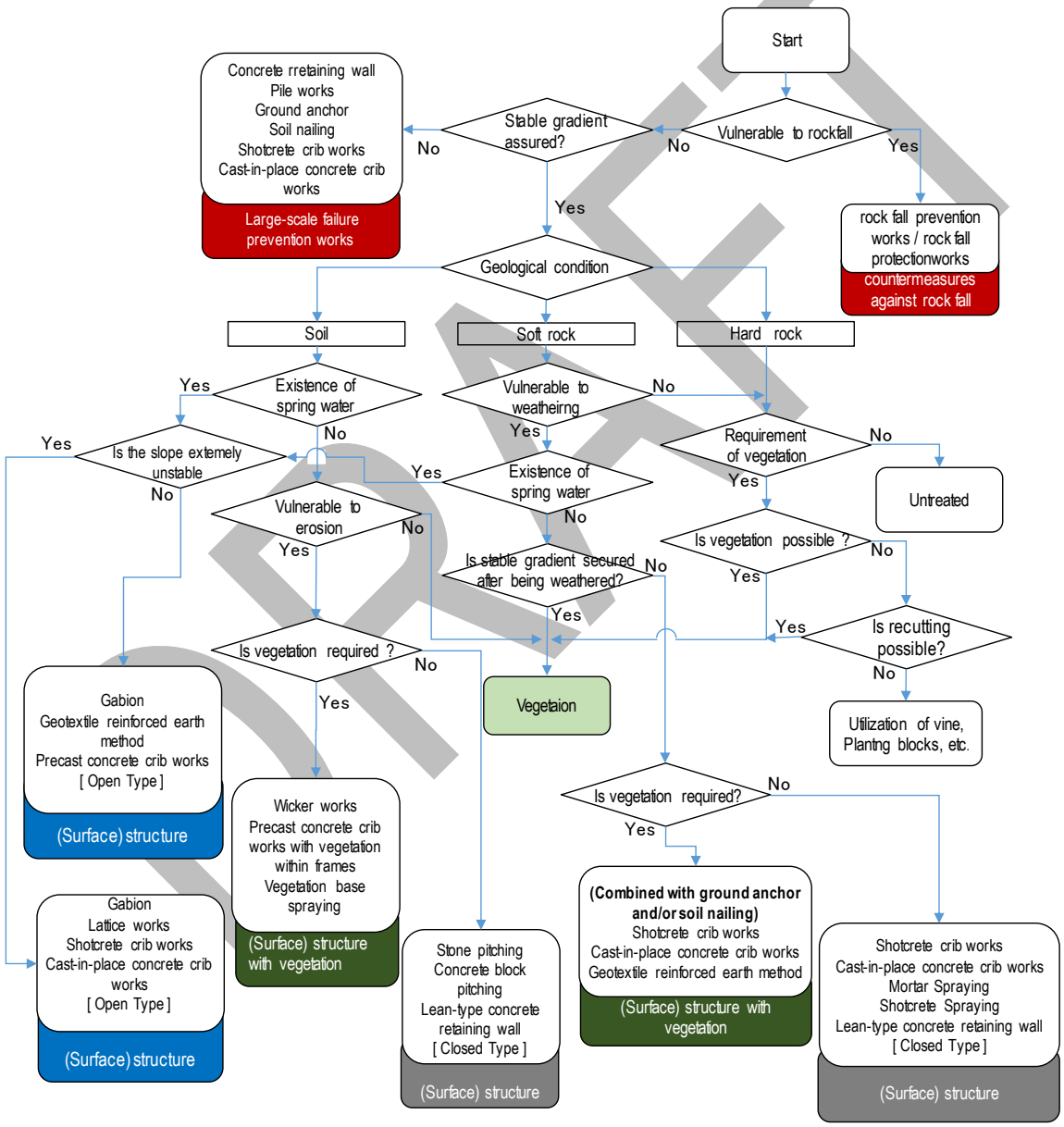


Figure 2-20 Selection Sequence of Surface Protection

Source: JICA Project Team

2.3.3 Points of Concern in Selection of Slope Protection / Landslide Countermeasures

(1) Life-span of Works

In the previous section, the concept of selection of slope protection and landslide countermeasures is described. In this section, points of concern in the selection process are explained.

Life-span of the works is important issue for the authorities of hill roads. Life-span has, however, two different meanings in slope protection. One is literally longevity of the works, which is governed by aging resistance of materials to be used. Another life-span depends on possibility of landslides/failures overwhelming design requirement of the works.

Firstly, literal longevity is discussed. The durable years of the works depends on the shortest durable years of the main members of the works. For example, the durable years of reinforcing concrete, which is mainly composed of reinforcing bars and concrete, are considered as 50 to 100 years, which are durable years of reinforcing bars. Thus we can assume life-span of concrete structures as 50 to 100 years.

To counteract the possibility of landslides/failures overwhelming design requirement, setting target possibility is often considered. Landslide is often caused by heavy rainfall. Thus target possibility can be amount of rain fall. When 100 years possibility of rain fall is targeted for countermeasure works, it should endure the heaviest rainfall once in 100 years. Targeted possibility of rain fall can be set by analyzing historical records of rainfall and often used to decide requirement of the civil works. Important point of target possibility is that a rainfall exceeding 100 years possibility may occur tomorrow. 100 years possibility simply express the possibility and does not assure when it happens. The event exceeding 100 year possibility may happen tomorrow or 100 years later.

Usually the life-span for concrete structure is considered as 50 years due to durable years of materials. Thus the target possibility of rain fall is often set as 50 years as well.

(2) Control and Prevention Works for External Stability

To assure external stability of landslide, gravity deformation, and large slope failure, both control and prevention works are applicable. Control works are to directory deal with the causes of instability of slope, by changing balance of weight of slope or reducing groundwater pressure. Prevention works are to resist driving force of landslides / failures by resistance given by structures, such as ground anchors and prevention piles.

Among the control works, soil removal and buttress fill are to directly change the balance of landslide mass. The balance between driving and resisting forces varies depending on the position on slip surface. Soil removal is effective if it is carried out to the part where driving force exceeds resisting force. Soil removal and buttress fill are cheaper options but the effects of them are assured and effective. This is the reason why soil removal / buttress fill works are examined at first in Figure 2-18. Soil removal / buttress fill works should be adopted as much as possible in the design of countermeasure to improve factor of safety as much as possible, so that necessary increase of factor of safety by other expensive countermeasures could be minimized.

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Groundwater drainage is another type of control works and has abundant successful experiences as landslide countermeasures. Maximum effects of dispersing pore water pressure by groundwater drainage are, however, difficult to evaluate. Thus, in the design of countermeasure, empirical values are set as decrease of groundwater level in slope stability analysis.

For prevention works, in the design of countermeasures, resistance force borne by such works are calculated by multiplying assumed driving force by required safety factor specific to the type of the works.

Regarding life-span of the works, soil removal and buttress fill has a long longevity until the landform is again reshaped.

Life-span of groundwater drainage depends on durable years of the main material as long as proper maintenance is executed.

Life-span of prevention works depends on durable years of the main material as well. Prevention works may, however, lose its function when overwhelming driving force acts on the works, which exceeds the assumed one in the design.

(3) Control Works and Monitoring

Even though it is obvious that groundwater drainage is effective for securing external stability of landslide, gravity deformation and large slope failure, as long as achieving design factor of safety in slope stability analyses primarily governs design of countermeasures, evaluation of groundwater drainage is always unclear.

Evaluation of prevention works simply depends on function and quantity of the works. So it is very clear. For example, increase of factor of safety by ground anchor works depends on resistance force provided by each array of anchor and numbers of arrays on the profile of slope stability analysis.

On the other hand, instead of increasing factor of safety, groundwater drainage provides restrain effect to the causes which decrease factor of safety. By groundwater drainage, increase of pore water pressure is restrained at certain level; factor of safety remains at certain level. This is the reason why partial increase of factor of safety by groundwater drainage is unclear and empirical values are used for the design.

Groundwater drainage is considered effective as long as the volume of drained water does not exceed the capacity of the drainage pipes. It is practically impossible, however, to decide effective range of collecting groundwater by each drainage pipe. Unless effective range of collection by each drainage pipe is clearly decided, calculation of quantity of groundwater drainage depends on empirical values.

Due to the use of empirical value, if the effects of groundwater drainage need to be strictly verified, monitoring of such effects is required. For verifying the effects of groundwater drainage, monitoring of groundwater level is usually performed to observe decrease of groundwater level from that of before installing groundwater drainage. Monitoring of groundwater level also provides the records of highest groundwater level caused by heavy rainfalls, which should be decreased from the level before installing groundwater drainage. After continuous monitoring, effects by groundwater drainage are precisely evaluated.

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(4) Prevention and Protection Works against Rock Fall / Slide

Prevention works against rock fall are placed at the sources of fallen rocks while protection works are placed in the middle and/or toe of slopes and prepared to trap or stop fallen rocks from the sources.

For the design of prevention works, probable scale and mechanism of rock fall should be understood for deciding requirements of the works; assumed scale and mechanism of rock fall govern the function and capacity of prevention works. If rock fall occurs with overwhelming scale over the assumed, the prevention works may not properly work as designed. Hence necessity of monitoring arises.

Generally, rock fall entails precursor. Monitoring of stress level is difficult but deformation or displacement by precursor is possible. This means monitoring is possible for an imminent rock fall even though it is overwhelming the assumed scale in design. By monitoring, precursor of rock fall can be detected and then precautions can be executed, such as orders of road closure or evacuation.

On the other hand, protection works are waiting for fallen rocks to trap or stop them before causing damage to hill roads and its users. Protection works are to deal with the incident already occurs. Thus monitoring cannot supplement the function of protection works. This means, against the maximum threat of rock fall assumed in the design, a scale of protection works should be as large as a budget allows.

The aforementioned difference affects the cost of prevention and protection works. In terms of construction cost, protection works should cost more than prevention works does, including necessary land for construction. Prevention works, however, requires operation and maintenance cost if it requires monitoring.

Prevention works and some kind of protection works require substantial cost for temporary works as well as safety precaution.

(5) Summary

As uncertainties are inevitably involved in the design of slope protection and landslide countermeasures, combination with monitoring is recommended, which may supplement uncertainties of design.

In addition, combination of Early Warning System (EWS) is recommended, which is elaborated in the guideline for operation and maintenance.

2.3.4 Combination of countermeasures/mitigations

Types of the countermeasures, as mentioned above, should be selected based on comprehensive understanding of the properties of each landslide type which may be involved. And the design should be on the safer side. In addition, from topographical, geological, and hydrological viewpoints, properties of cut slopes are not even and vary place by place. Thus single type of the countermeasure may not be sufficient for such complicated conditions. Accordingly, a combination of multiple types of the countermeasure should be considered.

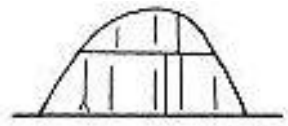
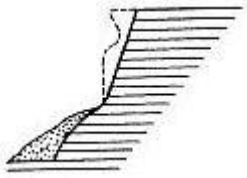
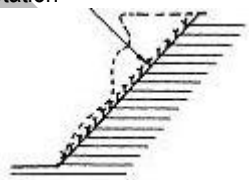
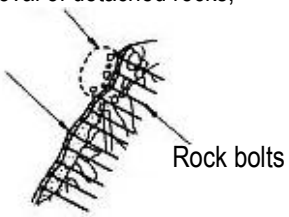
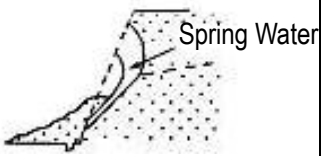
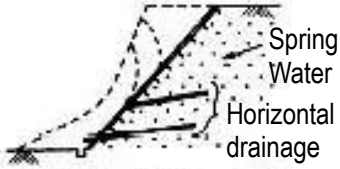
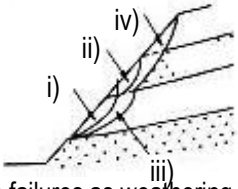
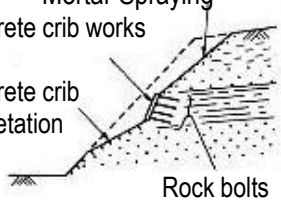
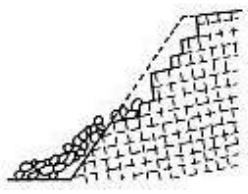
Table 2-14 shows combination of countermeasures against various slope failures assumed on cut slopes.

In addition to the cased in Table 2-14, along hill roads, rock fall prone areas often exist at the upper part of cut slopes and, at some risky places, debris flow and avalanches, which are not described here, may occur.

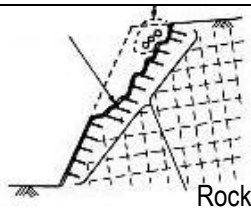
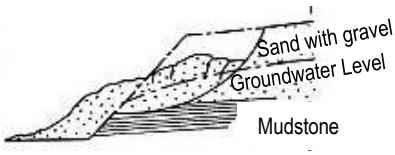
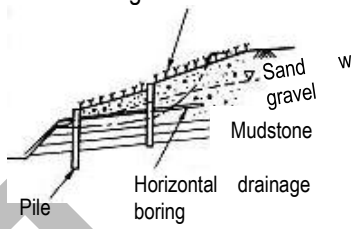
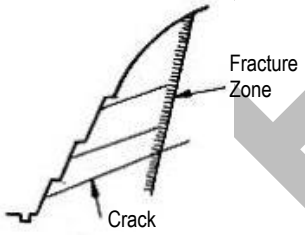
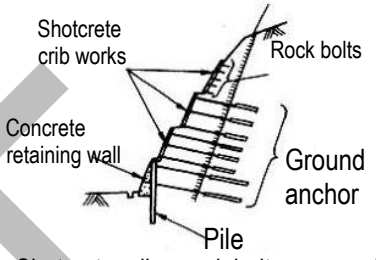
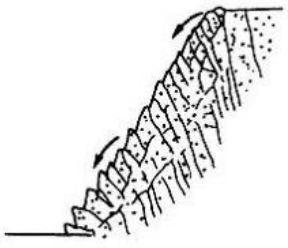
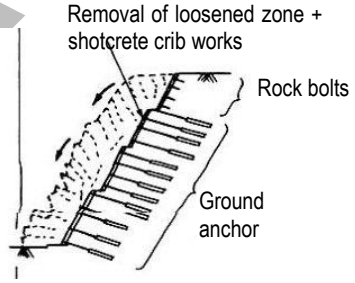
The more complicated an assumed landslide is, the more complicated the combination of measures will be. So, combination of countermeasures should be selected based on comparison of the cost performance including maintenance costs.

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Table 2-14 Slope Failures on Cut Slopes and Combination of Countermeasures

Category	Basic Concept	Collapsed shape	Examples of Countermeasures
Erosion and Collapse	1) Moisture, freezing, rainfall, etc. cause exfoliation or gully erosion on the surface, which may deform to a deep collapse if left untouched.	 Gully erosion by surface water	Precast crib works  Plastering works + vegetation or Precast crib works + vegetation
	2) Collapse of overhanging		Vegetation  Cutting + vegetation
	3) Rock slope with densely developed joints and cracks collapses.	 Fall of detached Rock	Removal of detached rocks, Mortar Spraying  Rock bolts Mortar Spraying + removal of detached rocks + rock bolts
Surface Failures	1) When surface soil slides, strongly weathered rock formation in the lower layer is involved. Spring water often causes the collapse.	 Spring Water Collapse Due to piping of spring water	Precast concrete crib work  Spring Water Horizontal drainage Cutting + precast concrete crib filled with boulders + horizontal drainage boring
	2) Surface of rock slope collapses due to weathering etc.	 iv) ii) i) iii) Surface failures as weathering proceeds.	Mortar Spraying Shotcrete crib works  Shotcrete crib + vegetation Rock bolts Cutting with appropriate gradient + shotcrete crib + vegetation + rock bolt + mortar spraying
	3) Rock slope collapses in dip slope structure or along cracks on bedrocks (e.g. joint, small fault and thin layer). In the latter case,		Removal of unstable rock Mortar Spraying

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	wedge failures are often seen	Collapse occurs along cracks.	 Rock bolts Removal +mortar spraying + rock bolt
Large Slope Failure and Landslide	1) As groundwater level rises, slopes consisting of soft and less consolidated layers or geologically weak layers collapse.	 Sand with gravel Groundwater Level Mudstone Landslide on the surface of permeability difference	Vegetation  Sand gravel w Mudstone Horizontal drainage boring Pile Cutting +pile and horizontal drainage boring + vegetation
	2) Massive failure occurs with dip slope structure or faults and fracture zones	 Fracture Zone Crack Landslide along fractured zone	 Shotcrete crib works Rock bolts Concrete retaining wall Ground anchor Pile Shotcrete crib + rock bolts + ground anchors + piles
	3) Plunging slope or rock slope with densely developed cracks topples.	 Toppling of plunging slope	 Removal of loosened zone + shotcrete crib works Rock bolts Ground anchor Removal of loosened zone + shotcrete crib works + rock bolts + ground anchor

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2.4 Consideration of Priority of Landslide Mitigation / Slope Countermeasure Works

2.4.1 General

Ideally, as long as problems lie, any natural / artificial slopes along the hill road shall be treated with slope protections or landslide mitigation measures. From a practical perspective, however, due to limitations of budget and tremendous length of the stretches of the hill roads in India, applying slope protection or mitigation measures to all slopes along the hill roads is quite difficult. Prioritization of slopes for landslide mitigation / slope protection is, therefore, required.

On the other hand, prioritization of slopes may provoke sensitive and delicate discussions among stake holders. Process of prioritization, therefore, shall be transparent as much as possible.

Prioritization of slopes can be done through evaluations of various aspects, such as stability of slope, triggers of landslide, cost of damage, and strategic importance of roads. Each aspect is explained in the following chapters.

2.4.2 Stability of Slope

Stability of slope can be evaluated based on the topographical, geological, and hydrological factors along with mode of landslide/failure as well as cost of countermeasures, as shown in Table 2-15

Table 2-15 Factors for Stability of Slope

Topographic Factors	Geological Factors(cont'd)
Landslide topography	Rock type with swelling / slaking property
Steps and subsidence (new or old)	
Deformation	Hydrological Factors
Double ridge	Spring / Seepage
	Trace of water
Geological Factors	History
Fault	History of landslide (topography, disaster record, witness)
Fractured / Shared zone	Damage on road, road facility and others.
Dip slope	Countermeasures
Colluvium	
Rock type with weak plane (foliation, bedding)	
Rock type with weak weathering resistance	Cost
Rock type with weak material property	Cost of countermeasures

Source: JICA Project Team

Factors in Table 2-15 are evaluated by adding score to each factor. Examples of scoring are shown in Chapter 4.1 of this guideline, which explains Slope Stability Assessment Charts (SSAC) for various landslide types along hill roads. The SSAC should be prepared by skilled geologists or engineers, through which priority for countermeasures from the aspects of stability of slope at certain slopes is assessed.

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2.4.3 Cost of Damage

Cost of damage is a convincing factor in prioritizing slopes for introducing countermeasures. The damage by a disaster at a slope is divided into 4 parts depending on the possible bearers as follows:

- Casualties
- Tax payers
- Road users
- Residents

In this guideline, the following costs represent the damage borne by the possible bearers:

(1) Cost of casualties --- casualties
(2) Cost of road recovery --- tax payers
(3) Cost of detour --- road users and residents

Cost of damage is calculated in monetary value, which is easily compared with other factors in the field of public investment.

(1) Cost of Casualties

(i) Basic Idea of Assessment

In a landslide or rock fall along hill roads, causalities are caused by direct hit by rock fall or debris and/or crash with debris which reaches to the carriageway. Thus Cost of Casualties (D_1 (INR)) is mainly depends on the factors listed below:

(i) Volume of debris or rock fall reached to the road
(ii) Vehicles involved in a disaster (volume of traffic, travel speed, speed at crash, number of passenger)
(iii) Mode of damage of the vehicles involved in a disaster

The mode of damage is classified into 3 types as listed below and explained in Figure 2-21.

A) Causalities who are directly hit by rock fall or debris and their vehicles are totally buried by the debris. (buried victims)
B) Causalities who are directly hit by rock fall or debris and their vehicles are partially buried by the debris. (unburied victims)
C) Causalities whose vehicles slam into debris and fallen rock. (crashed victims)

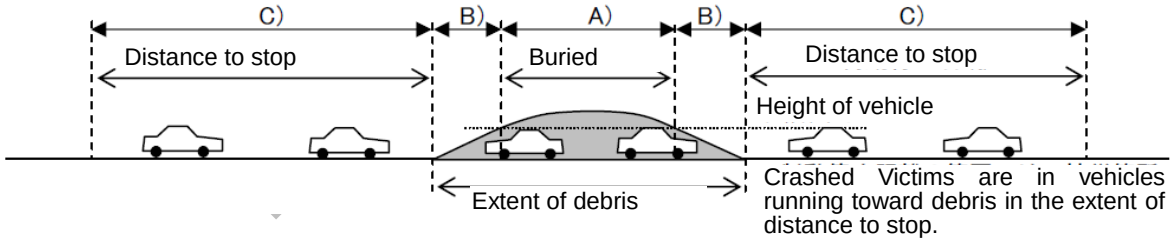


Figure 2-21 Mode of Damage and Extent of Debris

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A) buried victims occurs when the height of debris on the center of road (H_0 (m)) is not less than the height of vehicle (small vehicle: H_S, large vehicle: H_L (m)); the volume of the debris which reached to the road (V_0 (m^3)) where H_0 exceeds H_S is V_{DS}(m^3) and that of H_L is V_{DL}(m^3).

The tendency among volume of debris, mode of damage and number of causalities are summarized in Table 2-16.

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Table 2-16 Volume of Debris and Situation of Damage / Numbers of Casualties

Volume V0 (m3)	Mode of Damage	0 ∞		VDS (VDL)
Situation of Damage	A) Buried Victims		-	Dead (constant)
	B) Unburied		Worsens as volume increases	Almost constant
	C) Crashed		Worsens as volume increases	Almost constant
Numbers of Casualties (person)	A) Buried Victims		Not occurs	Worsens as volume increases
	B) Unburied		Worsens as volume increases	Almost constant
	C) Crashed		Almost constant regardless of volume of debris	

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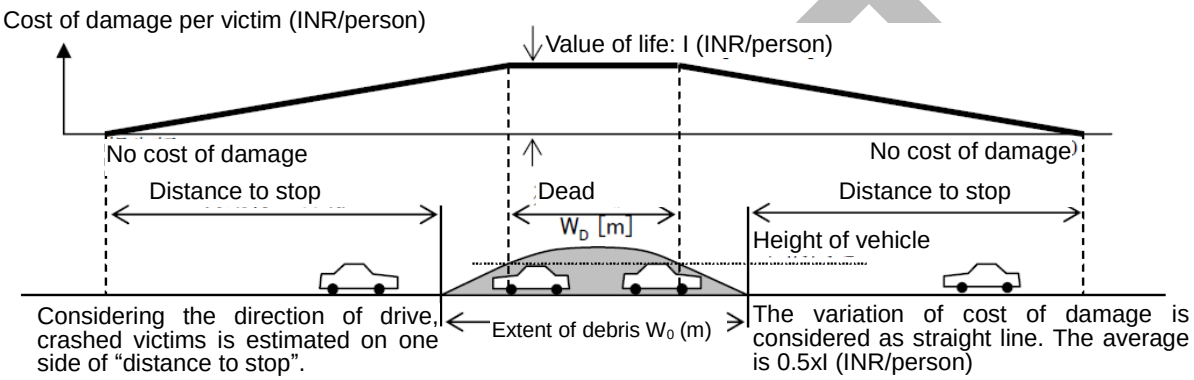


Figure 2-22 Distribution Model of Cost of Damage per Victim

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Cost of damage per victim including human and physical loss is distributed in a trapezoid shape shown in Figure 2-22. Based on Figure 2-22, the cost of damage from A) buried victim is set as the value of life (I (INR/person)) and those of B) unburied and C) crashed victims are set as the half of I.

Then converted casualties (M (person)) are calculated by assigning 1 person to A) buried victim and 0.5 persons to B) unburied and C) crashed victims. With the Converted Casualties and the value of life (I), the cost of casualties (D_1) is calculated by the following formulae:

$$D_1 \text{ (INR)} = M \text{ (person)} \times I \text{ (INR/person)}$$

In case volume of debris (V_0) is smaller than V_{DL} or V_{DS}, where A) buried victim is not assumed, converted casualties (M) decrease as volume of debris decreases and M becomes zero when debris does not reach the road. For this case, M depends on the height of debris at hill side road shoulder (H_1 (m)). In case of rock fall, diameter of rock fall (H_R (m)) substitutes H_1.

(ii) Assessment Method

The symbols to be used for the assessment are explained in Table 2-17.
The process of assessment is depicted in Figure 2-23.
The method of assessment is explained in the following pages.

Table 2-17 Symbols for Assessment of Cost of Casualties

V0 (m3): Volume of debris which reaches to the road
VDL (m3): Minimum volume of debris which reaches to the road and buries large vehicle
VDS (m3): Minimum volume of debris which reaches to the road and buries small vehicle
M (person): Converted casualties
ML (person): Converted casualties on board large vehicle
MS (person): Converted casualties on board small vehicle
MA (person): Buried victims
MAL (person): Buried victims on board large vehicle
MAS (person): Buried victims on board small vehicle
MB (person): Unburied victims
MBL (person): Unburied victims on board large vehicle
MBS (person): Unburied victims on board small vehicle
MC (person): Crashed victims
MCL (person): Crashed victims on board large vehicle
MCS (person): Crashed victims on board small vehicle
WAL (m): (In case of MAL is assumed) extent of road where MAL is assumed
WAS (m): (In case of MAS is assumed) extent of road where MAS is assumed
WBL (m): (In case of MAL is assumed) extent of road where MBL is assumed
WBS (m): (In case of MAS is assumed) extent of road where MBS is assumed
WC (m): extent of road where MC is assumed. WC equals to distance to stop. WCL=WCS
WDL (m): Extent of road on the center line buried by debris of VDL (m3)
WDS (m): Extent of road on the center line buried by debris of VDS (m3)
HR (m): (In case rock fall) diameter of rock or average of it when rock is nonspherical.
HL (m): Height of large vehicle
HS (m): Height of small vehicle
H0 (m): (In case landslide) height of debris on the centerline of road
H1 (m): Height of debris at hill side road shoulder
HDL (m): Height of debris at hill side road shoulder of VDL (m3)
HDS (m): Height of debris at hill side road shoulder of VDS (m3)
I (INR/person): Value of life

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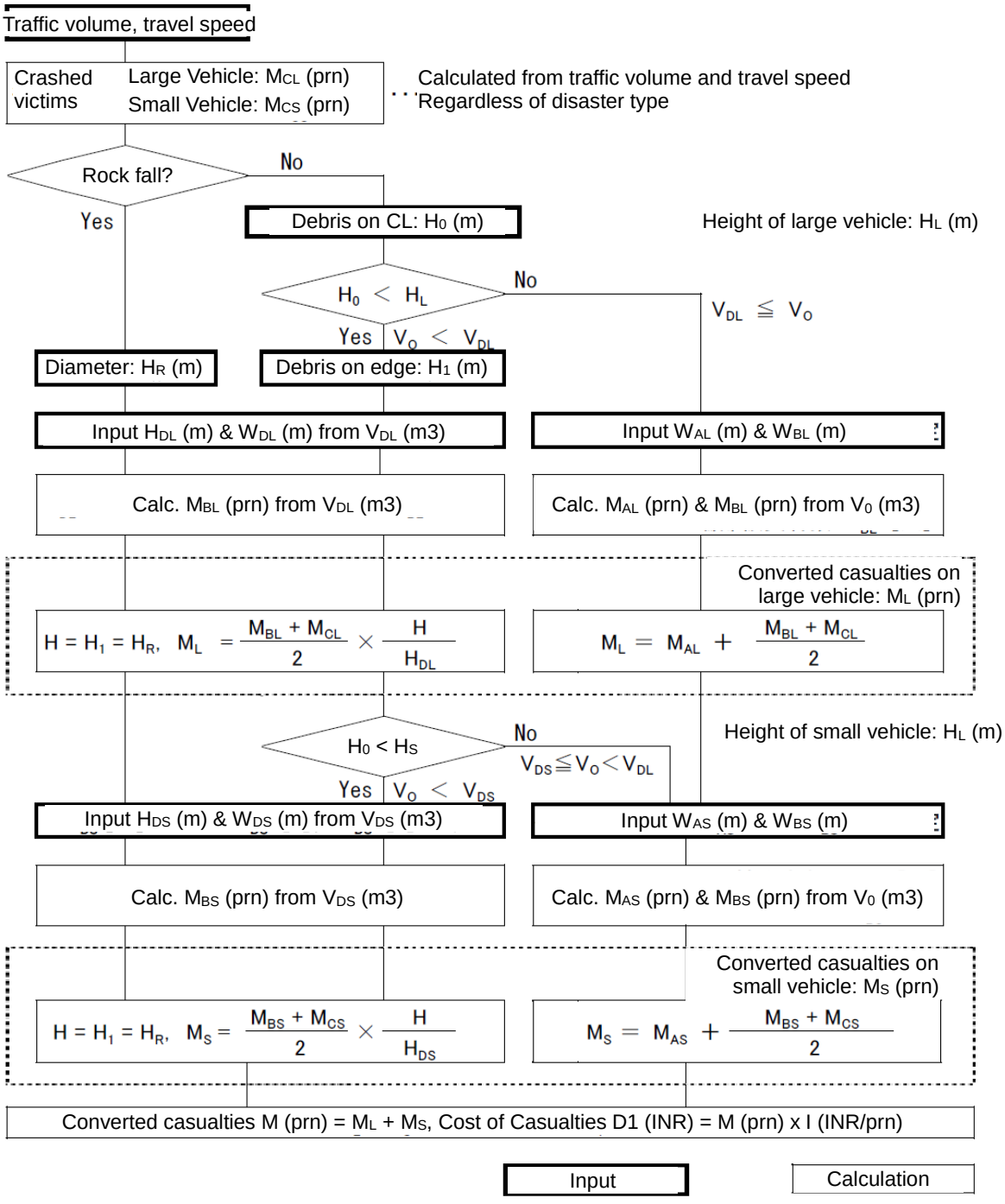


Figure 2-23 Process of Assessment of Cost of Casualties

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(iii) Formulas for Assessment of Number of Casualties

(1) In case A) buried victims are assumed, a number of buried victims M_A (person) is calculated from the formulas below, as a total of M_{AL} for large and M_{AS} for small vehicles:

$$M_{AL}=\{TV_L / (1000 \times VS)\} \times PB_L \times W_{AL} \quad \text{F 2-1}$$
$$M_{AS}=\{TV_S / (1000 \times VS)\} \times PB_S \times W_{AS} \quad \text{F 2-2}$$

Where TV_L: traffic volume of large vehicles per hour (vehicles/hour)
TV_S: traffic volume of small vehicles per hour (vehicles/hour)
VS: vehicle speed (km/hour)
PB_L: average onboard person of large vehicles (person)
PB_S: average onboard person of small vehicles (person)

(2) A number of B) unburied victims M_B (person) is calculated from the formulas below, as a total of M_{BL} for large and M_{BS} for small vehicles:

a) Where A) buried victims are assumed,

$$M_{BL}=\{TV_L / (1000 \times VS)\} \times PB_L \times W_{BL} \quad \text{F 2-3}$$
$$M_{BS}=\{TV_S / (1000 \times VS)\} \times PB_S \times W_{BS} \quad \text{F 2-4}$$

b) Where A) buried victims are not assumed,

$$M_{BL}=\{TV_L / (1000 \times VS)\} \times PB_L \times W_{DL} \quad \text{F 2-5}$$
$$M_{BS}=\{TV_S / (1000 \times VS)\} \times PB_S \times W_{DS} \quad \text{F 2-6}$$

(3) A number of C) crashed victims M_C (person) is calculated from the formulas below, as a total of M_{CL} for large and M_{CS} for small vehicles:

$$M_{CL}=\{TV_L / (1000 \times VS)\} \times PB_L \times W_C \quad \text{F 2-7}$$
$$M_{CS}=\{TV_S / (1000 \times VS)\} \times PB_S \times W_C \quad \text{F 2-8}$$

(iv) Extent of Affected Road

Extent of affected road shall be assumed based on the volume of debris to be reached to the road.

Case (a) $V_{DL} < V_0$, where large vehicle is buried,
Case (b) $V_{DS} <= V_0 < V_{DL}$, where small vehicle is buried but large is not, and
Case (c) $V_0 < V_{DS}$, where even small vehicle is not buried or case of rock fall.

Table 2-18 Extent of Affected Road

Case		(a)	(b)	(c)
Extent of affected road	W_{DL} (m)	N/A	Need to set	Need to set
	W_{DS} (m)	N/A	N/A	Need to set
	W_{AL} (m)	Need to set	0	0
	W_{AS} (m)	Need to set	Need to set	0
	W_{BL} (m)	Need to set	N/A	N/A
	W_{BS} (m)	Need to set	Need to set	N/A
	W_{CL} (m)	Distance to stop: $W_{CL} = W_{CS}$		
	W_{CS} (m)			

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For the mode of damage with A) buried victims, the extent where large vehicle is buried is W_{AL} and that for small is W_{AS}. The extent where large vehicle is affected but unburied is W_{BL} and that for small is W_{BS}.

For the mode of damage where A) buried victims are not assumed, the extent to be affected is represented by W_{DL} and W_{DS} based on V_{DL} and V_{DS}, respectively.

Excluding rock slide or large group of rock falls which totally demolishes or buries vehicles, rock fall shall be considered as the latter mode.

The extent relating to C) crashed victims is the distance to stop the vehicle and thus shall be constant regardless of the mode of damage.

(v) Assessment of Converted Casualties and Cost of Damage

The converted casualties (M (person) are calculated from the formula below.

In case A) buried victims are not assumed, M shall depends on the height of debris at hill side road shoulder (H_1 (m)) or the diameter of fallen rock (H_R (m)).

$$M\ (\text{person}) = M_L + M_S$$

$$H = H_1 = H_R\ (\text{m})$$

$$M_L = M_{AL} + (M_{BL} + M_{CL}) / 2 \qquad (V_{DL} <= V_0)$$

or

$$M_L = \{(M_{BL} + M_{CL}) / 2\} \times (H / H_{DL}) \qquad (V_0 < V_{DL}) \qquad \text{F 2-9}$$

$$M_S = M_{AS} + (M_{BS} + M_{CS}) / 2 \qquad (V_{DS} <= V_0)$$

or

$$M_S = \{(M_{BS} + M_{CS}) / 2\} \times (H / H_{DS}) \qquad (V_0 < V_{DS}) \qquad \text{F 2-10}$$

Cost of Damage (D_1 (INR)) is assessed with M (person) and value of life (I (INR/person))

$$D_1 = M \times I \qquad \text{F 2-11}$$

(2) Cost of Road Recovery

(i) Basic Idea of Assessment

Cost of recovery (D_2 (INR)) is composed of the cost to be required to reopen the road, including the works for recovery as well as works for removal and transportation of the debris which reached to the road, but excluding the cost for the works which prevent reoccurrence of the landslide.

(ii) Assessment Method

Necessary data for the assessment are as follows:

(i) Volume of debris which reached to the road (and is to be removed) (V_0 (m^3)),
(ii) Unit cost for the works involved
(iii) Depreciation cost of the machineries

(ii) and (iii) may be listed in Schedule of Rate (SOR) of concerned circle of State's Public Works Department or MoRTH Standard Data Book

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Based on the (i) volume of debris, in case methods of removal and transportation of debris are assumed, cost of recovery (D_2) is estimated by accumulating the cost of the works assumed.

(*Reference) In case methods are not assumed, cost of recovery (D_2) is estimated referring past records of recovery works. In Japan, based on the past records, the following formula is used for the estimation:*

$$D_2 \text{ (1,000JPY)} = 9.6246 \times V_0 + 1361.1 \qquad \text{F 2-12}$$

(iii) Days of Recover

When estimating cost of recovery (D_2 (INR)), it is required to estimate the days of recover (T), which is the basis of estimating the cost of detour (D_3 (INR)). The days of recover (T) is calculated by dividing V_0 by the rate of removal of debris per day.

(3) Cost of Detour

(i) Basic Idea of Assessment

Cost of detour (D_3 (INR)) is an additional cost borne by road users due to a detour caused by a road closure and assessed from a difference between generalized costs of normal and detour multiplied by the days of recover (T).

(ii) Assessment Method

Cost of detour (D_3) is assessed through the following procedure:

(i) To estimate the days of recover (T),
(ii) To select the detour route,
(iii) To estimate generalized costs (C (INR/vehicle)) of normal and detour for each vehicle type,
(iv) To assess cost of detour for each vehicle type per day(D_3'), and
(v) To assess (D_3) by summarizing (D_3') and multiplying by the days of recover (T).

(iii) Selection of Detour

A detour shall be selected from the roads of which grade is equal to or more than that of the targeted section where road closure is assumed. In selecting a detour, the roads which may be closed by the same reasons with the targeted section shall be eliminated.

(iv) Generalized Cost

Generalized cost (C (INR/vehicle)) shall be calculated with the formula below:

$$C \text{ (INR/vehicle)} = TT \times \alpha + TD \times \beta \qquad \text{F 2-13}$$

Where TT: travel time (minutes), for normal and detour
TD: travel time (km), for normal and detour
α: travel time unit cost (INR/vehicle·minutes)
ß: vehicle operation unit cost (INR/vehicle·km)

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Generalized cost shall be estimated for both normal and detour for each vehicle type.

(v) Cost of Detour

Cost of detour for each vehicle type per day (D_3') is assessed with the formula below:

$$D_3\text{' (INR/day)} = Q_0 \times (C_1 - C_0) \qquad \text{F 2-14}$$

Where Q_0: traffic volume of normal (vehicle/day)
C_0: generalized cost for normal (INR/vehicle)
C_1: generalized cost for detour (INR/vehicle)

Cost of detour (D3 (INR)) is total of D3' for all vehicle type multiplied by the days of recover (T).

$$D_3\text{' (INR)} = T \times (\text{total of } D_3\text{' for all vehicle type}) \qquad \text{F 2-15}$$

2.4.4 Triggers of Landslides

Heavy rains of monsoon seasons cause landslides every year in India. Earthquakes also cause landslides when it provides strong quakes enough to initiate a landslide. Thus rainfall and earthquake data are factors of prioritization.

As for the rainfall, precipitation data are available at India Meteorological Department (IMD) and based on precipitation, priorities are given to certain areas along a hill road. If it were disaster records related to rainfall data prioritization by rainfall would be more reliable.

As for earthquake, a seismic zoning map is available in Figure 3.10 of IRC 75-2015.

Both factors shall be evaluated in scores so that overall evaluation can be explained clearly.

2.4.5 Strategic Importance

Strategic importance, especially in the country defense, shall be highly prioritized. The hill roads which constitute communications to the important border posts or ensure swift move of the troops shall have higher priority.

Other factors to give this weighting are economically important corridor and access to religious sites important to the nationals.

Strategic importance shall be given as scores so that overall evaluation can be explained clearly.

2.4.6 Overall Evaluation

Overall evaluation is made through a tabulated explanation, such as shown in Table 2-19.

Firstly the column for stability of slope shall be filled and scored depending on the evaluation of stability.

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Then the column for cost of damage is filled with cost and then scored depending on the cost. In the example of Table 2-19, cost of damage was assessed only for the slopes which need countermeasures or monitoring in the evaluation of stability.

The column for triggers is filled based on the rainfall information and seismic zoning which may be a similar value for a certain section.

The column for strategic importance is also filled and then scored.

For the scoring of each factor, simple tables for deciding scores may be helpful.

(Note: such tables shall be revised flexibly based on the results of actual operation.)

At the last, overall evaluation is made based on the total scores of each factor for the slopes which need countermeasures or monitoring in the evaluation of stability. The slope with the highest score shall be the 1st priority and then the slopes are prioritized based on the scores.

Table 2-19 Overall Evaluation of Priority of Slopes

NH#	Slope #	Stability		Cost of Damage		Triggers			Strategic Importance		Overall Evaluation	
		Counter-measure	Score	INR Cr.	Score	Annual Rainfall (mm)	Earth-quake	Score	Description	Score	Score	Priority
NH XXX	XX1	*Not Necessary*	**0**	*N/A*	**N/A**	*3,000*	*Zone IV*	**100**	*N/A*	**0**	**N/A**	N/A
	XX2	*Monitoring*	**30**	*5*	**100**	*3,000*	*Zone IV*	**100**	*N/A*	**0**	**230**	75
	XX3	*Necessary*	**100**	*15*	**300**	*4,000*	*Zone IV*	**150**	*Important for logistics*	**200**	**750**	1
	XX4	*Monitoring*	**30**	*3*	**50**	*4,000*	*Zone IV*	**150**	*Important for logistics*	**200**	**430**	33
	XX5	*Necessary*	**100**	*10*	**200**	*3,000*	*Zone IV*	**100**	*Important for logistics*	**200**	**600**	15
	XX6	*Not Necessary*	**0**	*N/A*	**N/A**	*3,000*	*Zone IV*	**100**	*Important for logistics*	**200**	**N/A**	N/A
	.	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.	.

Source: JICA Project Team

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2.5 Physical Countermeasures and Early Warning System (EWS)

2.5.1 General

Early warning system (EWS) is to issue warnings to road users and residents in the aim of minimizing human loss or injury, based on monitoring of rainfall, expansion of crack, or inclination of the slope. Based on the information from EWS, road administrators may physically close the roads in danger with gates and traffic police and/or advertise warnings through traffic information boards, sign boards, and radio broadcasting.

On the other hand, physical countermeasures are structures and facilities as well as modifications of landform by civil works.

Both are treatment of slope hazards with different ranges of effect and cost. The prioritization discussed in the previous chapter helps road authorities in deciding which types of treatment should be adopted against hazards along hill roads. The option of no treatment will not cost the authorities any expenses in the initial stage of construction or improvement of hill roads, but human and goods damage on transport and cost of recovery are claimed when slope disasters occur at dangerous slopes.

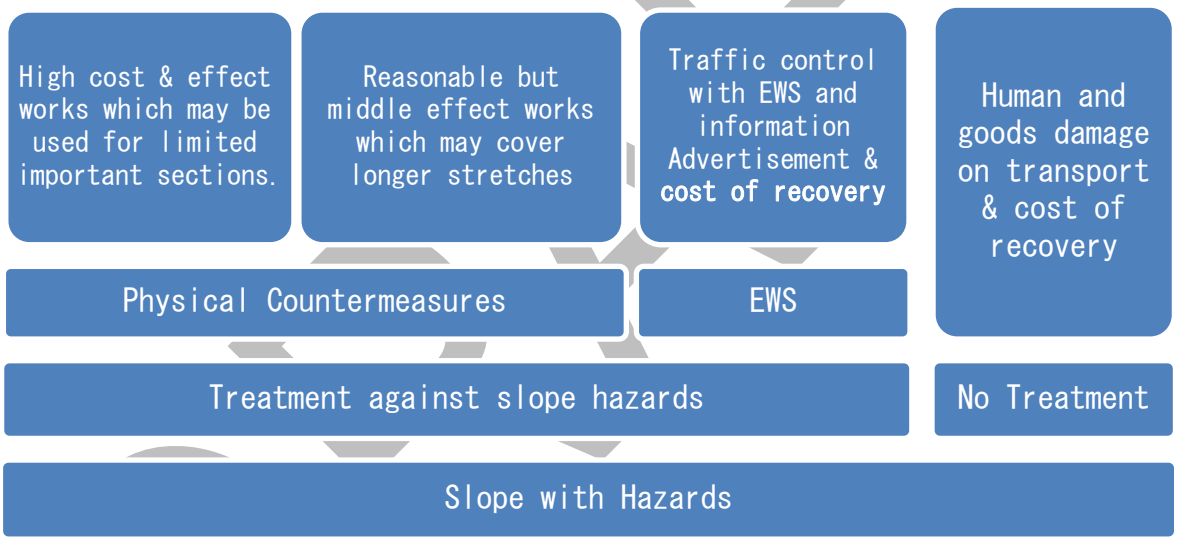


Figure 2-24 Types of treatment against slope with hazards

Source: JICA Project Team

2.5.2 Advantage and Disadvantage of Physical Countermeasures and EWS

The advantage and disadvantage of physical countermeasures and EWS can be summarized to the relation between cost and effects, as explained in Table 2-20.

Physical countermeasures claim certain amount of initial cost for construction but minimize or eliminate the damage of road users and goods on transport as well as cost of recovery by preventing or mitigating landslides. The higher cost may deter application of physical countermeasures for longer stretch of hill roads. But it should be applied to important sections of hill roads where constantly traffic is disturbed or road is damaged by landslides.

EWS may claim less initial cost for installation. It prevents or minimizes the damage of road users and goods on transport but cost of recovery from landslide, such as removing debris and reconstructing structures/facilities of hill roads, is required once landslides occur. Its reasonable cost may facilitate installation of EWS for long stretch of

hill roads. But it should be noted that EWS will not physically prevent landslides; EWS provides information to road administrators to save lives of road users and to secure safety of road transportation.

On the other hand, physical countermeasures and EWS can be used in combination. EWS can cover long stretch of hill roads with certain hazards and physical countermeasures can be installed for the most critical sections in such stretch.

Table 2-20 Cost and Effects of Physical countermeasures and EWS

Treatment against slope hazards			
Physical Works High cost & effect To minimize damage to road users as well as road blockade and cost of recovery by disaster.	Physical Works Reasonable but middle effect To minimize damage to road users by disaster. But road blockade or cost of recovery might occur.	EWS To minimize damage to road users by disaster. But road blockade and cost of recovery inevitably occur .	No treatment Damage to road users as well as road blockade and cost of recovery by disaster inevitably occur.

Source: JICA Project Team

2.5.3 Details of EWS

Since EWS is one part of operation of hill roads, the details of EWS are discussed in Chapter 3 of the guideline for operation & maintenance.

Basically, EWS is composed of two major parts, devices for monitoring natural conditions and system for analyzing data and issuing warnings.

Rainfall is the most basic target of monitoring for EWS. Rain gauges are essential device to observe rainfall. For important highways/expressways, weather radars are incorporated in EWS for the purpose of estimating imminent massive rainfalls which may hamper or obstruct the traffic. Other monitoring devices may compose EWS depending on the condition of hazards. Groundwater level gauge and extensometer are used for EWS against landslide. The use of multiple inclinometers placed on slope is now being tested in Japan.

Each monitoring device should be connected with analysis system which issues warnings. Wireless connection is dominantly used for such purpose.

In addition, analysis system should have reliable criteria for issuing waring, which requires substantial accumulation of data relating to natural condition and disaster occurrence.

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2.6 Design of Countermeasures / Mitigation with Advanced Technology

The main countermeasures against landslides are classified into seven categories in terms of their functions and purposes, as listed in Table 2-21. In this section, from the works in Table 2-21, the types of the works that are considered to be frequently used for hill roads are described.

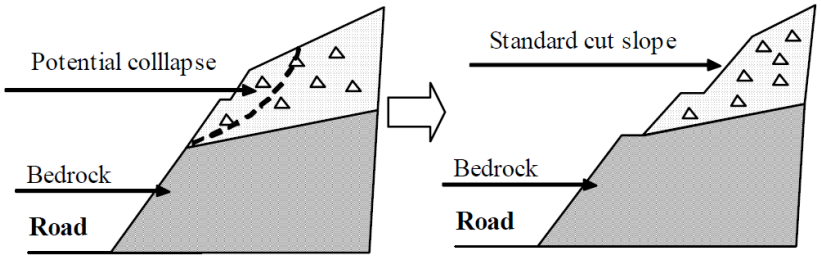
Table 2-21 Classification of countermeasures against landslides

CLASSIFICATION		TYPE OF WORK
1. EARTH WORK	Earth Work	Cutting and Recutting
		Filling and Refilling
2. VEGETATION	Vegetation	Hydroseeding
		Vegetation
3. DRAINAGE	Surface Drainage	Drainage Ditches and Channels
	Subsurface Drainage	Culverts
		Horizontal Drain Holes
		Drainage Wells
4. SLOPE WORK	Pitching Work	Stone Pitching
	Shotcrete Work	Shotcrete (mortar and concrete)
	Crib Work	Crib Work (Precast)
5. ANCHORING	Anchoring	Rock Bolts with Concrete Crib Work
		Ground Anchors
6. WALL AND RESISTING STRUCTURES	Retaining Walls	Gabion Walls
		Stone and Concrete Block Masonry Walls
		Concrete Retaining Walls
	Catch Work	Catch Walls and Catch Embankments
7. PILING WORK	Piling Work	Steel Pipe Piles
		Concrete Piles

[14]

Considerations include the anticipated causes, shape, mechanism, and size of the collapse, as well as the appearance of the structure. Drainage works, especially surface drainage works, shall be given priority regardless of the results of the stability analyses. Generally, the following criteria shall be used for the selection:

a) Wherever possible, cutting or re-cutting works are preferred. In planning cutting works, slope stability and harmony with the surrounding environment should be considered (Figure 2-25);



a) Instable cutting slope **b) Re-cutting slope**

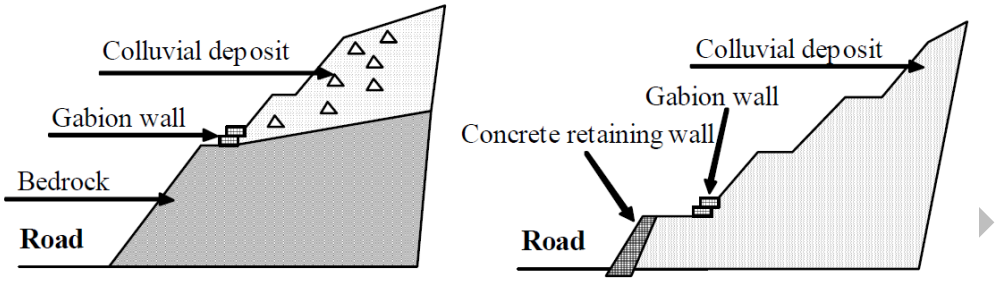
Figure 2-25 Schematic Diagrams for Re-cutting Slope

[14]

b) In principle, surface drainage is considered positively. Subsurface drainage is adopted if spring water exists during normal times and/or rainfall, or a depression exists near the top of the slope;

c) Whenever the slope gradient and soil conditions will allow vegetation to grow, it shall be used to prevent erosion due to rainfall. Where slopes are unsuited to vegetation, pitching works, shotcrete works, and crib works shall be considered;

d) Retaining walls are selected if the foot of a slope must be stabilized or if it is to be used as the foundation for other measures (Figure 2-26);



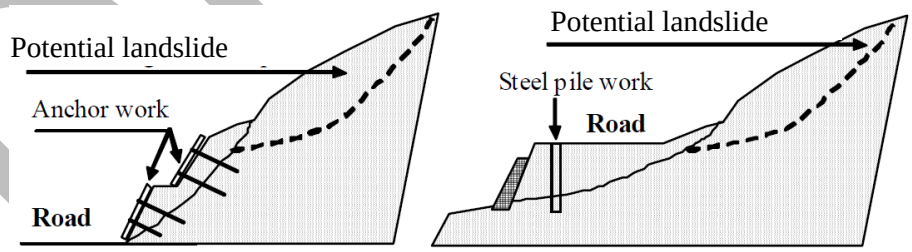
a) Slope foot protection by gabion wall **b) Slope foot protection by retaining wall**

Figure 2-26 Schematic Diagram of Slope Foot Protection

[14]

e) Even though costly, anchoring or piling should be planned if other methods are not expected to control landslide (Figure 2-27);

f) When a potential landslide is large, avoiding the unstable area by using an alternate route or by the construction of a bridge or similar structure shall be considered.



a) Slope stabilization by anchor **b) Slope stabilization by pile**

Figure 2-27 Schematic Diagrams of Anchor and Pile Works

[14]

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2.6.1 Design methods for Pile and Shaft Works

In this section, important points in design of pile and shaft works are described.

Figure 2-28 shows a selection sequence for prevention works to be applied to gravity deformation and landslides.

As mentioned in Chapter 2.3, for large-scale slope deformation, control works such as earth removal / buttress fill works and groundwater drainage works should be incorporated into the design as much as possible. Prevention works should be adopted to fulfil the gap between design factor of safety and achieved factor of safety by the control works.

Large-scale slope deformation to be stabilized by the prevention works are mainly gravity deformation and landslides. The distinctive difference between gravity deformation and landslide is the gradient of slip surface. As shown in Figure 2-28, in case the gradient of slip surface exceeds 30 degrees, it may be recognized as gravity deformation, where creep deformation occurs in loosened zone of rock. On the other hand, landslides are characterized by slip surface of around 10 degrees in gradient, where resisting force is controlled by residual strength of landslide clay along the slip surface.

The design concepts of pile works are largely different between gravity deformation and landslide. For gravity deformation, only cantilever pile, such as large-diameter steel pipe pile and shaft work, can be used whereas cotter and shearing piles are used for landslide.

The important point in the selection sequence for prevention works in Figure 2-28 is that pile works and ground anchor works are not used in combination; either pile works or ground anchor works should be selected. This is because ground anchor works assume no displacement of land mass, whereas pile works assume slight displacement of land mass to which resistance force of piles acts.

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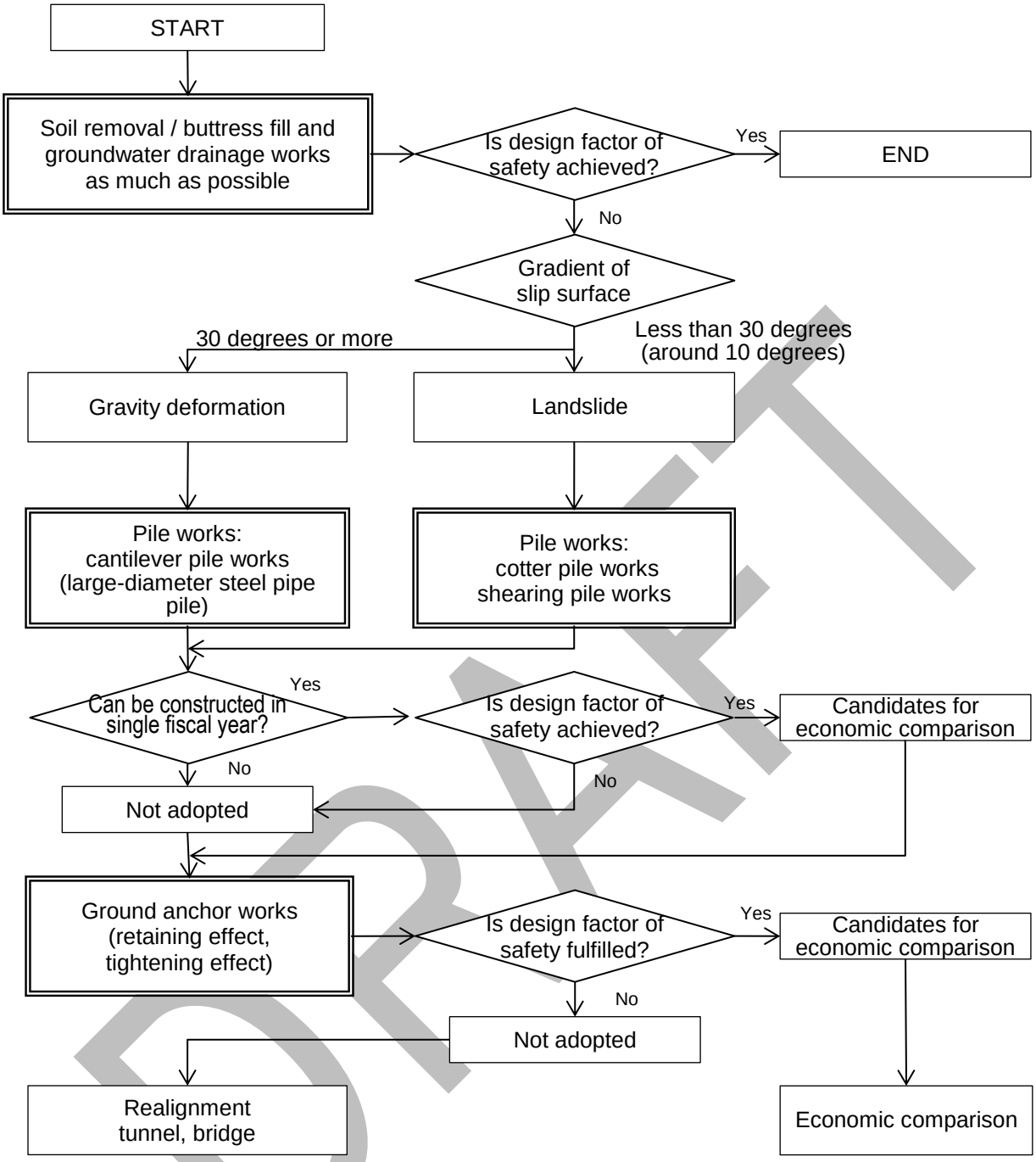


Figure 2-28 Selection Sequence Prevention Works against Large Slope Deformation

Source: JICA Project Team

(1) Steel Pipe Piles

Similar to ground anchor, steel pipe piles are costly but reliable. The work is especially recommended when the ground below the sliding surface is firm and has sufficient resistance against landslide mass. Moreover, steel pipe piles are generally used when the slope of a landslide area or sliding surface is relatively gentle or a landslide has a large scale.

Steel pipe pile systems are classified, in terms of its effect, into shearing piles — by using the shearing strength of the piles, and bending piles — by using the bending and shearing effect of piles. Steel pipe piles generally have smaller bending

strengths than shearing strengths and should therefore be installed in positions subject to small bending forces.

Moreover, bending piles can be conveniently subdivided into cantilever piles and cotter piles based on the positions of the piles in relationship to the landslide block. The former is constructed in the tensile zones of a landslide block and the subgrade reaction force of the sliding mass behind the pile is ignored; therefore the pile is considered to be a cantilever beam. Whereas the latter is constructed in the compressive zones of a landslide block with a large subgrade reaction behind the pile and it functions as cotter pin to keep the sliding mass and the stable ground below the sliding surface together, as shown in Figure 2-29.

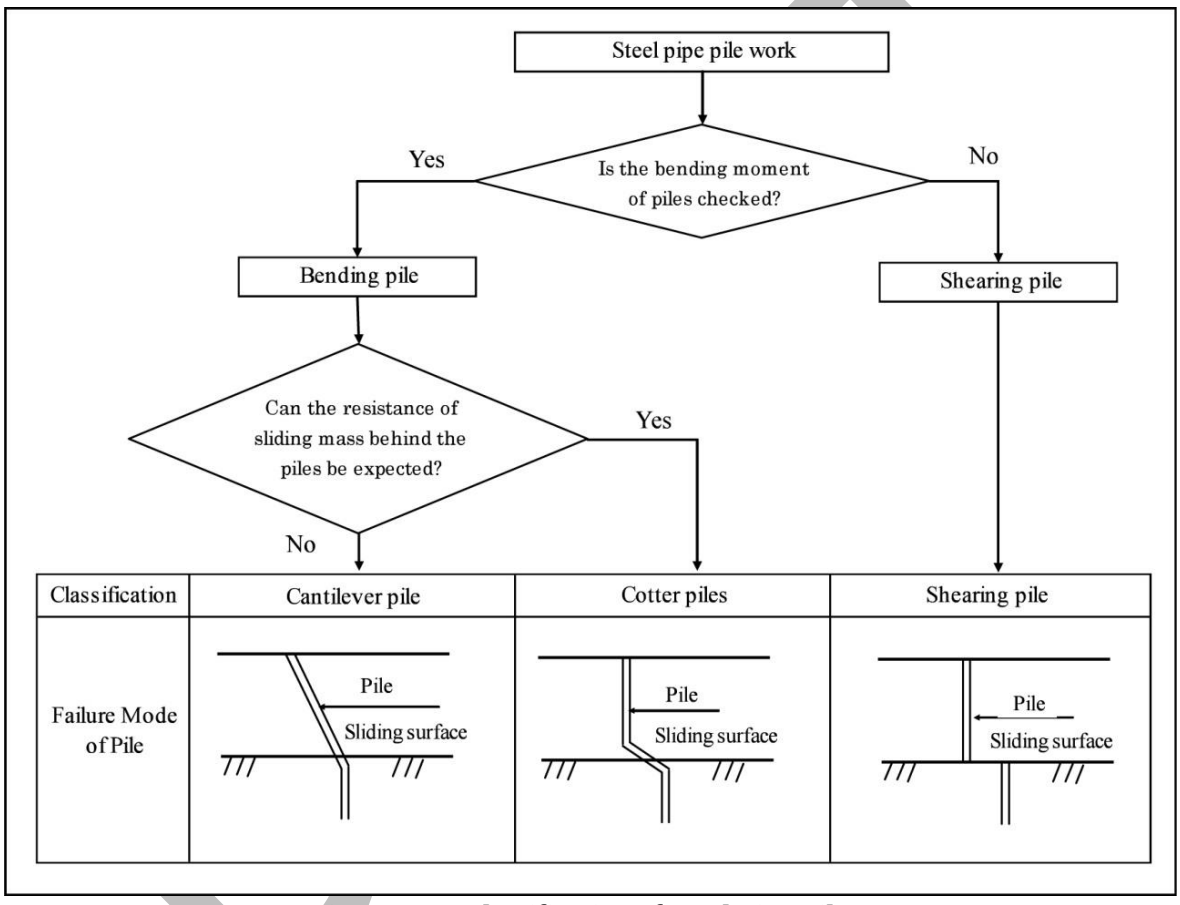


Figure 2-29 Classification of Steel Pipe Piles

[14]

(i) Purposes

Steel pipe piles are intended to prevent landslides with a doweling effect between the landslide mass and stable ground by applying the shear strength and bending resistance of the steel piles.

(ii) Design Considerations

i) Items to be examined

In designing pile systems, the items to be examined are summarized in Table 2-22. Moreover, the piles must be placed close enough together to prevent segments of the soil from sliding in the space between the piles.

Table 2-22 Recommended Allowable Adhesive Stresses

Pile Type	Items				
	Shear force	Moment	Deflection	Passive failure	Horizontal resistance
Bending pile	1	1	3	1	1
Shearing piles	1	2	2	1	2

Notes: 1=must be evaluated, 2=no need to be evaluated, 3=be evaluated only where the displacement of the pile head has an effect on the facilities surrounding the pile.

[15].

ii) Design procedure

Figure 2-30 shows the design flowchart for steel pipe piles. Important considerations for the works include 1) design method, 2) the preventive force of a pile, 3) pile intervals, 4) pile material and 5) pile length. It should be noted that piles are installed at the lower portion of a landslide area in an appropriate position so that passive earth breakdown will not induce a landslide at the top end of a sliding surface.

iii) Selection of design method

The design method for piles is based on the distribution of inner horizontal resistance behind the piles and the location of pile installation, as shown in Table 2-23. Shearing piles are installed in a position where there is sufficient subgrade reaction at the back of piles. Empirically, when piles are installed in a position defined by PS > R, the bending piles will be considered as cantilever piles, otherwise, as cotter piles.

Table 2-23 Design Conditions for Piles

Pile Type	Design Criteria	Conditions
Cantilever pile	$R < P_S$	**- Taking no account of horizontal resistance behind the pile**
Cotter pile	$P_R \leqq R$	**- Taking account of horizontal resistance behind the pile**
	$0.7P_S < R \leqq P_S$	**- Considering the decrease in the deformation coefficient of the sliding mass**
Shearing pile	$P_S \leqq R$	**- Just checking the shear force of piles**

Notes: P_S = Sliding force, R = Inner horizontal resistant force of sliding mass.

[15]

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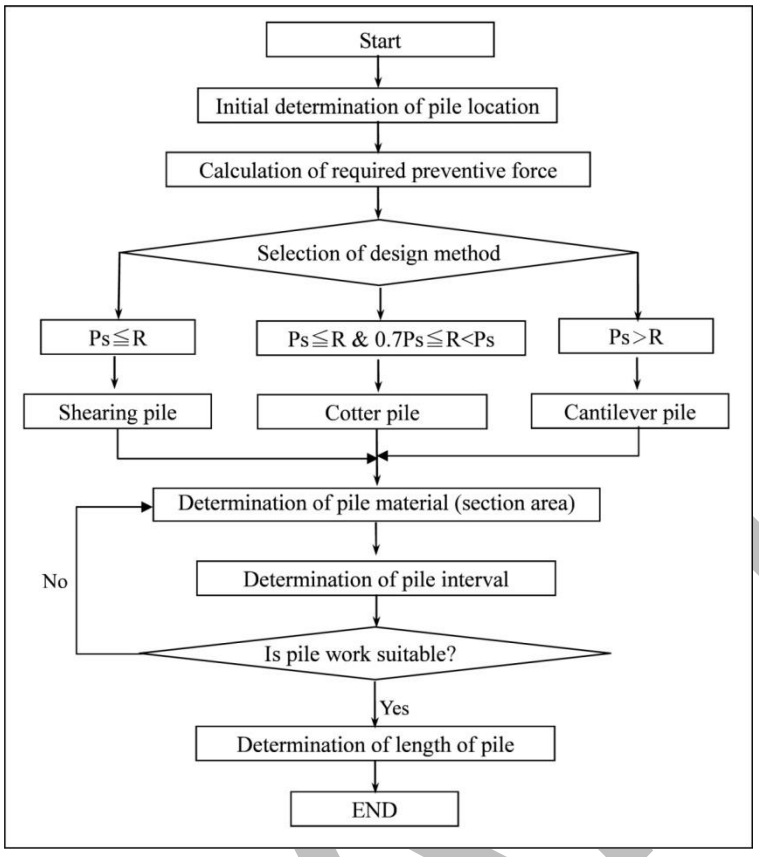


Figure 2-30 Determination of length of pile

[14]

iv) Calculation of design pile power

The additional shear strength required to satisfy the proposed safety factor for piling works is calculated from Equation 2-1.

$$P_R = PF_s \times \sum T - \sum (N - U) \tan \emptyset - C \times \sum L \quad \cdots\cdots\cdots\

$$\beta = \sqrt[4]{\frac{K_h \times d}{4 \times EI}} \quad \cdots\cdots \textbf{(2-4)}$$

Where,

K_h (N/cm^3) = Coefficient of horizontal subgrade reaction of the ground
d (mm) = pile diameter
EI (Ncm^2) = Rigidity of steel pile to bending

vi) Determination of pile intervals

The distance, D, between the centers of the piles is determined in consideration of bending moment and shear stress of the piles by using the following equations:

$$\sigma = \frac{N_f}{A} \pm \frac{M}{Z} \leq \sigma_a \quad \cdots\cdots \textbf{(2-5)}$$

$$D \leq \frac{\sigma_a - \frac{N_{f1}}{A}}{\frac{N_{f2}}{A} + \frac{M_{\max}}{Z}} \quad \cdots\cdots \textbf{(2-6)}$$

$$\tau_{\max} = a_0 \frac{S}{A} \leq \tau_a \quad \cdots\cdots \textbf{(2-7)}$$

$$D \leq \frac{1}{a_0} \times \frac{\tau_a \times A}{S_{\max}} \quad \cdots\cdots \textbf{(2-8)}$$

Where,

σ (kN/m^2) = Bending stress on pile
σ_a (kN/m^2) =Allowable bending stress intensity of the steel pile
N_f (kN) = Axial force on piles
N_{f1} (kN) = Axial force on a pile
N_{f2} (kN) = Axial force on pile per unit width
A (m^2) = Cross-sectional area of steel material in pile
M (kN・m) = Bending moment on pile
Z (m^3) = Section modulus of steel material in pile
D (m) = Distance between centers of piles
τ (kN/m^2) = Shear stress on pile
τ_a (kN/m^2) = Allowable shear stress intensity of steel pile$S$
S (kN) = Shear force on pile
$S_{\max}$ (kN) = Maximum shear force on pile
a_0 = Coefficient, generally a_0 =2

Furthermore, some design manuals in Japan provide a general guideline for the interval between piles as follows:

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(a) Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.

To set generally at less than 2.0 meters

(b) MANUAL FOR RIVER WORKS IN JAPAN, Published by River Bureau, Ministry of Construction, November 1997.

To set in principle at 1.5 to 4.0 meters

(c) GUIDELINE FOR STEEL PIPE PILE DESIGN FOR LANDSLIDE CONTROL, Committee for the Survey of Design and Execution of Landslide Steel Pipe Pile, 1990.

Table 2-24 Standard Interval between Piles

Vertical Thickness of Sliding Mass (meters)	Interval Between Piles (meters)
Less than 10	2.0 or less
Between 10 and 20	3.0 or less
20 m or thicker	4.0 or less

[15]

In most cases in Japan, the interval between piles is set at about 2.0 m. The standard interval between piles is set at 2.0 m in principle based on the above-mentioned manuals.

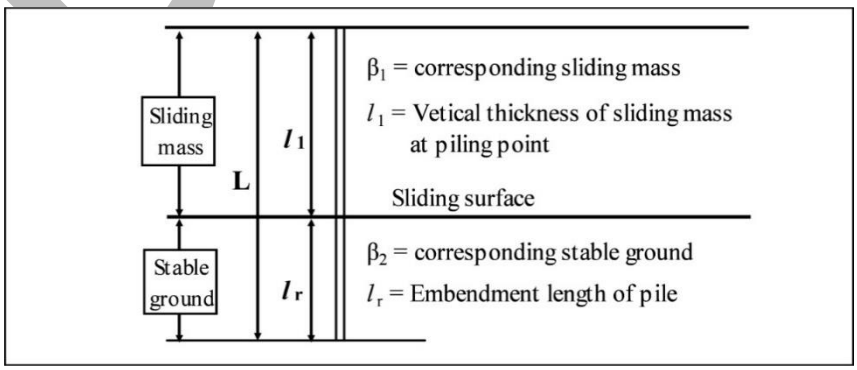
vii) Determination of pile length

The embedment length, l_r, of piles to be driven into the ground below the sliding surface is obtained according to the following table.

Table 2-25 Embedment Length of Piles

Pile Type	l_r (m)	Remarks
Cantilever pile	π/β_2	Generally, (1～1.5) π/β_2
Cotter pile	π/β_1	Generally, (1～1.5) π/β_1
Shearing pile	L/3	Ground below sliding surface is soft rock.
	L/4	Ground below sliding surface is hard rock.

Notes: Symbols in the above table are the same as those shown in the following figure.



[14]

(2) Shaft Works

(i) Purposes

When a scale of landslide is large and pile works are not sufficient to resist driving force, shaft works should be planned. Shaft works are also applied to the ground conditions where drilling for steel piles by a large-diameter boring machine is difficult to execute. In both cases, stable bearing layer for foundation of shaft works should be secured.

(ii) Design Considerations

For shaft works, a vertical shaft with a diameter of 3.0 to 6.5 meters should manually or mechanically be excavated to the stable bedrock with supports by liner plates or similar earth retaining supports. Then re-bar cages of D 32 to D 51 as main reinforcements are assembled in a cylindrical shape in the excavated vertical shaft and concrete is cast. In this way, large diameter columns of reinforced concrete are continuously formed.



(a) Assembling Re-bar Cage **(b) Casting Concrete**

Figure 2-31 Construction of Shaft Works

[16]

i) Design procedure

Figure 2-32 shows the design procedure for shaft works. As shaft works is large structure and construction cost is also expensive, before examining the selection sequence in Figure 2-32, it is required to confirm advantages of shaft works to other prevention pile works, including large-diametric steel pipe pile, thick steel pipe pile or steel pipe pile works with ground anchors, from viewpoints of economic efficiency, workability and safety.

ii) Selection of type of shaft works

For the design of shaft works, the type of shaft should be determined at first; rigid pile (caisson) or flexible pile.

Rigid pile (caisson) is considered to resist the load without deformation of the pile. Structural design is carried out assuming that the pile body is stabilized by the horizontal and vertical reaction forces of the ground (Figure 2-33 (a)).

Flexible pile is considered to resist the load by bending of the pile body. Even though the pile is made of rigid reinforced concrete, if it has a long columnar body, it can be slightly bended in the ground like a steel pipe. The pile works through

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transaction of force between the pile body and the surrounding ground, which is regarded as the elastic body, as shown in Figure 2-33 (b).

Selection of the type of shaft should be performed using the following formula for selection.

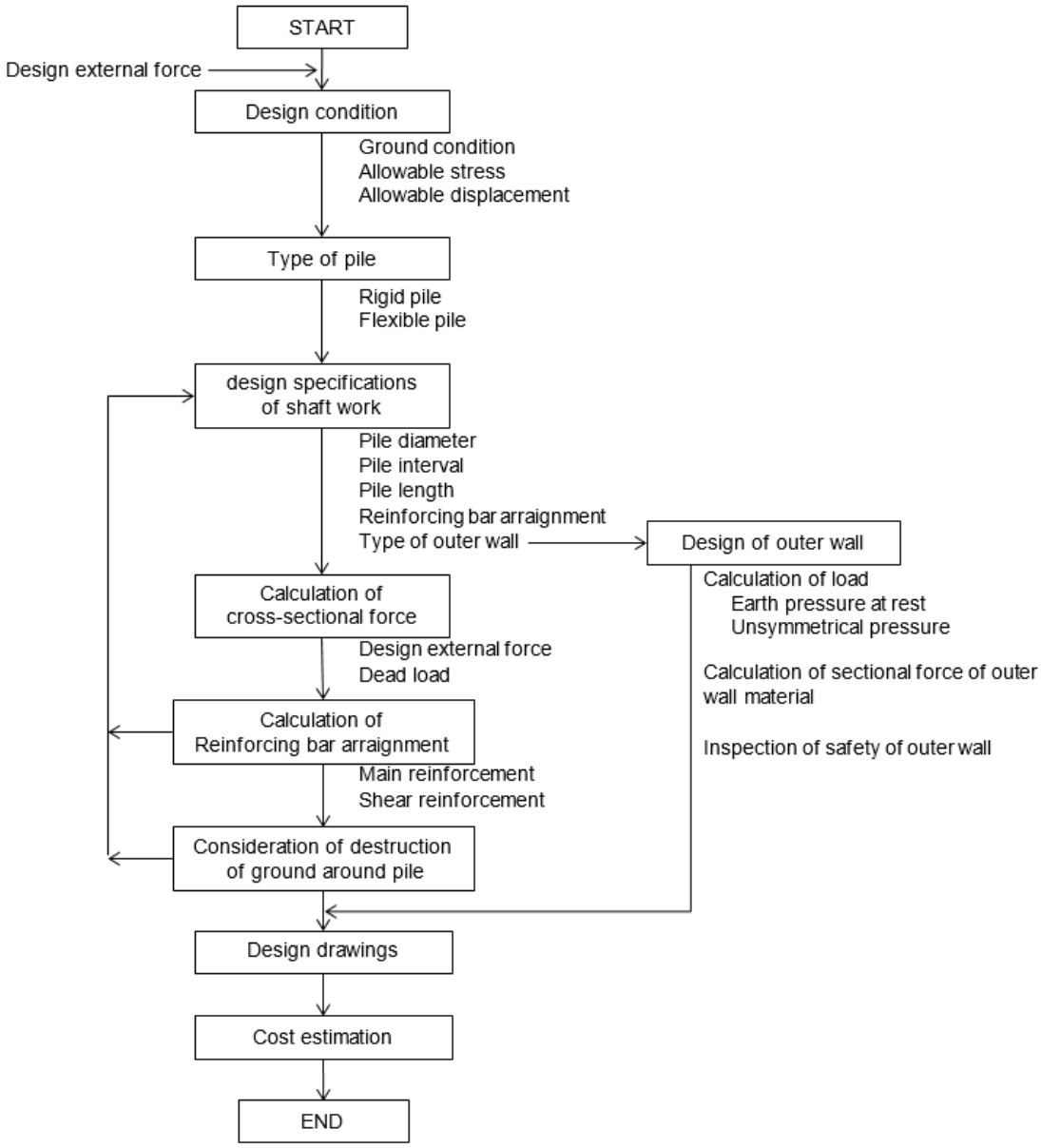
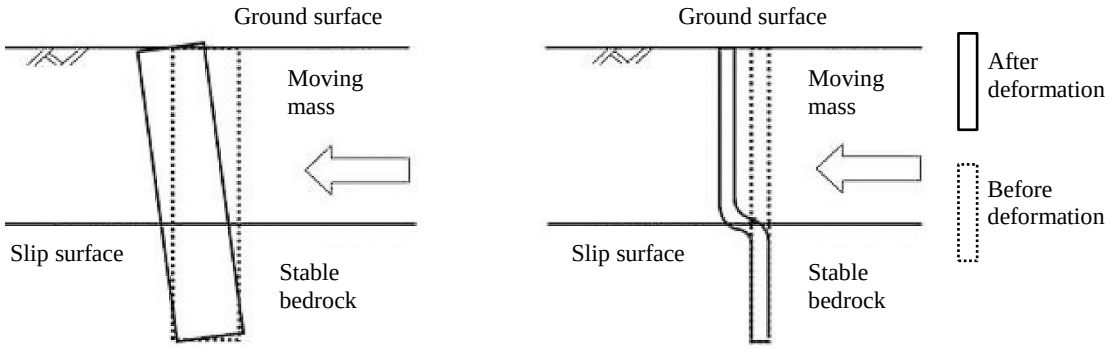


Figure 2-32 Sequence of Design for Shaft Work

[16]



(a) Rigid pile (b) Flexible pile

Figure 2-33 Image of Rigid and Flexible Piles

[16]

$$\beta = \sqrt[4]{\frac{K_h \times d}{4 \times EI}} \quad \cdots\cdots\cdots\

Pile diameter (d): 3.0 - 6.5 meters
Pile interval: 2d ~ 10 meters + d
Embedded depth of piles: 1/3·L (L: total length of pile)
Reinforcing bar arraignment: 2 rows to 4 rows radially
(Reinforcing bar interval, concrete cover, position and length of joint, and lateral ties (hoop and stirrup) shall be based on the general criteria)
Type of outer wall: liner plate, steel segment, or RC segment

However, if stability is ensured by structural calculation, the above listed specification does not have to be followed.

b)
Next, the cross-sectional force generated in the pile should be calculated. The cross-sectional force can be obtained by the same calculation method as the steel pipe pile. Selection of type of pile should also be in the same process （Table 2-23）. The calculation method of the cross-sectional force should be referred to the cross-section of the steel pipe pile.

c)
Calculation of reinforcing bar arrangement should be performed with the obtained cross-sectional force. The calculation of reinforcing bar arraignment should be performed with the general method for circular cross-section.

d)
Finally, the destruction of the ground around the pile (the embedment section) should be examined. When the ground stress is changed due to the deformation of the shaft, the ground may be yield and the restraint effect of the embedment section of the pile may be impaired. The confirmation of stability for embedment section of shaft works should be examined with the same method with steel pipe pile. Two-dimensional elastic FEM analysis may be used.

e)
If the stress and displacement obtained through these design calculations exceed the allowable stress and displacement of concrete, reinforcing bars, and the surrounding ground of the pile, the design specifications for the pile should be reconsidered and the process of design calculations should be repeated until allowable limits are ensured.

f)
At the same time, outer wall to resist to earth pressure should be designed. Calculations of stability should be conducted on the assumption that earth pressure at rest and unsymmetrical earth pressure act to the outer wall. Although the outer wall does not ultimately resist the force of the landslide, it is an important structure for securing the shape of the pile body and safety of workers during construction.

Difference with design of steel pile…

While cross section of a steel pile is determined by the degree of tensile stress, cross section of a shat is often determined by the degree of shear stress. In particular, shear stress of concrete often exceeds allowable limit near slip surface and reinforcement is required. As a method of shear reinforcement, additional reinforcing bars or H steel are arranged horizontally at the place where shearing plane or slip surface traverses a shaft. （Figure 2-34）.

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Figure 2-34 Main Re-bars for Outer Edge and Horizontal Shear Reinforcement

[18]

Section deformation…

In the design of shaft works of bridge foundation, the cross section of reinforcing bar arraignment often changes according to the distribution of bending moment from the viewpoints of economic efficiency. This policy can be adopted in the design of landslide prevention shafts only when depths of slip surfaces are surly specified. If depths of slip surfaces are uncertain, as a part of design of safer side, the maximum amount of reinforcing bars is often installed over the whole length.

[19]

Other points to consider…

The landslides which require shaft works are generally very large in scale and construction cost should also be very high. Thus design should be carefully done.

For the design of the shaft works, stability analysis should be performed not only on the main profile but on sub profiles passing through other pile locations, through which each cross-sectional structure is determined. In that case, piles with similar slip surface depth or pile length may be designed all together.

From the center to both flanks, thickness of landslide mass is getting thinner. So, even though the calculation condition of a semi-infinite length cotter pile is applicable on the main profile, the calculation conditions may not be applicable on the sub profiles. In such cases, it is desirable to consider as “a pile of finite length”.

[16]

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2.6.2 Introduction of design technologies for concrete crib works (concrete frame) and horizontal drainage boring

In this section, design of concrete crib works and horizontal drainage boring are explained, which are among the most useful and effective methods for cut slope protection.

Concrete crib works ate to secure long term stability of a cut slope where considerable risks are not assumed but concerns in long term stability lie. (For the slopes with considerable risks, which are worth to pay high cost to stabilize them, pile or ground anchor works may be adopted).

Horizontal drainage boring is an essential method to secure long term stability of cut slopes which requires slope protection.

(1) Crib Works

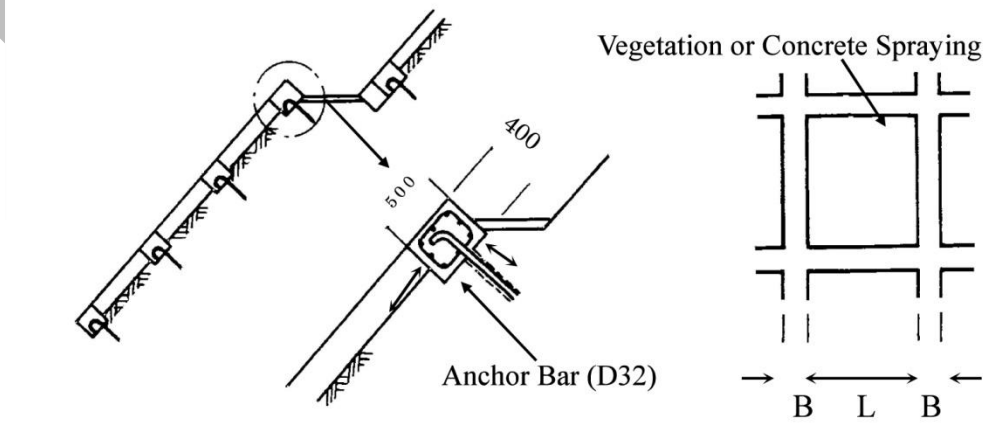
Crib works include concrete block cribs, shotcrete cribs and cast-in-place concrete crib works. These are commonly used on steep slopes of highly weathered or heavily jointed rocks with abundant springs, especially where spalls cannot be fixed with shotcrete works.

(i) Purposes

Crib works are chiefly applied to (a) prevent surface weathering, scouring and erosion, and in some cases, (b) control both rock fall and small-scale slope failure. Concrete block crib works offers little or no resisting force against the driving force of the unstable slopes, while shotcrete crib and cast-in-place concrete crib works have some resistance, depending on the size and space of the cribs.

(ii) Design considerations

Concrete block crib works are used for slopes with gradients less than 1H1V and when vegetation is suited to the slopes. Shotcrete crib and cast-in-place concrete crib works are used when the long-term stability of the slope is questionable, or when the slopes are likely to collapse on a large slope or on a slope of weathered and jointed rocks with spring water. The crib (or frame) usually ranges in size from 200 x 200 millimeters to 600 x 600 millimeters at intervals of 2 to 5 meters. The spaces inside the cribs are filled and protected by stone pitching, mortar spraying, or vegetation, depending on the slope conditions (gradient, spring water, etc.). Each intersection of the crib is anchored with stakes or anchor bars. Table 2-26 shows the applications of crib works. Figure 2-35 presents details of cast-in-place concrete crib works



Note: B=200 to 600mm, L=B×(5 to 10)

Figure 2-35 Details of Cast-in-place Concrete Crib Works

[1]

Table 2-26 Application of Crib Works

Type of crib works	Gradient (V:H)	Vertical height (m)	Condition of slope
Concrete block crib	**Less than 1:1.0**	**Less than 5 m**	**Flat slope with spring water and large slope of gradient below 1:0.8**
Shotcrete crib	**Over 1:0.8**	**Less than 10 m**	**Slope of gradient above 1:0.8 and weathered or jointed rocks where spring water is present or where the soil is lacking in long-term stability**
Cast-in-place concrete	**Over 1:0.8**	**Less than 10 m**	

Note: This table is only preliminary. Further detailed analysis is to be carried out by the engineer.

Edited from [3]

(2) Rock Bolts with Concrete Crib Works

Where other works cannot meet the degree of safety required for a road slope, rock bolts with concrete crib works are used. The method is generally planned to cope with a small, shallow surface collapse of about 3 to 5 m in thickness.

Rock bolts with concrete crib works are similar to ground anchors in terms of function and design considerations.

(i) Purposes

Rock bolts in association with concrete crib works are applied to stabilize a shallow surface collapse by exerting a force - the increased resisting power against shear force by the tension force of the rock bolts. The rock bolts with concrete crib works keep the overall slope together, consequently preventing local collapse.

(ii) Design considerations

Design considerations for rock bolts with concrete crib works include (i) Stability analysis and calculation of required preventive force; (ii) Design of the rock bolts; (iii) Design of the concrete crib; and (iv) Design of the bearing plates.

(i) Stability analysis and calculation of required preventive force

Stability analysis is conducted using the Swedish slice method. Parameters for the stability analysis are generally estimated on the basis of visual soil observations, as given in Table 2-27. In a unit width, the prevention force (Pr) required for stabilizing the potential local collapse is calculated using the following equation

$$P_R = PF_S \times \sum T - (\sum N \times \tan \emptyset + C \times \sum L) \cdots\cdots (2\text{-}10)$$

Where,

PR (kN/m) = Required preventive force
PFs = Proposed safety of factor
N (kN/m) = Normal force attributable to gravity of the slice, $N = W \cdot \cos \alpha$
T (kN/m) = Tangential force attributable to gravity of the slice, $T = W \cdot \sin \alpha$
U (kN/m) = Pore water pressure acting on the base of the slice
L (m) = Length of sliding (or collapse) surface acting on the slice
C (kN/m^2) = Cohesion of sliding (or collapse) surface
Φ (degree) = Internal friction angle of sliding (or collapse) surface

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Table 2-27 Recommended Internal Friction Angle and Cohesion

Material	State	Unit Weight (kN/m^3)	Internal friction angle (Degrees)	Cohesion (kN/m^2)	Group symbol 1)
Gravel	Dense or well graded	20	40	-	GW,GP
	Not dense or poorly graded	18	35	-	
Gravely sand	Dense	21	40	-	GW,GP
	Not dense	19	35	-	
Sand	Dense or well graded	20	35	-	SW, SP
	Not dense or poorly graded	18	30	-	
Sandy soil	Dense	19	30	-	SM, SC
	Not dense	17	25	-	
Clayey soil	Firm	18	25	Less than 50	ML, CL
	Slightly soft	17	20	Less than 30	
	Soft	16	15	Less than 15	
Clay and silt	Firm	17	20	Less than 50	CH, MH,
	Slightly soft	16	15	Less than 30	
	Soft	14	10	Less than 15	

Note: l) Group symbols of the Unified Soil Classification System. 2) $1tf/m^3 = 10kN/m^3$, $1tf/m^2 = 10kN/m^2$
Edited from [20]

(ii) Design of rock bolts

The design tensile force (Td) for one rock bolt is calculated using the following equation:

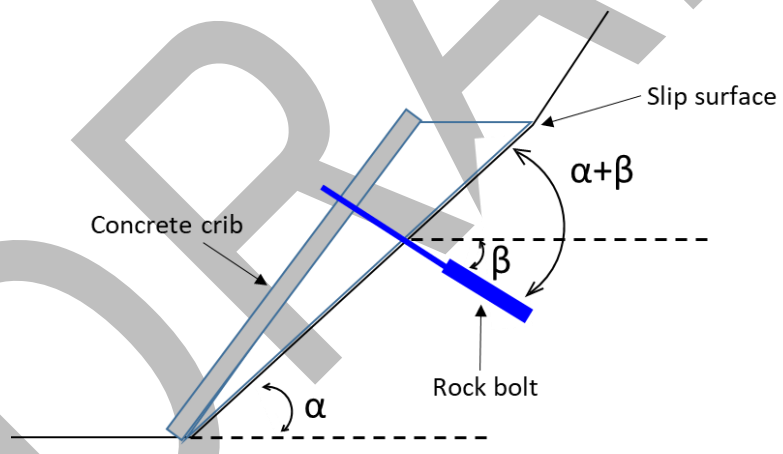


Figure 2-36 Model of Soil Slope Collapse and Arrangement of Rock Bolts

Source: JICA Project Team

$$Td = \frac{P_R}{(\sin(\alpha+\beta)\cdot\tan\emptyset+\cos(\alpha+\beta))\times\lambda}\cdot\frac{B}{N_1} \quad \cdots\cdots (2\text{-}11)$$

Where,

P_R (kN/m^2) = Required preventive force
α (degrees) = Angle of slip surface
β (degrees) = Angle of rock bolt installation
Φ (degrees) = Internal frictional angle of collapse surface
B (m) = Interval between rock bolts in horizontal direction
N_1 = Number of steps for rock bolt installation
λ = Reduction factor of tension force of rock bolt (=0.7)

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The tensile stress (q) required against the tensile force of the rock bolt is calculated using the following formula:

$$\sigma_s = \frac{Td}{As} < \sigma_{sa} \quad \cdots\cdots (2\text{-}12)$$

Where,

As (cm^2) = Section area of steel material.

σ_{sa} (kN/m^2)= Allowable limit of tension force of rock bolt

Table 2-28 Allowable Tensile Stress (σ_{sa}) of Rock Bolt Material (Unit: N/mm^2)

Type of steel	SR235	SR295	SD295AB	SD345	SD390
In normal case	140	160	180	200	210
In case of corrosion	120	140	160	180	190

[14]

Shear force (Ts) acting on one rock bolt shall be calculated using the following formula:

$$Ts = \frac{P_R \times B}{N_1} \quad \cdots\cdots (2\text{-}13)$$

The shear stress ($\sigma_{\tau a}$) required against the tensile force of the rock bolt is calculated using the following formula:

$$\sigma_{\tau a} = \frac{Ts}{As} < \tau_{sa} = 80\, N/mm^2 \quad \cdots\cdots (2\text{-}14)$$

For the design tensile force (Td) of a rock bolt to meet the allowable tensile force, the length of contact between the ground and grout is compared with that between the steel material and the grout. Whichever is greater is used as the fixed length (L_a).

The length (L_{a1}) of contact between the steel material and the grout is calculated as follows:

$$L_{a1} = \frac{Td}{\pi \times d \times \tau_{ca}} \quad \cdots\cdots (2\text{-}15)$$

Where,

d (mm) = Diameter of rock bolt

τ_{ca} (N/mm^2) = Allowable bond stress between the grout and the rock bolt

Table 2-29 Allowable Bond Stress between the Grout and Steel Material

Type of steel	Design standard strength (N/mm^2)			
	18	24	30	More than 40
Different shape	1.4	1.6	1.8	2.0

Edited from [1]

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The length (L_{a2}) of contact between the ground and the grout is calculated as follows:

$$L_{a2} = \frac{Td \times f}{\pi \times D \times \tau_{pa}} \quad \cdots\cdots (2\text{-}16)$$

Where,

D (mm) = Diameter of Drilling Borehole
τ_{pa} (N/mm^2) = Friction resistance of contact between the ground and the grout
f = Safety factor for rock bolts (generally f = 2.0)

Table 2-30 Friction Resistance of Ground with Rock Bolt

Ground Type			Friction resistance (N/mm^2)
Rock	Hard Rock		1.2
	Soft Rock		0.8
	Weathered Rock		0.5
	Semi-Consolidated Soil		0.5
Sand and Gravel Layer	N-Value	10	0.08
		20	0.14
		30	0.20
		40	0.28
		50	0.36
Sand Layer	N-value	10	0.08
		20	0.14
		30	0.18
		40	0.23
		50	0.24
Cohesive Soil			0.8* C (C: Cohesion)

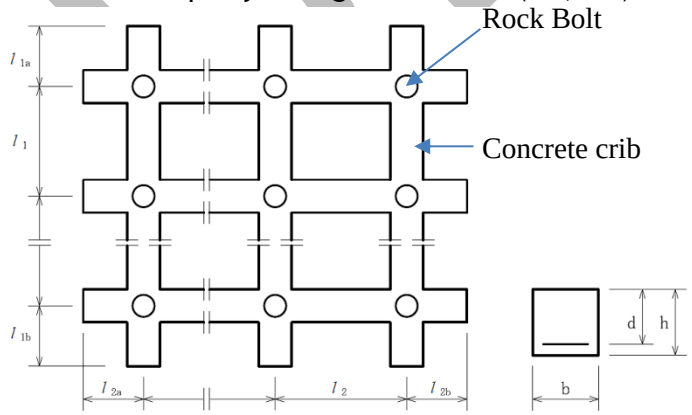
Note: 1 tf/m^2= 0.01 N/mm

Edited from [1]

(iii) Design of concrete crib works

Since concrete crib works offer little resisting force against the driving force of the soil slope collapse, each intersection of the crib should be anchored with a rock bolt, as shown in Figure 2-37.

Since the concrete crib is hard in comparison with the ground soil, the design load acting on the concrete crib is considered to be uniformly distributed. Calculation of the force equally acting to the cribs (w1, w2) is as follows:



n_1 : number of vertical span
l_1 : span length of vertical frame
l_{1a} : upper excess of vertical fr
l_{1b} : lower excess of vertical fr
n_2 : number of horizontal span
l_2 : span length of horizontal fr
l_{2a} : left excess of horizontal fr
l_{2b} : right excess of horizontal fr
b : witdh of frame
h : height of frame
d : effective height of frame

Figure 2-37 Arrangement of Rock Bolts

Source: JICA Project Team

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Length of vertical frame for loads from each rock bolt (l_h)

$$l_h = \frac{l_{1a}+l_1 \cdot n_1+l_{1b}}{n_1+1} \quad \cdots\cdots (2\text{-}17)$$

Length of horizontal frame for loads from each rock bolt (l_w)

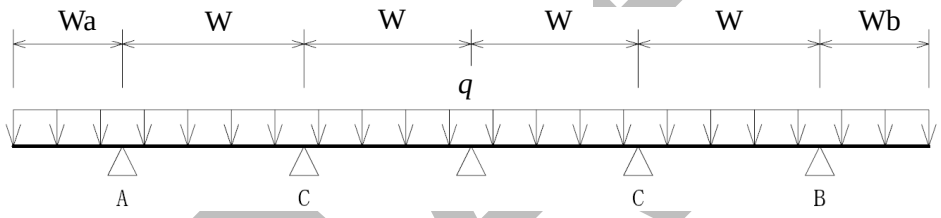
$$l_w = \frac{l_{2a}+l_2 \cdot n_2+l_{2b}}{n_2+1} \quad \cdots\cdots (2\text{-}18)$$

Then

$$w_1 = w_2 = \frac{T_d}{l_h+l_w-b} \quad \cdots\cdots (2\text{-}19)$$

The maximum moment (Mmax) and the maximum shear force (Smax) acting on the concrete crib are calculated using the following formula. Moments and shear forces are calculate for horizontal and vertical frames. For each horizontal or vertical frame, the maximum values are adopted for design.

For crib works with one span, calculation should be done at the location of rock bolts and middle of frames. For crib works with 4 spans or more, calculation should be done at the locations of excess and 1st internal bearing points.



A, B: Excess, C: 1st internal bearing points

Figure 2-38 Loads on Horizontal Frame (4 spans)

Source: JICA Project Team

The maximum bending moment at 1st internal bearing point (for vertical frame)

$$Mmax_C = \frac{w_1 \times {l_1}^2}{9} \quad \cdots\cdots (2\text{-}20)$$

The maximum bending moment at excess (for vertical frame)

$$Mmax_A = \frac{w_1 \times {l_{1a}}^2}{2} \quad \cdots\cdots (2\text{-}21)$$

The maximum shear force (Smax) acting on the concrete crib (or frame) is calculated using the following formula. The location for review (x) is a distance from a rock bolt.

The maximum shear force to act on the outer side of 1st internal bearing point (for vertical frame)

$$Smax_C = \frac{3 \times w_1 \times l_1}{5} - w_1 \times x \quad \cdots\cdots (2\text{-}22)$$

The maximum shear force to act on excess (for vertical frame)

$$Smax_A = w_1 \times l_{1a} - w_1 \times x \quad \cdots\cdots (2\text{-}23)$$

The sectional area (As) and effective height (d) of steel material is given in Table 2-31.

Table 2-31 Type and Size of Steel Material Used for Different Concrete Cribs

No.	Size of Concrete Crib	Nominal Weight	Weight (kgf/m)	Sectional Area (cm^2) As	Number to be Used for the Crib	Effective Height (cm) (d)	Diameter (cm)
1	150* 150	D10	0.56	0.7133	2	7.5	0.953
2	200* 200	D10	0.56	0.7133	2	15.5	0.953
3	200* 200	D10	0.56	0.7133	2	15.5	0.953
4	300* 300	D13	0.995	1.267	2	23.5	1.27
5	300* 300	D16	1.56	1.986	2	23.5	1.59
6	300* 300 with stir-lap	D16	1.56	1.986	2	23.5	1.59
7	400* 400 with stir-lap	D16	1.56	1.986	4	31.5	1.59
8	400* 400 with stir-lap	D16	1.56	1.986	4	31.5	1.59
9	500* 500 with stir-lap	D19	2.25	2.865	4	41.0	1.91
10	600* 600 with stir-lap	D22	3.04	3.871	4	51.0	2.22

Edited from [3]

The ratio (p) of the steel material in the concrete crib is calculated using the following formula:

$$p = \frac{As}{b \times d} \quad \cdots\cdots (2\text{-}24)$$

Calculation of the ratio (k) of the distance between the compressive surface and neutral axis to the effective height is calculated using the following formula:

$$k = \sqrt{2 \times p \times n + (p \times n)^2} - p \times n \quad \cdots\cdots (2\text{-}25)$$

The ratio (j) is calculated using the following formula:

$$j = 1 - {}^{k}/_{3} \quad \cdots\cdots (2\text{-}26)$$

The tensile stress (σ_s) of the steel material is calculated using the following formula:

$$\sigma s = \frac{Mmax}{A_s \times j \times d} < \sigma_{sa} \quad \cdots\cdots (2\text{-}27)$$

The compressive stress (σ_c) of the concrete crib is calculated using the following formula:

$$\sigma c = \frac{2Mmax}{k \times j \times b \times d^2} < \sigma_{ca} \quad \cdots\cdots (2\text{-}28)$$

The shear stress (τ) of the concrete crib is calculated using the following formula:

$$\sigma s = \frac{Smax}{b \times j \times d} < \tau_{ca} \quad \cdots\cdots (2\text{-}29)$$

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The adhesive stress (τ_o) between the concrete crib and the steel material is calculated using the following formula:

$$\tau_o = \frac{Smax}{U \times j \times d} < \tau_{oa} \quad \cdots\cdots (2\text{-}30)$$

Table 2-32 Allowable Stress for Concrete (Mortar) Crib

l.	**Design standard strength (N/mm^2)**	**18**
2.	**Allowable compressive stress (N/mm^2) σ_{ca}**	**7**
3.	**Allowable shear stress (N/mm^2) τ_a**	**0.40**
4.	**Allowable adhesive stress (N/mm^2) τ_{ba}**	**1.4**

Edited from [21]

(iv) Design of Bearing Plates

The size (B) of the bearing plate depends on the allowable compressive stress, and is calculated using the following formula. Allowable compressive stress (σ_{ba}) should be 50 % or less of the design standard strength (σ_{ck}):

$$B = \sqrt{\frac{Td}{\sigma_{ba}} + a} \quad \cdots\cdots (2\text{-}31)$$

$$\sigma_{ba} \leq \left(0.25 + 0.05 \times \frac{A}{A_a}\right) \times \sigma_{ck} \quad \cdots\cdots (2\text{-}32)$$

Where,
B : the minimum width required (mm)
Td : Design tensile force for one rock bolt (kN/nos)
σ_{ba} : Allowable compressive stress (N/mm^2)
σ_{ck} : Design standard strength (N/mm^2)
$a = \frac{\pi \times D^2}{4}$: hole area (mm^2)
D : Diameter for the hole of rock bolts (mm)
$A = B^2 - a$: Area of the minimum required plate contacting with the concrete frame (mm^2)
$A_a = u^2 - a$: Effective area of bearing plate (mm^2)
u : Width of bearing plate (mm)

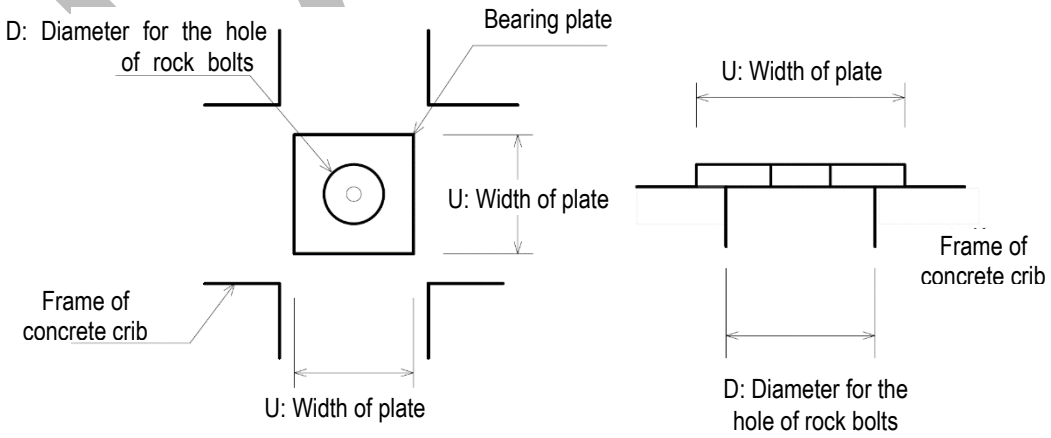


Figure 2-39 Arrangement of Bearing plates

Source: JICA Project Team

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(3) Horizontal Drainage Borings

Groundwater is generally divided into two types, shallow and deep. Shallow groundwater, 0 to 5 meters below the ground surface, is due mainly to rainfall accumulated in the short-term. Shallow groundwater frequently causes a shallow failure or the toe failure of a large-scale landslide. In such cases, culverts and horizontal drainage borings are effective.

The amount of reduction in the pore water pressure that must be achieved through the construction of drainage works in order to satisfy the proposed safety factor is obtained using Equation (2-33), as schematically shown in Figure 2-40.

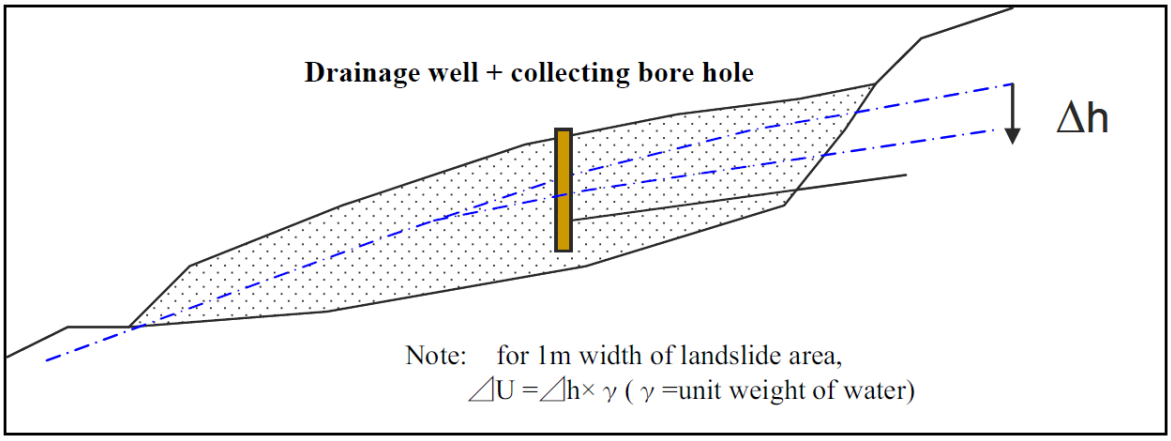


Figure 2-40 Schematic Diagram of Effectiveness of Horizontal Drainage Works

Source: JICA Project Team

$$\Delta U = \frac{1}{\tan \emptyset}(PF_s \times \sum T - \sum(N - U)\tan \emptyset - C \times \sum L) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}33)$$

Where,

ΔU (kN/m) = Required reduction in pore water pressure

(i) Purposes

Horizontal drainage borings are used to drain both shallow and deep groundwater to stabilize the landslide by decreasing the pore water pressure that is responsible for activating the sliding surface. Horizontal drainage is useful as a temporary countermeasure to decrease the progress of an active landslide.

(ii) Design considerations

Horizontal drainage borings are constructed for the drainage of shallow groundwater and deep groundwater. If topography prevents the groundwater from being drained on a gentle gradient, then drainage wells or tunnels with horizontal drainage borings shall be used to achieve drainage. In designing horizontal drainage borings, the following items should be carefully considered:

a) Horizontal drainage borings are designed to traverse aquifers or penetrate into the sliding surface if it is deeper than 5 meters.
b) “Horizontal” drainage borings, usually 20 to 50 meters in length, should be drilled at an upward gradient of 5 to 10 degrees from the horizon.

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c) Hard polyvinyl chloride pipes or gas pipes with an internal diameter of 50 to 100 mm are used as casing pipes. Either the parts of the casing pipes traversing the aquifer or the whole length of the pipe is perforated to collect the underground water.

d) Outlet protection for horizontal drainage borings is undertaken using gabions or concrete.

A typical layout of horizontal drainage borings is shown in Figure 2-41. In the case of the standard-scale landslide with a landslide depth of 20 m, the reduction in the groundwater level by installation of horizontal drainage borings may be expected to be 1 to 3 meters.

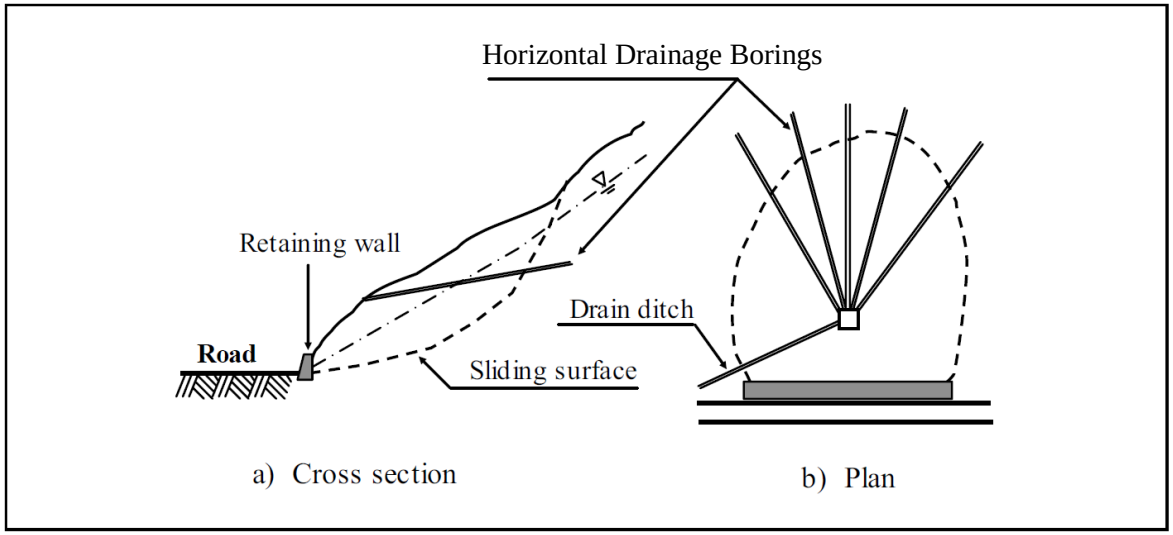


Figure 2-41 Typical Layout of Horizontal Drainage Borings

[1]

(4) Drainage Wells

Drainage wells consist of three parts: a) catchment well - collecting water through the wall of the well, b) collecting bore holes - collecting water in the same way as horizontal drainage borings, and c) draining bore holes - draining the collected water from the catchment well.

(i) Purposes

Similar to horizontal drainage borings, drainage wells are used to drain deep groundwater for stabilization of the landslide.

(ii) Design considerations

Drainage wells are used when horizontal drains or culverts cannot achieve efficient drainage because of the large scale of the landslide or the gradient of the slope surface.

In designing drainage wells, the following items are to be carefully considered:

a) The location of catchment wells shall be determined on the basis of the distribution of groundwater and in consideration of the well's safety. In principle, wells should be located in stable ground within an area from which it is possible to effectively collect groundwater.

b) Wells are usually between 2 to 4 meters in diameter and 10 to 30 meters in depth. Liner plates, reinforced concrete segments, and other materials generally support the sidewalls of the wells.

c) Collecting bore holes are similar to horizontal drainage borings in terms of design considerations.

d) The diameter of discharge bore holes is determined on the basis of the amount of groundwater collected.

Figure 2-42 shows the details of drainage wells. A typical drainage well layout is shown in Figure 2-43. The safety of the catchment wells shall be evaluated by checking the earth pressure of the surrounding area, as shown in the following equations:

$$P_h = K_a \times \gamma \times h \quad (h < 15m) \cdots\cdots (2\text{-}34)$$

$$P_h = K_a \times \gamma \times 15 \quad (h \geq 15m) \cdots\cdots (2\text{-}35)$$

Where,

P_h (kN/m^2) : Active earth pressure at depth h (m)
γ (kN/m^3) : Unit weight of soils
Ka : Coefficient of active earth pressure

a) Sandy soil : $K_a = \tan^2\left(45° - \frac{\emptyset}{2}\right)$

b) Clayey soil : $K_a = \tan^2\left(45° - \frac{\emptyset}{2}\right) - \frac{2C}{h\gamma}\tan\left(45° - \frac{\emptyset}{2}\right)$

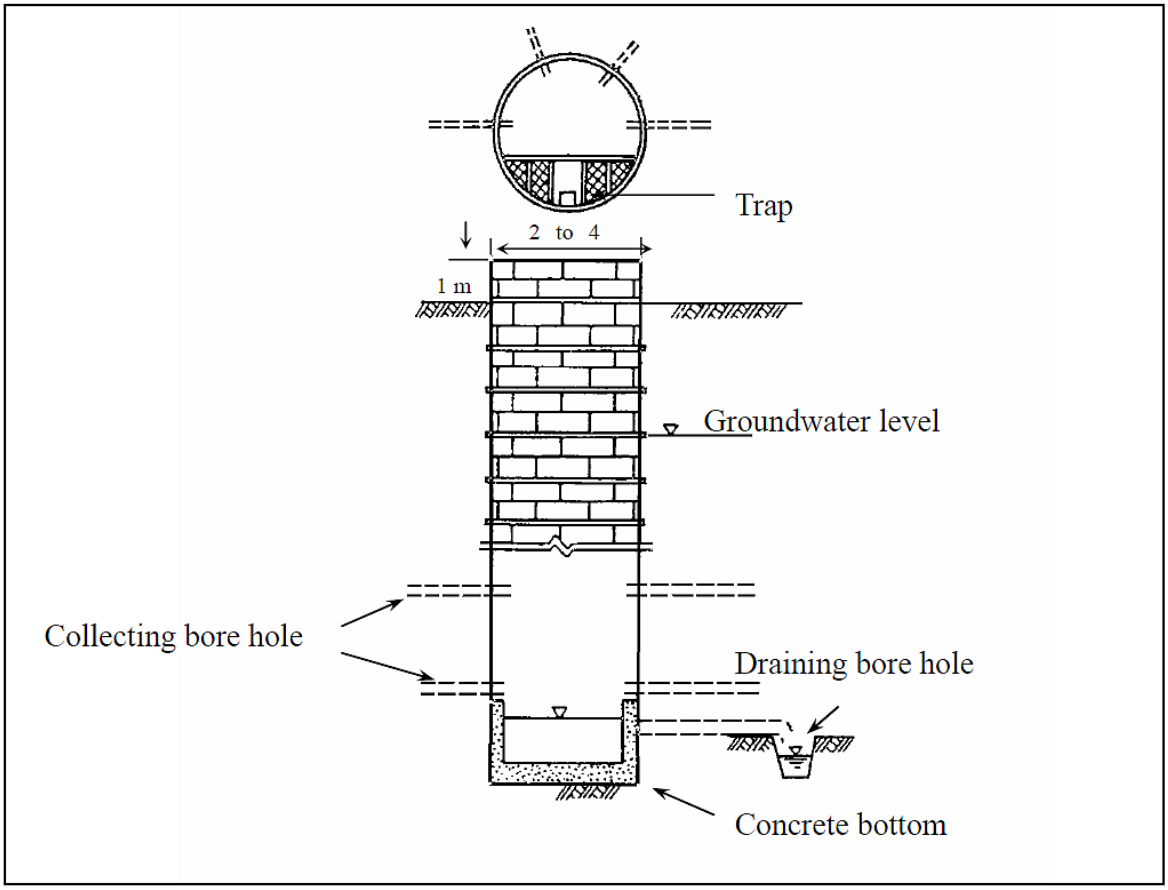


Figure 2-42 Structural Details of Drainage Well

[14]

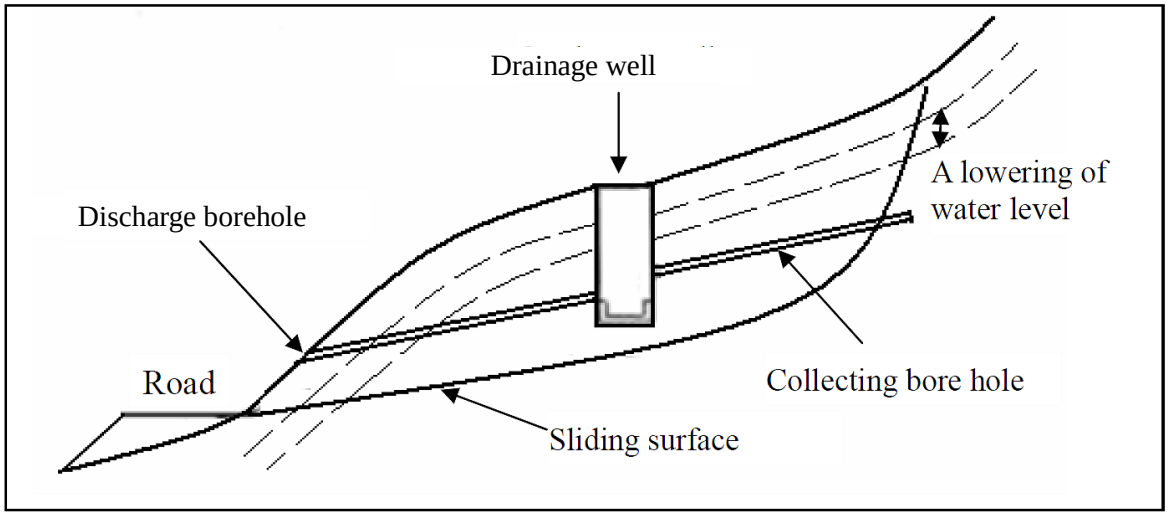


Figure 2-43 Typical Layout of Drainage Well

[1]

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2.6.3 Difference between "ground anchor work" and "soil nailing work"

Soil nailing works are to reinforce slopes by installing reinforcing bars or rod shaped reinforcing material with high rigidity to the boreholes drilled from the surface of slopes and filling grouting to the boreholes to fix the reinforcing materials to the ground for the entire length of the reinforcing materials. Soil nailing prevents internal deformation of the slope by tensile strength of the reinforcing materials and bond stress between reinforcing materials and grouting as well as grouting and the ground. Rock bolt has the same structure and mechanism with soil nailing but mainly used for rocky slope or tunnels.

Soil nailing resembles ground anchors in the structure of reinforcing material or anchor body installed in boreholes in slopes. Such resemblance often brings confusions in proper application of both works, which are sometimes mixed up and improperly applied to the slopes.

In this section, the purposes, function, specification and arrangements of both works are explained while highlighting the difference between them to optimize and maximize the effect of both works.

(1) Difference between Ground Anchors and Soil Nailing / Rock Bolt

Table 2-33 explains the features of both works. To distinguish the structures of both works, typical structures are explained in Figure 2-44 for ground anchors and in Figure 2-45 for soil nailing/rock bolt.

Table 2-33 Difference between Ground Anchors and Soil Nailing / Rock Bolt

Items		Ground Anchors	Soil Nailing / Rock Bolt
Purpose		To secure external stability	To secure internal stability
Pre-stress / Tension to be applied		Pre-stress / tension is applied to tendon part.	Not applied.
Effect to Stabilize Slopes		Retaining and tightening effects by pre-stress.	Shear strength and rigidity of material composite installed in the ground limited by allowable strength / stress of the composite.
Arrangement		Aligned in rows at particular zone, usually between the middle to toe of slopes / landslides.	Arranged in entire slope surface.
Structure	Surface	Anchor head with wedge structure to retain pre-stress.	None / nuts and plates to fix reinforcing materials
	Free length	Necessary for pre-stress	No free length Reinforcing materials are fixed for entire length
	Anchor length	Cement grouting, injected by pressure	Cement grouting
Material	Type	Tendon for pre-stressed concrete (for applying tension)	Reinforcing bars for reinforced concrete (for giving reinforcement)
	Anti-corrosion	Covered by grease and resin	Galvanizing
Drilling	Borehole diameter	φ90mm～φ165mm	φ45m～φ65mm
	Machinery	Rotary percussion drilling machine with double tube drilling function	Jackhammer, rock drill, drill equipped on crane, portable drilling machine or portable percussion drilling machine Self-drilling rock bolt is available.
	Scaffolding	Necessary Width of 4.5 meters or more.	Basically not necessary Width of 2.0 meters or more for portable drilling machine

Source: JICA Project Team

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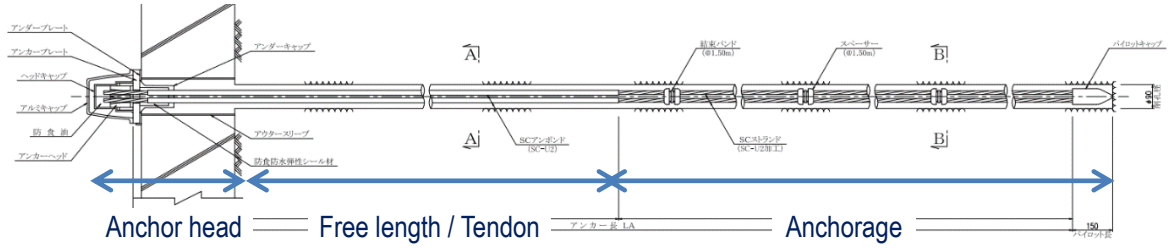


Figure 2-44 Typical Structure of Ground Anchor

Source: JICA Project Team

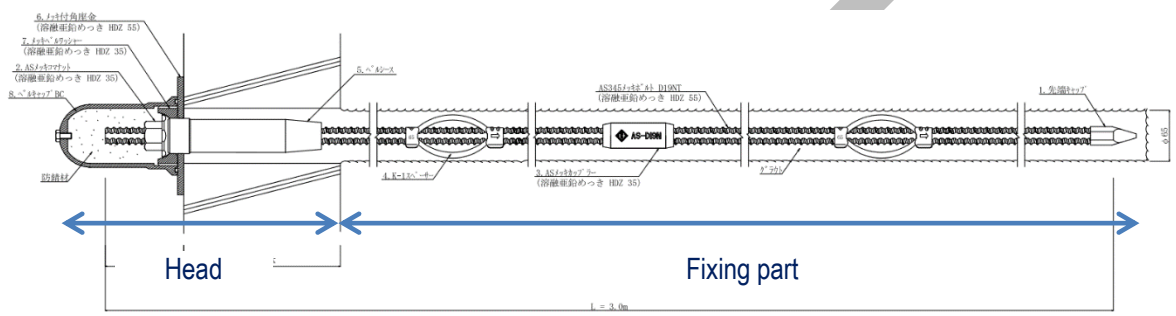


Figure 2-45 Typical Structure of Soil Nailing / Rock Bolt

Source: JICA Project Team

(i) Tension (Pre-stress)

The biggest difference between ground anchors and soil nailing is applying pre-stress.

Ground anchor applies tension to tendon part so that pre-stress / compression stress is applied to the ground. When pre-stress is applied, retaining and tightening effects on slip surface become effective.

On the other hand, soil nailing / rock bolt does not apply pre-stress to the material. Only after material of slope slightly deforms and stress between the reinforcing material and the ground acts, shear strength and bond stress of reinforcing composite become effective.

At the same time, soil nailing / rock bolt consolidates the slope where the works are installed, by the effects of grouting filled into the boreholes of soil nailing / rock bolt up to the surface. Thus, only when the slope slightly deforms, the shear strength and rigidity of reinforcing material act as resistance of the ground against deformation, in the whole area and depths where soil nailing/ rock bolt works are installed

From the viewpoints of deformation of the ground, obvious difference between ground anchor and soil nailing / rock bolt is understood.

Ground anchor does not allow deformation of the ground by the landslides or failures to which the ground anchor is designed to stabilize with a certain design factor of safety.

On the other hand, soil nailing / rock bolts increases resistance by reinforcing material as slight deformation of the ground accumulates; on the course of achieving the design factor of safety, certain deformation within allowable limits must occur.

From the viewpoints of arrangements, another difference is observed between the works as explained in Figure 2-46.

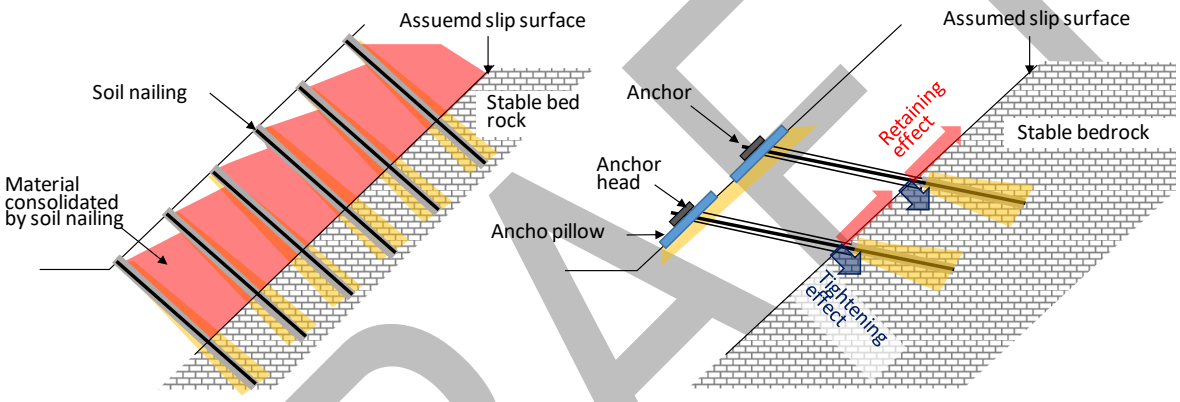
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Soil nailing aims to assure internal stability by consolidating the slope by reinforcing material and grouting filled in the boreholes. Thus soil nailing / rock bolts should be arranged to the entire slope to protect.

On the other hand, based on the strength of the ground and bearing capacity behind anchor pillows, design of ground anchor decides intervals of ground anchors in an alignment (or row) and locations and numbers of alignments to arrange. In addition, design of ground anchor assumes that internal stability of entire slope is assured; free length of tendon is feasible because sliding mass is rigid.

Thus soil nailing / rock bolt works are for securing internal stability and ground anchors are for external stability.

At the last, ground anchor should maintain the applied tension for long terms of service period. Thus high quality materials with anti-corrosion precaution as well as specially arranged head and anchorage structures are required for ground anchors. These requirements need special construction method as well as high cost for construction.



(a) Soil Nailing (b) Ground anchor

Figure 2-46 Difference in Function between Soil Nailing and Ground Anchor

Source: JICA Project Team

(ii) Effects by Ground Anchors

Ground anchors have two kinds of mechanical effects: the tightening effect (P1) - to increase the resistance against shear force by applying a normal force to the sliding surface; and the retaining effect (P2) - to decrease the sliding force of a landslide by component of pre-stress along slip surface.

The required resistance force of ground anchors shall be obtained from Equation (2-36), as schematically shown in Figure 2-47.

$$P = \frac{(PF_S - F_S) \times \sum T}{\cos(\alpha+\theta) + \sin(\alpha+\theta) \times \tan\emptyset} \quad \text{(2-36)}$$

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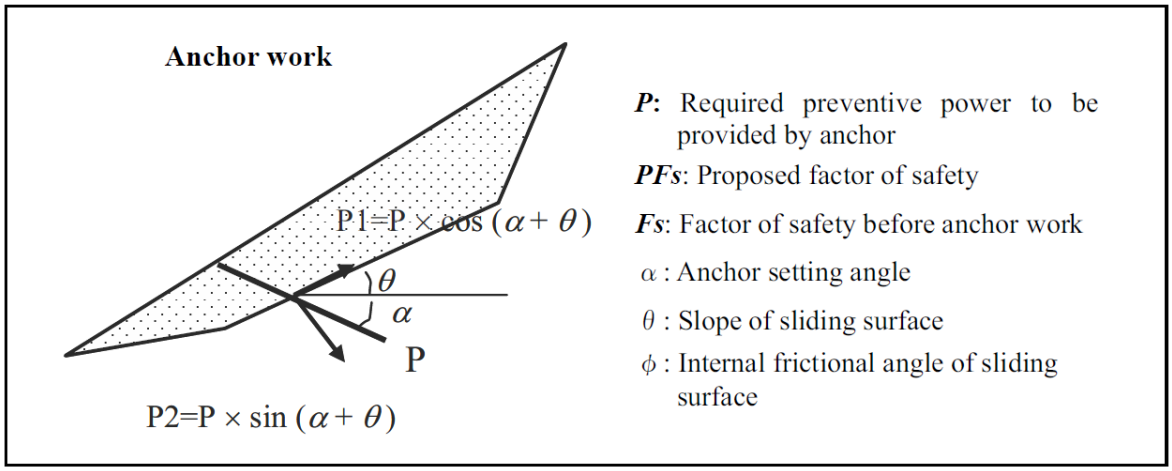


Figure 2-47 Effects by Ground Anchors

Source: JICA Project Team

(iii) Effects by Soil Nailing / Rock Bolt

The effects of soil nailing / rock bolt are expressed in Formula (2-11) previously explained as well as Formula (2-37). If compared with the formula for ground anchor of Formula (2-36), both formulae resemble each other.

The difference is as follows; for ground anchor, design anchor force calculated from slope stability analysis are used for calculation whereas, for soil nailing / rock bolt, allowable tension strength of reinforcing material deducted by reduction factor is used.

$$P_R = (\sin(\alpha + \beta) \cdot \tan \emptyset + \cos(\alpha + \beta)) \times T_{pa} \times \lambda \cdots\cdots\cdots\

Thus design of ground anchor strictly considers the numbers of rows, which the design of soil nailing / rock bolt does not care so much. This is due to cost and purpose of each type of works.

Ground anchor aims to secure external stability, which requires clear assumptions of the shape, depth, and shear strength of slip surface as well as mechanism of sliding/failures. At the same time, design of ground anchor considers the sliding mass as rigid and deformation of sliding mass is not discussed. Thus purpose of design is limited to slip surface which extends three dimensionally.

To assure uncertainty of the shape and depth of slip surface, three check borings should be done for each row of ground anchor installation at the middle and both ends.

Soil nailing / rock bolt aims to secure internal stability by consolidating the slope by grouting and reinforcing materials. Thus soil nailing / rock bolt works should be installed for the entire slope to stabilize.

Such arrangements of soil nailing / rock bolt may provide some excess margin of factor of safety. If achieved factor of safety is expected to far exceed the design factor of safety, economic comparison of reinforcing material may save cost of construction. Some excess margin should be allowed for soil nailing / rock bolt, however, due to uncertainty of erratic conditions of slope, which are difficult to estimate for the entire slope.

To secure internal stability effectively and reasonably, soil nailing / rock bolts may assume surface failure of 3 meters depth or shallower. This condition requires 6 meters borehole and reinforcing materials. For such scale, self-boring rebar and portable drilling machine are easy to introduce, which substantially save construction cost.

The stability against failure or landslide with a slip surface of deeper than 3 meters should be considered as external stability. For such case, adopting ground anchors are recommended.

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2.6.4 Introduction of design technologies for ground anchor works

Ground anchors are reliable, but costly compared with other countermeasures. This method has been applied increasingly to artificial landslides to cut off the toe of the landslide. Compared with rock bolts and soil nailing, ground anchors have a relatively large resistance to sliding force and are therefore used to stabilize relatively large-scale slope failures.

(i) Purposes

Ground anchors are intended to prevent landslides through the tensile strength of high tensile strength steel wire or bars installed across the slip surface.

(ii) Design considerations

When the slope of a landslide area or sliding surface is relatively steep, ground anchors are more effective than piles. Figure 2-48 gives a conceptual diagram of a ground anchor installation.

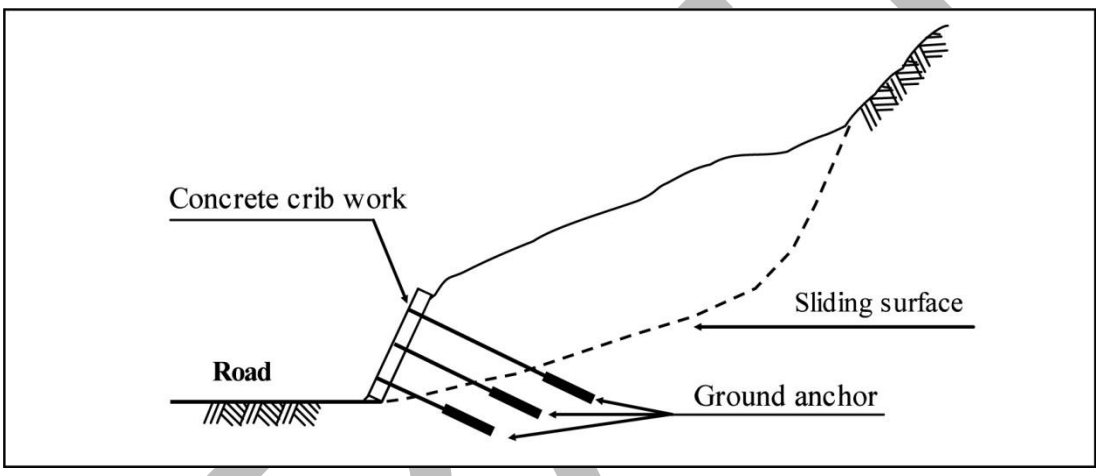


Figure 2-48 Landslide Stabilized with Ground Anchors

[14]

i) Design procedure

Figure 2-49 shows the design flowchart for ground anchors. Important considerations for ground anchors are the bearing capacity of the ground under the bearing plate and the bond strength between the anchor grout and rock at the attachment point. In planning ground anchors, a bond strength test at the attachment is to be carried out.

Further, in planning and designing ground anchors, at least the following site tests should be performed at intervals of 20 to 30 m.

(a) Bond strength test at fixation part (extraction test)
(b) Bearing capacity test of soil mass under the bearing plate

ii) Anchor functions

Anchors are installed to achieve two objectives (Figure 2-50):

(a) Increase the resisting power against shear force by applying stress normal to the sliding surface (tightening effect), and
(b) Decrease the sliding force of a landslide by using steel members as anchors (retaining effect).

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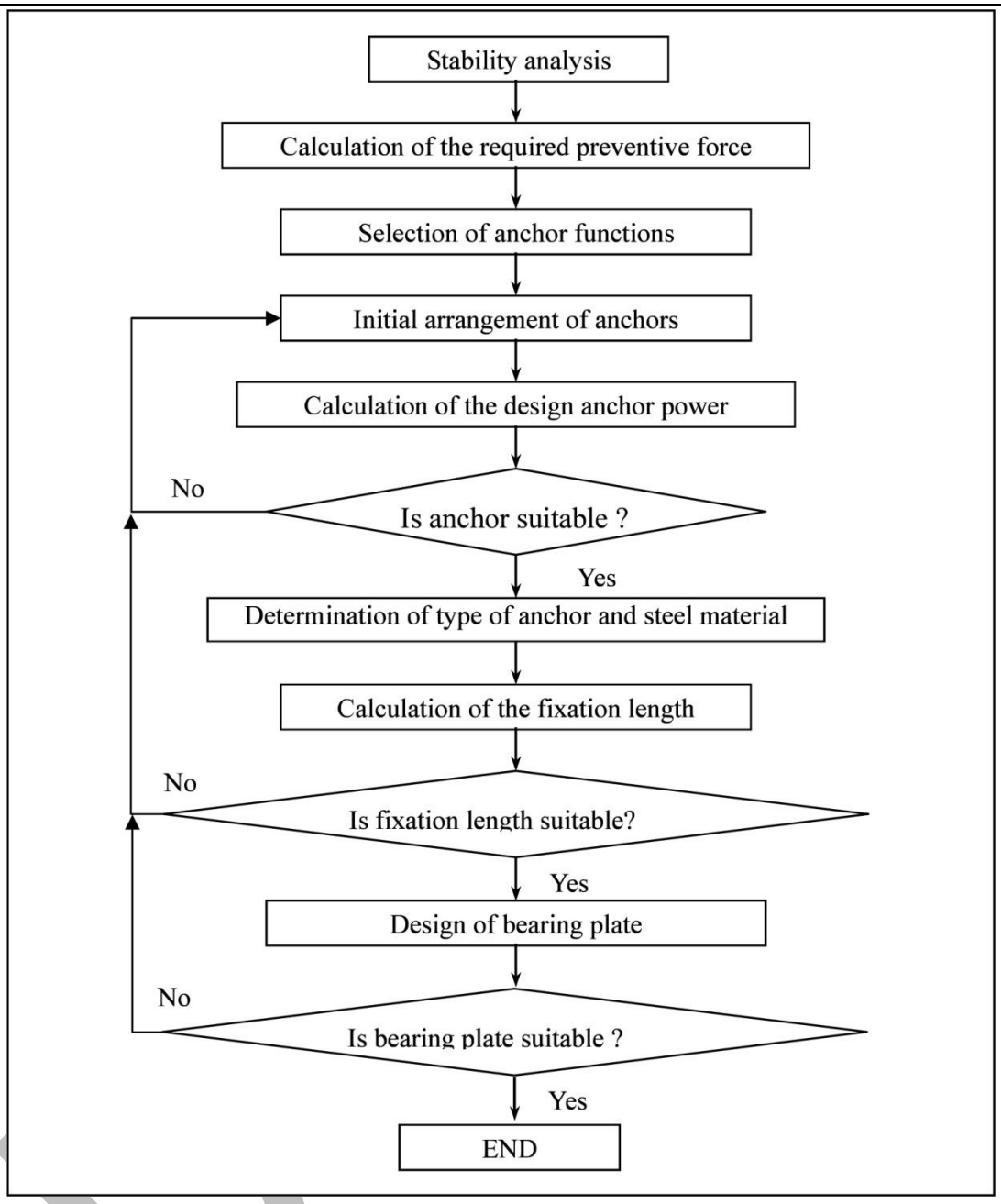


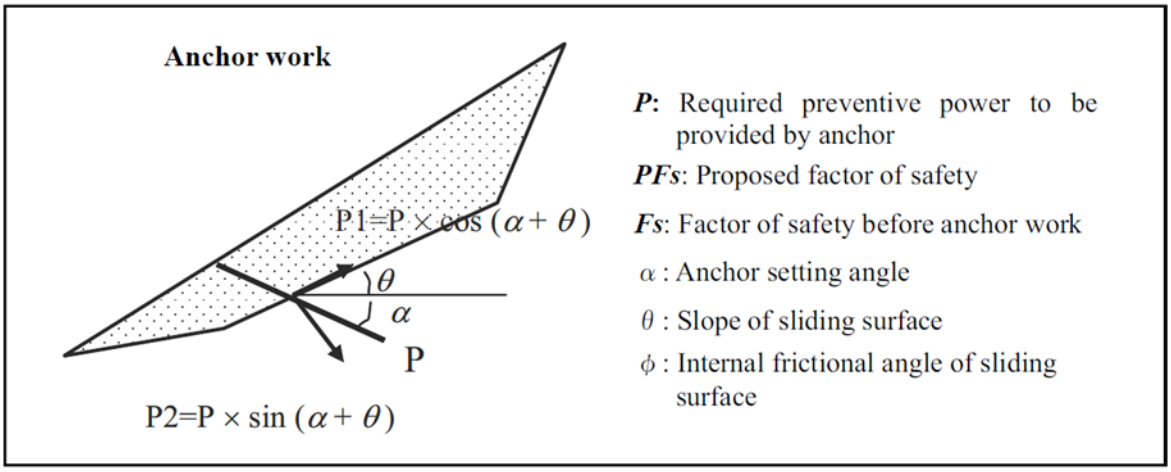
Figure 2-49 Design Flowchart for Ground Anchors

[14]

iii) Arrangement of anchors

The position, direction and intervals of anchor installation shall be determined during the initial stage of design.

(a) Ground anchors shall be installed at a spacing of at least 2 meters in 2 or more rows.
(b) The inclination of the anchors in a range from + 5° to - 5° from horizontal must be avoided for the reasons related to anchor installation, such as residual slime, bleeding of grout, etc.
(c) The direction of anchoring is parallel to the direction of movement of the landslide.
(d) Anchor interval is determined based on the interaction between anchors, which can be verified by reviewing anchor force, diameter of anchors, depth and ground properties.



i

The design anchor force (Td) is calculated by using the following formulas:

Source: JICA Project Team

$$Td = \frac{P}{\sin(\alpha+\theta)\cdot\tan\emptyset+\cos(\alpha+\theta)} \cdot \frac{B}{N} \quad \cdots\cdots (2\text{-}38)$$

Where,

P (kN/m^2) = Required resistance force

α (degree) = Anchor setting angle (the angle to a perpendicular axis)

θ (degrees) = Angle of slope of the sliding surface

$\emptyset$ (degrees) = Internal frictional angle of sliding surface

B (m) = Interval between anchors in horizontal direction

N = Number of anchors set in vertical direction

v) Determination of type of anchor and steel material

Generally, the type of anchor is determined by comparing the tension strength of steel material with the surface frictional resistance between the ground and the grout as well as the allowable adhesive stress between the tendon and the grout.

vi) Determination of fixation length

Fixation length should be 3 to 10 meters, and the free length should be more than 4 meters.

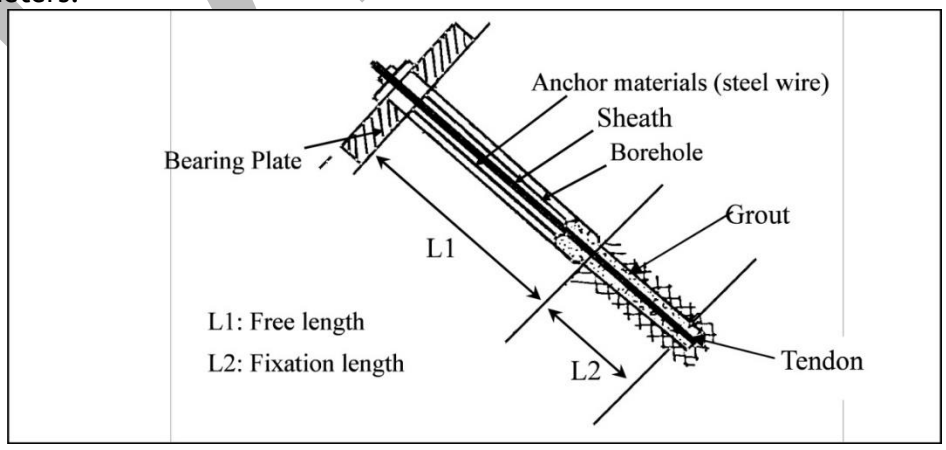


Figure 2-51 Outline of Anchor Structure

[14]

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To allow the design anchor force to meet the allowable anchor extraction force, the length of contact between the ground and the grout must be compared with that between a tendon and grout. Whichever is longer should be defined as the fixation length.

$$l_{sa} = \frac{T_d}{3.14 \times D_s \times \tau_{ab}} \quad \cdots\cdots (2\text{-}39)$$

$$l_a = \frac{f \times T_d}{3.14 \times D_a \times \tau_{ag}} \quad \cdots\cdots (2\text{-}40)$$

Where,

l_{sa} (m) = Required length between the tendon and the grout

l_a (m) = Required length of contact between the soil and the grout

Td (N/piece) = Design anchor force

D_s (m) = Diameter of a tendon

τ_{ab} (N/m^2) = Allowable adhesive stress between the tendon and the grout (Table 2-34)

f = Safety factor (generally be defined as 2.5)

D_a (m) = Diameter of the anchor

τ_{ag} Surface frictional resistance (Table 2-35)

Table 2-34 Recommended Allowable Adhesive Stresses

Standard Ground Design Strength (unit: N/cm)		**240**	**300**	**400**
Type of tendon	**l. Prestressing steel wire**	**80**	**90**	**100**
	2. Prestressing steel bar			
	3. Standard restressing steel wire			
	4. Multi-standard prestressing steel wire			
	5. Deformed prestressing steel bar	**160**	**180**	**200**

Note: (1) 1 kgf/cm^2 = 10 N/cm2, (2) unit: N/cm^2.

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Table 2-35 Recommended Surface Frictional Resistance of Anchors

Type of Ground			Frictional Resistance (N/cm^2)
Bedrock	Hard rock		150 to 250
	Soft rock		100 to 150
	Weathered rock		60 to 100
	Mudstone		60 to 120
Sand and gravel	N value	10	10 to 20
		20	17 to 25
		30	25 to 35
		40	35 to 45
		50	45 to 70
Sand	N value	10	10 to 14
		20	18 to 22
		30	23 to 27
		40	29 to 35
		50	30 to 40
Cohesive soil	Representative Cohesion C		10C

Note: 1 kgf/cm^2 = 10 N/cm^2

Edited from [1]

vii) Design of bearing plates

Cribs, plates or cross-shaped blocks set on the surface of the ground are used as pressure bearing plates. The most appropriate pressure bearing plate is selected in consideration of specifications, operational efficiency, cost-effectiveness, maintenance, landscape, etc.

Figure 2-52 shows a typical example of a landslide stabilized with ground anchors.

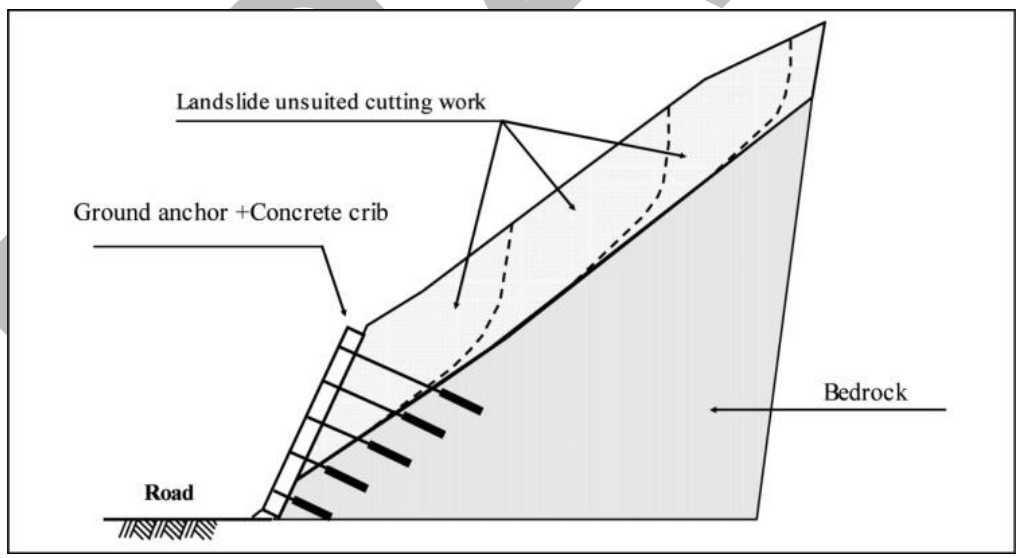


Figure 2-52 Typical Example of a Landslide Stabilized by Ground Anchors

[14]

2.6.5 Countermeasures against Debris Flow

Debris flow is the fast movement of rock fragments, earth and mud mixed with water, along a valley or a mountainous stream. Because of its speed, debris flow is dangerous to life and property, destroying objects in its path. Debris flow countermeasure plans for hazardous streams are, in principle, formulated to cope with debris flow rationally and effectively, considering the frequency and scale of debris flow occurrences.

Debris flows involve three areas, namely, the source area, transport zone, and accumulation area. The countermeasures for debris flow are different for each of these areas and they should be considered separately. For source areas, the type and extent of conceivable countermeasures shall basically be the same as those for soil slope collapses and landslides. However, because of the wide area involved, vegetation and cutting works are the most cost-effective.

This section will focus on methods to be used for the transport zones and accumulation areas relevant to road facilities. Moreover, design of river works relevant to road slope disasters shall refer to Technical Standards and Guidelines for Planning and Design, Volume III, SABO (EROSION AND SEDIMENT CONTROL) WORKS, *Project for the Enhancement of Capability in Flood Control and Sabo Engineering of DPWH*, March 2002.

(1) Classification of Countermeasures

Table 2-36 provides the general classification of countermeasures for debris flow. The principal countermeasures are classified into three categories according to their functions and the location of implementation; a) Debris flow capturing works, b) Debris flow guiding works and c) Debris flow prevention works.

Table 2-36 Classification of Countermeasures for Debris Flow

CLASSIFICATION		TYPE OF WORK
1. EARTH WORK	Earth Work	Removal
		Cutting
		Embankments
2. VEGETATION	Vegetation	Hydroseeding
		Re-Vegetation
3. DRAINAGE	Surface Drainage	Drainage Ditches (Channels)
	Water Ways	Stone Pitching Water Ways
		Concrete Pitching Water Ways
4. SLOPE WORK	Shotcrete Work	Shotcrete (mortar)
		Shotcrete (concrete)
	Crib Work	Crib Work
6. WALLS AND RESISTING STRUCTURES	Retaining Walls	Gabion Walls
		Stone Pitching Walls
		Retaining Walls (Gravity Type)
		Retaining Walls (Supported Type)
	Catch Work	Catch Gabions and Concrete Walls
	Causeways	Causeways
7. PROTECTION WORK	Rock Sheds	Debris Flow Sheds
	Sabo (Check) Dam	Slit Dams
		Check Dams (Sabo Dams)
8. OTHERS	Avoiding Problem Areas	Bridges (or Culverts)
		Route Relocation

[14]

(i) Debris flow capturing works

Sabo dams (stepped dams) are a typical example of this type of structure, and include impermeable and permeable types. Their main functions are to: (1) reduce the volume of sediment discharge and (2) prevent the movement of sediments on streambeds, consequently reducing the impact of debris flow, as shown in Figure 2-53.

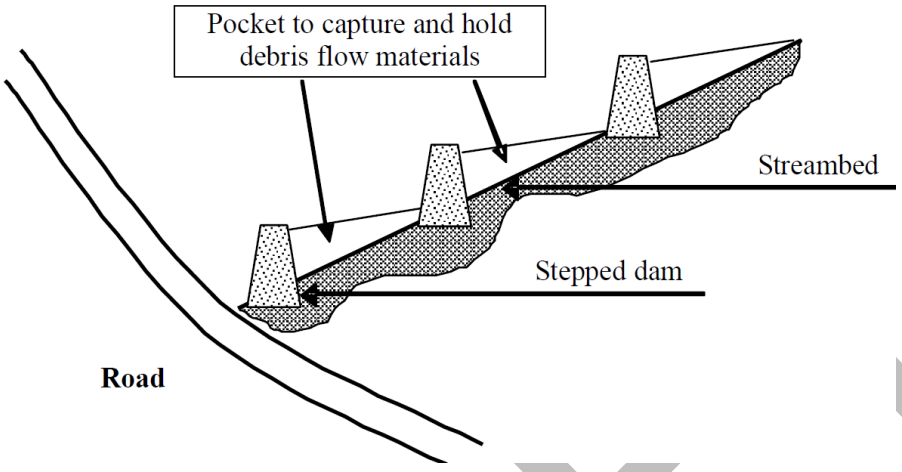


Figure 2-53 Conceptual Diagram of Stepped Dams

[14]

(ii) Debris flow guiding works

Typical works are revetments, guiding levees, channels, bridges, culverts, and sheds. These measures are used to direct debris flows to a safe place and control the direct impact of debris flow on the objects (roads) to be protected, as shown in Figure 2-54.

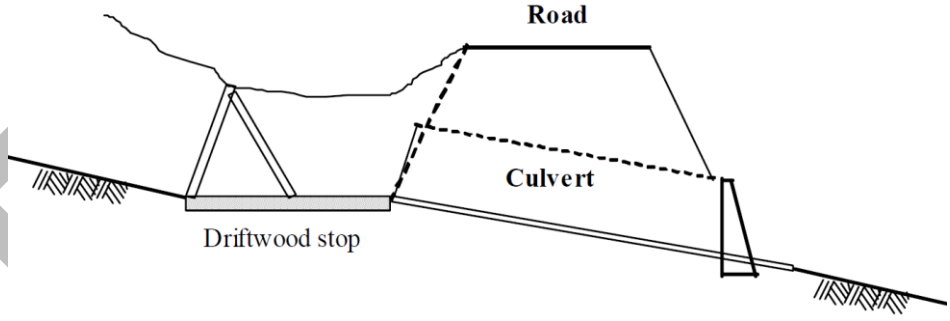


Figure 2-54 Conceptual Diagram of a Culvert

[1]

(iii) Debris flow prevention works

Debris flow usually occurs in which unstable sediments in a stream are abundant; thus, it is useful to prevent the supply of stream sediments from the mountainous slopes. Debris flow prevention works should be undertaken on mountainous slopes through forest work, vegetation and some types of structures to prevent soil slope collapse, landslides and other slope failures.

(2) Criteria for Selection of Countermeasures

Figure 2-55 shows a flowchart for the selection of countermeasures for debris flows. In planning the countermeasures for a stream prone to debris flow, various types

of countermeasures can be reasonably combined in consideration of the likely occurrence, frequency, volume (scale), flow characteristics, topography, and the objects to be protected. The basic sabo plan for debris flow should be formulated to effectively control the harmful sediments within the affected area.

The heights of the streambed and road surface are the most important conditions for the selection of countermeasures against debris flows. For streams with a high frequency of debris flow occurrence, the following criteria are used for selection and planning.

a) If a road exists in the upper part of the debris flow accumulation area (where the slope of the streambed is steeper than 3 degrees), it is advisable for road to be relocated upstream or downstream of the existing road, as shown in Figure 2-56.

b) When the path of the debris flow passes below the road surface, a bridge or culvert is applicable, as shown earlier in Figure 2-54. Whereas a debris flow shed or cover would be used when the path of the debris flow is higher than the road surface, as shown in Figure 2-57.

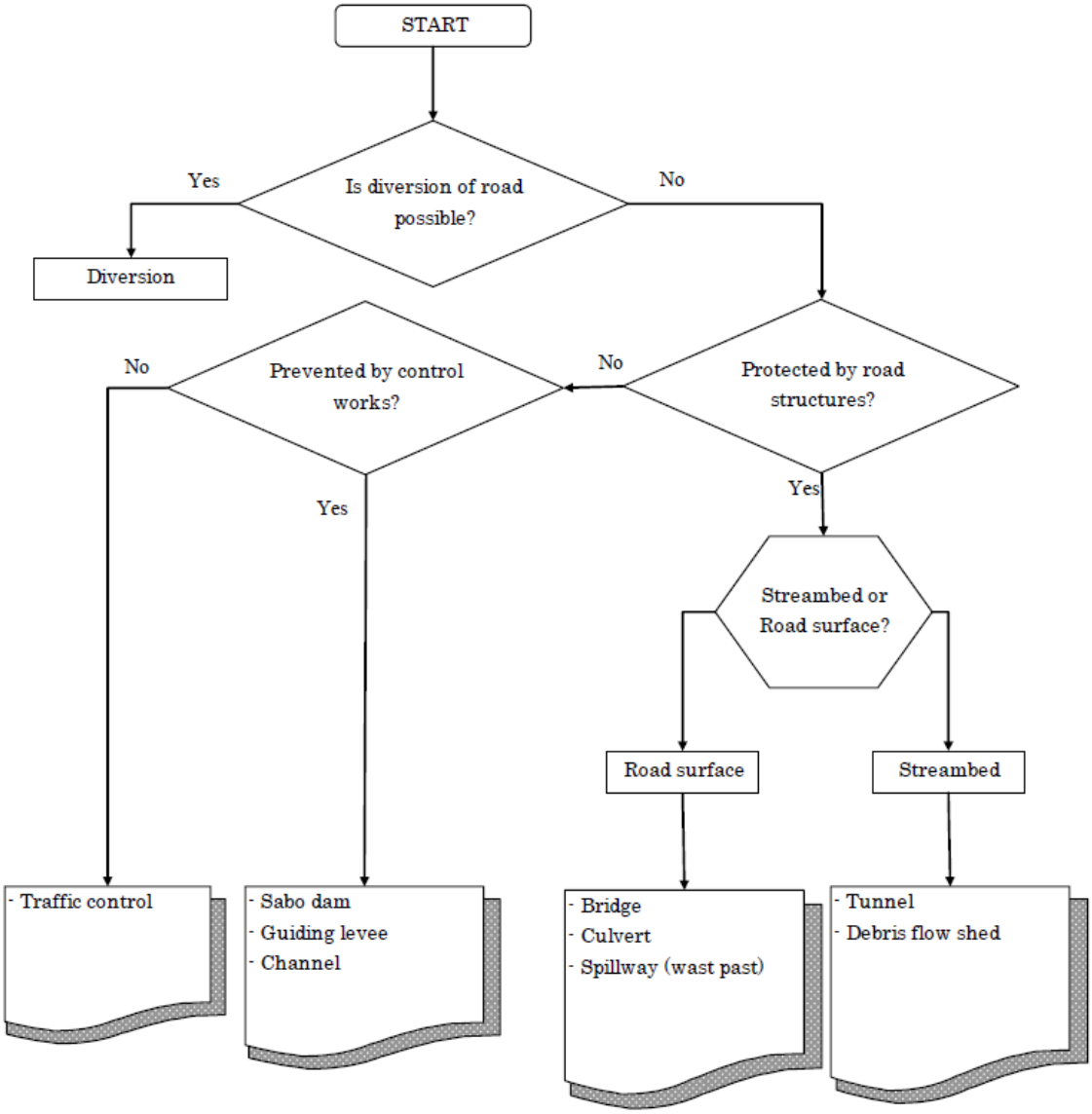


Figure 2-55 Selection Flowchart for Countermeasures against Debris Flows

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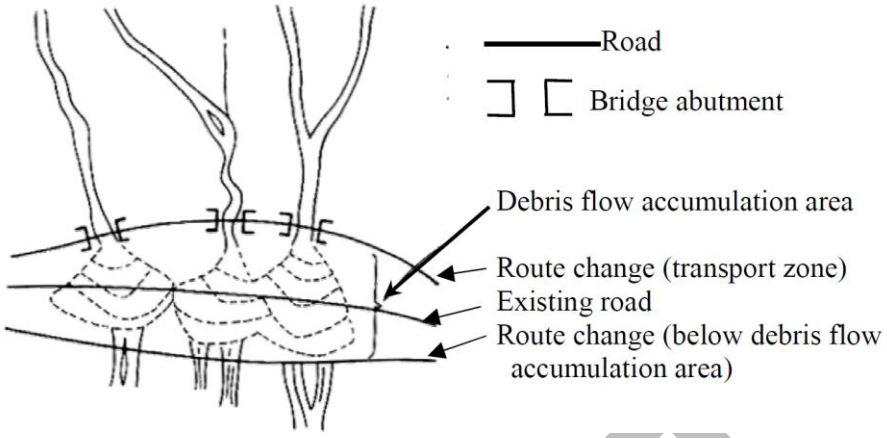
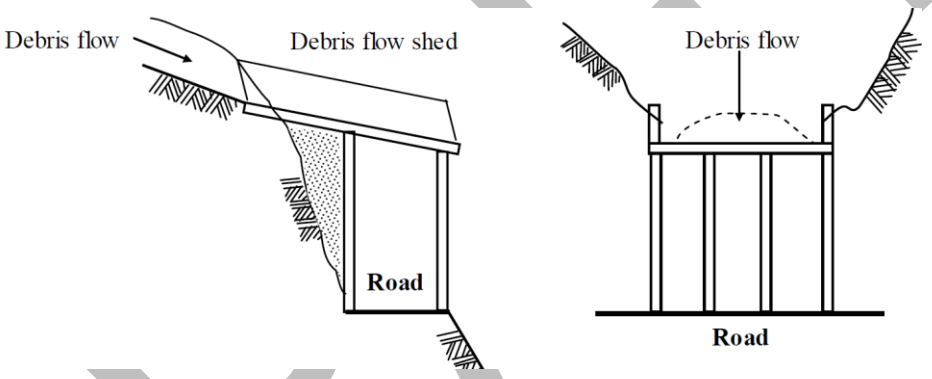


Figure 2-56 Conceptual diagram for route change

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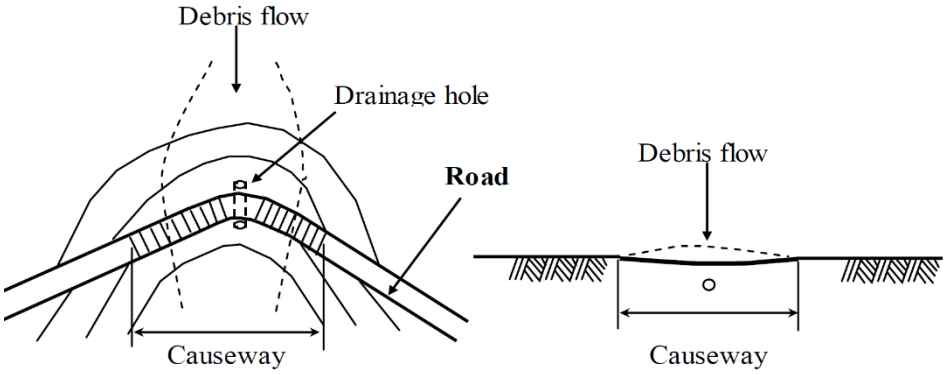
a) Side view **b) Front view**

Figure 2-57 Conceptual Diagram of Debris Flow Sheds

[1]

c) When the path of the debris flow and the related road surface are of the same height, a causeway is cost-effective (Figure 2-58), where debris flow is allowed to pass over the road surface without presenting an obstacle to the debris flow. In this case, the road surface should have thick pavement that is resistant to the scouring caused by debris flows.

d) The design sediment volume (sediment discharge) is calculated on the basis of surveys of deposits within the streambed, including topographical analysis, field surveys, and records of past debris flow.



a) Plan view **b) Front view**

Figure 2-58 Conceptual Diagram of Debris Flow Causeway

[1]

(3) Design of Main Countermeasures

(i) Sheds

Purposes

This method is applied to reduce road disasters due to avalanche, rock fall, rock slide or debris flow by absorbing the impact force of a fallen rock or changing direction of fallen rocks.

Classifications

Sheds aim to protect road traffic and facilities from avalanches, rock fall, and debris flow. It is assumed (for the design) that the debris which accumulates on the sheds should be removed. According to the target load, sheds are classified into the following categories.

1. Snow shed
   Target load includes that of avalanche but exclude debris or fallen rocks.
2. Rock Shed
   Target load includes that of fallen rocks, excluding large rock mass and soil.
3. Earth shed
   Target load includes that for rock shed including load of soil.

Snow shed is planned to endure avalanche tractive force and should not be against fallen rock or debris. Accordingly, the scale of snow sheds is smaller than those of rock or earth sheds and, considering efficiency of construction, steel structure is often adopted.

Rock shed is a protection measure against relatively small-scale rock fall and should not be considered against a large-scale rock slide. The target load protected by the shed should be carefully considered based on the site conditions; baseless large loads shall be avoided. Considering the scale of load, for rock sheds, pre-stressed or reinforced concrete with high rigidity is normally adopted.

Earth shed should not be planned against large-scale failures. In case debris is expected to accumulate on the shed, it should be removed principally. If

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removal work is considered dangerous or impossible, debris accumulation should be incorporated into the design. For such case, intensive site survey should be conducted before the design and prevention measures at the source of debris should be considered. Considering the scale of load, for rock sheds, pre-stressed or reinforced concrete with high rigidity is normally adopted.

Design considerations

The following loads should be considered in the design of sheds according to the site condition (see Table 2-37).

(1) Dead load --- self weight, buffer material (sand cushion)
(2) Fallen rock load --- impact force of rock fall
(3) Debris load --- self weight of accumulated debris, tractive force of flowing debris, impact force of debris from collapse
(4) Snow load --- snow load, tractive force of avalanche, impact force of avalanche, debris load, snow eaves load, settlement force of snow
(5) Others --- earth and water pressure, seismic effects, wind load, buffer load, ground displacement, effect of bearing point movement, construction load

Table 2-37 Target load for each shed type

Type of load			Snow shed	Earth shed	Rock shed
Dead load	Self-weight	P	+++	+++	+++
	Buffer material		-	+	+++
Snow load	Snow load	PP	+++	+	+
	Avalanche load	PA	+++	+	+
	Impact force of avalanche		+	+	+
	Debris load		+	+	+
	Snow eaves load		+	+	+
	Settlement force of snow		+	+	+
Fallen rock load	Impact force of fallen rocks	PA	-	+	+++
Debris load	Debris load	PA	-	+++	-
	Tractive force of flowing debris	PA	-	+	-
	Impact force of debris from collapse		-	+	-
Others	Earth pressure, water pressure	P	+	+	+
	Seismic effects	S	+++	+++	+++
	Others	PA	+	+	+

P: Primary load, S: Secondary load, PP: Special load corresponds to the primary load, PA: Special load corresponds to the secondary load,
+++: Taken into consideration, +: Taken into consideration when particularly affected from site conditions, -: Consideration is not required

Source:

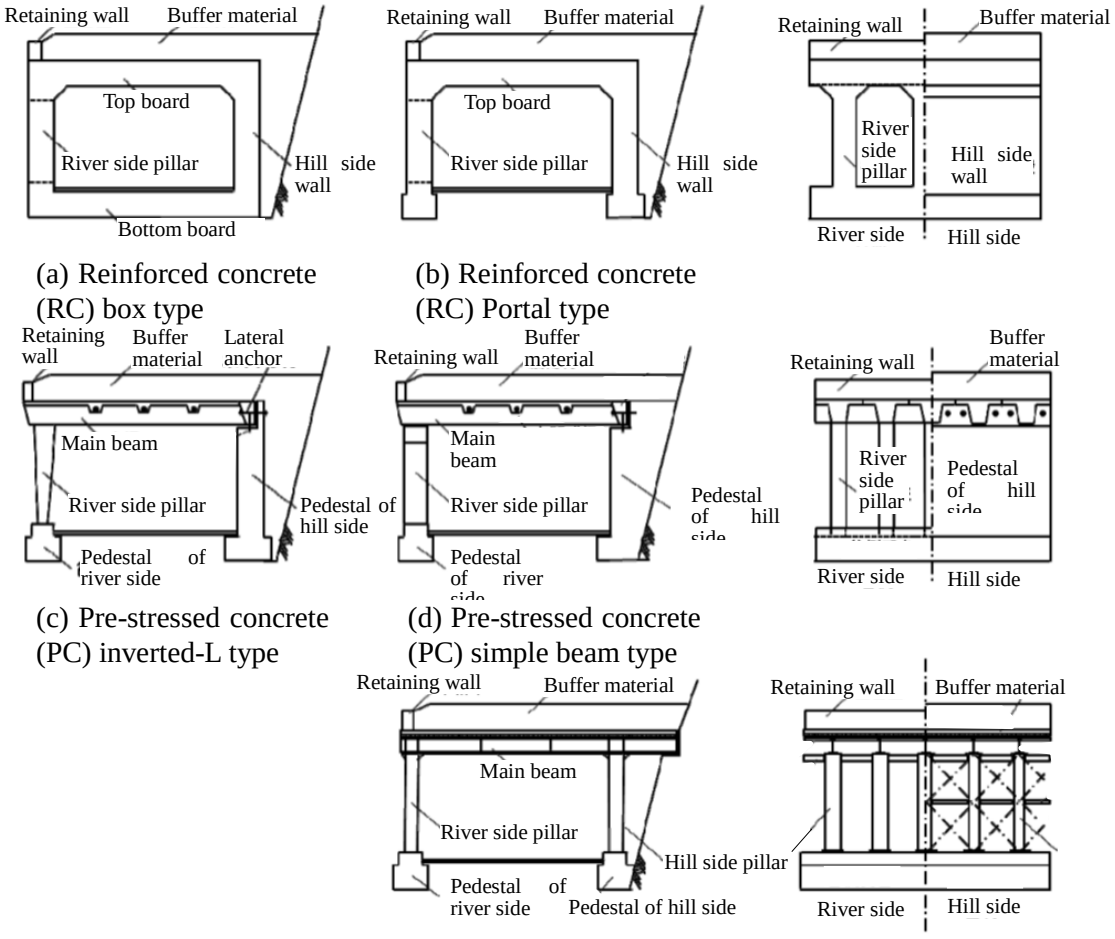
As shown in Figure 2-59, reinforced concrete (RC) box type and portal type, pre-stressed concrete (PC) inverted-L type of and steel inverted-L type are included in the structural types frequently used for sheds. In addition, there are PC portal type and steel portal type. For such types, as the load on hill side of shed is larger than the other side, it is desirable for the pedestal of hill side is to be formed by rigid RC wall structure. As large-sized vehicles have often damaged the braces, the batter brace type shed should not be applied unless special reasons exist. In addition, if snow

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cornice is expected at the entrance of sheds, snow cornice prevention fence should be installed to prevent dropping of snow to the road.

When considering the loads that flow on the roof of sheds, such as snow or debris, the standard gradient of roof should be set as 10 degrees based on the past experiences and workability. On the contrary, when the load flowing on the roof are not considered, the standard gradient of roof slope may be set as 5 %, considering drainage of water on the roof. For earth sheds, roof gradient of 10 degrees has an advantage in economic reasons.

Depending on site conditions, multiple types of loads, such as avalanche and fallen rocks, may be considered to act on a shed. For such cases, design of the shed should meet the requirement for each type of sheds.



(a) Reinforced concrete (RC) box type

(b) Reinforced concrete (RC) Portal type

(c) Pre-stressed concrete (PC) inverted-L type

(d) Pre-stressed concrete (PC) simple beam type

(e) Steel portal type

Figure 2-59 Standard structure of the sheds

Source:

As shown in Figure 2-60, placing pockets on the hill side is strictly prohibited. Such pocket may cause large lateral force against pedestal or retaining wall on hill side if avalanches, fallen rocks or debris flow strike it.

Such pockets should be backfilled and reshaped with the appropriate gradient of the roofs.

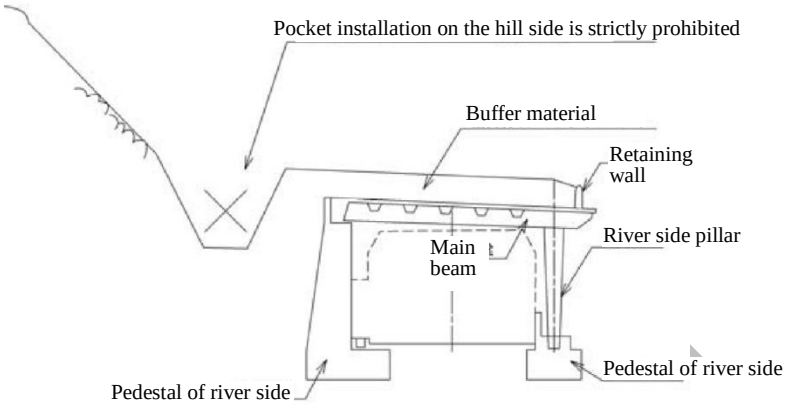


Figure 2-60 Illustration to explain the reason why the pocket should be for avoided between the hill slope and the shed

Source:

The design concept of rock shed is explained in the existing guidelines (State of The Art: Design and Construction of Rock Fall Mitigation Systems, Special Report 23, IRC Highway Research Board New Delhi, 2014).

The design concept for the earth shed is described in this section. For design of earth sheds, Table 2-37 requires consideration of load of flowing debris and impact load of debris from collapse, which is not considered for snow or rock sheds. The following shows how to calculate the load of flowing debris and the impact load of debris from collapse.

i) Load of flowing debris (Tractive force)

When flow of debris on the roof is assumed, the load of flowing debris (tractive force) should be considered. In terms of calculation, the load is divided into vertical and horizontal components as uniform loads to act on the shed. The load strength is calculated by the following equation.

$$q_{ev} = (1 + \mu_e \cdot \sin\theta \cdot \cos\theta) \cdot \gamma_e \cdot h_e \qquad (\text{kN/m}^2)$$

$$q_{eh} = \mu_e \cdot \cos^2\theta \cdot \gamma_e \cdot h_e \qquad (\text{kN/m}^2)$$

Where,

q_{ev} : Vertical component of load of flowing debris (kN/m^2)
q_{eh} : Horizontal component of load of flowing debris (kN/m^2)
h_e : Thickness of flowing debris (m)
μ_e : Kinetic friction coefficient of flowing debris
θ : Gradient of roof or buffering material of shed (degree)
e : Unit weight of flowing debris (kN/m^3)

The load of flowing debris means the tractive force that the debris flowing down the slope gives to the shed.

The thickness of flowing debris should be examined comprehensively from the site conditions. It is reported, however, that the thickness of flowing debris does not exceed the thickness before flowing.

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As for the unit weight of the flowing debris, an empirical value of 10 to 14kN/m3 is generally used. It is important, however, to comprehensively examine from the site conditions.

When debris flows on the roof, the coefficient of friction is considered not to exceed the coefficient of static friction. So, the coefficient of friction may be set referring to the static friction between the debris and the roof. The following formulae are reference:

Between soil and concrete,
Coefficient of friction:
$\mu = tan\left((2/3) \cdot \emptyset\right)$ (∅:angle of shear resistance of the ground)
Adhesive force: $c = 0$.
Between soil and soil, $\mu = tan\,\emptyset$.

ii) Impact load of debris from collapse

In principle, the impact of falling debris from collapse against sheds should be avoided. If it is inevitable, however, the impact force should be calculated by the following equations:

$$P = \left(\frac{\gamma_e}{g}\right) \cdot V^2 \qquad (\text{kN/m}^2)$$

$$P_V = P \cdot \sin^2(\alpha - \theta) \qquad (\text{kN/m}^2)$$

$$P_H = \mu \cdot P_V \qquad (\text{kN/m}^2)$$

$$t = \frac{T}{\sin(\alpha - \theta)} \qquad (\text{m})$$

Where,

P : Impact load of debris fall (kN/m^2)
PV : Vertical component of impact load of debris fall on the roof (kN/m^2)
PH : Horizontal component of impact load of debris fall on the roof (kN/m^2)
t : Width of impact force of debris fall on the roof (m)
e : Unit weight of debris fall at a time of strike (kN/m^3)
V : Impact velocity of debris fall (m/sec)
g : Gravitational acceleration = 9.80665 (m/sec^2)
α : Gradient of slope (degree)
θ : Gradient of roof (degree)
μ : Kinetic friction coefficient of debris fall
T : Thickness of debris fall in the direction perpendicular to the slope (m)

The impact load of debris fall is the impact force acting on a shed as in Figure 2-61 when the debris fall flows down. To calculate impact force of debris fall, impact velocity is necessary. For the calculation of impact velocity, several formulas including Fukuoka's and Ikuta's are proposed. Ikuta's formula is explained below:

$$V = \sqrt{2g \cdot h} \qquad (\text{m/sec})$$

Where,

h: Vertical falling height of debris (m)
g: Gravitational acceleration=9.80665 (m/sec^2)

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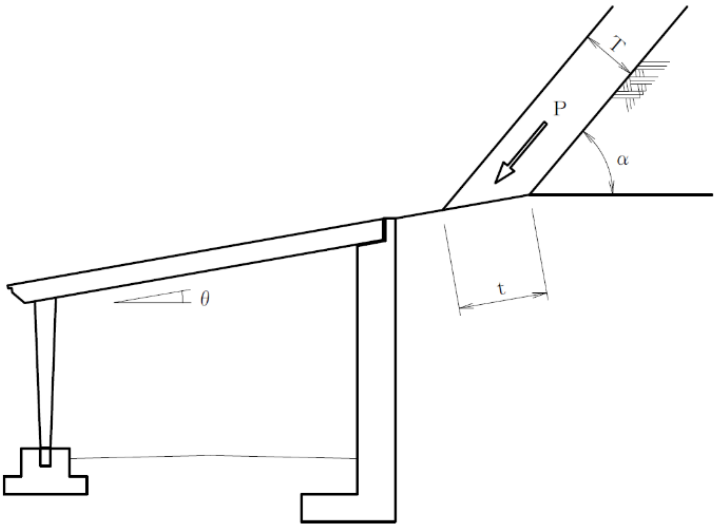


Figure 2-61 Impact load of debris falls

Source:

(ii) Sabo Dam for Debris Flow

Classifications

Sabo dams are the most common countermeasure against debris flow. They are generally constructed from masonry, concrete, reinforced concrete, steel cribs, etc. Figure 2-62 diagrammatically illustrates the dam section and nomenclature. Sabo dams are classified into the following five types according to their purpose.

i) Spur consolidation dam
ii) Riverbed erosion control dam
iii) Riverbed sediment runoff control dam
iv) Debris flow control dam

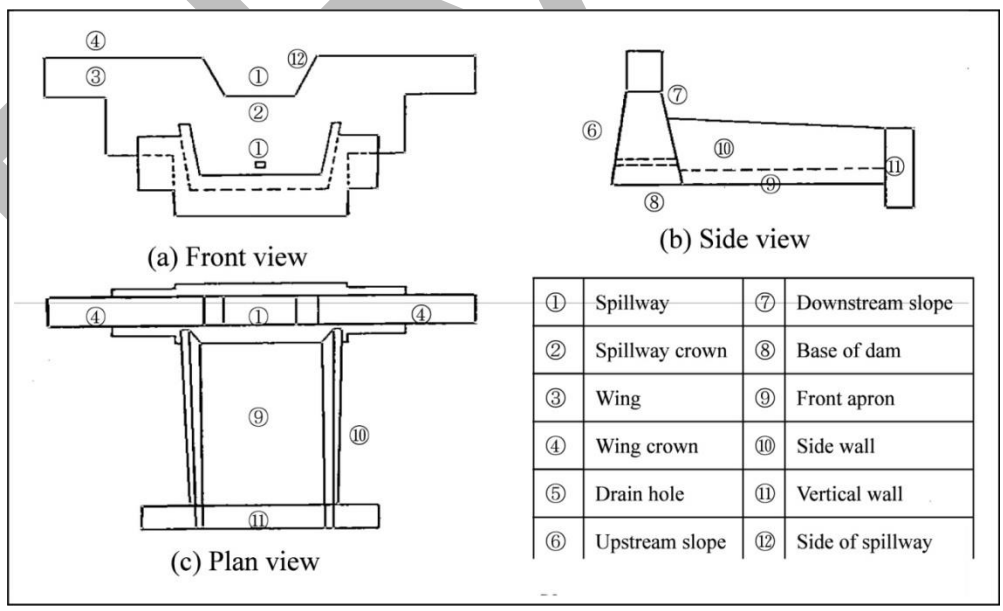


Figure 2-62 Diagrammatical Dam Section and Nomenclature

[14]

i) Spur consolidation dam

A spur consolidation dam prevents hillside failure and further collapse of an adjacent area by raising the riverbed at a spur (hillside foot) through the accumulation and consolidation of sediment (Figure 2-63). It is constructed immediately below the hillside to be protected from erosion. The height of the dam should be adequate to contain the projected sediment volume.

ii) Riverbed erosion control dam

A riverbed erosion control dam prevents riverbed erosion and sediment production (Figure 2-64). It is constructed immediately downstream of a riverbed erosion area. Its height should be adequate to contain the riverbed erosion and sediment accumulation areas.

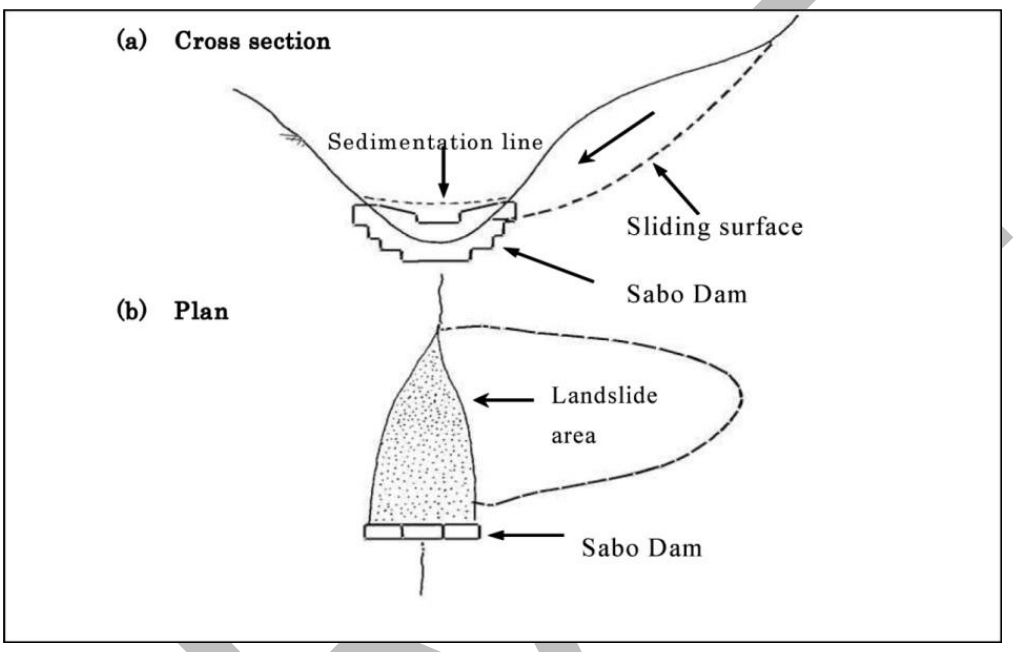


Figure 2-63 Typical Example of Landslide Stabilized by a Sabo Dam

[14]

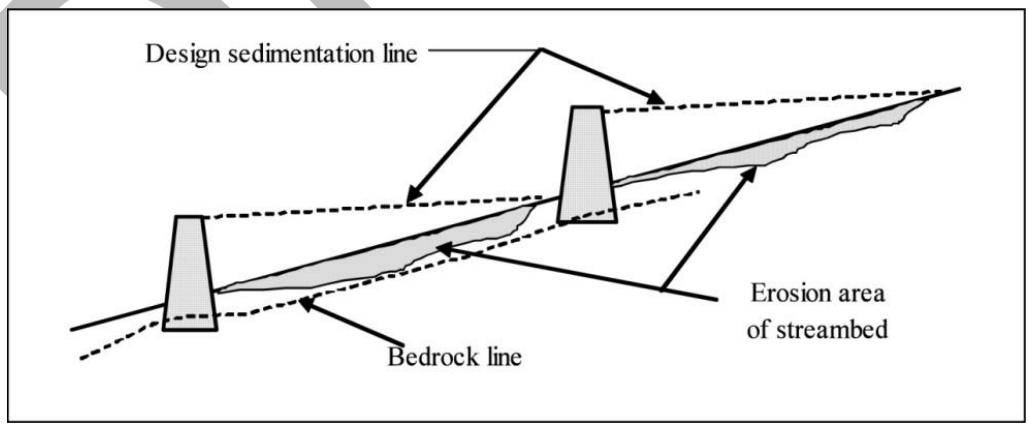


Figure 2-64 Stepped Dams for Riverbed Erosion Control

[14]

iii) Riverbed sediment control dam

Similar to a riverbed erosion control dam, a riverbed sediment control dam prevents further transport of unstable sediments that have accumulated on the riverbed. It is constructed immediately downstream of the accumulated riverbed sediments. The

height of the dam should be adequate to contain the riverbed sediments within the accumulation area.

iv) Debris flow control dam

A debris flow control dam prevents or controls debris flow sediments. Its location and height is determined according to its purpose, such as prevention and elimination of debris flow.

In planning a sabo dam for the prevention of debris flow, its accumulating capacity is determined to provisionally be more than 30% of the design excess sediment that causes debris flow. For eliminating debris flow, the location, height, shape and number of dams should be able to change debris flow area into a bed-load area.

Purpose

Sabo dams are implemented to (i) prevent erosion and toe failure of potentially unstable slopes; (ii) prevent and eliminate damage from debris flow; and (iii) improve the stability of a slope through sedimentation behind the dam.

Design Considerations

In designing a sabo dam, the location and scale (height and section) of the dam is determined according to its purposes. The height of dam is sometimes restricted by the geological and topographical conditions at the dam's location, and therefore these should be given due consideration. In principle, the dam is located on stable ground beyond the unstable area because sabo dams are easily destroyed by slope failure when constructed in an unstable area. Locating the dam in a narrow section with a wider section upstream is desirable for improving cost-effectiveness. Also, the sabo dam should be located close to the related road. Sabo structures are designed according to the intended functions/purposes and should be stable enough to withstand all the expected design forces. Figure 2-65 gives the general design procedure for a sabo dam for debris flow.

In designing the opening section for debris flow, the width of the crest opening, generally over 3m, should be determined on the basis of the width of the existing streambed. The height of the opening is determined considering the design depth, freeboard and the maximum diameter of the boulders expected to be contained in the debris flow. The design of the dam body is based mainly on the stability analyses of the dam body in terms of overturning, sliding and foundation bearing resistance. The general criteria for stability analysis for sabo dams are given in Table 2-38. Stability against the settlement of the foundation ground as well as the potential for the dam base to slide across the foundation ground should be considered.

Table 2-38 Criteria for Stability Analysis of a Dam Body

Item	In Normal Case	In Seismic Case
l) Overturning	$e \leq B/6$	$e \leq B/3$
2) Sliding	$Fs \geq 1.5$	$Fs \geq 1.2$
3) Bearing capacity	$Fs \geq 3.0$	$Fs \geq 2.0$
4) Compressive strength	$Fs \geq 3.0$	$Fs \geq 2.0$

Note: e = Acting range of resultant, Fs = Factor of safety, B = Base width of dam body.

Edited from [22]

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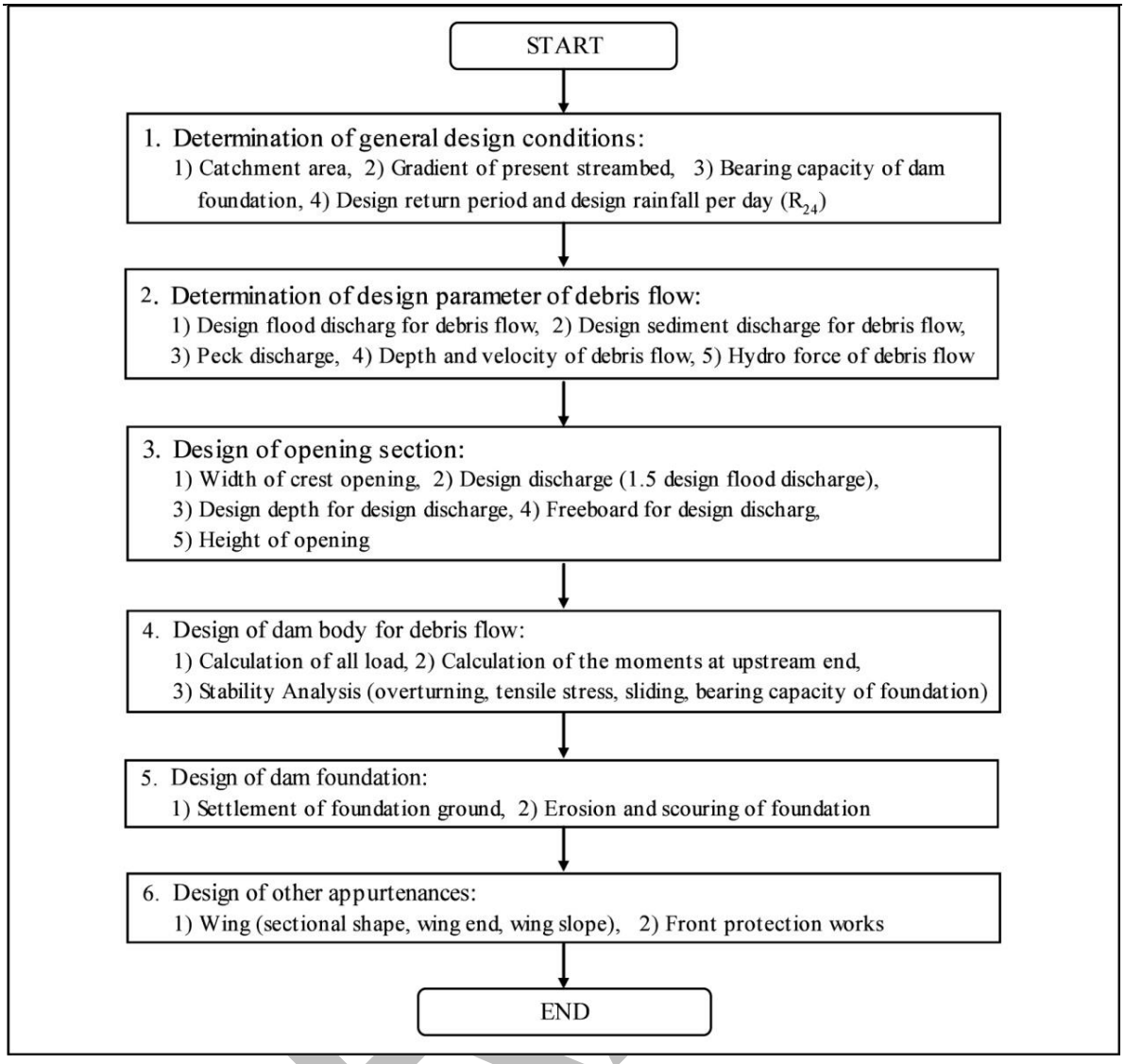


Figure 2-65 Design of Sabo Dam for Debris Flow

[14]

The combination of loads to be used for the stability calculations of the dam section for sabo dams considering the debris-flow hydro force are summarized in Table 2-39. The unit weight of mud water in the calculation of the hydrostatic pressure in a debris flow should be 11.8 kN/m3 because the earth and uplift pressures are not considered.

Table 2-39 Combination of Loads for Stability Calculations of a Dam Body

Dam height	During ordinary time	During debris flow	During flood
Less than 15 m		・Hydrostatic pressure ・Earth pressure ・Debris-flow hydro force	・Hydrostatic pressure
More than 15m	・Hydrostatic pressure ・Earth pressure ・Uplift force ・Inertial force during earthquake ・Dynamic water pressure during earthquake	・Hydrostatic pressure ・Earth pressure ・Uplift force ・Debris-flow hydro force	・Hydrostatic pressure ・Earth pressure ・Uplift force

[14]

The foundations of a dam, especially where the height of the dam exceeds 15 meters, should be determined in consideration of the bearing capacity and permeability of the foundation rock. When the dam foundation conditions are poor, foundation treatment should be considered. The height from the base of the dam to the crown of the overflow section (dam height) should be determined by considering the ground conditions, the proposed sediment discharge and the purpose of the dam.

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2.6.6 Introduction of design technologies for light-weight embankment

Light-weight embankment is useful filling method to widen hill roads and restore damaged hill road. The application and features of light-weight embankment are explained in Chapter 2.2.3, including three representative types of the works and its properties.

The details of design of each method should be referred to the respective provider of each method. In this section, important points in design of light-weight embankment are explained when it is applied to hill roads.

(1) General Requirement

Typical drawing of light weight embankment is shown in Figure 2-66.

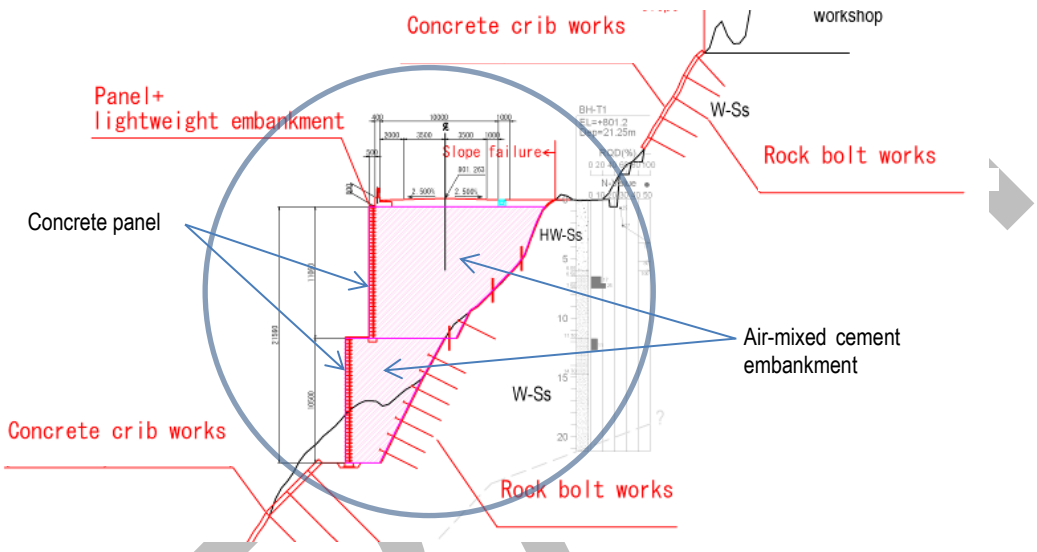


Figure 2-66 Typical Drawing of Light-weight Embankment (Air-mixed Mortar)

[23]

When light-weight embankment is used for hill roads in a manner like Figure 2-66, the following considerations should be made during the design:

- Stabilization of the slope behind light-weight embankment by other works
- Treatment of spring water from the slope behind
- Treatment of surface water infiltrating into embankment body
- Fixing of embankment body to the ground
- Considerations required for retaining wall
- Precautions against shrinkage cracks of concrete (for air-mixed cement / mortar)

(i) Stabilization of Behind Slope

Light-weight embankment itself is not countermeasures against slope failure or landslide. Thus, if stability of the slope behind the light-weight embankment is in question, it should be secured by other measures.

Rock bolts / soil nailing is widely used for the purpose. The typical drawing in Figure 2-66 shows rock bolts for the lower part of the slope behind.

Since maintenance and of pre-stress applied to ground anchors is required, ground anchors should not be adopted for stabilization of the slope behind.

(ii) Treatment of Spring Water from Behind Slope

If groundwater spring and/or seepage are expected on the slope behind, it should be immediately drained with proper treatment. Groundwater from behind slope causes deterioration of light-weight embankment or buoyancy which may destruct the embankment.

To drain groundwater immediately, drainage material, such as geotextile drainage mat as shown in Figure 2-67, should be applied before applying shotcrete or tarpaulin (impermeable seat) to the slope. The drainage board should cover entire areas of groundwater spring / seepage.

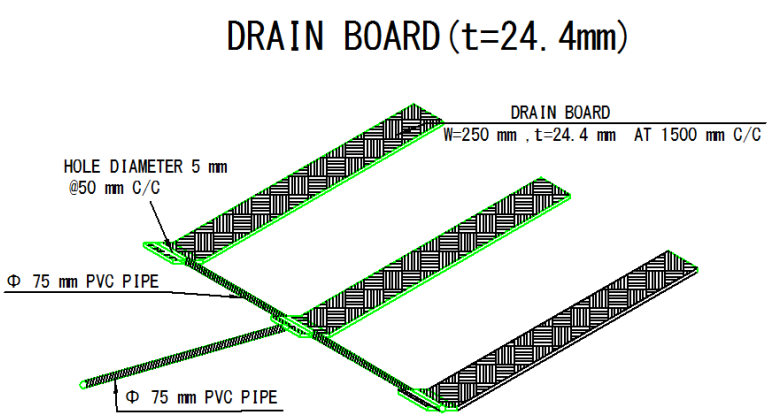


Figure 2-67 Example of Drainage Board

[23]

The collected groundwater by drainage boards should be drained outside of the embankment through drainage pipe installed at the toe of the slope behind and the foundation of the embankment, such as shown in Figure 2-68.

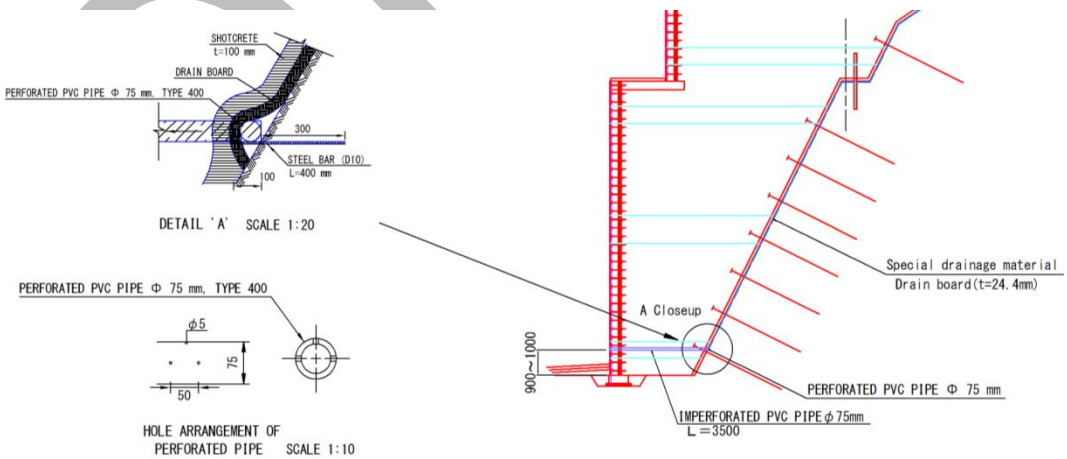


Figure 2-68 Drainage Pipes Connecting to Drainage Board

[23]

After applying drainage sheets and drainage pipes, to protect the surface of behind slope and avoid water infiltration, shotcrete or impermeable seat should be applied to entire slope behind.

(iii) Treatment of Surface Water Infiltrating into Embankment Body

The infiltrated water from the surface into light-weight embankment may deteriorate the body of light-weight embankment. Thus proper sealing, such as impermeable liner seat or sealing concrete, should be made on the top of embankment body.

(iv) Fixing of Embankment Body to the Ground

Due to its light weight, light-weight embankment should be tightly fixed to the ground, with helps of tie rods connecting to the head of rock bolts, anchor bars, and dowel bars.

(v) Considerations Required for Retaining Wall

In the design of light-weight embankment, when it is applied as shown in Figure 2-66, considerations for retaining wall should be examined, such as stability, sliding, overturning, and bearing capacity of the foundation.

(vi) Precautions against Shrinkage Cracks of Concrete (for air-mixed cement / mortar)

For the light-weight embankment with air-mixed cement or mortar, precautions against shrinkage cracks should be considered in the design, such as joint filler installed vertically and wire-mesh installed horizontally at certain intervals.

(2) Reference for Air-mixed Cement or Mortar

Air-mixed cement or mortar is useful for establishing light-weight embankment for hill roads for its flexibility to use locally available material and conventional concrete plant. In this section, basic design information for FCB Method using air-mixed cement or mortar is briefed for reference.

(i) Unconfined Compression Strength of Design

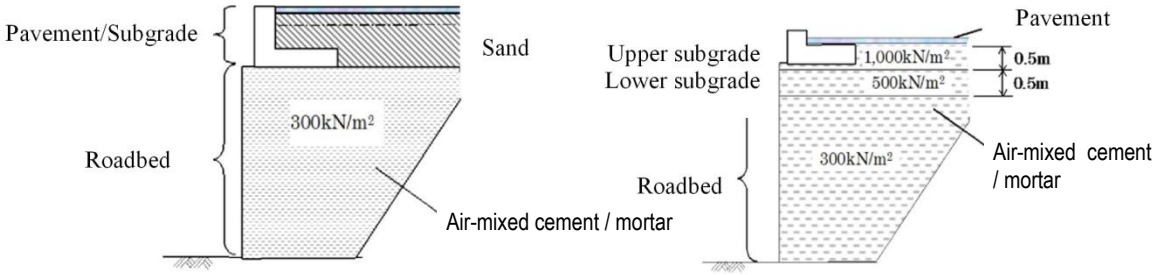
Design unconfined compression strength of air-mixed cement / mortar for subgrade and embankment for hill roads is shown in Table 2-40.

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Table 2-40 Design Unconfined Compression Strength Subgrade and Embankment

Item	Design unconfined compression strength qck	Remarks
Upper subgrade	1,000 kN/m^2	
Lower subgrade	500 kN/m^2	
Embankment Body	300 kN/m^2	I

[24]



Standard Including Subgrade

Figure 2-69 Embankment Structure with Air-mixed Cement / Mortar for Hill Road

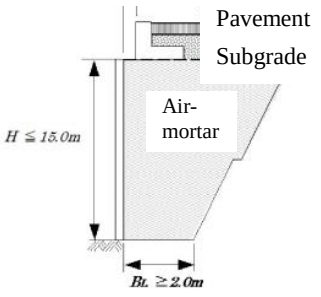
[24]

(ii) Typical Shape of Air-mixed Cement Embankment for Hill Road.

Table 2-41 shows a typical shape of air-mixed mortar embankment for hill road.

Table 2-41 Typical Shape of Air-mixed Cement Embankment for Hill Road

Items		Coverage	Remarks
Critical height	H_{max}	15.0 m	When H>15 m, application should be closely examined
Minimum base width	BL	2.0 m	When BL<2.0 m, application should be closely examined.
Minimum thickness		0.5 m	Except for cavity filling
Clearance		0.5 m	
Section		Margin width 0.5 m	



[24]

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(iii) Unit Weight by Provisional Trial Mix

The unit weight of the air-mixed cement/mortar with provisional trial mix is shown in Table 2-42.

Table 2-42 Unit Weight of Air-mixed Cement / Mortar (Flow Value: 180 mm)

Mix proportion	Design unconfined compression strength qu (kN/m^2)	Unconfined compression strength predicted value qup (kN/m^2)	Air content (%)	Water cement ratio W/C (%)	Unit weight (kN/m^3)
K0-3	300	500	66.5	92.0	5.1
K0-5	500	700	64.0	88.0	5.5
K0-8	800	1000	61.0	84.0	6.1
K0-10	1000	1200	59.5	82.0	6.3

[24]

(iv) Design Safety Factor

Design safety factors for the stability of air-mixed cement / mortar embankment are shown in Table 2-43.

Table 2-43 Design Safety Factors for Lightweight Embankments

Internal stability (safety factor for the strength)	Long period		3.00
External stability	Sliding	Normally	1.25
		At earthquake	1.00
	Overturning	Normally	$e \leqq b/6$
		At earthquake	$e \leqq b/3$
	Landslide on slide area		1.20
	Floating		1.20
	Bearing capacity of ground		3.00

[24]

(v) Fixing Material and Accessories

Figure 2-70 illustrates arrangements of fixing material and accessories.

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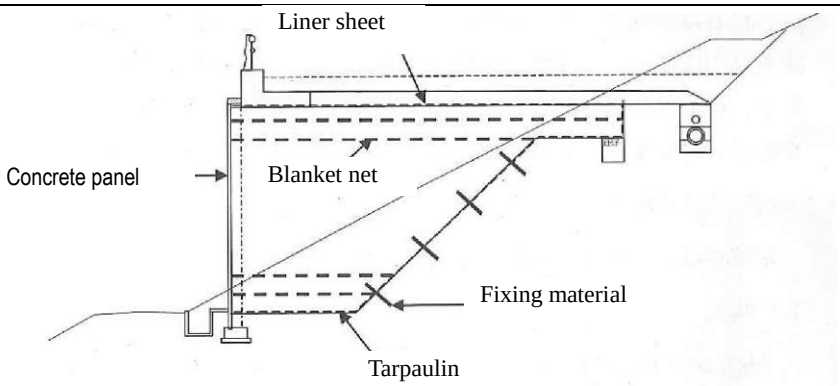


Figure 2-70 Fixing Material and Accessories for Air-mixed Cement / Mortar Embankment

[24]

As the fixing material, steel pipes are often used. In addition to the fixing material in the figure, tie rods connecting concrete panel and heads of rock bolts are used if rock bolts are installed for stabilization of behind slope.

(vi) Structural Items and Accessories

Structural items and accessories for air-mixed cement / mortar embankment are shown below.

Table 2-44 Structural Items and Accessories for Air-mixed Cement / Mortar Embankment

Items		Examined aspects, setting parameters	Remarks
Structural items	Margin width	0.5 meters margin between the face of concrete panel of air-mixed mortar embankment and guard wall should be secured.	Design construction guideline for foamed cement banking method, p. 33
	Guard wall	Strength, structural element, and foundation of guard wall should be reviewed.	Design construction guideline for foamed cement banking method, p. 34
Accessories	Blanket net	Installed on the top, interval and bottom of air-mixed mortar embankment.	Prevention of cracks
	Impermeable liner	Placed across the full width of the top surface of the air-mixed mortar embankment.	Prevention of infiltration of surface water prevention of weathering
	Tarpaulin	Installed over the entire surface of the slope behind.	Prevention of infiltration of ground water prevention of weathering
	Joint filler	Placed every10 meters.	Prevention of cracks
	Fixing material	Rock bolts and/or steel pipes shall be used. Tie rods connecting concrete panel and head of rock bolts are often used.	Improved connection between air-mixed mortar embankment and the ground
	Drainage facilities	Placed in front of the concrete panel and at the toe of slope behind air-mixed mortar embankment..	Stability of embankment and prevention of deterioration

[23]

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Ministry of Road Transport and Highways
India

Japan International Cooperation Agency (JICA)

Capacity Development Project on Highways in Mountainous Regions

GUIDELINE FOR SLOPE PROTECTION AND EMBANKMENT WITH ADVANCED TECHNOLOGY

DRAFT

August 2019

Oriental Consultants Global Co., Ltd.
Kokusai Kogyo Co., Ltd.
East Nippon Expressway Co., Ltd.
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List of Abbreviations and Acronyms

BRO	Border Roads Organization
C/P	Counterpart
C/R	Completion Report
EPC	Engineering, Procurement and Construction contract
GNSS	Global Navigation Satellite System
GoI	Government of India
IAHE	Indian Academy for Highway Engineer
JCC	Joint Coordination Committee
JICA	Japan International Cooperation Agency
MoRTH	Ministry of Road Transport and Highways
MS	Monitoring Sheet
NHDP	National Highways Development Project
NHIDCL	National Highways and Infrastructure Development Corporation Ltd.
OJT	On-the-Job Training
OSV	On Site Visualization system
PDM	Project Design Matrix
PO	Plan of Operation
PPP	Public Private Partnership
PWD	Public Works Department
R/D	Record of Discussion
TG	Technical Group
TOT	Training of Trainers
WP	Work Plan

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CHAPTER 3 CONSTRUCTION

3.1 Cutting / Slope Protection / Stabilization Works

3.1.1 Construction Safety

Construction of hill road is affected by topographic and weather conditions particular to hilly area, and thus more dangerous than that for the roads on flatlands. Progress of the works at construction site, therefore, may often delay from planned work schedule. For the construction of hill roads, in addition to the severe natural conditions, social conditions such as supply of materials, costs for transportation and temporary works, and personnel assignment are also restricted compared to the construction in urban and suburban areas on flatlands, and may cause delays in work schedule.

Constructions on hill slopes are generally under complexed situation, where several types of works proceed simultaneously. If such works suffer from insufficient labors, unsafe circumstances, or unreasonably short work schedule, therefore, accidents may arise from sudden or unscheduled changes to the coordinated process among the simultaneous works. As described above, in the construction of hill roads, extra attention should be paid for the safety of the works.

The purpose of this section is to deepen the understanding of construction managers and workers on the safety measures which should be applied to the construction sites of hill roads to assure safe implementation of the works. The contents of this section are as follows:

(1) Basic recognition of dangers at construction sites on hill slopes
- Danger of construction site on hill slopes
- Causes of accidents at construction sites on hill slopes
- Measures against such accidents

(2) Approach to assure safety in construction on hill slopes
- Points to keep high level of safety and quality of construction and construction plan to realize such purposes
- Framework and contents of construction plan
- Methods for construction management

(3) Safer methods for construction of hill slopes
- Top-down construction method
- Installation of h-shaped steels or sheet piles to hill slopes
- Safety measures for cutting slopes
- ICT (Information and Communication Technology) construction

(1) Basic Recognition of Dangers at Construction Sites on Hill Slopes

Accidents at construction sites are induced by factors peculiar to each site and caused by triggers of inappropriate response and behavior of workers against the factors. In the construction sites of hill roads, accidents often occur due to circumstances peculiar to slopes, such as steep slope, weak bearing resistance of shoulder of slope, and narrow flat working area on slope. For example, construction

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workers fall from a height or being pressed by fallen/toppled construction machines or material are particular accidents to the sites on slopes.

Risks of accidents in construction sites are evaluated by scale and number of accidents, and efforts to reduce small accidents on a daily basis lead to reduction of serious accidents. In order to carry out the works on slope safely, in addition to improving working circumstances to eradicate unsafe factors from the sites, safety training of workers is required, which instructs workers to actively avoid dangers on site and to discipline them to stop their dangerous actions and behaviors at the sites on slope.

In addition, keeping smooth communication among managers and workers of construction team is essential. Daily hazard prediction training is effective as well.

(i) Danger of Construction Site on Hill Slopes

Generally, the most frequent fatal accident in road construction is "falling down from a height". Then "accidents caused by construction machines", "traffic accidents", and "accidents caused by landslide" follow. These accidents frequently occur at construction sites on slope as well.

In particular, the following trends are indicated for the accidents related to the construction on slopes:

- Many accidents of falling down occur during the construction of shotcreting and netting of slopes.
- In addition, accidents during construction of stone masonry, gabion wall, and retaining wall accounts for the most parts of the accidents caused by landslide. The causalities are hit by fallen rocks and debris from upper slope or buried by collapse of shoulder of upper slope.

[1]

Furthermore, the following trends are pointed out regarding the accidents caused by collapse of slopes during excavation:

- About 70% of the accidents occur during construction of retaining walls.
- Accidents frequently occur on the steep slope with a gradient of 1H2V or steeper.
- Accidents due to small collapse of less than 50 cubic meters frequently occur.
- In many cases, rainfall is recorded within three days before accidents.

[2]

As mentioned above, the works on hill slopes is especially dangerous among the various road constructions. Thus, from the viewpoints of safety management, construction managers and workers who are involved in the works on hill slope should recognize the particular dangers of the works on hill slopes along with its features, such as cause of and measures against the accidents.

(ii) Causes of Accidents at Construction Sites on Hill Slopes

i) Factors and Triggers of Accidents Relating to Construction on Hill Slopes

Recognizing factors and triggers of possible accidents at construction sites are important for prevention of accidents. For example, regarding an accident of falling from a height at a construction site on slope, the following causes are assumed:

- "Workplace was at a height and footing was unstable"
- "If the victim properly recognized the situation that the stage was unstable and the possibility of falling down, he may have worn a safety helmet and a safety belt properly. In that case, the accident may be avoided."

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For this case, a relation between a factor and a trigger of the accident is summarized as below:

"Workplace was at a height and footing was unstable" ====>[Factor]
“Proper safety measures were not taken” ====>[Trigger]

The relationship between the factor, the trigger and the result (accident and disaster) is shown below.

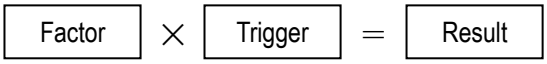


Figure 3-1 Law of Cause of Result

[3]

Recognizing factors of accidents at construction site means to grasp hidden dangers of the site.

Assuming works on hill slopes, if a slope is considered "prone to collapse” and the works on such slope is regarded as “footing is unstable”, these conditions should be recognized as factors. Thus measures should be planned and implemented as much as possible.

Change of conditions may make a hidden factor tangible. In case a slope has a spring at its toe and quantity of spring water is small under normal weather but sudden increase in the quantity of spring water is assumed once rainfall comes, such slope should be recognized as a factor of an accident. So the construction should pay caution to such slopes.

Recognizing triggers of accidents means to understand which types of unsafe actions/non-actions trigger accidents. By improving or stopping such unsafe actions/non-actions recognized as triggers, accidents can be prevented.

Assuming works on steep hill slopes, if an experienced worker may climb up the slope without wearing safety equipment properly, such as safety helmet and belt, such actions should be recognized as a triggers of an accident. If the experienced worker loses the footing and falls from the slope, the accident of falling down happens as a result. Although one can climb steep slopes without wearing safety equipment, such unsafe actions should be avoided. By wearing safety helmet and belt properly, the trigger of the accidents of falling down is removed and the accident can be prevented.

Factors and triggers of accidents at construction sites are of great variety, however. Examples of such factors and triggers are shown in Figure 3-2. Not only natural conditions of a site but various conditions, situation, and circumstances surrounding workers may cause accidents.

In most cases, factors are difficult to control but triggers are relatively easier to control. Thus construction managers and workers should pay their efforts to eliminate factors and triggers which are under their control.

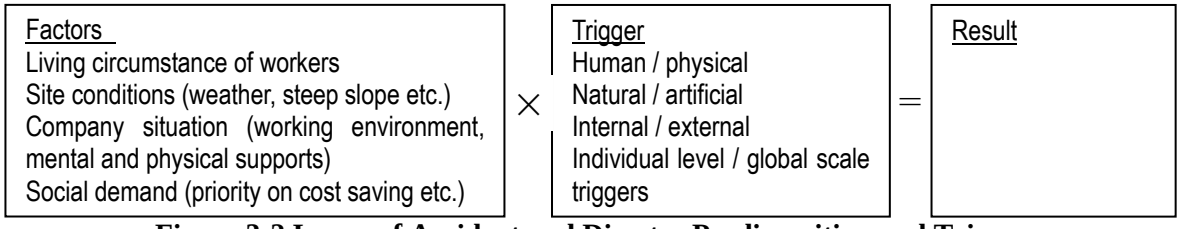


Figure 3-2 Image of Accident and Disaster Predisposition and Trigger

[3]

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ii) Reducing Risks of Accidents

In order to reduce a risk of a fatal accident, preventing minor accidents is effective.

"Risk" is a degree of danger at a site and calculated by multiplying frequency by scale of an accident. Theoretically the risk of a site with frequent minor accidents is similar to that with a few fatal accidents. By preventing minor accidents, the risk of a site is reduced; the risk of a fatal accident is also reduced.

Risk (consequence/unit of time or space)	=	Frequency (event/unit of time or space)	×	Magnitude (Consequence/event)

Figure 3-3 Formula of Degree of Risk

[4]

Regarding the possibility of accidents, Heinrich's Law provides valuable suggestion. The famous “safety pyramid” or the “accident triangle” illustrates Heinrich's Law or “the 300:29:1 theory”, which implies a fatal accident occurs in the situation where lots of minor accidents happen. In other words, accumulation of minor accidents leads to a fatal accident.

From this point, reducing minor accidents or incidents effectively works to prevent a fatal accident.

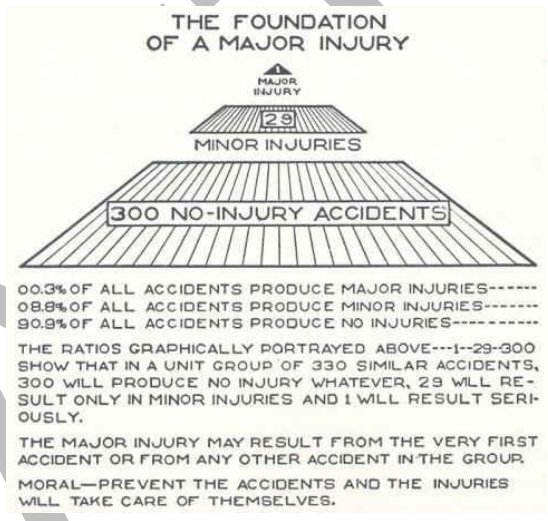


Figure 3-4 Foundation of a Major Injury

[5]

(iii) Measures against Accidents at Construction Sites on Hill Slopes

i) Measures against Factors; Safety Management Based on Circumstances Surrounding Construction Sites on Slope

Factors of the accidents at slope construction sites are not limited to unfavorable conditions of slopes as discussed above. Various conditions, situation, and circumstances surrounding a construction site and workers may cause accidents, such as living and working circumstances of managers and workers, supports provided by companies, and social demands of priority on cost reduction. In other words, not only unfavorable natural conditions of the site but unfavorable social circumstances may lead to an accident.

By improving such conditions and circumstances, a risk of accident can be reduced. During construction, therefore, after evaluating the factors surrounding the site, construction managers should improve such conditions and circumstances as much as possible.

ii) Measures against Triggers; Measures Required to Avoid Accidents by Eliminating Elements Which May Cause Accidents

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At the construction sites on slopes, although available precautions against the tangible factors of accidents are implemented as much as possible, substantial factors still remains on slopes. Under such circumstances, risks of accidents will increase if workers need to bear severe burden in carrying out their works on slopes. If workers need to work overtime so long, their fatigue makes them careless about danger of the works, which may trigger an accident. Also, insufficient safety equipment at work may lead to falls and injury accidents.

Such triggers of accidents should be eliminated as much as possible from the construction site by the construction managers as long as their responsibilities allow. At the same time, workers are required to make their efforts to improve their behaviors and actions not to cause accidents. Accordingly both construction manager and workers should learn which kinds of behaviors lead to accidents at the construction site.

iii) Effectiveness of Risk Communication

Among measures to prevent accidents, the following three perspectives are important:

(a) Taking measures in advance to prevent an accident
(b) Promote risk management assuming an actual accident
(c) Taking measures to prevent recurrence of the accident

Risk communication is important to effectively progress with “risk prevention", “risk management” and “recurrence prevention”. According to Donna Laquidara-Carr (2017), Toolbox Meeting (TBM) is considered the best way for workers as the most effective way to convey safety messages to workers at construction sites.

TBM is a meeting where problems of the contents and process of the works of the day are discussed among construction managers and workers. Communication on the safety among construction managers and workers, which is called “risk communication”, is very effective for securing safety on site.

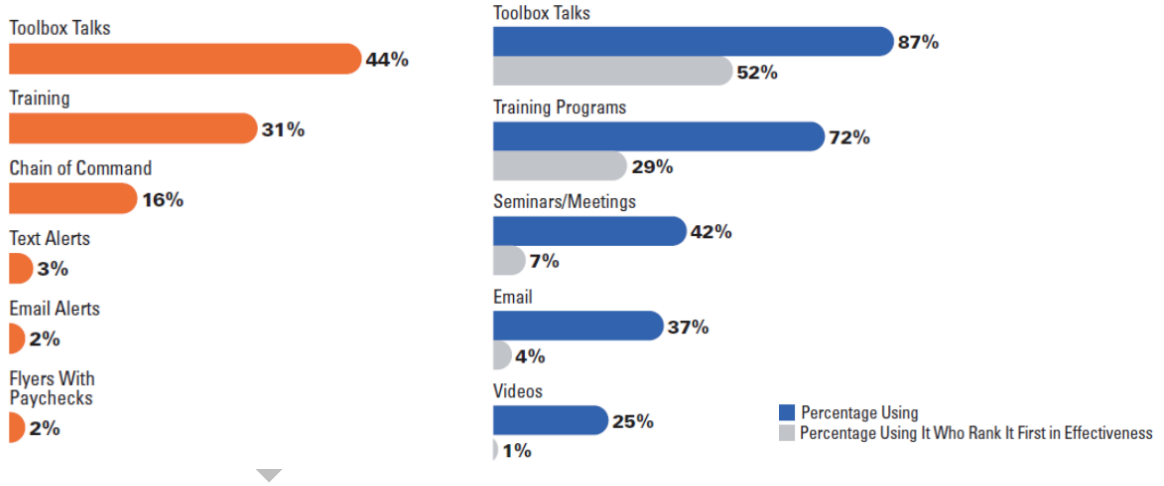


Figure 3-5 Method for Communicating Safety Message Ranked First (Left), Top Methods for Providing Information on Safer Tools, Equipment, Materials and Processes (Right)

[6]

iv) Risk Prediction Activity

As mentioned above, workers' actions and behaviors are important triggers of accidents. Although a worker intentionally avoids dangerous actions, an unintentional human error may trigger accidents. Negligence of safety procedures, which often arises from the demand of cost reduction in the forms of reducing time and labor force and omitting procedures, may lead to unintentional human errors. So is lack of careful

attention due to repeated works and long experience of workers. To reduce unintentional human errors as much as possible, risk prediction activities at construction sites are effective.

This activity is an effort to raise worker's sensitivity to dangers and concentration to solve problems and to motivate them to practice the solutions to the problems. This activity includes discussion within a small group of hidden dangers in a work place and their tangible signs as well as consequence arisen from such dangers. The discussion is made with pictures of the works to be discussed or after actual experience of the works by members of a small group, in which deep and candid discussion is encouraged. After finding out dangerous points and/or setting up important safety procedures, the member of the small group again confirms such points and procedure by pointing and calling, pointing out by their fingers and calling in a harmonized manner the points and procedure they acknowledged.

A risk prediction activity should be carried out by a construction team before executing the actual works, based on the four steps (or methods) listed below.

- Round 1: What are the hidden dangers?
  (Understanding the actual situation)
- Round 2: These are the dangerous points.
  (Investigating the nature of the works and its dangers)
- Round 3: What would you do to deal with the dangers?
  (Establishing solutions)
- Round 4: We will do this. (Setting actions for the solutions)

[7]

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(2) Approaches to Construction Safety on Hill Slopes

In this section, the approaches for safety implementation of works on hill slopes are explained.

For securing safety of construction works on hill slope, in addition to understanding dangers of the site, dealing with conditions specific to hill slopes is required, which is more complicated than that in flat lands. Once an accident occurs, due to severe conditions of slopes, damage to workers and third parties, if any, as well as construction equipment and temporary and permanent works tends to heavier than that in flat lands. Such damage inevitably affects schedule, quality, and cost of the works and thus endangers fulfillment of the requirements of the civil work contract.

The goal of a construction project is to complete the works with the required quality, within the planned schedule and cost, and without accidents. For that purpose, proper management is required for schedule, quality, and cost, in consideration of construction safety.

To meet the above necessities, three approaches for construction safety are explained below with specific measures for each.

- Planning approach to ensure safety and quality in construction
  ... Construction management plan with consideration for safety
- Construction management plan
  ... Plan to secure quality and safety
- Implementation of Construction Management Plan
  ... Actual management of construction site based on construction management plan

(i) Planning Approach to Ensure Safety and Quality in Construction

A construction project should execute the required works with required quality within the limited costs and schedule. For that purpose, a construction project should properly manage the “5Ms”, sometimes the “7Ms” as follows:

1 Manpower
2 Material
3 Method
4 Machinery
5 Money for 5Ms

6 Measurement
7 Mother Nature (means environment) for 7Ms

A project for hill road construction should also properly manage the “5Ms” or ‘7Ms”.

A plan for such management of the “5Ms” or ‘7Ms” under limitation of civil works contract is a “construction management plan”, on which “construction management” should be implemented.

[8]

(ii) Construction Management Plan

Construction management plan is a plan to execute the works based on the contract documents, and a part of management cycles of planning, implementing and controlling the project.

A construction management plan is prepared through "preliminary survey", "basic plan", "detailed plan", and “management plan". Among them, "detailed plan",

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and “management plan" are the main part of a construction management plan and "preliminary survey" and "basic plan" are preparation for a construction management plan.

	＜Purpose＞	＜Contents＞
1.preliminary survey	Clarification of issues and points of concern of the construction site for safe and secure implementation of construction management plan	・ Natural condition survey ・ Survey for conditions of transport, resources, material, labor, land, rights, and laws and regulation ・ Other necessary surveys for construction
⇩		
2.basic plan	Outline program for the project including solution for the issues and points of concern highlighted in preceding preliminary survey.	・ Comparison among applicable methods for the project ・ Evaluation of combination of machinery and its cost effectiveness
⇩		
3.detailed plan	Organize detailed plans for each process in the schedule, including input of resources.	・ Examination of detailed construction methods for each work item/process ・ Organize necessary resources, such as manpower, material, machinery, temporary works, and working funds for each work item/process
⇩		
4.management plan	Organize management plan for implementation of the preceding detailed plans	・ Formulation of plans for feasible management of organizations, manpower, safety, schedule, costs, quality, and environmental consideration.

Figure 3-6 Preparation Process of Construction Management Plan

(JICA Project Team)

The relations among the “7Ms” to manage in a construction management plan and the 3 planning stages from 2 to 4 in Figure 3-6 are explained in Table 3-1.

The approaches for construction safety are surrounded by the bold lines in Table 3-1, which is to be carried out after specific examinations of necessary resources for each work item/process. Thus the approaches for construction safety are considered in the "management plan" stage. In other words, construction safety should be considered in all process examined in the basic and detailed plans.

A construction management plan should suit site conditions. For that purpose, "preliminary survey" should precede each stage of planning. "Preliminary survey" is to extract issues and points of concern of construction sites.

“Basic plan” is to set up outline program and seek solution for the issues and points of concern. In this stage, comparison of applicable methods for the project is done to find out an optimal method. Similar consideration should be done for machinery and equipment.

“Detailed plan” deals with the details. Plans for each process/work items should be prepared.

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"Management Plan" deals with how to achieve targets of each process/work items by planning proper management plans.

Table 3-1 "7Ms" to Consider in 3 Stages of Construction Management Plan

Preparation of construction management plan

		contents at each stage (contents described in each plan)		
Preparation Stage		Basic plan	Detailed plan	Management plan
Contents / Viewpoints		Outline program Comparison of options	Detailed plans for each process in the schedule, including input of resources	Management plan for each process
1	Manpower (Personnel Arrangement)		Personnel Arrangement by work items 【⇒Procurement plan (Labor) 】	Organization and Personnel Arrangement plans for implementation of detailed plan
	Working circumstance (Safety and Health)			Consideration of safety and health 【⇒Safety management plan】
2	Material (procurement and consumption)		Necessary materials by work items 【⇒Procurement plan (Materials) 】	
3	Methods	Outline of construction methods and schedule	Work order and temporary works by work items 【⇒Schedule plan】 【⇒Temporary works plan】 【⇒Procurement plan】	Checking and revising construction plans during the project as appropriate. 【⇒Safety management plan】
4	Machine	Combinations of machinery	Selecting machinery to use 【⇒Procurement plan】	Safe operation of machinery 【⇒Safety management plan】
5	Money	Economic evaluation	Integration (considering Necessary personnel, work and materials)	Funding, execution budget, cost control 【⇒ Cost control plan】
6	Measurement			Measurement plan for quality assurance 【⇒Quality control plan】
7	Environmental consideration (Mother nature)			Environmental Consideration 【 ⇒ Environment Management Plan】

The space in the bold frame border is related to safety management

(JICA Project Team)

In the "detailed plan" and "management plan" stages, "individual plans" for specific items and targets are prepared, which are indicated in the bold brackets in Table 3-1. The accuracy of these individual plans has a great influence on the progress and quality of the project.

Main items and points of concern to be considered in individual plans are summarized in Table 3-2.

More detailed information is attached to Appendix X for further understandings.

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Table 3-2 Main Items to Describe in Individual Plan

Preparation Stage	Individual Plan	Main Items to Consider	Points of Concern for Individual Plan
Detailed Plan	Schedule Plan	・ Determine construction order of each process ・ Calculate work schedule such as number of workable days and average output per day ・ Determine combination of machinery, capacity, scale, and numbers of machinery and equipment ・ Prepare overall schedule of the project	・ Basic scheldule management to complete the project within the required time period
	Procurement Plan	［Labor plan］ ・ Calculate necessary numbers of each class of labors by work items. ・ Determine labor procurement plan of each class of labors by work items. ・ Prepare labor schedule based on the schedule	・ Determination of working time by day and assigned period by considering processes of each work item ・ Consideration to reduce the maximum required numbers of labors per day as much as possible and flatten the fluctuations of the required numbers of labors
		［Material plan］ ・ Estimate required volume/quantity of materials and costs for procurement, transport, and storage. ・ Prepare storage place for materials. ・ Decide procurement methods.	・ Adjustment with process plan ・ Reasonable plan considering the budget (cost for materials, machine, and transport accounts for nearly half or more of whole construction costs)
		［Machinery plan］ ・ Prepare machinery schedule ・ Estimate costs for machinery operation ・ Prepare storage place for machinery ・ Decide procurement methods.	
		［Transport plan］ ・ Estimate costs for transportation ・ Decide mode of transport	
	Temporary Works Plan	・ Plan temporary works for construction, including procurement, transport, installation, maintenance, removal, cleanup, and cost.	・ Durability against impact and vibration during construction ・ Design and implementation in consideration of capacity and period of works. ・ Assuring safety in consideration of property of temporary works
Management Plan	Cost control plan	・ Prepare a working budget (preliminary cost) ・ Prepare construction cost ledger ・ Collect and organize evidence for cost ・ Control actual cost ・ Compare working budget and actual cost and revise working budget accordingly ・ Maintain system for budget and cost control ・ Evaluate the project for the company's management	・ Organization of a working budget and actual costs in a manner for easier comparison ✓ Early preparation of a working budget for prediction of construction profit to achieve the goal of cost control ✓ Collection and organization of data for unit cost analysis, to improve accuracy of a working budget
	Quality control plan	・ Set quality standards based on the required accuracy and specified values in technical specification, employers requirements, and other contractual documents as well as effective standards and regulation ・ Establishment of internal inspection protocol	・ Proper understanding of requirement by the Employer/Authority ・ Organizing important quality indices through construction process ・ Selection of important quality indices to achieve the requirement. ・ Organizing inspection and management items in consideration of the important quality indices and the requirement. ・ Set important quality items from management items.

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Preparation Stage	Individual Plan	Main Items to Consider	Points of Concern for Individual Plan
	Safety management plan	・ Set a safety management target ・ Establish and manage implementation of various safety management method such as: ✓ Safety training and education at site ✓ Safety management activities including safety inspection, patrol, and meeting ✓ Safety inspection for construction machine, facilities, and equipment ✓ Safety measures for each work item ・ Plan temporary works in a manner securing safety of construction and confirm its safety ・ Prepare safety measures for the surroundings of the sites ・ Establish regular and emergency safety management system	・ Compliance with laws and regulation of construction safety ・ Formulation of safety management approaches to comprehensively cover the works to construct. ・ Incorporation of requests from related authorities. ・ Aware of possibility of harming the third parties by activities of the works. ・ Clarification of order of command line, contact numbers, mode of communication, work assignment, and organization for safety management in regular and emergency situations
	Environmental management plan	・ Plan and implement the following measures: ✓ For natural and social environmental conservation ✓ To prevent pollution ✓ To prevent roadside disturbance by construction vehicles ✓ To protect working circumstance ✓ To treat properly construction soil, sludge, asphalt and concrete block, metal scrap etc.	・ Understanding natural and social conditions of the construction site in advance ・ Compliance with relevant laws and regulations ・ Minimizing disturbance of environment ・ Advance explanation of environmental management plan to locals ・ Health damage prevention at site ・ Minimizing construction waste ・ Formulation of proper separation, collection, transportation and disposal plan

(JICA Project Team)

(iii) Implementation of Construction Management

The purpose of construction management is to implement the works as the preceding construction management plan stipulates.

At the same time, the important factors of construction management are to achieve the required quality of the works in a faster and cheaper manner. These factors correspond to the individual plans in the detailed and management plans of quality, schedule, and cost control.

In addition, accidents significantly affect the factors of quality, schedule and cost. Thus by adding safety management, the four factors are specially explained in this section as the major management items.

These four factors, which are quality, schedule, and cost control and safety management, affect each other. Thus relations among the four factors are discussed as well.

Relations among the four main management factors

Besides the safety management, which should be prioritized first, the three main factors of quality, schedule, and cost affect each other as shown in Figure 3-7. If each factor is managed separately without paying careful attention to the correlations among the factors shown in Figure 3-7, the project may become unbalanced.

In addition to managing each factor to achieve its independent target or goal, therefore, construction management should balance the main factors by focusing close attention to the correlations among the factors.

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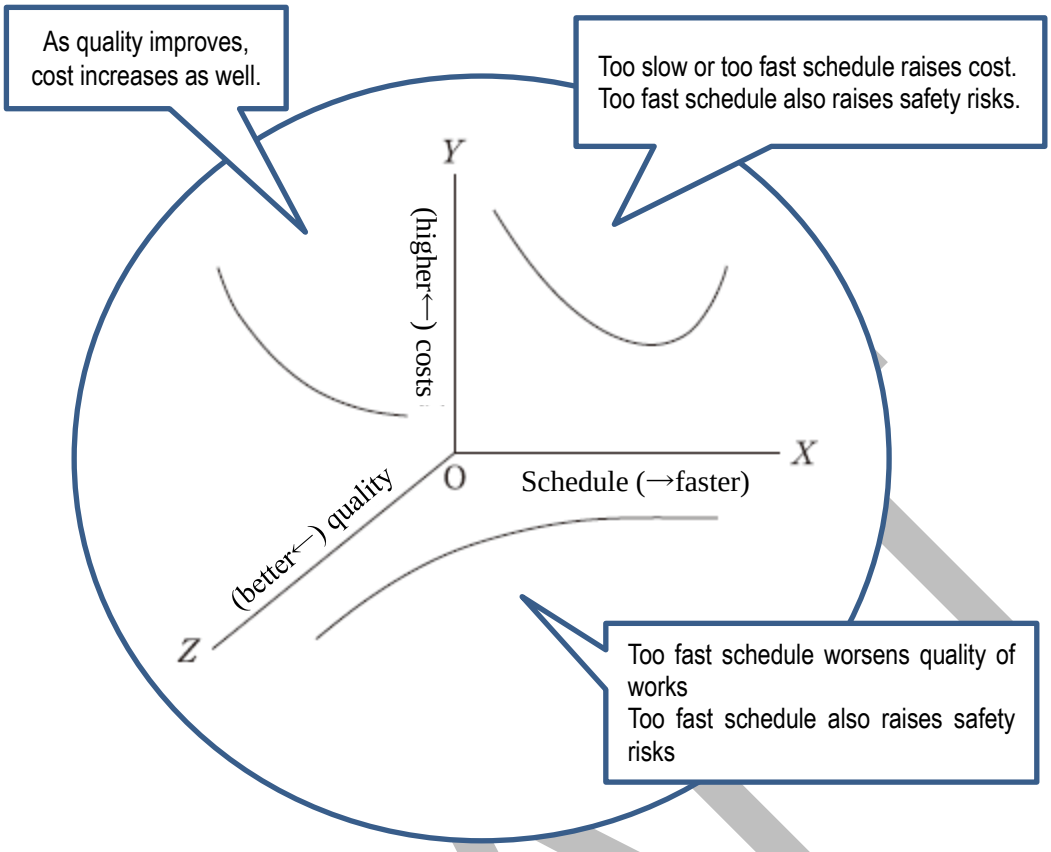


Figure 3-7 Correlations among Quality, Schedule, and Cost, with Safety Aspects

[9]

Correlations in Figure 3-7 also explain the relations among safety management and three other management items as explained below:

- Case 1: If labors are decreased to reduce costs, each worker bear more burdens and their attention is distracted. Then quality of the works suffers while safety risks increase.
- Case 2: If a schedule is shortened, quality of the works suffers while safety risks increase.

Important points in correlations among the main management factors including safety management are summarized as follows.

(i) The factor of quality "better" is in a trade-off relation with the factor of cost "cheaper".
(ii) The factor of schedule "faster" is in a trade-off relation with each factor of quality "better" or cost "cheaper".
(iii) Since an accident adversely affects all other factors of quality, schedule, and cost, safety management should be prioritized first.

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Not only pursuing the goals of each main management factor, but keeping appropriate balance among the four management factors is required for construction management.

Methods of Construction Management

The methods of construction plan are described in this section, specifically, PDCA, progress management table, and checklist methods. These methods should be used in combination.

i) PDCA Method

PDCA method is a technique related to continuous improvement model for business management. PDCA method manages each item by following the stage of plan-do-check-Act, and, by repeating all stages, makes it possible to manage the project better. PDCA method can be used for managing various factors of in construction management. It can be also applied to management of various levels ranging from daily works by an individual to an entire process of a work item.

By applying PDCA method at all times, a manager may notice a delay in a process immediately and take appropriate actions. For safety management, PDCA method can confirm a result of a required action for safety and then improve the action based on the result. Thus PDCA method can test measures to prevent accidents beforehand.

P of PDCA: (Plan)
Establishing the objectives and processes required to get results according to the target or goals. It includes work policy of the construction manager, objectives of the site office, safety and health management plan, work schedule, construction plan, completion drawings, working drawings, minutes of meeting for safety and sanitation, and so on.

D of PDCA: (Do)
Comparing and monitoring the actual progress to the planned progress according to the construction plan.

C of PDCA: (Check)
Evaluating the progress of the plan at certain intervals or when required.

A of PDCA: (Action)
Analyzing the differences between the actual and plan and identify its causes. The plan will be modified if required. For example, when difference from the original working schedule occurs depending on various working environments such as weather conditions, the construction plan will be modified accordingly.

[10] [11]

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The diagram of PDCA method applied to construction management is shown in Figure 3-8. As described above, establishing a construction plan corresponds to "Plan". "Do" means the performance of actual construction and monitoring, "Check" is to evaluate monitoring results, and "Act" is taking measures against the problems recognized in "Check". Then the process returns to "Plan" again and a new cycle begins.

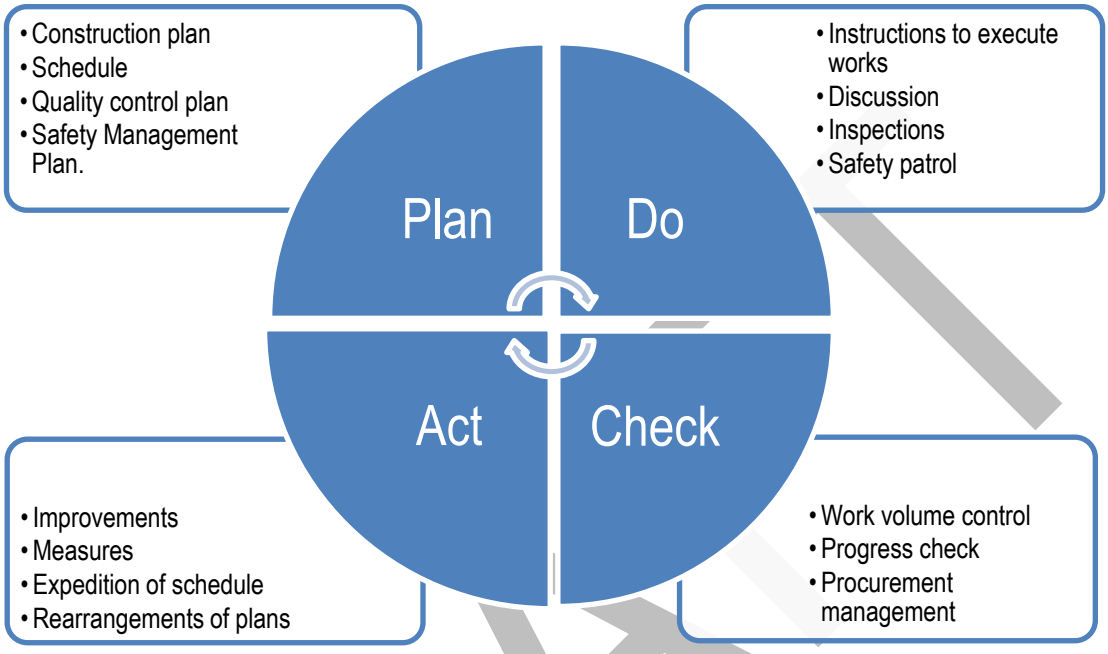


Figure 3-8 Diagram of PDCA Method Applied to Construction Management

(JICA Project Team)

ii) Progress Management Table Method

To formulate a progress management table is one of the process management methods. In a progress management table, type, order, and timing of work items are displayed. Thus by checking a progress management table, progress of each work item of a project is understood.

Before construction works commence, a progress management table should be prepared so that it can be used by construction manager and workers effectively during the construction.

Combination with PDCA method extends the advantage of applying progress management tables for construction management. Through PDCA cycles, if a significant delay is noticed, revisions of a progress management table are required, which is followed by sharing the revised table among the concerned parties.

Advantages and disadvantages of the basic types of progress management tables are described in Table 3-3, with the examples shown in Figure 3-9.

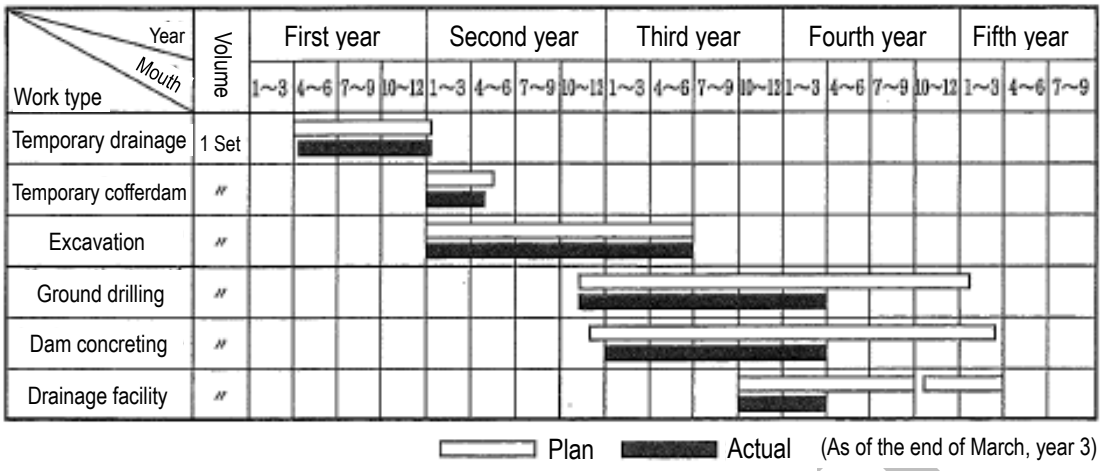
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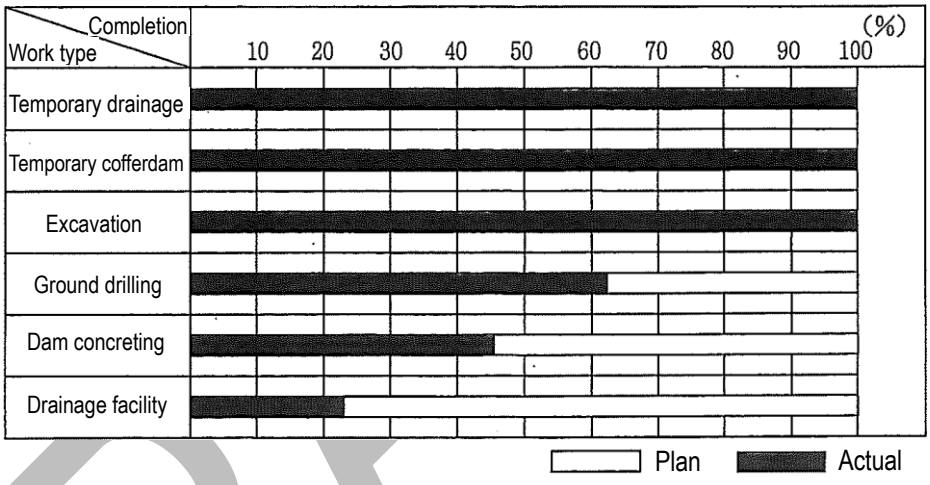
Table 3-3 Advantages and Disadvantages of Progress Management Tables

Name	Advantage	Disadvantage
Horizontal Line Type (Bar Chart, Gantt Chart)	・ Easy to prepare ・ Easy to modify ・ Easy to understand the progress	・ Unclear correlation among work items ・ Unclear effect of partial change to entire schedule ・ Easy to include ambiguous elements ・ Less accurate progress
Coordinate Type (Shaded Type or Linear Schedule)	・ Simple explanation of progress within one frame of all work items, which are controlled by distance like tunnel and road construction ・ Easy to understand work order of items and deviation between plan and progress ・ Easy to understand progress and location of work items	・ Unclear correlation among work items ・ Unclear effect of partial change to entire schedule ・ Easy to include ambiguous elements (if used with bar charts, the above disadvantages may be relieved to certain extent)
Curve Type (Banana Curve)	・ Easy to understand overall progress of the works, which is based on the total amount of the works executed.	・ Unclear procedure and order of work items ・ Difficult to understand necessary period for work items ・ Unclear critical path (if used with bar charts, the above disadvantages may be relieved to certain extent)
Network Type	・ Clear correlation among work items ・ Clear effect of partial change to entire schedule, in quantitative manner. ・ Suitable for comprehensive management of complex projects ・ Able to manage important items selectively	・ Time consuming preparation ・ Long experience to understand the method ・ Special skills required to prepare networks ・ Complicated modification process

[12]

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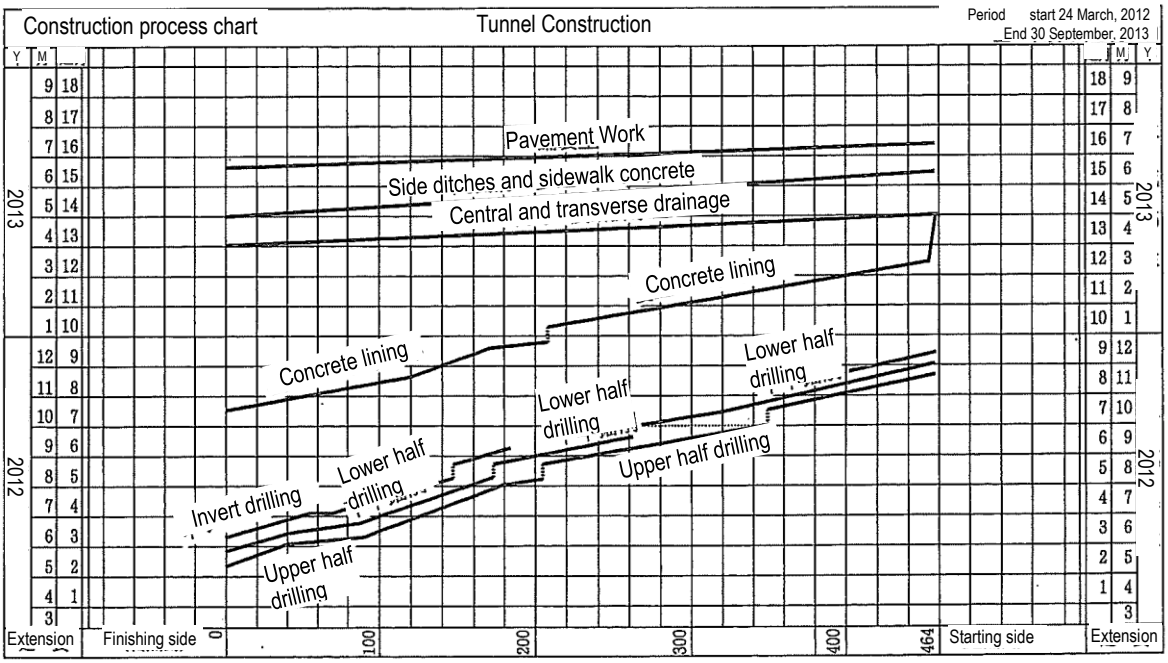


Figure 3-9 Sample Progress Management Tables (Top: Bar Chart, Middle: Gantt Chart, Bottom: Shaded Type)

[13]

iii) Checklist Method

For the works on hill slopes, engineers should understand that slopes are naturally unstable and sometimes the stability of slope is remarkably undermined by the changes of natural conditions. Although a preliminary survey was carried out for construction works, therefore, pre-construction inspection should be done to reconfirm the natural conditions including stability of slopes.

During construction, daily inspections to detect abnormality or precursors of collapse should be continuously conducted. In case abnormality or precursors are detected, more detailed inspection for abnormal conditions should be carried out at shorter intervals to continuously monitor the situation.

The details of the pre-construction inspection, daily inspection, and inspection for abnormal conditions are described below. In addition, examples of the checklists are attached as Appendix XX.

a) Pre-construction Inspection

Pre-construction inspection is to be carried out just before the commencement of the construction.

Preliminary survey for the project was conducted in the planning or design stages. Since a preliminary survey deals with the entire project areas, therefore, evaluation of stability of a specific slope may contain some errors.

Pre-construction inspection aims to examine again the property of the ground and signs of collapse of the specific slopes treated by the construction. In case difference in the ground conditions from those assumed in the preliminary survey is detected, design of the works should be scrutinized to check whether revisions of design are required or not. In case revisions are required, the design should be so revised to accommodate such difference in the ground conditions.

b) Daily inspection

Daily inspection should be carried out every day during construction period to detect abnormality or precursor at the site. Especially after an event which may destabilize the slope, such as heavy rainfall or earthquake, careful inspection should be conducted.

Although monitoring equipment is installed at sites, such equipment usually observes deformation or displacement of limited sections of whole slopes. Thus visual inspection to cover entire slope should be performed.

When abnormality is found during daily inspection, such abnormality or changes of slope conditions should be recorded in detail in accordance with the checklist for “inspection for abnormal conditions”. Construction manager should prepare countermeasures against possible collapse, including deciding applicable measures for each step of the construction. The construction manager should also seek revisions of design to counteract the possible collapse and have discussion with the employer/authority.

c) Inspection for abnormal conditions

The purpose of the inspection for abnormal conditions is to evaluate risk of collapse and monitor development of the risk, by closely monitoring the precursors detected in the preceding inspections. This inspection should be performed in shorter intervals than daily inspections.

In case the events listed in Table 3-4 are observed, appropriate measures should be prepared and executed accordingly.

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Table 3-4 Precursors

Level of event	Details of event	Measures to reduce or avoid risks
Precursor warning collapse	・ Cracks (on structures such as retailing wall, crib works, shotcrete, pavement, and on earth) ・ Swelling/bulging of slope ・ Groundwater spring ・ Single fallen rock ・ Escape of animals	・ Tightening monitoring to the precursors. ・ More cautious daily inspections ・ Installation and reinforcement of measuring equipment ・ Consideration of countermeasure including change of design
Precursor of probable collapse	・ Development of displacement ・ Development of cracks to stair shaped displacement (development of scarps) ・ Multiple cracks aligned linearly ・ Development of swelling/bulging ・ Turbidity of spring water ・ Continuous fallen rocks and small-scale collapses ・ Sound of wood bursting due to collapse ・ Rumbling of mountain	・ Imposing off limits restriction of the dangerous sites ・ Implementation of emergency measures
Small collapse which suggests incoming greater ones	・ Continuous small-scale collapse ・ Collapse including berms ・ Destruction of structures	・ Estimation of scale of the biggest collapse ・ Evacuation and traffic regulation ・ Liaison to and coordination with the related authorities and concerned parties.

[1]

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(3) Safety-conscious Construction Methods

Recent safety-conscious construction methods are expected to reduce danger of slope excavation, which is naturally dangerous with the conventional methods. In this section, the following four methods are discussed.

- Top-down construction method
- Installation of H-beams and sheet piles to temporarily retain slopes
- Safety measures for cutting works
- ICT construction

(i) Top-Down Construction Method

The conventional excavation places an excavator at the toe of the slope, where the excavator executes cutting operation as far as its arm reaches.

On the other hand, with top-dawn construction method, excavation starts from the top part or shoulder of the planned cut slope, and slope protection and/or reinforcement works for the excavated surface follow. The excavation proceeds downward while the cycles of excavation and protection/reinforcement repeat to protect the excavated surface shortly after the excavation.

With this method, the cut slope increases its stability after each cycle and will not remain unstable for a long period. Thus the risk of rapid destabilization of the slope by cutting remains low.

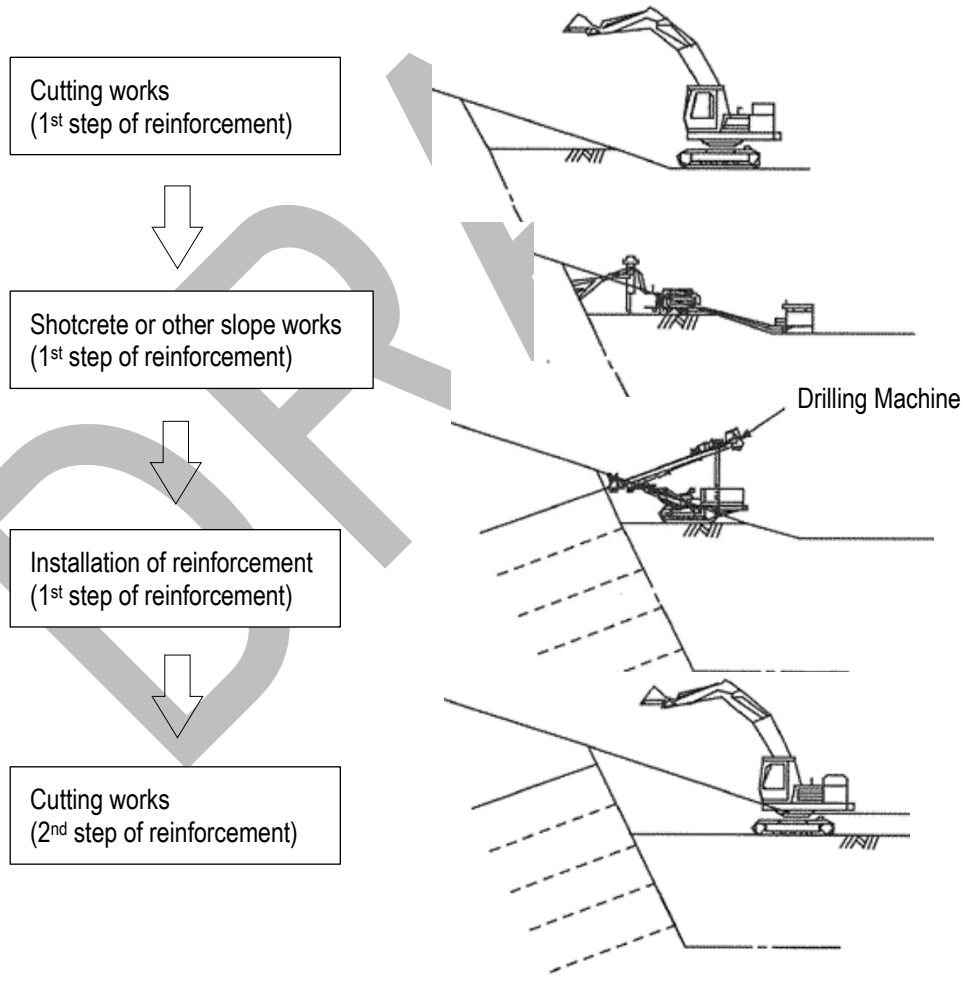


Figure 3-10 Process of Top-Down Construction Method

[14]

For execution of the top-down construction method, however, additional safety measures are required, such as installation of temporary roads for deploying excavators to upper part of slopes and assembling temporary stages for carrying heavy machinery and materials along steep slopes.

(ii) Installation of H-beams and Sheet Piles to Temporarily Retain Slopes

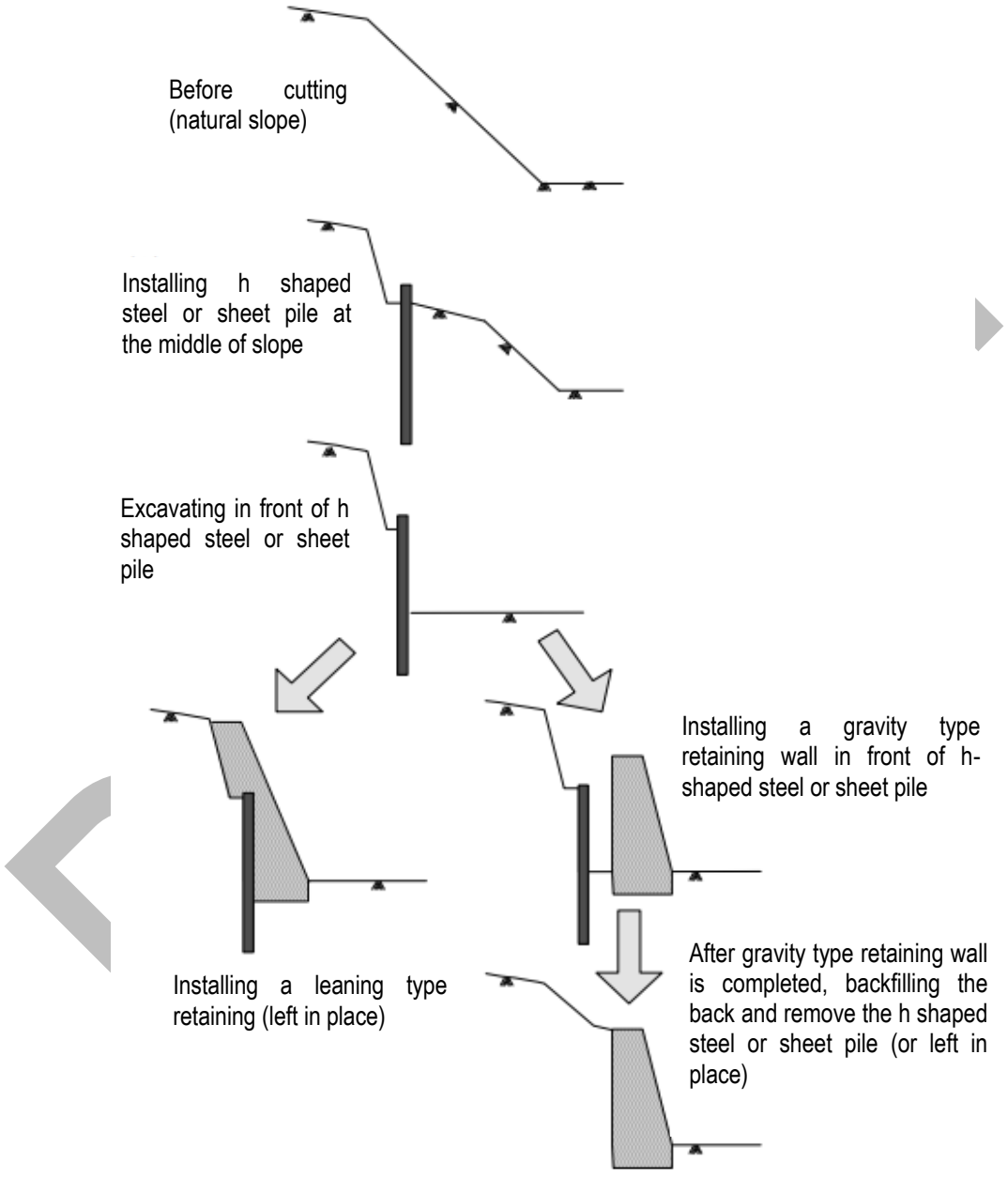


Figure 3-11 Example of Protection Method for Slope Failure

[15]

After cutting, the excavated slope and the upper slope remain unstable until proper retaining or reinforcement measures are installed.

Prior to large excavation, therefore, H-beams and sheet piles are driven into the ground to retain the excavated slope, until construction of retaining walls before the slopes.

As shown in Figure 3-11, in this method, sheet piles are driven among H-beams to temporarily retain the slope. And then retaining walls are constructed in front of the temporary retaining with H-beams and sheet piles.

(iii) Safety Measures for Cutting Works

By the excavation of cut slopes, internal shear stress of the ground behind the slope often increases and thus stability of the slope decreases. In addition, unlike landslides, the precursors of cut slope failure are not clear and the slope collapses rapidly once it occurs. Such features of cut slope failure make it difficult for the workers to escape being buried by debris.

The dangers in cutting works and measures to avoid them are explained below for representative work items in cutting works.

i) Avoiding risks when working at the toe of the slope of being or after cut

In the construction of retaining wall, many accidents occur during excavation. One of the reasons of such accidents is the excavation for retaining walls is often carried out at the toe of unstable steep slopes.

After excavation of slope for retaining wall, workers have to work at the toe of the cut slope for excavating and leveling foundation, setting slope stakes, and stacking stone masonry. Working at the toe of slope after excavation is dangerous. Thus, instead of manual works, using machinery is recommended, such as excavator or backhoe loader.

Furthermore, safety of workers should be secured with temporary earth retaining works, which are installed to support excavated walls or slopes with H-beams, sheet piles, or other simple materials, before manual works are carried out.

[15]

ii) Risk of accidents in assembly and demolition of formwork

In retaining wall construction, accidents during assembling or disassembling formwork often occur at the toe of cut slope. The works are done in a narrow space between steep slope and retaining wall. Thus once collapse occurs, the workers are often trapped by debris, which lead to a fatal accident.

[15]

iii) Monitoring and inspection necessary for execution of cutting slopes

Although cut slopes are designed and excavated based on preceding surveys and technical standards, the slopes may collapse due to the reasons listed below. Appropriate safety management is, therefore, required during construction of cut slopes, with properly planned inspection and monitoring of slopes including that with devices.

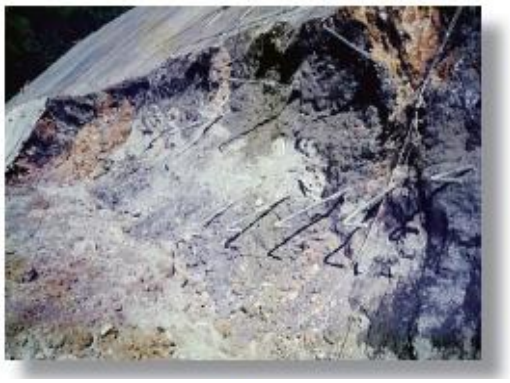
(a) During and after excavation of steep rocky slopes composed of bedrock, depending on the dominant direction of joints, bedding, and foliation, wedge or planner failure may occur on dip slope and toppling may occur on plunging slope structures.

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(b) Unexpected fragile part of the ground (e.g., fractured zone)
(c) Activation of an unexpected old landslide by excavation
(d) Failure due to spring water from the surface of cut slopes



(a) Instability due to excavation of bedrock showing dip slope structure



(b) Slope failure of fractured zone, to which planned reinforcement does not work



(c) Displacement caused by an old landslide activated by excavation



(d) Instability of slope due to spring water

Figure 3-12 Cause of Collapse of Cut Slope during Excavation

[2]

(iv) ICT Construction

ICT construction utilizes information and communication technology (ICT) for survey, construction, and inspection for quality and quantity of the works, and is expected to perform higher productivity and quality than conventional construction method. For the works on hill slopes, where various types of risks exist, the advantages of ICT construction is expected to be fully utilized, such as listed below:

- Various types of automatic monitoring devices (e.g. optical fiber sensors, laser range finder, and rain gauges) for slope monitoring and early warning system
- Automated machine guidance (AMG) technology to constantly monitor the difference between actual site conditions and 3D design data, based on the position of construction machinery and as-built shape of the works obtained by automatic tracking total station (TS) and global navigation satellite system (GNSS)
- Technology to automatically control construction machinery in real time according to 3D design data, by combining the AMG and hydraulic control system of construction machinery,

- Unmanned construction utilizing the aforementioned automatic control technology for construction machinery
- Technology to survey as-built shape of the works with TS and GNSS, to compare as-built shape with 3D design data, and to prepare documents and data sheets from electric data.

In addition, ICT construction is expected to bring tax payers, clients, and contractors its advantages as follows.

i) Advantages for tax payers

- High quality public structure
  The quality of the works is traceable by monitoring and electric data stored to electric reports, which leads to higher quality of public works.
- High quality of living environment
  Shorter construction period leads to minimizing social loss (e.g. traffic jam, noise and vibration, and pollution by emission etc.).
- Benefit for carbon dioxide reduction
  Shorter construction period leads to reduced operation time of construction machinery, which reduces fuel consumption and emission of carbon dioxide

ii) Advantages for clients

- Efficient inspection and supervision of the works
  Monitoring data of construction continuously provided to the client enable them to optimize their construction supervision activities, including inspection and supervision of the works.
- Efficient and sophisticated operation and maintenance
  During operation and maintenance stage, electric records of construction data support diagnosis and analysis of the works, which facilitates more sophisticated operation and maintenance activities.
- Supports for engineering judgment
  Abundant electric data obtained and organized through survey, design, construction, and operation and maintenance of the works help engineers to make appropriate engineering judgement.

iii) Advantages for contractors

- Efficient construction work
  Efficient construction work shortens construction period and minimizes necessary work force.
  Quality, as-built form, and construction speed are assured without heavily depending on skilled operator, which reduces errors in operation.
- Improved safety
  Automatic measurement of as-built form reduces risks of workers to work simultaneously with construction machinery.

[16]

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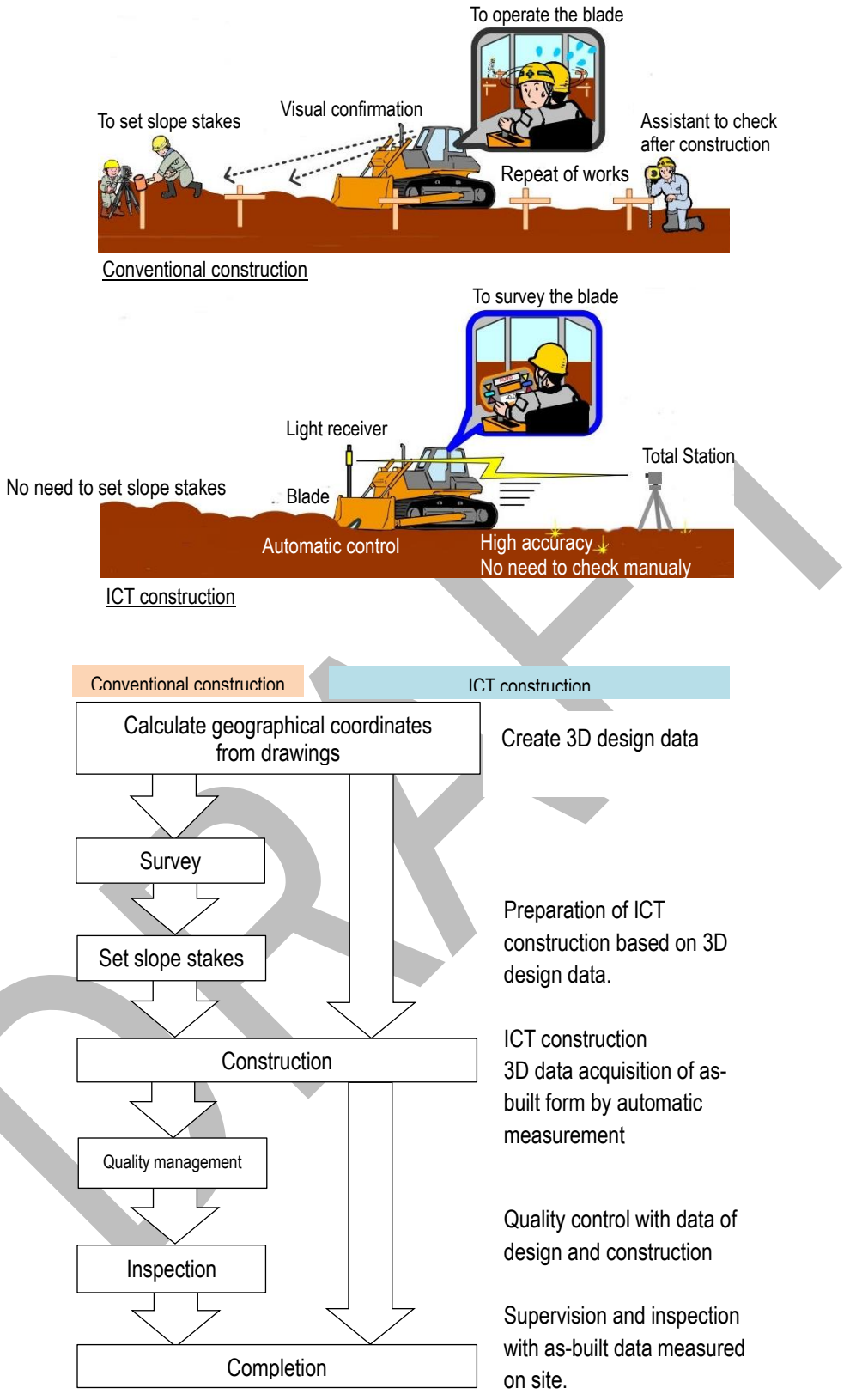


Figure 3-13 Comparison between Conventional and ICT Construction

[16]

3.1.2 Cutting Works Controlled with Slope Stake

(1) General

In this clause, the cutting works with slope stake, one of the survey methods at the construction stage, is described.

Slope stake is defined as follows:

> "Slope stake" is a survey index on site that indicates position, height, and direction of structures to be built. Slope stake is required for showing dimension of drawings and helping control and execution of the works. Slope stake is placed on the surface of site and visible as well as touchable during construction. (Suzuki 2015)

For the construction of cut and fill slopes along hill roads, accuracy is one of the important factors to ensure quality. Installing slope stake is a basic technology to secure accuracy of construction.

[17]

A general image of slope stake is shown below.

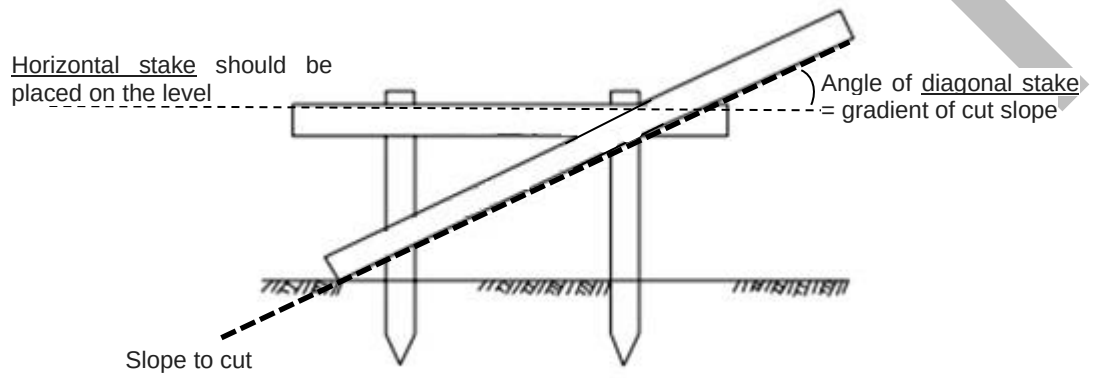


Figure 3-14 Slope Stake Showing Slope to Cut

(JICA Project Team)

Slope stake is a temporary structure that functions as a guide for cutting and filling works.

In cutting or filling of slopes in road construction, the works should be executed based on design drawings such as plan, profile, cross section, and structural drawings as well as survey data of actual terrain surface. By installing slope stakes at the beginning of the works, accuracy and safety of the works can be assured.

Based on the results of topographic survey, slope stakes should be installed at each control point in a manner to accurately indicate heights and gradient of finish shapes of cut or fill slopes. For high and long cut or fill, where the ground surface may be changed frequently due to cutting, filling, or transporting of material, updating of references for the works by continuously installing new slope stakes are important for effective quality control of the works.

(2) Procedure of Installing Slope Stakes

The procedures for installing slope stakes for cutting works of hill roads are explained in this section for the cases of gentle and steep slopes.

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(i) Procedure of installing slope stakes for cutting on gentle slopes

Conditions for the installation

- Formation elevation: FL (m)
- Design gradient: 1:z (= horizontal/vertical length)[1]

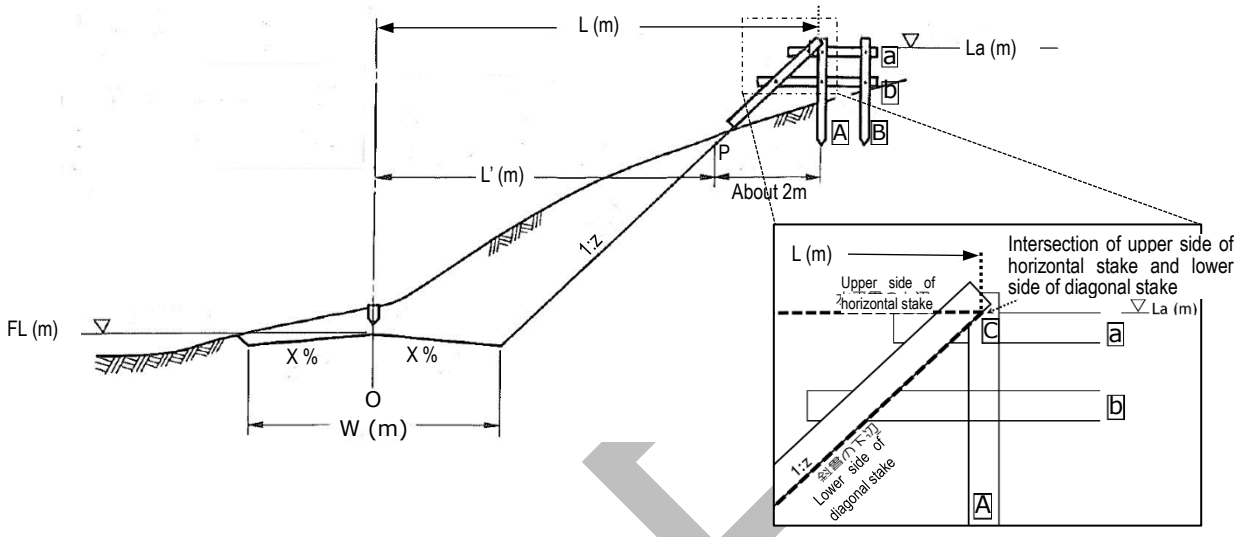


Figure 3-15 Procedure of Installing Slope Stakes for Cutting on Gentle Slopes

[18]

1 Measure the horizontal distance L '(m) in the cross section from the center of the road as "O" in Figure 3-15 to the intersection of the excavation line and the ground surface as "P".
2 Install columns "A" and "B" for the slope stake on site, at upslope positons of "P" with around 2 meters apart from "P".
3 Fix a horizontal stake of "**a**" to the columns "A" and "B" at a position of 1 meter high from the ground.
4 Measure the elevation La (m) of the horizontal stake "a" with a level.
5 Calculate L (m) with the following formula:

$$\mathrm{L} = \frac{1}{2}W + \left\{L_a - \left(FL - \frac{1}{2}W \cdot \frac{1}{100}X\right)\right\} \cdot z$$

6 Measure the distance of L (m) from the center of the road "O" to the horizontal stake "a" and mark the point as "C".
7 Attach an auxiliary horizontal brace of "b", and fix a diagonal stake to the horizontal stake "a" and "b", showing the design gradient of 1:z from the point "C".

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[1] For example, the gradient of 1H2V is 1:0.5 (=1/2). For this case z=0.5. The gradient of 2H1V is 1:2 (=2/1). For this case, z=2.0. The gradient of 3H2V is 1:1.5 (=3/2). For this case z=1.5.



Figure 3-16 Slope Stakes for Cutting on Gentle Slope

[19]

(ii) Procedure of installing slope stakes for cutting on steep slopes

Conditions for the installation

- Formation elevation: FL (m)
- Design gradient: 1:z (= horizontal/vertical length)

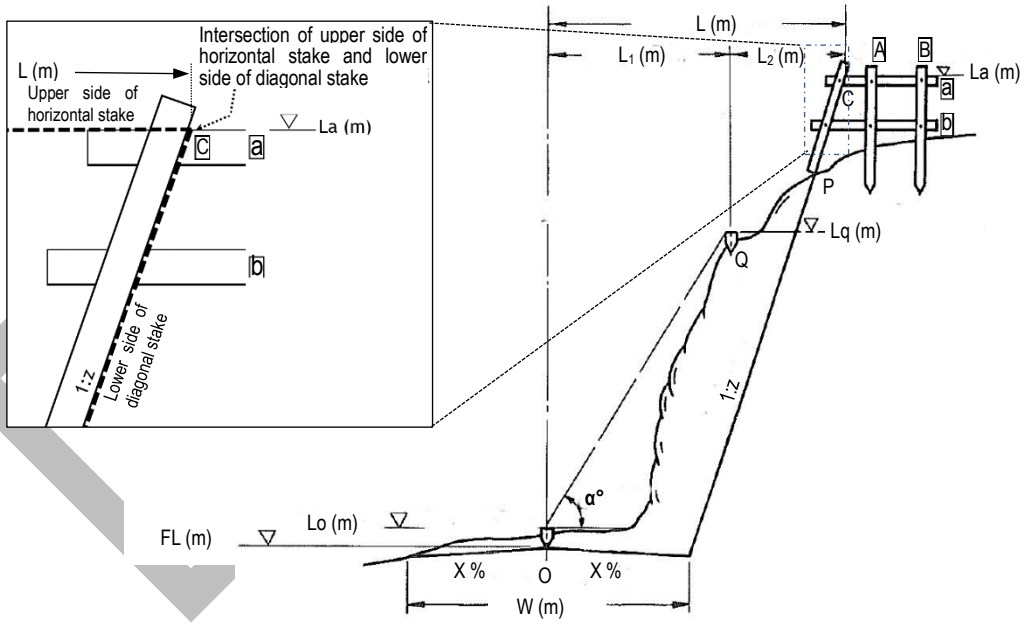


Figure 3-17 Procedure of Installing Slope Stakes for Cutting on Gentle Slopes

[18]

1 Measure the horizontal distance in the cross section from the center of the road as "O" in Figure 3-17 to the intersection of the excavation line and the ground surface as "P".
2 Install columns "A" and "B" for the slope stake on site, at upslope positons of "P" with some margins from "P", and fix a horizontal stake of "a" to the columns "A" and "B".

3 Install a temporary stake at a point of "Q" that can be viewed directly from the center of the road "O".

4 Measure the elevation Lo (m) at point "O", the elevation Lq (m) at point "Q", and the elevation La (m) of the horizontal brace "**a**" with a level. The calculate L with the following formula:

$$\mathrm{L} = \frac{1}{2}W + \left\{L_a - \left(FL - \frac{1}{2}W \cdot \frac{1}{100}X\right)\right\} \cdot z$$

5 Put a flat plate at point "O", tighten a leveling string between "O" and "Q", and measure angle "α" with a slant rule or transit.

6 Calculate the horizontal distance L_1 (m) of the segment "OQ".

7 Measure the distance of L_2 (= L-L_1) from the temporary stake "Q" to the horizontal stake "a" and mark the point as "C".

8 Attach an auxiliary horizontal brace of "b", and fix a diagonal stake to the horizontal stake "a" and "b", showing the design gradient of 1:z from the point "C".



Figure 3-18 Slope Stakes for Cutting on Steep Slope

(JICA Project Team)

(3) Technical Points

Slope stakes should be installed at the following intervals.

Table 3-5 Standard Intervals

Installation position	Interval
Straight part	10m
Curve part (radius is more than 300m)	10m
Curve part (radius is less than 300m)	5m
Complex terrain part	Under 5m

[20]

If subsidence or consolidation settlement of the ground as well as filling is expected, a certain level of subsidence should be taken into account when installing slope stakes.

If slope stakes are installed for fill slopes to indicate the designed gradient as it is, such as "a" in Figure 3-19, the stakes will be affected by subsidence and show gentler gradient than the designed. This leads to gentler finish shapes than the designed and steeper gradient around the shoulder to adjust the height. If slope stakes are installed with some margins for the subsidence, finish slope is expected to complete almost as designed.

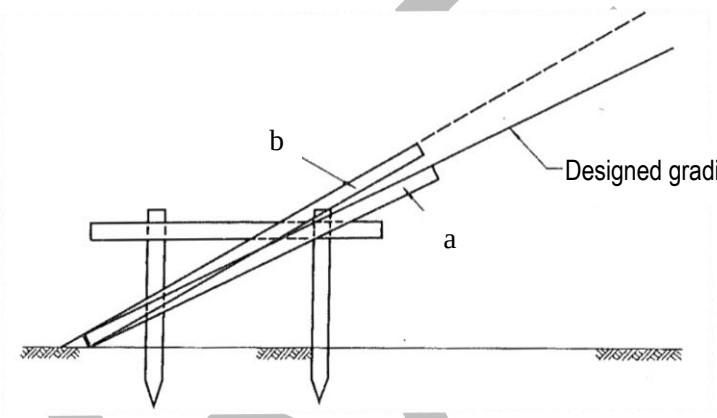


Figure 3-19 Securing Margin for Expected Subsidence of the Ground

[20]

(4) Precautions for Securing Workers' Safety

(i) Accidents during installation of slope stakes

For the safety management of workers, an example of a fatal accident that occurred during installation of slope stakes is described in this section. This accident occurred during the restoration work of a revetment. Fallen rocks detached from the upper slope caused the accident when slope stakes for placing leveling concrete are were installed.

- A direct factor is the inadequate inspection of the upper slope before the work, in which the unstable parts of rock was missed.
- One of the indirect factors is that, although the risk of rock fall was recognized, the workers were allowed to work in the site without being provided sufficient safety measures.
- Another indirect factor is that no temporary safety measures were placed on the upper slope to prevent falling or jumping rocks.

[21]

(ii) Measures for safety management

The following actions for safety management are considered effective.

- Establish a safety management system and enhance safety measures such as appointing a person in charge of inspection.
- Improve the inspection system of the slope, inspect natural conditions such as detached or unstable rocks, wet condition, freezing, temperature, and weather conditions, and select the working method suitable for the conditions.
- Conduct daily inspections on site before the work of the day begins, and inspect unstable or detached rocks and fissures or open cracks to induce rock fall.
- If a serious hazard to workers due to failure of slope or rock fall is noticed, reshape the slope gentler, remove unstable or detached rocks, and install safety nets to prevent rock fall.
- Conduct safety education for workers, in which risks such as jumping rocks, falling rocks, and collapse of slope as well as necessity of safety protection measures are instructed.

[21]

3.1.3 Concrete Crib Works

The concrete crib works are one of the main methods of slope protection works. In this clause, the shotcrete crib works and cast-in-place concrete crib works, which are adopted in various countries as effective countermeasures against slope failure, are explained.

(1) General

The concrete crib works are one of the slope protection works with structures. The purpose of the works are to stabilize natural or artificial slopes by controlling erosion and preventing surface failure of slope surface with grid-shaped structure of mortar or concrete on slopes. This method is effective to prevent weathering, erosion, and shallow failures of the slope surface of the following conditions:

- Slopes of soil that is not suitable for plant growth
- Slopes which may collapse before vegetation works settle and protect the surface
- Slopes with many cracks and/or weak weathering resistance

Shotcrete crib works are to spray mortal or concrete to the formworks assembled on slopes. Cast-in-place concrete crib works are to cast concrete into the formworks assembled on slopes. Table 3-2 explains features of these works. Examples of shotcrete crib works and cast-in-place concrete crib works are shown in Figure 3-40.

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Table 3-6 Shotcrete Crib Works and Cast-in-place Concrete Crib Works

Type of Works	Process of Works	Material	Note
Shotcrete Crib Works	1. To assemble re-bar and formwork on the slope, 2. To spray mortal or shotcrete	Mortar Shotcrete	・ Suitable for high, steep, and rugged slopes. ・ Applied to high and long cut slopes, slopes with weak weathering resistance, and cut slopes with a lot of joints and cracks. ・ Applied to undulating slopes difficult to smooth or trim ・ Also applied when prompt construction is required. ・ Embedded formwork is prevailing.
Cast-in-place Concrete Crib Works	1. To assemble re-bar and formwork on the slope, 2. To cast concrete	Concrete	Suitable for low and gentle slopes. Not suitable for undulating surfaces, which requires trimming and smoothing. With ground anchors or soil nailing at intersections of frames, stability of slope is improved. If it is used with ground anchors and/or soil nailing, formwork to provide large cross section of frame is required.

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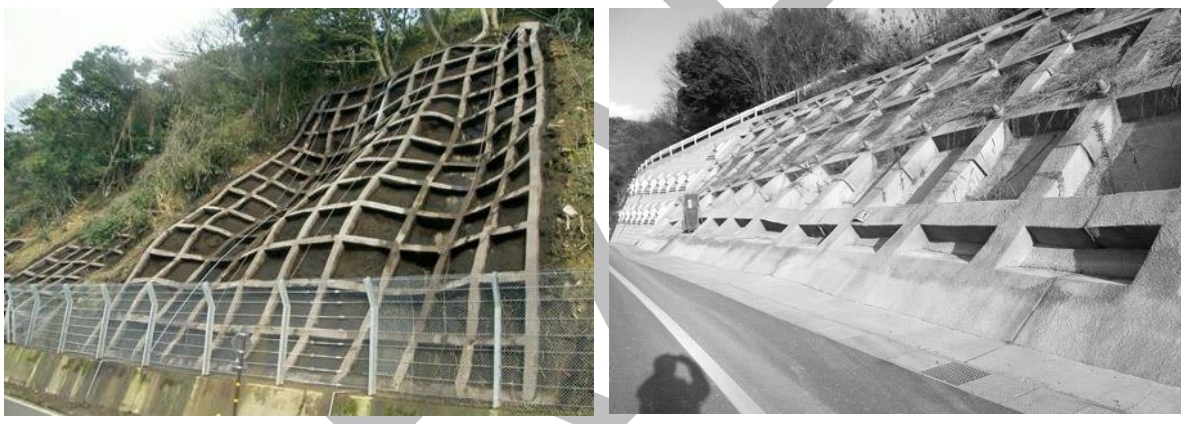


Figure 3-20 Shotcrete Crib Works (Left) & Cast-in-place Concrete Crib Works (Right)

Left [23], Right [24]

(2) Procedure of Construction

The construction of spraying or casting concrete on slopes is different from those on flat sites. For example, quality of concrete may be affected due to unequal spraying or casting, resulting from uneven surface. Furthermore, safety issues should be highlighted due to the risks of slope failure and rock fall during construction and falling accidents of workers. Thus, construction plans considering such features of the works on slopes should be formulated. Establishing a construction team that can dully execute the plan is also important.

The procedure of construction is explained below for shotcrete crib works and cast-in-place concrete crib works.

(i) Shotcrete Crib Works

Figure 3-21 shows a typical construction procedure of shotcrete crib works and the details of each stage are described below.

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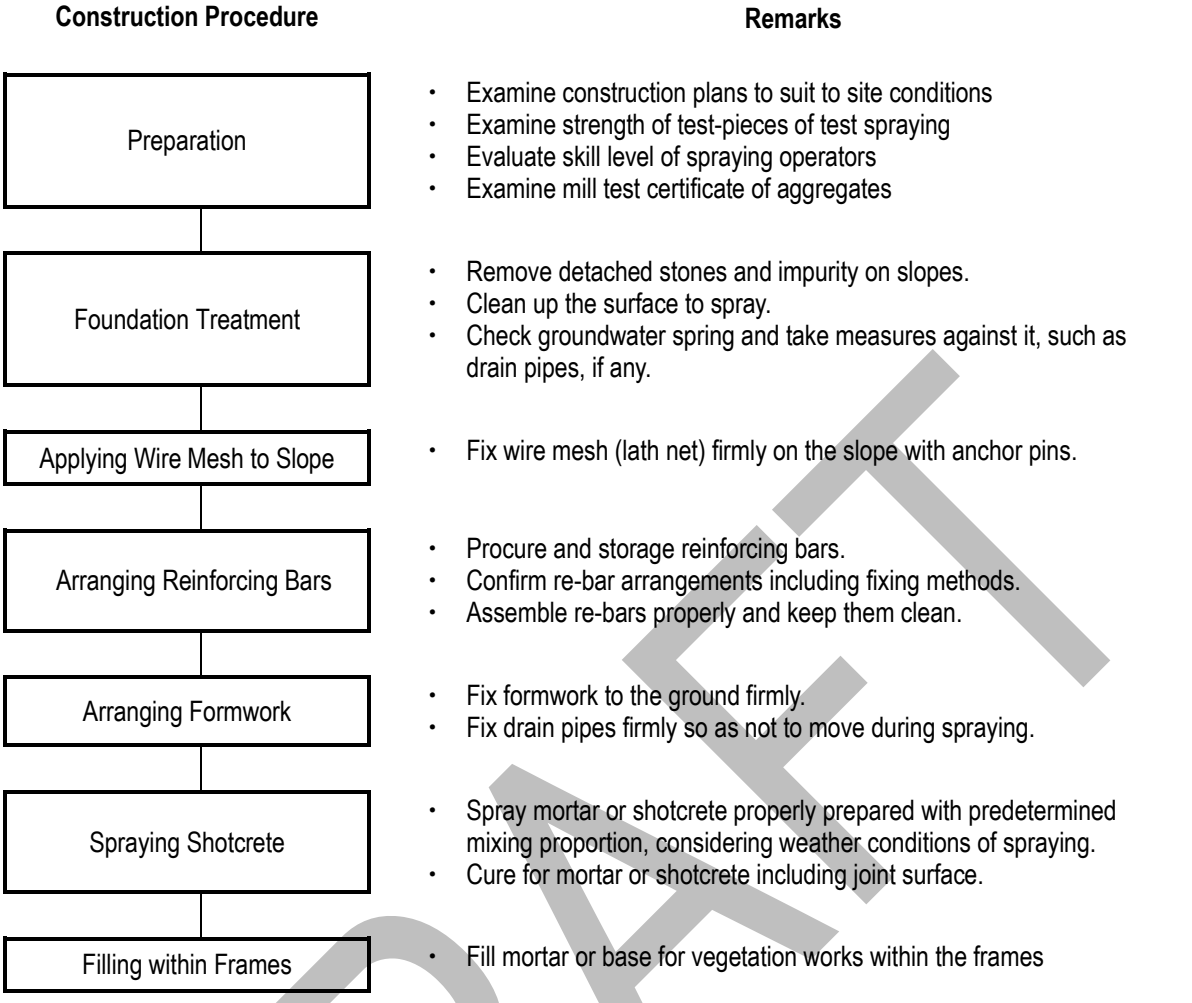


Figure 3-21 Construction Procedure of Shotcrete Crib Works

[25]

i) Preparation

Before execution of the works, surveys of the site should be performed to confirm actual site conditions, such as location and area of structures to be constructed. In addition, tests for aggregate as well as trial mix of mortar or shotcrete to be used should be done. Skill level of spraying operators should be examined as well.

Important points for shotcrete preparation, such as quality requirement, method of spraying, and workability, are described below.

・ Quality Requirement of Shotcrete

Shotcrete is required to have stable property and durability to withstand long-term service. Also, even in case that spraying shotcrete is executed far from concrete plant, homogeneity and liquidity are required to be kept stable, to prevent separation or obstruction of pneumatic transport hose.

The above-mentioned points should be taken into consideration in the selection of materials for shotcrete, design mixed proportion, selection of mixing facilities, and mixing methods.

Table 3-7 shows general requirement of shotcrete for slopes by the standard pneumatic conveying method (wet mixed shotcrete).

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Table 3-7 General Requirement of Standard Shotcrete for Slopes

Material		Basically, shotcrete is composed of cement, water and fine aggregate, and if necessary, additives such as an air-entraining agent and a water reducing admixture, and short fibers are used.
Composition	Maximum Size of Coarse Aggregate	15 mm or less
	Slump	0～5cm
	Air Content	Optional
	Unit-cement Ratio (W/C)	Generally, in the range of 50 to 60%
	Unit Cement Content	Concrete: about 360 kg / m^3 Mortar: about 360-420 kg / m^3
	Unit Water Content	Determined by strength, ability of pneumatic transport, and others.
	Rate of Coarse Aggregate	Generally, in the range of 70 to 100%
	Additive	As needed
	Short Fibers	As needed
Production	Batching, Mixing	Batching and mixing of all compositions should be done at concrete plants

[26]

Mortar is usually used for shotcrete crib works due to easiness of spraying unless it is0020in cold region or required to increase thickness of shotcrete.

A set accelerating agent is not used except for overhanging slope.

Amounts of coarse aggregate and air content in the proportion of shotcrete usually change before pumping and after spraying. Thus requirement should be fulfilled with the shotcrete sprayed on slopes.

- Method of Spraying, Transport Distance

Usually, wet mixed process is used for spraying shotcrete. Wet mix process is more accurate in mixed proportion and stable in quality than dry mix process is. Furthermore, spraying is executed with less dust, rebound of shotcrete, and loss of cement and the sprayed volume per unit hour is larger than dray mix process. On the other hand, dry mixed process has an advantage in longer pneumatic transport distance by pumping.

To assure quality of shotcrete, pneumatic transport distance by pumping should be less than 100 meters in length and 45 meters in height for the works on high and steep slopes. Concrete plant should be located in consideration of transport distance between the plant and the slope to be sprayed.

- Workability of Spraying

"Workability of spraying" is an indicator of shotcrete being transported and sprayed smoothly with lesser dust and rebound and without causing pulsation or blockage of pneumatic transportation hose. Specifically, they are ability of pneumatic transport, dust density, rebound ratio, and repletion.

By keeping the workability appropriately, segregation and rebound of shotcrete are reduced and repletion is increased, and then concrete structures with stable quality and durability are constructed on slopes with specified composition. Workability of the spraying is, therefore, important to ensure quality and thus is required to be specified in a construction plan.

Standard requirements for workability of spraying are tabulated in Table 3-8.

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Table 3-8 Standard Requirements for Workability of Spraying

Item	Requirement	Remarks
Pneumatic transport	Transport distance is less than 100 meters in length or 45 meters in height	For shotcrete on slopes of 15 to 18 N/mm^2
Dusts	Covering with sheets to control diffusion	Impact on neighboring houses or third parties should be examined as required
Rebound Ratio	As small as quality is secured.	Priority is given to securing quality of shotcrete. Reduction of the rebound ratio can be adjusted by lowering pressure of spraying. It also affects adhesion and solidity of shotcrete.
Repletion	Method to densely fill shotcrete in formwork should be adopted to avoid less repletion or voids under the re-bars.	Proper arrangement of reinforcing bars should be designed to enable good repletion. Using mortar may increase repletion.

[26]

- Spraying Material

- Cement

Portland cement is generally used for shotcrete of slopes. However, in the following cases, blended cement (for example, blast-furnace slag cement type B) shall be used.

- ✓ Under special conditions affected by acid water or water containing salinity
- ✓ In case aggregate harmful of alkali silica reactivity is used

- Aggregate

Fine aggregate occupies the largest volume among components of shotcrete for slopes. The quality of the fine aggregate, therefore, affects workability of shotcrete.

The best material for fine aggregate is river sand. The particle size is generally having a fineness modulus of fine aggregate of 2.5 to 3.1.

When spraying is carried out with the pneumatic transport system, the coarser particle is, the more shotcrete rebounds. On the contrary, the finer particle is, the greater resistance in pneumatic transport hose is and the more blocking occurs. In case pneumatic transport system is used, aggregate should be selected depending on ability of pneumatic transport by pumping.

- Admixture

As an admixture, AE (air-entraining) agents, water reducing agents, AE and water reducing agents, and high-performance AE water reducing agents are used in order to achieve suitable consistency. The use of these admixtures can reduce unit water content to achieve required workability of spraying.

In order to improve resistance of hardened concrete against frost damage, use of AE agent, AE and water reducing agent, and high-performance AE water reducing agent is effective for mixing air bubbles into the mixed material of concrete.

- Required Strength

Mix proportion of shotcrete should be decided based on the results of in-situ spraying test with the equipment actually used. Prior to the construction, it can be decided based on the past experiences.

The compressive strength of shotcrete for slope shall not be lower than the compressive strength specified in the design.

The standard mixed proportion under usual construction conditions with specified concrete strength of σck = 15 N/mm2 is shown in Table 3-9.

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Table 3-9 Standard Mixed Proportion of Shotcrete (Mortar)

Unit-cement ratio	60% or less
Unit cement content	400 kg/m^3 or more
Air content	Generally assumed about 4%

[22]

ii) Foundation Treatment

Concrete crib works should be adhered tightly to the surface of slopes. For that purpose, before spraying shotcrete on slopes, surface for spraying should be inspected and treated if required.

Detached rocks and impurities on the surface to spray should be removed. Groundwater spring should be properly treated. Table 3-10 shows treatment and measures before spraying shotcrete.



Figure 3-22 Treatment of Slope before Spraying Shotcrete

[27]

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Table 3-10 Treatment of Slope before Spraying Shotcrete

Condition	Desirable Measures	Remarks
Detached rocks, grass, roots of trees on slope	Detached rocks or impurities that may fall should be removed	To make shotcrete adhered tightly to the surface. To secure safety during the works.
Groundwater spring	(General) Mixed proportion of shotcrete should be adjusted suitable for wet condition with spring (Spring of wide area) Before spraying, sheet of filter material should be applied to cover the area of spring with proper drainage. (Spring at limited location) Before spraying, drainage pipe or hose with vinyl chloride pipe or other proper material should be placed. (Spring out from fissures) Before spraying, drainage pipe should be applied. (Spring with large amount of water) Conduit or pipes should be installed to drain out the water to drainage ditches on berms or toe of slopes.	Water reduces adhesion of shotcrete to the surface of slopes. Degradation of quality of shotcrete, washout of shotcrete before hardened, Increase of back pressure of crib works, and cracking or peeling by freezing may be caused by spring water.
Surface of water-absorbent property	Water should be sprayed to the surface of slope to moisturize it. Then water-rich cement paste should be sprayed.	Soil with high water absorbing property will take water from the sprayed shotcrete. Quality of shotcrete is negatively affected.
Treatment of the shoulder	Drainage ditch should be placed along the shoulder of slopes so that surface runoff from the upper slope can be trapped before entering to the slope. Earthen ditches should be dug along the shoulder and shotcrete should be sprayed on the ditches so as to integrate with concrete crib works. (except when the ground consists of hard rock)	
Considerably undulating slope surface	Surface preparation should be made with lean mortar or soil cement in which amount of cement is less. For the shotcrete crib works, for which formworks are difficult to keep close contact with undulating surface, before arranging re-bars and formworks, shotcrete should be applied to make the surface smooth.	"Considerably undulating slope surface" means the unevenness of the surface is more than half of the cross section of the frame of the crib works to be applied.

[26]

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iii) Applying Wire Mesh (Lath Net) to Slope

The wire mesh or lath net is installed to hold the soil layer, stabilize the growth base for vegetation, and protect and retain it until the root system of the plant invades into ground. The wire mesh is also effective to increase resistance of vegetation against freezing and thawing. During construction, wire mesh should be fixed at the specified position.

· Installation

Rhombic wire net or lath net is recommended to be used as it follows flexibly to undulation of slope surface. When installed, wire mesh should be placed as close as possible to the surface of slope because it tends to be separated from the ground at concave parts. The ends of a roll of wire mesh should be overlapped by another roll of wire mesh with a length of about 1 to 2 lattices.



Figure 3-23 Applying Wire Mesh on Steep Slope

[28]

iv) Arranging Reinforcing Bars

If embedded formwork is used, wire mesh formwork to be embedded in shotcrete should be installed on the slope and reinforcing bars should be assembled inside the formwork, as shown in Figure 3-24.

The wire of the mesh formwork should have a diameter of 2.0 mm or more, and the minimum interval of the wires should be about 10 mm.

Connection of main re-bars should avoid intersections of crib works. When connected, re-bars should be aligned and fixed perpendicular to slope surface, so that voids of shotcrete should be minimized.

Anchor pin should be fixed tightly to avoid deformation of the formwork and re-bar cage until spraying and hardening are completed.

During construction, appropriate storage and processing of re-bar, position of joints, cleanliness before assembling, and fixing method of re-bars should be ensured.

· Fixing

Improperly fixed reinforcing bars and wire mesh formworks cause cracking of shotcrete due to vibration of wire mesh during spraying of shotcrete or impact of being

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hit by spraying equipment. Assembled re-bars and wire mesh formworks should, therefore, be firmly fixed with anchor pins to the surface of slopes, as shown in Figure 3-24.



Figure 3-24 Reinforcing Bar Arrangement

[28]

v) Arranging Formwork

If embedded formwork is not used, arranged after assembling re-bars, formworks should be so placed that mortar or shotcrete could be densely sprayed and filled within the re-bar cage without causing any voids.

At first, formworks for vertical frames should be assembled and fixed with anchor pins. Then formworks for horizontal beams should be placed.

Drainage pipes should be installed in a manner to avoid being moved or clogged during spraying.

After assembling, the following items should be checked:

- Soundness of assembly of formwork is firm enough not to cause deformation of designed cross section of crib work.
- Spacing of formworks meets requirements.

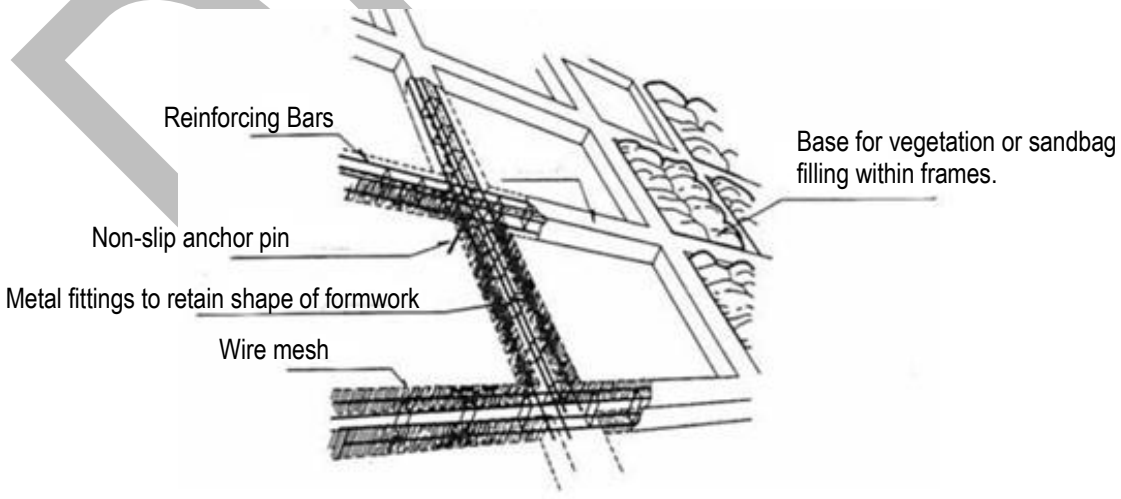


Figure 3-25 Re-bar and Formwork Arrangements for Shotcrete Crib Works

[29]

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In case undulation of slope surface hampers tight fitting of formwork or re-bar cage to the slope surface, such undulation should be rectified so that re-bar and formwork could be tightly fixed to the slope until sprayed mortar or shotcrete for crib work becomes hardened.

Before assembling re-bar and formwork, concaves of slope surface should be filled by sprayed mortal so that smooth surface for fixing re-bar and formwork is assured as seen in Figure 3-26 and Figure 3-27.

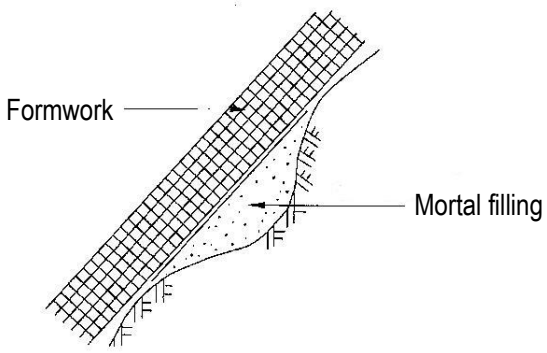


Figure 3-26 Rectifying Undulation by Spraying Mortar

[22]

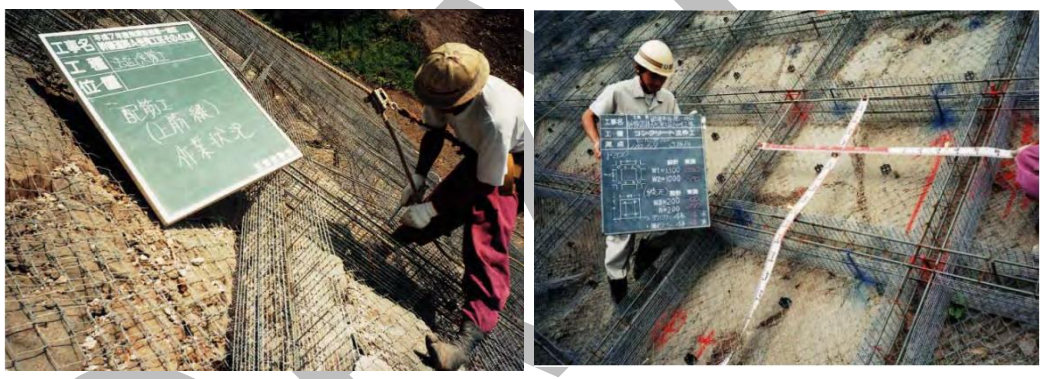


Figure 3-27 Re-bar and Formwork (Left : Assembling Formwork Right: Inspection)

[27]

vi) Spraying Shotcrete

The check points for spraying mortar or shotcrete to concrete crib works are as follows:

- Trial mixed proportion of mortar or shotcrete is appropriate or not. If it is not appropriate for the works, trial mixed proportion should be tested again and adjusted.
- Rebound is properly treated or removed.
- Working condition should be suitable for maintaining quality of mortar or shotcrete.
- Mortar or shotcrete should be properly sprayed at joints of placing.
- Segregation should not be occurred during transport and spraying.
-

Important points for spraying of mortar or shotcrete are shown in Table 3-11.

Table 3-11 Important Points for Spraying Mortar or Shotcrete

Item	Method / Standard	Purpose
Pneumatic Transport Distance	Transport distance should be less than 100 meters in length and 45 meters in height. ※If transport distance exceeds the above limitation, rearrangement of mixing plant and spraying machine or change of spraying method should be considered.	Mixed proportion should be kept until spraying to ensure quality and workability of shotcrete.
Thickness of Shotcrete	Thickness should be kept even by spraying at once. • Measurement pins should be set. • Spraying operator should check the thickness with a measurement pin.	To prevent sagging of shotcrete.
Distance and Angle of Spraying	Nozzle of spraying machine should be kept perpendicular to slope surface. Distance between nozzle and target surface should be in a range of 1.0 to 1.5 meters. Notwithstanding the above, mortar or shotcrete should be sprayed in a manner to fill the space behind of reinforcing bars.	To spray mortar or shotcrete densely.
Rebound of Shotcrete	Careful attention should be paid when spraying downward. As preparation, undulating surface should be smoothed by filling mortar to concaved parts.	Since rebound causes uneven solidification or voids, to prevent rebound to be mixed to mortar or shotcrete.
Construction Joint	Before spraying, remove impurities and non-adhered aggregate with air brush or wire brush and clean up with water. Immediately before spraying operation, applying mortar or adhesive reinforcement to the joint surface improves adhesion of the joint.	To prevent fragile joints.
Finishing	Trowels should not be used for finishing.	Using trowels causes bleeding water from sprayed shotcrete and eventually generates cracking.
Skill of Operators	Both spraying operators and spray machine operator should be well skilled to be able to stably transport and spray good-quality mortar or shotcrete.	Cooperative work of spraying operators and spray machine operator is required.

[26]



Figure 3-28 Spraying Mortar or Shotcrete

[27]

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Figure 3-29 Crib Works by Spraying Mortar (Tokamachi, Niigata, Japan)

[30]

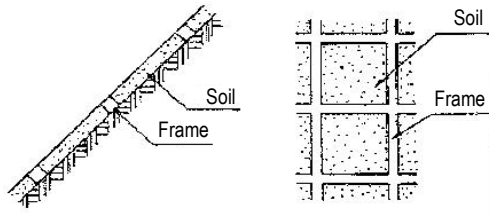
vii) Filling within Frames

As shown in Figure 3-30, according to the requirement, spaces within frames should be properly treated.

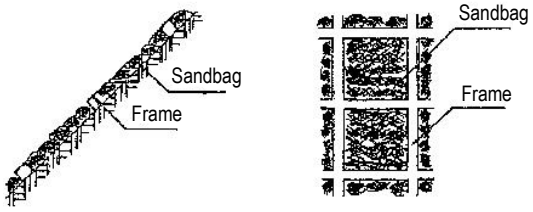
Filling within frames should pay attention for the followings:

- Slope surface within the frames are suitable for treatment, such as spraying mortar or vegetation base, or not.
- In case vegetation base is sprayed, suitability of slope surface should be checked whether it allows plant growth or not.
- Timing of spraying vegetation base is also important. Vegetation base should be sprayed just before or at the beginning of the season which allows plant growth.
- Vegetation base should be properly mixed, sprayed, and cured.

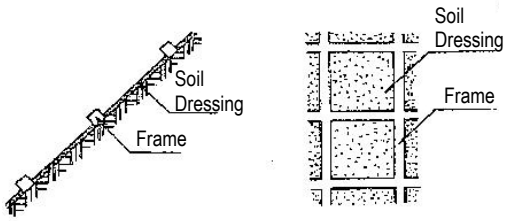
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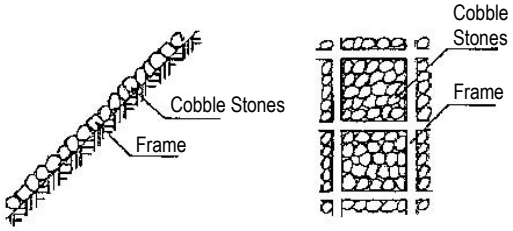
(1) Soil Fill
Soil is filled within frames.



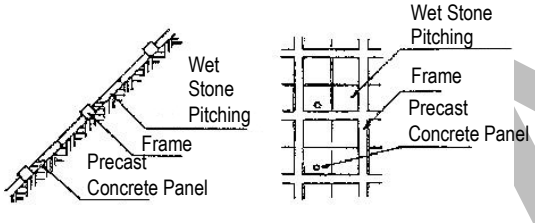
(2) Sandbag Fill
Sandbags filled with soil are laid within frames.



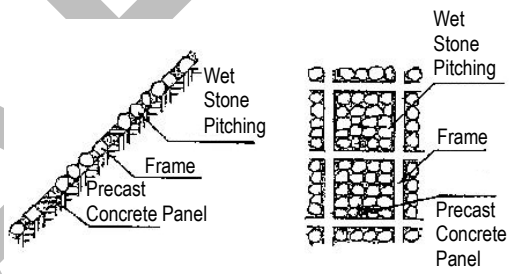
(3) Spraying Soil Dressing
Soil mixed with seeds and fertilizer is sprayed with a thickness of 1-3cm within frames.



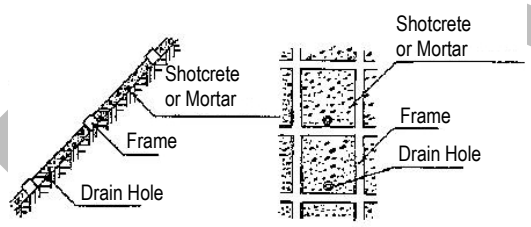
(4) Dry Stone Fill
Rubble and cobble stones are placed within frames.



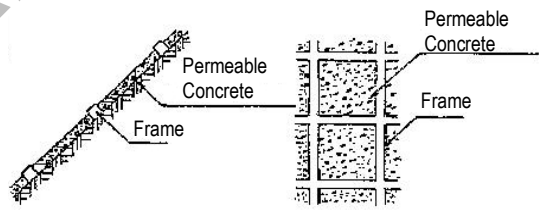
(5) Flat Concrete Block
Precast concrete panels are laid within frames.



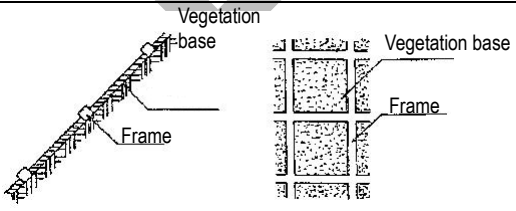
(6) Wet Stone Pitching
Rubble and cobble stones with mortal filling are placed within frames.



(7) Pitching (including mortar)
Spraying mortar or shotcrete within frames.



(8) Permeable Concrete
Permeable concrete is placed within frames.



(9) Spraying vegetation base
Vegetation base is sprayed with a thickness of 3-10cm within frames.

Figure 3-30 Types of Filling Works

[22]

viii) Important Points during Construction (Treatment of Surface Runoff or Groundwater Spring, Curing of Concrete

- Treatment of Surface Runoff and Groundwater Spring

If surface runoff is expected to flow into the cut slope where crib works are constructed, drainage ditches should be installed along the shoulder of the cut slope. And vertical drainage ditches with proper cross-section to drain water flowing into the slope from the upper slope or catchment area should be installed as required.

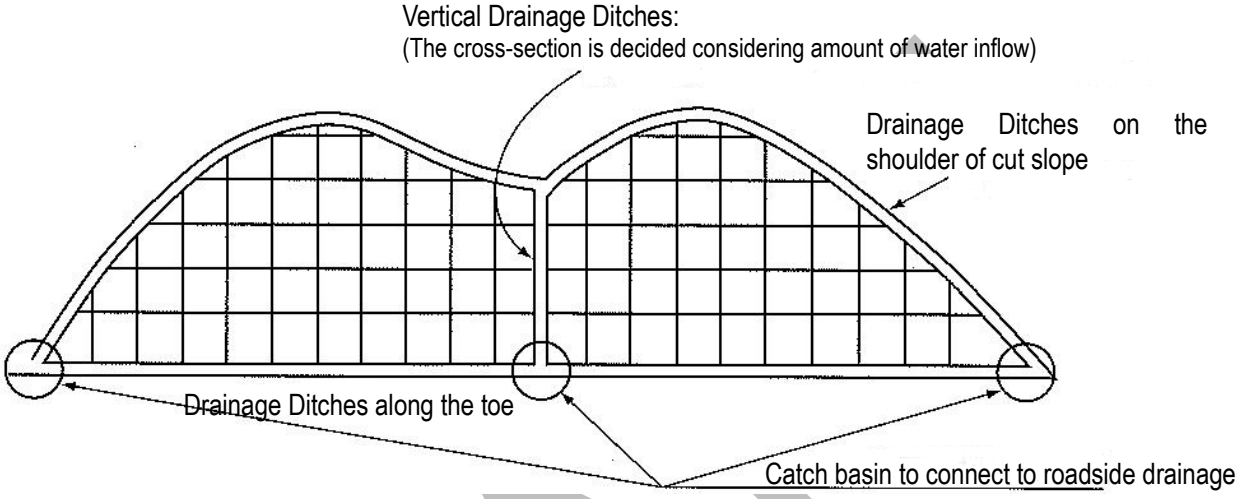


Figure 3-31 Drainage Ditches

[22]

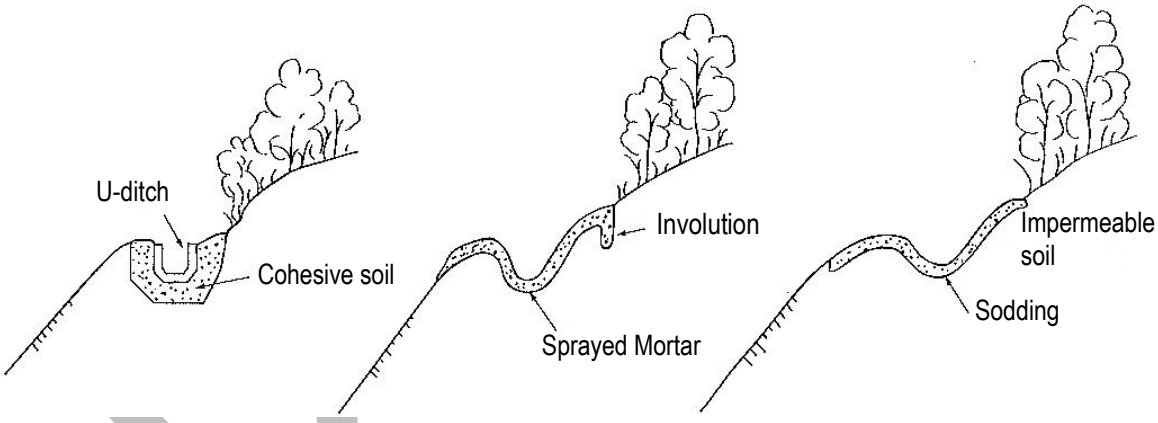


Figure 3-32 Drainage Ditches Installed along Shoulder of Cut Slope

[22]

On cut slopes, since velocity of surface runoff increases along with its amount as it flows downward, slope surface is more intensely eroded. Drainage ditches should, therefore, be installed along berms to decrease velocity of surface runoff and to prevent concentration of water as shown in Figure 3-33.

Generally, U-ditches are used along berms. The surface of drainage ditches should be coated with impermeable soil or concrete to prevent infiltration from the ditches, which may destabilize the slope. In case drainage ditches are installed, the width of berms should be 1.5 meters or wider.

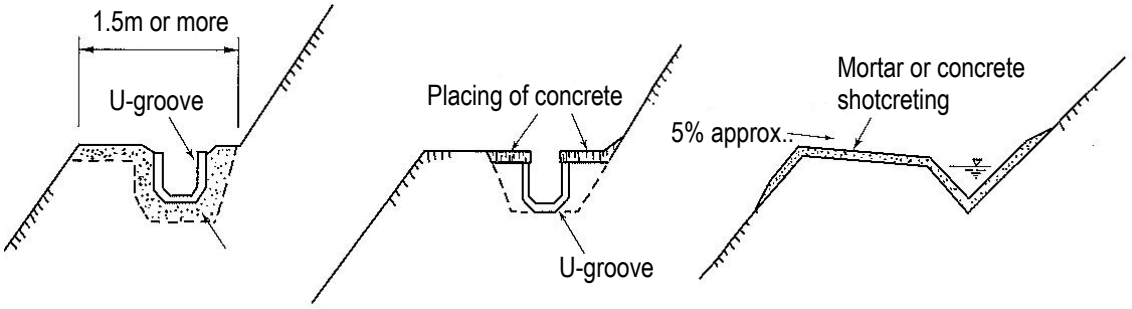


Figure 3-33 Drainage Ditches along Berms

[22]

In principle, the spring water flowing out from cut slope should be drained through underdrains installed behind of concrete crib works and discharged to the drainage ditches along berms or the toe of slope.

When groundwater spring is confirmed on slopes, applying impermeable materials within frames, such as spraying mortar or shotcrete, should be avoided. Impermeable cover on the slopes make groundwater behind the cover raised and stored, which leads failure of slope, erosion of the ground behind the cover, and freezing and frost heaving of the surface of the slope. Even though the amount groundwater spring is very small like seepage, vegetation works or permeable concrete should be applied so that groundwater could flow out without being retained on the slope.

For the groundwater spring on rock slopes, drainage ditches should be placed from the spring to the toe of slope. Such ditches should be filled with cobbles and gravels or protected with gabions.

For the slopes consisting of soil, thick permeable drainage mats should be installed to drain water to the toe of slope.

If large amount of groundwater flows out, installation of horizontal drainage borings should be considered.

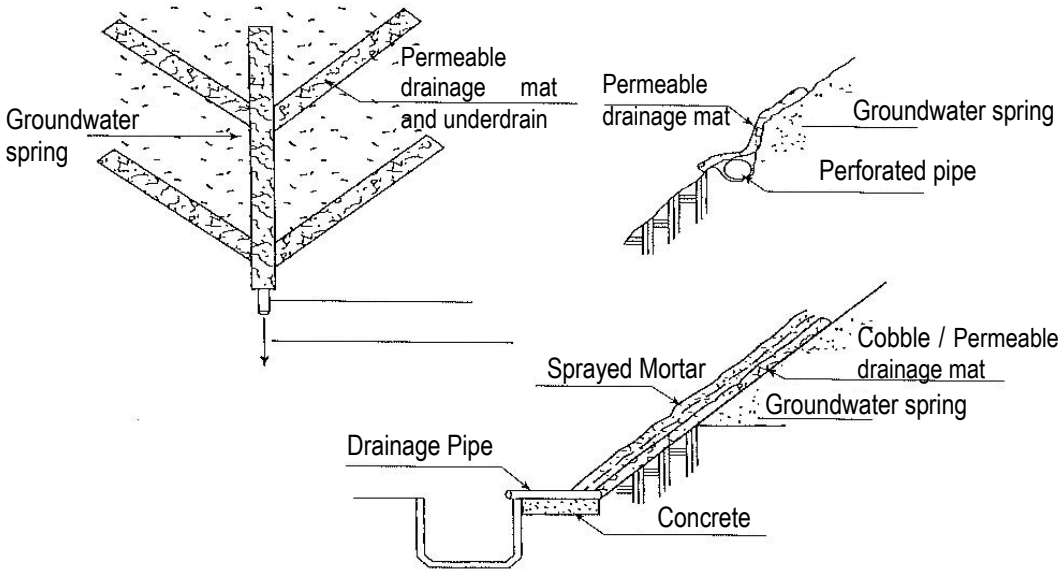


Figure 3-34 Treatment for Groundwater Spring

[22]

- Curing

Thicknesses of sprayed mortar or shotcrete for crib works on the slopes are relatively thin in comparison with the area to be applied. Curing of mortar and needs following consideration:

Basically, construction should be carried out at an appropriate season which does not require special curing. Otherwise curing, such as spraying water, moisturizing, and keeping temperature, is required to achieve designed strength of mortar or shotcrete.

Construction under strong sunlight during summer and low temperature below freezing level in winter should basically be avoided.

Methods of curing include moistening with wet cover, spraying water, covering, and surface coating. Curing with spraying water is applied in summer, and curing with sheet or heater to keep moisture and temperature is used in winter.

(ii) Cast-in-place Concrete Crib Works

Cast-in-place concrete crib works are applied in the similar way to shotcrete crib works, for the purpose of preventing surface failure.

It is also applied when stable gradient of cut slope is not assured or where soil quality of slope is not suitable due to groundwater spring.

Furthermore, cast-in-place concrete crib works are applied in combination with soil nailing or ground anchor to the slope where joints and cracks of rock are remarkably developed or where detached rocks cannot be fixed by shotcrete.

Cast-in-place concrete crib works include two types; surface failure prevention type and leaning-type retaining wall type. The former conforms to the design of shotcrete crib works, and the latter conforms to the design of leaning-type retaining wall. The design for leaning-type retaining wall should be applied to the slopes with gradient of 4H5V or steeper. Cast-in-place concrete crib works are, however, generally applied to the slopes with smooth surface and lower height.

A typical construction procedure of cast-in-place concrete crib works is similar to that of shotcrete crib works as shown in Figure 3-35.

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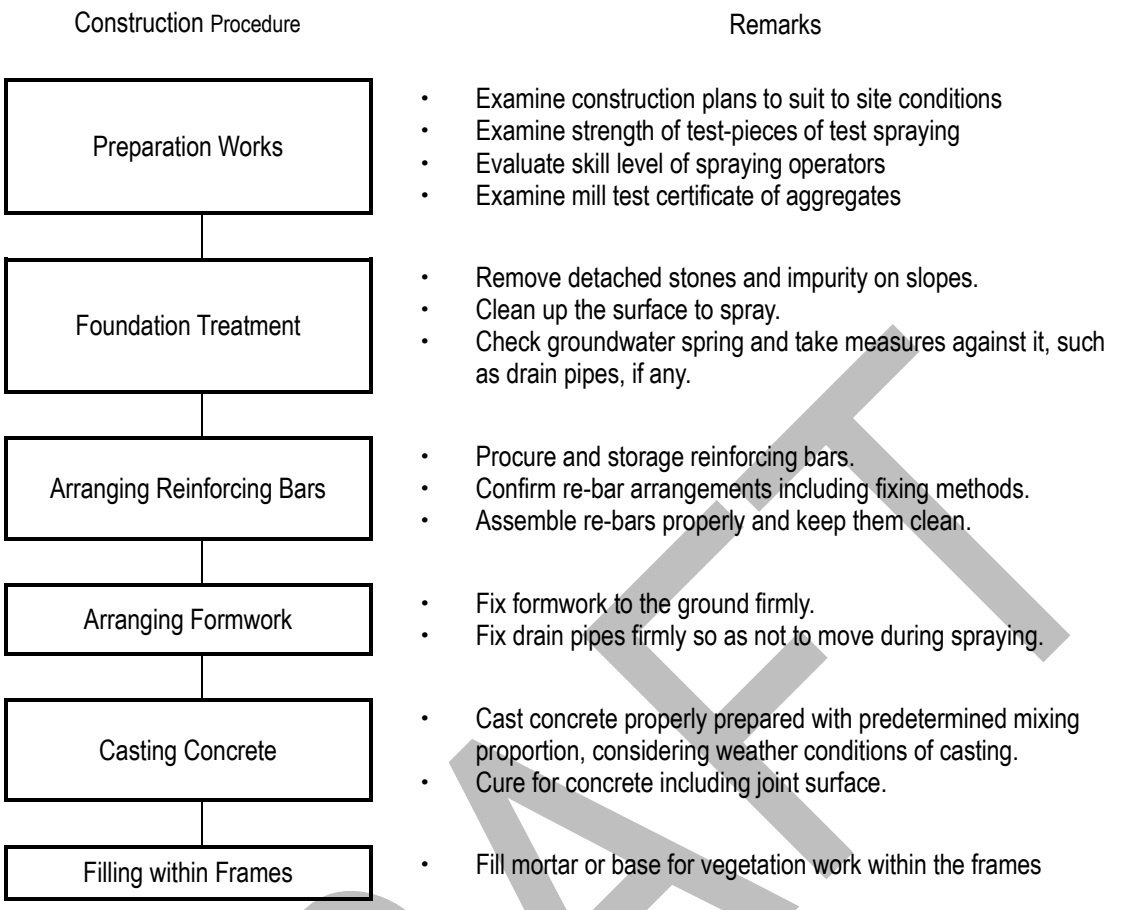


Figure 3-35 Construction Procedure of Cast-in-place Concrete Crib Works

[25]

The construction process of cast-in-place concrete crib works is almost similar to that of shotcrete crib works and important points during construction are basically in common. Thus the important points particularly for cast-in-place concrete crib works are explained in this section.

・ Strength

For cast-in-place crib works, basically the following requirement should be applied.

- Plain concrete: σck≧18N/mm2 (σck: design standard strength, Nominal strength in case of ready mixed concrete)
- Reinforced concrete: σck≧24N/mm2

・ Minimum Thickness of Concrete

The minimum thickness of concrete covering reinforcing bars is 4 cm or more.

・ Span of Frame

Typical spans of frame for particular geological conditions are shown in Figure 3-36. In case cast-in-situ concrete crib works is applied as a measure against large-scale slope failures, wider spans and cross-section of frames should be applied.

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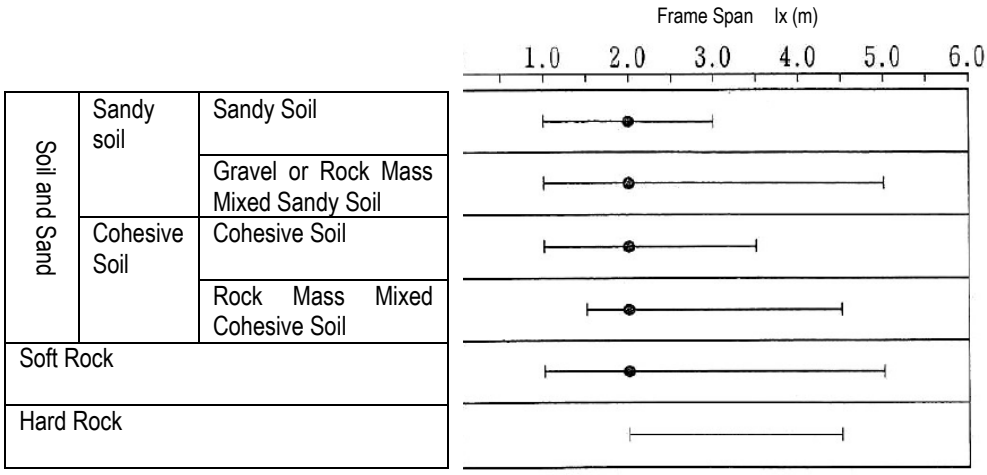


Figure 3-36 Geological Condition and Frame Span for Cast-in-place Concrete Crib Works

[31]

Cross section of frame depends on gradient of slope and loads from slope failures acting on vertical frames. Figure 3-37 shows reference for widths of frames in relation to gradient of slopes.

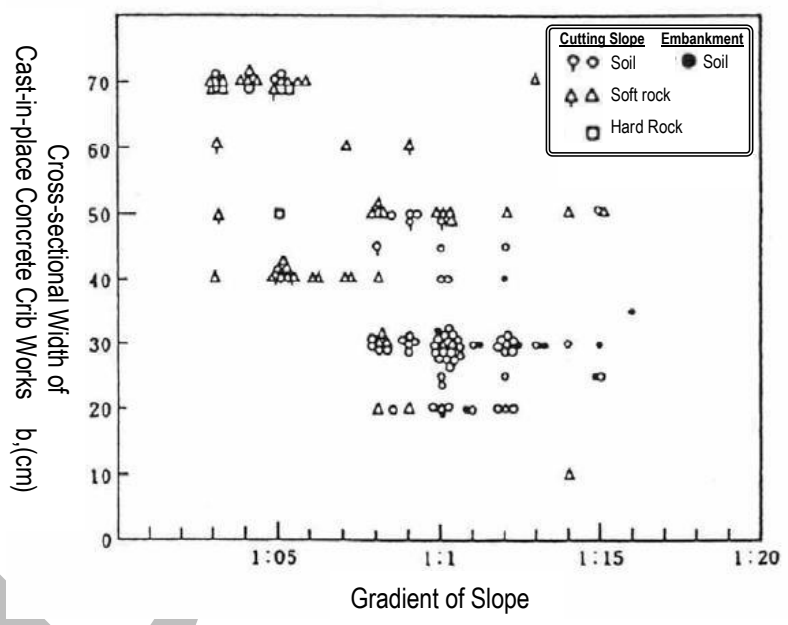


Figure 3-37 Relation between Gradient of Slope and Width of Frame for Cast-in-place Concrete Crib Works

[31]

(3) Safety Management for Workers

(i) Important Points for Health and Safety

Construction of concrete crib works involves particular threats to the health and safety of workers. Rebound of sprayed mortar/shotcrete and dusts are health hazards to workers. In particular, use of accelerating agents requires careful attention; many of such agents are strongly alkaline and stimulatory. The workers involved in construction of crib work should, therefore, wear appropriate protective equipment, including helmets, dust respirator, windshield glasses, and waterproof coats, for their safety and health.

Spraying works on slopes are usually carried out at high places. The workers should, therefore, wear safety harnesses connected to main ropes to prevent falling accidents. If fixed scaffolding or mobile scaffolding of an aerial work platform vehicle is available, it would be more desirable; works on such scaffolds is safer than works on slope only with safety harnesses connected to main ropes.

For reference, examples of accidents of falling down of labors during works at height, and efforts of safety management are described hereinafter.

(ii) Fall Accidents from Slopes

Falling accidents related to concrete crib works are described below.

According to the statistics on construction accidents in Japan (The Japan Construction Occupational Safety and Health Association, 2011), 919 died in fall accidents out of 2,267 deaths in construction accidents in Japan between 2005 and 2009. Among them, 110 workers had died in "fall accidents from the cliff or slope" and those related to road construction exceeded 30% (35 people). In particular, many accidents occurred caused by nonuse of safety harnesses or disconnection of lanyard from main ropes during works on cliffs or slopes.

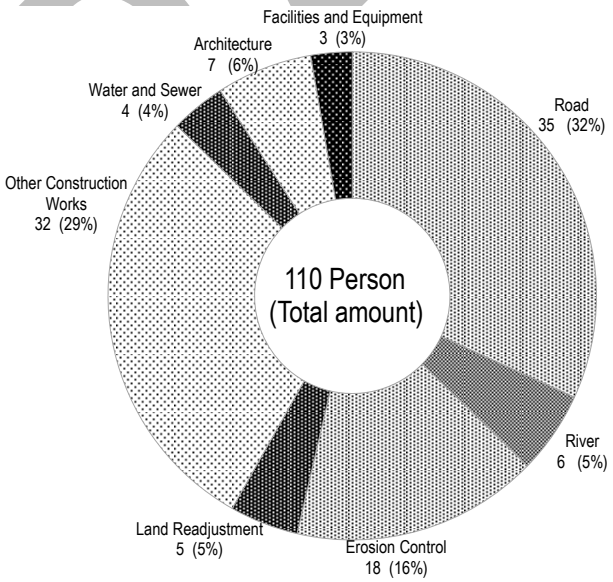


Figure 3-38 Fatal Fall Accidents from Cliff and Slope (in Japan, 2005-2009)

[32]

i) Examples of Fall Accidents during Spraying Shotcrete

In the construction of concrete crib works, fall accidents occur during spraying shotcrete. An accident during spraying shotcrete caused by improper connection between safety harness and main ropes is explained below. The fall accident occurred during spraying shotcrete on a roadside cliff of a height of around 9 meters with almost vertical gradient.

・ Direct Factor

The snap hook of the victim's safety harness was not correctly latched to the main rope. As a result, the snap hook was detached from the main rope during spraying works, and the victim dropped.

・ Indirect Factor

Health and safety education was not conducted for the workers at the site of the accident. Although the slope of the corresponding site was very steep and the spraying work there had a high risk of falling, sufficient health and safety education was not conducted on safe working procedures, such as handling of safety harness and connection to main ropes.

[33]

(iii) Effort for Safety Management (Risk Management)

In order to prevent accidents during crib works construction, health and safety education should be properly provided to the workers, such as proper use of rolip of safety belt which should be always fastened to main ropes during the works at high places, and snap hook of lanyard which should be surely attached to main ropes.

Another important factor is risk management of falling accident at the site. To implement risk management, the client should provide survey results of the site to the contractor, who should conduct risk assessment prior to preparation of an implementation plan, based on the survey results and confirmation of the actual site conditions. The implementation plan should incorporate measures against the risks highlighted in the risk assessment. Table 3-12 is an example of how to arrange work procedures based on risk assessment.

Table 3-12 Review of Work Procedure Based on Risk Assessment

Items		Description / Evaluation
Work item		Compaction
Risks of danger or noxious factor		During the compaction of embankment, a roller may fall from the slope due to absence of a guide for operation.
Degree of seriousness		10
Possibility		2
Evaluation points *See Table 3-13		12
Priority (risk level) *See Table 3-14		**4**
Measures to eliminate or reduce risks		For the compaction works near the shoulder of the slopes: Measurement poles with red and white colors should be arranged along the off-limit line for compaction machinery. Operator of machinery should be follow instruction by a guide. Machinery with a fall / turnover protection system should be used. Operator should wear a seat belt.
Re-evaluate after measures	Degree of seriousness	6
	Possibility	1
	Evaluation points	7
	Priority (risk level)	**2**

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Table 3-13 Evaluation Points by Adding Method (Four-Grades Evaluation)

Severity / Possibility	Mortality / Disability (10 pts)	Accidents with Sick Leave (6 pts)	Accidents without Sick Leave (3 pts)	Minor Accidents - No Treatment Required (1 pts)
Certain or probable (8 pts)	18 (10+8=18)	14 (6+8=14)	11 (3+8=11)	9 (1+8=9)
Highly possible (4 pts)	14 (10+4=14)	10	7	5
Possible (2 pts)	12 (10+2=12)	8	5	3
Scarce (1 pts)	11 (10+1=11)	7	4	2

Evaluation points are total of points of severity and possibility.

Table 3-14 Risk Status and Priority for Measures (Five-Grades Evaluation)

Evaluation Point 4-Grades	Status	Priority (Risk Level)	Criteria for Measures
18~14	Emergent, problems in the work process should be solved immediately	**5**	Prompt measures are required
13~10	Serious, considerable problems in the work process	**4**	Drastic measures are required
9~8	Substantial problems in the work process	**3**	Measures are required
7~5	Some problems in the work process	**2**	Not necessary at moment
4~2	Less problems in the work process	**1**	Not necessary

[34]

At the construction sites, proper understanding of the following measures by each personnel entering to the sites will significantly improve working conditions of the sites.

i) Examples of Measures to Establish Safety Conditions at Construction Site

- Workers are recommended to work on platforms or scaffolding with handrails. If such platforms or scaffolding is not available, main ropes bound to at least two supporting points of trees or anchors above the shoulder of slope or upper slope should be used. The main ropes should not be extended by attaching another rope. The main ropes should have enough length to cover the work area up to berms or toe of slopes. Workers should properly wear a harness, the rolip or grip of which should be tightly connected to the main ropes as fall arrest measures.
- For deploying main ropes, two main ropes method or safety block method is recommended, as shown in Figure 3-39.
- When works are carried out at shoulders of slopes or cliffs, or on berms, temporary guard fences with firmly equipped handrails should be installed. In case work procedure includes risk of falling, safety belts or harnesses should be used.

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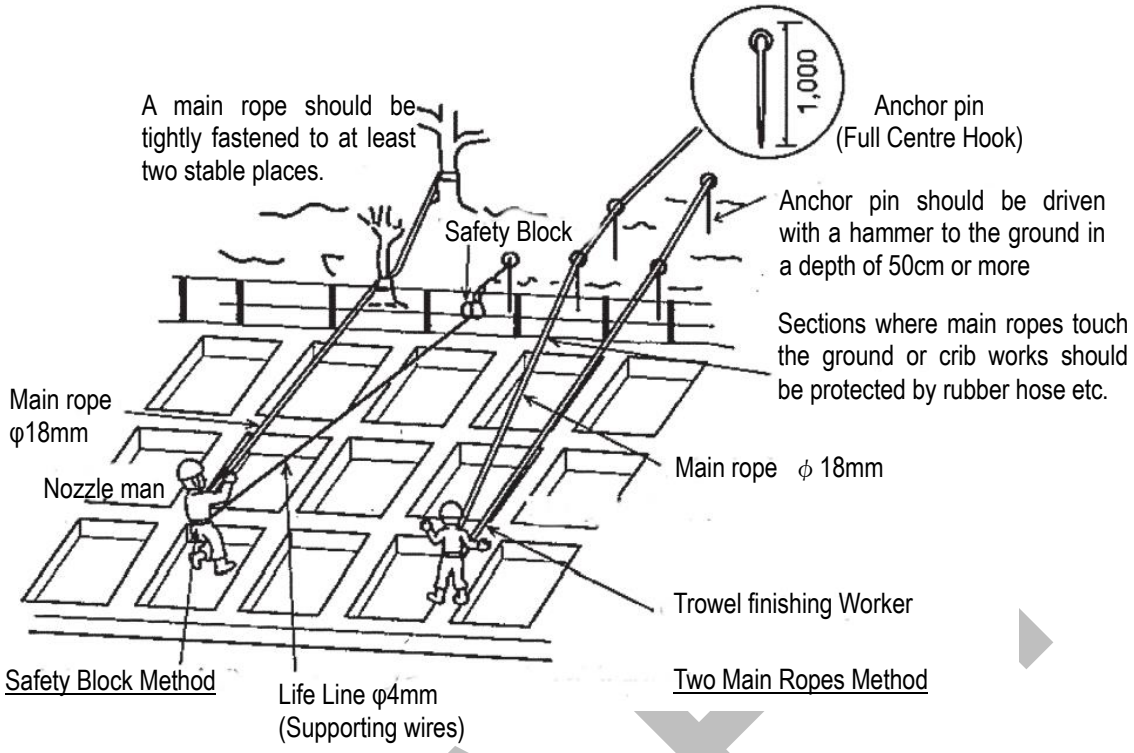


Figure 3-39 Main Rope Method (Right) and Safety Block Method (Left)

[32]

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3.1.4 Horizontal Drainage Boring

Horizontal drainage boring is to drill boreholes in the hill slopes slightly upward from the horizon and then install perforated casing pipes into the boreholes, aiming at collecting groundwater from the perforation and draining it through the casing pipes. Horizontal drainage boring is mainly adopted as groundwater control works to stabilize landslides, by draining groundwater from around slip surfaces of landslides or from along faults or fractured zones.

Horizontal drainage boring does not construct large-scale structures but drills boreholes and installs perforated casings. With drilling machines and scaffolding for the works, horizontal drainage boring can be executed at any place where the drilling machine and scaffolding are placed. Thus vast amounts of application have already been achieved in numerous landslide sites over the world.

Application has just started, however, to loosened bedrock slopes and gravity deformation blocks along hill roads, where road administrators often suffer from sinking and slope failures of hill roads. As mentioned in Chapter 1, it is obvious that groundwater control works including horizontal drainage boring are effective to mitigate deformation of the slopes where gravity deformation proceeds and to prevent devastating deep-seated landslides which may develop from gravity deformation. Thus horizontal drainage boring will be more widely employed in hill road construction as well as improvement hereafter.

On the other hand, horizontal drainage boring is accident-prone and has risks of fatal accidents due to simple and easy setup and construction.

This section explains the construction method of horizontal drainage boring, along with important precaution for safety management to avoid accidents involved with the works.

(1) General

In general, the horizontal drainage borings is designed to penetrate slip surfaces of landslides with a penetrating length of around 5 meters, with a total length of boring/perforated casing of from 20 to 50 meters.

In case the boring/casing does not reach slip surfaces, drainage wells may be adopted by which groundwater drainage network is connected and extended. Horizontal drainage borings are drilled from a drainage well, in which groundwater is collected through horizontal borings and discharged by a discharge boring.

The left of Figure 3-40 shows a profile of horizontal drainage boring and the right shows that of drainage well with horizontal drainage borings to collect groundwater and a discharge boring to drain groundwater. In a wide landslide site, drainage wells are connected with discharge borings so that collected groundwater is drained for a long distance.

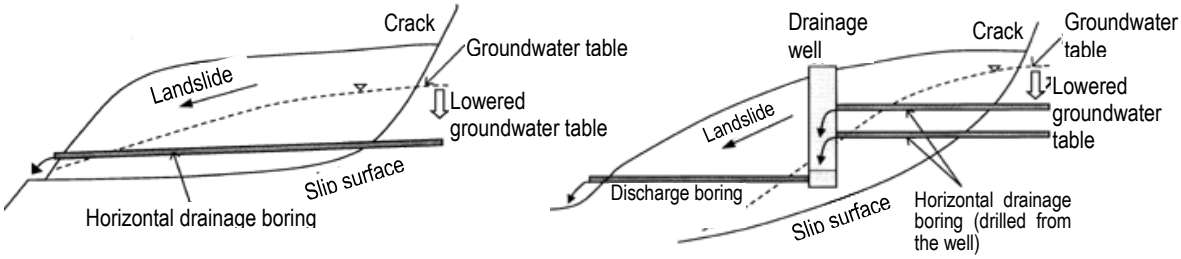


Figure 3-40 Left: Horizontal Drainage Boring and Right: Drainage Well

[35]

Figure 3-41 shows an example of outlets of horizontal drainage borings.

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Figure 3-41 Outlet of Horizontal Drainage Boring with Discharged Groundwater

[36]

Drainage wells are deep shafts to collect deep groundwater which is unable to collect by horizontal drainage borings drilled from the surface. The deep groundwater along slip surface is collected through horizontal drainage borings drilled from the wells and discharged through discharge borings to the surface/downward drainage wells. The photo on the left of Figure 3-42 shows inside of drainage well looked from the platform on the surface. The photo on the right shows groundwater flowing into drainage well from the outlets of the drainage borings. Figure 3-43 shows well platform on the surface.



Figure 3-42 Drainage Well (Left) & Inflow from Outlets of Drainage Boring (Right)

Left [37], Right [38]

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Figure 3-43 Well Platform of Drainage Well

[39]

(2) Construction Procedure and Points of Concern

A typical construction procedure horizontal drainage boring is shown below.

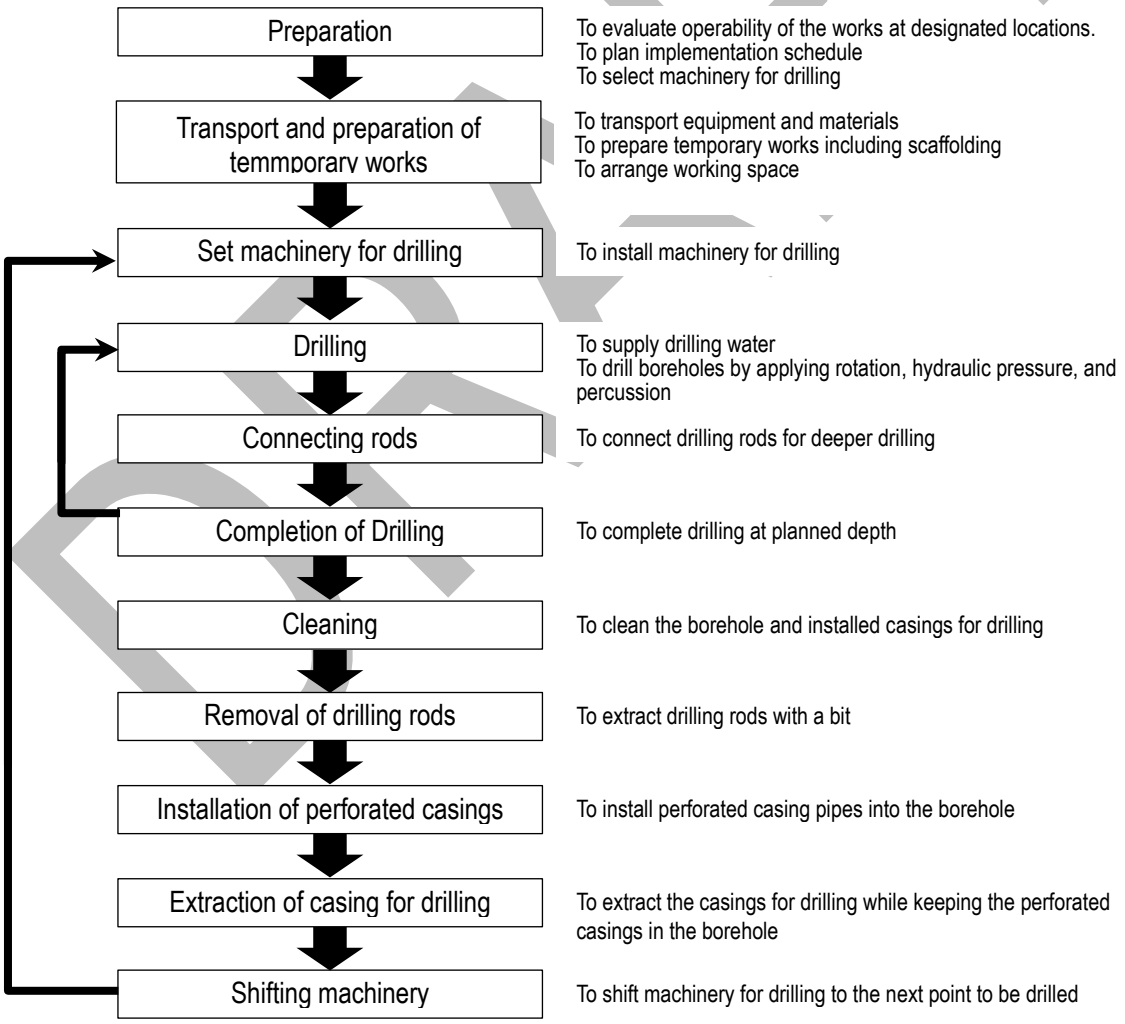


Figure 3-44 Typical Procedure for Construction of Horizontal Drainage Borings

[40]

The points of concern in the construction are explained below.

(i) Preparation for Construction

The locations of the outlets of the horizontal drainage borings indicated in the tender/contract drawing should be checked on site to evaluate operability of the work. Then, as a part of construction planning, mobilization and temporary works should be planned to enable the horizontal drainage borings to be executed.

In case the works at the indicated locations are impossible due to physical reasons, such as lack of the height for the working stage, substitute locations should be proposed by the contractors. The proposals should be checked by the design engineers for the consistency with the slope stability analysis and design, and, with the advice from the design engineers, approved by the employer.

Evaluation of Operability

The points to consider during preliminary survey are listed below:

(a) Topographic and geological aspects
- (If the works are done at cut slope,) stability of slope during works
- (If the thickness of overburden is thin at the tip of drilling,) penetration of boring to the surface of the upper slope or flat land.

(b) Temporary works
- Safety of transport route during construction, for both the workers and the third parties
- Sufficient widths for transport and works
- Sufficient space for storage of machinery and materials as well as stockyard and site office

(c) Obstacles (ex. telephone lines/poles, electric cables, trees, & buildings)
(d) Underground utilities and other obstacles
(e) Surrounding environment, including houses and water wells for locals
(f) Stakeholders of the sites, including land owners and other right holders.
(g) Laws and regulation.

Execution Timing

Emergency works are often required when risks of landslide increase. Such situation, however, requires careful attentions for and swift execution of the works.

Increase of groundwater due to heavy or continuous rains as well as snow melting is considered as one of the triggers of landslides. In rainy seasons, groundwater potential in landslide mass increases, therefore, the timing for execution should be carefully considered, taking the following conditions into account:

(a) For the works in and around active landslides, daily/continuous monitoring of landslide movement is essential to secure safety.
(b) For the works of horizontal drainage boring, when groundwater potential in landslide mass is high, careful attention should be paid to prevent borehole wall collapse during drilling and installation of perforated casings and extraction of perforated casings when drilling rods and casings are removed.

Selection of Drilling Machine

Drilling machine should be selected based on the requirements, such as planned depth, borehole diameter, geological conditions, and available space for the works.

Dominant types of drilling machines often used for horizontal drainage boring are explained in Table 3-15. Hydraulic rotary drilling machines are compact and easily placed and used in narrow working spaces, such as inside of drainage wells. Rotary

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percussion drilling machines display fast drilling rate and high construction efficiency but generate noise in operation. Rotary percussion machines can be used for drilling through boulder bearing gravelly layers or talus deposits, in which hydraulic rotary machines often suffer from delays.

Table 3-15 Main Drilling Machines Used for Horizontal Drainage Boring

Name Performance	Hydraulic rotary boring machine	Rotary percussion drilling machine
Rotation	To the right	To the left
Drilling depth	Long/deep drilling is available	100-200m
Drilling speed	Low	Fast
Application to Geology	Drilling speed is lower in hard rock	Applicable to both soft and hard strata

[41]

Hydraulic Rotary Drilling Machine



Small model 5.5kw class
Size: L 1,600 W 800 H 1,500(mm)

Rotary Percussion Drilling Machine



55kw class
Size: L 2,750 W 1,890 H 1,370(mm)

Figure 3-45 Dominant Types of Drilling Machines for Horizontal Drainage Boring

[40]



Figure 3-46 Drilling from the Surface

[42]

(ii) Transport

If temporary roads with sufficient widths are secured, machinery and materials can be transported by ordinary vehicles. In case where temporary roads for ordinary vehicles are not secured, crawler (caterpillar) carrier, temporary simple monorails, highline (cableway), airborne transport, manual transport, or other transport

methods should be arranged. Table 3-16 shows application of transport method in steep slopes or irregular ground.

Table 3-16 Comparison of Transport Methods

	Suitable Distance	Suitable Terrain				Efficiency	Remarks
		Flat	Gentle slope	Moderate Slope	Steep slope		
Manual transport	Less than 200m	A	B	N	N	N	Applicable to any landforms but trails are required.
Crawler carrier	100-500m	A	A	B	N	B	Equipped with caterpillar Applicable without roads but speed is low
Truck	Over 500m	A	A	C	N	A	Roads with sufficient widths are required.
Simple monorail	100-200m	-		B	A	B	Temporary track for monorail should be installed, which requires preparation period.
Highline (cableway)	300-500m	-		B	A	B	Infrastructure for highline should be installed, which requires lengthy preparation period.
Airborne transport by helicopter	Over 500m	-		B	A	A	Large open space is required for loading and unloading of cargo. Cost is high in case of small volume.

Evaluation Index

	Applicability	Efficiency
A	Very applicable	Highly Efficient
B	Applicable	Efficient
C	Depending on cases	-
N	Not applicable	Not Efficient

Source: JICA Project Team

(iii) Temporary Works - Scaffolding

Scaffolding should be planned and assembled depending on conditions of working area of the sites as well as type and weight of drilling rigs. The scaffolding used for the works of horizontal drainage borings is explained below.

Tube Scaffolding

Tube scaffolding provides wide adjustability to secure sufficient working stages suitable to various terrain conditions. Tube scaffolding is applicable to both natural and artificial slopes and composed of pipes, clamps and stage planks.

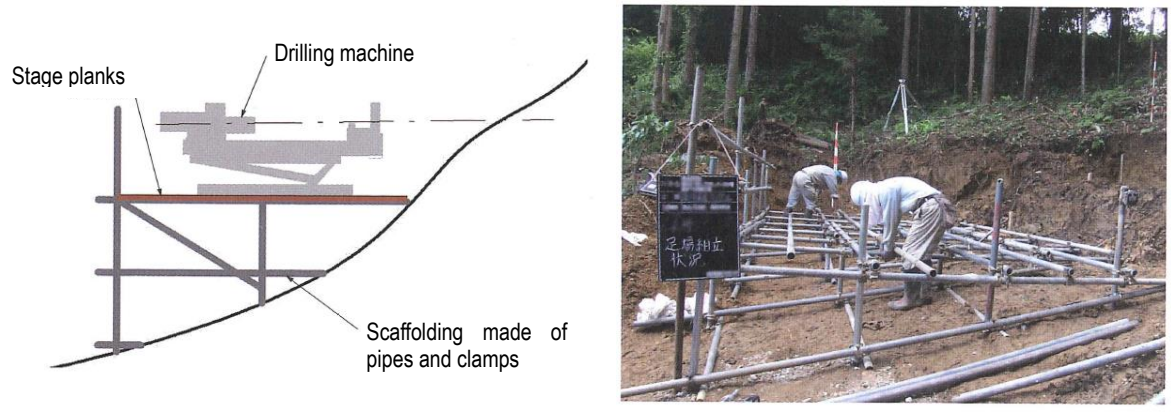


Figure 3-47 Preparation of Tube Scaffolding

[40]

Leveled Earth Stage for Drilling Works

On relatively gentle natural or artificial slopes, flat stage formed by earthwork is used for working space for drilling works. If surplus soil is available at construction site, this method is cheaper than tube scaffolding.

(iv) Working Space for Drilling

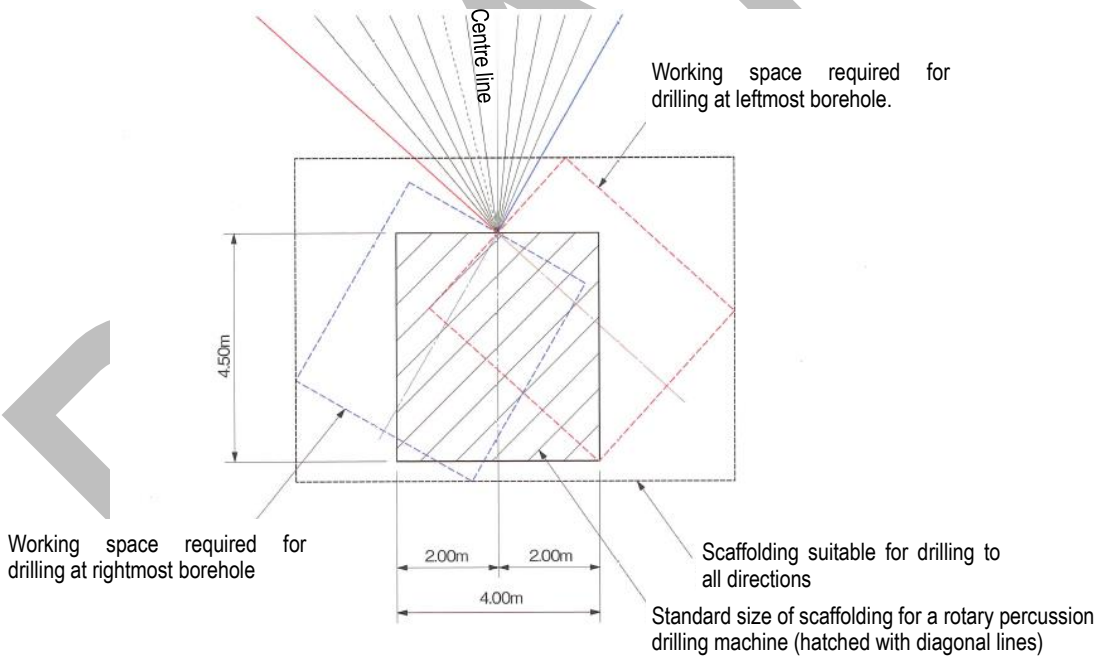
Required work space depends on the drilling machines to be used for the work. In general, a rotary percussion drilling machine requires a wider working space than a hydraulic rotary drilling machine does.

The standard length of the scaffolding for a rotary percussion drilling machine is 4.5 meters. If boreholes are required to drill from drainage wells, however, available working space is much narrower; a diameter of drainage well is usually 3.5 meters and the scaffolding should be smaller than the section area within a well.

For horizontal drainage borings, working space of a width of 2 meters on both sides of boreholes should be secured. Thus scaffolding for such works should be prepared to secure sufficient length and width for the works. In case drainage borings are designed in a fan-shape arrangement, scaffolding should have a suitable space, which enables a drilling machine to change directions of boreholes to drill. Thus a wider working space is required.

Generally, a hydraulic rotary drilling machine is smaller than a percussion drilling machine and necessary work space is slightly smaller.

Drilling rods of 3 meters long are often used for horizontal drainage boring. Longer drilling rods, however, require wider working space. If the works are done in a narrow space, such as inside a drainage well, therefore, use of shorter drilling rods of 1.0 or 1.5 meters long should be considered, along with adopting smaller drilling machines.



Scaffolding does not have to be installed symmetrically on the center of drainage boring works

Figure 3-48 Required Size of Scaffolding for Fan-arranged Horizontal Borings

[40]

(v) Fixing Drilling Machines

Fixing a drilling machine to scaffolding or the ground is important for quality control of the works. Poorly fixed machine may cause problems of bentness of borehole due to wobbling during drilling. Since vibrations are generated by hammering, a rotary percussion drilling machine requires special attention for fixing.

When the works are done on scaffolding, a drilling machine should be fixed with scaffolding with chains and lever blocks, as shown in Figure 3-49. When the works are done on the ground, a drilling machine should be firmly set directly on the ground, which should be well compacted and flattened before setting a machine to prevent sinking or wobbling of the machine.



Figure 3-49 Fixing Rotary Percussion Machine on Tube Scaffolding

[40]

(vi) Drilling of Horizontal Boreholes

Arrangements of Boreholes

Boreholes should be drilled in a manner to form fan-shaped or parallel arrangements. Since multiple boreholes are drilled from one location, fan-shaped arrangements can save time for preparation of scaffolding and setting and shifting of drilling machines. Intervals between the tips of boreholes or the points where boreholes penetrate a slip surface should be from 5 to 10 meters.

To ensure that boreholes reach the targeted groundwater aquifer or passage, before drilling starts, depth and location of groundwater aquifer or passage should be checked by groundwater logging or other survey methods. In Figure 3-50, suitable arrangements of horizontal drainage borings are illustrated.

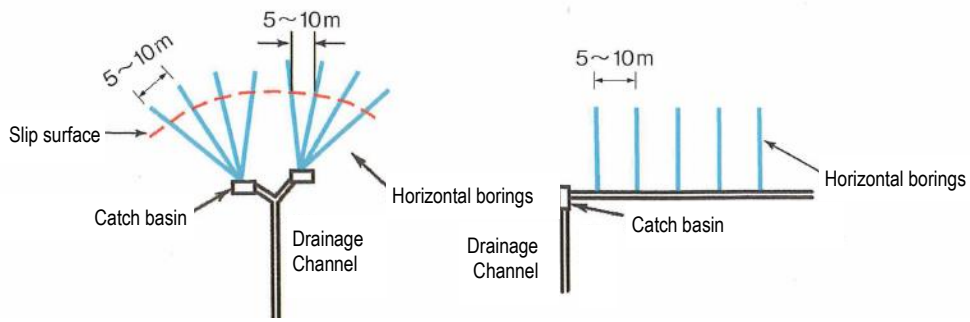


Figure 3-50 Arrangements of Horizontal Drainage Borings

[40]

Inclination of Horizontal Boreholes

As shown in Figure 3-51, horizontal boreholes should be drilled with upward inclination of 5 to 10 degrees from the horizon. Due to the inclination, collected groundwater is easily discharged and flown out of landslide area by the action of the gravity.

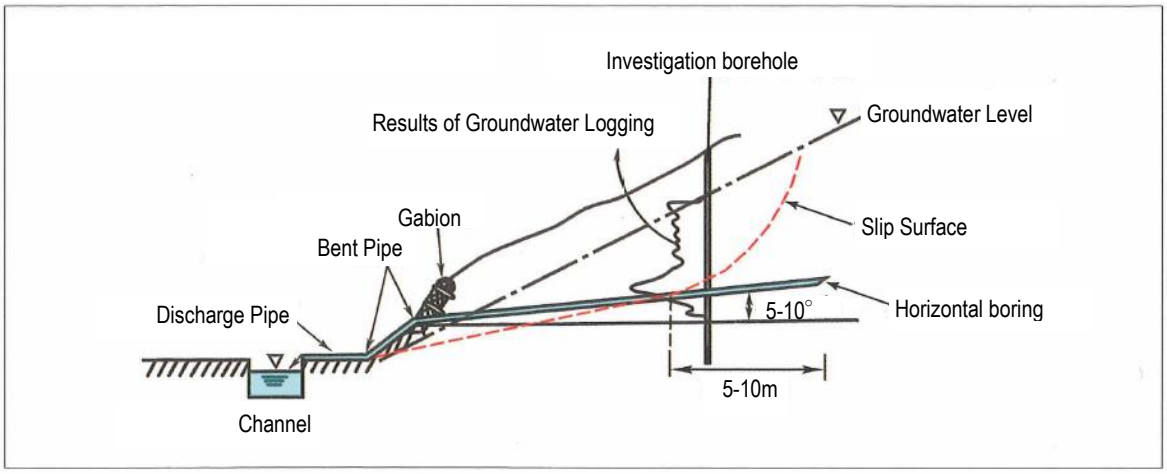


Figure 3-51 Cross Section of Horizontal Drainage Boring

[40]

Borehole Diameter

Diameter of borehole should be 66 mm or more. If landslide mass is composed of cohesive soil with low permeability, boreholes with larger diameter should be adopted. In general, the borehole diameter of horizontal drainage boring is 90 mm, and that of discharge boring is 115 mm.

Drilling Length

Drainage borings should penetrate a slip surface with 5 to 10 meters length embedded to the stable ground. Direction and length of boreholes should be carefully decided so as to avoid ground anchors and steel piles as well as existing monitoring wells and investigation boreholes.

Perforated Casing Pipes

Perforated PVC or steel pipes should be inserted into the boreholes. The tips (or ends) of pipes should be protected by attached caps. To avoid clogging or closure, perforated pipes are often wrapped with filters, which prevent soil and tiny particles from entering into the pipes.

In many cases, PVC pipes are adopted as perforated pipes. Steel pipes are adopted when applying pressure is required to insert casing pipes, such as boreholes in active landslides or with abundant groundwater inflow.

Protection for Outlets of Drainage Boreholes

As shown in Figure 3-51, in case outlets of drainage boreholes are exposed from the surface, protection should be provided with concrete retaining walls or gabions, to avoid collapse of outlets caused by the discharged water from the outlets.

(3) Safety Management

Major work-related accidents during operation of horizontal drilling are summarized in Table 3-2Table 3-17. The most frequent as well as dangerous work item in drilling works is attaching and detaching of casing pipes and drilling rods. On the

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other hand, vital accidents are caused by getting caught in the rotating parts of drilling machine.

Table 3-17 Major Work-related Injuries by Groundwater Drainage Borings

Type of Works	Types of Hazards	Examples
Drainage Horizontal Boring	Stuck/caught in a machine	Caught in rotating parts of machine. Get stuck in a connecting part of tools
	Falling down of workers	Falling from scaffolding
	Falling object	Drop of materials during crane operation
	High temperature/ Exposed to hazardous substance	Heatstroke Exposed to / inhaling toxic gas
Drainage well	Falling down of workers	Falling from well platform on the surface, Falling from stairs of drainage well
	Falling object	Drop of materials during crane operation Drop of materials and tools
	Crash	Crash against Heavy Machinery
	High temperature/ Exposed to hazardous substance	Heatstroke Oxygen deficiency Carbon monoxide poisoning

[40]

Among the accidents in Table 3-17, the most careful attention should be paid for getting caught in rotating drilling rods. By studying an actual case of such accidents explained below, causes and measures are discussed below.

(i) Summary of Accident (Direct factor)

- The rods were exposed within the area of work while it was rotating. The clothes of the worker were caught on the surface of couplings of rotating drilling rods.

(ii) Indirect Factor of the Accident

- Sufficient working space was not secured.
- Safety aisle to avoid rotating parts of the drilling machine were not prepared.
- The worker involved in the accident wore clothes that did not fit well to his body. The clothes had extra parts easy to get caught by rotating rods.
- The operation lever of the drilling machine was not appropriately located for safe operation.
- The drilling was not carried out by two or more workers for immediate response to the emergency.

(iii) Measures Against the Accident

- Attaching covers or protections to rotating parts of machines, which workers may touch or get involved to, as shown in Figure 3-52.
- Safe space and safety aisle should be secured for workers where workers can work or move without touching rotating or functioning parts of machine.
- Workers should wear the working clothes that are tightly fit and comfortable to move around.
- Towels should not be wrapped around the neck.
- Control levers and pressure gauges for operation should be placed with safe distance from rotating or functioning parts of machine, so that workers can operate machines in safe place.
- Required numbers of personnel should be assigned for safe work.

[43]

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Figure 3-52 Safety Cover for Rotating Parts of Drilling Machine for Horizontal Boring

Source: JICA Project Team

To prevent such accidents, workers should aware of the dangers behind their work. Furthermore, construction plans with an emphasis on a safe working environment should be formulated and well understood by the workers.
In addition, making the workers be aware of protecting themselves from the dangers in work place is important. And for that purpose, before starting the daily work, making an effort in each site is essential to let the workers discuss the dangers in work place along with its measures as well as manners to work safely.

Examples of such activities to reduce accidents in horizontal drilling works are listed below:

(a) Morning assembly, light exercise, and risk prediction activities.
- Risk prediction activities on daily work by supervisors and workers in a morning assembly at the site
- Coordination among and within working parties on work items, information to share, dangerous risks, and measures against the predicted risks.
- Light exercise warms workers' physical condition up

(b) Recognition of dangerous risks around the site
- Recognition of landform, boulders on slope, unstable rock, and other dangerous risks around the site.
- Sharing information to workers, and instruction of safety measures

(c) Provision of safety facilities to the site
- Restriction of entry to the dangerous areas by installing fences around the risk,
- Highlighting dangerous points with signs

(d) Safe operation of machinery
- Clarification of function of each control lever for machine operation
- Efforts to eradicate human errors by machine operators, with clear indication of methods of operation and function of control levers, by color coding or easy signs, etc.

(e) Provision of Evacuation Routes
- Utilizing safety aisle as evacuation route

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(For drilling works, most of the works are done on temporary scaffolding. Thus, for an emergency such as earthquake, clarifying evacuation routes for workers to quickly and directly evacuate from the scaffolding is essential.)

- Safety Training
  - Providing regular safety training, monthly or quarterly.
  - Daily safety training for a few minutes after morning assembly
    (Even for a few minutes, training on each day has an effect of raising workers awareness of safety)
- Safety Patrol by Company
  - Implementing monthly safety patrol by the company
  - Site inspection by safety managers who are not involved in the works to obtain points to correct. (Inspection by third party is effective)

[44]

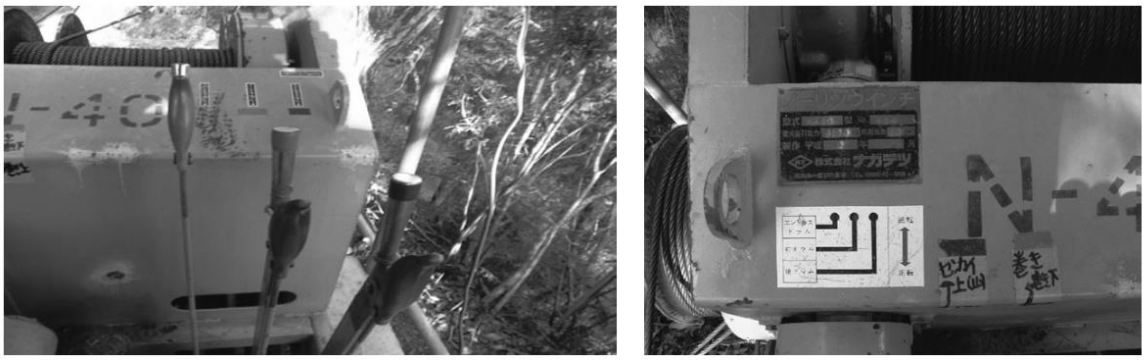


Figure 3-53 Left: Color-coded Display, Right: Clear Indication of Operation Method

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3.2 Embankment Works

In this section, the construction embankment of hill roads is described. At first, the factors to destabilize embankment slope are explained along with actual examples of embankment failures. Then points of concerns of embankment construction are explained in term of the purpose and methods of improvement works for foundation ground as well as embankment itself and field observation during construction.

For the light-weight embankment, which is effective in reducing the load to the ground, based on the features and construction methods described in Chapter 2, construction procedure and the methods for construction management and quality control are explained

Furthermore, as points of concerns for the embankment construction at particular places, technical points for the following construction methods are explained; half-bank and half-cut, transition zone of cutting and filling, widening of embankment, boundary between embankment and structures, embankment slope, and slope drainage.

3.2.1 Factors to Destabilize Embankment Slopes and Points of Concerns of Construction

(1) Factors to Destabilize Embankment

Hill road construction often requires high embankments or embankments on hill slopes, which often include factors to destabilize the embankments.

Destabilization of embankment slopes are caused by external and internal factors as shown in Table 3-18. External factors include natural conditions, such as rainfall and earthquake as well as influence from landform and geology, and degraded facilities or related works which cannot provide functions as designed. Internal factors include deterioration of embankment body itself, caused by improper construction, such as insufficient compaction and use of inadequate material for filling.

Table 3-18 Destabilizing Factors of Embankment Slopes

External factors	Natural environment factors	Erosion by rainwater or snow melt runoff, increase of pore water pressure by seepage water or groundwater, earthquake, etc.
	Topographic factors	Crossing section of valley-filling, catchment area in hinterland, embankment of steep slope or soft ground, etc.
	Factors due to degraded facilities	Poor maintenance of drainage system, poor growth of vegetation works, etc.
Internal factors	Material of filling	Material with slaking property, inhomogeneous embankment material, etc.
	Improper manner of construction	Inadequate bench-cut of the ground, insufficient compaction, etc.

[45]

Factors in Table 3-18 often cause collapse of embankment slope in combination with other factors. Among them, earthquake is the most prominent cause of collapse.

Embankment slope is naturally an artificial slope that is constructed under proper design and construction management. Even against the heavy rain which damages natural slopes, embankment slope is often stable when the risk of heavy rain is properly excluded by design and construction. On the other hand, due to extremely

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high costs of countermeasures against earthquakes, embankments are often designed and constructed with a design that ensures the stability at normal conditions.

The examples of collapsed embankment slopes are explained in the following section for the embankments on natural slopes, high embankment, valley-filling, stream-filling, approach, and widened embankments, which are all caused by earthquakes. At the same time, however, other negative factors which facilitate collapse are understood.

(2) Examples of Collapsed Embankment Slope

(i) Embankment on Hill Slope



Figure 3-54 Collapsed Embankment on Hil Slope (Nanao, Ishikawa Pref., Japan, 2007)

[46] [47]

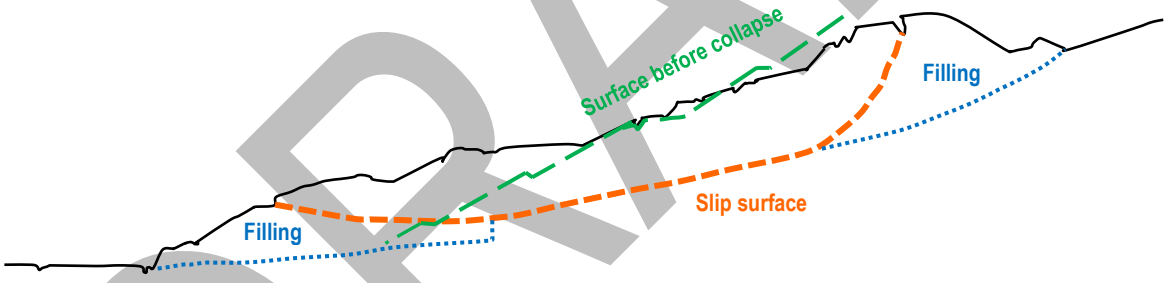


Figure 3-55 Cross Section of Collapsed Embankment (Nanao, Ishikawa Pref., Japan, 2007)

[46] [47]

a) Summary of the Collapse

- The collapse occurred in the section where stream-filling asymmetrical embankment, cut-and-fill and valley-filling symmetrical embankment continue, filling height of which is 20 to 25 meters.
- The collapse engulfed a section of about 200 meters in length, leaving one lane of the two-lane road.
- At the collapsed section, three streams joins and a small hollow of marsh lies behind the road. At the cut slope section between the streams, slope failures was not observed.
- Groundwater spring was confirmed near the center of the collapse. At the end of collapsed section, a pond was constructed behind of the symmetrical embankment and a large amount of water was drained through the crossing culvert.
- The ground around the toe of the embankment slope was used as paddy fields and thus considered constantly saturated.

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- A trace of repair of a longitudinal crack was observed on the pavement in the section of the asymmetrical embankment, which suggests constant deformation of embankment.

[46], [47]

b) Date and Scale of Triggering Earthquake

- Date: March 25, 2007
- Epicenter: Off of the west coast of the Noto Peninsula (lat. 37°13.2'N. and long. 140°41.1'E.)
- Focal Depth: about 11 kilometers deep
- Scale: 6.9 Mj (Mj is the local magnitude defined and calculated by Japan Meteorological Agency (JMA).)

[47]

(ii) High Embankment

i) Collapse of High Embankment 1 (Nanao, Ishikawa Pref., Japan, 2007)



Figure 3-56 Collapse of High Embankment by Earthquake (Nanao, Ishikawa Pref., Japan, 2007)

[46] [47]

a) Summary of the Collapse

- A series of large-scale collapse occurred at high embankment sections (filling height h = 18 to 36 meters). In addition, collapse also occurred on stream-filling embankments of collecting slope of catchment area.

b) Date and Scale of Triggering Earthquake

- Date: March 25, 2007
- Epicenter: Off of the west coast of the Noto Peninsula (lat. 37°13.2'N. and long. 140°41.1'E.)
- Focal Depth: about 11 kilometers deep
- Scale: 6.9 Mj

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ii) Collapse of High Embankment 2 (Oushu, Iwate Pref., Japan, 2008)



Figure 3-57 Crack Appeared at High Embankment (Oushu, Iwate Pref., Japan, 2008)

[48], [49]

a) Summary of Collapse

- A high valley-filling embankment of a height of about 30 to 35 m deformed. Cracks appeared on the pavement at the boundary between cut and fill with a vertical displacement of about 20 cm. However, remarkable deformation was not observed on the embankment slope.
- Most cracks appeared in the embankment section. Vertical displacement was observed behind abutments and at crossing box culvert.

b) Date and Scale of Triggering Earthquake

- Date: June 14, 2008
- Epicenter: Inland area of southern Iwate Prefecture (lat. 39°01.7'N. and long. 140°52.8'E.)
- Focal Depth: About 8 kilometers deep
- Scale: 7.2 Mj

[48], [49]

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(iii) Valley-filling / Stream-filling Embankment

i) Collapse of Valley-filling/Stream-filling Embankment 1 (Sakae, Nagano Pref., Japan, 2011)



Figure 3-58 Collapse Caused by Earthquake (Sakae, Nagano Pref., Japan, 2011)

[50]

a) Summary of Collapse

- Scale of the Collapse: Width of 20 meters, length of 45 meters, slope gradient of 60°, and thickness of 3 meters.

b) Date and Scale of the Triggering Earthquake

- Date: March 12, 2011
- Epicenter: Near the prefectural border between Nagano and Niigata (lat. 37°00'N. and long. 138°36'E.)
- Focal Depth: About 8 kilometers deep
- Scale: 6.7 Mj

[51]

ii) Collapse of Valley-filling/Stream-filling Embankment 2 (Kurihara, Miyagi Pref., Japan,2008)



Figure 3-59 Damage on the Asymmetrical Embankment Constructed Filling a Small Stream (Kurihara, Miyagi Pref., Japan, 2008) Left: Embankment Constructed in Parallel with Valley, Right: Stream-filling Embankment

[48], [49]

a) Summary of Collapse

- An asymmetrical embankment constructed by filling a small stream was damaged, and large cracks with vertical displacement of up to 20 cm appeared near the boundary between the embankment and the ground.

b) Date and Scale of the Triggering Earthquake

- Generation date: June 14, 2008
- Epicenter: Inland area of southern Iwate Prefecture (lat. 39°01.7'N. and long. 140°52.8'E.)
- Focal Depth: About 8 kilometers deep
- Scale: 7.2 Mj

[48], [49]

(iv) Approach Embankments and Widening of Embankment



Figure 3-60 Cracks Caused by Earthquake (Kurihara, Miyagi Pref., Japan, 2008) Left: Approach Embankments, Right: Widening of Embankment

[48], [49]

a) Summary of Collapse

- A widened embankment of a filling height of 5 meters was damaged. Cracks appeared on the pavement of one lane of carriageway and pedestrian (Figure

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3-60 left)

- An asymmetrical embankment constructed by filling a small-scale stream was damaged. A relatively large crack with a level difference up to 20 cm occurred near the boundary between the embankment and the ground. (Figure 3-60 right)

b) Date and Scale of the Triggering Earthquake

- Date: June 14, 2008
- Epicenter: Inland area of southern Iwate Prefecture (lat. 39°01.7'N. and long. 140°52.8'E.)
- Focal Depth: At a depth of about 8 kilometers
- Scale: 7.2 Mj

[48], [49]

(3) Points of Concerns on Construction

In hill road construction, high embankments and embankments on natural slopes are planned and designed under restricted land conditions. On the other hand, a high embankment, which has a filling height of 15 meters or more, has a larger load to the ground than a normal embankment does. Thus bulging of embankment slope is easily occurred. In addition, compaction and subsidence of a high embankment itself cause a large amount of deformation. Therefore, if a high embankment collapses, deformation of the embankment cause serious damage to the road on it.

When a hill road is constructed only with embankment on hill slopes without cutting the slopes, high and larger embankments should be constructed to secure the required widths of the road. Such high and large embankments are prone to collapse due to rainfall or earthquakes, however. Furthermore, when a high and large embankment is constructed on a hill slope, the lower slope of the embankment itself becomes prone to collapse due to the huge weight of the embankment itself. In some cases, the huge load of high embankments may cause failure of the bearing ground or activate a landslide lying on the lower slope due to the load on its head. The huge load of high embankments may even cause gravity deformation of the lower slope.

Surface runoff provided by rainfall and shallow ground water flow along the shape of a valley and concentrated at the bottom of a collecting slope of a catchment area. And an embankment at the bottom of the collecting slope may be affected by such abundant surface and ground water. Especially, at narrow valleys where groundwater discharges slowly, valleys with narrowed outlets (bottleneck-shaped landforms), or fractured zones along which large amount of groundwater is stored, embankments are vulnerable to collapse.

Furthermore, if groundwater level in an embankment rises due to infiltration of groundwater behind as well as surface runoff, entire embankment may collapse. Especially a valley-filling embankment is prone to loose stability due increased groundwater level, which is raised by surface runoff and groundwater infiltrated into an embankment during rainfall.

When groundwater level in an embankment is high, landslides may be induced by the liquefaction at the bottom of an embankment during an earthquake.

Along hill roads, collapse of embankments is caused by multiple conditions related to embankment as well as rainfall and groundwater. Figure 3-61 shows possible reasons of collapse of widened embankment on slopes. The figure suggests a possible flow of embankment collapse, such as shown below:

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1. Surface runoff flows to an embankment from surrounding slopes.
2. Rainwater infiltrates directly into an embankment from a flat area on hill side made by filling or from embankment slopes on valley side.
3. An embankment may compressively subside or deform due to poor compaction or improper material or internal erosion by seepage pressure of groundwater. In case the bearing layer at the toe of an embankment is soft and cause consolidation settlement. Such settlement, subsidence and deformation causes many cracks on slope surface, shoulder of slope, drainage ditches, and pavement on an embankment, which allow surface water to infiltrate into the embankment.
4. Infiltration of groundwater causes a rise of ground water level in an embankment, which leads to reduction of effective stress. Drainage ditches and underdrains installed during construction may be clogged and lose their function.

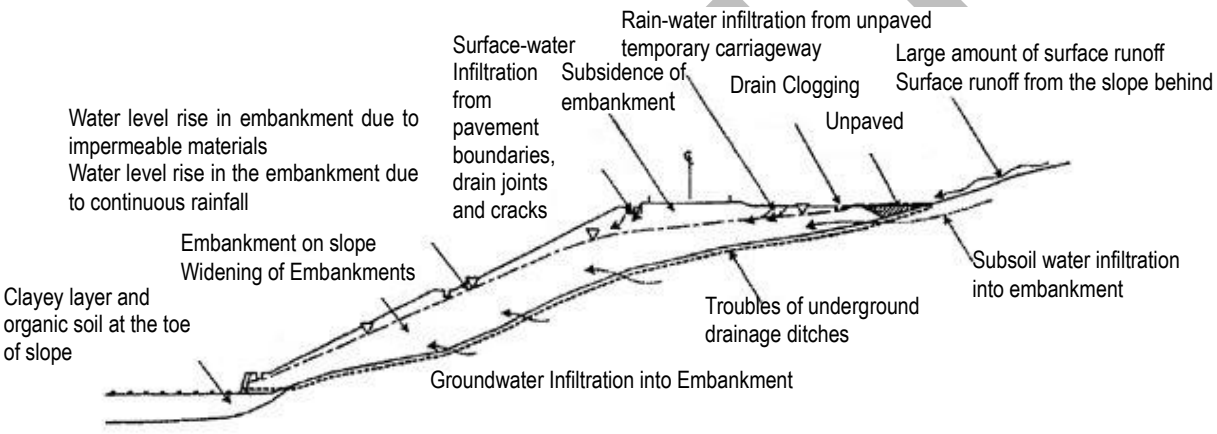


Figure 3-61 Concept of Factors of Collapsing

[52]

For the construction of the embankments on hill roads, careful attention should be paid to foreseeable hazards. For that purpose, detailed topographic and geological survey should be conducted in advance of the construction as required. In addition, it is important to take measures in accordance with the ground conditions of the target area, including appropriate measures for securing drainage.

In addition, lack of sufficient compaction and use of improper materials for filling can result in degradation of embankment, which may cause sliding triggered by an earthquake. Similar to embankment construction on flatland, therefore, proper construction management is required for the embankment on hill roads, including securing sufficient compaction and adopting proper material for filling.

(4) Technical Points for Construction

(i) Methods of Construction

Possible method of Construction for the embankments on hill slopes are summarized in Table 3-19 in accordance with the purpose of improvement. In addition, the outline of each method is described in Table 3-20.

Table 3-19 Method of Construction of Embankment on Hill Slopes

		Improvement of Ground Characteristics (Consolidation / Heat Treatment)					Structural Change				Re-place	Reinforcement						
		Deep Mixing Method (Mechanical / Jet Mixing)	Chemical Injection	Sintering Method	Freezing Method	Surface Mixing Method	Counterweight (Buttress) Fill Method	Light-weight Embankment (Styrene Foam etc.)	Sheet Piles and Various Foundation Method	Soil Reinforcement Method (Terre Armee Method etc.)	Replacement Method	Pile Net/Cap/Slab Method	Deep Mixing Method	Sand Compaction Pile Method	Mattress Structure Method	Earth Cover Method (Sand Mat Method)	Surface Covering Net Method	Root Piles / Soil Nailing
Purpose of Improvement	Prevention of Sliding or Collapse	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓			
	Prevention of Settlement	✓	✓	✓	✓				✓			✓	✓					
	Mitigation of Settlement	✓	✓	✓	✓		✓	✓			✓			✓				
	Prevention of Shear Deformation	✓	✓	✓	✓													
	Prevention of Heaving	✓	✓	✓	✓													
	Ensuring Trafficability					✓										✓		
	Deformation of Surrounding ground								✓			✓						
	Prevention of Embankment collapse									✓								
	Prevention of Local Failure and Mitigation of Settlement																✓	
	Expediting Consolidation Settlement													✓				
	Strengthening the Foundation Ground													✓				
	Stress Dispersion														✓			
	Ensuring Slope Stability / Forming Soil and Structures																	✓

Source:

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Table 3-20 Outline of Construction Method for Embankment on Hill Slopes

Category	Construction Methods	Outline
Improvement of Ground Characteristics (Consolidation / Heat Treatment)	Deep Mixing Method (Mechanical / Jet Mixing)	A deep in-situ soil stabilization technique using cement, lime or cement/lime-based special binders.
	Chemical Injection	Stabilizing the ground by injecting chemicals (i.e. water glass)
	Sintering Method	Drying the ground hard by blowing air into the ground.
	Freezing Method	Stabilizing the ground by freezing artificially (temporarily)
	Surface Mixing Method	Stabilizing surface soil of the ground by mixing lime or cement
Structural Change	Counterweight (Buttress) Fill Method	Reducing moment of slide by filling at the toe of slope.
	Light-weight Embankment Method	Ensuring stability and reducing consolidation settlement by reducing the load to the ground.
	Sheet Piles and Various Foundation Method	Stabilizing the ground by installing sheet piling.
	Soil Reinforcement Method (Terre Armee Method etc.)	Stabilizing embankment body by reinforcement of steel or other material inserted in the body
Replace	Replacement Method	Improving soft ground by replacing soft soil with good material.
Reinforcement	Pile Net/Cap/Slab Method	Supporting upper structures directly with piles (Connecting pile heads)
	Deep Mixing Method	Forming underground structures by stabilized soil column.
	Sand Compaction Pile Method	Improving soft ground by compacted sand columns (Expediting consolidation, compacting and reinforcing)
	Mattress Structure Method	Placing wooden and steel mattress structures in soft ground and disperse load of embankment.
	Earth Cover Method (Sand mat Method)	Covering the ground by sand to disperse stress
	Surface Covering Method	Laying sheets, nets or ropes, combining together appropriately on the surface of soft ground to stabilize the filling.
	Root Pile / Soil Nailing	Installing steel rods into boreholes and with grouting cement to reinforce the ground.

Source:

(ii) Field Observation

The most serious trouble in the construction of embankments is sliding failure involving embankment body and foundation ground. Sliding failure of embankment tends to occur during construction, especially immediately after filling of embankment.

Against sliding failures, continuous field observation is essential for control of stability and consolidation settlement of embankments through construction period. Based on field observation, appropriate measures should be taken at proper timings, including adjustment of filling speed and waiting time for settlement as well as revision of design.

In order to take utmost advantage of field observation, which is an indicator of stability of embankment, it is important to prescribe criteria to evaluate instability of embankment, along with specific actions to be taken. For example, when a sign of instability is detected by field observation, filling speed should be reduced. If signs of instability are still indicated, filling works should be suspended until proper solution is

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provided by reviewing the design with updated ground conditions, including additional measures to assure stability, or stability is assured by longer waiting time.

The procedure of control of stability and consolidation settlement by field observation is shown in Figure 3-62.

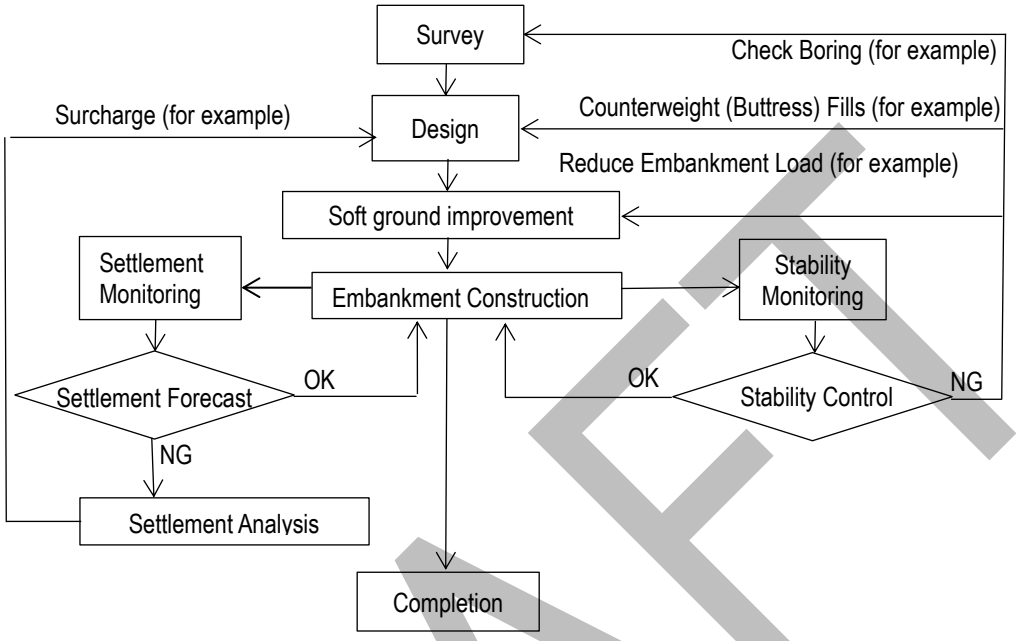


Figure 3-62 Example of Stability Control by Field Observation

Source:

3.2.2 Construction and Quality Control of Lightweight Embankment

Light-weight embankment is to reduce the loads on foundation ground by using lighter material for filling. As described in "Chapter 2.2.3 Embankment with Advanced Technology", by using a light-weight material of a weight of only about 1/100 to 3/4 of conventional filling material, earth pressure by filling and load to foundation ground are reduced. In addition, the materials with self-standing property can significantly reduce pressure acting on side walls, which enable side walls to be more simplified to the extent of keeping functions of slope protection. Accordingly, in recent days, light-weight embankment is introduced to many countries.

In this section, the essential points on the construction process and quality control are explained for the light-weight embankment methods explained in the Chapter 2.2.3.

(1) Expanded Polystyrene Construction Method

(i) Construction Process

1. To excavate soft ground to form foundation or bench cut slopes to form horizontal formation level.
2. To install drainage facilities properly. Drainage is important during and after construction. In particular, preventing float of EPS blocks is essential by temporary drainage measures during construction. Drainage facilities include drainage of internal water in embankment by filter layers, drainage of infiltration flow from the ground behind by permeable layer applied on the

ground behind, and drainage of the water between the ground and embankment by subsurface drainage ditches.

3. To apply leveling treatment for foundation of EPS Blocks, to install the blocks horizontally. Normally sand mat is applied for the purpose. For soft ground, crushed stone may be placed under sand mat or simple soil stabilization may be applied.
4. To install EPS blocks. EPS blocks should be installed manually for each layer. After reference line for the installation is set and unevenness of sand mat is rectified, the bottom layer of EPS block is installed and fixed with the neighboring blocks each other with binding metal fittings.
   EPS blocks should be so stacked as to ensure unity as embankment body. Thus vertical joints should not be continued three layers or more. Openings of 20 mm or more in curving or other sections should be filled with sand or mortal or the equivalent.
   When EPS blocks are placed directory on bedrock, unity between blocks and the ground should be ensured by filling void space along the boundary with sand or mortar, so that the boundary should not act as a slip surface.
5. To cast concrete slab on the top end of EPS blocks. Concrete slab should act as protection of EPS blocks, leveling the height, and subgrade for pavement. If embankment is high, intermediate concrete slab is desirable.
   Besides, in order to protect EPS blocks, side walls, slope protection, and earth cover should be applied according to the shape of embankment.

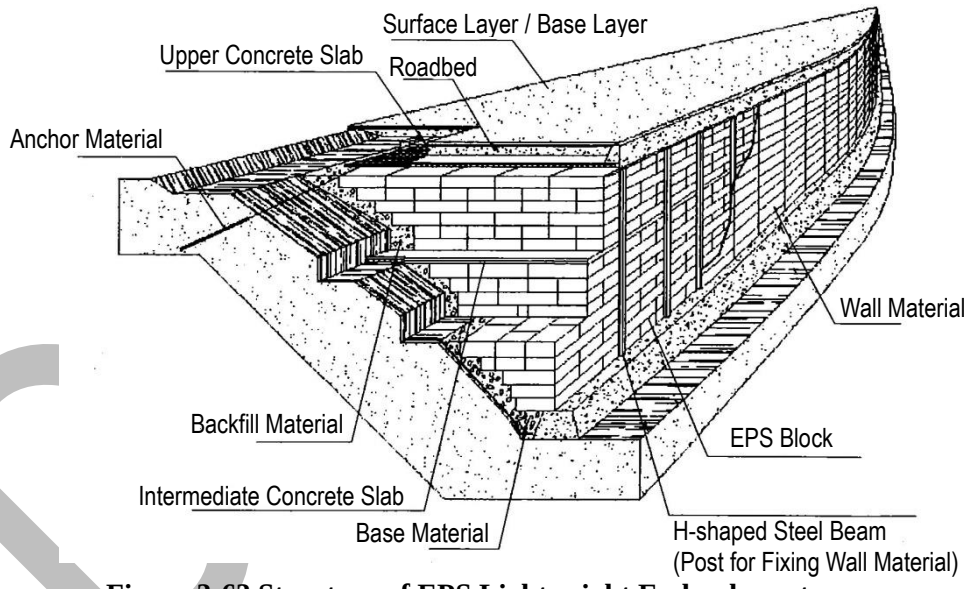


Figure 3-63 Structure of EPS Lightweight Embankment

Source:

(ii) Construction Management and Quality Control

Shape and dimension, density, compressive strength, and flammability of EPS blocks should be tested at the manufacturers before shipping.

At the construction site, inspection at delivery and as-built should be done, including check of connection by binding metal fittings at designated location and manner. Quality control for the strength of concrete slab is also required.

(2) Foamed Cement Banking Method (Air-mixed cement / mortar)

(i) Construction Process

1. To excavate soft ground to form foundation or bench cut slopes to form horizontal formation level. Then, to install drainage facilities for drainage of water or seepage control. (same as EPS method)
2. (If side wall is planned), to install foundations and supporting pillars for side wall. To install anchors and tie rods for reinforcement of pillars if required.
3. To fix wall panels (cum formwork for air-mixed cement / mortar) to the supporting pillars of side wall. To pay due attention not to allow air-mixed cement / mortar, which has high fluidity, to flow out from joints among wall panels.
4. To secure water resources, prepare batching plant, and arrange delivery pipes of air-mixed cement / mortar.
5. To mix water, cement, sand and stabilizer in mixer or blender and then add pressured air and forming agent. To convey air-mixed cement / mortar through delivery pipes with flow meters by pneumatic transport with pumping, and cast air-mixed cement / mortar.
   Since air bubbles may be compressed by the weight of cement / mortar, when the height of casting exceeds 1 meter. Thus casting air-mixed cement / mortal should not exceed the height of 1 meter at one shot.
   After casting, bubbles disappears under rainfall. Thus casting and curing under rain should be avoided.
   If casting underwater is required, tremie pipe should be used for casting, with its tip being kept in the casted air-mixed cement / mortar.
6. To apply wire mesh to resist deformation, if concentration of load is expected. Wire mesh should be applied before casting.
7. To furnish finishing works in accordance with the purpose of the embankment, such as pavement guardrail. As wall panel is thin and unable to support the excessive load of superstructure, Structures such as guardrail foundations should be placed on air-mixed cement / mortar, avoiding the top of wall panels. (See Figure 3-64).

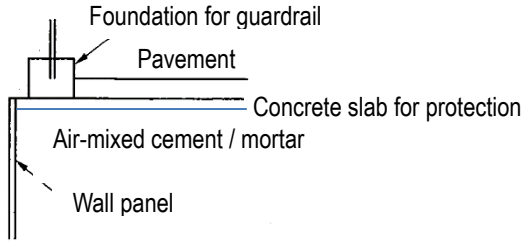


Figure 3-64 Wall Material and Road Structure

Source:

(ii) Construction Management and Quality Control

For quantity control, light-weight embankment should be controlled by as-built shape and filling of void space by air-mixed cement / mortar, such as behind lining of tunnel, should be controlled by the volume recorded with flow meters.

For quality control, water content of sand as well as density, flow value, and strength of air-mixed cement / mortar should be tested. For density test, fixed volume containers are often used. For flow value, Cylinder Method (JHS313) is often used. Density and strength are also tested with specimens casted in testing molds, through

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unconfined compression strength (UCS) test. When the strength of the embankment body is questioned, coring of embankment and UCS test may be done.

(3) Method by In-situ Foaming Urethane

(i) Construction Process

1. To excavate soft ground to form foundation or bench cut slopes to form horizontal formation level. Then, to install drainage facilities for drainage of water or seepage control. (same as EPS and Air-mixed cement / mortar method)
2. To install foundations and supporting pillars (H-beam steal) for side wall and place side panel for side walls.
3. To install tie rods if required for reinforcement of H-beam steal pillars. On steep slopes, to install anchors on the slope and fix it to H-beam steal pillars.
4. To prepare temporary shed to prevent rainwater from infiltrating to the embankment. In case groundwater seepage is expected at steep slopes, primer treatment may be applied.
5. After confirming non-existence of water, to spray urethane foam from the end of objective space and fill the space in layers. In most cases, the urethane foam is sprayed in a thickness of 10 cm and the height of one layer is set as 1 meter.
6. After completion of urethane form filling, to cast top concrete slab.
7. To furnish finishing works in accordance with the purpose of the embankment, such as pavement guardrail.

(ii) Construction Management and Quality Control

For quantity control, urethane form filling should be controlled by as-built shape and quantity of material.

For quality control, density and strength of urethane form are tested with specimens formed in testing molds during spraying, through unconfined compression strength (UCS) test.

3.2.3 Points of Concerns Regarding Embankment Construction at Special Locations (Technical Points)

(1) Half-cut and Half-fill (cut and fill), and Transition Zone of Cutting and Filling

After completion of hill road construction, at cut and fill sections as well as transition zones between cutting sections and filling sections, subsidence and level differences are generated on filling side, which is prone to cause cracks in the pavements. The followings are assumed as the causes:

(a) Bearing capacity and subsidence are uneven between cutting section and embankment.
(b) Spring and seepage water tends to concentrate at the boundary between the ground and embankments, which deteriorates strength of embankment.
(c) Insufficient compaction of embankment along the boundary with the ground causes subsidence of filling sections.
(d) Contact between filling and the inclined ground at the boundary of cut and fill causes deformation.

Among the above-mentioned causes, (a) and (b) should be dealt with in design and construction.

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In design, to counteract the cause of (a), the contact zones between cut and fill should have a gradient of 4H1V to avoid discontinuity of bearing capacity, as shown in Figure 3-65.

To prevent the cause (b) water infiltration into embankment body, subsurface drainage ditches and drainage ditches / layers at the toe of embankment slope should be installed, as shown in Figure 3-65.

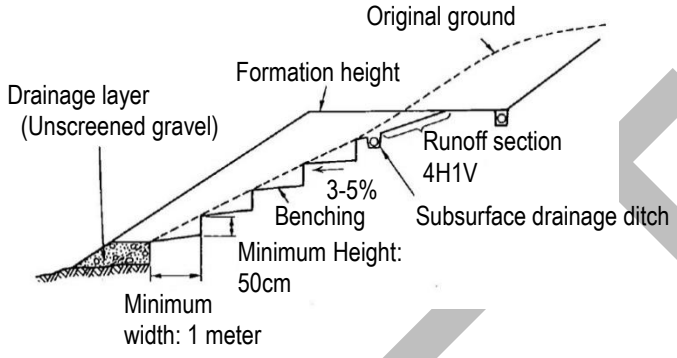


Figure 3-65 Drainage and Foundation Treatment for Half-cut / Half-fill (Cut and Fill)

[53]

Drainage should be considered during the construction as well. Specifically, by installing a temporary drainage channel along the boundary of the cutting and filling, to prevent the surface water from infiltrating into the embankment from the cutting surface (see Figure 3-66).

During the construction, this temporary drainage channel should be shifted upward sequentially along with construction progress. When an embankment is completed, underground drainage ditches should be installed to drain water along the boundary of cut and the fill. In addition, it is advisable that the top surface of embankments under construction should have a gradient of 4% or more in the transverse direction so that rainwater easily flow on the surface during rainfall.

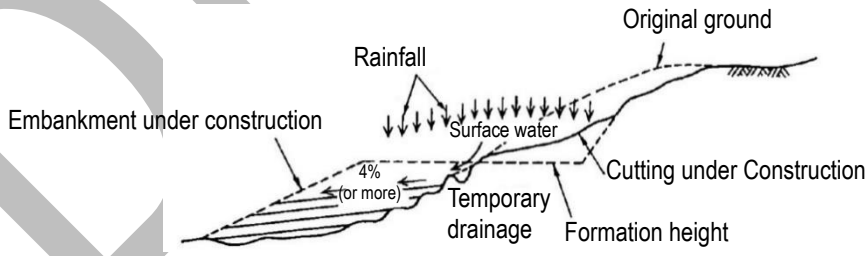


Figure 3-66 Drainage Treatment for Half-cut / Half-fill under Construction

Source:

The cause (c) insufficient compaction is a problem of construction. If the excavated soil produced by cutting is directly dumped to the downslope where embankment will be constructed, the dumped and spread soil is often too thick for proper compaction as shown in Figure 3-67. Thus, such thick dumped and spread soil causes insufficient compaction throughout the embankment. Through such insufficiently compacted parts, surface runoff or groundwater easily infiltrate into embankment, which leads to deterioration of embankment. Consequently subsidence or collapse of embankment may be caused. Excavated soil by cutting should be

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immediately transported to proper location of filling under construction, spread in a predetermined thickness with proper machinery, and compacted with road roller.

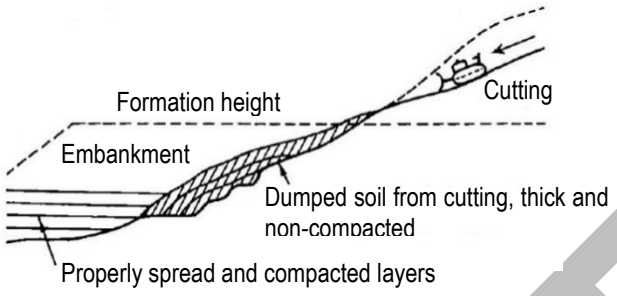


Figure 3-67 Non-compacted Soil at Transition Zone of Cutting and Filling

[53]

As a measure against the cause of (d) insufficient contact between inclined ground and filling, bench-cut should be adopted to ensure the contact so as to prevent sliding or deformation, as shown in Figure 3-65.

The bench cut is generally applied to the slope with a gradient of 4H1V or steeper. The bench cut should be constructed one by one with bulldozers or other machinery according to the progress of filling. Dimensions of the bench cut is generally 50 cm in minimum height and 1 meter in minimum width. In case hard rock is encountered, the bench cut may be made by ripping or blasting. For such case, the dimensions of the bench cut may be reduced in accordance with the conditions.

(2) Widening of Embankment

If widening of a road is made by an embankment on natural slope, bench cut should be applied to prevent sliding and deformation, as explained in the previous section.

If widening of embankment is carried out, bench cut is also required on the slope of the existing embankment. The dimension of the bench cut should be limited, however, not to negatively affect the existing embankment. To avoid subsidence of embankment body caused by insufficient compaction, filling material should be compacted carefully in thin spread layers, as explained in the previous section.

Widening of embankment often causes deformation of the existing embankment due to consolidation settlement of soft ground by additional load of widening. Improvement of soft ground, inserting sheet piles to cut relation between the existing and widening embankment, light-weight embankment are among the possible measures against such deformation.

(3) Boundary between Embankment and Structures

At the boundaries between embankment and structures, such as abutments or culverts, level differences often appears due to differential settlement. As a result, the flatness of pavement may be impaired. Sufficient compaction is, therefore, required with good quality materials for backfilling. The measures to avoid the level differences between embankment and structure are summarized below:

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(a) Discontinuities of bearing capacity and differential settlement appear between cut slope and embankment. For backfilling or refilling, therefore, materials with stable properties should be selected, such as low compressibility, high permeability, and low degradation of strength in wet condition. Table 3-21 shows examples of suitable material for back filling and refilling.

Table 3-21 Particle Size and Plasticity Index of Materials Suitable for Backfilling

Items	Range
Maximum particle size	Less than 100mm
Amount passing a 4.75mm sieve	25-100%
75 μm	0-25%
Plasticity index (passing 475 μm sieve)	Less than 10

Sieve sizes are based on Geotechnical Engineering Association standards JSF T 131-1990.

[53]

(b) Backfilling tends to be high-turn construction because of narrow-limited areas for the work. Compaction work should be, therefore, done for thinly spread layers to assure sufficient degree of compaction.

(c) Water tends to be collected at backfilled part around the structure during and after construction, which may cause subsidence or failure. Thus drainage facilities, such as drainage ditches and holes, should be placed, as shown in Figure 3-68.

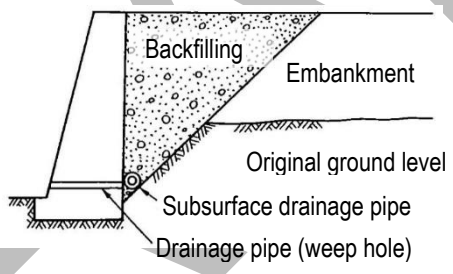


Figure 3-68 Drainage of Backfilling

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(4) Construction of Embankment Slope

If degree of compaction of embankment slope is insufficient compared to that of embankment body, slope failure may lead to collapse of embankment in case of heavy rain. To prevent such slope failures, compaction of embankment slope should be performed with construction machinery as much as possible. Figure 3-69 shows the method of compaction of embankment slopes:

(a) Compaction with Bulldozers (for gentle slope)

- If good quality material is used for filling, compaction with bulldozers is possible on the slope where gradient of slope is 9H5V or gentler.
- Generally, this method is applied for embankment slopes with a gradient of 2H1V or gentler.
- If cohesive soil with high moisture content is used for filling, wetland bulldozers are more effective.
- Compaction with bulldozers leaves trace of crawler belts on slope surface, which is suitable for hydraulic seeding. After vegetation

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grows, rugged surface of slope is hidden. Thus manual finishing work is not required.

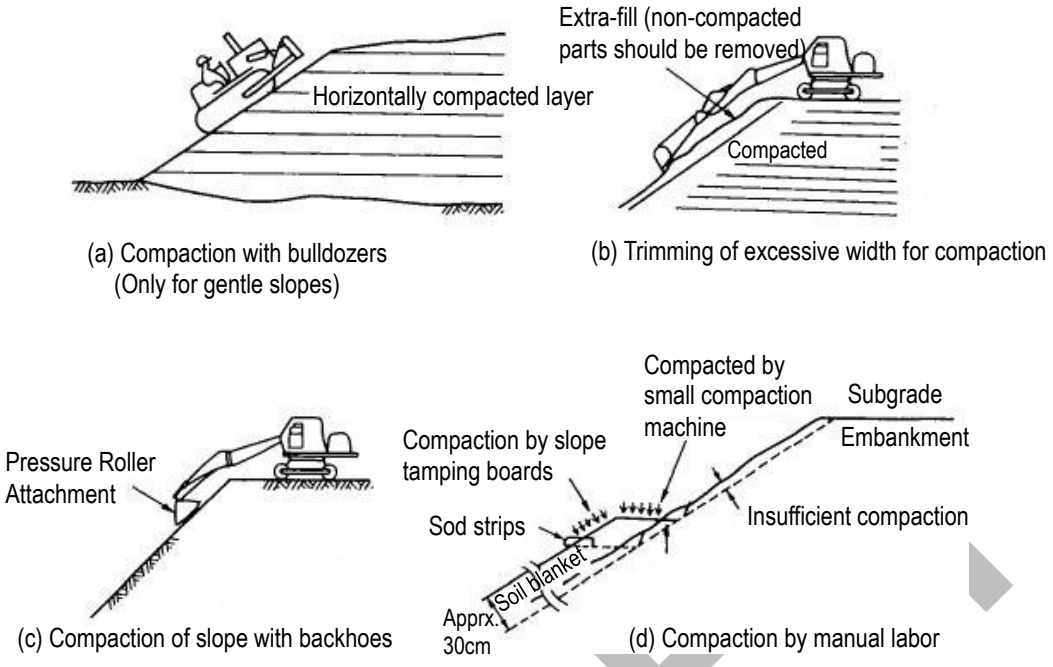


Figure 3-69 Compaction Methods for Embankment Slope

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(b) Compaction with additional width of embankment for compaction
- Embankment is constructed with additional width of 0.5 to 1.0 meters to ensure compaction by machinery, such as road rollers. The additional width enables road rollers to run on the shoulder of slope of designed (or as-built) shape. After compaction ends, additional parts of embankment is trimmed with backhoes or excavators.
- This method is applied for the case where construction site has enough width for additional width of embankment or frontage roads are planned or exist along the toe of embankment.

(c) Compaction of loose boulders and cobbles placed on embankment slope with bottom of buckets of machinery
- With attachment for slope finishing to bucket of backhoe or excavator, compaction of embankment slope by bottom of the bucket can be performed.

(d) Compaction by manual labor
- For small-scale embankment slopes, slopes close to structures, or soil blanket covering the surface of embankment slope, compaction is generally performed by manual labor with small equipment.
- After establishing the main part of embankment, while supplying materials for slope surface, compaction by manual labor is carried out with small equipment, such as vibro-rammer or small vibrating roller.
- After compaction by manual labor, sod strips or sodding are placed.
- Soil blanket covering the surface of embankment slope is finished by manual labor with slope tamping boards. As the compaction by

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manual labor tends to be insufficient, careful implementation is required.

(5) Drainage

(i) Temporary Drainage during the Construction

As mentioned above, in order to prevent infiltration of surface water into the embankment, the top surface of embankment should be treated with a gradient of about 4% to facilitate drainage of rainfall. In addition, to remove traces of crawler belts of bulldozers on the top surface, top of embankment should be compacted with road rollers.

For the high embankment with wide finished surface on the top, side ditches should be placed along the shoulder to prevent rainwater from flowing on embankment slopes. These side ditches should have a sufficient hydraulic gradient and be installed about 1 meter inward from the shoulder.

On the other hand, side ditches along the toe of embankment slope should be placed by keeping a distance of 30cm from the toe, which provide margin for fallen soil from upper embankment slope.

Generally, these side ditches should be and lined with soil cement or asphalt emulsion to prevent collapsing and losing function.

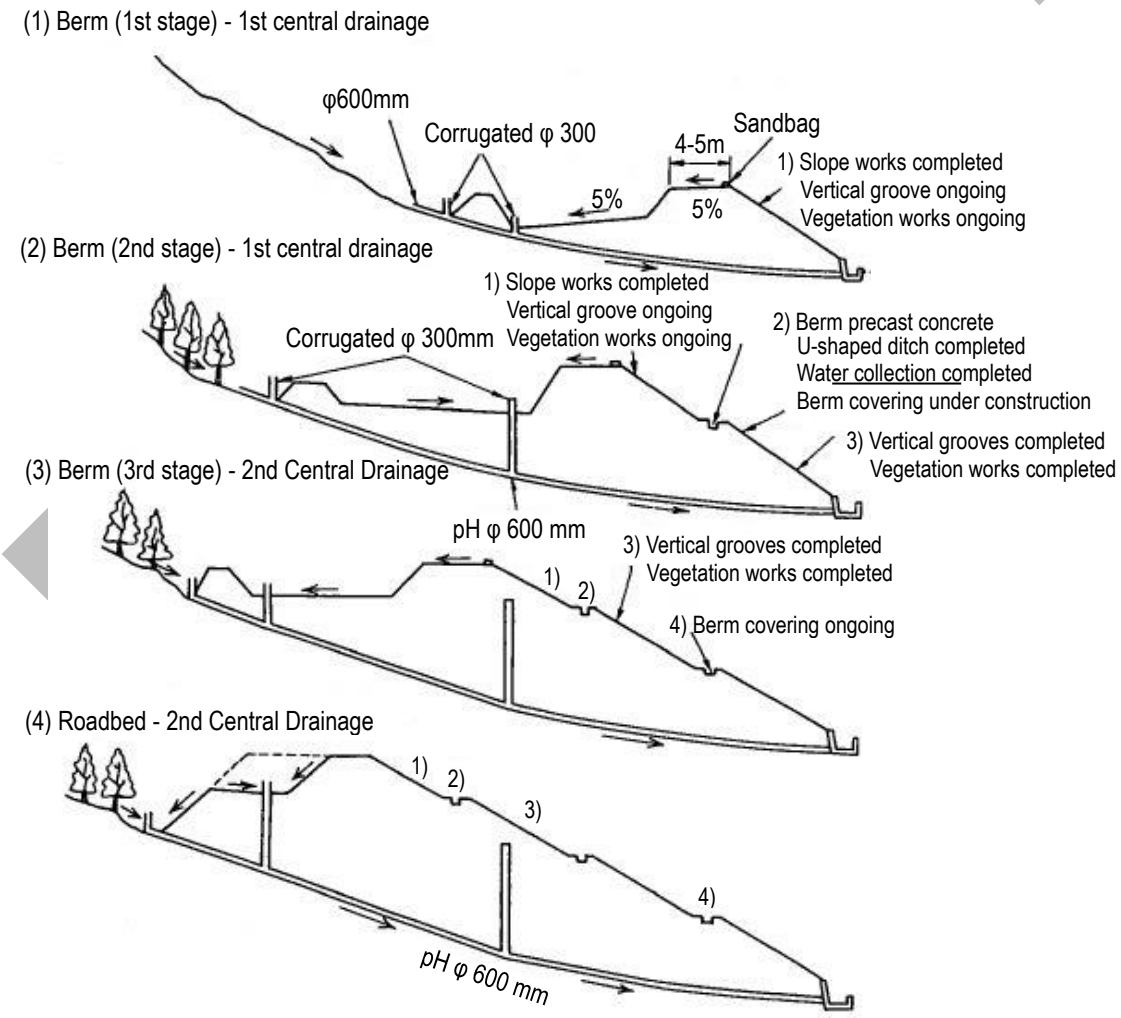


Figure 3-70 Construction Procedure of Central Drainage System

[53]

Soils with less cohesive among particles, such as course sand with gravel, and residual soil of heavily weathered and decomposed granite, tend to be remarkably eroded by rainfall and surface runoff during construction of embankments. The eroded soil will cause problems when it is transported and deposited on farmlands and houses surrounding the construction sites. Thus proper drainage arrangement is required for such types of soil.

On the other hand, embankment of cohesive less soil tends to collapse from the shoulder due to seepage pressure o infiltrated water if earthen temporary drainage ditches are placed along the shoulder. Thus central drainage system is effective because it does disturb the shoulder of embankments.

Central drainage system consists of vertical drainage pipes in the middle of embankment and subsurface drainage pipes placed on the foundation of embankment and connected to vertical drainage pipes. The water collected by vertical drainage pipes is drained out from the embankment through subsurface drainage pipes.

The construction procedure of the central drainage system is shown in Figure 3-70. Details of the vertical drainage pipes are shown in Figure 3-71.

(ii) Drainage of Embankment Surface

The purpose of drainage of top surface embankment is to quickly drain surface runoff provided from rainfall or snow melting from the top surface of embankment through side ditches or central drainage system. Drainage of embankment should prevent infiltration or stagnation of water into embankment as well as flow of surface runoff on embankment slope, which may flow out of the construction yard or Right of Way. Thus surface drainage should be properly planned and placed along the boundary of construction yard as well as along the shoulder of cut slope as side ditches and cross drainage of earthworks.

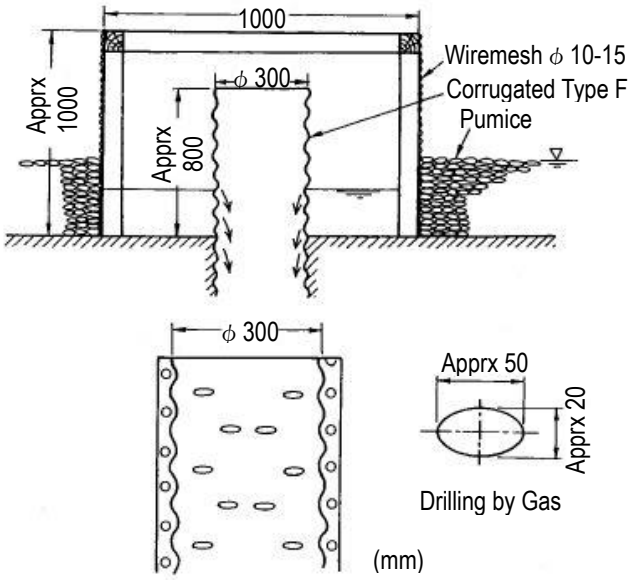


Figure 3-71 Inlet of Vertical Drainage Pipe for Central Drainage System

[53]

The types of side ditches include earthen, stone pitched, and concrete drainage ditches as well as half-moon shaped corrugated pipes. The drainage ditches are basic requirement and the first step for collecting and draining water from embankments. Thus shape, dimension, material and structure of drainage ditches should be decided in the design stage based on various factors like application, purpose, location, required drainage capacity, cost, efficiency, durability, and easiness of construction.

Earthen ditch may be used as a semi-permanent drainage facility if the construction site is enough wide and importance the ditch is low. But usually used as temporary facility during construction.

In addition to side ditches, surface drainage facilities include inlets, catch pits, conduits, drainage pipes and manholes. Damage on surface drainage facilities

after construction may be caused by consolidation settlement or actions by water, such as erosion and flown out of fine particles from embankment.

Unevenness of drainage gradient of ditches and sedimentation of drainage facilities may cause degradation of drainage function of the facilities.

(iii) Drainage in Embankment

If cohesive soil or permeable sandy soil, which drastically decreases its strength by infiltrated water, are used for high embankment construction, drainage filter layers should be placed within the embankment body as shown in Figure 3-72 to keep stability of the embankment. For drainage filter layers, permeable sand and gravel are often used. Use of geotextile as drainage filter is increasing due to economic reasons and construction efficiencies.

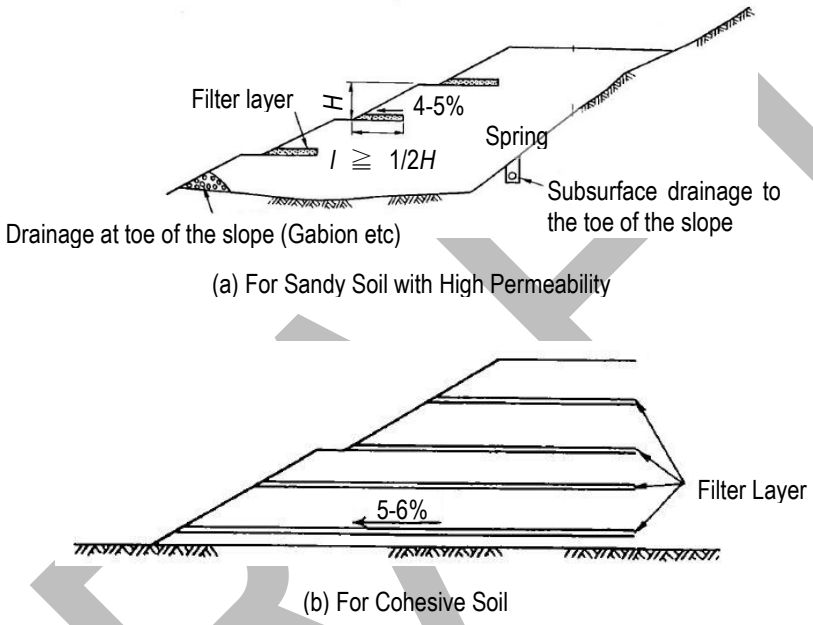


Figure 3-72 Example of Horizontal Drainage Layers within Embankment

[53]

The drainage filter layers using sand or gravel generally should have a thickness of 30 to 50 cm and a gradient of 3 to 5% downward to embankment slope. The drainage layers should be installed at every 2 to 3 meters in height or at each berm.

Use of perforated pipes for connecting drainage layers to ditches at berms are effective, such as shown in Figure 3-73. .

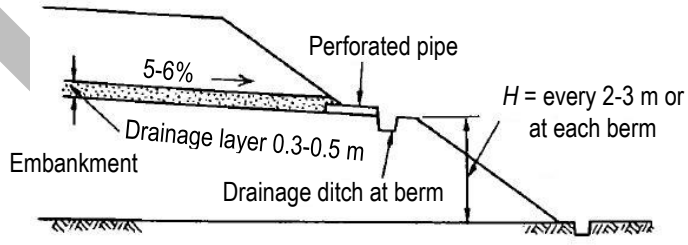


Figure 3-73 Example of Drainage Layer

[53]

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Ministry of Road Transport and Highways
India

Japan International Cooperation Agency (JICA)

Capacity Development Project on Highways in Mountainous Regions

GUIDELINE FOR SLOPE PROTECTION AND EMBANKMENT WITH ADVANCED TECHNOLOGY

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August 2019

Oriental Consultants Global Co., Ltd.
Kokusai Kogyo Co., Ltd.
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List of Abbreviations and Acronyms

BRO	Border Roads Organization
C/P	Counterpart
C/R	Completion Report
EPC	Engineering, Procurement and Construction contract
GNSS	Global Navigation Satellite System
GoI	Government of India
IAHE	Indian Academy for Highway Engineer
JCC	Joint Coordination Committee
JICA	Japan International Cooperation Agency
MoRTH	Ministry of Road Transport and Highways
MS	Monitoring Sheet
NHDP	National Highways Development Project
NHIDCL	National Highways and Infrastructure Development Corporation Ltd.
OJT	On-the-Job Training
OSV	On Site Visualization system
PDM	Project Design Matrix
PO	Plan of Operation
PPP	Public Private Partnership
PWD	Public Works Department
R/D	Record of Discussion
TG	Technical Group
TOT	Training of Trainers
WP	Work Plan

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CHAPTER 4 MAINTENANCE

Although countermeasures against forecasted hazards are fully completed, disaster risks on hill roads still exist. Although construction of countermeasures are flawless, time-dependent deterioration may prevent functions of countermeasures. In addition, any hazards exceeding forecasted ones in design may affect slopes and countermeasures of hill roads at any time. Needless to say for the slopes without any countermeasures or natural slopes.

To prevent landslides along hill roads in service, abnormalities related to landslides should be detected as early as possible through daily or periodic inspection so that proper countermeasures could be implemented before landslides occur.

For such purpose, stability of slopes should be properly assessed through understanding factors/triggers of possible landslides on a particular slope. Once factors/triggers of possible landslides are identified, the points to inspect the abnormalities related to landslides, items of inspection, the optimal timing and items of inspection to properly assess the abnormalities are decided.

Fixed forms for assessment of slope stability as well as slope inspection facilitates daily and periodic inspection by road administrators. By compiling assessments and periodic inspection records, slope inventories are prepared, by which necessity and urgency of countermeasures against possible landslides are evaluated. Preparation of such inventories should be prioritized for proper hill road maintenance.

Chapter 4.1 and 4.2 describe preparation of slope inventories, which should be used in daily or periodic inspection by road administrators. Chapter 4.1 explains slope stability assessment charts, including its assessment policy and points to inspection. Such stability assessment charts are supposed to be prepared by well-experienced engineering geologist or geotechnical / landslide engineers. Chapter 4.2 explains daily inspection with slope inventories.

Chapter 4.3 and 4.4 explain important points for maintenance of countermeasures. Chapter 4.3 features maintenance for vegetation works on roadside slopes and Chapter 4.4 deal with maintenance for other works.

4.1 Assessment of Slope Stability

For preparation of a slope inventory for a particular hill road, assessment of slope stability should be done for the roadside slopes where landslides are expected. Figure 4-1 shows the procedure of preparing a slope inventory including assessment of slope stability.

Firstly, sections of a hill road to be recorded in a slope inventory should be selected, in terms of danger of landslide and necessity of disaster management.

Then the slopes to assess its stability should be selected, based on the regional characteristics and the existing information relating to landslides, including disaster records, daily patrol and inspection records, and results of map and aerial photo

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reading. And stability of such slopes should be assessed through field surveys with predetermined forms.

Based on the assessment of slope stability, the targeted slopes should be categorized into 3 types; countermeasures should be implemented, monitoring of slope should be continued in periodic inspection, and no treatment is required. All assessed slopes should be recorded in the slope inventory, but the slopes where new countermeasures are implemented or monitoring is made in periodic inspection should be updated. Particularly, the results of periodic inspection should be recorded in sequential orders.

Stability of slope is assessed by scoring method. The predetermined forms of "Slope Stability Assessment Chart (SSAC)" have scores for the factors of landslides. Through field surveys, each factor shown in SSAC is evaluated and scored. Based on the total scores, stability of the slope is assessed.

The policy of stability assessment is different by the types of landslides. Thus SSAC should be prepared for each type of landslides.

In the following sections, examples of SSAC and points of inspection are summarized for the types of landslides, which hill roads in India often suffers from. The featured types are rock fall & slope failure, gravity deformation & deep-seated landslide, normal landslide[1], and debris flow

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[1] The landslide in this meaning is a mass movement on hill slopes gentler than 30 degrees, which slides repeatedly on slip surface with landslide clay

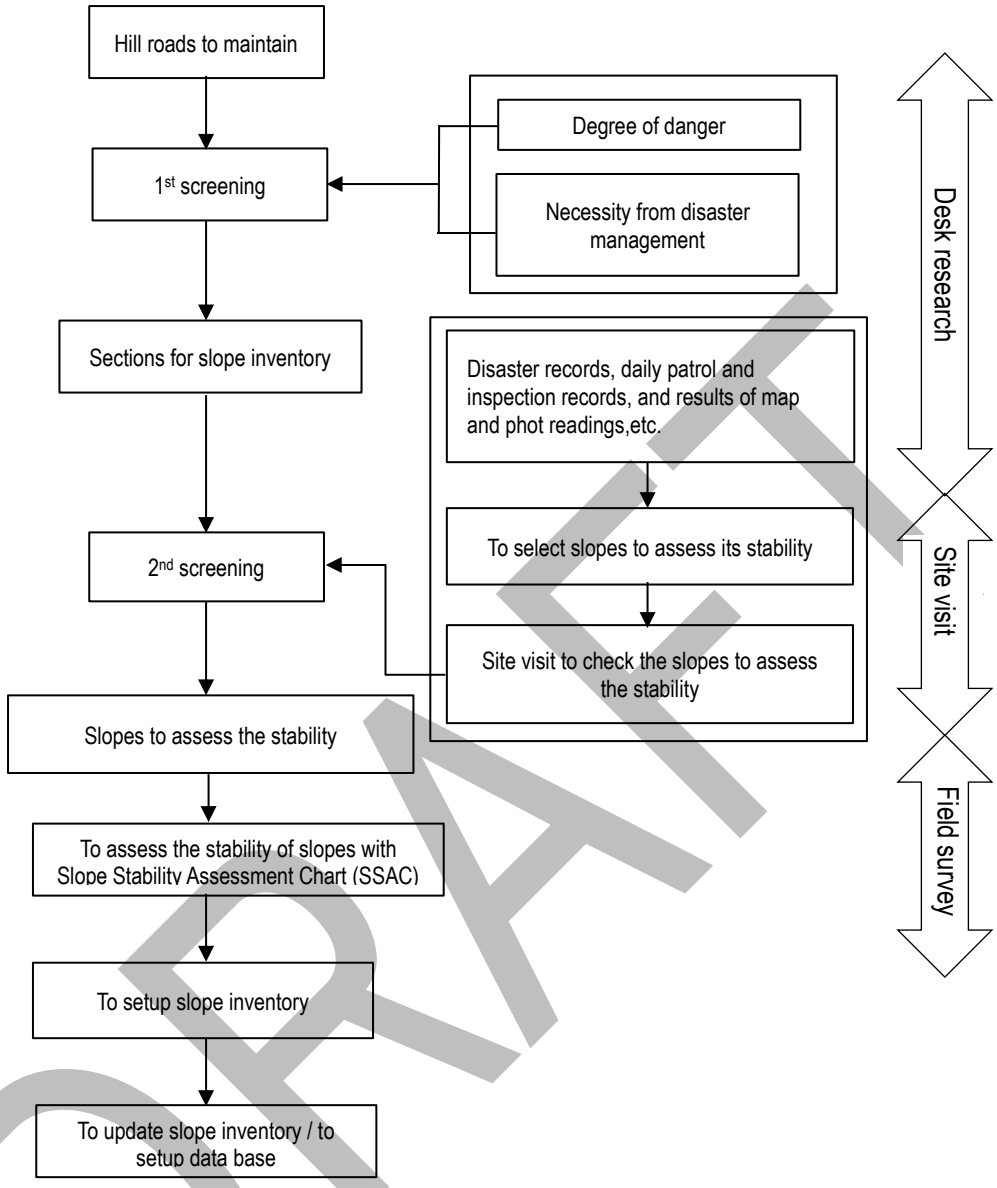


Figure 4-1 Preparation of Slope Inventory with Slope Stability Assessment Chart (SSAC) [1]

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4.1.1 Rock Fall / Slope Failure (Collapse)

The SSAC for falling rocks and slope failure / collapse is shown in Figure 4-3 and Figure 4-4.

(1) Method of Assessment

Stability of rock fall and collapse is comprehensively assessed based on the scores on factors, countermeasures, and disaster records.

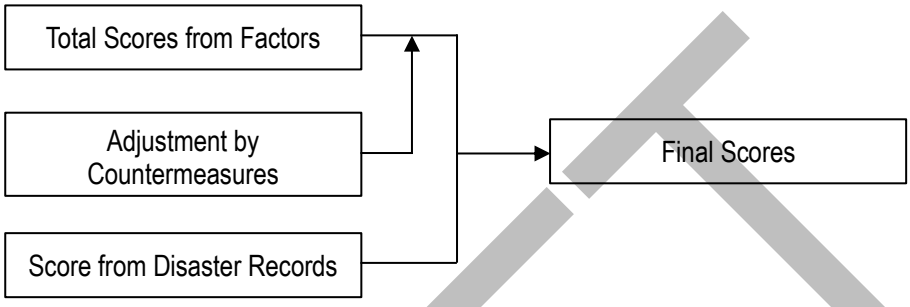


Figure 4-2 Concept of Slope Stability Assessment（Rock Fall and Collapse）

[1]

1 The factors are to be scored and summarized separately for artificial and natural parts of the targeted slope.
2 Separately for artificial and natural parts of the slope, the summarized scores of Step 1 are adjusted based on the conditions of the countermeasures on each part of the slope.
3 The larger score of Step 2 is selected.
4 The disaster record is scored and compared with the selected score of Step 3. The larger one is selected as the final score.

[1]

(2) Points of Stability Assessment

1 Although it is prone to surface failure during rainfall, small catchment areas with concave shape of slope are often missed in inspection.
2 On ridges or convex terrain of slopes (or free face), seismic energy of an earthquake is often magnified, which triggers rock fall and/or collapse.
3 Due attention should be paid to geological structure. For example, dip slope structure is prone to slide. Plunging slope structure with high angle of bedding / foliation is prone to toppling and that with gentle angle is prone to gravity deformation.
4 Debris and small fallen rocks behind rock fall fence / net suggests rock fall / collapse of the upper slope. The source of such debris and fallen rocks should be checked on site.
5 Due attention should be paid to change of landform or tree cutting after the previous inspection.
6 For scoring of countermeasures, distance between possible rock fall/collapse and road section to be affected should be considered when effect of countermeasures is estimated.
7 Record of disasters of adjacent areas should be referred.

[1]

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Control Number	N	7	1	7	R	0	1	0	Sub Number		

[Factors] (Ai)

Item		Factor	Artificial Slope					Natural Slope				
			Evaluation Criteria			Score	Evaluation	Evaluation Criteria			Score	Evaluation
Topography	Terrain with Factors to Cause Slope Failure	G1: Talus G2: Trace of slope failure, Clear convex knick line G3: Foot of terrace / hill, erosion of toe of slope, overhanging cliff, catchment slope, trace of debris flow G4: Convex terrain such as end of ridge, Overhanging cliff	Matches G1			3		Matches two or more factors of G2			3	
								Matches one factor of G2			2	
			Not match G1			0		Not Match G2			0	
			Matches two or more factors of G2 and G3			3		Matches two or more factors of G1 and G3			3	
			Matches one factor of G2 and G3			2		Matches one factor of G1 and G3			2	
			Not match G2 or G3			0		Not match G1 or G3			0	
			Matches G4				(6)	Matches G4				(6)
Soil, Geology, and Structure	Soil prone to collapse	Soil vulnerable to erosion or prone to degradation of strength when it is wet or saturated	Remarkable			8		Remarkable			2	
			Slightly remarkable			4		Slightly remarkable			1	–
			N/A			0	(8)	N/A			0	(2)
	Rock prone to collapse	Dense fissures, cracks, and weak layers / soft rock vulnerable to erosion / rock with rapid weathering property	Remarkable			12		Remarkable			8	
			Slightly remarkable			6		Slightly remarkable			4	
			N/A			0	(12)	N/A			0	(8)
	Geological structure prone to collapse	Dip slope (bedding, foliation, and weak layer)	Matches the condition			8		Matches the condition			2	
			N/A			0		N/A			0	
		Debris on impermeable bedrock / Hard rock overlying fragile rock	Remarkable			6		Remarkable			4	
			Slightly remarkable			4		Slightly remarkable			3	
			N/A			0	(14)	N/A			0	(6)
Condition of the Surface	Condition of the surface, detached rocks or boulders		Unstable			12		Unstable			24	
			Slightly unstable			6		Slightly unstable			12	
			Stable			0		Stable			0	
	Condition of detached rocks / boulders: unstable to slightly unstable		Matches the condition				(12)	Matches the condition				(24)
	Condition of groundwater spring		Groundwater spring			8		Groundwater spring			4	
			Groundwater seepage			4		Groundwater seepage			2	
			N/A			0	(8)	N/A			0	(4)
	Condition of surface protection		Bare land or by vegetation			5		Bare land or grassland			16	
			By complex of vegetation and structures			3		Complex of bare land, grassland and woods			10 6	
			Mainly by structures			1	(5)	Mainly woods			6	(16)
Shape	Gradient (g) and height (H) * Standard: standard gradient of slope, such as shown in Table 2-1 for cut slope		Soil	H＞30m		18		Height (H)	H≧50m		10	
				H ≦ 30, g ＞ Standard		15			30≦H＜50m		8	
				g ≦Standard, 15≦ H＜30		10			15≦H＜30m		6	
				g ≦ Standard, H＜ 15		5			H＜15m		4	(10)
			Rock	H≧50m		18		Gradient (g)	g≧70°		10	
				30≦H＜50m		16			45° ≦g＜70°		10	
				15≦H＜30m		12	(18)		g ＜45°		5	(10)
				H＜15m		10						
Deformation	Deformation of slope (exfoliation, small rock fall, gully erosion, scouring, soil pipe, subsidence, bulging, bent tree, fallen tree, crack, open crack, deformation of countermeasures)		Clearly matches two or more factors			12		Clearly matches two or more factors			10	
			Matches one or not clear			8		Matches one or not clear			5	
			N/A			0	(12)	N/A			0	(10)
	Deformation of adjacent slopes (rock fall, collapse, crack, bulging, other deformation)		Clearly matches two or more factors			5		Clearly matches two or more factors			4	
			Matches one or not clear			3		Matches one or not clear			2	
			N/A			0	(5)	N/A			0	(4)
	Total		Artificial slope:				pts. (A1)	Natural slope:				pts. (A2)

Figure 4-3 Slope Stability Assessment Chart (Rock Fall and Collapse) (Continued)

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[Countermeasures] (Bi) = (Ai) + α or (Ai) × 0

Select best the matching description for artificial / natural slope

Effectiveness of Existing Countermeasures	Adjustment (α)	Evaluation	
Expected rock fall or collapse of slope are sufficiently prevented, or road is protected from rock fall or collapse once it occurs.	× 0 pt.	Artificial Slope A1 x 0	Natural Slope A2 x 0
Expected rock falls or collapse are substantially prevented, or road is substantially protected from rock fall or collapse once it occurs, but not totally protected.	−20 pts.	A1 -20	A2-20
Expected rock falls or collapse are partially prevented, or road is partially protected from rock fall or collapse once it occurs, but unprotected part remains unsafe.	−10 pts.	A1-10	A2-20
No measures, or effects of the existing measures are not expected.	±0 pt.	A1±0	A2±0
	Total	(B1: Artificial slope) pts.	(B2: Natural slope) pts.

[Disaster Records] (C)

* In case no rock fall or collapse has occurred since construction of the latest countermeasures, evaluation from disaster records is not required; score of (c) is "0".

Frequency and degree of damage	Score	Evaluation
Despite the existing countermeasures, traffic of road was disturbed. (The countermeasures are not effective.)	100 pts	
Although traffic was not disturbed, relatively large rock fall or collapse reached to the road surface. (The countermeasure is not enough)	70 pts	
Small fallen rocks or collapse reached to the toe of slope. (The countermeasures are partially effective but requires additional works.)	40 pts	
	(C) pts	

(D)=MAX (B,C)

Evaluation by factors	(B)=MAX(B1,B2) 0 pts.
Evaluation by disaster records	(C) 0 pts.
The larger of (B) and (C)	(D)=MAX(B,C) 0 pts.

[Comprehensive Evaluation]

Necessary Actions	Evaluation
Countermeasures are required.	
Continuous monitoring is required.	
Specific measures are not required.	

[Stability against Earthquakes]

Stable	
Not stable	

* In case the condition matches the factor G4 of the topography "Detached rocks or boulders are unstable", tick "Not stable".

[Main Object of Inspection]

Artificial Slope	
Natural slope	

* Tick the slope which marks higher score between B1 or B2

[Main Disaster Form]

Rock fall	
Slope failure (collapse)	

* Tick the most expected hazard type at the section.

Figure 4-4 Slope Stability Assessment Chart (Rock Fall and Collapse) (Concluded)

[1]

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4.1.2 Gravity Deformation and Deep-seated Landslide

The SSAC for falling rocks and gravity deformation / deep-seated landslide is shown in Figure 4-6 and Figure 4-7.

(1) Method of Assessment

The assessment of gravity deformation / deep-seated focuses on rock slope with a height of 15 meters or more. The assessment of stability is based on the scores from factors and countermeasures. Disaster record is not counted for assessment.

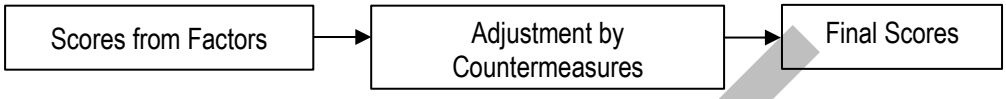


Figure 4-5 Concept of Slope Stability Assessment (Gravity deformation / Deep-seated landslide)

[1]

(2) Points of Slope Stability Assessment

1 Loosened status of fractured bedrock and conditions of geological discontinuities reflect instability of rock slope and compose important check points through field surveys. Especially aperture, continuity, interval, and direction of geological discontinuities, such as cracks, joints, bedding, foliations and fissures, should be carefully checked.
2 Potential cracks of behind or upper slope should be checked not only on the surface of rock slope but at the outcrops of the flank of gravity deformation block.
3 Shape of slope should be carefully examined, especially the relation between cracks and slope shapes such as overhanging and convex part of slopes.
4 Traces of deep-seated landslide and disaster records at surrounding slopes provide valuable information on scale and form of gravity deformation and deep-seated landslide. In addition, surrounding slopes of known gravity deformation and deep-seated landslide should be carefully checked. Gravity deformation and deep-seated landslide occur at the similar topographic and geological conditions.
5 It is also effective to interpret possible blocks of gravity deformation and deep-seated landslide using bird's-eye aerial photographs and precise topographic maps.
6 For the sections where disaster recovery takes time once it occurs or huge disaster is expected, inspection should be prioritized.

[1]

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Control Number									Code Number		

[Factors] (A)

Item	Factor	Evaluation Criteria	Score	Evaluation
Phenomena / Precursor	Aperture of open cracks	Large	30	
		Small	15	____
		N/A	0	(30)
	Direction of successive low angle cracks	Dipping direction	10	
		Plunging direction	5	____
		N/A	0	(10)
	Small collapse / rock fall	Small collapse / rock fall occurs	7	____
		N/A	0	(7)
Conditions of Cracks	Hard rock	Regularly developed with intervals of 1 meter ore more	15	
		Regularly developed with intervals of less than 1 meter	11	
		Irregular	7	____
		N/A	0	(15)
	Soft rock	Regularly developed with intervals of 1 meter ore more	11	
		Regularly developed with intervals of less than 1 meter	7	
		Irregular	4	____
		N/A	0	(11)
Combination of Rock Properties	Upper hard / lower soft strata		7	
	Upper soft / lower hard strata		5	
	Mostly soft		2	____
	Mostly hard		0	(7)
Plunging / Dip Slope	Dip Slope		15	
	Plunging Slope		5	____
	N/A		0	(15)
Topography	Gradient of artificial or natural slope	Overhanging	4	
		60 ° or More	2	____
		Less than 60 °	0	(4)
	Height of cliff / slope	100 meters or More	10	
		50 to 100 meters	7	
		30 to 50 meters	4	____
		Less than 30 meters	2	(10)
	Type of slope	Ridge type	4	
		Slope of talus deposits	3	
		Valley type	1	____
		Intermediate between ridge and valley types	0	(4)
	Knick line	Clear	7	
		Not distinguishable	4	____
		Not clear	0	(7)
Groundwater / Precipitation	Freezing / thawing groundwater spring	Frozen puddles last for a long period. Constant flow form groundwater spring.	4	
		Frozen puddles melt soon. Ground water spring after rain.	2	____
		Puddles do not freeze.	0	(4)
	Icicles formed with groundwater spring	Formed in vertical cracks	2	
		Formed in low angle boundaries of strata	1	____
		Rarely observed	0	(2)
		Total	(A)	pts.

Note: ( ) shows full score of each factor. If a given condition clearly matches a criterion, mark the criterion with a circle and put the indicated score. If a condition falls between criteria, put an intermediate score of the criteria.

Figure 4-6 Slope Stability Assessment Chart (Gravity Deformation / Deep-seated Landslide) (Continued)

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[Countermeasures] (B) = (A) + α or (A) × 0 Select the best matching description.

Effectiveness of Existing Countermeasures	Adjustment (α)	Evaluation
Gravity defamation is sufficiently stabilized, or road is protected from deep-seated landslide once it occurs.	× 0 pt.	A x0
Gravity deformation is substantially stabilized, or road is substantially protected from deep-seated landslide once it occurs, but not totally protected.	-20 pts.	A - 20
Gravity deformation is partially stabilized, or road is partially protected from deep-seated landslide once it occurs, but unprotected part remains unsafe.	-10 pts.	A -10
No measures, or effects of the existing measures are not expected.	±0 pt.	A ±0
Total	(B) pts.	

[Comprehensive Evaluation]

Measures	Evaluation
Countermeasures are required.	
Continuous monitoring is required.	
Specific measures are not required.	

Figure 4-7 Slope Stability Assessment Chart (Gravity Deformation / Deep-seated Landslide) (Concluded)

[1]

The following viewpoints are also important in the inspection of gravity deformation and deep-seated landslide.

1 Record or traces of deep-seated landslide
2 Traces of slope failures (suggesting flanks or toe of gravity deformation).
3 Overhanging, toppling or buckling.
4 Direction and property of cracks.
  ・Combination of cracks along with its directions (Type of collapse; wedge or planner failure)
  ・Intervals of cracks (Scale of collapse)
  ・Aperture of open cracks (Stability)
  ・Freshness of cracks (Progress / recent development of collapse)
5 Existence of groundwater spring/seepage or icicles.
6 Open cracks or step-formed subsidence in the upper slope of the knick line.

[1]

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4.1.3 Landslide

The landslide explained in this section is a mass movement on hill slopes gentler than 30 degrees, which slides repeatedly on slip surface with landslide clay. The SSAC for landslide is shown in Figure 4-9 and Figure 4-10.

(1) Method of Assessment

If landslide blocks are located adjacently or overlapping / overlapped and related to each other, the target unit of inspection / assessment should cover all related blocks. Assessment should be based on the block with the highest score. So is the comprehensive evaluation.

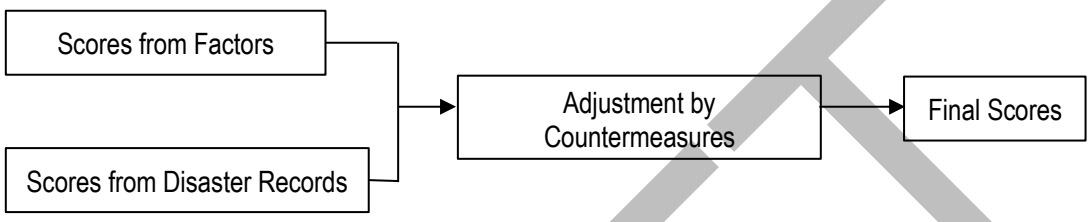


Figure 4-8 Concept of Slope Stability Assessment (Landslide)

[1]

(2) Points of Slope Stability Assessment

1 Reference of existing materials and interpretation of landslide topography through map /photo reading should be done in advance of field survey.
2 Signs of landslides should be examined, such as full view of landslide blocks, extent of deformed zone, effects on the targeted road, and deformation of structure. In particular, recently developed cracks and subsidence are important signs of landslide activity.
3 Particular attention should be paid to boundary of landslide blocks, especially the deformations suggesting boundary, such as cracks at the head and behind the crown as well as extrusions and rising / bulging at the toe of the landslide blocks.
4 Surface water and groundwater spring should be checked in field survey, and if necessary, rechecked at the time of snow melting and immediately after rainfall if necessary.
5 Interviews with residents often provide valuable information.

[1]

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Control Number									Code Number		

[Factors] (A)

Item		Viewpoint		Score	Evaluation
Topography / Landslide Landform		One or more landforms particular to landslides are recognized, such as head scarps, convex ridge / hilly terrain, gentle slope, disturbed contour lines, and bend of river course.	Clear	30	(Choose one)
			Slightly Clear	15	____ (30)
			Not Clear	7	
Geology	Geological Structure	Fault / fractures zone		18	* (Choose one)
		Hydrothermal alteration zone, clay formed by hydrothermal alternation.		18	
		Dip slope structure		14	
		Plunging slope structure		7	
		Intrusive rock, cap rock		3	____ (18)
		Others		0	
	Age and Lithology of Bedrock	Mesozoic/Paleozoic strata (metamorphic / sedimentary rock)		7	(Choose one)
		Tertiary strata (sedimentary Rock)		7	
		Quaternary strata (soil)		3	____ (7)
		Others (Volcanic / igneous rock)		0	
	Ground water Spring	Groundwater spring/ seepage including traces		10	(Choose one)
		N/A		0	____ (10)
		Total (up to 65)		(A) Pts.	

Note: ( ) shows full score of each factor.

* If a given condition matches multiple viewpoints, the highest score should be selected and the selected viewpoint should be marked with a circle

Figure 4-9 Slope Stability Assessment Chart (Landslide) (Continued)

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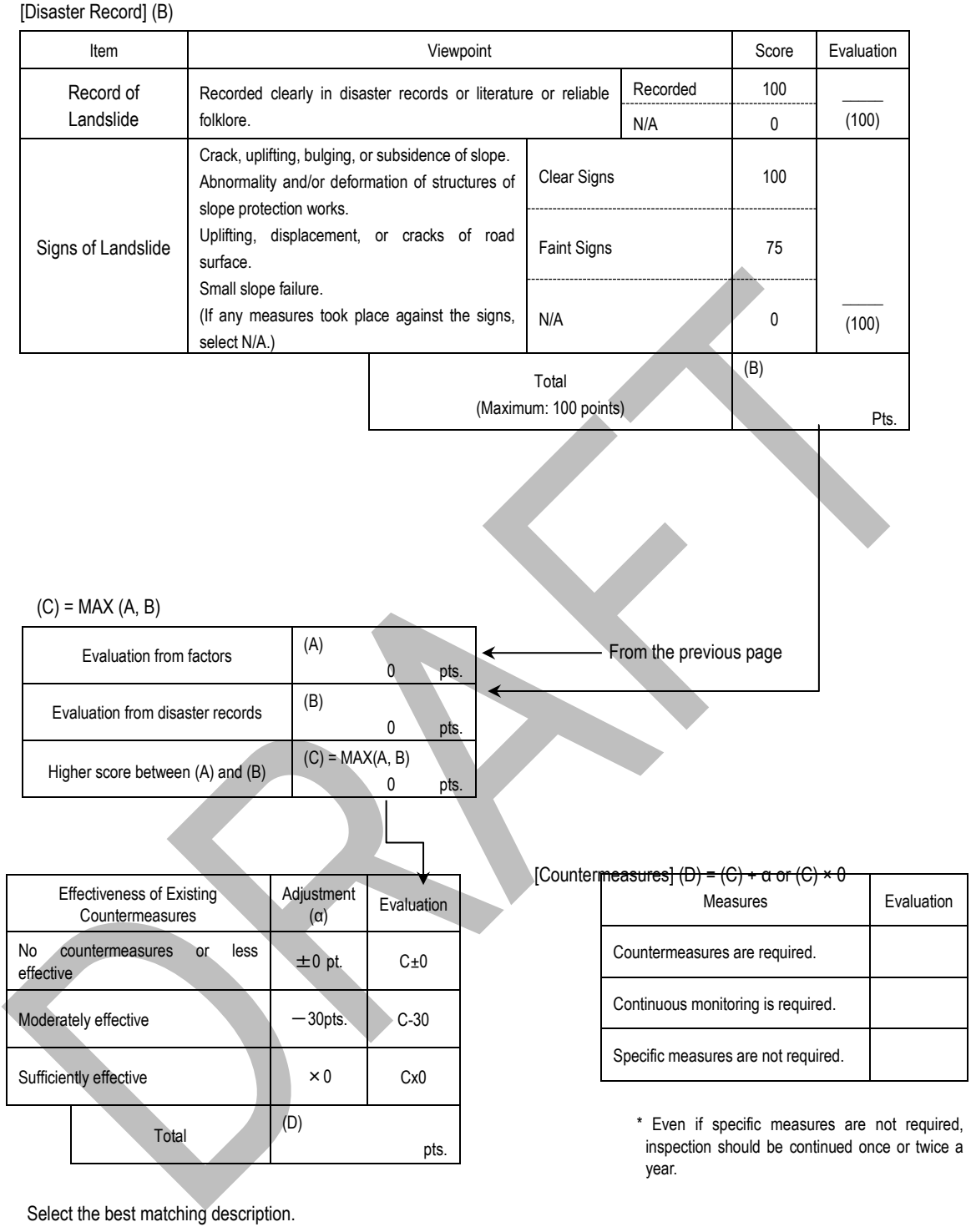


Figure 4-10 Slope Stability Assessment Chart (Landslide) (Concluded)

[1]

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4.1.4 Debris Flow

The SSAC for debris flow is shown in Figure 4-12 and Figure 4-13.

Although its catchment area is not so wide, debris flow may affect the road which crosses the stream/river in problem. Thus, through field surveys for slope stability assessment of debris flow, conditions of slopes as well as river / stream beds should be inspected where even a narrow stream crosses the targeted road.

(1) Method of Assessment

The following factors should be evaluated in the assessment for debris flows: Catchment area, steepest gradient of stream/river bed, slope property, effectiveness of existing countermeasures, adjustment by road facilities which allow debris flow to run over/below the road, and disaster records.

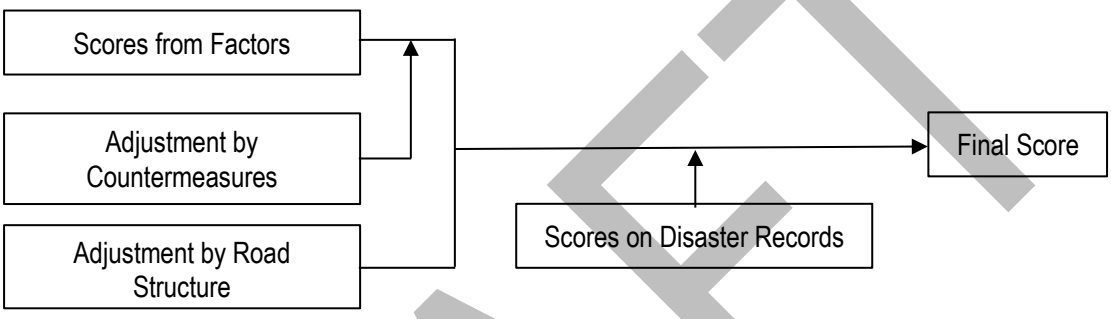


Figure 4-11 Concept of Slope Stability Assessment (Debris Flow)

[1]

1 Evaluate and summarize scores from the factors and then adjust it by countermeasures and road structure.
2 Evaluate score from disaster records.
3 Select higher score between 1 and 2 and set it as final score.

[1]

(2) Points of Slope Stability Assessment

1 In the field survey for slope stability assessment, the supposed condition in the 2nd screening (see Figure 4-1) should be checked on site to confirm whether it largely differs from the actual site condition. Construction records of Sabo dam (check dam) should be checked, if any.
2 Stream bed conditions of the targeted stream should be checked in terms of debris deposit, slope failures on valley walls, and the remaining height of unfilled storage of check dams, if any.
3 In case no disaster records are available, frequency of debris flow should be estimated based on interviews with local residents, vegetation conditions along the stream including age of trees and degree of thriving, and conditions of debris flow cones.
4 Although its size, narrow stream often provides distinctive damage to hill roads through debris flow which occurs along the stream. Even at a narrow stream, therefore, comprehensive evaluation should be done based on field surveys of stream crossing structure, conditions of stream bed deposit, disturbed conditions of upper stream, and traces of slope failures and erosion on valley walls

[1]

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Control Number									Code Number		

[Factors] (A)

Item	Factor	Evaluation Criteria	Score	Evaluation
Streams Conditions	Area of source of debris flow; catchment area where a gradient of stream bed profiles is 15 degrees or more.	0.50 km^2 or more	10	____ (10)
		0.15 km^2 or more and less than 0.50 km^2	8	
		Less than 0.15 km^2	4	
	Steepest gradient of stream bed	40 degrees or more	10	____ (10)
		30 degrees <= gradient < 40 degrees	5	
		Less than 30 degrees	0	
Slopes Conditions	Area of slopes with a gradient of 30 degrees or more	0.20 km^2 or more	8	____ (8)
		0.08 km^2 or more and less than 0.20 km^2	6	
		Less than 0.08 km^2	2	
	Area covered by grassland or shrubs (a height of 10 meters or less)	0.20 km^2 or more	8	____ (8)
		0.02 km^2 or more and less than 0.20 km^2	4	
		Less than 0.02 km^2	0	
	Unstable slope produced by earthwork	Found	5	____ (5)
		N/A	0	
	Newly generated cracks or scarps	Found	5	____ (5)
		N/A	0	
	Record of relatively large collapses	Matches the condition	10	____ (10)
		N/A	0	
		Total	(A)	(56) Pts.

[Countermeasures] (B)

Item / Evaluation Criteria		Total scores from factors (A)				
		20 pts. or more	15 pts. <= (A) < 20 pts.	10 pts. <= (A) < 15 pts.	Less than 10 pts.	
Effectiveness of existing countermeasures	Not or scarcely effective	100 pts.	70 pts.	50 pts.	30 pts.	
	Acceptable	70 pts.	50 pts.	30 pts.	10 pts.	
	Effective	50 pts.	30 pts.	10 pts.	0 pt.	(B) pts.
	Sufficient	0 pt.				

Score of (B) is decided from the above table depending on the score of (A) and effectiveness of the countermeasure.

Note: ( ) shows the perfect score of each item.
If a given condition clearly matches a criterion, mark the criterion with a circle and put the indicated score.
If a condition falls between criteria, put an intermediate score of the criteria.

Figure 4-12 Slope Stability Assessment Chart (Debris Flow) (Continued)

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From the previous page

[Road Structure] (C) = (B) + α + β

Structure	Criterion for Evaluation	Adjustment (α or β)	Evaluation
Channel Width	10 meters or more	−40 pts.	α
	5 to 10 meters	−30 pts.	
	3 to 5 meters	−20 pts.	
	Less than 3 meters	±0 pt.	
Height of Bridge Girder	Less than 1 meter or no bridge or box culvert	±0 pt.	β
	1 to 2 meters	−5 pts.	
	2 to 3 meters	−15 pts.	
	3 to 5 meters	−30 pts.	
	5 meters or more	−40 pts.	
Total		(C) **(B) + α +β** pts.	

[Disaster Record] (D)

Criterion for Evaluation	Score	Evaluation
Despite the existing countermeasures, traffic of road was disturbed by debris flow.	90	
Although traffic was not disturbed, debris flows were occurred.	40	
No records of debris flow	0	
	(D) pts.	

(E)=MAX(C, D)

Evaluation from factors	(C) pts.
Evaluation from disaster record	(D) pts.
The larger between (C) and (D)	(E)=MAX(C,D) pts.

[Comprehensive Evaluation]

Measures	Evaluation
Countermeasures are required.	
Continuous monitoring is required.	
Specific measures are not required.	

[Expected Damage]

Damage to bridge	
Erosion / flow out of embankment	
Disturbance by debris depositing on carriageway	

Tick on the expected damage type.

Figure 4-13 Slope Stability Assessment Chart (Debris Flow) (Concluded)

[1]

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4.2 Maintenance for Slopes

In order to effectively maintain roadside slopes, establishing a hill road management plan including disaster management is essential. A hill road management plan shall include preparing and updating inventories of roadside slopes as well as structures, preparing and operating standards for road closure in case of heavy rains and other natural disasters, and establishing organization / structures for patrol and inspection, considering intervals of patrol / inspection.

For the management of roadside slopes, assessment of slope stability with SSAC, which is explained in the previous chapter, is the essential step for preparing and updating a slope inventory. By utilizing SSAC, dangerous slopes are sorted out with its conditions, and check points to observe in usual inspection are organized. By updating a slope inventory, results of executed inspection are reflected to the inventory, which may update a plan for inspection. The key is to plan and perform effective and efficient inspection so that abnormalities and deformations of roadside slopes and structures can be detected in the earlier stages.

Figure 4-14 shows a general flow of O&M of roadside slopes.

Regular inspection consists of daily patrol and periodic inspection. In daily patrol, visual observation should be conducted mainly from patrol vehicles. In periodic inspection, detailed inspection should be conducted on slope condition in semiannual or annual inspection.

If an abnormality or deformation, such as bulging of slope, subsidence of the surface of a hill road, or open cracks on the pavement or slope surface, is detected in inspection, repair or reinforcement should be done to keep stability of the slope as well as function of the hill road.

At the time of natural disasters, such as heavy rains and earthquakes, emergency inspection should be carried out to quickly find abnormalities, deformation and landslides, which may disturb the traffic on hill roads. If any of such disturbance are detected, emergency measures should be taken to keep service of the hill road and rehabilitation plan should be prepared to recover the service level to the required standard.

In addition, it is important to store and utilize the information obtained through topographic and geological surveys, design and construction, regular and emergency inspection, and repair and reinforcement of a hill road, including reports, design / as-built drawings, disaster records, and maintenance / inspection records.

4.2.1 Type of inspection

Inspection is a basic procedure to recognize the condition of roadside slopes. Depending on the purpose, various types of inspection should be done; daily patrol and periodic semiannual or annual inspection and emergency inspection by road administrators as well as preparing and updating of slope inventory including slope stability assessment with SSAC by specialized engineers for landslide or slope stability.

For the slopes which require monitoring, preparation of General Information Sheet is required, in which check points to observe in regular inspection are listed along with general information of slope and instruction of inspection such as frequency and necessary range to inspect. A General Information Sheet should be prepared for each slope during the slope stability assessment. An example of General Information Sheet is shown in Figure 4-15.

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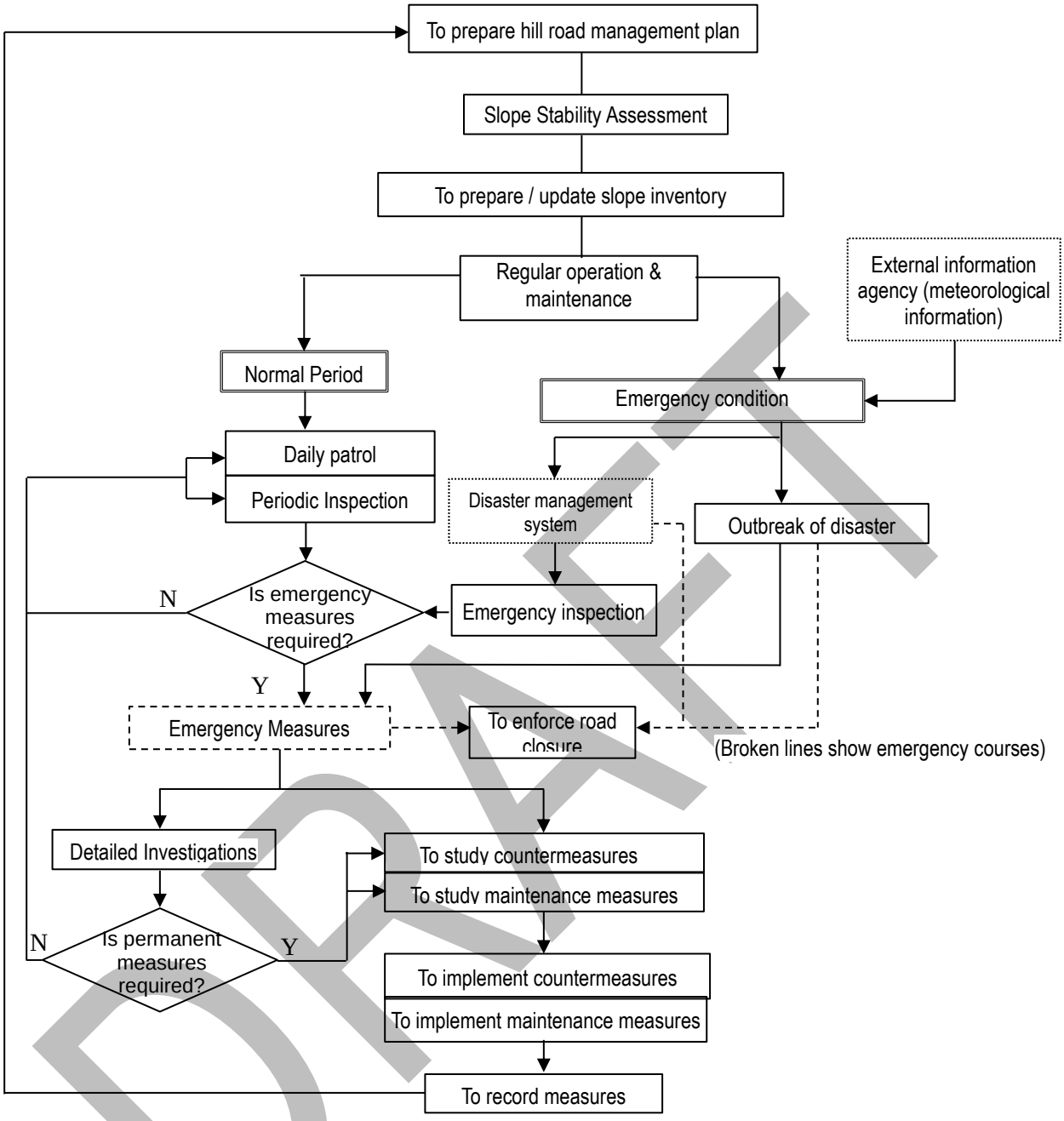


Figure 4-14 General Flow of Maintenance

[2]

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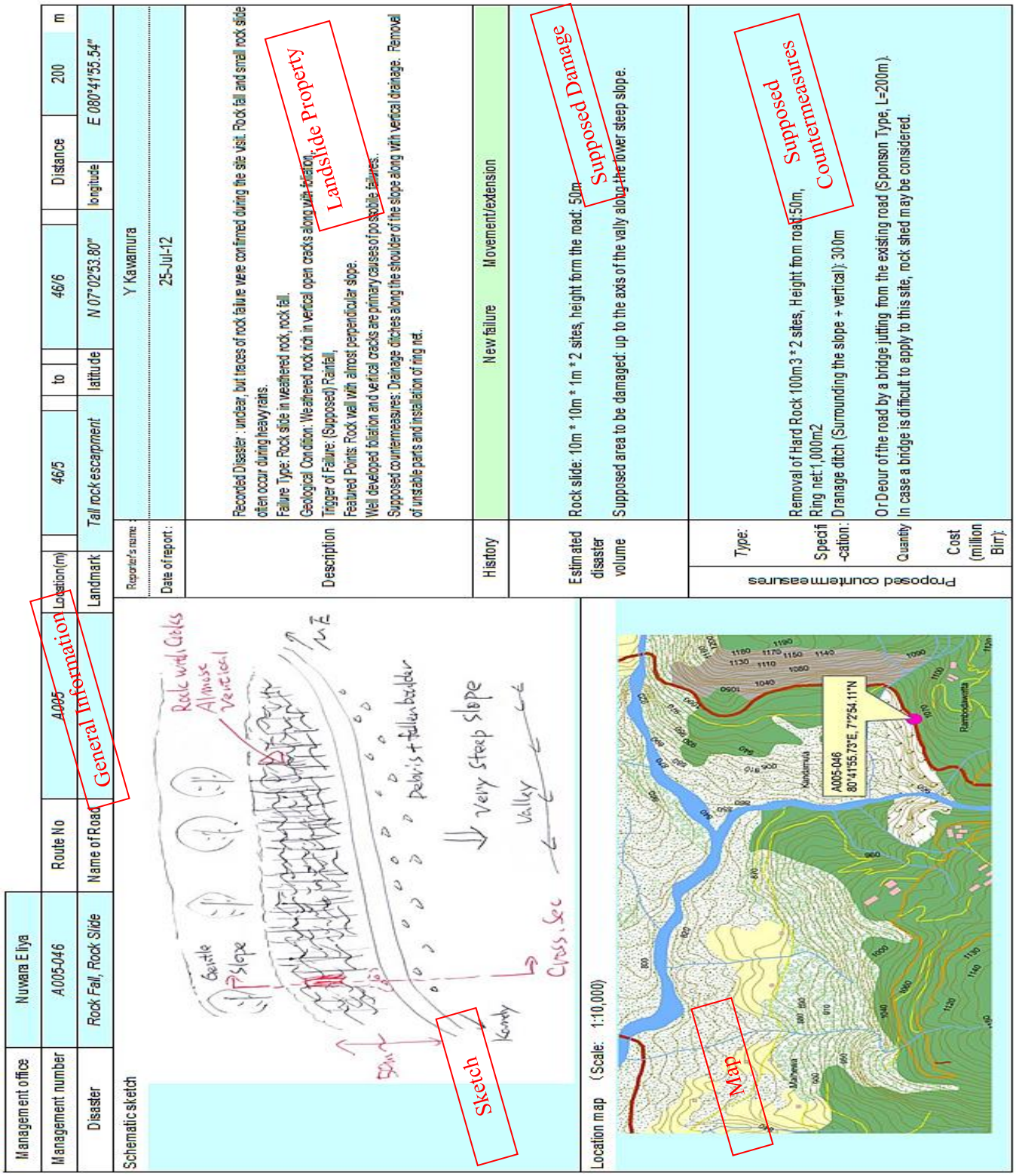


Figure 4-15 Example of General Information Sheet

[3]

4.2.2 Regular inspection

Important points of regular inspection are described below.

In regular inspection, abnormality and deformation of roadside slopes, slope protection works or landslide prevention works should be detected. If it is considered necessary, the degree of deformation should be measured on site to secure accuracy.

In daily patrol, attention should be paid to various abnormalities, such as bulging of slope or slope protection, shallow failure or cracks on slopes, damage of rock fall prevention works, fallen or accumulated debris on roads, cracks on pavement caused by embankment failure, and gaps between roads and structures.

Periodic inspection should be done for the sections where construction faced problems, serious disturbance of traffic is expected once landslide or damage occurs, or Slope Stability Assessment evaluated that monitoring should be continued. Among such sections, particular focus should be placed to landslide areas, soft ground areas, sections where large amount of stream flow or groundwater is observed, slopes prone to freezing and thawing, and sections where rock fall and debris flow frequently occur. Attention should be paid to slope surface, deformation and abnormality on slope protection, drainage works, and rock fall countermeasures, growth of vegetation works and thriving weeds, change of locations of detached rock and unstable boulders, and flow course of surface runoff and groundwater.

A development project or change of land use around roadside slopes may negatively affect stability of slope. Thus proper attention should be paid to changes on the surrounding environment of the targeted hill road. Especially, the changes of landform on the upper slope may increase amount of surface runoff flowing into roadside slopes and overwhelm the capacity of existing drainage facilities. Thus due attention should be paid to the upper slope.

In case deformation or abnormality is noticed in regular inspection, evaluation should be made on whether countermeasures are require or not. In case detected deformation is expected to continue and eventually cause serious damage to structures or disturbance to traffic on the hill road, countermeasures should be planned. For such case, due investigation should be done for the cause of deformation and design of countermeasures. Emergency measures and/or road closure should be implemented, if necessary.

Figure 4-16 shows typical abnormality or deformation to appear on slope when a landslide is developing in and around a slope. Such deformation often reflects internal deterioration of the slope and thus should be properly understood by the engineers who perform regular inspection.

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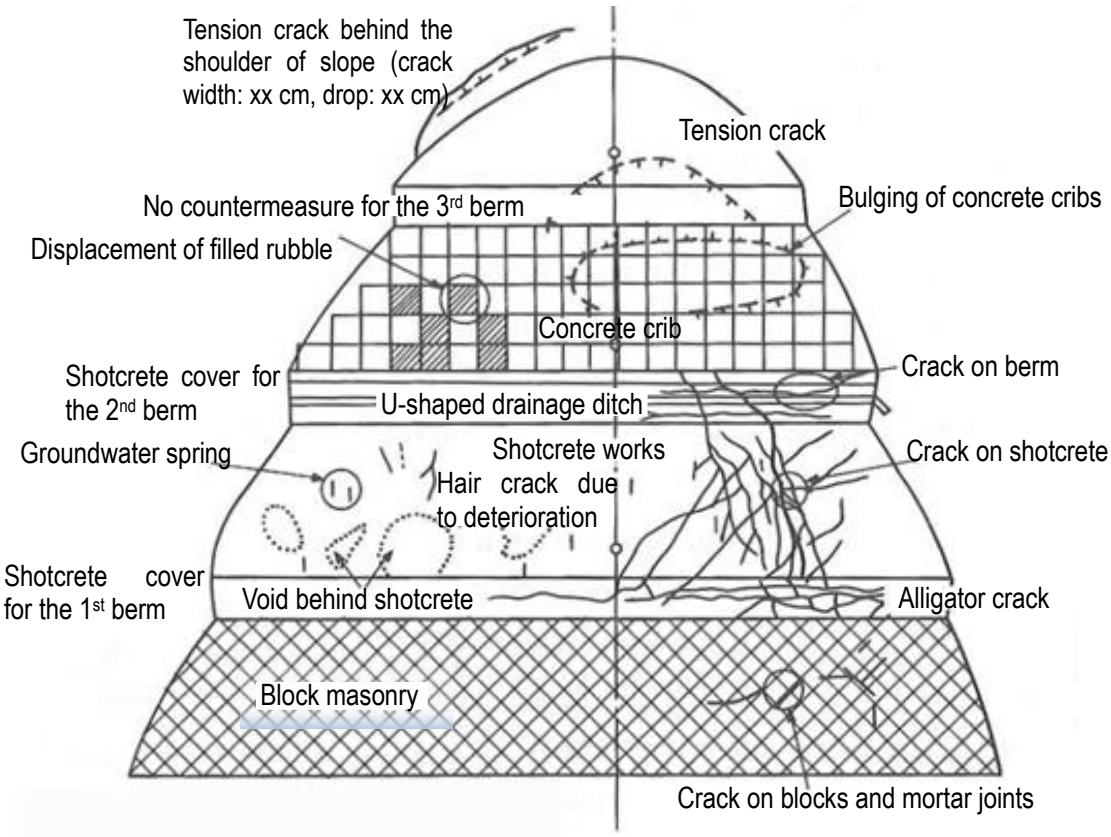


Figure 4-16 Front View Sketch during Inspection to Record Deformations on Slope

[2]

4.2.3 Emergency inspection

In the event of natural disasters, such as cyclone, heavy rain, high wave, and earthquake, roadside slopes and structures of hill road may be damaged. For such case, emergency inspection should be done, especially for the sections where Slope Stability Assessment evaluated countermeasures are required or monitoring should be continued. If considered necessary, specialized engineers for landslide or slope stability should be invited for extensive survey. In addition, the sections where landslide is expected based on regular inspection, emergency inspection should be done.

If any deformations or abnormalities are detected, an emergency survey should be done for the cause of deformation and design of countermeasures. Emergency measures and/or road closure should be implemented, if necessary.

If such natural disasters cause damage on slope with certain conditions, similar slopes should be extracted and studied for future damage by similar causes. If considered necessary, appropriate measures should be planned and implemented for such slopes.

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4.3 Management of Vegetation Works on Slope

After completion of hill road construction, management of vegetation works on slope requires survey and inspection of vegetation works after completion as well as management of growth of plants and maintenance of them. Management of vegetation aims to facilitate growth of target plant colony while securing stability of slope and maintain plant colony after the target colony is achieved.

Vegetation works should deal with live plants. Thus the target of the works should be completed after the required period for vegetation growth elapsed, which is often after completion of slope works. During the period of vegetation growth, adequate treatments should be done at the proper timings of plant colony development.

4.3.1 Items and Viewpoints of Inspection

In order to properly implement vegetation management on slopes, proper inspection is essential. Inspection aims to check settlement and growth of the introduced plants, damage by disease and vermin, and interruption by invading plants. The items of the inspection include flowing out and deterioration of planting base material, drainage condition and collapse of the ground, and soundness of planting foundation.

Table 4-1 shows items and viewpoints of the inspection for vegetation management.

Table 4-1 Inspection for Vegetation Management of Cut / Fill Slopes

Plant Type	Inspection Items	Viewpoints of Observation
Introduced Plant	Plant vitality	Leaf color, Growing condition of stems, branches and leaves
	Thickness	Condition of overgrowth, traffic disturbance and obstacle for sight distance
	Insect damage	Species of harmful insects and occurrence of insect damage
	Damage	Withering or damage caused by girdling, wearing, wild fire or tread pressure.
Invading Plants	Plant species	Existence of target vegetation growing on naturally in the surrounding area
	Thickness	Influence of invading plant against introduced plant
Planting Base	Planting base	Flowing out or deterioration of planting base material
	Drainage	Existence of spring water, or overflowing water from drainage ditches
	Collapse	Existence of cracks, subsidence, or collapse
	Planting foundation	Stability of planting foundation

[2]

Due to the difference in growth speed between herbaceous plants and trees, at the initial stage after the construction, attention should be paid for evaluation on the results of inspection. In general, trees grow slowly in the first 1 to 2 years period after seeding. So, if planting works of trees are performed by applying forest soil or mixed seeding with herbaceous plants, within a year of implementation, clear sign of growth of trees may not be noticed. For such case, inspection should check soundness of planting

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base material and its foundation. Slight expose of planting base material is considered normal in that period.

4.3.2 Contents of Vegetation Management

(1) Management on Plant Growth

Management of plant growth aims to facilitate formation of a target plant colony. Specifically, in the initial stage of plant growth after completion of slope works, management should aim to facilitate plant cover of whole slope, protection and growth of plants for early realization of slope protection by plants and for forming a target plant colony, and plant succession by invasion of peripheral vegetation.

The contents of management before completion of a target plant colony are listed below:

1 If covering condition by plants is extremely poor, vegetation works should be implemented again from the planning of plants. The reasons of poor growth should be studied in terms of timing and manner of planting works as well as suitability of plants for the works. Then timing and manner of the works as well as types of plants should be decided for re-construction.
2 In case the plants which once germinated are weakened for the reasons of drying or freezing, or in case planting base material is collapsed and washed away due to erosion or freezing of surface water, over-seeding or replanting should be implemented. The timing and manner of over-seeding and replanting should be decided considering certainty of the works.
3 Trees need a longer nursing period for germination and growth. If additional fertilizer is applied too early, growth of trees are impeded by herbaceous plants growing around the trees. In the initial period of growth of trees, therefore, if no abnormalities are found in planting base material, keeping observation is considered adequate.
4 Etiolation or decline during growth of plants is often caused by insufficient application of fertilizer. For such case, in general, additional fertilizer should be applied. If plant succession is intended, however, keeping such condition without applying fertilizer is worth to consider depending on the actual site condition, because invading plants would easily infiltrate from the surroundings as long as planting base material is stable.

[2]

In case problems occur after completion of construction and inspection, appropriate measures should be taken after due investigation of the causes.

(2) Maintenance of Vegetation

Maintenance of vegetation aims to maintain a target plant colony after the formation of the same. Specifically, re-sowing, replanting of withered plants, and partial repair of planting base material and should be carried out, as required based on inspection. In such case that plants grow more than expected, trimming should be done for control of plant growth.

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1 To keep grassland in good condition, periodical mowing is required. In case decline of grassland is noticed, additional fertilizer should be applied.
2 Weeds clearing is not recommended unless the weeds hamper the growth of target trees.
3 In case harmful weeds impeding the growth of target plants, such weeds should be removed. Unintended plant growth which is unfavorable for landscape or disturbing traffic should be removed as well. If certain plants, such as kudzu or Robinia pseudoacacia, are overgrown and repel other plants, such plants should be removed by cutting or herbicide coating.
4 If planted trees withers or dies, the reasons should be investigated. If possible, according to the conditions for plant growth, supplemental planting should be implemented.
5 Damaged base material often affects vegetation on slopes. Plant base material often damaged by heavy rain and snowfall as well as snowmelt. Especially, plant base is damaged by surface water from outside of slopes, avalanche and snow removal work, overflow due to poor maintenance of drainage ditches at the shoulder and berms of slopes. Once damaged, plant base material keeps deteriorating. Thus proper treatment should be done. Early detection by inspection is important for proper management.
6 If temporary protection are used for planting works, growth of plants and condition of protection, such as pillars and mulching, should be examined. If damage is found on protection, it should be repaired promptly. When trees sufficiently grow and do not require protection any more, it should be removed.

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4.4 Maintenance of Countermeasure / Mitigation Works

Technical points on operation and maintenance of the countermeasures / mitigation works, which are not explained in the existing guidelines, are described below:

4.4.1 Cut Slope

(1) Check Points for Inspection

Check points for and method of inspection should be prepared for each type of slope works, considering the following points:

1. Function and strength properties intended in design
2. Stability of slope against erosion and cracks caused by rainfall and groundwater spring
3. Influence of detached parts of the works and sliding of foundation ground.

In regular inspection, a detailed examination of durability of structure may be omitted. If considered required, however, it should done separately.

If deformations are observed on cut or fill slopes, it may be caused by instability of natural slope behind. Comprehensive maintenance including natural slopes behind should be done, therefore.

During inspection, in addition to the targeted slopes, careful attention should be paid to hydrological as well as topographic and geological condition including the surroundings.

The important points for maintenance of cut slopes are explained below for i) under construction, ii) during service period, and iii) for the surroundings.

(i) Under Construction and at Completion

Maintenance of structure should start right after its completion. The structures that obtained completion certificate should have the required quality and functions, which degrades by the time elapses.

In case repairs are made for the sections where deformation of the ground caused damage of slope and structures, photographs and records of damage and repair should be well-organized so that inspection during the service period could take advantage of such records. Especially, such deformation or damage forces change of design during construction, such records of change should be kept properly and reflected to plans of inspection. The slopes where deformation or damage occurs during construction often cause problems of deformation and loosening during its service period. Thus due attention should be paid.

(ii) During Service Period

For daily patrol and periodic inspection, an appropriate inspection plan should be prepared for implementation, with reference to Slope Stability Assessment and records of survey, design and construction.

Process of maintenance consists of three stages; evaluation of inspection results in which cracks and deformation are evaluated whether it implies further

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damage or not, detailed investigation in which drilling survey and design of countermeasures are conducted, if any, and construction of the countermeasures planned in the detailed investigation.

Among the said stages, the most important is the evaluation of inspection results in which precursors of collapse or damage should be detected. Due to erratic condition of the ground, survey and design for cut slope construction inevitably include uncertainties. To counteract such uncertainties, during several years after the completion, daily patrol and periodic inspection should pay due attention to deformation on slopes.

(iii) Condition of Surrounding Area

Deterioration of slope protection works due to deformation and damage are often caused by deformation of the upper slope behind the shoulder of slope, deterioration of slope protection itself, or an external force exceeding the assumption in design.

In the surrounding area of slopes, deformation of the ground appears as erosion proceeds due to receding of vegetation, or subsidence, cracks or cavity develops. Regardless of the types of slope protection works, therefore, inspection should pay attention to the following items

1 Cracks and fissures, subsidence or detached rocks at the upper slope behind the shoulder of slopes.
2 Change of vegetation on the upper slope behind the shoulder, including receding of vegetation.
3 Condition of surface runoff concentration to the shoulder.
4 Erosion, scoring, cracks and fissures, or cavities at the boundary between slopes and structures.
5 Erosion, scoring sinking, or subsidence at the surrounding ground of structures.
6 Condition of slope drainage system, especially decreased flow capacity and clogging of the drainage.
7 Groundwater flowing out of the springs at the sides and lower parts of slopes.

If any changes are recognized, detail investigation should be conducted and countermeasures should be designed, depending on the degree of danger which the changes poses.

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(2) Response to Emergency

Emergency inspection and response should be done when a natural disaster strikes the road, or large deformation or collapse damages roadside slopes.

For such emergency, evacuation of residents and road closure should be first prioritized, along with allocation of watchmen and guards. Then emergency measures should be implemented depending on the factors of the emergency such as shown in Table 4-2.

Table 4-2 Emergency Measures in Case of Abnormality (Example)

Major Factor	Phenomena	Emergency Measures (Example)
Surface Water	Development of gully erosion, and erosion due to concentration of running water	Covering with plastic seat, and diversion of flow path
Seepage Water	Rise of seepage line / increase of groundwater from spring, and small collapse at toe of slope	Covering with plastic seat, and putting gabions
Groundwater	Subsidence, cavities, fallen trees, soil pipes, and bulging	Filling of soil or sandbags, and drainage boring
	Ground heave, cracks on the ground, landslide, and fallen trees,	Buttress filling, putting gabions piles, soil removal, and drainage well
Sliding of the Ground	Toppling, and gap between structures and the ground	Cutting, mortar spraying Grouting
	Unstable slope, rock mass, and fallen rocks	Rock fall trap embankment of large sandbags, and rock fall trap fence

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After situation becomes calm, detail investigation should be conducted to design permanent countermeasures. Detailed investigation should pay attention to deformation and abnormality on structures and slopes, vegetation works and its foundation base, and the surroundings.

4.4.2 Drainage of Cut and Fill Slopes

Maintenance of drainage system on slopes includes cleaning of drainage to secure its designed function as well as periodic inspection and repair / improvement, if any.

(1) Points of Maintenance

Proper timing and frequency of effective cleaning should be decided, considering the following conditions:

1 Seasonal factors, such as monsoon, cyclone, and snowmelt
2 Condition of road surface, social environment, and traffic volume
3 Types and structure of drainage system

Through inspection, location of defect and damage should be detected along with its causes, and proper measures should be planned and implemented. Usually inspection of drainage system should be done along with that of slopes; it should focus on flow through drainage system and change in flow volume from groundwater spring.

Generally, inspection of drainage system should be conducted with regular inspection (daily patrol and periodic inspection) and emergency inspection of slope protection works. Inspection during and immediately after rainfall has advantage in checking drainage condition as well as detecting malfunction and problems in drainage system.

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Table 4-3 Inspection for Maintenance of Drainage System of Slopes

Purpose	Cause of Damage	Inspection Items
Prevention of Erosion of Slopes	Overflow from drainage facilities	1) Condition of drainage facilities immediately after rainfall 2)Accumulation of soil or driftwoods in the drainage facilities 3)Erosion of slopes 4)Deformation or damage of drainage system
Prevention of Collapse of Slopes	Ground water spring at slope surfaces, which is supplied by infiltration of surface water	1) Saturation of slope surfaces immediately after rainfall 2) Change of groundwater volume flowing out from spring on slopes 3) Change of discharge volume from outlets of drainage system 4) Choke / clogging of drainage system 5) Cracks and damage of bottom of drainage

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In particular, during monsoon, cyclone, and snowmelt seasons, inspection with special caution should be conducted. Especially, when land or estate development projects are implemented in the proximity of a hill road, vegetation and drainage condition in the surroundings of roadside slopes should be changed, and, as a result, surface runoff flowing into roadside slopes may overwhelm the designed capacity of the roadside drainage system. For such case, improvement of existing drainage and/or reinforcement by new drainage facility are required to maintain drainage function as a whole.

(2) Maintenance

(i) Drainage of Cut / Fill Slope

To maintain the function of slope drainage is particularly important for high embankments and long and high cut slopes. The ditches on berms and at the shoulder of slopes should be kept clean so as to prevent clogging by debris, fallen rocks and/or driftwoods. In addition, careful attention should be paid to ensure that the water in such ditches should flow down only through the vertical drain connected to such ditches. If the vertical drain is covered by U-shaped corrugated steel, in case splash out of flowing water or erosion of back soil by leaked water are observed, U-shaped corrugated steel should be removed for repair of damage of the foundation ground and vertical drain itself.

If any groundwater springs that may cause erosion or collapse of slopes, countermeasures should be immediately installed, such as installation of drainage pipes or additional ditches which prevent erosion of slope surface. In case substantial groundwater is considered to be stored behind a structure, which may be suggested by quantity and color of leaked water from cracks or weep holes as well as location of leakage, proper countermeasures should be installed, such as additional weep holes or drainage pipes; groundwater pressure behind structure should increase stress affecting it.

Since drainage pipes / weep holes in retaining walls, concrete pitching, and concrete-block pitching are prone to be choked with soil and weeds, cleaning should be done properly.

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(ii) Connection of Drainage Facilities

At the junctions between vertical and horizontal drains, such as connections among vertical drains and ditches on berms or along the shoulder or the toe of slopes, cross section of drains often changes and water flow may be disturbed, which may cause deformation and damage. In addition, connections of different types of product such as precast and cast-in-place concrete may act as structural weak points. Deposition of sediment may occur by disturbed water flow due to change of cross section, which may cause detachment of drains at the connections.

In addition, if a junction among a vertical drain and horizontal drainage ditches is located at a boundary between cut and fill sections, surface water often infiltrates into the part of embankment, which may deteriorate the embankment. Accordingly, larger catch basins are desirable for boundaries between cut and fill.

(iii) Subsurface Drainage

Subsurface drainages secures drainage capacity by two types of materials; placing perforated pipes or drain material underground or filling coarse material with high permeability into ditches. In either case, outlets of drainage should be kept clean so as not to disturb flow of water. Direct observation of subsurface drainages are generally difficult. So, deterioration of drainage function is usually detected by observing amount of water from at the outlets after rainfall.

In case significant or total loss of drainage capacity is found, repair or reinforcement of subsurface drainage should be planned. In case additional subsurface drainage is planned, placing additional drainage at fresh location is more effective and economical compared to utilize the existing location of the same. Thus careful consideration is required.

(iv) Road Drainage Facilities

Road crossing culverts should be regularly inspected focusing on the following points; deposition of soil and driftwoods in culverts as well as at inlets and outlets, erosion around inlets and wing walls, opening of joints inside of culverts, cracks of culverts, and leakage from culverts and related structures.

(v) Horizontal Drainage Borings

Regular and emergency inspections should be done for horizontal drainage borings. As a regular inspection, visual inspection should be conducted at least annually for the visible parts of the works including outlets. As an emergency inspection, visual inspection similar to annual one should be conducted after severe earthquake or heavy rain. A visual inspection should examine damage of pipes, clogging /choking of outlets of drainage pipes by fixation of scale or slime produced by iron-oxidizing bacteria such as shown in Figure 4-17, and drainage system which drains discharged water from outlets to outside of landslide blocks. At the same time, a visual inspection should check deformation caused by landslides, such as cracks and displacement of the ground and damage and deformation structures.

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Figure 4-17 Slime Adherence / Fixation at Outlets of Boreholes

[4]

4.4.3 Slope Protection Works

For maintenance of slope protection works, target of service level during maintenance period should be firstly formulated in consideration of structural performance and durability of the works as well as aesthetic points of view. The predetermined service level should be kept through inspections and forecast of degradation as well as execution of repair and improvement. Particularly, concrete crib works are composed of mortar / concrete frames and fillings within frames. Thus different service levels and maintenance are required for frames and fillings.

The slope protection works may be deformed or damaged due to ageing deterioration or external force unexpected in the design. The deformation of slope protection works includes joint cuts, cracks, bulging, surface failure and collapse of slope.

The deformation of fillings includes relaxation, bulging, depression, erosion, and cracking. If left untreated, such deformation proceeds and leads to larger collapse. Thus, through inspections and surveys, road administrators should pay due attention to find out such deformation in an earlier stage and implement appropriate repair and reinforcement of slope protection works to keep expected function of the same.

In addition, inspection as well as repair and reinforcement should be recorded including condition of deformation and damage.

(1) Inspection and Evaluation

In this section, the items to check in an inspection are organized by type of slope protection works. Basically, as long as effective, an inspection can be done through visual inspection from the shoulder, berms, or toe of slopes. If abnormality is expected, visual inspection on the slopes between berms and survey with simple equipment or measuring devices should be added, as required.

a) Shotcrete (including fillings within frames)
   1 Upheaving from the ground (void space behind the shotcrete)
   2 Cracks
   3 Exfoliation of the surface of sprayed mortar or concrete
   4 Deterioration of weep / drain holes (clogging by soil and/or weed, weathering of the ground at the tip of holes)
   5 Opening of construction joints or overgrowth of vegetation
   6 Groundwater spring or seepage from cracks

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b) Vegetation (including fillings within frames)
   1 Bulging, subsidence, cracks of vegetation base material
   2 Runoff, including traces, of vegetation base material
   3 Decay, fallen trees, discoloration, or abnormal growth of vegetation

c) Concrete Crib Works (Shotcrete and Cast-in-situ Concrete)
   1 Relaxation or subsidence of fillings within frames
   2 Cracks of frames
   3 Exfoliation of the surface of frame
   4 Efflorescence
   5 Deformation of construction joints

d) Drainage System
   1 Clogging inside or at outlets of drainage system
   2 Deformation of drainage ditches (subsidence and bulging)
   3 Water leakage or overflow from connections of structures

(2) Maintenance

Paying due attention to the close relationship between slope protection works and the ground condition, which is different from general concrete structures, appropriate methods should be selected for repair or reinforcement.

The purposes of repair are to control deterioration and deformation, to prevent fallen concrete pieces peeled off from the surface, to refill the material of fillings which is locally bulging, to treat groundwater spring, and to restore durability of structure as a maintenance measure, including repair of cracks and damage on frames of crib works.

Reinforcement is to recover and improve load resistance performance of slope protection works. Increasing cross section of frames is one of reinforcement method.

Since deterioration or deformation of slope protection is caused by external forces, weathering of the ground behind of the works, and/or inappropriate initial design conditions, sufficient survey and investigation should be carefully conducted for planning of repair and reinforcement.

Table 4-4 explains items of inspection for slope protection works

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Table 4-4 Inspection Items and Treatment for Slope Protection Works

Works	Inspection Items	Causes of Damage	Examples of Treatment
Spray Crib, Cast-in-Situ Concrete Crib Works	Cracks of mortar / concrete frame	Drying shrinkage Plastic cracking	Continuous observation of width and length of cracks. If considered required, repair.
		Excessive load acting to frames	Evaluation of damage and investigation for causes. If considered required, reinforcement / repair.
		Factors resulting from improper design and construction	
	Void space behind frame	Erosion by water	Filling of void space with mortar. Proper drainage of surface water Drainage boring of groundwater
	Exfoliation of surface of frame	Freezing Deterioration by carbonation	Evaluation of damage and investigation for causes. If considered required, treatment, such as repair and carbonation control
	Bulging of frame	Effect of abnormal earth pressure	Investigation for causes. Countermeasures against the cause.
	Efflorescence	Efflorescence is produced by dissolved calcium hydroxide in concrete to water and absorption of carbon dioxide in the air.	Basically, no measures to prevent efflorescence is available, excluding reconstruction. For re-construction, the followings should be paid attention; • To decide mix proportion while paying attention to controlling unit water content to prevent bleeding • To reduce rebounding to cast denser concrete • To add short discrete fibers to prevent cracking
Shotcreting Works	Cracks	Drying shrinkage Plastic cracking, Sliding of sprayed mortar in wide area	Continuous observation of width and length of cracks. If considered required, treatment including repair, re-construction, or coating permeable waterproofing agent to reinforce concrete. For re-construction, the followings should be paid attention; • To add short discrete fibers to mortar to thicken shotcrete • To install reinforcing bars to prevent sliding
	Void space behind shotcrete	Erosion, Suction	Filling of void space with mortar. Proper drainage of surface water Drainage boring of groundwater

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4.4.4 Large-scale Prevention Works (Ground Anchor Works)

Among prevention works, ground anchor works require careful and periodic maintenance to keep its designed function including applied prestress to tendon. Inspections and surveys should be well planned and conducted during maintenance period. Periodic inspection should be carried out regularly, but in cases of emergency including excessive rainfall, strong cyclone, and severe earthquakes, emergency inspection should be conducted.

As a result of inspection, if considered required, soundness evaluation should be conducted, which decides necessity of treatments, such as reloading or relaxing of prestress and re-construction.

(i) Inspection

Inspection items should be selected in consideration of site condition. Periodic inspection should be carried out regularly, the intervals of which should be decided based on the purpose and usage of ground anchors as well as surrounding conditions.

Results of inspections should be recorded for reference for future inspections and consideration for necessity of further detailed investigation.

Table 4-5 Standard Intervals, Method and Quantity of Inspection (Reference)

Type of Inspection	Timings and Intervals	Method and Quantity
Initial Inspection	After completion of the works	Visual inspection of all ground anchors to prepare inventories
Daily Inspection	During daily patrols	Visual inspection from vehicles
Periodic Inspection	Until 3 years after completion: annually After 3 years: every 3 to 5 years (Important anchors: annually)	Visual inspection of all anchors at close-range Detailed inspection of 3 nos. or 10% of all anchors, whichever larger
Emergency Inspection	Immediately after abnormal climate event, such as heavy rain, strong cyclone, and severe earthquake	Visual inspection of all anchors at close-range

[5]

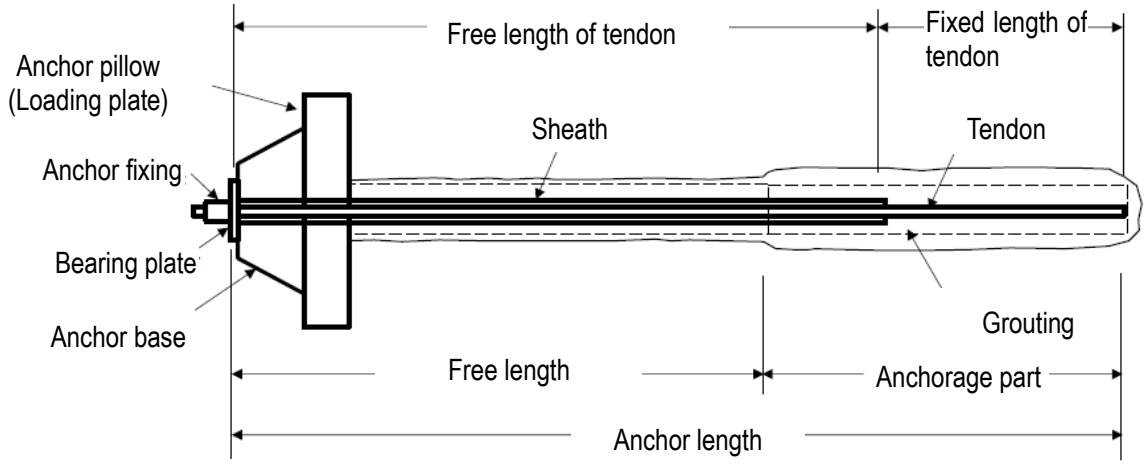


Figure 4-18 Structure of Ground Anchor

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Table 4-6 Necessity of Soundness Evaluation Based on Inspection (Example)

Inspection Item		Contents of Inspection	Score Note 1)
Documents	Documents of investigation, design and construction	Corrosive ground conditions	III
		Abundant groundwater.	III
		Geological conditions prone to degradation and weathering.	III
Condition of ground anchors	Extrusion of Anchors	Length of extrusion of anchor heads	I
	Residual load (When a load cell is Installed) Note 2)	Measured value of load cell (Almost no residual load)	I
		Measured value of load cell (Less than 0.8 times of the prestress at fixation)	II
		Measured value of load cell (More than design anchor force) Note 3)	II
		Measured value of load cell (1.1 times or more of design anchor force)	I
Condition of anchor heads	Head concrete cover of anchor	Destruction or partial defect	II
		Cracks over 1 mm wide	II
		Segregation of free lime from head concrete cover	III
		Unnatural gap behind head concrete cover	I
		Void space behind head concrete cover	III
		Leakage of water from behind head concrete cover	II
	Head cap of anchor	Damage of head cap	II
		Deterioration and corrosion of head cap	II
		Destruction or corrosion of bolts or wedge or PC strand	III
		Stain by leakage of anti-corrosion oil around head cap	III
	Bearing plate	Lift of anchor head and bearing plate (visual inspection)	II
		Bearing plate is rotatable by hand	I
		Leakage of water from the ground behind of bearing plate	II
		Stain around bearing plate	III
Condition of anchor pillow and base	Cracks and fissures	Cracks of several mm wide or more or continuous cracks	II
	Deformation or Subsidence	Large deformation of other structures	II

Note 1) score is guidance only. Judgments should be made such as giving strict score for an inferior state.
I: Soundness of the ground anchor is in question.
II: Soundness of the ground anchor is possibly in question.
III: Soundness of the ground anchor is affected
Note 2) when a load cell is installed and working properly.
Note 3) in case where much lesser prestress than design anchor force was applied, expecting retaining effect of ground anchor

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Figure 4-19 Anchor Head

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(ii) Soundness Evaluation

Survey items and methods for soundness evaluation should be selected in consideration of the condition of the targeted ground anchors and the site conditions. Through evaluation of soundness of the targeted ground anchors, necessity as well as methods of treatment are considered.

Table 4-7 Item and Quantity of Tests and Surveys for Soundness Evaluation (Reference)

Type of Test and Survey	Quantity
Detailed investigation of anchor heads: visual inspection of outer appearance	Decided by results of preceding inspection
Detailed investigation of anchor heads: direct inspection by removing caps or covers	A) Anchors selected for soundness evaluation and the surrounding anchors (up and down, left and right) of the selected. B) 5 nos. or 20 % of the anchors excluding those selected in A), whichever larger.
Lift-off Test	A) Anchors selected for soundness evaluation and the surrounding anchors (up and down, left and right) of the selected. B) 3 nos. or 5 % of the anchors excluding those selected in A), whichever larger.
Inspection of behind of anchor head	A) Anchors selected for soundness evaluation and the surrounding anchors (up and down, left and right) of the selected. B) 3 nos. or 5 % of the anchors excluding those selected in A), whichever larger.
Monitoring	Anchors with monitoring devices

For lift-off test as well as reloading or relaxing of prestress may require some margin or excessive length of tendon above fixing part

[5]

In conventional method, a load cell attached to head of a ground anchor is used for measuring residual load or prestress of the anchor. The use of a load cell at head of a ground anchor requires some cost, but it can only measure residual load, by which identifying the cause of defect is difficult.

In recent years, a new economical measurement system utilizing the mechanism of borehole extensometer is being developed. The system with wire measurement enable long-term maintenance of ground anchors and the slope where it is installed, with simple and easy visual inspection.

The measurement system shown in Figure 4-20 observes displacement of 3 wires, which are fixed at extra boring, anchorage, and free length parts of a ground anchor. By attaching this system to a load cell, movement of slope is observed along with change of residual load. Thus cause of change of residual load can be identified. .

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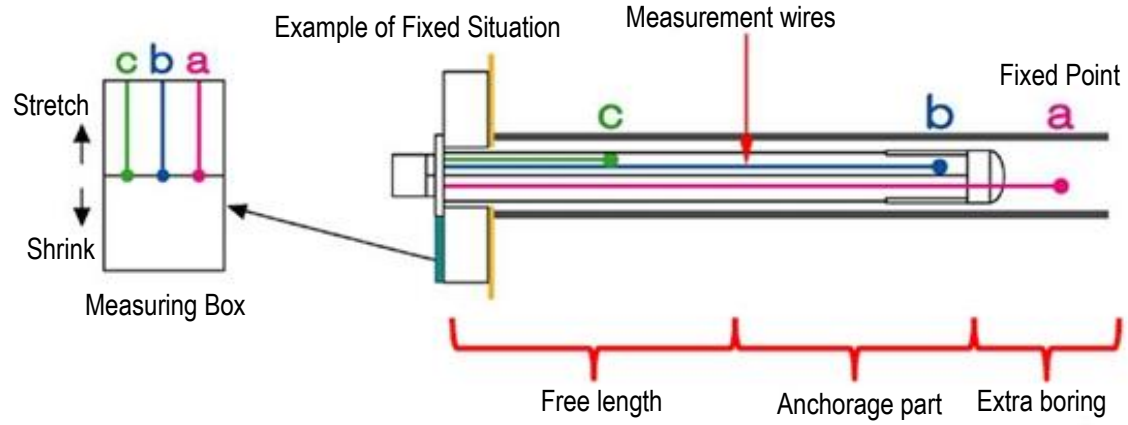


Figure 4-20 Example of Soundness Evaluation with Wire Measurement

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(iii) Records and Treatment

Results of inspections and soundness evaluation should be recorded and stored in a safe place during service period of ground anchors, for future reference.

Treatment should be planned and implemented with clear target, such as reinforcement, repair, improvement of durability, and renewal.

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