ANNEX 3

Sample of the Investigation Sheet for Rock Fall Inventory

September 2017

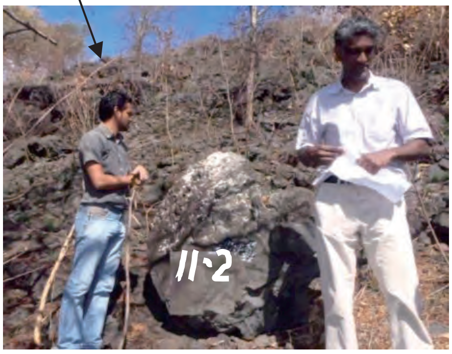
This photo is a good example because it shows not only the target rock but also the situation around the rock.

Site Investigation Sheet for Rock Fall Inventory

Rock No.	11-1	25/10/2016
[Photo]		

(1) Site Name		Signal Mountain
(2) Section (ch)	(From)	1100
	(to)	1200
(3) Rock No.		11-1
(4) Coordination	Latitude	S 20 10 30.5
	Longitude	E 57 29 39.0
(5) Size (cm)	Length	500
	Width	700
	Height	500
(6) State of Stability		1
(7) Type of Countermeasure		A
(8) Site Investigation	Date	25/10/2016
	Inspector	S. Anadachee

Rock No.	11-2	25/10/2016
[Photo]		



(1) Site Name		Signal Mountain
(2) Section (ch)	(From)	1100
	(to)	1200
(3) Rock No.		11-2
(4) Coordination	Latitude	S 20 10 30.3
	Longitude	E 57 29 38.7
(5) Size (cm)	Length	1350
	Width	980
	Height	810
(6) State of Stability		3
(7) Type of Countermeasure		B
(8) Site Investigation	Date	25/10/2016
	Inspector	S. Anadachee

Rock No.	11-3	25/10/2016
[Photo]		

(1) Site Name		Signal Mountain
(2) Section (ch)	(From)	1100
	(to)	1200
(3) Rock No.		11-3
(4) Coordination	Latitude	S 20 10 30.5
	Longitude	E 57 29 39.0
(5) Size (cm)	Length	500
	Width	700
	Height	500
(6) State of Stability		1
(7) Type of Countermeasure		A
(8) Site Investigation	Date	25/10/2016
	Inspector	S. Anadachee

Rock No.	11-4	25/10/2016
[Photo]		

(1) Site Name		Signal Mountain
(2) Section (ch)	(From)	1100
	(to)	1200
(3) Rock No.		11-4
(4) Coordination	Latitude	S 20 10 30.3
	Longitude	E 57 29 38.7
(5) Size (cm)	Length	1350
	Width	980
	Height	810
(6) State of Stability		3
(7) Type of Countermeasure		C
(8) Site Investigation	Date	25/10/2016
	Inspector	S. Anadachee

(6) State of Stability
- 1 : Rockfall will occur in near future.
- 2 : Although it is difficult to predict the failure time, rockfall will occur at this site.
- 3 : The possibility for rockfall is high.
- 4 : The possibility for rockfall exists.
- 5: There is no possibility for rockfall.

(7) Type of Countermeasure
- A : To remove a loose rock
- B : To stabilize a loose rock by concrete and anchor
- C : To stabilize a loose rock by net and/or wire

This photo is a bad example because it shows only the target rock, and the situation around the rock is not included in a photograph.

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
MINISTRY OF PUBLIC INFRASTRUCTURE AND LAND TRANSPORT (MPI)

Procedure Manual for Landslide

December 2014

(Revised in September 2017)

KOKUSAI KOGYO CO., LTD.

NIPPON KOEI CO., LTD.

CENTRAL CONSULTANT INC.

FUTABA INC.

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0 Preface

0.1 Definition of Landslides

The term “Landslide” is defined variously in different literature. For example, United States Geological Survey (USGS) defines “Landslide” referring to Cruden, 1991, and Varnes 1996 as follows;

A landslide is defined as "the movement of a mass of rock, debris, or earth down a slope" (Cruden, 1991)[1]. Landslides are a type of "mass wasting" which denotes any down slope movement of soil and rock under the direct influence of gravity. The term "landslide" encompasses events such as rock falls, topples, slides, spreads, and flows, such as debris flows commonly referred to as mudflows or mudslides (Varnes, 1996)[2]. Landslides can be initiated by rainfall, earthquakes, volcanic activity, changes in groundwater, disturbance and change of a slope by man-made construction activities, or any combination of these factors.

The classification by Varnes, 1978 through USGS is widely adopted worldwide. Table 0.1.1 presents the updated classification.

Table 0.1.1 Classification of Types of Landslides (Modified after Varnes, 1978)[3]

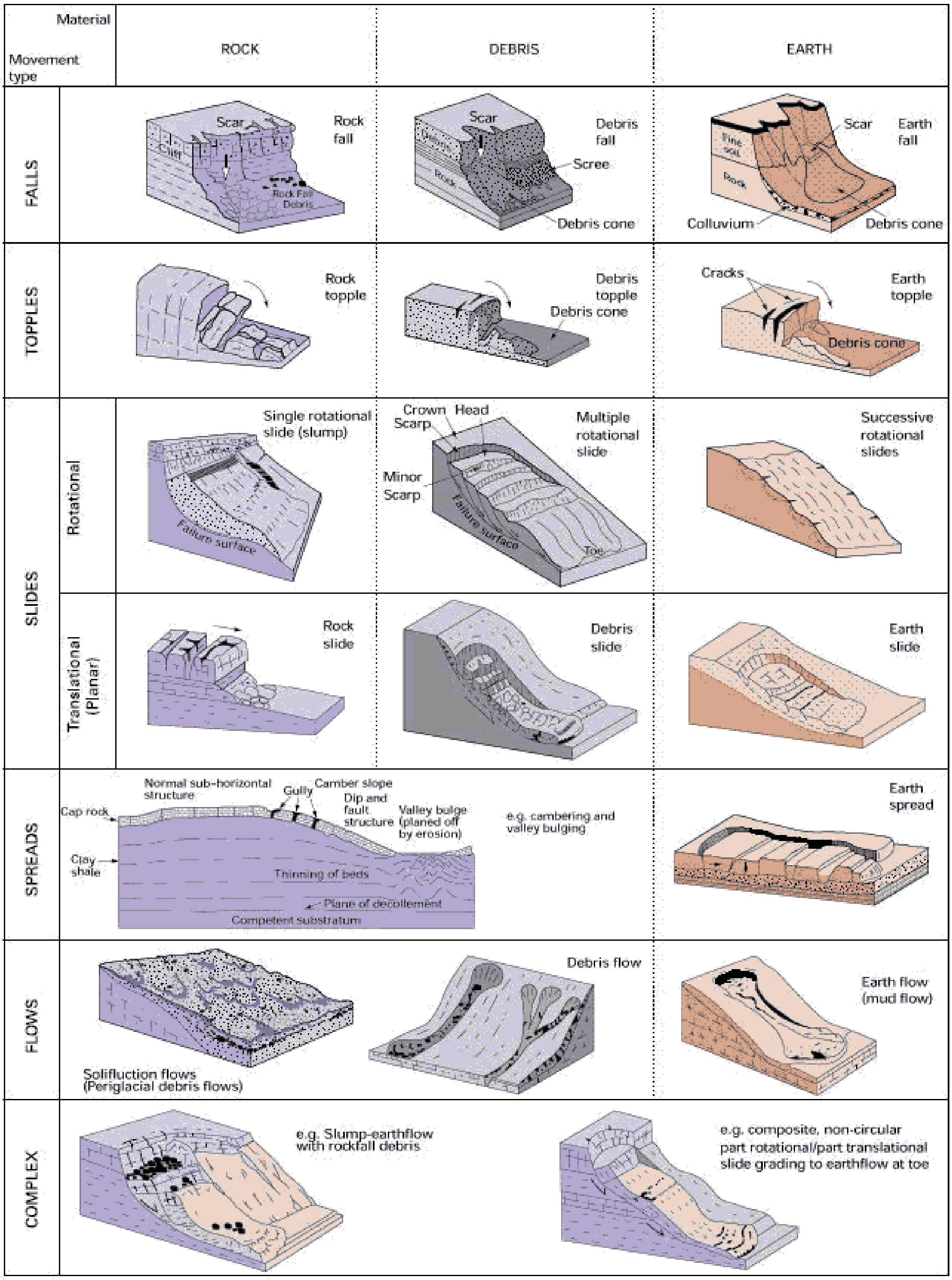


Figure 2 Classification of type of landslip (modified after Varnes, 1978 and DoE., 1990).

Falls mass detached from steep slope/cliff along surface with little or no shear displacement, descends mostly through the air by free fall, bouncing or rolling.
Topples forward rotation about a pivot point.
Rotational slides sliding outwards and downwards on one or more concave-upward failure surfaces.
Translational (planar) slides sliding on a planar failure surface running more-or less parallel to the slope.
Spreads fracturing and lateral extension of coherent rock or soil materials due to liquefaction or plastic flow of subjacent material.
Flows slow to rapid mass movements in saturated materials which advance by viscous flow, usually following initial sliding movement. Some flows may be bounded by basal and marginal shear surfaces but the dominan movement of the displaced mass is by flowage.
Complex slides slides involving two or more of the main movement types in combination.

Generally speaking, a landslide is classified as follows:

(1) Landslide

A landslide refers mainly to “SLIDES” as described in the Table 0.1.1. A landslide is a phenomenon where the soil mass on one or more failure (slip) surfaces deep in the ground gradually shifts downward, triggered by heavy rain or earthquake, river erosion, or earthworks. Landslide sites tend to be concentrated in areas with specific geology or geological structure. Compared to slope failure, in a landslide the gentler slope moves on a large-scale forming specific topography (landslide topography). The inclination angle of the landslide slopes is at relatively low angles (about 5-20 degrees).

(2) Slope Failure

A slope failure refers to “FALLS” of debris and earth material as shown in the Table 0.1.1, but it does not include “Rockfall”. The slope failure mass detaches from a steep slope/cliff along a surface with little or no shear displacement. It may be called a “Surface Failure”. Compared to landslides, the slope failure moves quickly on a small-scale and the inclination angle is relatively high (over 20 degrees).

(3) Debris Flow

A debris flow is equivalent to “FLOWS” of debris and earth material as shown in the Table 0.1.1. A debris flow is a phenomenon where soil and boulders are liquefied by surface water or groundwater and tend to flow downward rapidly through a mountain torrent. It usually has huge energy and destructive force. Debris flows tend to occur in places where there is a massive amount of unstable sediment along a steep torrent, or a significant risk of slope failure due to heavy rain in the catchment basin.

(4) Rockfall

A rockfall refers to “FALLS” and “TOPPLES” in Table 0.1.1. A rockfall is a phenomenon where foliated rocks and gravel due to enlarged cracks in the bedrock or outcropped rocks start to fall down a slope.

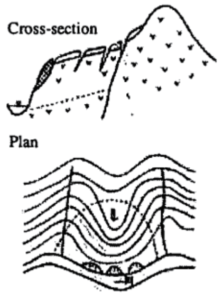
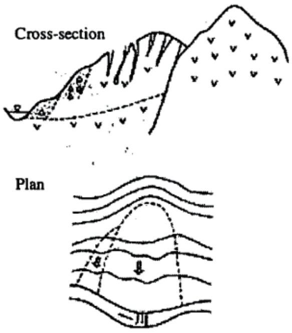
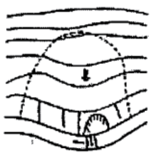
In this manual, “a slope disaster” is defined as the four (4) above mentioned types of natural disasters.

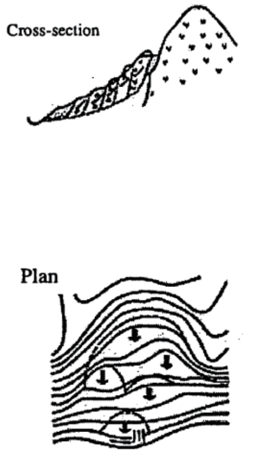
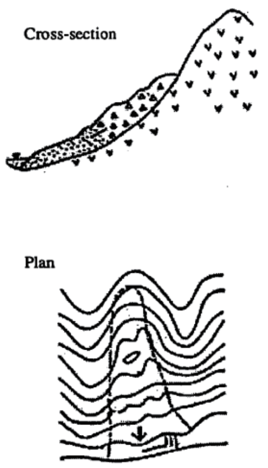
0.2 Classification and Mechanisms of Landslides

0.2.1 Classification of Landslides

Table 0.2.1 shows the classification of landslides which have slip surfaces and repeated activity. Landslides are classified into several types by the topographic and geological characteristics. This classification makes it possible to estimate the cross-section, longitudinal profiles and depths of landslides. As a result, the estimations are used as significant information to plan landslide surveys.

Table 0.2.1 Classification of the Landslide Type[4]

Category	Description	Schematic Drawing	Typical Geological Features	Remarks
(1) Bedrock Landslide	1) Convex ridge terrain with a chair or boat-type sliding surface; often starts at a saddle section 2) Bedrock or lightly weathered at the head and weathered rock at the bottom 3) Sudden occurrence makes its prediction very difficult; careful reconnaissance and a detailed survey are required	 Convex ridge terrain	Often affected by a fault or fracture zone; Tertiary formations, crystalline schist and Mesozoic and Paleozoic formations	Triggered by large-scale earthworks, submersion of part of the slope, earthquake or heavy rain
(2)Weathered Rock Landslide	1) Convex plateau terrain, single hill, concave plateau terrain with a chair or boat-type sliding surface 2) Weathered rock with many cracks at the head and sediment mixed with boulders at the bottom	 Single hill terrain  Concave plateau	Crystalline schist, Mesozoic/Paleozoic formations or Neogene formation affected by a fault or fracture zone	Triggered by a downpour, abnormal thawing, earthquake or medium-scale earthworks
(3) Colluvial Deposit Landslide	1) Multiple hill or concave plateau terrain with a stair or layer-type sliding surface which can be divided into 2 – 3 blocks 2) Mainly consists of sediment		Colluvial deposit from crystalline schist, Mesozoic/Paleozoic formations, Neogene formation or serpentinite	Triggered by thawing, typhoon, downpour or medium-scale earthworks

	containing gravel and becomes clay at the bottom 3) Intermittent activity repeated every 5 – 20 years; landslide hysteresis is clear from the topographical point of view and can be checked with a topographical map of 1 to 5,000 or 1 to 10,000; interviews with local people are also useful	 Multiple hill terrain		
(4) Clayey Soil Landslide	1) Gently sloping concave terrain with a multi-blocked stair or layer type sliding surface; closer relation between the blocks than (3) 2) Mainly consists of clay or clay containing gravel 3) As landslide movement is semi-continuous with a recurrence every 1 – 5 years, its presence is well-known locally.	 Gently sloping concave terrain	Neogene formation, fracture zone and solfataric soil	Easily activated by a downpour, thawing, river erosion or small-scale earthworks

0.2.2 Mechanisms of Landslides

A landslide is a phenomenon where the soil mass on one or more slip (failure) surfaces deep in the ground gradually shifts downward (Figure 0.2.1). As one of the characteristics, the inclination angle of the landslide slope is a relatively low angle (about 5-20 degrees). Mechanism and movement direction of landslides can be estimated by checking the following points:

- Small deformations and surface anomalies such as steps, subsidence or heaving
- Main scarp, tension crack, compression crack, radial crack, lateral crack
- Deformation of artificial building such as house or stone wall
- Anomaly of vegetation such as bending of tree root.

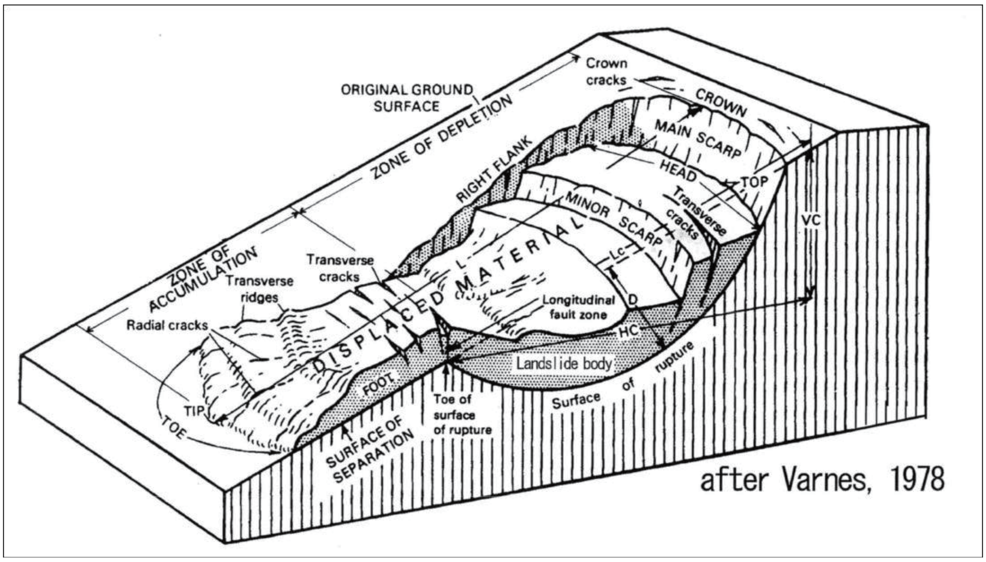


Figure 0.2.1 Structure of Typical Landslide[5]

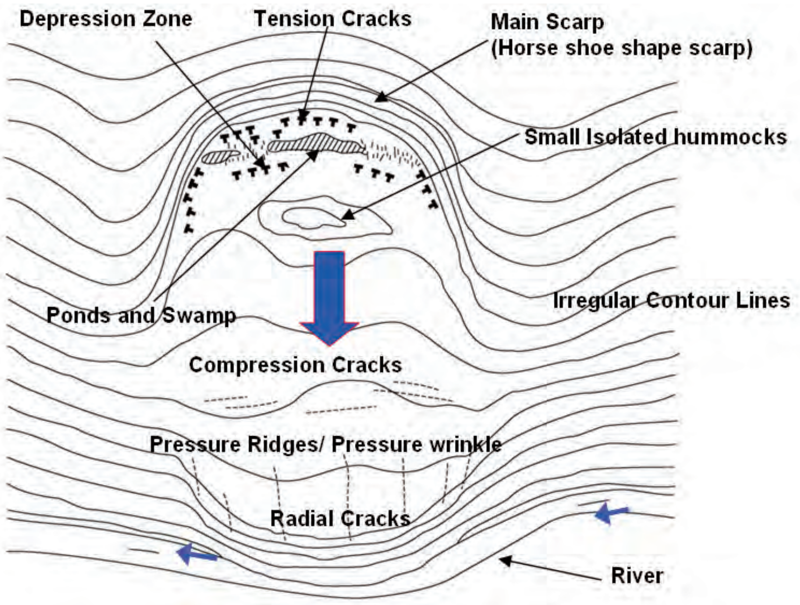


Figure 0.2.2 Schematic Diagram of Landslide Landforms[6]

0.2.3 Landslide Factors

Basic factor (Mechanical factor): In general, landslides occur frequently in a landslide area that has its own natural characteristics as basic factors. Most basic factors are natural even when the inducing factor is man-made. The basic factors are: topographical (water collecting nature), geological (nature of creation of slip surface such as bedded structure, mud-clay layer, tuff etc., and thick loose formations on an unstable slope), geological structure (faults, anticline, syncline, etc., which will become a factor of the landslide), the condition of groundwater and so on.

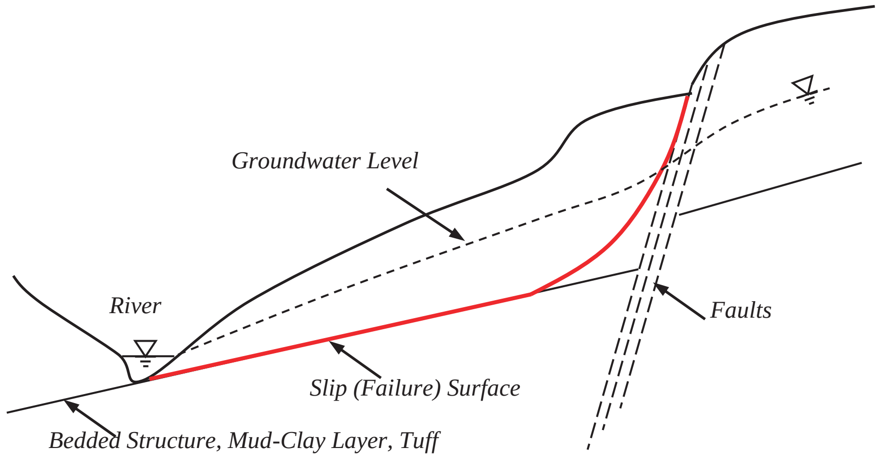


Figure 0.2.3 Schematic Cross Section of Basic Factors of Landslides (source: JET)

Inducing factors: In areas prone to the basic landslide factors, floods during the rainy season, and other changes to the natural environment (wash out of the slope toe by rivers, formation or blockage of new waterways at surface and subsurface) are triggers of landslides (inducing factors).

Artificial cause: The man-made causes which lead to landslide are: embankment at the upper landslide mass, cut slope at the toe of a landslide, slope submersion under water and blockage of surface drainage.

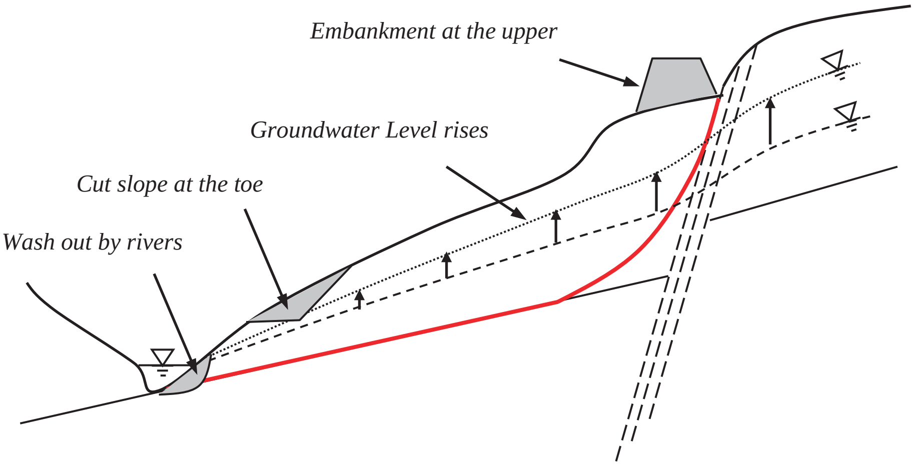


Figure 0.2.4 Schematic Cross Section of Inducing Factor and Artificial Cause (source: JET)

0.3 Outline of Landslides in Mauritius

0.3.1 Classification of Hazard area in Mauritius

The 37 landslide hazard areas, selected based on the "Cyclone and Other Natural Disasters Scheme 2011-2012", includes several disaster forms besides landslides. Therefore the 37 hazard areas are classified into nine (9) kinds of disasters, given in Table 0.3.1, while Table

0.3.2 gives a description of these kinds of disasters.

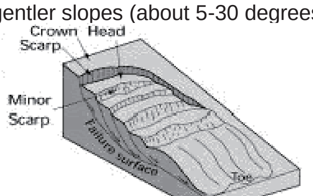
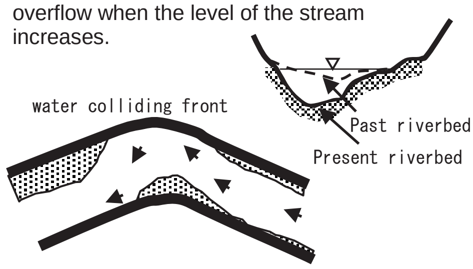
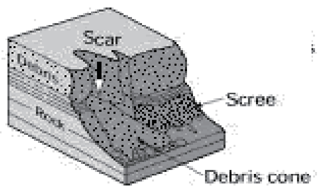
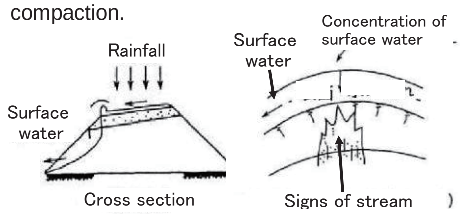
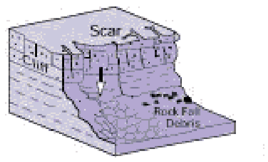
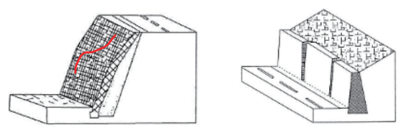
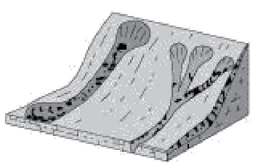
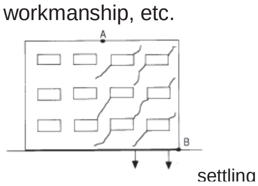
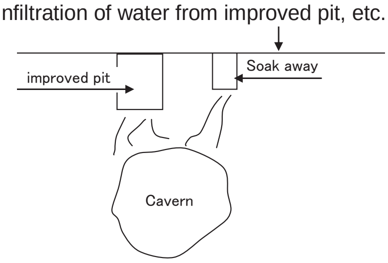
General classification : At first, the 37 hazard areas selected based on the "Cyclone and Other Natural Disasters Scheme 2011-2012" are classified into two kinds of disaster, Slope disasters and other disasters.

Sub classification : Slope disasters are further classified into Landslide, Slope failure, Rock fall, and Debris flow. Other disasters are classified into Stream erosion, Damage of embankment, Damage of wall, Damage of house, and Cavern.

Table 0.3.1 Classification of Hazard Area in Mauritius (source: JET)

General classification			Sub classification		Summary
Disaster	Slope	15 areas	Landslide	6 areas	Can be classified as a Landslide Hazard Area
			Slope failure	7 areas	Because it is not a "Landslide", it cannot be classified as a Landslide Hazard Area
			Rock fall	1 areas	
			Debris flow	1 areas	
	Other	22 areas	Stream erosion	10 areas	
			Damage of Embankment	4 areas	
			Damage of wall	5 areas	
			Damage of house	1 areas	
			Cavern	2 areas	
			Total	37 areas	

Table 0.3.2 Description of the Disaster Type in Mauritius (source: JET)

Slope disaster		Other disaster	
Landslide	A landslide is a phenomenon where the soil mass on failure surfaces deep in the ground gradually shifts downward, triggered by heavy rain, an earthquake, river erosion or earthworks. Compared to slope failure, landslides are generally on a larger scale and occur on gentler slopes (about 5-30 degrees).  	Stream erosion	Stream erosion is the phenomenon where the soil of the bank is removed by the flow of the river. It occurs in riverbanks where the flow of the river hits with the most force. Water might overflow when the level of the stream increases. 
Slope failure	A slope failure is a mass becoming detached from a steep slope/cliff along surface with little or no shear displacement. Compared to landslides, the failure is rapid and on a small-scale, the inclination angle is a relatively high (over 30 degrees).  	Damage of embankment	The collapse of the road embankment is often triggered by rainfall, infiltration of underground water, erosion by surface water, or a partial catchment. It can be caused by weak embankment material or by lack of soil compaction. 
Rock fall	A rock fall is a phenomenon where foliated rocks and gravel start to fall down a slope as a result of enlarged cracks in the bedrock or outcropped rocks.  	Damage of wall	The disaster of a retaining wall doesn't occur suddenly as with a rockfall etc., rather the deformation occurs over a comparatively long time. The survey should investigate: ・ condition around the retaining wall ・ main body of the retaining wall ・ history of the retaining wall 
Debris flow	A debris flow is a phenomenon where soil and boulders are liquefied by surface water or groundwater and tend to flow downward rapidly through a mountain torrent. 	Damage of house	A crack that occurs on the wall of a house may be caused by: ・ Lack of bearing capacity ・ Subsidence of foundation ground ・ Shoddy workmanship, etc. 
		Cavern	A cavern may be caused by: ・Infiltration of water from soak away ・Infiltration of water from improved pit, etc. 

0.3.2 Location Map and Inventory

The landslide location map in Mauritius is indicated in Figure 0.3.1 and the characteristics are compiled in Table 0.3.3.

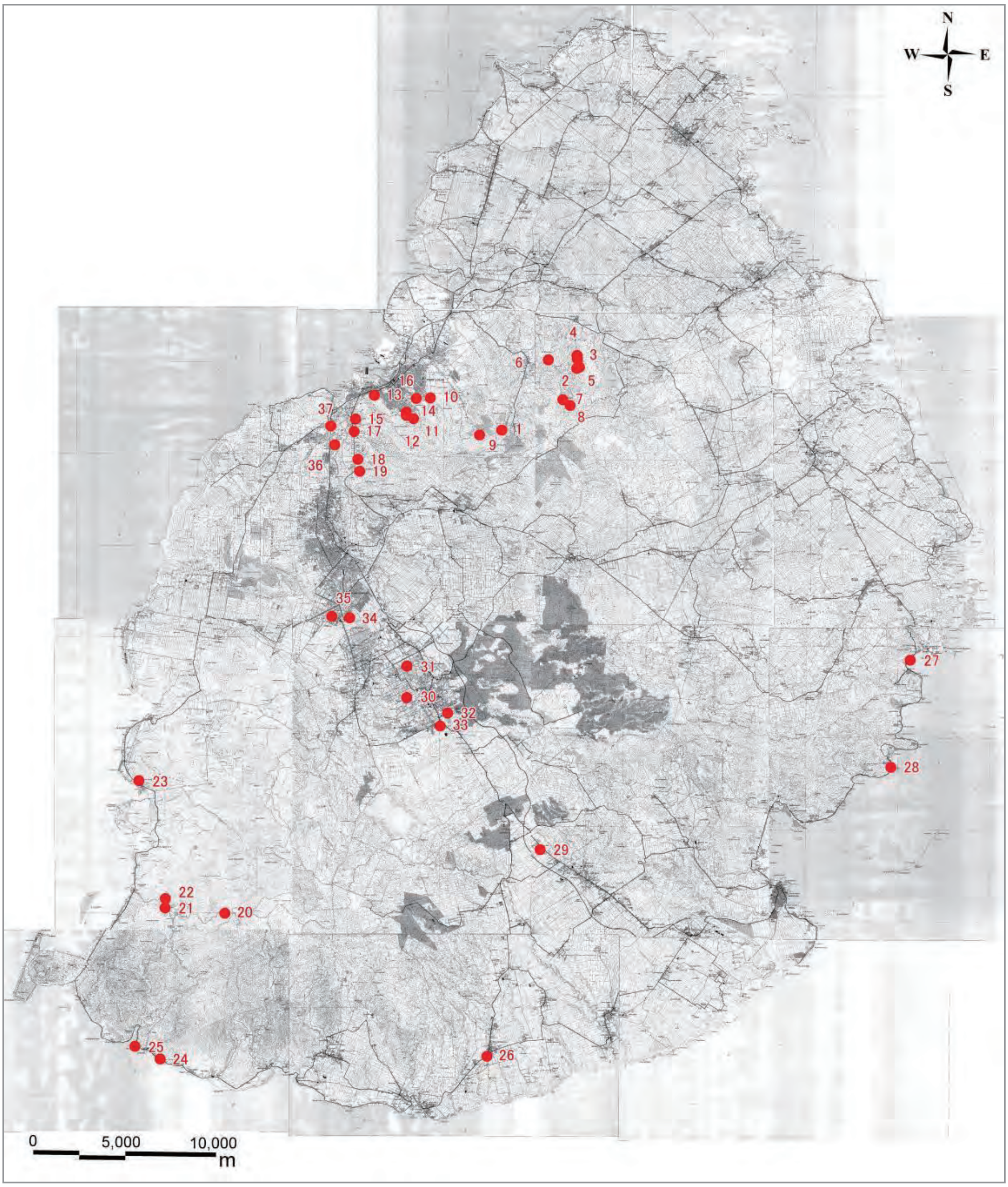


Figure 0.3.1 Landslide Location Map in Mauritius (source: JET)

Table 0.3.3 Landslide Inventory in Mauritius (source: JET)

no.	Area name	Summary of the field investigation and interview	Kind of the disaster	
			General	Sub
1	Temple Road, Creve Coeur	Deformation on the concrete block wall and house caused by embankment deformation at the front yard (parking area) was confirmed. Another problem was inadequate surface drainage causing surface water from mountains to flow directly at houses during heavy rain.	Other	Damage of wall
2	Congomah Village Council (Ramlakhan)	A small stream flows under the road through a concrete pipe culvert, however, because it is too small it causes flooding and bank erosion during heavy rain.	Other	Stream erosion
3	Congomah Village Council (Leekraj)	A 1m high retaining wall that was constructed to build the road was reported to be leaning but it was found to be stable and no slope failure was observed.	Other	Damage of wall
4	Congomah Village Council (Frederick)	The 1m high retaining wall along the road was found to have collapsed due to erosion by surface water flow during rainy season.	Other	Damage of wall
5	Congomah Village Council (Blackburn Lanes)	A slope failure was confirmed on the side of the road.	Other	Damage of Embankment
6	Les Mariannes Community Centre (Road area)	There are a few slope failures and a landslide in this site. The slope at the roadside collapsed during heavy rain in 2010 and a section of road was washed away. Since then, a retaining wall has been constructed and the site is currently stable.	Slope	Slope failure
7	Les Mariannes Community Centre (Resident area)	There appeared to be bank erosion on the left bank above the bridge.	Other	Stream erosion
8	L'Eau Bouillie	The cracks have been spotted on the road surface due to the deterioration of bearing capacity of the roadbed. However, the cracks have been repaired.	Other	Damage of Embankment
9	Chitrakoot, Vallee des Pretres	A clear landslide was confirmed. A landslide was reported to have damaged houses and a school after heavy rain in 2005. Drilling investigation and monitoring have been carried out, but not sufficiently. No countermeasures have been implemented. Therefore, a detailed investigation and monitoring are necessary while the countermeasures are expected in future.	Slope	Landslide
10	Vallee Pitot (near Eidgah)	Lately, housing developments are growing rapidly in this area. A landslide boundary of 35m x 20m was clearly detected. Several houses have been damaged and some cracks were observed. The situation of the damage was also reported in the newspaper.	Slope	Landslide
11	Le Pouce Street	Insufficient surface drainage means rain water concentrates in low area and erodes roads and houses in its path. Damage is negligible at present, although the maintenance of the surface drainage will be necessary.	Other	Stream erosion
12	Justice Street (near Kalimata Mandir)	An embankment has been constructed to build up the road, which caused an adjacent retaining wall to be pushed out and deformed. Insufficient surface drainage causing accumulation of groundwater could also be a factor causing this deformation.	Other	Damage of wall
13	Mgr. Leen Street and nearby vicinity, La Butte	The landslide of La Butte occurred in 1986, and many houses and a school were damaged. As for this landslide, countermeasures were carried out in 1998, therefore further investigation of the landslide is unnecessary. However, Port Louis City wants to continue the monitoring on this landslide in the future.	Slope	Landslide
14	Pouce Stream	Every side of the channel is covered by concrete. The water level rises until the upper edge of the channel and erodes beyond this point in the rainy season. The gabion has been set up at the lower part of slope at the channel and no damage has been reported yet. However, the deterioration of the concrete wall is remarkable and the extension of the wall height will be necessary. Therefore, further investigation and countermeasures are advisable.	Other	Stream erosion
15	Old Moka Road, Camp Chapelon	The landslide topography is not clear, but five houses and two retaining walls were damaged while the spring water was spotted in two places. There are two possible causes of this, creep transformation of weak surface soil or a shallow landslide. Therefore, landslide investigation and monitoring are necessary while the countermeasures are expected in future.	Slope	Landslide
16	Boulevard Victoria, Montague Coupe	The gabion was installed on the cut-slope when the road was constructed. There is no record of damage for this site but the angle of the wall is steep. Therefore, the monitoring of this wall is advisable.	Other	Damage of wall
17	Pailles: (i) access road to Les Guibies and along motorway, near flyover bridge	The slope failure has been spotted along the cut-slope (5m height) at the roadside of highway. The surface of the cut-slope has weathered, and it is eroded by rain.	Slope	Slope failure
18	Pailles: (ii) access road Morcellement des Aloes	Insufficient drainage is causing erosion at the base of the water tank. Immediate remedial work is needed.	Other	Stream erosion

	from Avenue M. Leal (on hillside)			
19	Pailles: (iii) Soreze region	Falling rocks at the upper slope and shallow slope failure at the middle and lower slope occurred in an area of housing. There is only slight damage for the time being, although shallow slope failure and cracks have been confirmed.	Slope	Slope failure
20	Plaine Champagne Road, opposite "Musee Touche Dubois"	Retaining walls have been constructed as countermeasures where the slope failure has been confirmed. It is currently stable, although there were a few cracks spotted in the retaining walls which are believed to be due to substandard construction.	Slope	Slope failure
21	Chamarel: (i) near Restaurant Le Chamarel	Cracks in the road shoulder have occurred due to a lack of bearing capacity. It is caused by insufficient soil compaction.	Other	Damage of Embankment
22	Chamarel: (ii) Roadside	Deformation of the road has been confirmed at the shoulder of the road due to a lack of bearing capacity. The embankment of stone masonry wall and retaining wall were constructed but it is insufficient.	Other	Damage of Embankment
23	Grande Riviere Noire Village Hall	The crack at the base of village hall area and edge of concrete basketball court has been confirmed. However, the surrounding structures are not affected, therefore it is considered unlikely this damaged was caused by landslides. Rather it is likely to be caused by lack of bearing capacity of the ground or a problem with the structure itself.	Other	Damage of house
24	Baie du Cap: (i) Near St Francois d'Assise Church	A debris flow has occurred in the past and a block wall has since been constructed. Also, small surface failures have been observed frequently in this area.	Slope	Debris flow
25	Baie du Cap: (ii) Maconde Region	A new road was built to reduce the damage from rock falls. However, rock falls and small rock failures are also a frequent occurrence along the new road. The rocks are weathered, and there is a high possibility of rock fall in future.	Slope	Rock fall
26	Riviere des Anguilles, near the bridge	There are many houses built on the cliff here. The cliff is weathered severely and stream erosion occurs frequently. Therefore, the house will need to be relocated.	Other	Stream erosion
27	Quatre Soeurs, Marie Jeanne, Jhummah Street, Old Grand Port	Landslide activity has been confirmed at the Quatre Soeurs area where many houses have been damaged. The groundwater level at the lower part of the landslide is high and is causing instability in the landslide. Drilling investigation and monitoring have been carried out, but not sufficiently. Further investigation and monitoring are necessary while the countermeasures are expected in future.	Slope	Landslide
28	Bambous Virieux, Rajiv Gandhi Street (near Bhavauy House), Impasse Bholoa	Slope failure was confirmed at the backyard of the house. No damage on the house was reported although the soil of the slope approached near the house. A retaining wall has been constructed independently.	Slope	Slope failure
29	Cave in at Union Park, Rose Belle	A cavity (4m x 4m x 3m depth) due to land subsidence was observed in the residential area. No damage was caused to the houses and the cavity was filled in with soil. Similar situation was confirmed nearby.	Other	cavern
30	Trou-AUX-Cerfs	The slope failure in the crater of the volcano occurred during heavy rainfall in 2005. The possibility of slope failure on the rear side is low. However, the slope failure on both sides can be expected.	Slope	Slope failure
31	River Bank at Cite L'Oiseau	Bank erosion and flooding is common in the rainy season when the river water level rises. There are more damage on the left side of the riverbank due to the strong collision of water. However, past damage has been restored by constructing a retaining wall.	Other	Stream erosion
32	Louis de Rochecouste (Riviere Seche)	The bank erosion and flood are common in the rainy season. The base of the houses has been eroded and the retaining walls of the houses are inclined.	Other	Stream erosion
33	Piper Morcellement Piat	The bank erosion and flood are remarkable in the rainy season. However, the past damage has been restored by constructing the retaining wall.	Other	Stream erosion
34	Candos Hill at Lall Bahadoor Shastri and Mahatma Gandhi Avenues	A clear landslide site was confirmed at the backyard of the house. The landslide topography and slope are clear while the spring water has been observed. The scale of this landslide is small (40m x 35m) and no house on the landslide area. Only slight crack has been confirmed on the retaining wall.	Slope	Landslide
35	Cavernous Area at Mgr Leen Avenue and Bassin	A cavity was reported during the house construction but it was filled with concrete. There is no further danger at this site.	Other	cavern
36	Morcellement Hermitage, Coromandel	At this slope, slope failure occurred in 2010, and a road was destroyed. After a retaining wall was made as a countermeasure, large-scale slope failures have not been found. However, the stone blocks from on top of the retaining wall have fallen down. This is likely caused by the ground behind the retaining wall sinking due to lack of compaction of the backfilling soil.	Slope	Slope failure
37	Montee S, GRNW	Weathered outcrops were detected on both sides of the bank. The erosion is remarkable in the rainy season.	Other	Stream erosion

Reference

[1] Cruden, D. M., 1991, A Simple Definition of a Landslide. Bulletin of the International Association of Engineering Geology, No. 43, pp. 27-29.

[2] Varnes, D. J., 1996, Landslide Types and Processes, in Turner, A. K., and R.L. Schuster, Landslides: Investigation and Mitigation, Transportation Research Board Special Report 247, National Research Council, Washington, D.C.: National Academy Press.

[3] Varnes, D. J., 1978, Slope movement 43. types and processes, in Schuster, R.L., and Krizek, R.J., eds., Landslides—Analysis and control: Transportation Research Board Special Report 176, National Research Council, Washington, D.C., pp. 11-23.

[4] Public Works Research Institute, 2004, Manual for Highway Earthworks in Japan Technical Memorandum of Public Works Research Institute, No. 3924-2

[5] Varnes, D. J., 1978, Slope movement 43. types and processes, in Schuster, R.L., and Krizek, R.J., eds., Landslides—Analysis and control: Transportation Research Board Special Report 176, National Research Council, Washington, D.C., pp. 11-23.

[6] Fujiwara, A., 1979, Analysis and Prevention-Plan of Landslides, Rikoh Pub. Co., Tokyo. (in Japanese)

1 Introduction

"Procedure Manual for Landslide (hereinafter the Manual)" has been prepared for the implementation of landslide countermeasures from both viewpoints of "hard" and "soft" (physical and non-physical) countermeasures.

The Manual covers what type and how to implement countermeasures to mitigate the disaster risk of landslides, and provides the Ministry of Public Infrastructure and Land Transport (MPI) support in conducting survey/analysis and planning/design/construction of countermeasures for landslides by themselves. It is also formulated based on the review of the early warning/evacuation procedures and the Planning Policy Guidance (PPG).

The scope of application of the Manual is indicated in the following figure and the detailed contents of it are in the table on the following page.

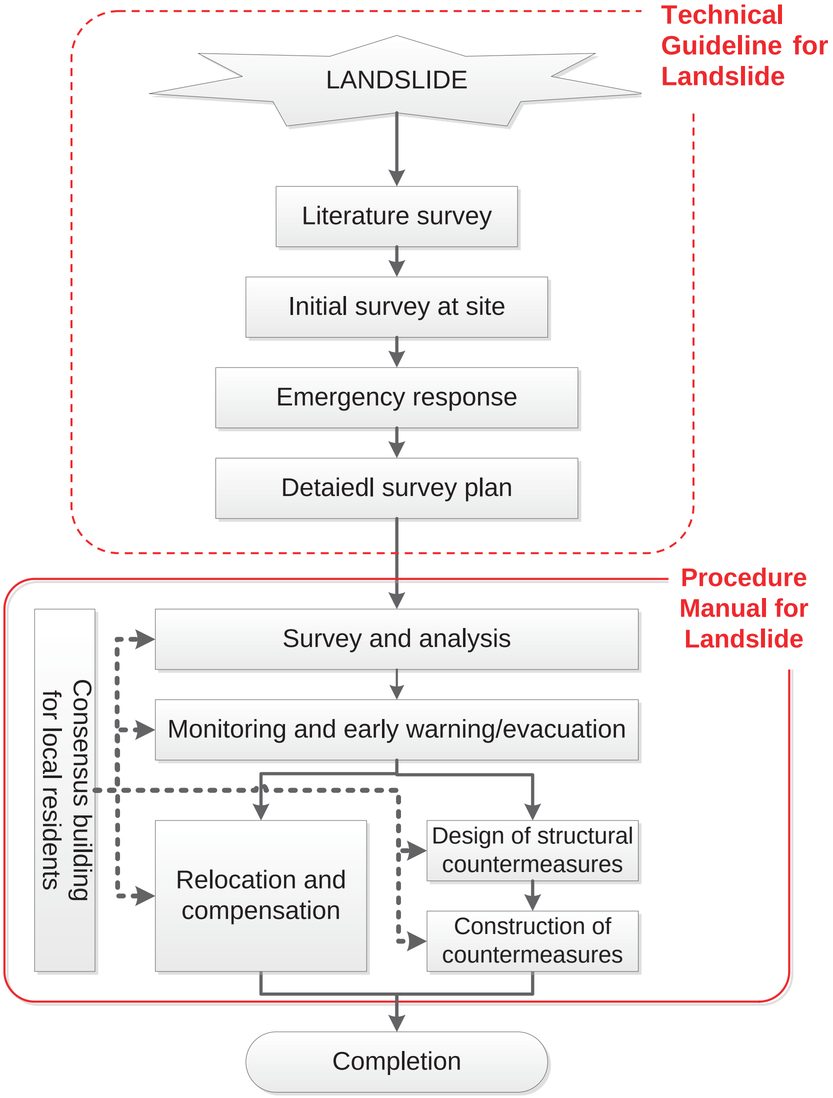


Figure 1.1.1 The Scope of Application of the Procedure Manual for Landslide (source: JET)

Table 1.1.1 The Contents of the Procedure Manual for Landslides (source: JET)

Cp.	Title	Contents
1	Introduction	- Contents, purpose, flow of the Manual - Application, composition of the Manual - Outline of landslides in Mauritius
2	Survey and analysis	- Topographic survey, aerial photo identification, field reconnaissance, drilling, geophysical exploration, laboratory test, water analysis - Installation of monitoring devices - Monitoring system and information transmission - Cross section, active areas/blocks, direction of movement, volume, discussion of slip surfaces - Basic factors and triggers - Stability analysis and safety factors
3	Landslide warning system	- Setting of thresholds for warning and evacuation - Responsibilities and roles of related organizations - Evacuation procedures
4	Relocation support and compensation	- Existing laws (PPG etc.) and planning schemes - Caution areas and special caution areas - Deciding on areas for relocation/compensation - Implementation of relocation - Implementation of compensation
5	Consensus building for local residents	- Significance of consensus building - Flow of consensus building - When and what to be built for local residents - How to deal with opinions and comments from residents
6	Design of structural countermeasures	- Basics of design of landslide countermeasures - Design of restraint works and control works - Environmental and social considerations
7	Construction of structural countermeasures	- Construction plan - Checkpoints for construction - Construction and supervision
8	Initial survey and emergency response	[Excerpt of "Technical Guideline for Initial Survey"]

The Landslide Management Unit (LMU) of MPI should renew appropriately the contents of the Manual after the Project for more usable and rational based on the case examples and issues in Mauritius.

2 Survey and Analysis

2.1 Landslide Survey

The survey and analysis should be implemented to establish preventive plans and to carry out the countermeasures for landslides.

The survey is generally divided into two stages: a preliminary survey and a main survey.

The preliminary survey is composed of the collection of documents, data and maps and the searching and analysis of related literature. Landslides often occur at specific locations under certain topographic and geologic conditions. Therefore, it is important to utilise existing data (history of the problem, records of restoration work, and data review) in order to understand the topography, geology, and properties of similar landslides. It is also important to understand their relationship with meteorological factors, period of activity, existence of any warning signs, groundwater conditions, chronologic topographic change or erosion by rivers, earthquakes, and other factors which may relate to the slope deformation surrounding the investigation site area prior to performing a detailed investigation.

The main survey for landslides primarily consists of a topographic survey, aerial photographic interpretation, a site reconnaissance, a drilling survey, geophysical exploration, laboratory soil testing, water quality testing and landslide monitoring. In the case an emergency response is needed for a moving landslide, only minimal surveys such as a slip surface survey and groundwater survey may be carried out to decide the emergency countermeasure beforehand. The analysis of landslides, such as preparation of geological cross sections, establishment of the safety factor and stability analysis should be implemented based on the specific results of the above mentioned surveys.

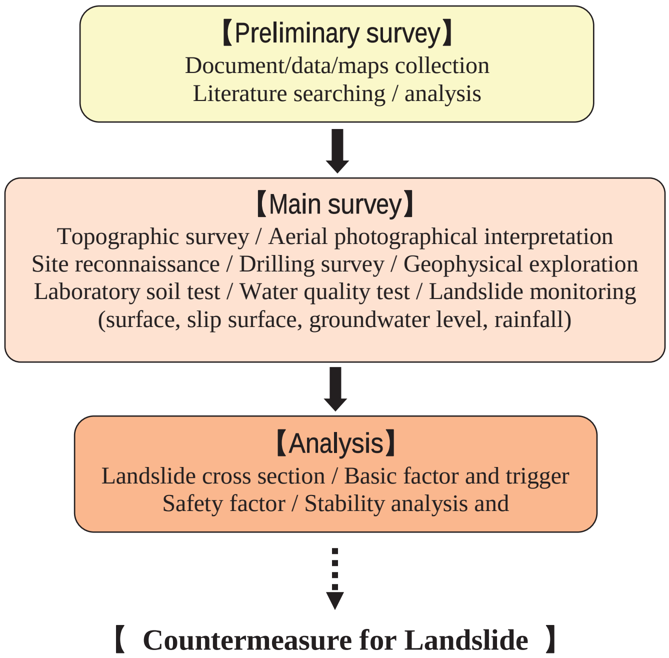


Table 2.1.1 Flowchart Summarizing Survey/Analysis for Landslide (source: JET)

2.1.1 Topographic Survey

The topographic survey is carried out to obtain the landslide plane map (1/1,000 or 1/500) and landslide cross sections, and the results of the topographic survey are used as basic data for the landslide investigation, analysis and countermeasures design.

a. Preparation Work

In the preparation work for the topographical survey, existing documents and maps concerned with the target landslide are collected (See Table 2.1.2), and a preliminary site investigation over a wide-ranging area including the landslide area is performed to establish a surveying plan. It is necessary for the landslide activity area to be confirmed by a preliminary site investigation, and the rough-coordinates of the landslide should be provided using Handy-GPS.

Table 2.1.2 The Information Collected by Preparation Work

1	Existing documents / data / reports
2	Information from inhabitants and the local authority
3	Existing maps (scale of about 1/25,000)
4	Aerial photographs / Available images such as "Google Earth"

b. Surveying Plan

Based on the results of the preparation work, the area of the plane survey should be established in an area that sufficiently covers the landslide activity area, and the cross section survey should be planned so that it is carried out on the main line of the target landslide. In addition, in the case that the landslide area is large and/or consisting of multiple landslides, several cross-section lines (sub-lines) should be established.

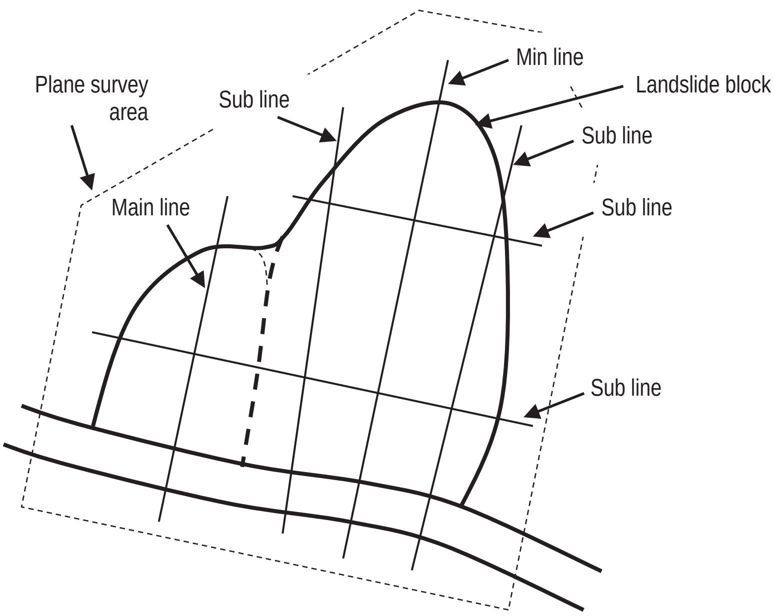


Figure 2.1.1 Image of Topographic Survey Plan (source: JET)

c. Survey Method

c.1 Coordinates and Elevation

For all the survey works, the coordinates and elevation shall be connected with the national coordinate grid system and the elevation of national benchmarks installed by ***the Ministry of Housing and Lands***.

c.2 Installation of Control Points

Prior to commencement of the survey works, the control point(s) on the site should be installed, and be connected to the nearest existing control points. Because a landslide moves, the control point(s) should be installed outside landslide activity areas.

c.3 Cross-section Survey

Each cross-section station shall be established by the survey plan and the coordinates and elevation shall be measured from the nearest control point(s). Observations shall be conducted along the section-line at 2m intervals and at every topographically changing point and artificial structure. The cross-section scale shall be as follows:

Drawing Scale: Vertical 1:100, Horizontal 1:100

c.4 Plane Survey

The plane survey shall be carried out to measure the elevation and distance of various spots using a total station or equivalent equipment such as a GPS. The location and position of cross-section lines and bench marks with a number or name shall be plotted on the topographic maps. The topographic maps by plane survey shall be drawn as follows:

Draw Scale: 1:500 , Contour Interval : 1 meter

In the case of the plane survey of the landslide, the characteristic landslide landforms (i.e. cracks, spring water, scarp or cliff, pond or swamp, etc) must be drawn. (Figure 2.1.2)

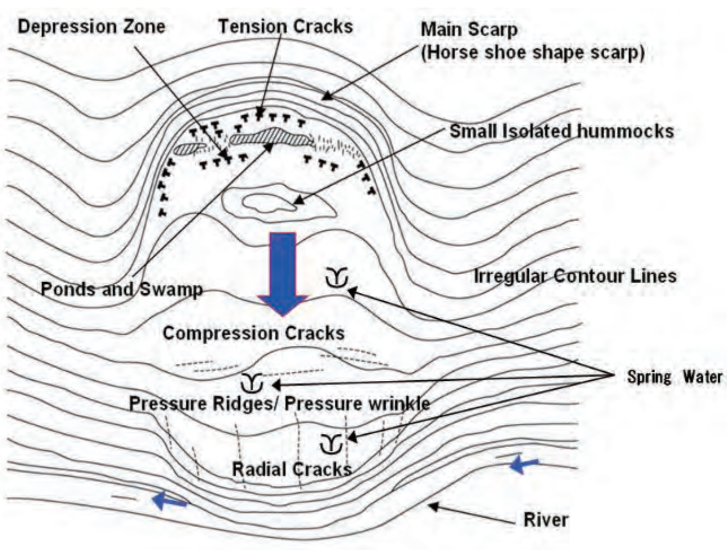


Figure 2.1.2 Schematic Diagram of Landslide Landforms (source: JET)

2.1.2 Photo Interpretation of Landslide Areas

Most active landslides appear in landslide prone areas, and are accompanied by certain micro landforms. Therefore landslide survey generally starts with topographical and geo-morphological survey. Geomorphologic survey begins with topographic map reading and aerial photo interpretation, then leads to identifying the landslides and potential landslide areas. The results shall be compiled into the landslide distribution maps. Then, the map shall be used for the field survey. The field survey is conducted to grasp the geo-morphology, geology, soil condition, surface anomalies and slip surface on site. Then the form and depth of the landslide shall be estimated.

Aerial photograph interpretation is therefore an essential part of landslide investigation.

a. Naked-eye Stereoscopy Method

A stereoscope is generally used for aerial photograph interpretation, but confirmation can also be carried out with the naked eye. Place a piece of paper standing perpendicular in between the two topography photographs and look at the photos from directly above. If you stare at the photos as if you were staring into the distance and let the image get fuzzy, both images will move to the centre and superimpose, enabling you to see a 3D topographical image. Training your eyes in this way to be able to master naked-eye stereoscopy can take anywhere from 2 or 3 hours to one week.

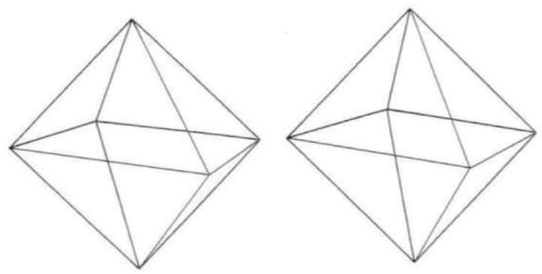


Figure 2.1.3 Practice Figures for Stereoscopy

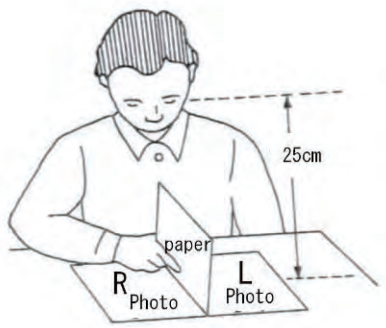


Figure 2.1.4 Stereoscopy Training
(source: JET)

b. Topographical Interpretation with a Stereoscope

By using a stereoscope, stereo images can be seen from stereotype photographs. From the stereo image, micro landforms caused by landslide movement and geo-morphological features can be identified.

By aerial photograph interpretation, wide range landforms and chronology of the landforms, land use, and vegetation can be observed and the relations between those features and landslide can be considered. Using a large-scale aerial photograph, like 1: 10,000 or larger, micro landforms formed by landslide movement can be interpreted.

Photo 2.1.1 Aerial Photograph Interpretation (source: JET)

Aerial photograph interpretation is a useful method of finding several causes of landslides over a wide area and from a broad perspective.

c. Outline of Structure of Landslide Topography

The legends of aerial photograph interpretation are shown in Figure 2.1.6. The result of aerial photograph interpretation summarized as a photo-map of landslide is shown in Figure 2.1.7.

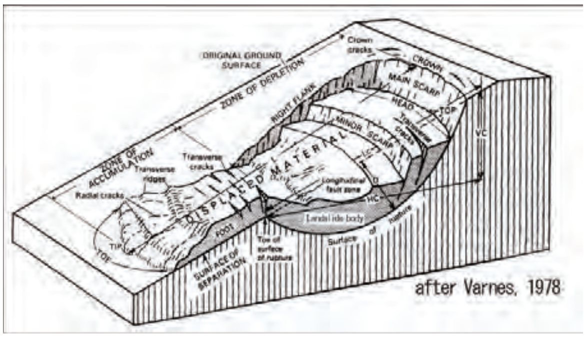


Figure 2.1.5 Block Diagram of Idealized Complex Earth slide to Earth Flow (after Varnes,1978)[1]

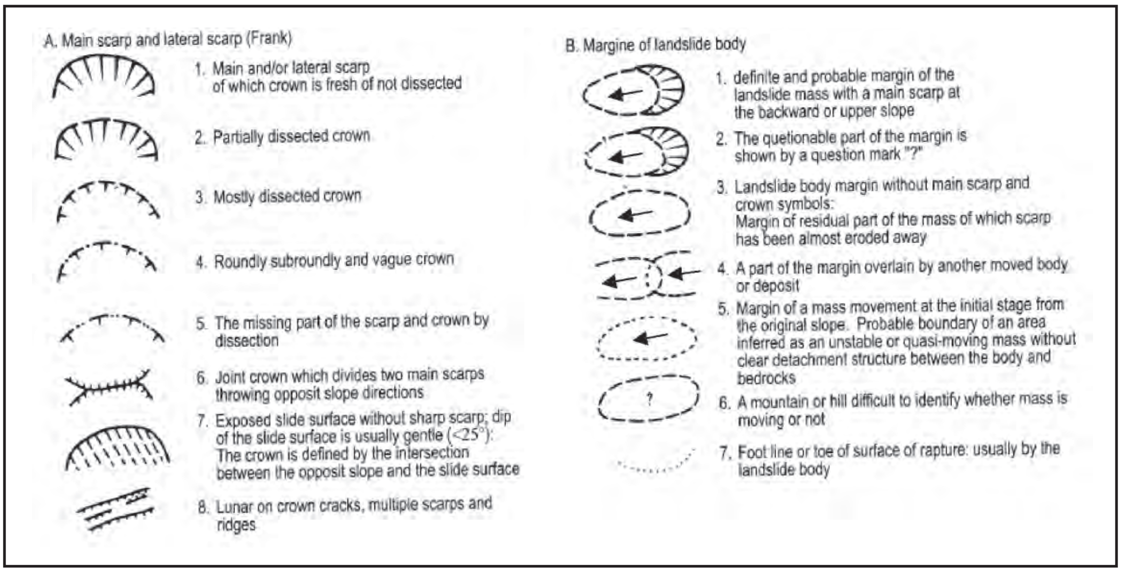


Figure 2.1.6 Legend of Aerial Photograph Interpretation[2]

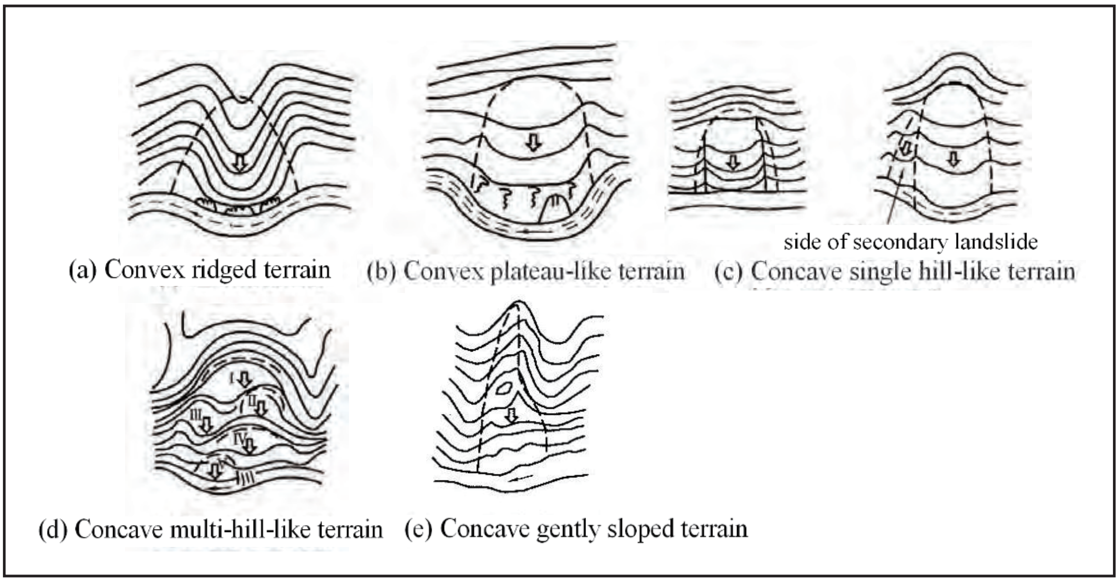


Figure 2.1.7 Sample of the Aerial Photo Interpretation[3]

2.1.3 Field investigation on Landslide Area

After understanding the overall geo-morphologic features of the spatial extent of the landslide, and providing a trace of landslide movement on the ground surface, a detailed field investigation plan can be developed. The field investigation can provide more detailed information such as geological structures, causes of landslide, and possible landslides for the assessment.

Field investigation shall be conducted following analysis of existing data and interpreting of aerial photograph. Field investigation should include areas where aerial photograph is not available or unclear. It also shall include areas where it could help in understanding the particular geo-morphological features and characteristics. Items of field investigation are shown in Table 2.1.3.

Table 2.1.3 Items of Field Investigation[4]

Geo-morphological information	Landslide landform	Distribution and orientation of main scarps, Distribution and orientation of steps and cracks Distribution and orientation of mounds and depressions
	Slope failure landform	Type and size of slope failure Old slope failures
	Erosion landform	Gullies and rills, erosion by stream
Geological information	Surface geology	Materials, hardness, thickness of soil, stability
	Base rock	Rock type, facies, hardness, age of rock, metamorphism, weathering
	Structure	Distribution and orientation of faults and fracture, strike and dip, joint,
Hydrological information	Surface water	Stream water channel, pond, swamp
	Ground water	Spring water
History of activities and damage	Activities	Date of the movement, rate of the movement,
	Damage	Date and period of damage, objects, type of damage, countermeasure work
Susceptibility of landslide		Activity, Influence on the objects, for example road and houses, risk evaluation

a. Landslide Area and Hazard Area

It is preferable to get topographical maps and aerial/satellite photos around the landslide area for the identification of the site. Macro scope observation is vital for the estimation of the landslide area and hazard area. Broad view from hill/upland is useful for the macro scope observation. Based on the observation results with the broad view and surface anomalies such as cracks and heaving/subsidence on landslide, landslide active area and hazard area should be estimated.

b. Geological Feature and Structure

The following observations for landslide soil are useful to estimate the age and the mechanism of landslide as well as the geological feature.

- Constituent materials and their grain size
- Lithology and configuration of gravels
- Colour of clay

The observation for the base rock at outcrop around landslide helps to understand the geology, stratigraphy, dip and strike and to grasp geological structure that is related to landslide mechanism. In case there are faults or fracture zones around the targeted landslide, it is very important to consider whether they are involved with the landslide or not, by clarifying the distribution of the faults or fracture zones.

c. Geo-morphological Structure Based on Small Deformation and Wide Range Landform

The observation and the analysis for small deformation and wide range landform on topography is useful to estimate the geological structure, because the topography is influenced with the geological structure. Characteristic deformation and landform for landslide is shown in Figure 2.1.8.

d. Groundwater

Ponds, swamps, wetlands and spring water points should be checked around and in landslide areas. The relationship between the amount of rainfall and the water level in pond/swamp or the amount of spring water helps surveyors to understand the situation of groundwater. More specifically, surveyors are able to estimate whether water in landslide area is attributed with shallow or deep groundwater level.

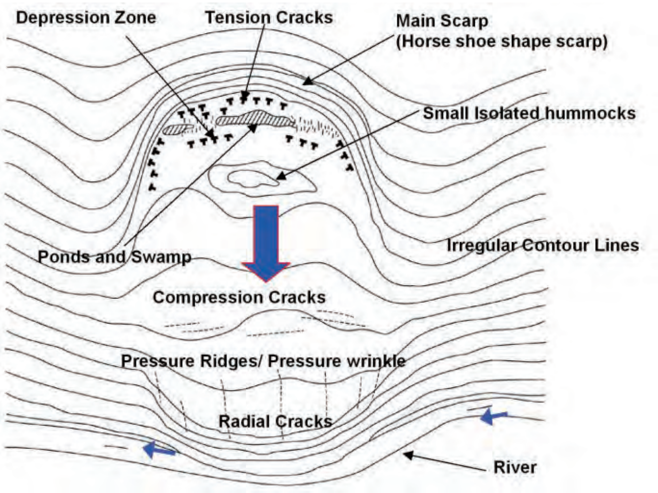


Figure 2.1.8 Schematic Diagram of Landslide Landforms[5]

e. Landslide Mechanism

Mechanism and movement direction of landslides are able to be estimated by the following points to be checked;

- Small deformation and surface anomaly such as steps, subsidence or heaving
- Main scarp, tension crack, compression crack, radial crack, lateral crack
- Deformation of artificial building such as house or stone wall
- Anomaly of vegetation such as bending of tree root.

f. Trigger of Landslide

Trigger of landslides should be estimated with the weather conditions when the landslide occurred and the mechanism of landslide. In general, triggers of landslide are as follows:

f.1 Rainfall

- Continuous rainfall in long term (especially rainy season)
- Heavy rainfall in short term (especially rainy season)

f.2 Surface Condition

- Erosion by river/lake on bottom of landslide
- Anomaly (change) of flow of surface water or groundwater

f.3 Artificial Causes

- Cut earth on bottom of landslide
- Earth fill on top of landslide
- Poor drainage works for surface water or groundwater

However, many landslides do not have a single trigger but combined/multiple triggers. Therefore, deliberate determination is needed when the trigger is discussed.

g. Potential Landslide Movement

Although it is not easy to predict the movement of potential landslide only by geological reconnaissance beforehand, the geological characteristics help surveyors to understand the movement. For example, a landslide related to “rock mass” is controlled by rock cracks or bedding plane. While a landslide located above a river or lake is controlled by erosion of them, a landslide that includes lots of water is prone to be like a debris flow. Therefore, potential landslide movement is able to be predicted based on detailed observation at site.

h. Risk Evaluation

In case landslides could occur based on previous surveys above, it is necessary to estimate degree of risk and area where the landslide has influence, and to implement appropriate measurements such as an establishment of early warning/evacuation system immediately. To estimate the risk and the hazard area, detailed observation is useful.

The hazard area is not only a debris deposited area but potential area where the landslide could be expanded toward upper land. It is also necessary to consider secondary movement of the deposited debris of the initial landslide by heavy rainfall. In case that debris of the landslide gets into a river, the debris flows away with much water, and the damage and the risk area would be expanded (Figure 2.1.9).

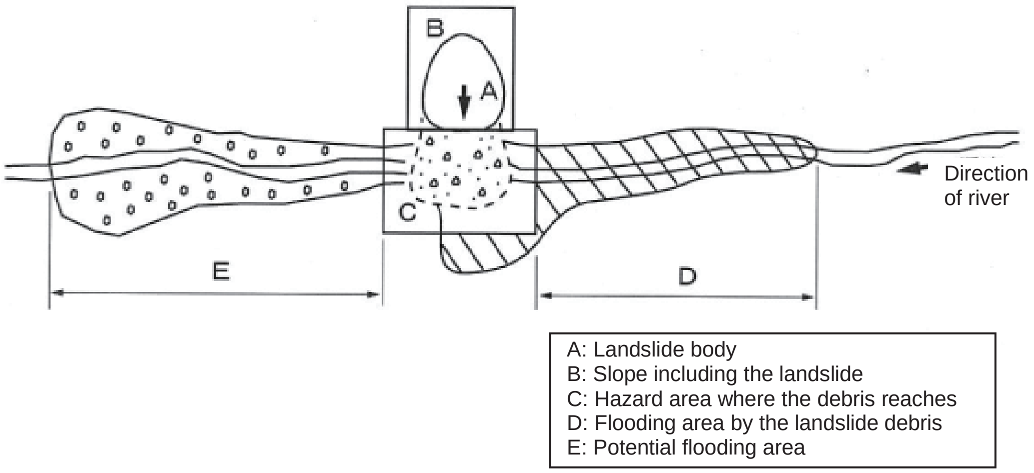


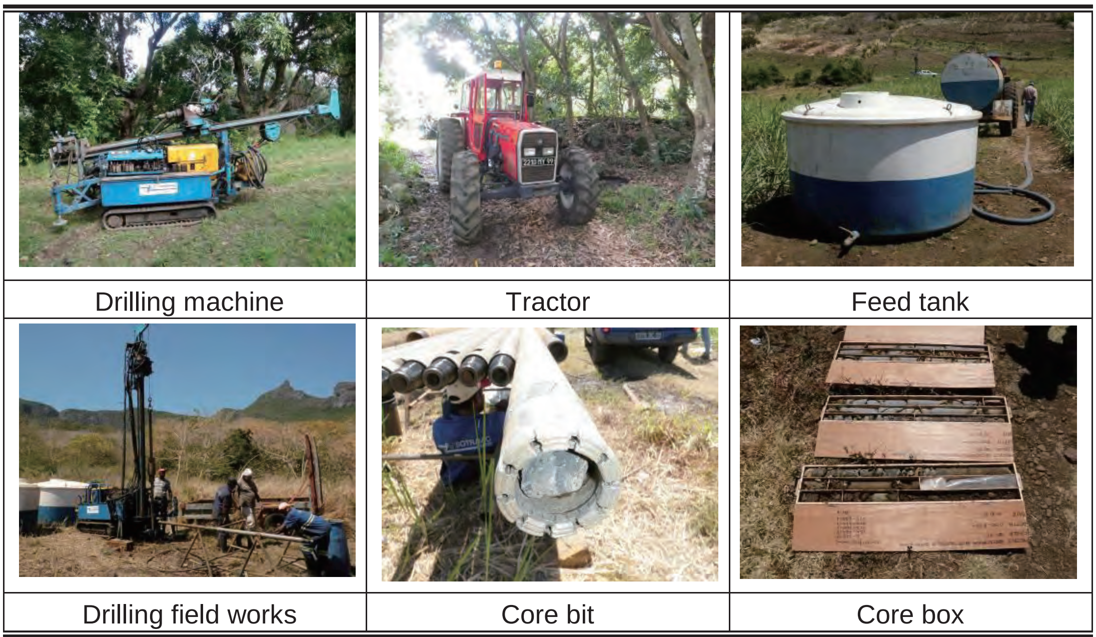
Figure 2.1.9 An Example of Landslide Risk Evaluation[6]

i. Emergency Response

In the case where the mechanisms of landslides are determined based on previous surveys above and a landslide could happen in the near future, emergency responses such as construction of gabion walls, establishment of early warning/evacuation and monitoring system would be needed.

2.1.4 Drilling Survey

Drilling survey is implemented to sample soil in the ground orderly and to clarify the geology, geological structure and slip surface. In principal, all-core sampling should be conducted. The diameter of the borehole depends on subsequent surveys and loggings such as inclinometer, extensometer, groundwater level meter or ground water logging etc.



Drilling machine | Tractor | Feed tank
Drilling field works | Core bit | Core box

Figure 2.1.10 Field Photograph for the Core Drilling Procedures (source: JET)

a. Location and quantity of drilling survey

Borehole points should be located along the centre line of the direction of landslide movement, at least 3 boreholes in the landslide area and 1 borehole in upper part of the landslide at 30-50m interval in principal (Figure 2.1.11). Additional boreholes should be implemented along sub lines which run parallel at 30-50m intervals when the landslide area is larger. In case that landslide area is small, 2 or more drillings are needed along the movement direction to understand the geology of the area. When there are faults, fracture zones and/or complicated structures in the landslide area, supplemental drillings are preferable.

Each drilling should be enough length to get to base rock which is stable. In general, 3 to 5m of the stable base rock should be confirmed at drilling core sample. In case that rock in the moving mass and stable base rock may be similar lithology, it is preferable to drill one borehole deeper to identify real stable rocks.

Based on drilling survey at early stage, location and quantity of the subsequent drilling plan can be rearranged. For larger scale landslide, it takes longer time (more than 1 year), the drilling plan can be rearranged and rescheduled a lot by mechanism analysis.

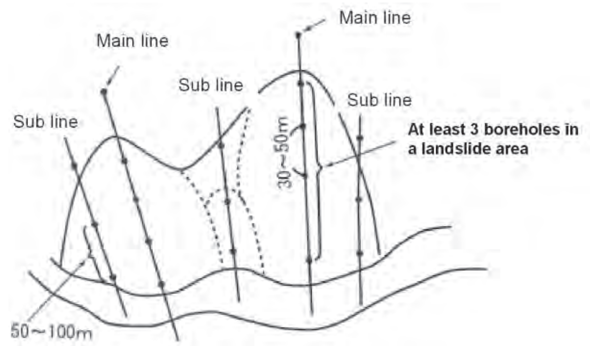


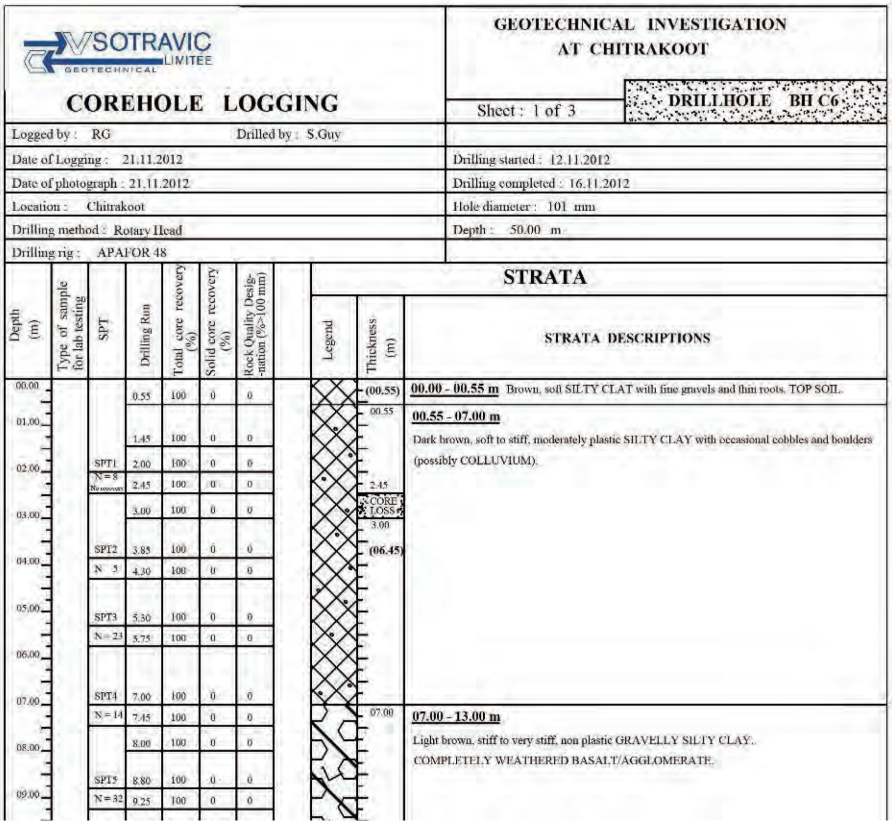
Figure 2.1.11 Location and Quantity of Drilling Survey[7]

b. Organizing Results

The drilling survey results are used to study the geological features, the soil properties, and slip surface of the landslide area, and findings observed concerning necessary items are summarized in a drilling log. The main points of the drilling log are observation of the geological features and soil properties according to the core, description of conditions during drilling, borehole groundwater level during and at the end of drilling, and the core recovery rate.

In the base rock survey, the degree of weathering, angle of cracks, angles of bedding plane and schistosity plane, and number of cracks are observed, and their vertical distribution is also described.

An experienced technician should carry out the observation of geology, soil properties, and slip plane. Furthermore, core photographs are taken as a record of the slip plane and landslide mass properties.



SOTRAVIC LIMITEE GEOTECHNICAL

COREHOLE LOGGING

GEOTECHNICAL INVESTIGATION AT CHITRAKOOT

Sheet : 1 of 3

DRILLHOLE BH C6

Logged by : RG Drilled by : S.Guy	
Date of Logging : 21.11.2012	Drilling started : 12.11.2012
Date of photograph : 21.11.2012	Drilling completed : 16.11.2012
Location : Chitrakoot	Hole diameter : 101 mm
Drilling method : Rotary Head	Depth : 50.00 m
Drilling rig : APAFOR 48	

STRATA

Depth (m)	Type of sample for lab testing	SPT	Drilling Run	Total core recovery (%)	Solid core recovery (%)	Rock Quality Designation (%>100 mm)
00.00			0.55	100	0	0
01.00			1.45	100	0	0
02.00		SPT1	2.00	100	0	0
		N = 8 No recovery	2.45	100	0	0
03.00			3.00	100	0	0
		SPT2	3.85	100	0	0
04.00		N 5	4.30	100	0	0
05.00		SPT3	5.30	100	0	0
		N = 23	5.75	100	0	0
06.00						
07.00		SPT4	7.00	100	0	0
		N = 14	7.45	100	0	0
08.00			8.00	100	0	0
		SPT5	8.80	100	0	0
09.00		N = 32	9.25	100	0	0

Legend	Thickness (m)	STRATA DESCRIPTIONS
	(00.55)	00.00 - 00.55 m Brown, soft SILTY CLAT with fine gravels and thin roots. TOP SOIL.
	00.55 / 2.45 / CORE LOSS / 3.00 / (06.45)	00.55 - 07.00 m Dark brown, soft to stiff, moderately plastic SILTY CLAY with occasional cobbles and boulders (possibly COLLUVIUM).
	07.00	07.00 - 13.00 m Light brown, stiff to very stiff, non plastic GRAVELLY SILTY CLAY. COMPLETELY WEATHERED BASALT/AGGLOMERATE.

Figure 2.1.12 Drilling Log (Chitrakoot BH-C6) (source: JET)

Photo 2.1.2 Core Sample Photo (Chitrakoot BH-C6) (source: JET)

2.1.5 Geophysical Exploration

Geophysical exploration applied to landslide investigation is primarily seismic exploration and electrical prospecting. These geophysical explorations are conducted together with the drilling survey in order to understand the scale and shape of the landslide moving bed and groundwater availability. In recent years, analysis accuracy has improved due to advances in exploration and analysis technologies, and cases of geophysical exploration application have increased. Nevertheless, because there are cases in which effective results cannot be obtained due to the geological structure of the landslide or the availability of groundwater, it is necessary to understand the application limits.

a. Seismic Exploration

In seismic exploration, an elastic wave (seismic wave) is artificially generated near the ground surface, and the refracted wave that refracts at the underground stratum boundary and returns is observed with a measuring device installed on the surface. It is an exploration method for determining underground velocity structure such as the thickness of each stratum and the velocity that the seismic wave transmits (seismic wave velocity).

Seismic exploration is applied to geological structures where the seismic velocity increases with depth. Furthermore, the stratum boundaries in seismic exploration are the boundaries between stratum whose velocity differs, and not necessarily the same as the geological stratum boundaries.

a.1 Principles

The principles of seismic exploration are shown below. Several receivers are lined up on the ground surface and a vibration is generated at a shaking point on an extension of those receivers and the waveforms observed on each of the geophones. The longitudinal wave, called the P-wave, is first to arrive, and then the vibrations such as the transverse wave called the S-wave, the wave reflected from the stratum boundary, and the surface wave that is transmitted near the surface arrive later. The time at which the first wave motion arrives is called the initial motion. When the time the vibration was triggered at the shaking point is recorded at the signal called the shot mark, it is possible to measure the time from the shot mark to the initial motion, or the time it takes the P-wave to transmit (travel-time). As in (c), a travel-time curve is drawn with the distance between the shaking point and the geophone on the horizontal axis, taking the travel-time on the vertical axis and plotting the initial motion travel-time. One can determine the velocity and thickness of the strata from the straight line that is the slope of the reciprocal of velocity V1 (direct wave) and the straight line that is the slope of the reciprocal of velocity V2 (refracted wave).

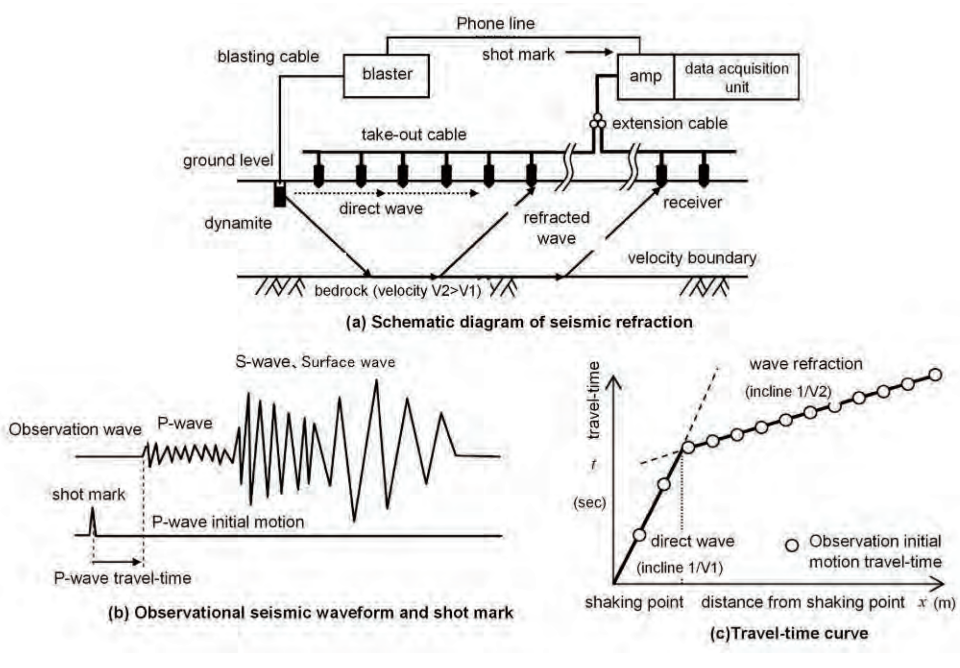


Figure 2.1.13 Principles of Elastic Wave Exploration[8]

a.2 Traverse Line Positioning

The traverse line is generally set on the main traverse line of the landslide, but in the case of a large-scale landslide, it is sometimes positioned on the transversal line perpendicular to the sub-traverse line or the main traverse line. The length of the traverse line is about 5～10 times the survey depth, and if this cannot be ensured, a remote shaking point is prepared on the extension of the traverse line.

a.3 Receiving Points and Shaking Points

When the survey depth is shallow, the spacing between receiving points is generally 5m, and 10m when it is deep. The shaking points are planned at spaces of 30-60m. In rough terrain, the shaking points in the vicinity of the terrain's transition point, such as the top of a ridge or the bottom of a ravine can be moved or added to improve analysis accuracy.

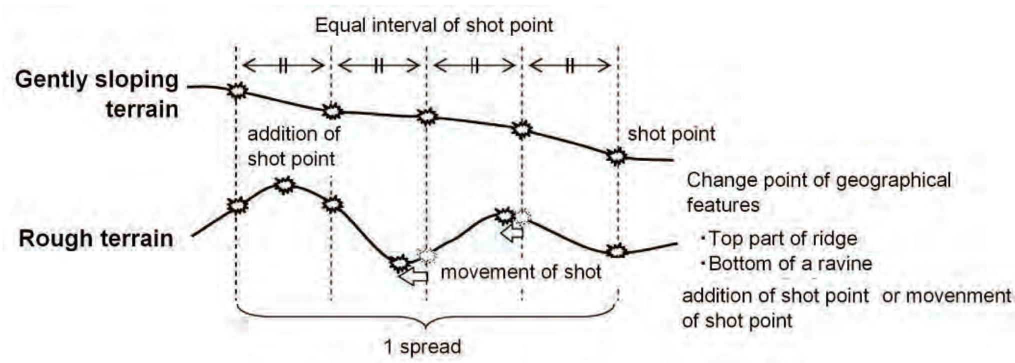


Figure 2.1.14 Arrangement of Shot Points considering Geographical Features[9]

a.4 Method of Shaking

Explosives are generally used, but in cases where the survey depth is shallow or when there are houses in the vicinity, hammering is used to induce shaking. With hammering, the wave that has been propagated at a receiving point far from the shaking point is weak, and in many cases the waveform is not clear. Therefore, shaking is repeated at the same shaking point and accuracy is improved by superimposing the data collected at the observation points. This is called the stacking method, and shaking is generally repeated about 2～10 times.

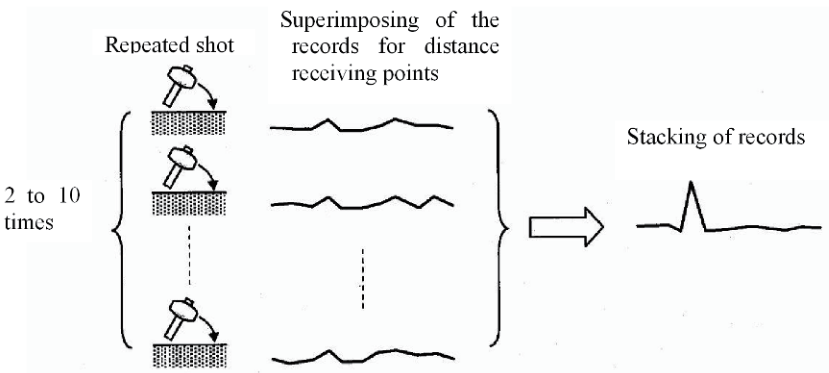


Figure 2.1.15 Stacking of Monitored Records by Generating Wave Source through Non-explosive Agent[10]

a.5 Data Processing and Analysis

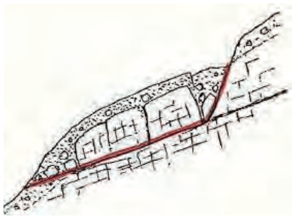
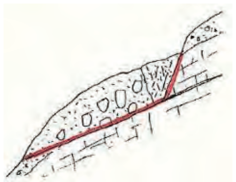
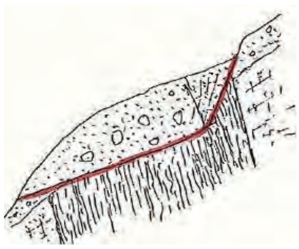
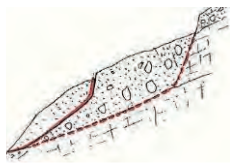
Data processing and analysis can be conducted with commercially available software. However, there are many aspects, such as reading the initial travel-time and checking and adjustment of the travel-time curve, that require experience. It is necessary to make sure there are no inconsistencies by placing the travel-time curve and the topographical cross-sections side by side. Analysis procedures have conventionally employed the Hagiwara method, but in recent years analysis by tomography is often conducted. Tomography is able to perceive complicated structures with severe changes in the transverse direction, which the Hagiwara method cannot grasp.

a.6 Interpretation of the Analysis Results

In seismic exploration, the depth and thickness of the velocity layer, geological factors, and the position and distribution of the low velocity layer are interpreted from the velocity structure obtained by analysis. Generally, it is essential to interpret the information in a comprehensive manner together with aerial photograph interpretation results, surface survey results, drilling survey results, etc.

The table below shows typical landslide structures and examples of geophysical exploration applications. Depending on differences in geological structures, application of geophysical exploration may be difficult.

Table 2.1.4 Typical Landslide Structures and Examples of Geophysical Exploration Applications[11]

Cross Section of Geological Structure	Description	Seismic Exploration	Electrical Prospecting
A 	When the landslide mass is one integrated block and there is no difference between it and the fresh base rock conditions of the immobile layer.	Determining the boundary between the two is difficult.	The head of the collapse zone is the low resistivity section. If the slip surface is thick, detection is possible with low resistivity.
B 	When a clear difference can be seen between the landslide mass and the base rock conditions of the immobile layer.	Detection of boundary between landslide mass and immobile layer is possible.	Detection of boundary between landslide mass and immobile layer is possible.
C 	When both the landslide mass and base rock conditions of the immobile layer are poor and there is no difference in state of core.	Detection of boundary between landslide mass and immobile layer is difficult. However, it is possible if there are differences in the degree of agglomeration or density.	Detection of boundary between landslide mass and immobile layer is difficult.
D 	When part of a large-scale landslide is active.	Sampling of a large-scale landslide is possible. Demarcation of the landslide mass and the immobile layer in an active landslide is difficult.	

b. Electrical Prospecting

Electrical prospecting is an exploration method to investigate the state of subsurface structure focusing on differences in resistivity, permittivity or electrochemical properties of the material constituting the strata, and measuring the potential generated by artificial or natural factors.

In landslide surveys, the resistivity method is usually used to measure potential generated when an electric current is artificially sent into the ground. In the resistivity method, the basic principle is to measure using 4 electrodes (2 current electrodes, 2 potential electrodes).

b.1 Principles of Electrical Prospecting

The resistivity method is a method of prospecting to determine the resistivity structure of the ground. It makes use of the fact that resistivity of the strata changes according to the kinds of mineral particles that constitute the stratum, the porosity between mineral particles, the amount and quality of water in the gaps, soil temperature and other factors. By examining the obtained resistivity structure and values together with results from the drilling survey and other surveys, the subsurface geological structure and ground conditions are interpreted.

The fundamental principles of the resistivity method are shown in the diagram to the right. Various prospecting methods are put into practical use according to the way in which the 4 electrodes are arranged. Two-dimensional resistivity prospecting is usually adopted in landslide surveys. By changing the spacing of the electrodes, it is possible to determine the ground resistivity distribution.

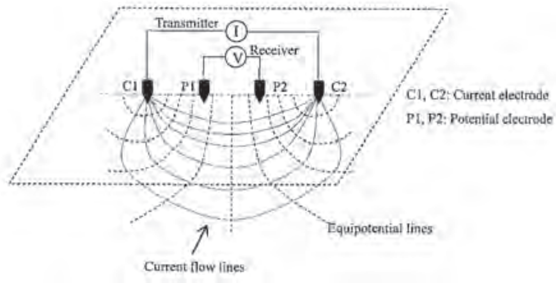


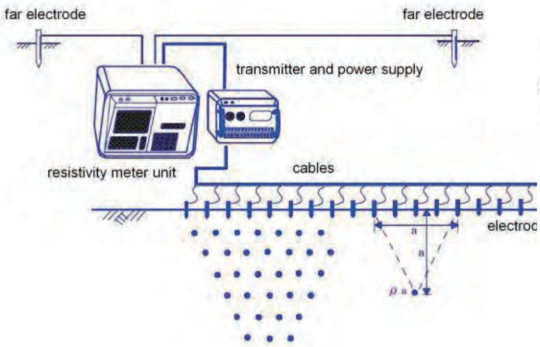
Figure 2.1.16 Schematic diagram of the resistivity method[12]

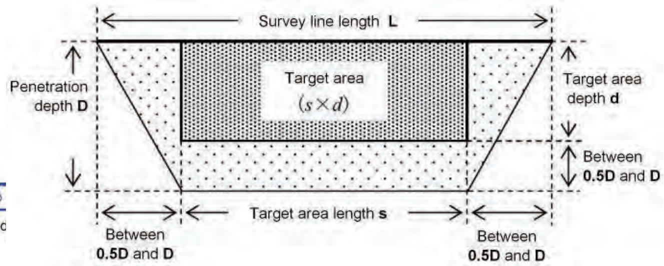
b.2 Survey Line Positioning

Survey lines shall be set in the same position as those in seismic exploration. In two-dimensional resistivity prospecting, many electrodes are arranged at regular intervals along the ground surface survey line, and measuring is conducted while sequentially changing the combination of electrodes.

b.3 Penetration Depth and Survey Line Length

The penetration depth and survey line length are closely related to each other, and the plan should fully cover the prospecting target area. The guideline for the maximum penetration depth is about 1.5-2 times the target area depth. In addition, because the depth at which penetration is possible becomes shallower at the ends of the survey line, care should be taken that it is sufficient.



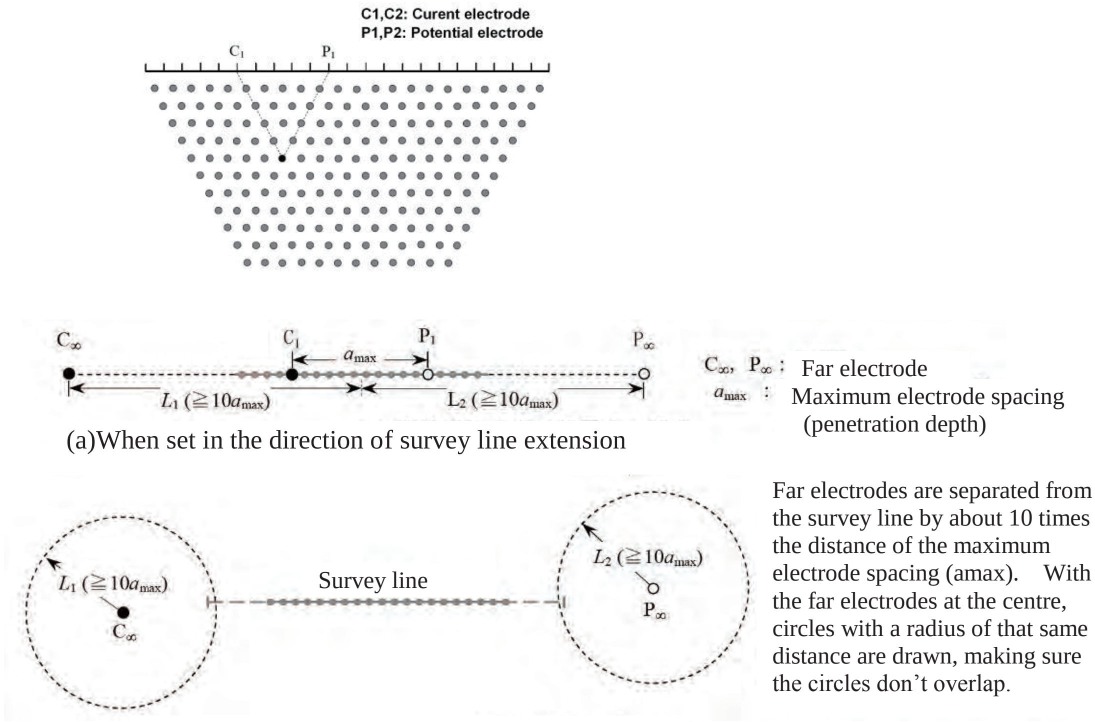


(a)Pattern diagrams of measurement (b) Design concept of a survey line for two-dimensional prospecting described by Shima et .al.

Figure 2.1.17 Measurement Schematic Diagram for Two-dimensional Resistivity Prospecting and Survey Area Setting Method [13]

b.4 Electrode Positioning

The positioning of electrodes is decided upon taking into account such factors as survey purpose, penetration depth, and geographical and geological conditions, but a two-pole arrangement (pole-pole array) is generally used in most cases. In a pole-pole array, the far electrode is positioned at a distance of more than about 10 times the distance of the maximum electrode spacing (penetration depth) away from the survey line.



(a)When set in the direction of survey line extension

(b) Philosophy of far electrode positioning

Figure 2.1.18 Two-dimensional Prospecting (pole-pole array)[14]

b.5 Data Processing and Analysis

Data processing consists mainly of creating measurement position diagrams, editing of measurement results, and creating apparent resistivity cross-sectional diagrams. The principles are clear for analysis, and it is carried out using commercially available software.

The selection of an analysis method, the creation of an analysis model, and the setting of analysis parameters should be adequately conducted, and a resistivity distribution map created.

b.6 Interpretation of Analysis Results

In two-dimensional resistivity prospecting, a qualitative evaluation is conducted on ground conditions and geological structure based on the resistivity structure obtained through analysis. Furthermore, combined with other survey and test results, a quantitative evaluation of the ground is also carried out in conjunction with the qualitative evaluation. An example of interpretation of two-dimensional resistivity analysis results is shown below.

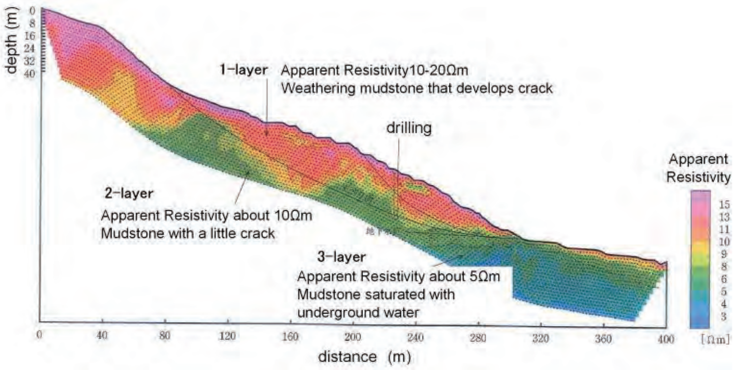


Figure 2.1.19 Sample of Interpretation of a Diagram of Two-dimensional Prospecting Results[15]

2.1.6 Laboratory Tests

Soil tests will be conducted when the ground investigation is conducted if required. There are basically two major soil tests, namely: 1) physical tests, and 2) dynamic tests. Both tests are performed to review stability of landslide, the mechanical tests are to grasp the strength property of slip surface, and the others to review the test results and grasp the general characteristics of the ground.

a. Physical Test

Physical tests are carried out in order to investigate the physical properties of the soil. The primary tests conducted in landslide investigation concern the slip surface and include the water content test, particle size test, liquidity and plasticity limit test, and bulk density test. Because it is possible to obtain results in a shorter period of time with physical tests than with mechanical tests, the slip surface can be determined by displaying the physical property values of the depth direction used in the drilling core in contrast to a histogram.

b. Box shear Test

In the box shear test of slip surface clay, a specimen is put into a shear box which is divided into upper and lower halves, and with the vertical stress loaded, one surface of the shear box is linearly subjected to horizontal displacement relative to the other and sheared. By conducting the test under different consolidation stresses for several specimens, it is possible to obtain strength parameters c and φ. A cyclic shear test device for determining residual strength has also been proposed and put into practical use.

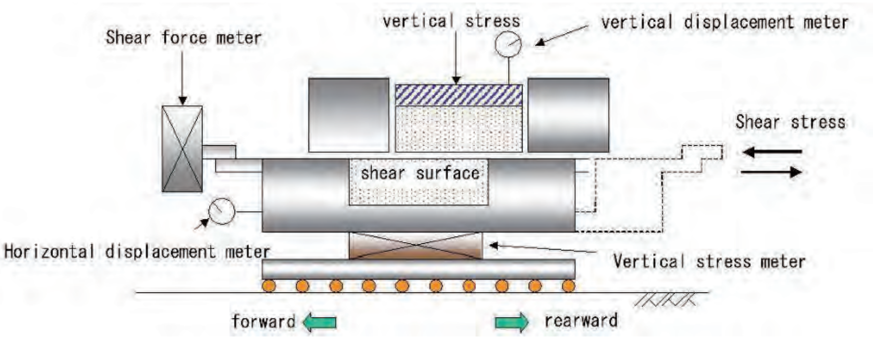


Figure 2.1.20 Structure of cyclic shear test device[16]

c. Tri-axial Shear Test

The tri-axial shear test is a test to indirectly determine the shear strength of a specimen by compressing it in a cylinder 3.5-5.0cm in diameter and 8.0-12.5cm in height. It is also possible to control the stress and pore pressure acting upon the specimen. The test has disadvantages as well, however, such as the specimen can only be compressed 15% of its height, and it is not possible to measure the residual strength.

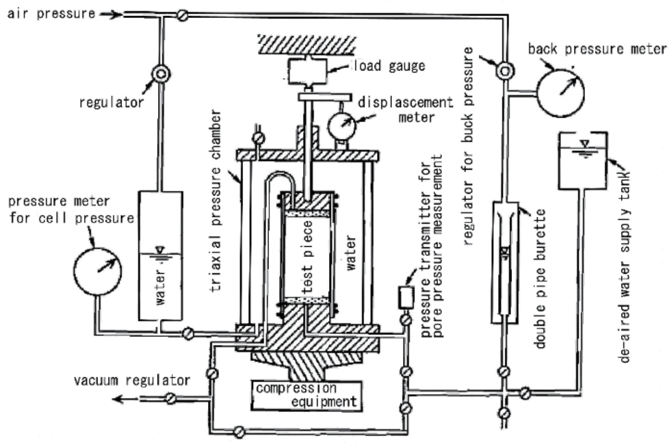


Figure 2.1.21 Structure of Tri-axial Shear Test Device[1]

d. Ring Shear Test

The specimen of slip surface clay for the ring shear test is made into a hollow ring shape, generally of an inner diameter of 6.0-10.0cm, an outer diameter of 10.0-20.0cm, and a height of 1.0-2.0cm. One of the features of this test is that since shearing progresses in the circumferential direction of the ring, it is possible to give an infinite shear displacement, and the repeatability of the strength properties (residual strength) in slip surface clay where large displacement has occurred is high.

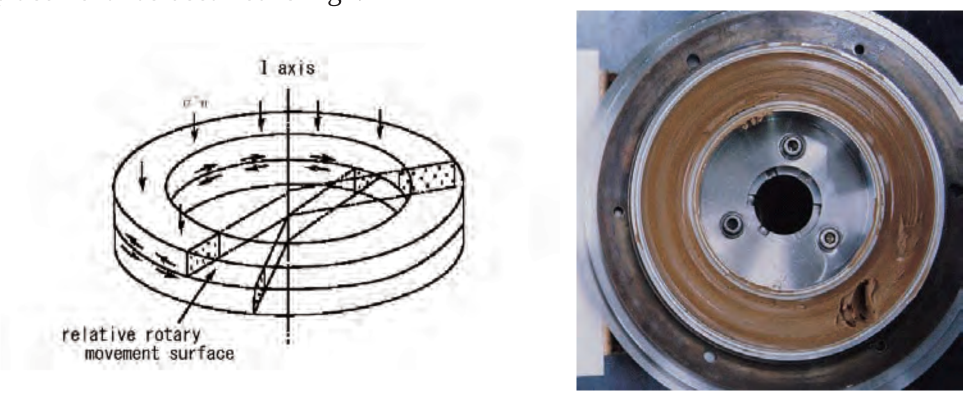


Figure 2.1.22 Schematic Diagram of Sample for Ring Shear Test[17]

e. Shear Strength of Slip Surface

Shear strength (of ground materials) decreases from its maximum shear strength to residual shear strength during the progress of shear deformation (Figure 2.1.23). The shear strength of landslides such as those that have clear topographic features and/or those that are active and recorded large movement, are considered to have similar strength of slip surface with residual strength as the slip surface experienced large movement in the past. There are several conditions of shear strength that may exist such as close to the fully softened strength or intermediate strength between fully softened and residual strength in accordance with the history of landslide movement.

The repeated single shear and/or ring shear strength tests are conducted for measuring the resistance shear strength of the slip surface. The original condition of the soil shall be maintained for the proper soil sampling.

For the purpose of dynamic test, 1) fixed piston sampler, and 2) multi-rod rotary sampler shall be used when test samples are taken from the drilling core so that the sample cores are not disturbed. The block samples from the surface of cut surface or large diameter wells are also considered a good sampling method for the test.

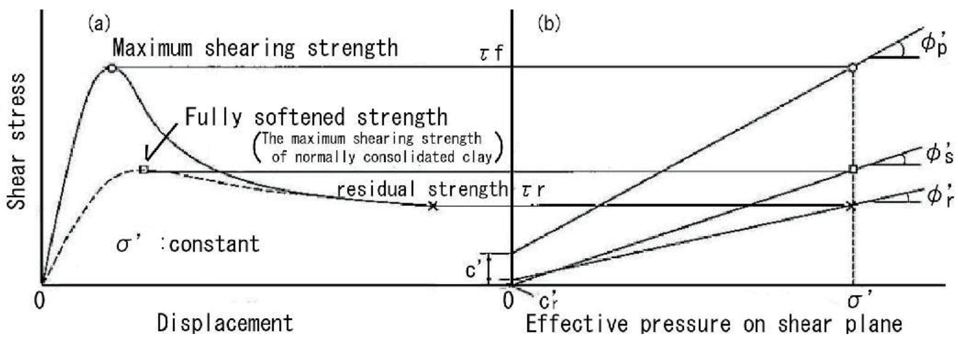


Figure 2.1.23 An Explanatory Drawing of Peak Strength and Residual Strength[18]

Table 2.1.5 Apply for Soil Strength and Mechanical Property Test[19]

Mechanical Property for Testing	Method		
	Triaxial Shear Test	Box Shear Test	Ring Shear Test
Residual Strength*1	△*2	○*3	○
Fully Softened Strength*4	○	○	△
Peak Strength of Undisturbed Sample	○	△	△

○: Most appropriate test method　　△: Appropriate test method

*1: Residual strength is little affected by the stress history of the clay and can be determined with sufficient accuracy from a disturbed sample. Therefore, either disturbed or undisturbed samples may be used.
*2: To measure the peak strength, the triaxial shear test is generally more precise than the box shear test and the ring shear test. However, special machinery is needed to measure the residual strength with this method, so box shear test and ring shear test results prevail for testing with typical apparatuses.
*3: In order to determine the residual strength with the box shear test, a cyclic shear test should be conducted. At this time, the quality of test results with this method and those with the ring shear test have not been determined, so under present conditions, results from both methods are given the same precedence.
*4: After reaching the maximum shearing strength of the slurry sample and the peak strength of the mass sample, this is the strength at which increase in water content and change in volumetric strain is no longer seen due to dilatancy. The fully softened strength is used in analysis of primary landslides.

f. Selection of Testing apparatus by Sample Type and Strength

Table 2.1.6 shows the selection of testing apparatus by type of strength according to the test sample.

Peak strength is usually determined with the tri-axial shear test using an undisturbed sample, but it can also be obtained with the cyclic shear test and ring shear test. Fully softened strength is usually determined by the tri-axial shear test using a slurry sample, but it can also be obtained by the cyclic shear test and ring shear test using either slurry or undisturbed samples. Residual strength cannot be measured by the tri-axial shear test, and it is necessary to measure it using either the cyclic shear test or the ring shear test. The state of the slip surface strength can be even more realistically reproduced in the samples containing the slip surface, but one drawback is that their setting to the testing apparatuses is difficult. The shear tests are determined from factors such as the state of activity of the landslide and implemented.

Table 2.1.6 Selection of Test Method for Kind of Sample and Expected Strength Item[20]

Strength / Specimen	Peak strength	Perfect softening strength	Residual strength	Testing apparatus
Undisturbed	*O.* $\overline{\text{CU}}$ *Δ CD, III* *Δ. CD. III*	*x* *Δ. CD. II* *Δ. CD. II*	*x* *O. CD I* *O. CD. I*	Tri-axial compression Cyclic box shear Ring shear
Slurry	*x* *x* *x*	*O. .* $\overline{\text{CU}}$ *Δ. CD. III* *Δ. CD. III*	*x* *O. CD. I* *O. CD. I*	Tri-axial compression Cyclic box shear Ring shear
Precut	*x* *x* *x*	*x* *x* *x*	*x* *O. CD. II* *O. CD II*	Tri-axial compression Cyclic shear Ring shear
Specimen containing a piece of a sliding surface	*Δ. .* $\overline{\text{CU}}$ *or CD* *O. CD. II* *O. CD II*			Tri-axial compression Cyclic box shear Ring shear

Measured strength: O: Usable, Δ: Usable in some cases, X: Unusable

Test conditions : $\overline{\text{CU}}$ *: Consolidated and undrained test (to measure pore water pressure)*

CD: Consolidated and drained test

Shear displacement: I : It should be considerably large, II: It should be large, III: It can be small.

2.1.7 Water Quality Test

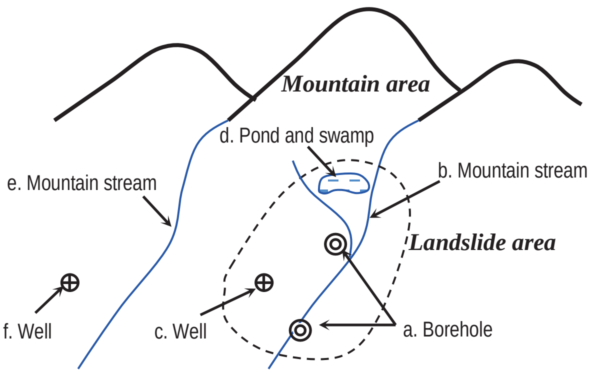
The purpose of water quality testing is to identify the distribution of groundwater in the survey area and to define the groundwater system (streak line) as part of the landslide survey.

a. Sampling

The water quality test samples will be collected in the landslide area and the neighbouring areas. The borehole samples will be collected using a water trap (bailer) lowered into the borehole. The existing water source (mountain stream, well, pond and swamp) samples will be collected using a plastic bucket. The samples should be immediately transferred to polyethylene bottles and taken back to the laboratory. In addition, at the time of sampling, the temperature of the water will be measured.

Table 2.1.7 Collection of Water Quality Test Samples (source: JET)

Landslide area	a. Borehole	Water trap (bailer)
	b. Mountain stream	Plastic bucket
	c. Well	Water trap (bailer)
	d. Pond and swamp	Plastic bucket
Neighbouring area	e. Mountain stream	Plastic bucket
	f. Well	Water trap (bailer)



The borehole sample is collected using a water trap (bailer), and immediately transferred to polyethylene bottles.

Figure 2.1.24 Location of the Sampling Points（source: JET）

b. Analysis

The water quality analysis items are the major dissolved components of ordinary groundwater and surface water. The analysis method for each item is as follows:

Table 2.1.8 Water Quality Analysis Method (source: JET)

Item		Unit	Method
Temperature	-	°C	Thermometer
Alkalinity	-	mg/l	Titration
Chloride ion	Cl	mg/l	Titration/Ion chromatography
Sulfate ion	SO4	mg/l	Spectrophotometry/Ion chromatography
Silicic acid (Silica)	SiO2	mg/l	Spectrophotometry
Calcium	Ca	mg/l	Titration (EDTA)/Atomic absorption spectrophotometry
Magnesium	Mg	mg/l	Titration (EDTA)/Atomic absorption spectrophotometry
Sodium	Na	mg/l	Atomic absorption spectrophotometry
Potassium	K	mg/l	Atomic absorption spectrophotometry

c. Groundwater Analysis Method by Water Quality Analysis

To ascertain the groundwater system (streak lines) by water quality analysis, the analysis results for major dissolved components will be arranged by graphic representation of the analysis values. More precisely, the water types will be classified using a trilinear diagram and a hexadiagram created, and changes in the water composition will be analysed.

c.1 Trilinear diagram

The purpose of a trilinear diagram is to identify the quantitative relationship of the major dissolved components using the molar equivalents (epm%) and to clarify classification of the water source type. In particular, the basic water categories will be shown on a rhombic coordinate diagram (called a key diagram), and will be generally classified into the domains Ⅰ-Ⅴ. The samples belonging to each domain are considered to have the following composition:

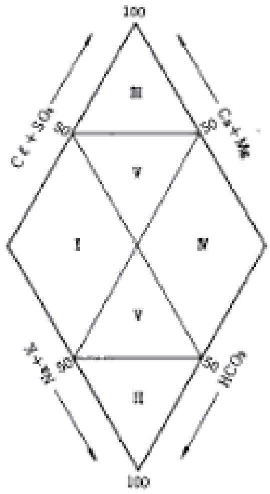


Figure 2.1.25 Example of the Rhombic Coordinate System of a Trilinear Diagram[21]

Table 2.1.9 Basic Water Categories, I-V (source: JET)

Domain No.	Domain name
Ⅰ	Alkaline-earth bicarbonate ($Ca(HCO_3)_2$)
Ⅱ	Alkali bicarbonate ($NaHCO_3$)
Ⅲ	Alkaline-earth non-carbonate ($CaSO_4$ or $CaCl_2$)
Ⅳ	Alkali non-carbonate (Na_2SO_4 or NaCl)
Ⅴ	Intermediate composition (in some cases, affiliated with II and III)

In general, SO42- is reduced by reduction action the longer the groundwater stagnates, while HCO3- increases, tending towards Ca2+<Na+ due to basic substitution. This change corresponds to the change from domain Ⅲ(Ⅴ) to Ⅰ to Ⅱ(Ⅴ). In the trilinear diagram, samples indicating a similar constitution are estimated to be from the same water system. By categorizing the collected groundwater using the trilinear diagram, it is possible to estimate to a certain degree the flow path and origin of the groundwater that causes landslides.

c.2 Hexadiagram

Taking the meq/L concentrations provided on each side of the vertical axis as the axis, the cations will be plotted on the left side and anions on the right side, and the point will be joined with straight lines to describe to the hexagonal-shaped diagram. The broad shape on each side of the hexadiagram shows a high concentration of the component while the narrower shape represents a lower concentration. Thus, the fact that there are many dissolved components in the groundwater means that the groundwater has been flowing for a long time.

In the hexadiagram, the samples of the similar shape isare estimated to be from the same water system. The shallow groundwater reacting for the rainfall conspicuously is often related to landslide activity. As for shallow groundwater, a common feature is the relatively small quantity of dissolved ions (particularly, SO4 and Cl) like rain water and river water.

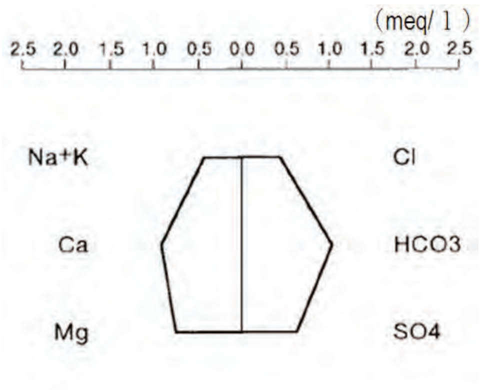


Figure 2.1.26 Example of Hexadiagram[22]

2.2 Landslide Monitoring

Monitoring is conducted to observe landslides and investigate the mechanisms behind them. When investigating landslide mechanisms, the main observations made are on the amount of movement, the circumstances of the slip surface, the change in groundwater level, and rainfall. Based on the results, the kind of rainfall events and details of the landslide (i.e. depth of the slip surface, the slide direction and the slipping velocity) are determined. In addition, monitoring makes landslide predictions possible. Therefore, it can prevent human injury or loss of life.

Landslide monitoring is divided into several types of observations in order to achieve the following goals: a) to measure the amount of landslide movement, b) to observing slip surfaces, c) to measure groundwater levels, and d) to monitor rainfall. Common observation equipment is shown below.

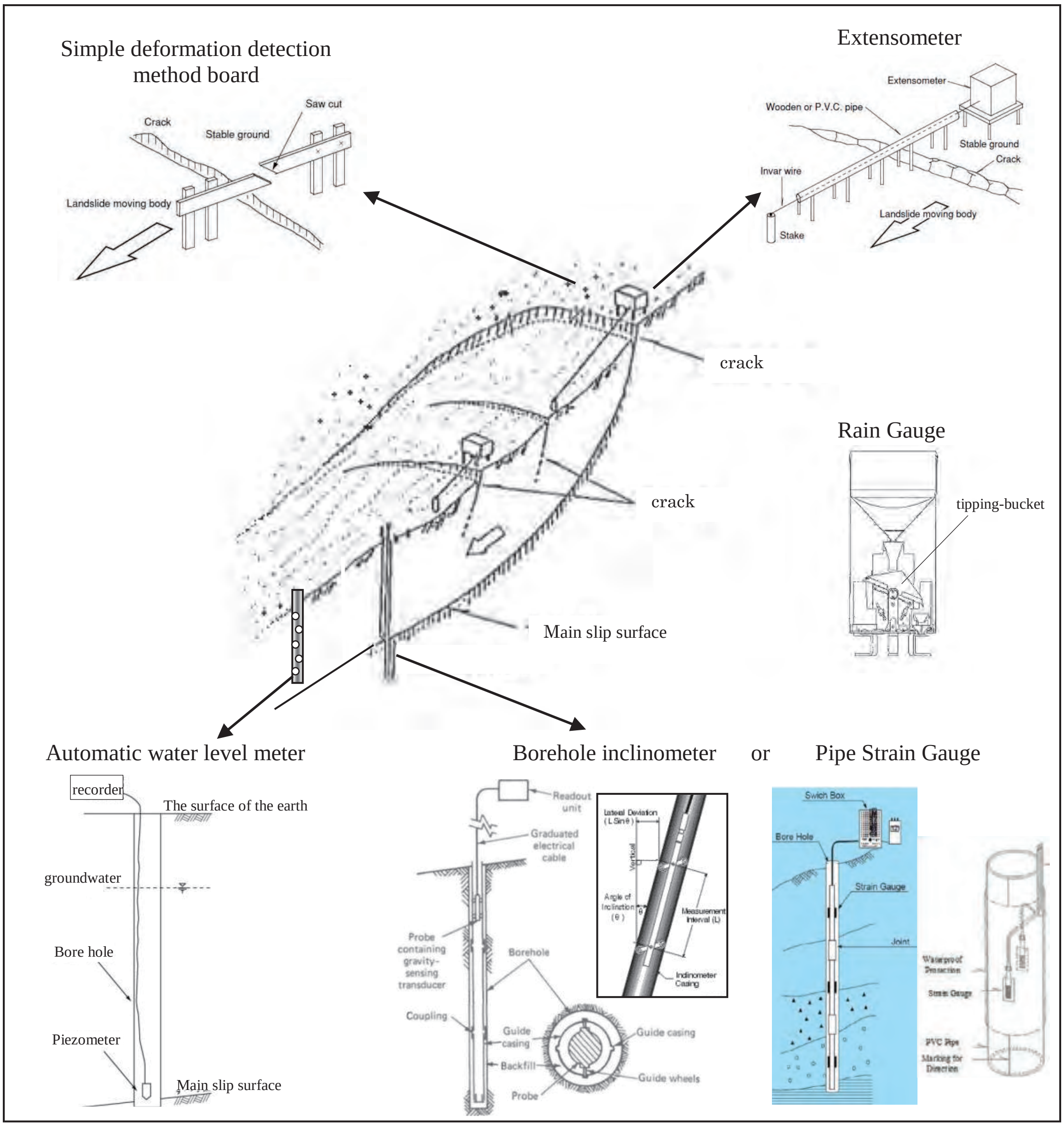
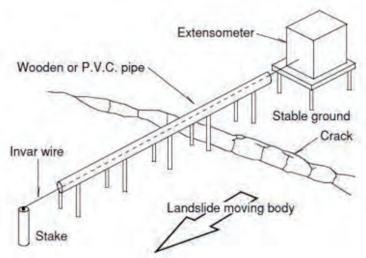
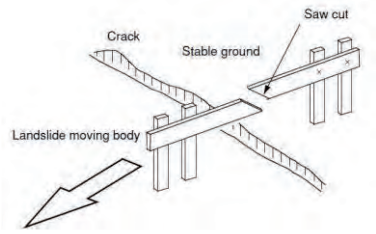
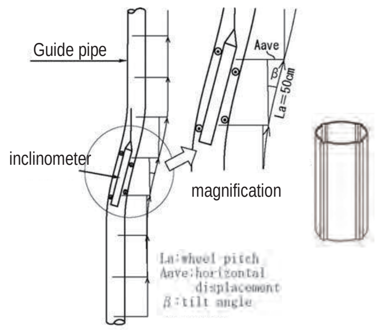
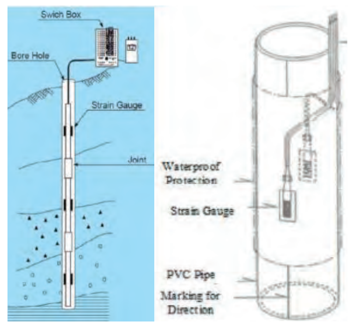
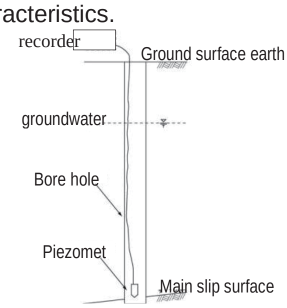
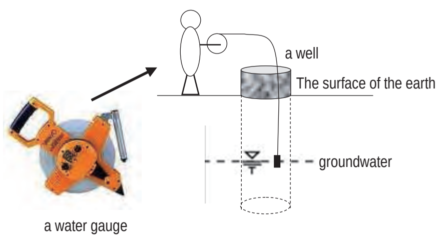
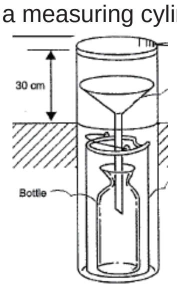
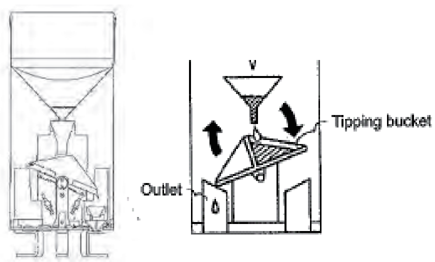


Figure 2.2.1 Setup Images of General Monitoring (source: JET)

Table 2.2.1 Observation Types and Equipment (source: JET)

<table>
<tr><th>Observation type</th><th colspan="2">Equipment</th></tr>
<tr><td>a. Measurement of the movement of a landslide</td><td><u>Extensometer</u>: measuring the amount of movement, recording data continuously

</td><td><u>Simple deformation detection board</u>: simplified extensometer, easy, and many can be set up

</td></tr>
<tr><td>b. Investigating the slip surface of a landslide</td><td><u>Borehole inclinometer</u>: measuring the amount of movement, investigating the position of a slip surface. It can NOT be used for active landslides

</td><td><u>Pipe Strain Gauge</u>: measuring the amount of a landslide movement and a position of a slip surface, records data continuously, is durable (1-2 years), It can be used for active landslides.

</td></tr>
<tr><td>c. Measuring groundwater level</td><td><u>Automatic water level meter</u>: investigating the distribution area, flowing directions and aquifer characteristics.

</td><td>※Usage confirmation of groundwater (as appropriate): conducting a measurement of groundwater level in the case of groundwater use.

</td></tr>
<tr><td>d. Monitoring rainfall</td><td>Standard rain gauge (reservoir-type): Rain is received in a reservoir and an observer measures the quantity accumulated over a certain period of time with a measuring cylinder.

</td><td><u>Tipping-bucket rain gauge</u>: If a certain amount of rainfall accumulates in a tipping-bucket, it will fall automatically.

</td></tr>
</table>

2.2.1 Installation of Monitoring Devices

a. Extensometer

An extensometer is a meter that is installed over cracks or gaps to measure movement and stress in an active sliding mass as shown below.

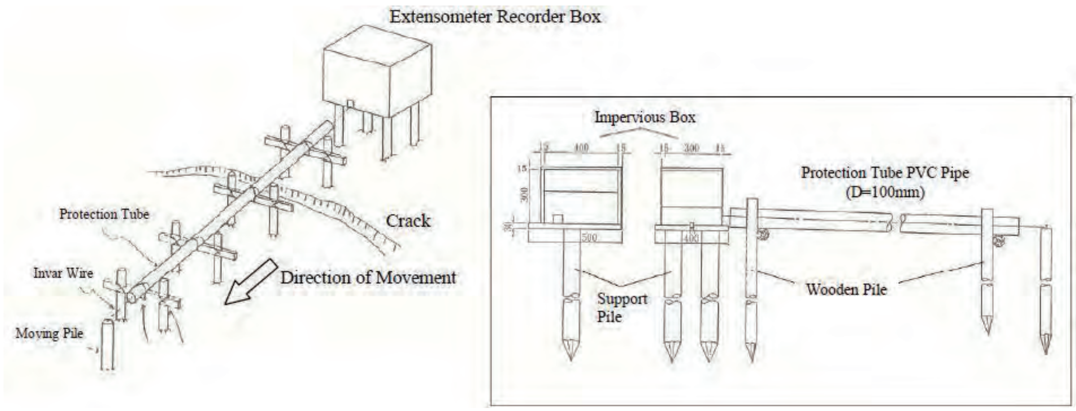


Figure 2.2.2 Extensometer Setting (source: JET)

Generally, a pile installed over firm ground and another pile installed over moving mass (on both sides of the crack) are connected with an invar wire. The function mechanism is that when the crack increases, stress in put on the invar wire connecting the piles and the meter and this stress is transmitted to the extensometer to be registered as digital information. (Invar: a kind of nickel iron alloy characterized by its low coefficient of thermal expansion).

When installing the extensometer, it is important to do this job in a way that the direction of the invar wire matches the movement direction. It is necessary to fix enough installation piles for the invar wire, and also support piles for the extensometer. The maximum length of the invar wire for each extensometer must be 20 meters, the right length being 10 meters.

Figure 2.2.3 Example of Extensometer (source: JET)

b. Borehole Inclinometer

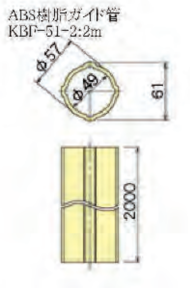
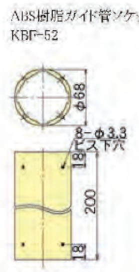
A borehole inclinometer investigates the position of a slip surface, and measures the amount of landslide movement on the slip surface. Installation of the guide pipe for the borehole inclinometer is performed as follows:

1) Excavate a borehole to the specified depth, and verify the depth of the bedrock.
2) Thoroughly embed the guide pipe in the bedrock. The concept is the same as for the pipe strain gauge.
3) One side of the guide pipe's guide groove is aligned in the anticipated direction of landslide movement, and the guide pipe is hooked up so that the guide grooves connect smoothly.

4) To avoid occurrence of initial deflection, do not push with excessive force when inserting the guide pipe. Insert the pipe so that it will extend straight and fix the bottom edge of the guide pipe securely to the bedrock.

Gradually fill the space around the guide pipe with sand, and install while compacting. Below is a description of the equipment used and photos of the installation process.

Table 2.2.2 Specifications of the Guide Pipe for the Borehole Inclinometer (source: JET)

Materials	Type	Materials	Type
 ABS Guide Pipe Length 2m	ABS Pipe KBF-51-2	 ABS Guide Pipe Socket	ABS Pipe Sockets KBF-52
 ABS Guide Pipe cap Bottom cap	ABS KBF-54-1	 ABS Guide pipe cap Top cap	ABS KBF-54-2


Special guide pipe


Insertion of the guide pipe


Setting of the guide pipe completed


Setting of the protection box

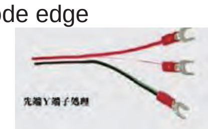
Photo 2.2.1 Installation of the Guide Pipe for the Borehole Inclinometer (source: JET)

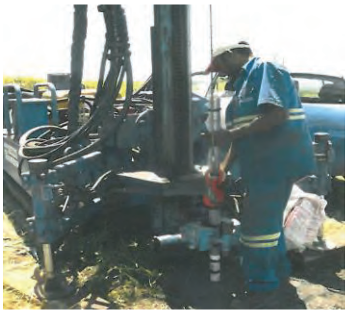
c. Pipe Strain Gauge

A pipe strain gauge is installed into the borehole to measure the amount of landslide movement and the position of the slip surface. The pipe strain gauge is installed according to the following procedures:

1) Excavate a borehole to the specified depth and insert the pipe strain gauge. At that time, match the alignment mark on the surface of the pipe with the direction of landslide movement, being careful the direction does not shift.
2) Thoroughly embed the pipe strain gauge in the bedrock of which the depth is specified as 3-5m.
3) Strain gauges are generally placed at 1-2m intervals. However, if the presence of a slip surface is ascertained with certainty, the intervals are less than 1m.
4) The annular space between the borehole walls and the pipes are filled with sand.
5) After pipe strain gauges are embedded, the leads are connected to the data logger.

Table 2.2.3 Specifications of the Pipe Strain Gauge (source: JET)

Materials	Type	Capability
Body of the pipe strain gauge  Code edge 	VP40	System : two gauges in one direction, Strain gauge system Measurement range : $\pm25,000\times10^{-6}$ strain Strain limit : 1×10^{-6} strain Accuracy : 0.5% Operational temperature : -20°-60°C Adjustment value : $\pm700\times10^{-6}$ Strain Effective length 1m, filter roll, processed strainer Surplus length of cable 2m, height from the land surface 1m



Installation of the pipe strain gauge

Setting of the pipe strain gauge complete

Setting of the data logger

Setting of the protection box

Photo 2.2.2 Installation of the Pipe Strain Gauge (source: JET)

d. Water Level Meters

A water level meter monitors the change in groundwater level in the landslide area. The water level meter is installed according to the following procedures:

1) Excavate a borehole to the specified depth, and verify the depth of the groundwater level.
2) Insert the screen-processed PVC pipe, and fill the gap between it and the borehole wall with sand.
3) Taking into consideration the expected margin of fluctuation in the groundwater level, determine the installation depth of the hydraulic water level detector.
4) Raise and lower the fixed depth of the piezometer in the water, checking that the change in water pressure corresponding to the changes in depth is being measured.

Below is a description of the equipment used and photos of the installation process.

Table 2.2.4 Specifications of the Piezometer (source: JET)

Materials	Type	Capability
	DS-1	Measurement range：0-10m Accuracy of measurement：0.1%FS Temperature characteristic：±0.09%FS/10°C Coverage of temperature：0-30°C Material of body：SUS316L Material of cable：Polyurethane (open air pipe built in) Material of pressure receiver：Hastelloy Size, Weight：φ25×130mm、about 120g


PVC pipe


Installation of PVC pipe completed


Installation of water level meter


Setting of the data logger

Photo 2.2.3 Installation of Ground Water Level Meter (source: JET)

e. Rain Gauge

When installing the rain gauge, the location of installation is very important. The location should be selected as follows:

1) Select an area where there are no obstacles such as buildings or trees, and flat land where there is little wind.

2) Whenever possible, isolate the instrument from the nearest obstacle by at least four times the height of the obstacle.

3) Moreover, grass should be planted around it or the receiver of the rain gauge should be put up higher so that rain does not splash into it off the ground.

4) If possible, select an open area measuring at least 10m×10m.

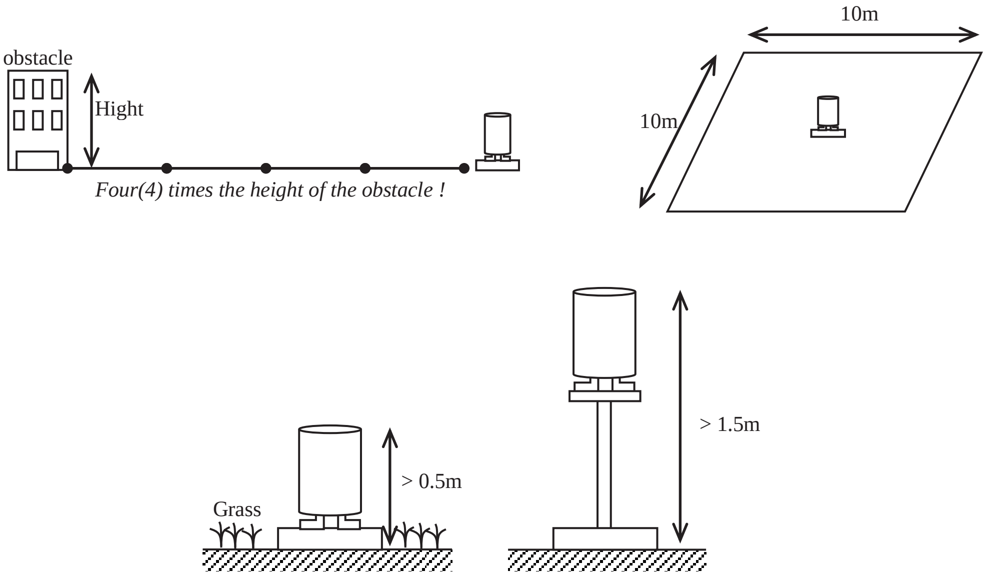


Figure 2.2.4 Installation Location of Rain Gauge

Chitrakoot (Height > 1.5m)

Quatre Soeurs (Height>0.5m) Grass has been planted around the rain gauge.

Photo 2.2.4 Installation of Rain Gauge (source: JET)

2.2.2 Fixing Observation Data Sets

a. Rain Gauge

It is very important that rain data are always installed because the movement of landslides could be linked to rainfall behaviour. The results of rain gauges are expressed as cumulative data as shown in Figure 2.2.5. Rainfall data should be put with the monitoring results of other devices.

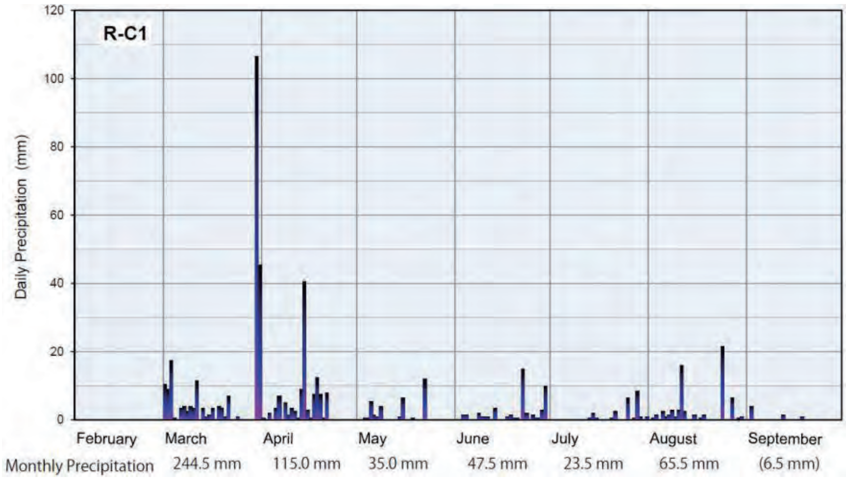


Figure 2.2.5 Sample Fixed Data-set of Rain Gauge, Chitrakoot (source: JET)

b. Extensometer

The results of extensometers are expressed as cumulative data as shown in Figure2.2.6. Rainfall data should be put with the results because the movement of landslides could be linked to rainfall behavior. They should be shown together to assess the landslide characteristics.

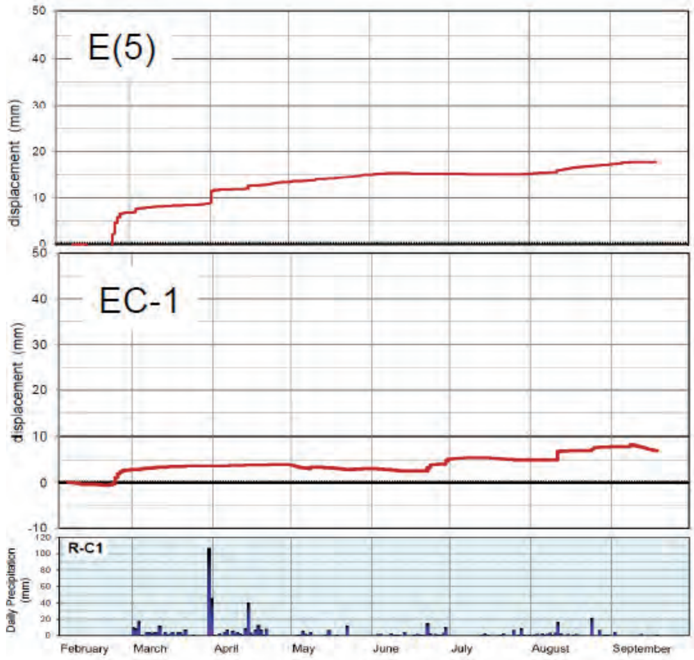


Figure 2.2.6 Sample Fixed Data-set of Extensometer, Chitrakoot (source: JET)

c. Borehole Inclinometer

The data from borehole inclinometers should be processed as shown in Figure 2.2.7. The X-axis is the amount of gradient change and the Y-axis is depth. The point where the amount of gradient is most changed is estimated as the slip surface of landslide.

In the case of the sample shown in Figure 2.2.7, it is estimated that the depth of the slip surface is GL-6.5m. Rainfall data should be put with the results, because the movement of landslides could be linked to rainfall behaviour.

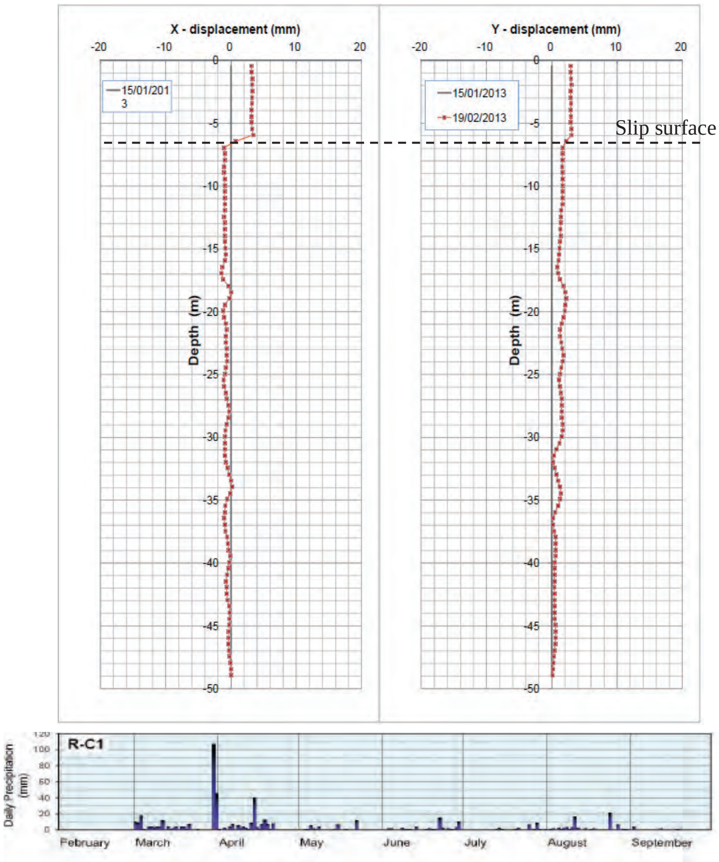


Figure 2.2.7 Sample Decision of the Position of a Slip Surface by Borehole Inclinometer, Chitrakoot (source: JET)

d. Pipe Strain Gauge

The data of pipe strain gauges should be processed as shown in Figure 2.2.8. The X-axis is the amount of strain change and the Y-axis is depth. The point where the amount of strain is most changed is estimated as the slip surface of the landslide. Rainfall data should be put with the results because the movement of landslides could be linked to rainfall behaviour.

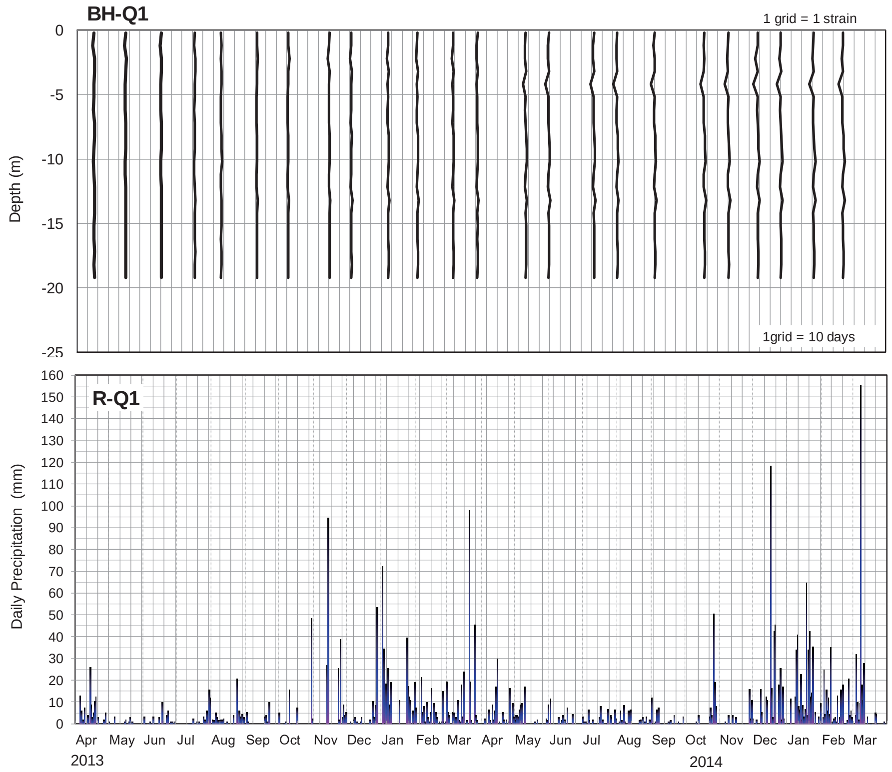


Figure 2.2.8 Sample Fixed Data-set of Pipe Strain Gauge, Quatre Soeurs (source: JET)

e. Water Level Meter

The results of water level meters are expressed as a graph of the groundwater level (Figure 2.2.9). Rainfall data should be put with the results because the groundwater level could be linked to rainfall behaviour. They should be shown together to assess the landslide characteristics.

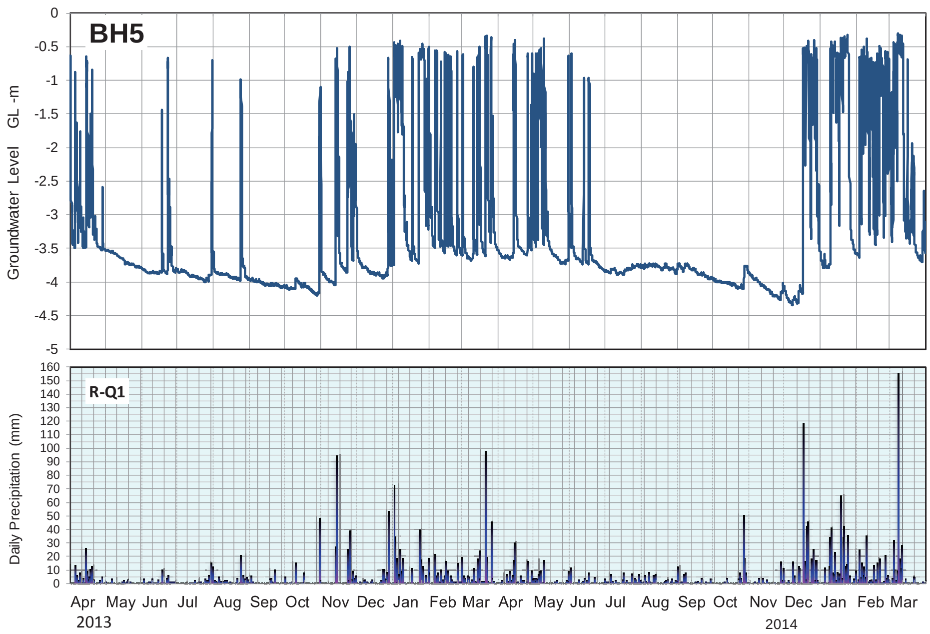


Figure 2.2.9 Sample Fixed Data-set of Water Level Meter, Quatre Soeurs (source: JET)

2.3 Landslide Analysis

In order to conduct mechanical analysis of landslides, there needs to be discussions about natural factors and triggers influencing landslides, area and scale of landslide blocks, shape and position of slip surfaces, groundwater situations and making landslide block maps and cross-sections. This analysis is very important to plan the countermeasures against landslides. The cross-sections are used to decide safety ratios and conduct stability analysis.

Table 2.3.1 shows the survey results to make the landslide block maps and cross-sections. The following are the procedures to make the cross-sections.

Table 2.3.1 Analytical Items and Applications in Surveys[23]

Item of analysis		applying survey items							
		preliminary study	site investigation	mapping of landform	geological survey	Slip surface survey	investigation for surface movement	investigation for ground water level	laboratory test for soil
map of micro-landform units of landslide									
	micro-landform units of landslide	○	○	○			○		
	land use / structure e.t.c.	○	○						
	feature of landslide topography		○	○					
	various result of investigation and observation				○	○	○	○	
	slip surface level contour line		○	○	○	○	○		
landslide cross section									
	geological cross section	○	○		○				
	groundwaster distribution		○					○	
	land use / structure e.t.c.	○	○						
	feature of Landslide cross section		○	○	○	○			
	various result of investigation and observation				○	○	○	○	
mechanism analysis of landslide		○	○	○	○	○	○	○	○

2.3.1 Identification of Landslide Areas and Hazardous Areas

It is preferable to get topographical maps and aerial/satellite photos around the landslide area for the identification of the site. Macro scope observation is vital for the estimation of the landslide areas and hazard areas. Broad view from hill/upland is useful for the macro scope observation. The landslide active area and hazard area should be estimated based on the observation results with broad view and surface anomalies such as cracks and heaving/subsidence on landslide.

A landslide distribution map is made by interpretation of aerial photographs and rough reconnaissance. The characteristic landforms of landslides (e.g. rear hollow, stepwise landform, extension cracks, compression cracks and sump water) become keys to segment landslide body into several blocks. Slipping direction and the situation of active landslide are estimated from the information of precipitation, each area of landslide block and quantity of soil mass. In addition, the survey results are used to predict behaviours of landslide blocks. Figure 2.3.1 shows the example of landslide scale which was predicted from counter map readings. Figure 2.3.2 shows the example of landslide blocks which was made by segmentation of landslide body into several small blocks.

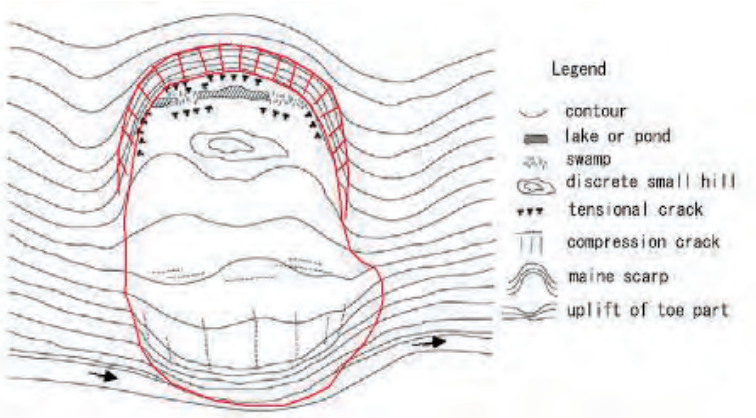


Figure 2.3.1 Example of a Landslide Area using Photographic Interpretation[24]

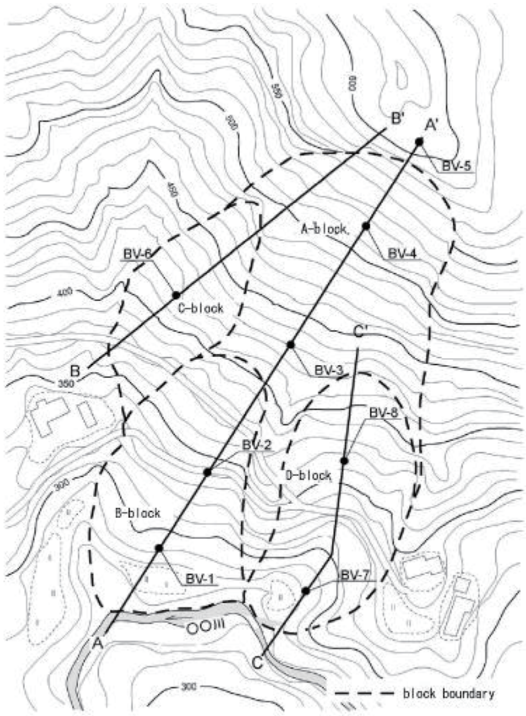


Figure 2.3.2 Example of Geomorphologic Analysis of a Landslide Divided into One Large Block and Three Small Blocks[25]

2.3.2 Identification of Direction and Mass Volume of Landslides

Moving direction of a landslide is discussed both regarding the entire area and each block based on the identified landslide blocks mentioned before. Mass volume of a landslide is discussed by the identified landslide block and the depth of slip surface of an entire area and each block.

The methods to identify the moving direction and the mass volume of landslides are as follows:

- Topographic identification/ aerial photo identification
- Geomorphological and geological reconnaissance
- Drilling core observation
- Monitoring (extensometer, inclinometer, etc.)
- Geophysical exploration

The moving direction of a landslide is identified by observation of the direction of cracks/steps/subsidence/uplifting in the field reconnaissance and by monitoring with various devices. The moving mass volume of a landslide is calculated by a landslide cross section which is prepared by drilling core observation, monitoring (extensometer, inclinometer, etc.) and geophysical exploration.

2.3.3 Preparation of Landslide Cross Sections

Landslide cross sections are drawn on geological cross sections. The cross sectional line is equal to the main traverse line or sub-main traverse line, which are in the same direction as the movement of the landslide. The cross section reflects the geological survey information and landslide anomaly information (such as position of crown and toe, angle of crown cliff and other information regarding the estimation of slip surface).

The procedures for the preparation of landslide cross sections are as follows:

i) The cross section shall be made at a scale of 1:200 or 1:500 (at same ratio on vertical and horizontal) along the traverse line. The sub-cross section along the sub-traverse line may be made at complex and large landslides.

ii) The information shall be gathered and marked on the cross sections. The information includes; variations of slope angle, cracks, steps, ponds, concaves, convexes, drilling points, measuring devices and equipment installation points, dips and strikes of surface soil and base rock, dividing lines of colluvial deposits and base rock, soil, faults, fractures, estimated slip surface(s), groundwater level and the position of fractures.

iii) Other necessary cross sections shall be made in cases where the landslide thickness differs in the vertical section.

iv) The topography line before the landslide occurrence and geological structures shall be added if available.

In general, the information such as the result of landslide surface survey, detailed drilling survey and expected slip surface represent only point information. Therefore, it is necessary to complement the data between these points from the observations made in a survey. The estimation of accurate cross sectional formation is required using vertical shape of the landslide blocks and the slip surface shape for the completion of the landslide cross section.

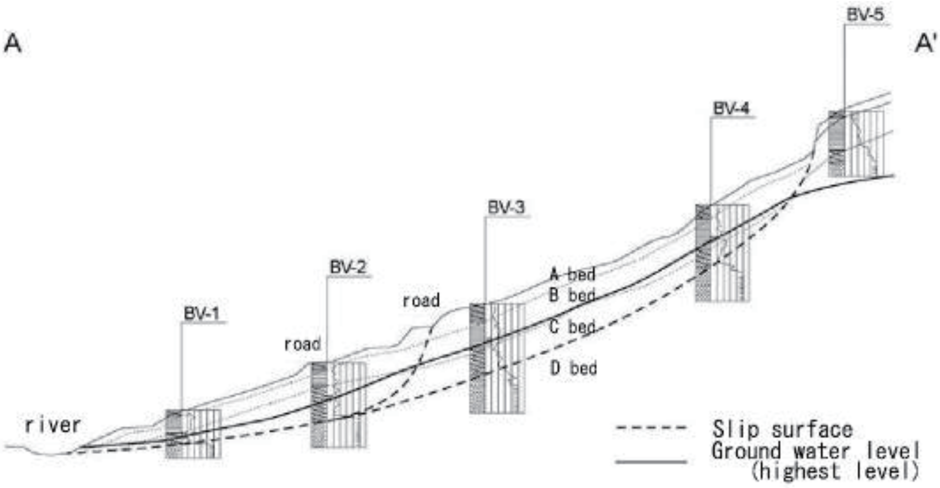


Figure 2.3.3 Example of Landslide Cross Section[26]

In recent years, estimations of landslide slip surfaces are formulated by the grid surface model in Japan. The movement of landslide is estimated from periodical topographical surveys on each fixed point of the grid (see following figure).

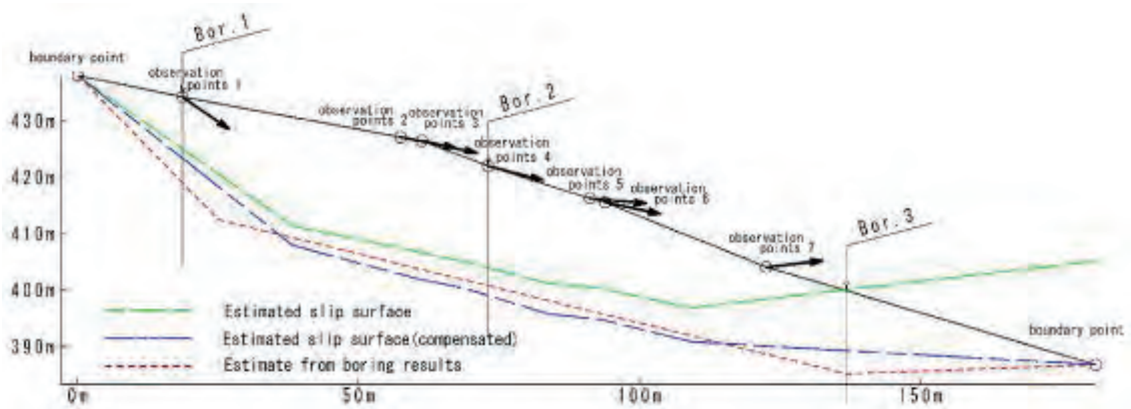


Figure 2.3.4 Landslide Slip Surface Section was Analysed by Time Difference Survey[27]

2.3.4 Decision of Slip Surface on Landslides

Slip surface survey is divided into two methods: by geological observation and by monitoring devices. Combining these methods is important to identify slip surface in the ground. The method by geological observation is a direct observation of the slip surface on the ground surface through field reconnaissance, drilling survey (core observation and drilling progress confirmation) and direct observation when drainage well is drilled. The method using monitoring devices is with: pipe strain gauges, borehole inclinometers and multilayer movement meters. Each method is described as follows.

a. Method by Geological Observation

a.1 Toe of Active Landslide

Slip surface on the ground can be observed in the toe area of an active landslide. It is necessary to grasp the geological conditions such as landslide clay and its thickness, geology on/under the slip surface and spring water. The following figure is an example of toe area of an active landslide in Japan. The photo shows toe area upheaval, and the upper part is highly weathered mudstone, which is almost sand/silt, and the lower part shows medium weathering.

Figure 2.3.5 Landslide Slip Surface in the Toe Area of an Active Landslide[28]

Slip surface on the ground can be also observed in the side area of an active landslide. It is also preferable to sample the soil including slip surface as a block sampling and to implement laboratory test for understanding of physical features of the slip surface.

a.2 Drilling Borehole

In case of an active landslide area, bending of the borehole as well as resistance at the same depth and sampling of half-moon shape core can be observed during drilling operation. These phenomena indicate the depth of slip surface in the ground.

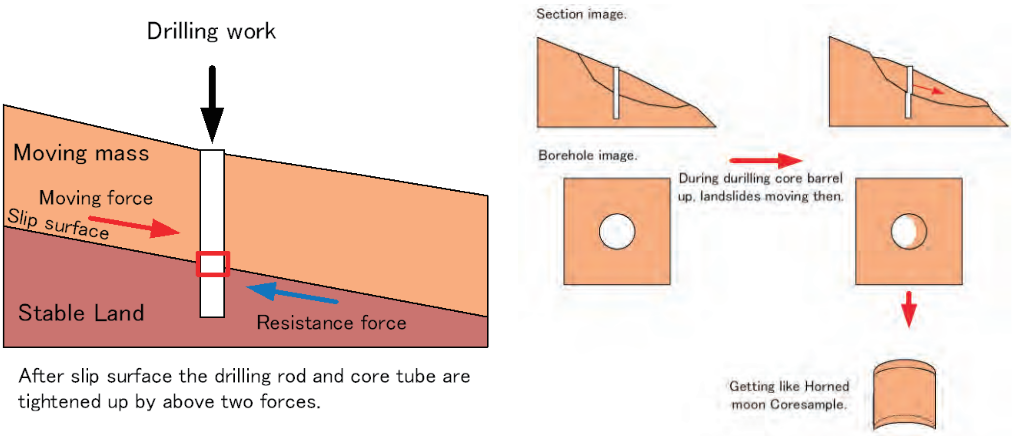


Figure 2.3.6 Schematic Figure of Borehole Bending by Landslide Movement (source: JET)

a.3 Drilling Core Sample

Core samples from drilling shall be used to conduct the complete analysis on the slip surface, by observing the colours, density of cracks and fissures, condition of clays, and existence of slick sides. The items to be checked on core samples are as follows:

(1) Soft clay layer with water
(2) Lower part of debris
(3) Upper part of weathered rock or fresh rock

(4) Boundary of different rocks
(5) Soft thin layer and fractured layer in rock
(6) Disarray on sediment structure in sedimentary rock
(7) Relationship between volume, shape and depth of landslide (ratio of depth and length: 1/5(small block) to1/10 (large block))

The schematic composition of landslide soil in vertical direction is shown in Figure 2.3.7. The slip surface indicates clayey, low permeability and darker colours, meanwhile the upper part of slip surface indicates high permeability and brownish colours. It is also important to heed groundwater conditions and soil conditions.

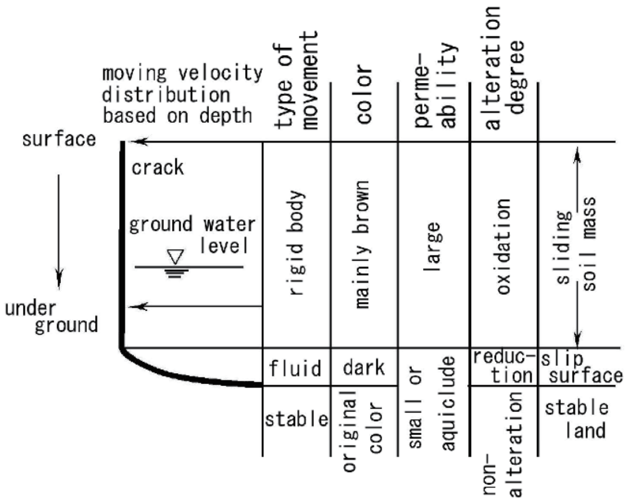


Figure 2.3.7 The Structure of Landslide Slope[29]

The observation points of slip surface estimation by drilling core are summarised as the following:

(1) The drilling location in landslide block: upper part of the block maintains the structure of the original rocks, meanwhile the lower part is fractured in many cases.

(2) The fracture zone: upper part of the slip surface is notably fractured, however, even the lower part may have a fractured zone. Slip surface has clay layer with much water, which is useful to identify the landslide fractures and fault fractures

(3) The cracks and original structure in rocks: slip surface in rock landslide which remains rock structure can estimate slip surface with borehole camera observation. Observation of original structure (bedding plane, flow structure and schistosity etc.) in rocks is also important.

Figure 2.3.8 Example of Slip Surface on Tuff Core that had a Clear Slickenside[30]

Photos of borehole camera are utilized for estimation of slip surface on the same perspective of drilling cores.

b. Method by Monitoring Devices

b.1 Borehole Inclinometer

A borehole inclinometer measurement is one of the most important factors to determine slip surface, and also quantitatively grasp the displacement of a landslide. Method of borehole inclinometer is to measure the inclination of the guide pipe that is installed in the borehole. When the guide pipe is installed in an active landslide, the guide pipe is bent by movement of the landslide. Hence the guide pipe is not straight at the initial state, initial value of inclination should be measured at the time of installation.

The results are expressed as integral values of the inclination measurements from the borehole's bottom. The notable inclined and strain-accumulation point is considered as a slip surface.

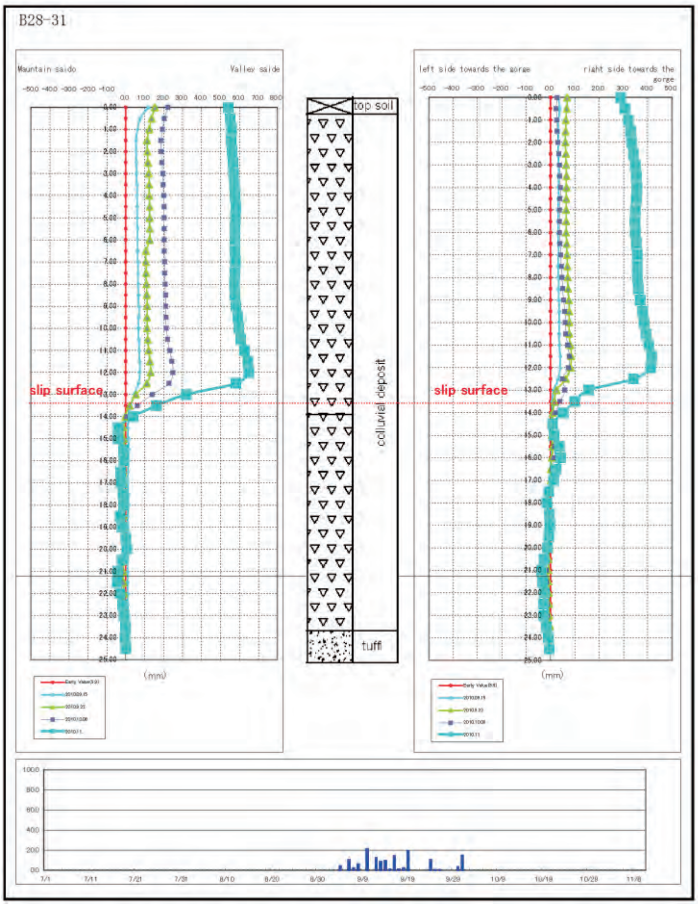


Figure 2.3.9 Example of Borehole Inclinometer Variation Diagram[31]

c. Pipe Strain Gauge

Pipe strain gauge can measure bending of borehole along its entire depth. It has high accuracy rate and can continue the measurement even when there is bending in the borehole. Therefore it can be used for active landslides which have several slip surfaces.

Pipe strain gauge is a section of PVC pipe with two strain gauges (one set) attached on opposite sides to measure the strain between the gauges. The direction of the gauges should be the same direction as the target landslide. The result is summarized as a graph of accumulative movement. When the landslide is active, the graph is twisted as in Figure 2.3.10.

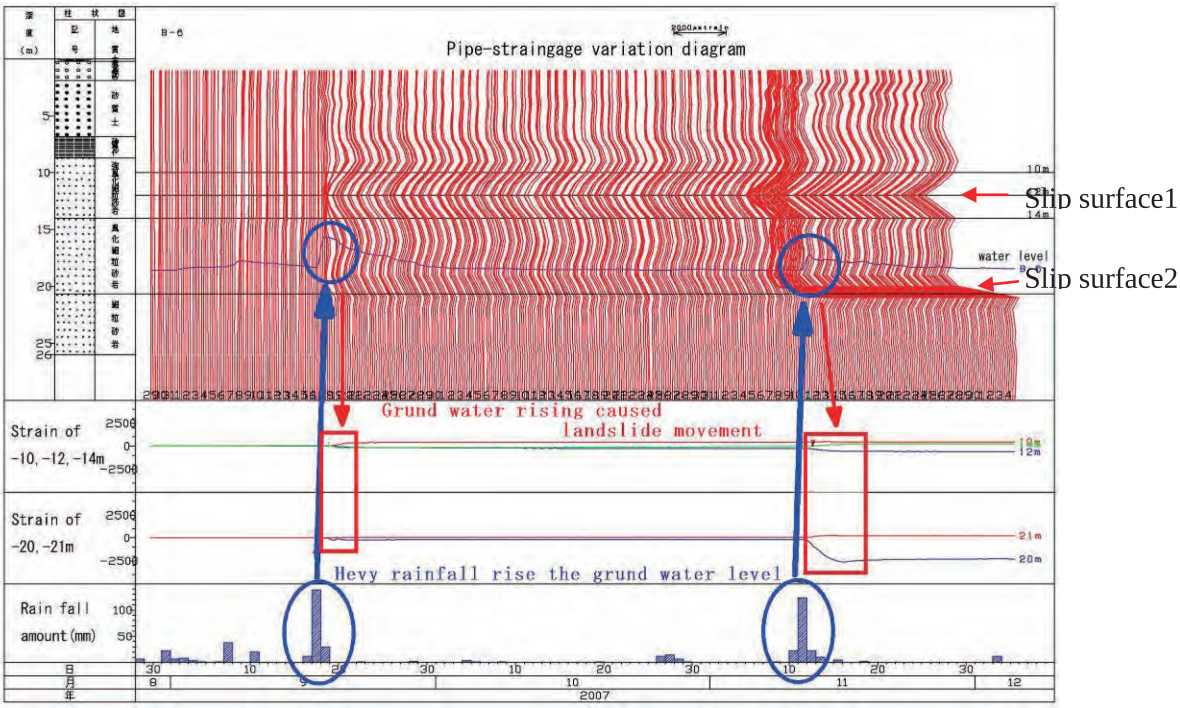


Figure 2.3.10 Example of Accumulative Movement Graph (source: JET)

2.4 Basic Factors and Triggers (Inducing Factors) of Landslides

2.4.1 Definition of a Basic Factor and a Trigger

A basic factor is “certain condition which landslide prone areas have originally” and a trigger (an inducing factor) is “certain external condition which initiates/activates landslide movement”. In general, landslides occur frequently in landslide areas which have their own characteristic nature as basic factors. Most of the basic factors are natural even when the trigger is artificial.

i) Basic factors: topographical condition (water collecting nature), geological condition (nature of creation of slip surface such as bedded structure, mud-clay layer, tuff etc., and thick loose formation at the unstable slope), geological structure (faults, anticline, syncline, etc., which will become a factor of landslide), groundwater condition (high water bearing layer), and cutting/filling by artificial construction.

ii) Triggers: raising groundwater level and pore-water pressure in soil mass by heavy rainfall, floods during the rainy season, other changes to the natural environment (wash out of the slope toe by rivers, formation or blockage of new waterways at surface and subsurface), earthquakes, and cutting/filling.

Artificial causes that may trigger a landslide are embankments on the upper landslide mass, cut slope at the toe of landslide, slope submersion under water and blockage of subsurface.

Table 2.4.1 Basic Factors and Triggers of a Landslide (source: JET)

Basic factors	Triggers
✓ Topographical condition ✓ Geological condition ✓ Ground-water condition ✓ Artificial cause	✓ Rainfall - Continuous rainfall - Torrential rainfall in a short term ✓ Surface Condition - River or lake erosion at the bottom of slope - Change in surface or ground water flows ✓ Artificial causes - Earth excavation at the bottom of slope - Earth fills on top of slope - Poor drainage system ✓ Others - Earthquake - Volcanic activity

It should be mentioned that many landslides are caused by not just a single trigger but by combined or multiple triggers.

2.4.2 Determination of Basic Factors and Triggers of Landslides

a. Basic Factors

In general, literature survey such as topographic map and geological map, topographic/geological reconnaissance and disaster record analysis are necessary to determine basic factors of landslides. According to the observation of Chitrakoot, Valle Pitot and Quatre Soeurs, the typical basic factors of the landslides in Mauritius are the following:

i) Topographical condition

- Catchment basin: areas where surface/subsurface water flow into from surrounding higher land and mountains. i.e. Chitrakoot.

- Water path: areas where surface/subsurface water passes through from high land and mountains. i.e. Chitrakoot, Vallée Pitot and Quatre Soeurs.

ii) Geological condition

- Alluvium and debris on base rocks: areas where alluvium and debris, which are generally soft, brittle and high water-bearing layer, are deposited on impermeable, hard base rocks. i.e. Chitrakoot, Vallée Pitot and Quatre Soeurs.

- Weathered rock and clay: areas where weathered rock and clay, which are generally one material of slip surface, are deposited. i.e. Chitrakoot, Vallée Pitot and Quatre Soeurs.

iii) Ground-water condition

- High groundwater level: areas where groundwater level is high under normal conditions such as several meters depth and where it rises easily after rainfall. i.e. Chitrakoot, Vallée Pitot and Quatre Soeurs.

b. Triggers

Although it is not easy to determine triggers of landslides, the discussion with monitoring results such as extensometer, inclinometer and groundwater and landslide disaster records from the past is useful to determine them.

Especially, the relation between the groundwater nature (distribution, groundwater level condition, direction of flow and quality) and the movement of the landslide should be examined after the groundwater level monitoring. The correlation between rainfall and groundwater level should also be examined to identify the effect of rainfall on groundwater and retention time of the groundwater level.

In the landslide project, the correlation between extensometer and rainfall has been analysed as in the following figure. As a result, the amount of rainfall is highly connected to the landslide movement (the extension). Since rainfall could be one of the main triggers of landslides in Mauritius, the rainfall condition should be identified at the time of landslides.

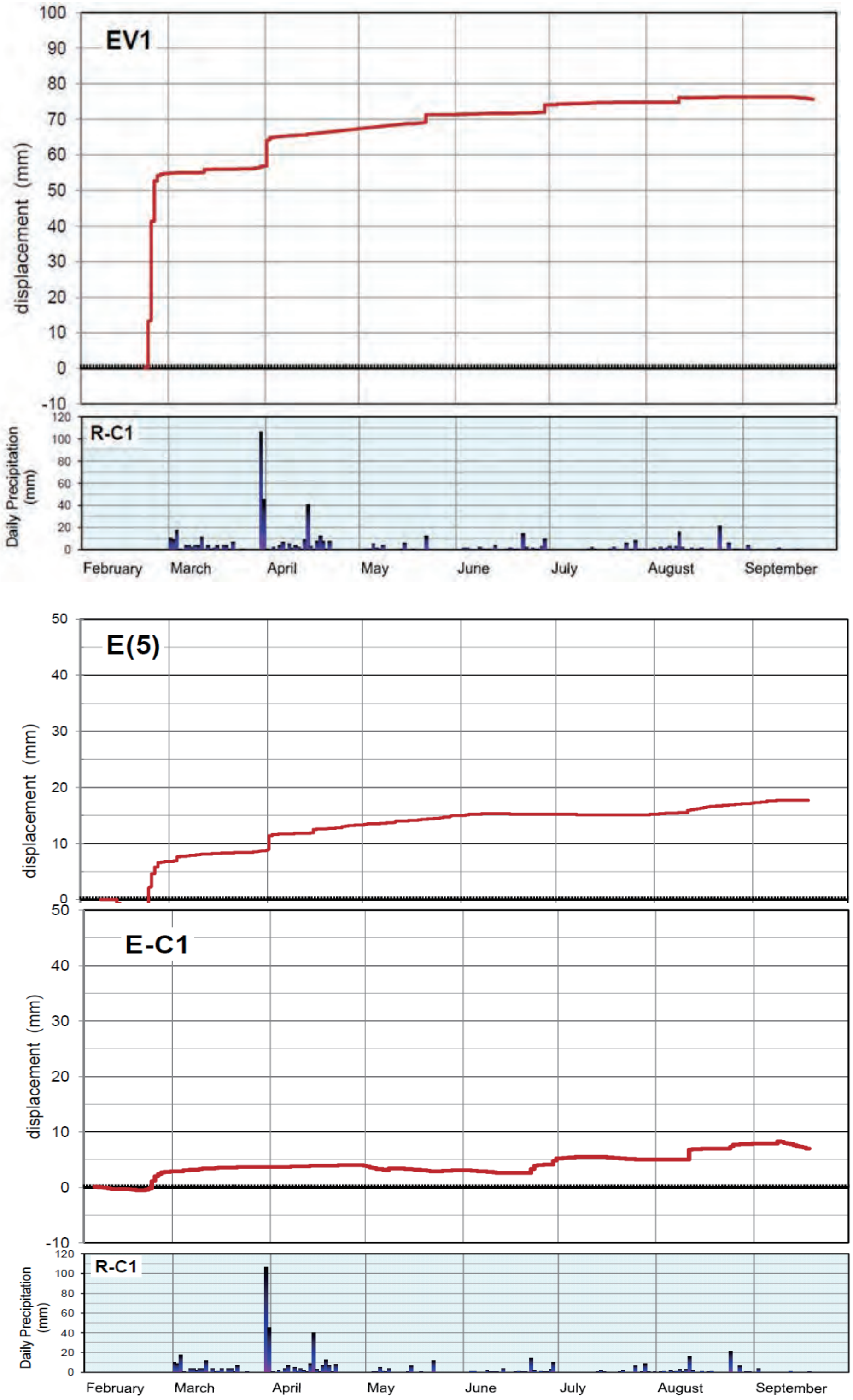


Figure 2.4.1 Correlation between Extensometer and Rainfall (upper: Vallée Pitot, bottom: Chitrakoot) (source: JET)

In order to determine triggers of landslides, observation and accumulation of monitoring data such as from extensometers, groundwater level meters and rainfall are essential. The following figure is an example of the monitoring of a landslide in Japan, and shows the results of monitoring using extensometers, groundwater level meters and rain gauges from the top. As can be seen in the figures, there is a clear correlation whereby the landslide becomes active (there is movement) as groundwater rises after heavy rainfall.

The monitoring of a landslide and the related parameters is necessary for the discussion of triggers and useful to predict the landslide movement.

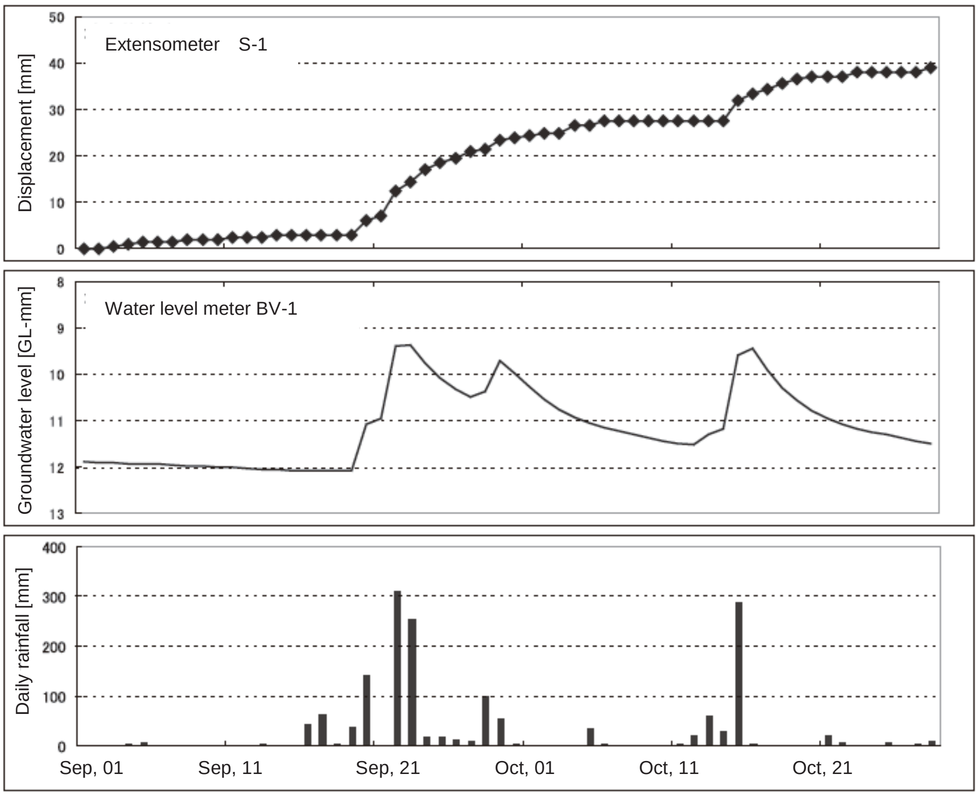


Figure 2.4.2 Example of Monitoring of a Landslide in Japan; Extensometer, Groundwater Level Meter and Rain Gauge Results from the Top[32]

2.5 Stability Analysis

2.5.1 Theory of Stability Analysis

Stability analysis is a fundamental procedure for the evaluation and designing of countermeasures. Based on the results of the analysis, the countermeasure works can be designed and implemented. Stability of the landslide is evaluated by the factor of safety obtained by stability analysis. When landslide soil mass starts sliding along the slip surface, the factor of safety (Fs) is defined as the ratio of resistance force against landslide soil mass to sliding force. Fs=1.0 means that the resistance force and sliding force are balanced. Fs>1.0 means that the landslide is stable, and Fs<1.0 that it is unstable or sliding.

$$Fs = \frac{\text{Resistance force against landslide soil mass}}{\text{Force when landslide soil mass starts sliding along the slip surface}} \qquad \text{(Formula 2-1)}$$

Required main parameters for the analysis are as follows,

Fs: Factor of safety
γ_t : wet unit weight (wet density)
u : pore water pressure
c': cohesion (as a shear strength constant)
φ': shear resistance angle (as a shear strength constant)

These parameters can be obtained by laboratory soil testing, geotechnical investigation and monitoring on the site.

- The wet unit weight can be obtained by weight testing in a laboratory using soil samples taken from the landslide mass.
- The pore water pressure is derived from the critical pore water pressure when the land starts sliding during the period of water level monitoring.
- Cohesion and shear resistance angles are obtained by the shear test or the triaxial compression test of the slip surface soil.

2.5.2 Factor of Safety

The stability of a landslide is evaluated based on the factor of safety. The factor of safety is obtained by stability analysis of the landslide using the results of monitoring and geotechnical investigations. In reality, the true factor of safety changes according to the response to triggering factors like groundwater level change.

The following figure provides an illustration of such a change in the factor of safety. The groundwater level when a landslide starts to slide is called the critical water level. The factor of safety at the very moment when sliding starts is the only true safety factor we can know for sure in a landslide. The factor of safety at that time is Fs=1.0.

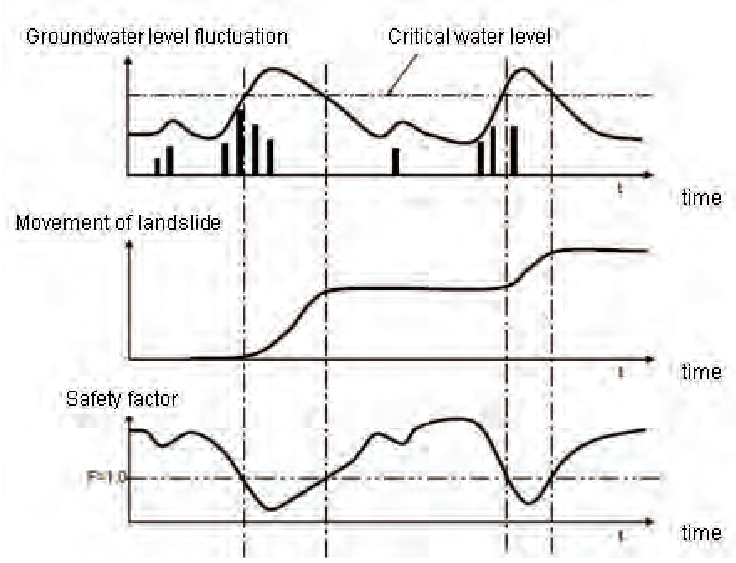


Figure 2.5.1 Changes in Groundwater Level Triggering Mass Movement while also Affecting Values of Safety Factor Over Time (source: JET)

The main purpose of landslide countermeasure work is to increase the value of the safety factor for those landslides with a factor of safety F<1.0, which indicates the landslide is in the most unstable state. At the time when the landslide is unstable, the groundwater level may be the highest or some other triggering factors may have reached their maximum point. Countermeasure work tries to achieve the factor of safety F≧P.Fs (planned/designed factor of safety). To make a suitable and appropriate countermeasure work design, it is necessary to calculate the factor of safety which can reflect the actual stability of a landslide because this calculated factor of safety will become the criteria for the design.

As already explained, the factor of safety of a landslide is always changing with the change in triggering factors such as groundwater level fluctuation. The current factor of safety is defined as the factor of safety when the groundwater level reaches its highest level or when the landslide indicates the most active conditions in a monitoring period. Hence, it is very important to understand the sliding process in response to groundwater fluctuation. The monitoring period is considered the period from the beginning of monitoring to the present in the case of before installation of a landslide countermeasure work, and it is the period from the completion of a countermeasure work to the present in the case of completion of a countermeasure work.

The factor of safety at the time of active landslide conditions is proposed for each condition as shown in the following table from Disaster Notebook edited by Japan Construction Engineer's Association (2010). The value of the factor of safety can be defined empirically.

Table 2.5.1 Definition of Safety Factor for Landslide[33]

Factor of safety	Landslide condition
Fs = 0.95	Landslide is moving continuously at all times
Fs = 0.98	Landslide is moving continuously corresponding to rainfall etc.
Fs = 1.00	Landslide is settling down

2.5.3 Method of Stability Analysis

Slope stability is analysed using the Fellenius method, the Bishop method, the Spencer method, the Janbu method and the Morgenstern-Price method. The selecting factors and the feature of each method are shown in Table 2.5.2. The appropriate method shall be selected based on actual conditions of the landslide.

Table 2.5.2 Landslide Slope Stability Methods and Selected Factors (source: JET)

Name of method	Selecting factor of stability analysis method						Feature
	Groundwater condition		Acceptable slip surface figure		Type of landslide		
	Confined	Free	Rotational	Others	Rock slide	Others	
Fellenius method	○		○			○	This formula basically gives small exact solution of the stability factor
Modified Fellenius method		○	○			○	Using free groundwater, but does not accept a seepage flow
Bishop method	○		○			○	Simplified Bishop method is applied generally for landslide stability analysis. This formula gives almost exact solution of the stability factor
Simple Bishop method	○	△	○				
Janbu method	○	△	△	○		○	This formula gives almost exact solution of the stability factor. On the other hand, the method proposes other formula for submerged slope, and for rotation slide
SHIN-Janbu method	○			○	○		The formula is modified from Janbu method for rock slide phenomenon analysis
Spencer method	○		(1)	(2)	△	○	This formula is good for exact solution of stability factor analysis, but this formula sometimes has multiple solutions depending on the way of putting parameter
Morgenstern & Price method	○			○		○	

Legend- ○ Available △ Available in some case

The Fellenius method (using confined groundwater) and the Modified Fellenius method (using free groundwater) are the most popular ways for stability analysis in Japan because (1) the calculation is very simple and (2) the calculated value could be safer for countermeasures. The Modified Fellenius method is explained below.

[Modified Fellenius method]

The Modified Fellenius method is based on the balance between soil weight and the shear resistance acting on the slip surface. In addition, the pore water pressure to act on the sliding surface by introducing effective soil weight (W-Ud) in substitution for soil weight is evaluated definitely. The landslide longitudinal section is prepared for stability analysis, and the landslide body is divided into multiple slices. Finally, the total of the sliding force and the shear resistance is calculated in each slice, and the factor of safety is provided as those ratios.

$$Fs = \frac{S}{T} = \frac{\sum\{c \cdot l + (W - U \cdot d)\cos\alpha \cdot \tan\phi\}}{\sum W \cdot \sin\alpha} \qquad \text{(Formula 2-2)}$$

Fs : Factor of safety
S : Shear resistance
T : Shear force (Sliding force)
c : Cohesion
φ : Shear resistance angle
l : Slice length of sliding surface
W :Slice weight, $W=\gamma t \cdot h \cdot d$
U :Pore water pressure, $U=\gamma_w \cdot h_w \cdot d$
γ_t :Soil unit weight
γ_w :Water unit weight
d : Slice width
h : Slice height
h_w : Water height
α : Inclination angle of sliding surface

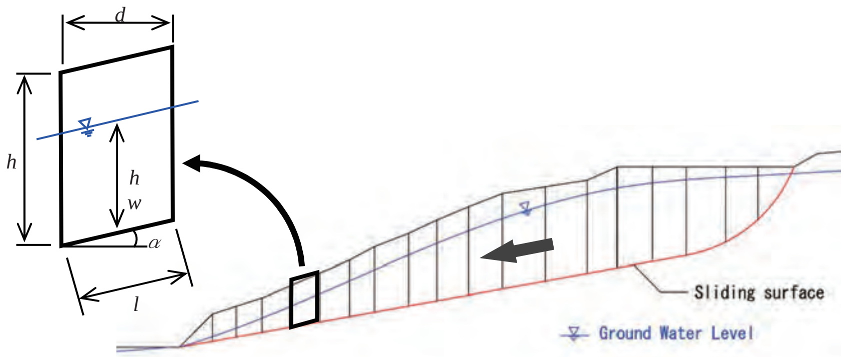


Figure 2.5.2 Schematic Diagram of the Modified Fellenius Method (source: JET)

[Simple Janbu method]

The Janbu method is, from the point of view of the balance of the horizontal stress and vertical stress in each slice, based on the total stress in the entire soil mass being balanced as zero. It is applied to tabular-shape slides controlled by the soil weight and the shear resistance on the bedrock, and to complex slides in which are mixed circular slides on the scarp zone and the end zone and tabular-shape slides on the middle zone in the slip surface.

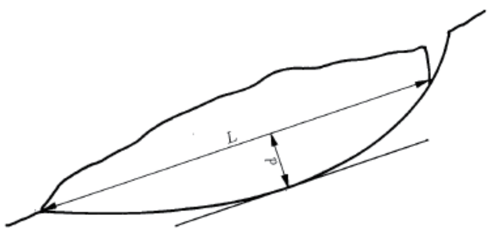


Figure 2.5.3 Schematic Diagram of the Simple Janbu Method (source: JET)

$$F_s = f_0 \frac{1}{\sum W \tan\alpha + Q} \sum \frac{c'b + (W - ub)\tan\phi'}{n_\alpha} \qquad \text{(Formula 2-3)}$$

Here, F_s : safety factor, *c*': cohesion, *φ*': shear resistance angle,
W: soil weight, *u*: pore water pressure, *b*: slice width,
α: inclination angle of slip surface,
Q: effective stress in tension crack of scarp zone,
L : distance between the toe and crack at the scarp
d: distance between *L* and a line of parallel to *L* tangential line on the slip surface.
n_α is defined as

$$n_\alpha = \cos^2\alpha(1 + \tan\alpha \cdot \tan\phi' / F_s)$$

f_0 : correction coefficient,

$$f_0 \cong \left(50\frac{d}{L}\right)^{1/33.6}$$

2.5.4 Back Analysis

Regarding stability analysis, the shear strength parameter of the slip surface as cohesion (c') and shear resistance angle (φ') shall be applied for landslide stability analysis. Therefore, test samples for the shear strength parameters shall be taken from the slip surface layer under undisturbed conditions. However, since the slip surface layer is very thin and it is difficult to know the exact depth, undisturbed sampling is difficult even though a sample could be taken in the drilling survey. In the case that the sample is taken from the drilling survey, it may show a lower shear strength than the actual one. Even though the sample could be taken from the slip surface layer, there are many cases where the factor of safety obtained by stability analysis using the shear strength parameters is not matched with actual landslide conditions. Therefore, in Japan, the shear strength parameters are derived from the back analysis empirically. The back analysis of a landslide is carried out according to the procedure shown in Figure 2.5.4.

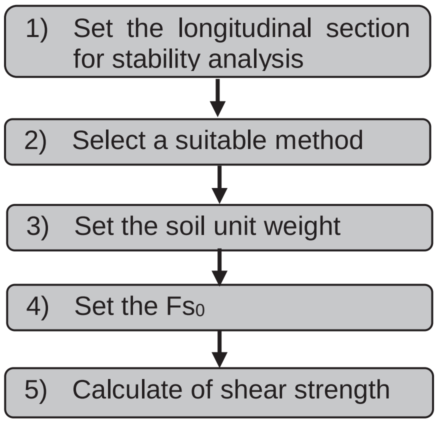


Figure 2.5.4 Flow for Back Analysis of a Landslide (source: JET)

a. Set the Longitudinal Section for Stability Analysis

A longitudinal section of the landslide for stability analysis shall be set up based on the geological section which is the result of the landslide investigation and monitoring. The ground surface, geological boundary line, sliding surface and groundwater level are drawn on the longitudinal section for stability analysis. As for the groundwater level, the highest water level during a monitoring period should be adopted.

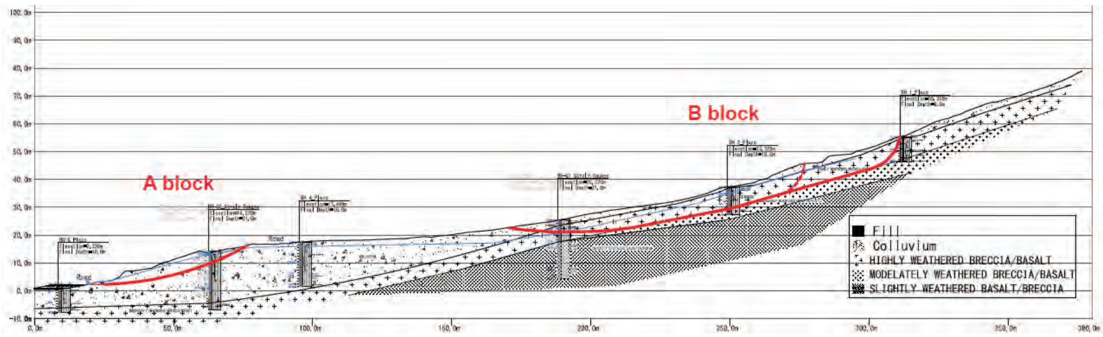


Figure 2.5.5 Sample of the Geological Section, Quatre Soeurs (source: JET)

Figure 2.5.6 Sample of the Longitudinal Section, A-block in Quatre Soeurs (source: JET)

b. Select a Suitable Method

Select a suitable method for stability analysis, which are shown in Figure2.5.2.

c. Set the Soil Unit Weight (γ_t)

The soil unit weight (γ_t) of the landslide mass, soil above the sliding surface, is set by the laboratory soil test using a sample provided in a drilling survey. In Japan, the soil unit weight of Landslide mass is generally shown Table 2.5.3.

Table 2.5.3 Design Value of Soil Constant in Japan[34]

Classification		Soil state		Wet unit weight [kN/m³]
Embankment	Gravel and Sand with Gravel	Compacted		20
	Sand	Compacted	Wide grain size	20
			Sorted	19
	Sandy Soil	Compacted		19
	Cohesive Soil	Compacted		18
	Kanto Loam	Compacted		14
Natural Ground	Gravel	Dense or wide grain size		20
		Not dense or sorted		18
	Sand with Gravel	Dense		21
		Not dense		19
	Sand	Dense or wide grain size		20
		Not dense or sorted		18
	Sandy Soil	Dense		19
		Not dense		17
	Cohesive Soil	Hard (yield under strong pressure of a finger)		18
		A little soft (penetrate under pressure of a finger)		17
		Soft (penetrate under pressure of a finger easily)		16
	Clay and Silt	Hard (yield under strong pressure of a finger)		17
		A little soft (penetrate under pressure of a finger)		16
		Soft (penetrate under pressure of a finger easily)		14
	Kanto Loam			14

d. Set the Fs_0 (Current Factor of Safety)

The factor of safety at the time of an active landslide is proposed for each level of activity as shown in the Table 2.5.4. According to the results of the landslide monitoring, the current factor of safety (Fs_0) must be estimated appropriately.

Table 2.5.4 Definition of Safety Factor for Landslide[35]

Factor of safety	Landslide condition
Fs = 0.95	Landslide is moving continuously at all times
Fs = 0.98	Landslide is moving continuously corresponding to rainfall etc.
Fs = 1.00	Landslide is settling down

e. Calculate of Shear Strength

Because the formula of the stability analysis is a linear function as shown in Formula 2-2, when stability analysis is carried out under the above conditions (a, b, c, d), the shear strength of the soil is shown as C-tanφ relations such as in Figure 2.5.7.

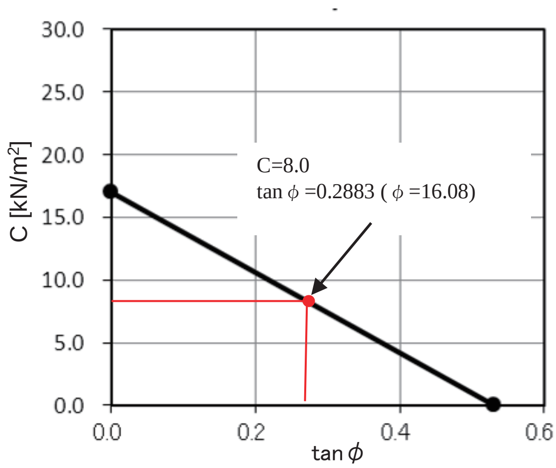


Figure 2.5.7 Sample of C-tanφ Relations, A-block in Quatre Soeurs (source: JET)

Therefore, the other is provided by c-tanφ relations if either cohesion (C) or shear resistance angle (φ) is estimated. The method to estimate C or φ is suggested as follows:

[Method to estimate C from the thickness of the landslide body]: For a method to estimate the shear strength of the sliding surface, based on past results of research, combination (C) is predicted by the thickness of the landslide body[36]. It has been reported that the cohesion and thickness of an average landslide body are almost equal. The value of cohesion (C) becomes larger as the thickness of the landslide body increases. This means that the cohesion of the soil becomes stronger by a permanent upper load.

Thickness of the landslide body : 5m cohesion (C) : 3-6 [kN/m^2]
Thickness of the landslide body : 10m cohesion (C) : 8-12 [kN/m^2]
Thickness of the landslide body : 15m cohesion (C) : 13-17 [kN/m^2]
Thickness of the landslide body : 20m cohesion (C) : 18-22 [kN/m^2]

[Method to estimate φ from the plasticity index (PI)]: The relationship between the plasticity index (PI) of various sliding surface clays and the shear resistance angle (φ) is shown in Figure 2.5.8. If a laboratory soil test provides the plasticity index (PI) of the soil of the sliding surface, the shear resistance angle (φ) is estimated based on the relationship shown in Figure 2.5.7.

[Other methods] : When, in the existing landslide investigation, the shear strength of the clay similar to the sliding surface clay of the landslide is provided, the results of the existing landslide investigation can be considered.

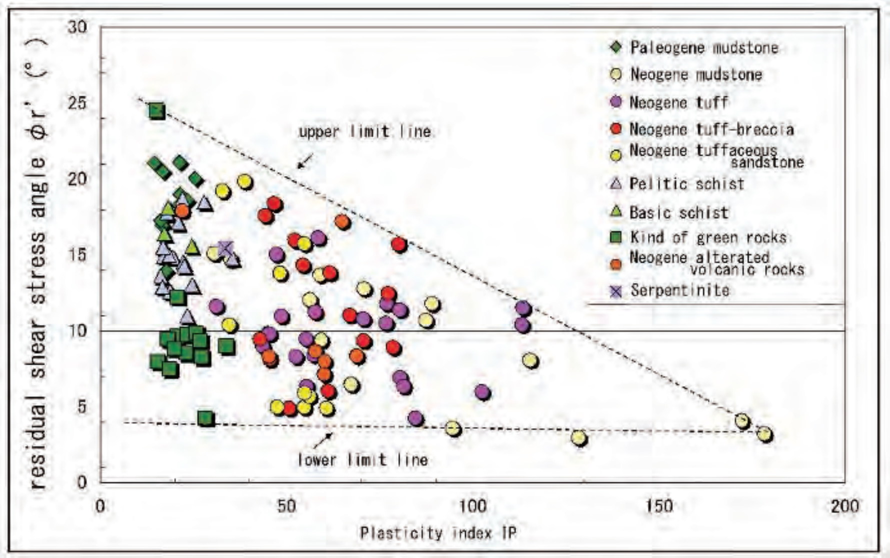


Figure 2.5.8 Relationship between the Plasticity Index and Residual Shear Resistance Angle for Various Geological Zones[37]

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3 Landslide Warning System

3.1 Introduction of Landslide Warning System

3.1.1 Risk Management

There are some ways to survive risks: prevent the risk, protect against the risk, avoid the risk, escape the risk and eliminate the risk. To survive landslide risk, the following three ways are realistic:

- Prevent (= Stabilization): stabilize the landslide by structural works
- Avoid (= Relocation): make people leave the landslide area and prevent people from living in the landslide area
- Escape (= Evacuation): make the people in the landslide area escape before the landslide disaster occurs

Of the above three ways, stabilization is the best way. With relocation and evacuation, the risk in the landslide area remains, while stabilization can remove the risk from the landslide risk area. After stabilization, relocation, which can remove the risk on people's lives and on properties in the landslide risk area, is the second best. Evacuation is a measure to secure only people's lives, and it does not secure their properties. Therefore, evacuation can be a temporary measure until the completion of stabilization works. Evacuation means that nobody is in the landslide risk area when the residential houses in the area are in danger by landslide activity. For the purpose of evacuating people from the landslide risk area, the landslide warning system is necessary to warn the people prior to the landslide disaster.

3.1.2 Landslide Warning System

The landslide warning system is used to predict landslide disasters in advance, and issue warnings to allow the residents in the landslide area to escape from the risk in order to prevent loss of lives. Do not try to secure the properties of residents with the landslide warning system. The system can only secure the lives of the residents in the area.

To bring the landslide warning system into effect, the system must predict the time and the location of the landslide disaster in advance. The location of the landslide disaster was determined by the inventory survey and the detailed investigation before installation of the landslide warning system. The most important matter for the landslide warning system is how to predict the landslide disaster in advance.

3.1.3 Prediction of Landslide Disaster

To predict a landslide disaster, causes of landslide, described below must be identified.

<u>Cause of landslides</u>

There are factors that cause the landslide to activate before the landslide disaster occurs. If the cause of the landslide are found, the landslide disaster may be predictable. There are only three causes of landslides: an external force, a change in the ground surface and a change in the subsurface. An earthquake is the only external force that can activate a landslide. However, earthquakes can be neglected in Mauritius. A change in the ground surface is generally due to the excavation or banking of soil on the ground surface by human activity. A change in the subsurface is a change in the groundwater. That is, an increase in groundwater pressures the landslide block. In brief, the only two things that can be the main cause of landslides in Mauritius are as follows:

- A change in the ground surface, i.e. excavation or embankment
- An increase in the groundwater

Changes in the ground surface are due to human activity. Therefore, this cause could be removed if human activity that changes the ground surface is prohibited by the authority. An increase in groundwater pressure could be the only cause that activates a landslide.

3.2 Landslide Monitoring and Warning

3.2.1 Instruments for the Landslide Warning System

The landslide warning system is made up of two equally important components: sensors to detect landslide activity and a communications infrastructure to issue timely alarms to permit evacuation of the landslide areas.

Generally, the landslide warning system detects the cause or the signs of a landslide disaster using sensors. The cause of a landslide disaster is only an increase in groundwater pressure. As the groundwater pressure is almost equal to the groundwater level, the groundwater level can be used as the indicator of a disaster. The monitoring of groundwater pressure and groundwater level is sometimes difficult since it requires heavy construction such as drilling. However, because an increase in groundwater pressure is mostly caused by rainfall, precipitation can be the indicator of a disaster instead.

There are two ways to detect the signs of a landslide disaster: to detect the small changes in the ground surface and to detect the small changes in the subsurface. There are many sensors to detect the groundwater pressure, precipitation, and changes in the ground surface and subsurface, as shown in the table below.

Table 3.2.1 Instruments for the Landslide Warning System (source: JET)

Instruments to detect change in the ground water	
Piezometer	To monitor the groundwater pressure.
Water Level Meter	To monitor the groundwater level.
Rain Gauge	To monitor the precipitation.
Instruments to detect change in the ground surface	
Extensometer	To monitor the relative change in the distance between two points on stable ground and the landslide block.
GPS	To monitor the absolute coordinate of the point in a landslide block.
Laser Distance Meter	To monitor the absolute distance between two points on stable and the landslide block.
Tiltmeter	To monitor the change in tilt on the ground surface. It cannot detect the amount of movement but can detect the change in the ground surface. The tiltmeter can be installed alone in the landslide block and does not require a reference point.
Crack Gauge	To monitor the change in width of cracks on the ground or structures.
Instruments to detect change in the subsurface	
Inclinometer	To monitor the relative movement of the landslide block to the stable base rock below the landslide.
Strain Gauge	To monitor the strain at the surface of rupture.
Borehole Extensometer	To monitor substantial movement of the subsurface in landslide. It is advisable to use borehole extensometer when large deformation is anticipated. The depth of the slip plane is not determined and accuracy of the extensometers is limited.

The instruments for the warning system must have an automatic data recorder (a logger) and an alarm device or an emitter to send the data to a control. These instruments must be installed in the proper place in or around the landslide in order to detect the groundwater pressure or the motion of the landslide. The detailed investigation to confirm the features of the landslide must be done prior to installing the warning system.

An extensometer, which can detect small movement of the ground surface, is often employed as the instrument for detecting small deformations in a landslide. This is because it is easy to install, less trouble due to its simple structure, easy to monitor automatically, and easy to attach a warning devise to. Extensometers are the most popular in Japan where installation is easier without protection barriers.

Other than extensometers, tiltmeters and crack gauges are often employed for monitoring in landslides. However, they are not as popular as extensometers because they cannot indicate the absolute value of the movement of landslides. They can only indicate whether it is active or not.

A rain gauge can be employed as the instrument of the landslide warning system for detecting an increase in the groundwater level indirectly. The rain gauge is easy to handle and easy to install. The advantage of a rain gauge is that it can be easily installed without heavy construction works such as drilling works in any open place around the landslide area.

3.2.2 Devices for Early Warning

Small signs of a landslide appear as cracks on the ground, cracks on structures and deformations of the houses. These signs of the landslide can hardly be found by sensors or even landslide experts. Only the residents can find these signs, and the residents appointed as designated inhabitant can monitor the signs on simple devices and see if the landslide disaster is imminent.

The following are examples of simple devices for monitoring landslides.

Crack monitoring

Motion of the landslide block causes cracks on the ground and the structures. The cracks open by landslide activity so monitoring of the widths of the cracks in the landslide could detect landslide activity.

Crack width changes can be measured directly by taping between stakes set on opposite sides of the crack. Crude, simple gauges can be constructed in the field to provide accurate and continuing indications of crack movement. Figure 3.2.2 shows one such device, which consists of two vertical reinforcing steel rods and a heavy-duty elastic rubber strap or band stretched between the two rods. Initial measurements of length, bearing, and inclination of the band provide a basis for comparison with subsequent measurements. Reduction of the field measurements provides values of lateral and vertical movements along the crack. Vertical offsets on cracks and scarps also may be obtained from direct measurement.

Quadrilaterals provide a convenient method for measuring slope deformation. A quadrilateral consists of an array of four stakes initially in a nearly square configuration. The geometry of a quadrilateral straddling a landslide boundary is illustrated in Figure 3.2.3.

Figure 3.2.1 Crack Monitoring with Vernier Calliper on Concrete Wall (source: JET)

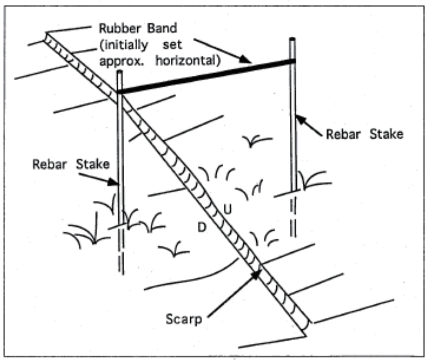


Figure 3.2.2 Crack Measurement with Rubber-band Extensometer[1]

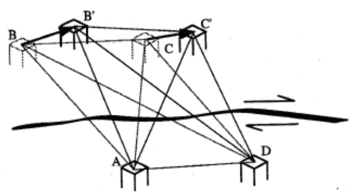


Figure 3.2.3 Quadrilaterals[1]

Quadrilateral configuration for determining displacement, strain and tilt across landslide flank. Initially deployed at positions A, B, C, and D, quadrilateral deforms to positions A, B', C', D at second observation. Quadrilateral defines four triangles.

Ground surface displacement survey (observation points)

The purpose is to monitor the absolute coordinates or the relative position of points using optical instruments such as a total station. The optical instrument survey is commonly used to determine lateral and vertical positions of points accurately. Bench marks and transit stations located on stable ground provide the basis from which subsequent movements of monuments can be determined optically. The total station survey can measure vertical and horizontal positions within a three-dimensional coordinate framework having x-, y-, and z-axes. As shown Figure 3.2.4, transit lines can be established so that the vertical and horizontal displacements at the centre and toe of the landslide can be observed.

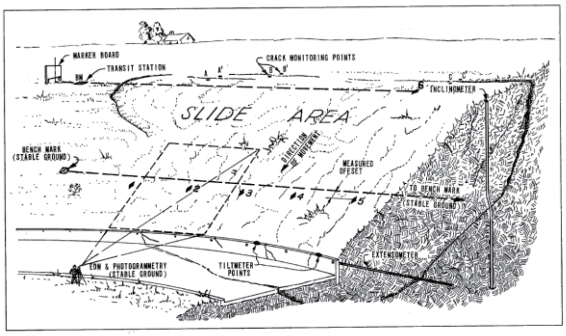


Figure 3.2.4 Movement Measurement by Optical Survey[1]

An optical instrument survey is commonly used to determine lateral and vertical positions of points accurately.

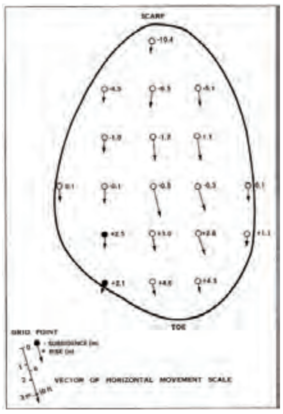


Figure 3.2.5 Example of Results of Optical Measurement[1]

Movement vectors show displacements at observation points in a landslide.

Extensometer

An extensometer is a device that is used to measure changes between two points by means of a wire, a tape, a laser or whatever can measure change of the distance. The tape and laser extensometers provide precise measurements of displacement.

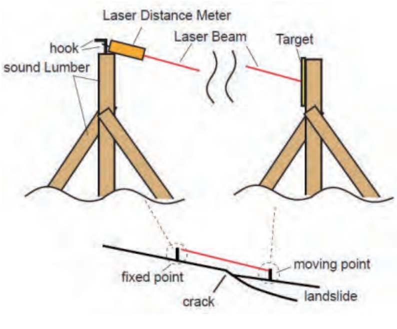


Figure 3.2.6 Extensometer Using Laser Distance Meter(source: JET)

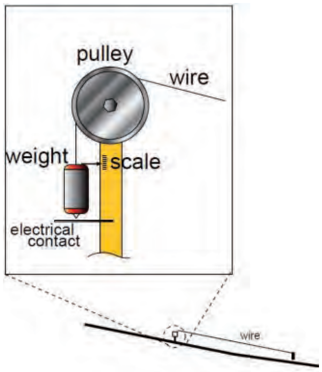


Figure 3.2.7 Simple Wire Extensometer (source: JET)

Tilt monitoring

Elevation differences or tilting of a floor of a house can be determined precisely by the water level or a manometer. The simplest way is to monitor the water level filled in a transparency hose with both sides up.

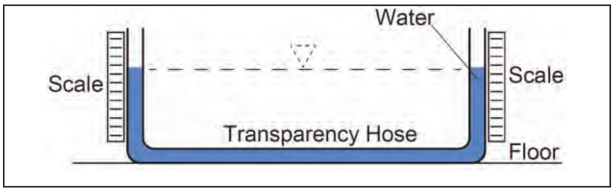


Figure 3.2.8 Level Using Transparency Hose (source: JET)

Precipitation monitoring

A rain gauge used for precipitation monitoring is an instrument that gathers rainwater and measures the amount over a set period of time. A simple gauge generally consists of a funnel emptying into a graduated cylinder. These simple rain gauges can be made with materials found in the local market and are inexpensive so they can be installed in some places to make sure monitoring is accurate and to prevent the absence of monitoring.

Regular monitoring by a watchman is required for the simple rain gauge.

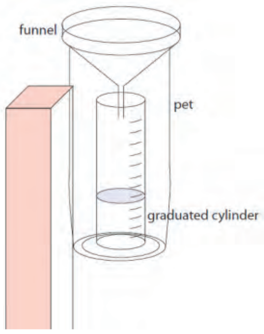


Figure 3.2.9 Example of Simple Rain Gauge (source: JET)

Figure 3.2.10 Simple Rain Gauge (white colour) in Quatre Soeurs installed and monitored by MMS (source: JET)

3.2.3 Criteria of Warning

The most important thing to establish the criteria of warning is to find the limit of movement of the landslide or the amount of rainfall to put people in danger. "People in danger" means the residential houses are destroyed by the landslide. The warning to evacuate the houses must be issued a few hours before the destruction.

In order to determine the timing of when the houses are destroyed in the landslide, we must verify the records of the extensometers, rain gauges and damage to houses to find the relationship between the displacement of extensometers and the damage to the houses or precipitation and the damage to the houses. However, as there are no such records in Mauritius, accumulation of records contributes for improvement of the landslide warning system.

a. Criteria of Warning in Japan

This section describes the criteria of landslide warnings in Japan and the way to get them. There are many ways to get the criteria of landslide warnings in Japan. However, most of them are for slope failure (or earth fall, debris fall) which moves rapidly. Slope failure can be predicted with detailed monitoring because it fails suddenly after some accumulation of the strain in the ground by the movement. However, the landslides in Mauritius discussed in this manual are landslides that move slowly or variable. Therefore, the following criteria cannot apply directly to landslides in Mauritius.

Warning based on extensometer

Figure 3.2.11 shows an example of the prediction curve which is based on actual wire extensometer monitoring of landslides in Japan. As shown in the figure, the remaining time (Tr) to the failure is predicted by the speed of ground surface movement (ε) using the following formula:

$$\log_{10} Tr = 2.3 - 0.9 \log_{10} \varepsilon$$

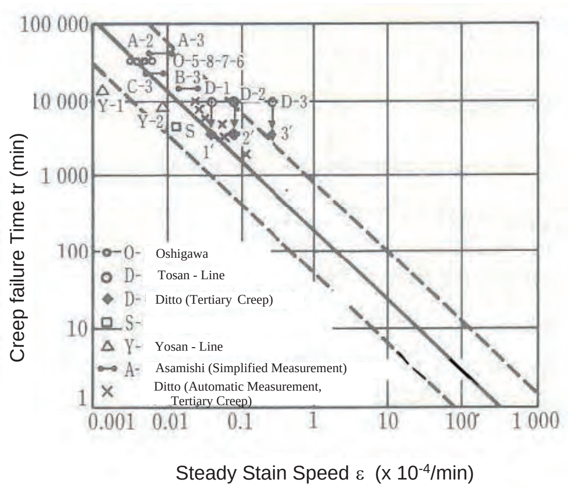


Figure 3.2.11 Time to Slope Failure – Strain Speed (Wire Extensometer) (Strain: conversion to 10 m long wire)[2]

For example, when the steady strain speed(ε) becomes 1（=100mm/10m/1min）, the slope will fail 200 minutes later. The criteria shown in Table 3.2.2 determined from the figure above are common in Japan.

Table 3.2.2 Example of Standard Criteria of Wire Extensometers[3]

Criteria	Daily displacement (mm)	Monthly displacement (mm)
Urgent Stage	2×10^{1}	5×10^{2}
Established Stage	1×10^{0}	1×10^{1}
Semi-Established Stage	1×10^{-1}	2×10^{0}
Latent change	2×10^{-2}	5×10^{-1}

Warning based on precipitation

Several methods to evaluate rainfall in terms of the relationship between landslide disasters such as collapse and debris flow have been proposed and applied in Japan as follows:

a) Hourly Rainfall Method
b) Accumulated Rainfall Method
c) Combined Method of Hourly Rainfall and Accumulated Rainfall
d) Effective Rainfall Method
e) Water Storage in-Soil Method

a.1 Hourly Rainfall Method

Hourly rainfall can be a good indicator of rainfall intensity, which can cause shallow slope failure (generally <1m depth)

a.2 Accumulated Rainfall Method

Accumulated rainfall (summation of rain that has fallen without a break) better reflects collapse or landslide than heavy rain over a short term.

$R = \sum Ri$ (Ri : hourly rainfall at i hours before)
If the rainfall has been stopped for "three hours" Ri shall be 0.

This is the simplest method applicable to urgent evaluation and is widely used in road management in mountain areas in Japan. This method is more reliable than the hourly rainfall method. However, it still has some error in predicting disasters.

a.3 Combined Method of Hourly Rainfall and Accumulated Rainfall

A combination of a) and b) is more reliable than an application of either one alone. This method is adopted by Japan Railways (JR). JR uses the following chart to control the train system. Figure 3.2.12 shows an example of train control by JR based on accumulated rainfall and hourly rainfall.

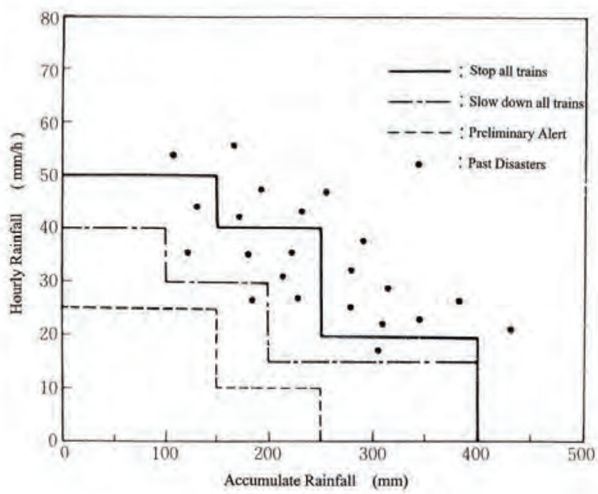


Figure 3.2.12 Train Control Based on Rainfall by Japan Railways[3]

Figure 3.2.13 shows traffic control based on accumulated rainfall and hourly rainfall by Japan Highway Corporation (JH, currently Nippon Expressway Corporation). The shadowed area in Figure 3.2.13 is considered to be the critical stage of slope failure.

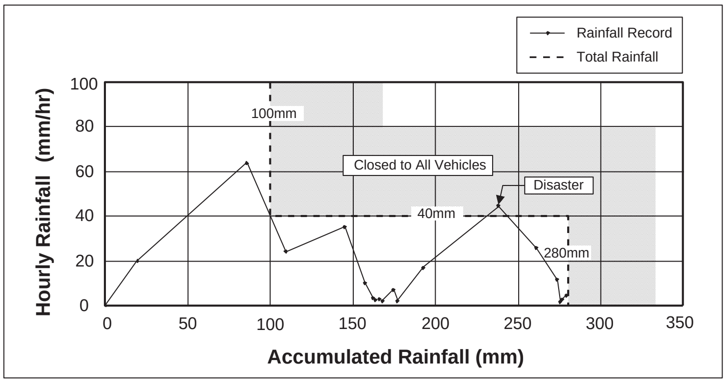


Figure 3.2.13 Time to Slope Failure – Strain Speed (Wire Extensometer)[4]

a.4 Effective Rainfall Method

Effective rainfall is defined as the accumulated rainfall with attenuation by the run-off effect of preceding rains. It is explained by the following formula:

$$R = \sum AiRi$$
(Ai = 0.5 i/T, T : half life of water level in the ground (depend on geology))

The relationship between rainfall and disasters has been clarified based on 15 years of data and graphed as shown in Figure 3.2.14. The example in the figure shows that the disasters increased in 80 - 130 mm of effective rainfall. Based on this result, the criteria rainfall could be established as 80 mm of effective rainfall.

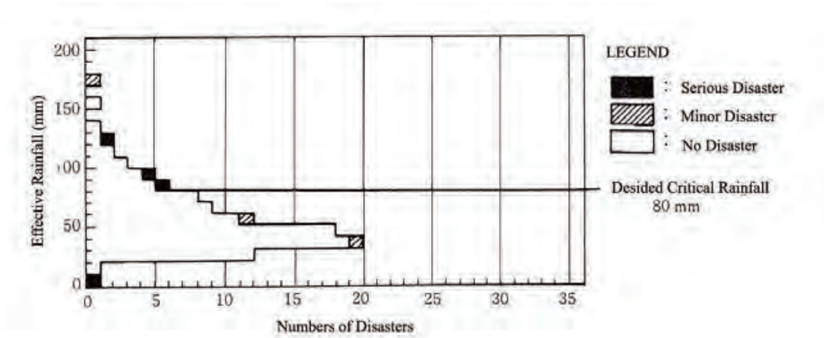


Figure 3.2.14 Effective Rainfall with Disasters[4]

a.5 Water Storage in-Soil Method

The change of water volume in the soil is evaluated using tank model analysis. It is disaster prevention information that the Meteorological Agency announces when the risk of sediment disaster arises in heavy rain, based on the Soil Water Index (SWI). The SWI indicates the content of rainwater in the ground. The SWI is expounded with tank model. With precipitation as input data into a model composed of a series of three tanks laid vertically, the index is the total amount of water heights of the three tanks.

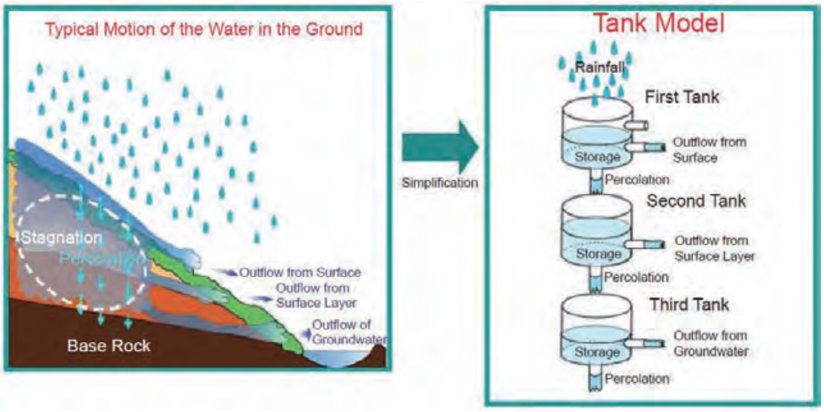


Figure 3.2.15 Tank Model (source: JET)

The Tank Model makes it possible to clarify the separation of surface runoff and percolation of rainwater into the ground. Furthermore, the mechanism of water seepage into the ground described by the Tank Model could provide effective alternatives of slope stability analysis of the slope in the rain.

First Tank

$$S_1(t+\Delta t)=(1-\beta_2\Delta t)\cdot S_2(t)-q_2(t)\cdot\Delta t+R$$

Second Tank

$$S_2(t+\Delta t)=(1-\beta_2\Delta t)\cdot S_2(t)-q_2(t)\cdot\Delta t+\beta_1\cdot S_1(t)\cdot\Delta t$$

Third Tank

$$S_3(t+\Delta t)=(1-\beta_3\Delta t)\cdot S_3(t)-q_3(t)\cdot\Delta t+\beta_2\cdot S_2(t)\cdot\Delta t$$

$$\text{Soil Precipitation Index}=S_1(t+\Delta t)+S_2(t+\Delta t)+S_3(t+\Delta t)$$

S_1, S_2, S_3 : Height of Water in Each Tank
$\beta_1, \beta_2, \beta_3$: Coefficient of Permeability of Permeable Hole of Each Tank
q_1, q_2, q_3 : Outflow from Side Holes of Each Tank

$$q_1(t)=\alpha_1\{S_1(t)-L_1\}+\alpha_2\{S_1(t)-L_2\}$$

$$q_2(t)=\alpha_3\{S_2(t)-L_3\}$$

$$q_3(t)=\alpha_4\{S_3(t)-L_4\}$$

$\alpha_1, \alpha_2, \alpha_3, \alpha_4$: Coefficient of Outflow from Each Outflow Hole
L_1, L_1, L_1, L_1 : Height of Each Outflow Hole

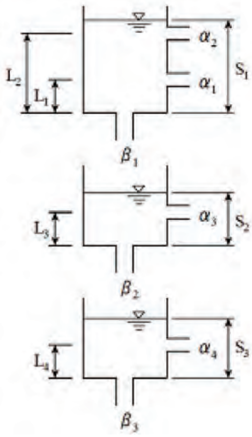


Figure 3.2.16 Tank Model[5]

Table 3.2.3 Parameters in Tank Model by JMA[5]

Parameters in Tank Model by JMA

	1st Tank	2nd Tank	3rd Tank
Heights of Outflow Holes (mm)	L_1 = 15 L_2 = 60	L_3 = 15	L_4 = 15
Coefficient of Outflow (1/hr)	α_1 = 0.1 α_2 = 0.15	α_3 = 0.05	α_4 = 0.01
Coefficient of Permeability (1/hr)	β_1 = 0.12	β_2 = 0.05	β_3 = 0.01

Ishihara & Kobatake (1979)

(ΔT = 20 min)

b. Criteria of Warning in Mauritius

Example of the criteria of warning on extensometers in Mauritius

There are three ways of using the displacement of extensometers for the landslide warning system: total displacement, daily displacement and hourly displacement. Small landslides, which account for most of the landslides in Mauritius, move fast immediately after they are activated, and their moving speeds are not constant. A short period of displacement of the extensometer such as an hourly displacement is not suitable for the warning system in Mauritius. The total displacement of the extensometer is not suitable in Mauritius either because many landslides in Mauritius are always moving, even in the dry season. Therefore, landslide management based on the daily displacement is the best way in Mauritius.

Extensometers were installed in two landslide risk areas, Chitrakoot and Vallée Pitot.

The criteria are obtained based on the relationship between the displacement of the extensometer and the landslide disaster. A landslide disaster occurred in Vallée Pitot on 25 February 2013, and a house was partially destroyed. The extensometer had been installed near the site of the disaster, and it recorded a big displacement of the landslide. The start of the displacement was recorded by the extensometer three days before the disaster. The total displacement in the three days leading up to the disaster was 54.2mm, the maximum daily displacement recorded two days before the disaster was 30.7mm, and the maximum hourly displacement was 1.9mm, as shown in Figure 3.2.17. The daily displacement of 30.7mm has been the biggest daily displacement recorded by all extensometers installed in the project.

Based on the relationship between the landslide disaster and the records of the extensometer in Vallée Pitot, a displacement of 30.4mm/day is the critical value to be evacuated. For the criteria for evacuation and warning, 20mm/day displacement of the extensometer is decided the criterion for evacuation with a safety factor of 50%. A 10mm/day displacement of the extensometer, which is half of the evacuation criterion, is the criterion for warning. These criteria have been decided based on only one landslide disaster. They may be reconsidered with the accumulation of records by the extensometers and landslide disasters.

Criterion for Evacuation: 20mm/day

Criterion for Alert: 10mm/day

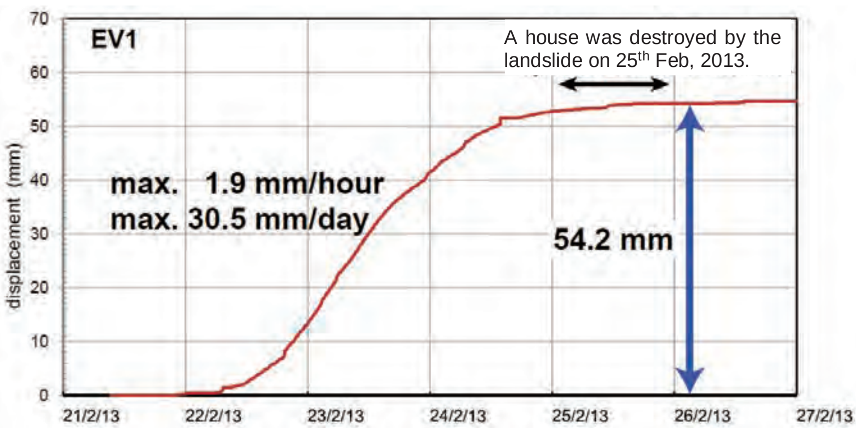


Figure 3.2.17 Record of the Extensometer on the Event of Disaster in Vallée Pitot (source: JET)

Example of the criteria of warning on extensometers in Mauritius

As there is not many records of the hourly precipitation at landslide disasters in Mauritius, the accumulate rainfall method is the best method in Mauritius. Figure 3.2.18 shows the relationship between precipitation and disasters in Chitrakoot and Vallée Pitot in Mauritius.

In Chitrakoot in 2005, landslides damaged houses with 376mm of accumulated rainfall. However, there was no damage to houses with 167mm of accumulated rainfall. In 2008 in Chitrakoot, landslides damaged houses with 117mm and 176mm of accumulated rainfall. In 2013, the extensometer recorded big displacements with over 100mm of accumulated rainfall. Although there are some exceptions, displacements of the ground could increase in over 100mm of accumulated rainfall and landslide disasters could occur in over 120mm of accumulated rainfall. Therefore, the criteria for evacuation in Chitrakoot can be 100mm of accumulated rainfall.

In Valee Pitot in 2007, landslides damaged houses with 385mm of accumulated rainfall. In 2013 in Vallée Pitot, a landslide damaged a house with 100mm of accumulated rainfall and the extensometer recorded big displacements. The criterion of the risk level of landslides in Valle Pitot is 100mm of accumulated rainfall.

Proposed criteria of warning by extensometers and rain gauges

Based on the results of the extensometers and rain gauges and the records of disasters in Mauritius, the criteria for the risk levels of landslides were determined. Table 3.2.4 shows the proposed criteria for the risk levels of landslides determined based on the monitoring records in this project and the disaster records.

Table 3.2.4 Proposed Criteria of Risk Levels in Mauritius (source: JET)

Stage		Monitoring	Criterion
Stage 1	Alert	Accumulated rain fall Ground displacement	75 mm 10 mm / day
Stage 2	Evacuation	Accumulated rain fall Ground displacement	100 mm 20 mm / day
Stage 3	Termination	Accumulated rain fall Ground displacement	No precipitation for 6 hours 0 mm/ 6 hours

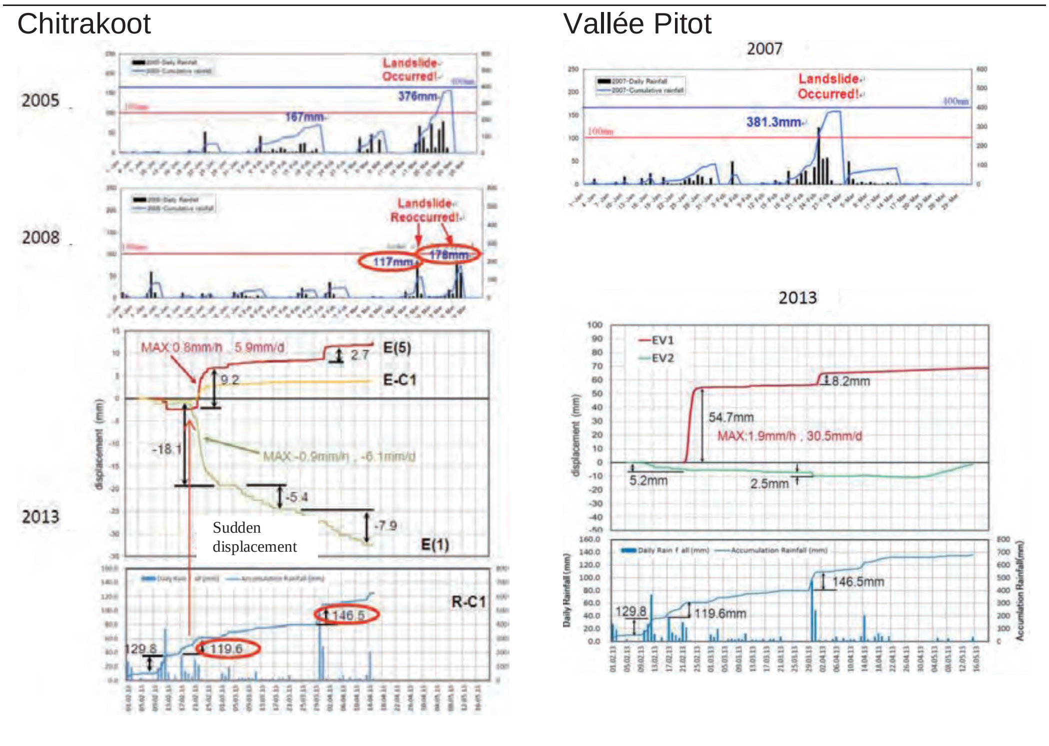


Figure 3.2.18 Relation between Precipitation and Disasters (source: JET)

3.3 Emergency Communication and Evacuation

3.3.1 Emergency Communication

There are many types of in-situ alarm systems but most of them warn with sound or light. Sirens are mostly sirens for sound alarms, but horns and bells are also used. For light alarms, is mostly a beacon, but sometimes a light bulb, a flush are used. In order to transfer the light or sound warning to all the residents in the area, a person must be assigned to monitor the light and sound devices. Therefore, the light and sound devices must be installed in a place where the person can see and hear the alarm.

NDRRMC controls the information in an emergency but technical information must be controlled by the landslide experts.

Figure 3.3.1 shows the recommended flow of the warning including the landslide warning system. All the warnings and information from the warning devices or the designated inhabitant should be channelled to the police and NDRRMC. All the information from the monitoring instruments and devices, and designated inhabitant must be transferred to MPI.

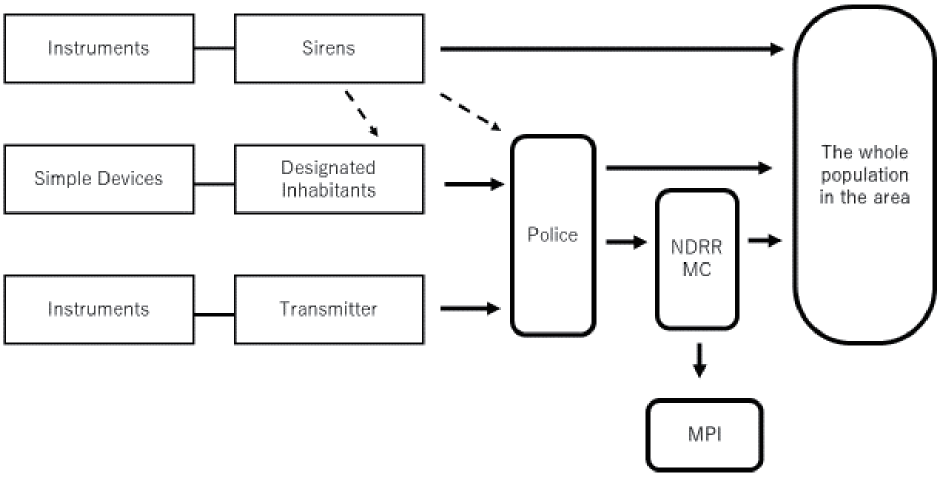


Figure 3.3.1 Flow of the Landslide Warning

A warning from the instruments in the landslide warning system is issued in three ways. First, the warning is issued by sirens from an alarm device directly to the population in the landslide risk area. Second, the police receives the warning from the instruments and the designated inhabitant in the landslide and third, the designated inhabitant transfers the warning based on the simple devices or his observation to the police.

When the warning is issued from an alarm device

The sound alarm in a warning system emits a loud sound to warn all people in the area like a fire alarm system in a building. The sound alarm is expected to reach all people in the area. Therefore, a number of sound alarm devices should be installed in the area. All the people in the area must be aware of the alarm system when the system is installed.

Furthermore, communication among residents in the risk area is very important to warn people in the area who may not hear the alarm due to bad ears or because they are listening to music with head phones. People in the area should be able to hear the sound alarm, and police should be notified of the alarm by the designated inhabitant assigned to the warning system.

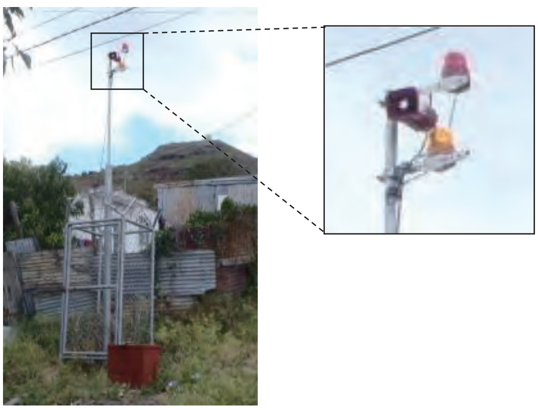


Figure 3.3.2 The in-site Alarm Devices,
Sound and Light, Vallée Pitot (source: JET)

When the NDRRMC receives the warning

If the data and alarm transmitter are attached to the instruments of the warning system, the alarm should be sent to the control office that receives the data and the alarm. The control office should be established in NDRRMC and NDRRMC should call to MPI to confirm the monitoring data sent from the warning system. MPI dispatch a landslide expert to the site for the technical advice to NDRRMC and police.

3.3.2 Evacuation

Injuries to the people in landslide disasters are due to being buried under the debris of the houses destroyed by the landslide. The victims of landslide disasters are usually only the people in residential houses in the landslide. Therefore, when a landslide warning is issued, residents in the landslide risk area should escape to anyplace away from the landslide risk area or out of their houses. A refuge, if established, should not be used to secure the lives of people but used as a shelter for the people whose houses have been destroyed.

The evacuation of residents should be controlled by the police, NDRRMC and Special Mobile Force.

3.4 Landslide Warning without Instruments

Landslide disasters are caused by only the motion of the ground. Even with heavy rain, a landslide disaster would not arise without ground deformation. On the other hand, without rainfall, a landslide could be activated by an increase in groundwater pressure caused by water from out of the landslide other than rainwater or by human activity. In this sense, a warning by the extensometer may be more accurate than by the rain gauge. However, the extensometer cannot cover the entire landslide risk area if the landslide consists of a number of blocks. Even if the extensometer of the warning system is not issuing a warning, a landslide disaster at another landslide block could arise. In other words, the rain gauge can cover a wide area but is not so accurate while the extensometer is accurate but can only cover a limited area.

Since the residents normally do not have professional knowledge of landslides, unusual things the residents find may not be caused by a landslide. MPI must confirm the cause of the unusual things the residents find. MPI should also educate the residents in the landslide risk area about landslides (i.e. what are the signs of landslides).

The signs of a landslide are listed as follows by the United States Geological Survey (USGS).

- Springs, seeps, or saturated ground in areas that have not typically been wet before.
- New cracks or unusual bulges in the ground, street pavements or sidewalks.
- Soil moving away from foundations.
- Ancillary structures such as decks and patios tilting and/or moving relative to the main house.
- Tilting or cracking of concrete floors and foundations.
- Broken water lines and other underground utilities.
- Leaning telephone poles, trees, retaining walls or fences.

- Offset fence lines.
- Sunken or down-dropped road beds.
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content).
- Sudden decrease in creek water levels though rain is still falling or just recently stopped.
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb.
- A faint rumbling sound that increases in volume is noticeable as the landslide nears.
- Unusual sounds, such as trees cracking or boulders knocking together, might indicate moving debris.

Reference

1. Turner, A, K, and Schuster R, L, 1996, Landslides, Investigation and Mitigation Special Report 247, National Academy of Science, USA
2. Saito,1968, Study on Prediction of Slope Failure, Railway Technology Railway Technical Research Institute Report No.626 (Japanese)
3. JR East, 1990, Reference to the regulations for railway operations in precipitation (Japanese)
4. Japan Highway Corporation Tokyo Administrative Bureau, 1998, Report on Criteria of Traffic Control based on the Precipitation (Japanese)
5. Japan Meteorological Agency <http://www.jima.go.jp> (Japanese)

4 Relocation Support and Compensation

4.1 Confirmation of the Legal Systems and Schemes

It is required to comprehend the basis acts of legal systems and schemes regarding the development restrictions and land-use controls to coordinate with related ministries/agencies/local authorities and review existing regulations.

The following figure shows legal systems/schemes which have a relationship with landslide disaster risk management (hereinafter LDRM) in Mauritius. The existence of the relevant legal systems/schemes in the object area should be confirmed for each site.

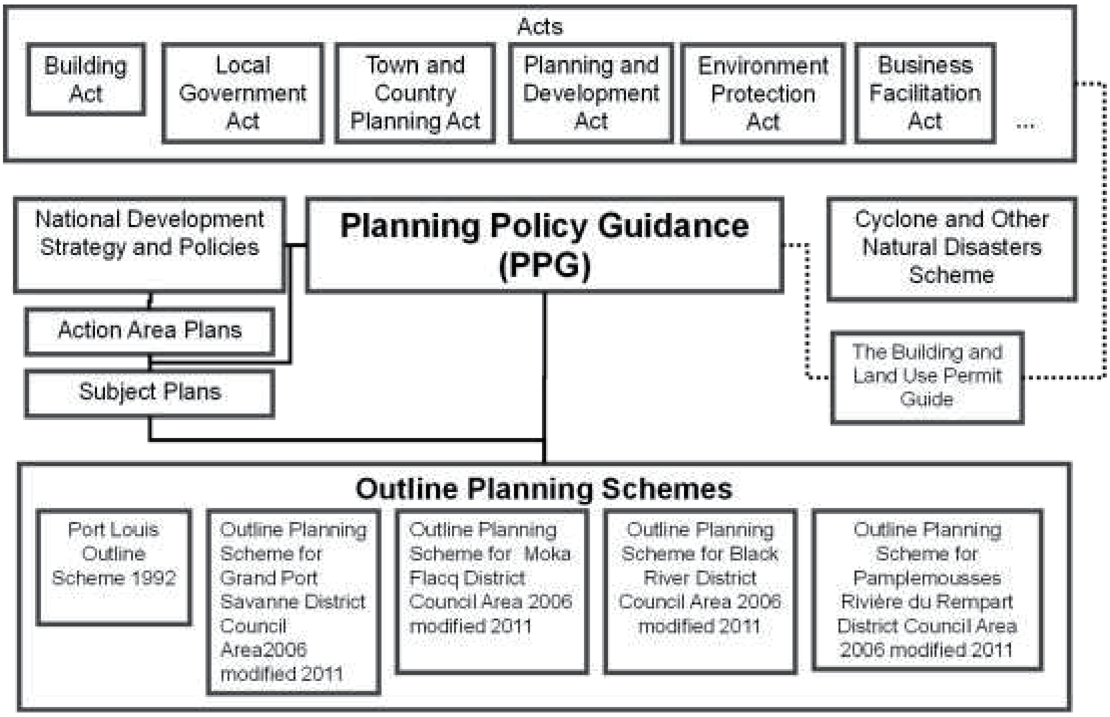


Figure 4.1.1 Acts and Schemes related with LDRM (source: JET)

The following table shows the detailed content of the principal legal systems/schemes related to LDRM.

Table 4.1.1 The Existing Mauritian Legal Systems/Schemes for LDRM (source: JET)

Legal system/scheme	Content
Planning and Development Act (PDA)	• The Planning and Development Act (PDA) is a new and modern piece of legislation enacted to bring the planning exercise more in line with the requirements of today's changes and challenges (globalization, structural changes in the economy, the need to provide for new sectors of activities). • It gives legal status to the National Development Strategy which had remained as a vision document only. • However, only a few sections of the PDA 2004 have been proclaimed to date. • The objectives of PDA: Sustainable development considering ecological systems; to provide for the appropriate sharing of

	responsibility for planning and development between the different levels of government; to establish appropriate institutions, structures and processes to achieve effective planning and development; to encourage appropriate private sector participation in planning and development, etc. ・ The Minister of the Ministry of Housing and Lands (MHL) is able to issue Planning Policy Guidance (PPG) regarding development and land use planning to the Local Authorities based on this Act (Article 13 of PDA).
Local Government Act (LGA)	・ The Local Government Act (LGA) is very closely related to the Local Authorities' jurisdiction over development plans. In particular, it covers decentralisation, appropriate financial and administrative operation, procedures for development permission, property taxation etc. ・ The LGA also contains the powers and functions of the Permits and Licences Committee, applications for permits, examination of applications for permits and licences by the committee, application to Judge in Chambers, etc.
National Development Strategy (NDS)	・ National Development Strategy (NDS) aims to adopt strategic guidance for the economic infrastructure development of government and local authorities with the goal of achieving development in a planned manner. ・ NDS is made up of two volumes: Volume 1, National Development Strategy & Policies, and Volume 2, Institutional and Legislative Aspects. ・ Volume 1 contains the introduction, context, vision and key development principles, core strategy for conurbation, countryside and coast, housing, social and community facilities, industry and commerce, tourism, agriculture, forestry, natural resources, environment and fisheries, transport, physical infrastructure. In the contents of the core strategy for conurbation, countryside and coast, the PPG is defined as a translated national strategy, namely, made easier to understand, for Local Authorities to actually achieve NDS implementation. ➢ Guidance notes are intended for use by officers involved in development control activities at central and local levels. ➢ It is expected that PPG will be an important element in preparing Local Councils' revised Local Plans and Action Area Plans by translating the NDS policies and principles for application at the local level. ➢ To provide this bridge between policy and implementation, a series of PPG notes has been prepared consistent with the NDS and policies and relevant Local Development Plans (Outline Planning Schemes) as revised.
Planning Policy Guidance 9 (PPG 9)	・ A Planning Policy Guidance is prepared and issued to Local Authorities under Section 13 of the Planning and Development Act (PDA) 2004 which stipulates that "Every local authority to which planning policy guidance is issued shall comply with such guidance" and "A planning policy guidance shall prevail, to the extent of any inconsistency, over a development plan whether the development plan was made before or after the planning policy guidance." ・ PPG 9: Development on Sloping Sites and Landslide Hazard Areas is effective since 28 March 2016. ・ PPG 9 is prepared to control and guide development over sloping sites with a view to protecting life and property. It should be used as a precautionary approach in determining development applications for such sites. ・ This Planning Policy Guidance serves as an additional statutory level of control besides the control provided as regards zoning in the

	relevant Outline Planning Schemes and guidelines issued under the Disaster Risk Reduction Strategic Framework and Action Plan. ・ It further intends to guide and assist developers, planners, relevant stakeholders and the general public in submitting and processing of development applications on sloped terrain ・ According to Section 5 of PPG 9: - as a general guide development should not be any higher than 45 metres above the mountain base, or in the case of slopes facing the sea, 45 metres above Mean Sea Level; and - development is not allowed on slopes greater than 20% ・ As per Section 8 of PPG 9, “Normally no new development would be allowed in landslide zones due to likely risks of heavy damage to life and property.”
Outline Planning Schemes (OPS)	Outline Planning Schemes (OPS) were legally established based on the TCPA. They are planned for each Local Authority. OPS have three functions: ・ To provide guidance to scheme promoters, developers and individuals contemplating a development project and the subsequent submission of a building and land-use permit application; ・ To assist Government officers at Ministry and Local Authority levels when offering advice to developers and when subsequently assessing permit applications; and ・ To provide the physical development focus for programmes and projects for the variety of Ministries and agencies, as well as the private and non-governmental sectors which have an interest in land development. The Outline Planning Schemes are in two parts: ➢ The Text section which includes: ✧ The Development Context for the Scheme which outlines key development trends, constraints, issues and objectives, and ✧ The Policies and Proposals, which are written in bold, followed by their reasoned justification. The policies are grouped together according to particular subject matter or by land-use type. ➢ The Map section which includes: ✧ The Development Strategy Map, covering major proposals for the whole of the District, and ✧ The Development Management Map, which shows settlements and zones where development is likely to be permitted and other areas where there are various constraints to development.

4.2 Confirmation of the Development Restriction/Land-use Control

The confirmation of the object area’s current situation is based on the investigation of development restriction, land-use control, act, planning scheme and is required for the implementation of the initial survey. This section describes the agenda items and points of these investigations which also are required in the initial survey.

The investigation items for the initial survey plan are as shown in the following.

- Settlement Boundary by Development Management Map in Outline Planning Scheme

- Environmentally Sensitive Area by The National Development Strategy

- Suitable Agricultural Land by The National Development Strategy
- Urban facilities such as parks, roads, sewage system, rivers and schools.
- Local Plans, Action Area Plans and Subject Plans
- Other related plans, schemes, frameworks, etc.

Following figure shows an example of the settlement boundary and a landslide prone area. According to the Outline Planning Scheme (OPS), which covers areas that are prone to landslides, such areas are designated as developable land upon gaining approval for development from the Local Authority (see figure below, orange coloured boundary shows the developable area and black frame shows the landslide prone area).

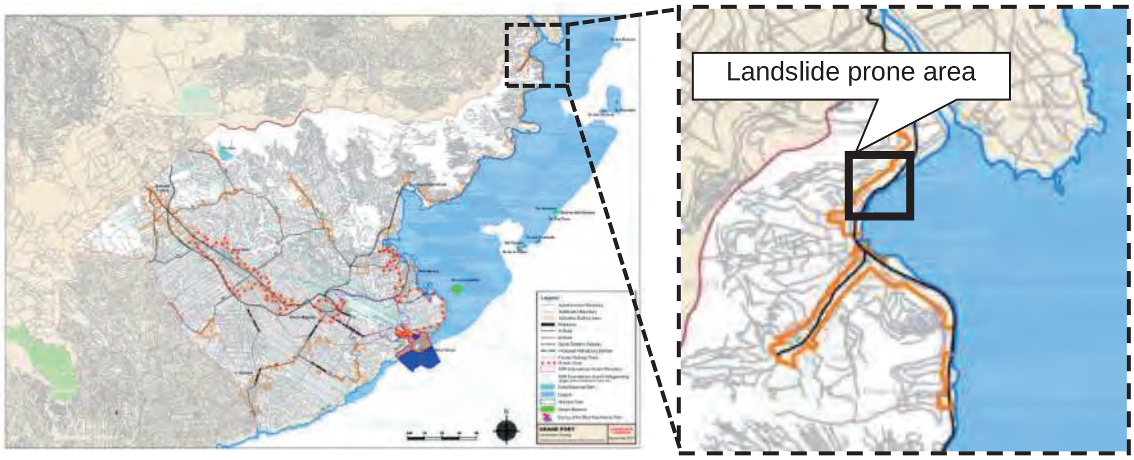


Figure 4.2.1 Example of a Settlement Boundary[i]

The information collection and examination regarding the development restrictions, land-use controls, hazard maps, existing research/studies and other related data are needed before the initial survey is conducted from the viewpoint of disaster risk management.

Additionally, the following information should be considered, if the object area is applicable with the disaster record/hazard map, and if there is an applicable area with the above regulation in/around the object area. Furthermore, it is required attention for location/position, extent, degree of risk and other factors in the record/hazard map.

- Landslide disaster damage record/map
- Topographical/geological condition map
- Flood disaster damage record/map
- Assumed flood area map
- Hazard map of landslides, slope failure, floods, etc.

The examination of problems regarding the development restriction/land-use control is required through the evaluation of the existing study/project, the data collection and hearing investigations/meetings with related ministries, agencies and local authorities.

The location of a development project is inclined to focus on site acquisition, transportation convenience, land-use plan, ambient surrounding and other factors; however topographical/geological conditions and ground/soil situations tend to be neglected. For this reason, the development project may need to be forced to increase its budget, delay the project implementation schedule and change its land-use plan from the viewpoint of disaster mitigation in works implementation phase.

The current circumstances and conditions are that there is little understanding in the new development area because so far land use has been low intensity and problems have not been encountered first hand. Therefore, in order to comprehend the development, the current information of the surrounding area needs to be surveyed. Also, the investigation of drainage systems, old and current rivers, water utilization and residential land development situations is needed.

4.3 Basic Concept of the Hazard Zone for Development Restriction

Planning Policy Guidance 9 (PPG 9) for Development on Sloping Sites and Landslide Hazard Areas is effective since 28 March 2016.

The following provision under PPG 9 are applicable:

- According to Section 5:
  - as a general guide development should not be any higher than 45 metres above the mountain base, or in the case of slopes facing the sea, 45 metres above Mean Sea Level; and
  - development is not allowed on slopes greater than 20%

- As per Section 8, “Normally no new development would be allowed in landslide zones due to likely risks of heavy damage to life and property.”

- Development on slopes may be allowed on:
  (a) Slopes below 20% where the integrity of existing slopes is retained on submission of information (**Site Constraint Analysis)** as per the following check list:
    - Topographical Map (contour intervals, property lines, ridgelines, rock outcrops, cliffs and slope transition and breaklines).
    - Geotechnical Evaluation if needed.
    - Slope analysis.
    - Constraints analysis (geology, hydrogeology, utility services, soils, vegetation, wildlife etc.).
    - Existing drainage course.
    - Building locations and foundation design.
    - Effect of surcharge due to proposed structures, retaining walls and future site grading for building platforms and accesses.

  (b) Development on slopes of average gradient of more than 20% with pockets below 20% exceptionally where the steep sections are limited to horizontal run of less than 10 metres and provided that there is a slope stability analysis by a qualified geotechnical engineer, creative design solution, risks to public safety mitigated and supported by the submission of relevant information.

- A Geotechnical Report for slope stability prepared by a qualified geotechnical engineer

/registered Civil Engineer is required for all sites where existing or final design grades reach a 20% gradient or where slope stability is an existing concern.

At the minimum, the required stability report should contain the following information:

- Property lines, easements and right of ways
- Stability limit, established with respect to most probable adverse ground water and loading conditions.
- Top of embankment or escarpment.
- Toe of slope.
- Soil types.
- Existing drainage course, Effect of ground water table and assessment of existing surface and subsurface conditions.
- Vegetation cover extent and types disturbed or native.
- Where the development at the toe of the slope is proposed, the report shall address the effect and extent of slope failure on the subject land and the adjacent properties and remedies to mitigate any failure.
- Erosion control and other mitigation measures e.g. drainage works, grading etc.
- Building foundations and foundation types.
- Effect of surcharges due to proposed structures, retaining walls and future site grading.

- Drainage Management Plan**:** Plans for all development on sloping sites must indicate how storm water run-off will be impacted by the development and how those impacts will be mitigated.
  Depending on the size of the development and complexity of the site conditions on steeper slopes, special attention must be paid to:
  - Hydrological conditions prior to and after development;
  - Protection of natural flow paths, volumes and storage resources;
  - Impacts on trees, vegetation and other environmental features due to changes in drainage patterns;
  - Water quality prior to, during and after development;
  - Sediment and erosion control;
  - On and off-site drainage impacts (e.g., drainage from an upper lot to a lower lot); and
  - Measures taken to prevent other properties being adversely affected by the proposed development.

Identification of landslide zones requires a thorough knowledge of geomorphology, geological structure of rock type of area and their reaction to external and internal forces. A slope experiences two sets of stresses, one set holding the slope together (**shear strength**) and the other acting to move material downslope (**shear stress**). When shear stress exceeds shear strength, the slope fails and a landslide occurs. Land with steep slopes should therefore be assessed with rigor, especially for any trigger of potential damage.

Identification and designation of landslides zones by the Japan International Cooperation Agency (JICA)

Three areas have been identified by JICA so far as actively experiencing landslides. They are Chitrakoot, Quatre Soeurs and Vallée Pitot**.**

The following contents are criteria for development control in the designated areas of the Landslide Hazard Zone and Slope Failure Hazard Zone.

<Risk Management for Landslide Disaster>

A Hazard Zone is designated by the following criteria:

- Landslide area Landslide Hazard Zone (Yellow Zone - see diagram) is an area where inhabitants and buildings may be damaged when a landslide occurs. It is an area where landslide has been active in the past and though inactive presently, may be prone to future landslide activity in future (area which is currently prone to landslides or possibly vulnerable to landslides in future).
- Special Hazard Zone (Red Zone – see diagram) is an area where inhabitants and buildings are expected to sustain heavy damage when a landslide occurs. It forms part of an active landslide block and an area below the bottom end (toe) of the landslide block that may be impacted by a landslide activity.
- Authorized research/study achievements by ministries and agencies (Example: Areas evaluated as more than a Medium rank of Landslide Hazard in the "Disaster Risk Reduction Strategic Framework and Action Plan, Ministry of Environment and Sustainable Development, 2012")

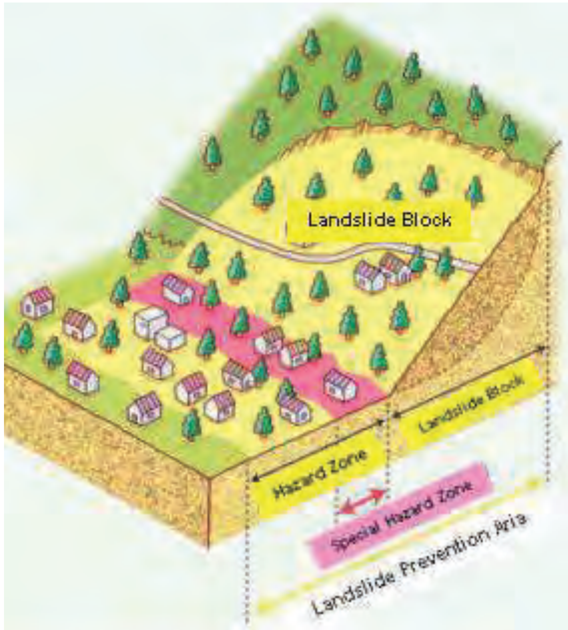


Figure 4.3.1 Landslide Hazard Zone[ii]

Table4.3.1 Designation of the two hazard zones (source: JET)

Landslide Hazard Zone (Yellow Zone) is designated as:	**Landslide Special Hazard Zone** (Red Zone) is designated as:
land potentially prone to instability/landslides.	land potentially prone to instability/landslides.
land with recorded history of landslide activity.	land having geomorphologic setting similar to those having recorded history of landslide activity.
an area within a distance equivalent to the length of the landslide mass from the bottom end of the landslide block (250m if the length of the landslide mass is longer than 250m)	an area within 60m from the bottom end (toe) of the landslide block

Development will not normally be permitted in a Hazard Zone. When designating a Hazard Zone, it should be publicized in advance, as well as finding out the opinions of ministries/agencies/local authorities.

When it is recognized that there is no longer any reason for the Hazard Zone designation because countermeasures for landslides have been undertaken, the Hazard Zone shall be rescinded in whole or partially through the same procedure of public notification and enquiry of opinions on the designation.

<Risk Management for Slope Failure>

The Hazard Zone is designated by the following criteria.

- Area having a slope gradient of 30 degrees (57.7% or 1 in 1.7) or more and slope height of 5m or more
- Area within a 10m horizontal distance from the edge of ridges and cliffs
- Area within a distance twice the slope height from the base of a slope (50m if the slope height is more than 50m)
- A slope failure hazard area identified by authorized research/study achievements of ministries and agencies

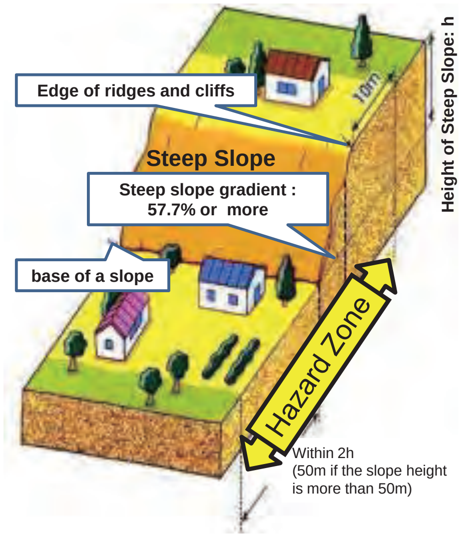


Figure 4.3.2 Slope Failure Hazard Zone[iii]

Development will not normally be permitted in the Hazard Zone.

When designating a Hazard Zone, it should be publicised in advance, as well as finding out the opinions of ministries/agencies/local authorities.

When it is recognised that there is no longer any reason for the Hazard Zone designation because countermeasures for the slope failure have been undertaken, the Hazard Zone shall be rescinded in whole or partially through the same procedure of public notification and enquiry of opinions on the designation.

4.4 Confirmation of the Proposed Landslide-Prone Areas and Landslide Hazard Zones

In the Project of Landslide Management in the Republic of Mauritius by JICA (hereinafter the Project), Landslide-Prone Areas and Landslide Hazard Zones are proposed to identify specific landslide affected areas for concrete and effective structural/non-structural countermeasures, even as the technical transfer for the identification and making a map which includes the information of the Landslide-Prone Areas and Landslide Hazard Zones has been conducted by the Landslide Management Unit (hereinafter LMU) of MPI.

The following figure shows an example of a sample image of a Landslide-Prone Area and a Landslide Hazard Zone.

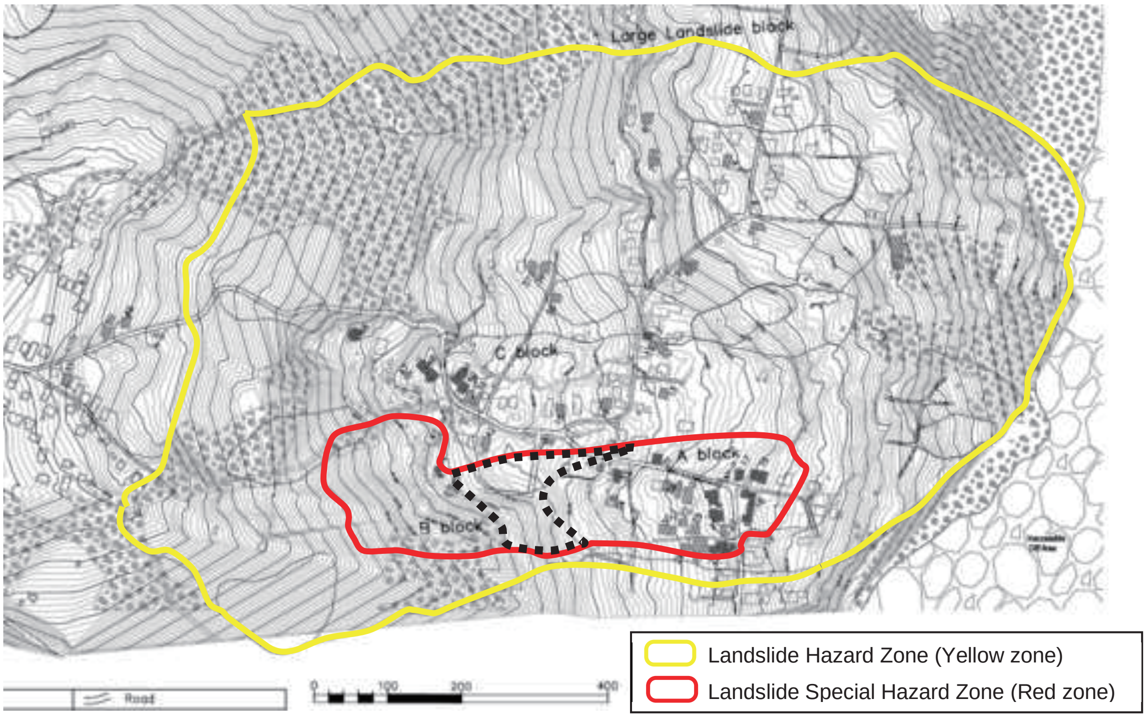


Figure 4.4.1 Example of a Landslide-Prone Area and a Landslide Hazard Zone (source: JET)

< Landslide-Prone Area>

- There is a possibility of occurrence of landslide disaster by development, climate change and others.
- Landslide-Prone Area is less active compared with a Landslide Hazard Zone.

< Landslide Hazard Zone >

- An area which poses a danger to the lives/bodies of the residents and building damage when a landslide disaster occurs in a Landslide-Prone Area.
- Area within a distance equivalent to the length of the landslide mass from the bottom end of the landslide area (250 m if the length of the landslide mass is longer than 250 m)
- Landslide area (area which is currently prone to landslides or possibly vulnerable to landslides in future)

When a landslide occurs or there is a concern of a landslide disaster occurring at a site, it should be checked whether the site is in a Landslide-Prone Area or a Landslide Hazard Zone to confirm the existing landslide block, affected area and others.

4.5 Identification of the Target Areas for Relocation and Compensation

(1) Initial Survey for Relocation

In the initial survey, the information which is shown on the following table will be collected through an interview survey of inhabitants and reconnaissance of a site. Based on the survey result, the basic policy of the response to the landslide disaster damage area such as countermeasure works, non-structural countermeasure and necessity of the relocation is considered by the related ministries/agencies.

In case the deliberation reaches a conclusion that relocation is necessary, the explanation of the relocation project will be conducted for the inhabitants (explanation of the survey result, the purpose of the relocation project and its schedule; as well as to obtain consent of detailed survey, etc.)

Table 4.5.1 Items and Content of the Initial Survey for Relocation (source: JET)

Category	Item	Content
Basic information of the affected area	Date and time of occurrence	year-month-day-time format
	Address, place name	
	Number of the victims	Total ___ persons (adult__, children__, vulnerable people)
	Class of disaster	Landslide, Slope failure, other ( )
	Number of damaged buildings	Total ___ buildings (houses ___, other ___)
	Extent of disaster damage	East to west ___m x North to south ___ m (___m2)
Basic condition of the affected area	Name of the hazard area	_____ Landslide Area
	Type of the hazard	Landslide-Prone Area, Landslide Hazard Zone, other ( )
	Designation date of the hazard area	
	Current situation of the disaster measures	Complied with, in operation, under review, other ( )
Basic information of the victims (head of the household)	Name	
	Address	(plot on a map)
	Age	
	Contact information	
	Occupation	
	Family structure	
Basic information regarding the affected lands	Name of owner/lessee	
	Date and time of disaster damage occurrence	year-month-day-time format
	Address	(plot on a map)
	Area	___m2
	Use	Residential, Commercial, Agricultural, Industrial, Forestry, Other ( )
	Possession type	Private, leased (private-owned, nationally-owned)
Basic information regarding the affected buildings	Name of owner/lessee	
	Date and time of disaster damage occurrence	year-month-day-time format
	Address	(plot on a map)
	Area	___m2
	Use	Residential, Commercial, Agricultural, Industrial, Forestry, Other ( )
	Possession type	Private, leased (private-owned, nationally-owned)

(2) Detailed Survey of the Land, Buildings and Others for Relocation

The information regarding the right of the land, buildings and others should be confirmed to implement the appropriate and effective work for relocation. In the detailed survey, the information which is shown on the following table will be collected through an interview survey of inhabitants, reconnaissance of a site, investigation of cadastral data/registration records, land survey and investigation of the buildings.

Table 4.5.2 Item and Content of the Detailed Survey for Relocation (source: JET)

Category	Item	Content
Detailed information of the victims	List of the victims (entire family)	Name, Address, Age, Contact information, Occupation, Relationship in family structure, Amount of revenue
	Situation of land acquisition for the relocation	Acquired (own land, lease) or Not acquired. (In case of acquired, address: ___)
	Situation of building acquisition for the relocation	Acquired (own building, lease) or Not acquired. (In case of acquired, address: ___)
	Necessity of the relocation	
	Conditions of a location for the relocation	
Detailed information of the damage about the land	Name of owner/lessee	
	Address of the land	(plot on a map)
	Address of the owner	
	Date and time of disaster damage occurrence	year-month-day-time format
	Condition of the damage	Buried in the ground, Swept away, other ( )
	Area of the land	
	Use	Residential, Commercial, Agricultural, Industrial, Forestry, Other ( )
	Photo of the damage	
	In case of own land, situation of a loan	Date of borrowing, Debt balance, Lender, Borrowing period
	In case of leased land	private-owned or nationally-owned, Name/address of lessor, Lease period, Rent, Other conditions
Detailed information of the damage about the building	Name of owner/lessee	
	Address of the building	(plot on a map)
	Address of the owner	
	Date and time of disaster damage occurrence	year-month-day-time format
	Structure of the building	Concrete block, Reinforced concrete, Steel, Steel framed reinforced concrete, Wooden, Other ( )
	Condition of the damage	Complete destruction, partial destruction, buried in the ground, swept away, other ( )
	Area of the building	Total ___m2 (1st floor ___m2, 2nd floor ___m2, 3rd floor ___m2, other ___m2)
	Use	Residential, Shop, Storage, Office, Workshop, Other ( )
	Damage in parts and hazardous situation	Roof ( ), Frame structure ( ), Wall ( ), Fittings ( ), Floor ( ), Foundation ( ), Other ( )
	Photo of the damage	
	In case of own house, situation of a loan	Date of borrowing, Debt balance, Lender, Borrowing period
	In case of leased house	private-owned or nationally-owned, Name/address of lessor, Lease period, Rent, Other conditions

The confirmation of the possessor, right holder and other stakeholders is required through the clarification of the location of the land/building and the registration record based on the investigation of the cadastral map of Ministry of Housing and Lands (MHL). The collected data and materials by the investigation of the cadastral map and registration record contain the personal information. The information must not be used for anything besides the intended purpose and the information must be managed carefully.

The land survey will be conducted after the location of the subject land of relocation, detailed address, cadastral data, possessor, right holder and other stakeholders are confirmed based on the investigation result of the cadastral map and registration record. The surveyors have to enter the land of the stakeholders to conduct the land survey. It is needed to obtain the stakeholder's consent for and notify them of the intention to enter their land for the survey.

For the investigation of the buildings the consent of the stakeholders needs to be obtained in order to enter their buildings to conduct the investigation. The objects of the investigation are building, machinery, productive facility, barn, plumbing, garden tree, farm product and others.

When the land survey and investigation are finished, the record for each land/building stakeholder should be prepared. And the records are required to be confirmed by stakeholders with their signature.

The landslide area (includes areas of landslide activity and/or extremely high risk of landslide damage) and areas adjacent to a landslide area (has a possibility of triggering a landslide or to have a negative effect on the landslide area) will be examined by the related ministries/agencies based on the survey result to consider the implementation of the relocation.

4.6 Implementation of the Relocation

(1) Basic Policy for Approach to Relocation

Evidently, relocating residents is a complex and challenging procedure, especially without any such actual experience. Furthermore, meetings and negotiations with the inhabitants are required to make adequate preparations for the relocation and to take care of the details. The way of undertaking the relocation should be organized and shared by related ministries to avoid the extension of meetings and negotiations of the relocation due to insufficient planning of meetings, repeating similar or same meetings covering the same topics or issues. The following shows a relocation procedure as a reference.

The recommendation of relocation is one of the ways to promote voluntary action of the inhabitants. However, the decision to comply with the recommended relocation absolutely depends on the residents. Furthermore, imposing an order to relocate or forcing residents to take remedial action should be avoided whenever possible because it infringes on the residents' basic rights. The ultimate goal is to get the residents to relocate of their own free will. Measures to support their actions based on the recommendation to relocate are effective at achieving this goal.

In the case of relocating a building, if it is recognized that the building owner has difficulties undertaking the relocation; measures will need to be taken such as demolition of existing building or acquisition of new land and/or a house. Furthermore, the government, related ministries and agencies and local authorities are required to endeavour to secure arrangements for building relocation.

The meetings regarding the relocation should be held with all households in the t area (not separate meetings) to avoid information inequality, miscommunication, confusion and opaque decision-making process.

(2) Points to Remember for the Implementation of the Relocation

The following points should be remembered when the activities regarding the relocation such as examination of the candidate site, negotiation and others will be conducted:

- The understanding and agreement should be obtained under the condition which is proposed by government side based on the consensus building and enhancement of awareness of the stakeholders regarding the voluntary action for the relocation.

- The appropriate relocation conditions (area of land, location, grade of building, equipment, public facility, etc.) should be considered from the viewpoint of the fairness, and the agreement should be signed with the appropriate conditions.

The responsible organization of the relocation should keep in mind the above points, and try to obtain the consent from the stakeholders regarding the relocation conditions.

(3) Examination of the Candidate Site for Relocation

The candidate site for the relocation has to be located in a safe area from a viewpoint of disaster risk. And, the following points should be examined to keep the equivalent level as the existing circumstances of the target inhabitants of relocation; distance from the origin of relocation to destination (candidate site), traffic accessibility, public services, public facilities, convenience of living, education environment, consideration of the working environment, commuting and others.

When the candidate site is examined, there is a way to ask the support of the National Housing Development Company (NHDC) through MHL, which have been conducting the housing land development. The NHDC should provide the information for the candidate site from their development site.

(4) Proposal of the Candidate Site of Relocation

Proposal of the candidate site of relocation and conditions (land, building, etc.), and feedback from the inhabitants (clear and detailed information is required in the explanation meeting of the proposal, which should be conducted before the agreement stage. The following figure shows an example that explains the conditions of the proposed relocation)

(Candidate site map and site plan)

(Photos of public facilities)

Figure 4.6.1 Example of the Information that Explains the Conditions of the Proposed Relocation (source: JET)

The following points should be considered regarding the land; same or more area/space compared with existing land (origin of relocation) and candidate site, car parking space, garden, shape of the land, positional relationship with road, public facilities and others.

The consideration for the building also will be required to keep the same or more level with existing house such as total area of floor, number of stairs/stories, number of rooms, facility/equipment, plan of a house and others.

(5) Agreement of Relocation between the Government Side and the Inhabitants

If it reaches a final consensus on the relocation between the government side and the stakeholders, the agreement document which has contents of rights, duties, prevention of conflict/disputes in the future and others will be signed. The government side has to explain the contents of the agreement document in the negotiation to obtain the understanding and consent from the stakeholders regarding the relocation conditions at a stage prior to the agreement. When the delivery of lands and buildings is implemented, the regular confirmation about the situation/progress of the relocation will be required without leaving the implementation of relocation by the stakeholders after the conclusion of the agreement. The reminder of the fulfilment of the agreement should be conducted on an as needed basis.

(6) Case Example of Approach/Effort for the Relocation

The following table shows the background and progress of the relocation in Quatre Soeurs according to the interview survey from MPI and MHL.

Table 4.6.1 Background and Progress of the Relocation in Quatre Soeurs (source: JET)

Date	Content
Mar 2005	- Inhabitants of Quatre Soeurs informed the landslide disaster damage to MPI. - MPI conducted the site survey based on the above information.
Nov 2010	- MPI conducted the detailed survey by consulting company. - The relocation was proposed as a countermeasure in the report of the detailed survey - The government started the negotiation for relocation with the inhabitants based on the above proposal in the report.
Dec 2010	- Ministry of Finance and Economic Development (MoFED) tried to evaluate the asset of the inhabitant's land/building based on the survey by MHL and MPI. But It was difficult to evaluate it, they could not obtain the result because of it is difficult to evaluate it.
Mar–May 2011	- The government side and inhabitants visited the candidate site of the relocation two times. - They could not obtain consensus for relocation.
Dec 2011	- MHL proposed the "Camp Ithier" where has been developed by National Housing Development Company (NHDC) as a candidate site of the relocation - They could not obtain consensus because there is difference between government's proposal and inhabitant's request regarding the area of site and building. - NHDC proposed standard type house which has one kitchen and two bedrooms. - The inhabitants have been lived in a house which has the same or more room/equipment/parking space than the NHDC's proposal. Therefore the inhabitants require the same or more than.
Jul-Sep 2012	- The government side (MPI, MHL and Local Authority) proposed larger house/site than the previous meeting (candidate site of relocation: Camp Ithier) - They could not obtain consensus because there is difference between government's proposal and inhabitant's request.
Feb 2013	- Deputy Prime Minister, MPI, MHL, Ministry of Education and Human Resources, Ministry of Foreign Affairs and the inhabitants (about 10 households) had a meeting in the deputy prime minister's office of Port Louis. - The government side proposed land (460㎡) and one story house (total floor area: 110㎡) in Camp Ithier as a compensation. - Nine out of ten households agreed of the above proposal.
Mar 2013	- The negotiation is continued for one household who did not agree. - The government side had collected the request regarding the detailed floor plan and equipment, etc. with the inhabitants who agreed with the above government's proposal.
May 2013	- The government side and the inhabitants had a meeting in Camp Ithier. - The drawings of the house and site were shown to the inhabitants. - Some inhabitants signed the agreement. Two inhabitants did not sign the agreement. (because the plot land area is smaller than the existing) - The agreement has only outline basics (willingness for relocation), it does not have detailed information such as compensation payment/contents, etc. - The location of the plot lands was discussed with the government side with inhabitants (location between the house and road, kindergarten, park, public facilities, etc.)

In addition to the above, the related information regarding the relocation is shown as below.

- Twenty or more meeting inside the government and ten ore more meeting with government side and the inhabitants were implemented aside from the above table's record.

- The precondition for the negotiation by the government: the government side would like to relocate the all inhabitants (not individual/separate relocation)

- The basic policy of the negotiation by the government: the government will not compensate by money (there is possibility to continue living by the inhabitants in the same landslide risk area after the payment of the compensation)

- The land of the landslide risk area in Quatre Soeurs is owned by the government. The inhabitants have borrowed the land from the government by a contract.

- If the government obtains the agreement with the all inhabitants, the inhabitants will sign to the agreement of the relocation and termination of the land lease.

- It takes about two years for completion of the relocation because the Camp Ithier is under construction. The structural countermeasure and non-structural countermeasure (early warning, evacuation, etc.) will be needed.

- Criteria of compensation for relocation: there is no regal scheme/framework which stipulates the designation of the area/household for the relocation, procedure of the compensation, financing, alternative site/house, etc.

In addition to the case example above, the organizational structure of recommendation for relocation is as follows.

- MPI: In charge of the identification of households which are required to relocate based on the landslide survey.

- MHL: In charge of the investigation of the cadastral data, formulation of land lease contracts (in case of government-owned land) and other related information based on the MPI's survey which has information of landslide area/extent, scale of the assumed landslide disaster and target households for relocation. Also, finding the candidate sites for the relocation in collaboration with related agencies such as National Housing Development Company.

- In addition to the above, related ministries and agencies took part in the meetings for relocation and took action as necessary. For example, Ministry of Education and Human Resources is assisting pupil that need to change schools as a result of their relocation.

An example of the compensation for relocation in Quatre Soeurs is shown below. This is only an example, therefore the compensation content should be considered depending on each landslide area.

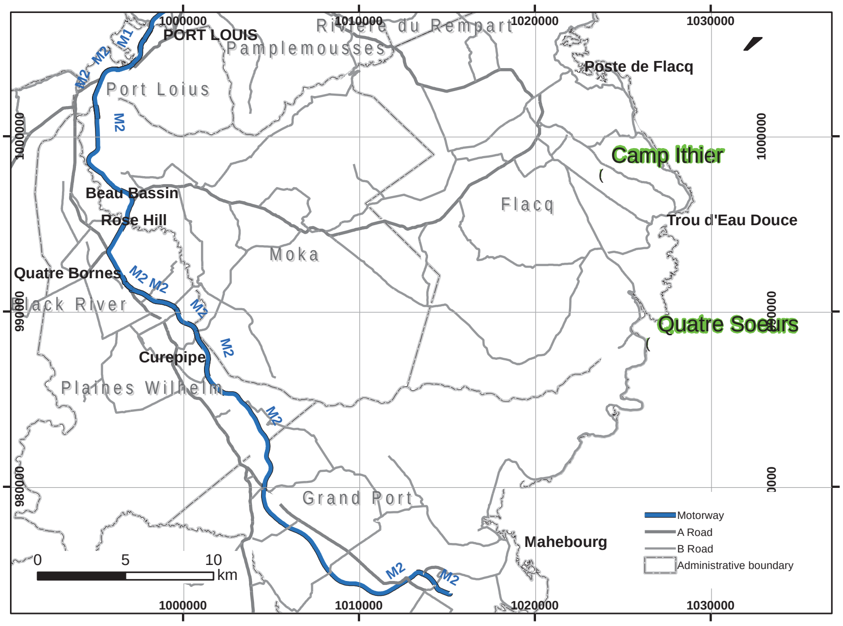


Figure 4.6.2 Location Map: Quatre Soeurs and Candidate Site of Relocation
(source: JET)

- Candidate site: Camp Ithier (see figure below). Camp Ithier is located north from Quatre Soeurs, thirty minutes by car. The National Housing Development Company has been conducting a housing development at Camp Ithier. Furthermore, Public facilities such as roads, an athletic field, a park, and a school have been developed. Also, its area is considered safe from disasters.

- Area of the land: about 460 m^2 (general figure of land price: 100,000 MUR/lot, estimated by MPI's engineer)

- Total floor area of the building: 110 m^2 (1,200 MUR/sq. ft., estimated by MPI's engineer)

- Number of stories: single-story building

4.7 Implementation of the Compensation

(1) Basic Policy for Approach to Compensation

The compensation for relocation covers land and buildings. Furthermore, there are some risks to compensate the inhabitants in cash. If the compensation is implemented with money, the meetings and negotiations may be difficult to achieve because of comparison of the compensation payment with other areas. Also, there is a possibility that the inhabitants will continue to live in their current house because they may use up the compensation money.

(2) Points to Remember for the Implementation of the Compensation

The following points should be remembered when the activities/negotiations of compensation for relocation will be conducted

- The property/asset, life, living and others could be confirmed and considered for the appropriate response to realize the implementation of the relocation.

- The coordination and cooperation with related ministries/agencies/local authorities are required to smoothly have the understanding and consent from the stakeholders as necessary. (If a family has children, consultation regarding the education environment such as transfer of schools, commute, academic fee and others will be required between parents and Ministry of Education and Human Resources. If an inhabitant has to change or loses their job, the Ministry of Labour, Industrial Relations and Employment would help the unemployed person to find employment.)

The responsible organization of the negotiation of relocation should keep in mind the above points, and try to obtain the consent from the stakeholders.

(3) Proposal of the Compensation Contents

Proposal of the compensation contents, and feedback from the inhabitants (clear and detailed information is required in the explanation meeting of the proposal) should be conducted before the agreement stage. The following points should be considered to keep the level as well or better than the existing circumstances (origin of relocation); traffic accessibility, public service, public facilities, convenience of living, education environment, consideration of the working environment, commuting and others.

(4) Agreement of Compensation with the Government Side and the Inhabitants

If a final consensus on the compensation is reached between the government side and the stakeholders, the agreement document which has contents of rights, duties, prevention of conflict/disputes in the future and others will be signed. The government side has to explain the contents of the agreement document in the negotiation to obtain the understanding and consent from the stakeholders regarding the compensation contents at a stage prior to the agreement. The regular confirmation about problems, difficulties and others by changing the living environment in conducting the relocation will be required without leaving the implementation of relocation by the stakeholders after the conclusion of the agreement. The assistance form related ministries/agencies/local authorities should be obtained when needed.

Reference

[i] Ministry of Housing and Lands on behalf of the Town and Country Planning Board, 2006, Outline Planning Scheme for Grand Port Savanne District Council Area (as subsequently modified in November 2011)

5 Information, Education, Communication (IEC)

Information, Education, and Communication (IEC) is an approach to change or reinforce individual behaviour, and/or change social community norms. The major objectives of IEC for landslide are to raise awareness of the public on landslide, and to affect their behaviours and attitudes on landslide disaster. The implementing agency/organisation is expected to implement needs-based, area-specific and target-oriented IEC activities. The IEC activities could be tools to provide more information and options in order to minimise the awareness gaps of landslide disaster management between the planners/engineers and inhabitants.

5.1 Importance of IEC for Landslide Management

a. International Trends (The Sendai Framework for Disaster Risk Reduction 2015-2030)

The Third United Nations World Conference on Disaster Risk Reduction was held in Japan in 2015, and adopted the Sendai Framework for Disaster Risk Reduction 2015-2030. Following the Hyogo Framework for Action 2005-2015, the Sendai Framework also emphasises on raising public and institutional awareness on disaster risk reduction (DRR) as well as empowering communities and local authorities to deal with disasters. Furthermore, it clearly states the importance of all-stakeholder engagement including individual participation in DRR.

Followings are extracts and summaries of the Sendai Framework relating to the IEC approach.

(1) DRR requires an all-of-society engagement and partnership. It also requires empowerment and inclusive, accessible and non-discriminatory participation, paying special attention to people disproportionately affected by disasters;

(2) While the enabling, guiding and coordinating role of national and federal State Governments remain essential, it is necessary to empower local authorities and local communities to reduce disaster risk, including through resources, incentives and decision-making responsibilities as appropriate;

(3) To achieve Priority 1of ‘Understanding disaster risk’, it is important to:

- To develop, periodically update and disseminate, as appropriate, location-based disaster risk information including risk maps to decision makers, the general public and communities at risk of exposure to disaster
- To build the knowledge of government officials at all levels, civil society, communities and volunteers through sharing experiences, lessons learned, good practices and training and education on DRR
- To promote the incorporation of disaster risk knowledge including disaster prevention, mitigation, preparedness, response, recovery and rehabilitation in formal and non-formal education as well as in civic education at all levels; and
- To enhance collaboration among people at the local level to disseminate disaster risk information through the involvement of community-based organisations and

non-governmental organisations (reference 1).

b. Community Involvement in the Project Planning Process

The information such as the needs of the Project, selection process of the project priority areas, project outline, and the role and responsibility of inhabitants should be shared with local inhabitants in the project planning process. The interactive communication process with local residents is essential as it will eventually create a more realistic project plan which reflects the community's real needs. Moreover, if the local residents are involved in the project planning process, they will be more supportive and more actively involved in the project activities.

c. Effective Implementation of the Project

In order to understand the mechanism of landslide occurrence and determine the exact location of hazard zones, works at the landslide areas such as topographic surveys, drilling works and installation of monitoring devices are required. These activities might directly or indirectly cause some troubles with inhabitants before/during/after the project implementation. Therefore, the implementing agency is required to build a consensus with inhabitants who live in the target landslide areas. Otherwise, the site works might be delayed as negotiation with inhabitants sometimes takes a long time.

d. Development of Effective Warning and Evacuation System

The IEC activities and early warning have a strong relationship to each other. Provision of early warning will allow individuals and communities to protect their lives and properties. In addition, the information empowers people to take necessary action when landslide disasters are imminent.

The aims of the IEC activities for landslide can be summarised as follows:

- To make people aware of the risks of landslide disaster in their neighbourhood and country;
- To improve people's knowledge on the potential landslide disasters and how they can prepare for the disasters;
- To make residents ready to take proper actions when the landslide disasters occur in future;
- To mitigate the landslide disaster risks by controlling negative human activities in the high-risk areas.

5.2 The Main Actors of the IEC Activities for the Landslide Management in Mauritius

The Government of Mauritius has developed the "National Disaster Scheme (NDS)". The Scheme clarifies the responsible organisations and their roles and actions for seven natural disasters: 1) cyclone, 2) heavy rainfall, torrential rain and flooding, 3) tsunami, 4) high waves, 5) water crisis, 6) earthquake and 7) landslide. The Landslide Emergency Scheme in the NDS 2015 edition includes some descriptions related to the IEC activities as shown in Table 5.2.1.

Table 5.2.1 IEC Activities Described in the Landslide Emergency Scheme in the NDS 2015 edition (source: JET)

Section	Description
7.2 General	- There is a need to warn the public and more particularly the inhabitants of these sensitive areas of the need for precautionary measures in case of likelihood of landslides.
7.3.1 The Government Information Service (GIS)	- In collaboration with Local Authorities, the MPI, the MMS and the NDRRMC, the GIS and the Mauritius Broadcasting Corporation (MBC) will prepare illustrated posters and film strips to remind the public of the dangers of landslide.
7.8.4 Distribution of Landslide Communiqué	- Landslide Communiqué will be broadcast by the MBC, the Press, the Private Radios, the telephone system including Mauritius Telecom Call Centre.

The main actors would be different depending on the IEC activities to be carried out. As shown in the Table 5.3.1, various stakeholders such as Local Authorities, MMS, GIS and MBC are engaged in the IEC activities. On the other hand, the MPI is responsible for the monitoring of landslides in the landslide-prone regions. The MPI is also in charge of designing the construction works such as drainage works, and developing criteria for the early warning and evacuation systems.

Table 5.2.2 IEC Activities Implemented by the Previous Project (source: JET)

	IEC activities (as countermeasures for issues)		
Identified issues	1) **Stakeholder Meetings** for inhabitants in high-risk areas	**2) Project Leaflet**	**3) Education and awareness materials** for disaster preparedness
1. Community participation and ownership in disaster risk reduction are insufficient.	◎	○	◎
2. Residents do NOT have necessary information such as on evacuation sites and hazardous spots around their homes.	◎	○	◎
3. Most residents do NOT know current restrictions on development actions and building construction in hazard areas.	◎	○	◎
4. Awareness and education programmes for landslide management are NOT implemented at schools and communities.	◎	○	◎
5. Local risk assessment and disaster preparedness programs are NOT implemented in communities and schools.	◎	○	○
6. Awareness materials, which are required to be developed under the Disaster Scheme, have NOT been developed yet.	○	○	◎
7. Most of residents do NOT know what to do when disasters are imminent	◎	○	◎
8. Residents living in priority areas have NOT shared the progress of Project activities and the monitoring results on a regular basis.	◎	◎	
9. The current Disaster Scheme is NOT focused on preparedness.	○		○

◎Directly contributed, ○Indirectly contributed

5.3 Types of the IEC Activities

Three types of the IEC activities: 1) stakeholder meeting, 2) distribution of the project leaflet, and 3) preparation of the sensitisation materials were conducted under the JICA Project of landslide management in Mauritius (Previous Project). These activities were considered to solve the issues on the landslide management which were identified under the Project. Table 5.3.1 summarises the issues and appropriate activities to solve these issues.

Table 5.3.1 IEC Activities Implemented by the Previous Project (source: JET)

Identified issues	**IEC activities** (solutions for the issues raised)		
	1)Stakeholder Meetings	**2) Project Leaflet**	**3) Sensitisation materials**
1. Community participation and ownership in disaster risk reduction are insufficient.	✓✓	✓	✓✓
2. Residents do NOT have necessary information such as on evacuation sites and hazardous spots around their homes.	✓✓	✓	✓✓
3. Most residents do NOT know current restrictions on development actions and building construction in hazard areas.	✓✓	✓	✓✓
4. Awareness and education programmes for landslide management are NOT implemented at schools and communities.	✓✓	✓	✓✓
5. Local risk assessment and disaster preparedness programs are NOT implemented in communities and schools.	✓✓	✓	✓
6. Awareness materials, which are required to be developed under the Disaster Scheme, have NOT been developed yet.	✓	✓	✓✓
7. Most of residents do NOT know what to do when disasters are imminent	✓✓	✓	✓✓
8. Residents living in priority areas have NOT shared the progress of Project activities and the monitoring results on a regular basis.	✓✓	✓✓	
9. The current Disaster Scheme is NOT focused on preparedness.	✓		✓

✓✓ Directly contributed, ✓ Indirectly contributed

5.3.1 Stakeholder Meeting

The stakeholder meetings are implemented with the following procedures.

(1) Development of a Stakeholder Meeting Plan

First, a plan for holding the stakeholder meetings needs to be developed. The following points should be included in the plan:

① Objective *(what outputs are expected from the meeting?)*

② Topics *(which topics should be covered?)*

③ Target *(who should be invited for the meeting: only the affected inhabitants or/and relevant organisations?)*

④ Schedule *(when is the meeting organised?)*

The following table shows the example of the stakeholder meeting plan under the JICA Landslide Management Project. In terms of the JICA project, the meetings were scheduled according to the progress of the Project. In general, the meetings would be preferably organised on a regular basis, such as every six months.

Table 5.3.2 Example of Stakeholder Meeting Plan (source: JET)

No	Schedule		Target	Objective	Topics
	Project Stage	Date			
1	At the start of the Project	Sep. 2012	Inhabitants	To explain the outline of the Project and request residents' cooperation	1) To explain the outline of the Project 2) To request their cooperation and understanding for the field survey and monitoring
2	After drafting the Project Implementation Plan	Apr. 2013	Inhabitants Local Authorities Ministry of Housing and Lands (only for Quatre Soeurs) Police Department SMF	To build consensus on the Project Implementation Plan and F/S	1) To share the results of the field surveys 2) To share the monitoring results, particularly during the rainy seasons 3) To collate residents' views on the basic policy of countermeasures (basic design of construction work, soft (non-structural) countermeasures)
3	Before finalisation of the Project Implementation Plan	Dec. 2013	Inhabitants Police Department (Local Police)	To build consensus on the Project evaluation and EIA	1) To collate residents' views on the draft design of the construction work 2) To share the results of EIA 3) To inform the proposed early warning and evacuation system 4) To conduct disaster drills
4	Before starting the Pilot Project	Apr. 2014	Inhabitants Police Department (Local Police) Local Authorities	To build consensus on the details of the Pilot Project	1) To explain the outline of the Pilot Project 2) To share the results of the field survey and monitoring 3) To gain the approval of the land use for the construction work (house-to-house visit will also be conducted) 4) To review the practicability of the proposed early warning and evacuation system (to identify good practices and issues)
5	During the implementation of the Pilot Project		Inhabitants Police Department (Local Police) Local Authorities	To share the progress of Pilot Project	1) To share the results of the field survey and monitoring 2) To conduct the field tour
6	At the end of the Pilot Project	Dec. 2014	Inhabitants Police Department (Local Police) Local Authorities	To share the results of the Pilot Project, feedback to the Landslide Management Plan	1) To share the results of the field survey and monitoring 2) To conduct the field tour 3) To explain the follow-up monitoring system after the Pilot Project

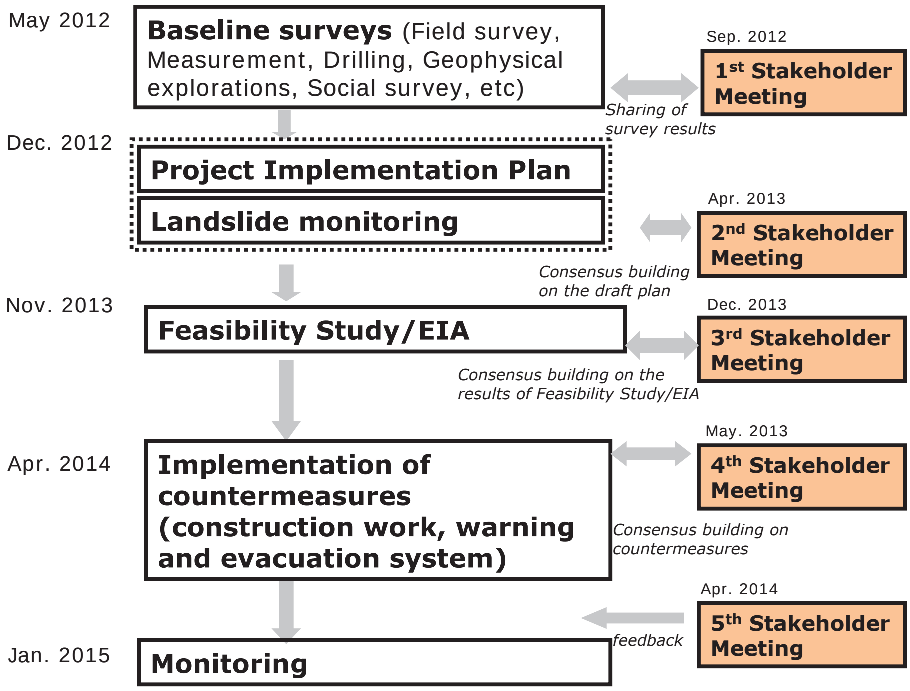


Figure 5.3.1 Timeline of the Stakeholder meetings (source: JET)

(2) Preparation for the meeting

a. Confirmation of the dates

The meetings should be arranged at convenient and available dates and times for inhabitants. Contacting the community representatives in advance is also highly recommended. The meetings would be better to be organised after 5 pm on weekdays or on the weekends as most of the inhabitants are at work during the day.

b. Venues of the meetings

The venue should be where inhabitants can easily access. If the venue is too far from their home, their participation will be less. The venues could be schools, community halls or on site. Door-to-door visits are also effective methods to deliver necessary information to inhabitants individually.

In case if the school is used for the meetings, contacting the Ministry of Education in advance is required to gain their approval for its use.

Meeting at school (Chitrakoot)

Meeting at community hall (Quatre Soeurs)

Meeting on site (Vallée Pitot)

Door-to-door visits (Vallée Pitot)

Photo 5.3.1Meeting with inhabitants (source: JET)

c. Distribution of invitation letters for inhabitants and related organisations

An official invitation letter, written on the organisation letterhead, is prepared by the administration office. In the letter, the following information should be clearly described;

- Purpose of the meetings
- Date
- Time (Starting time and Closing time)
- Venue

Photo 5.3.2 Invitation letter put up at the main entrance of the venue (source: JET)

Community representatives such as the village council officers and local police who are familiar with the local conditions and local inhabitants will be helpful for distribution of invitation letters to the target inhabitants.

d. Agenda

The agenda should preferably cover the certain topics depending on the progress of the works. Table 5.3.3 explains the examples of the topics for the meeting.

Table 5.3.3 Example of Agenda (source: JET)

	Item	Contents	Presenter
1	Welcome speech	- Express appreciation for participating in the meeting - Explain the purpose of the meeting	Implementing agency
2	Presentation	(1) Review of the previous meetings (2) Purpose of today's meeting (3) Results of the landslide site investigation (4) Results of the monitoring (5) Countermeasures (construction works, early warning and evacuation system) (6) Work schedule (future plan)	Implementing agency
3	Questions/Answers		
4	Filling in a feedback sheet		
5	Field visit (if necessary)		

e. Presentation in the meeting

- Language

As most of inhabitants cannot understand English well, the presentation materials and handouts should be prepared in French/Creole. All the explanations should be done in common language, which is Creole language, to make inhabitants fully understand the contents.

- Visual aids

Visual aids such as photos and illustrations will help audiences to understand the topics presented. As there are a wide variety of visual aids, the appropriate visual aids should be selected depending on the information to be presented.

- Demonstration

Demonstration is a useful and informative communication tool for explaining something to the audience on how it works and/or how to use it. For example, the alert system and simple rain gauges which were installed for the early warning and evacuation system under the JICA Project were demonstrated to inhabitants and relevant organisations.

Photo 5.3.3 Demonstration of the simple rain gauge (source: JET)

f. Field visit

Most of inhabitants cannot read maps, in other words, they are not able to point out the actual location of their houses active hazard areas and the location of the countermeasure works implemented on the map. Consequently, the field visit is useful to make inhabitants properly understand the actual locations of these sites.

Inhabitants checking the locations of the active hazard area on the map (Chitrakoot)

Field visit with inhabitants (Chitrakoot)

Photo 5.3.4 Field visit (source: JET)

g. Feedback sheet

Feedback sheet is useful to know the level of understanding and perspectives of inhabitants as sometimes they are hesitate to speak in the public. The sheet is distributed to all the participants after the meeting and is analysed. The analysed results of the feedback sheet should be shared with the related organisations. The example of feedback sheet which was developed under the Previous Project is shown in Table 5.3.4.

Photo 5.3.5 Inhabitants filling in the feedback sheet (source: JET)

Table 5.3.4 Example of the Summarised Results of Feedback Sheet (Chitrakoot) (source: JET)

	Questions on the feedback sheet	Summary of the results: Chitrakoot (Number of response : 32)		
		Yes	No	Not sure
1	Do you understand what landslide is?	100%	0%	0%
2	Is landslide a major concern for you?	97%	0%	3%
3	Do you think that your house is in one of the highest priority areas for landslide disasters in Mauritius?	84%	9%	6%
4	Do you understand what the Project is trying to do?	97%	0%	3%
5	Do you understand and support the surveys and works which the Project will implement at your residential area?	100%	0%	0%
6	Are you willing to be involved in the monitoring and maintenance activities in future?	88%	0%	13%
7	Are you willing to attend the next meeting?	94%	0%	6%
8	Any comments or suggestions for the Project			
	− The result of the previous monitoring equipment which was installed 7 years ago should be reviewed and be informed. − The local community should get all the information/results and regular progress reports. − Please come up with concrete solution − Very good project. I think we must make drain. − I appreciate the project. It is helping the habitants from difficulties. All the best. Well done. Go ahead this project. − Do the project quickly please.			
9	Any comments or suggestions for the whole session			
	− Very informative, effective and interactive. − To be informed regularly. − I have broken homes caused by not adequate foundation. It was not the cause of landslide. − Those residents presented have given their full commitments for this survey.			

(3) Comments collected from Inhabitants and Stakeholders

Various constructive comments and suggestions collected from inhabitants and stakeholders should be carefully examined, and their views should be reflected into the landslide management plan. In addition, the project implementation agency should explain how it will take inhabitants' opinion in to consideration in the project planning process. The following table shows an example of inhabitants' perspectives and how the MPI and JET responded to them under the Previous Project.

Table 5.3.5 Inhabitants' Views and Responses of the Project Implementing Agencies (example) (source: JET)

Topics	Inhabitants' Concerns/Suggestions/Requests	Responses by MPI/JET
1) Active landslide area [Chitrakoot]		
	As most residents do NOT have map-reading skills, they are concerned whether their own houses would be affected by landslides or not.	Stakeholder meeting is not effective to provide enough information to the residents of the specific sites which are prone to landslides. In order to give certainty and necessary information to all the target inhabitants, a door-to-door visit should be carried out prior to the construction works and other countermeasures.
	Residents suggest setting up a board at a site to demarcate an active landslide area from non-active areas.	MPI will examine how to implement once the proposed Warning Zone system is authorised by the modified PPG.
2) Mechanism of landslide occurrence [Chitrakoot]		
	Is the school construction a cause of landslide occurrence in Chitrakoot?	Although the causes of landslide are not clear, the geographical condition of the region is identified as a landslide prone area before the school construction.
3) Construction Work [Chitrakoot]		
	・Location of construction work *(Does installation of drainage pipes result in any impacts on inhabitants' cultivation activities and daily lives?)* ・Maintenance of installed pipes and other facilities *(Who and how is it done?)* ・Possibility of landslide occurrence (during the construction work)	The design of construction work should take these concerns into consideration. Environmental impacts and social considerations should be taken into account before, during, and after the construction work.
4) Current issues caused by current drainage system [Vallée Pitot]		
	The water accumulated in the creek often overflows during heavy rains and comes inside the houses. Water flow from the mountainside has also started coming into the residential areas since the road has been constructed near the cow yard.	NDU is planning to clear the creek (MPI to confirm) JET has drafted the basic concept of construction work as a countermeasure, however the MPI is still considering whether the MPI implements the construction work in this area or not.

(4) Minutes of Meeting

The minutes of the meetings should be taken during the meetings so that the discussion points in the meetings could be reviewed when necessary.

The minutes usually include:

(1) The names of the participants;

(2) The agenda items;

(3) Decisions made by the participants;

(4) The follow-up actions committed by participants;

(5) The requests from the participants; and

(6) Any other events or discussions worth documenting for the future review.

The information such as speakers and their comments should be mentioned in the minutes. The minutes are ideally circulated to the participants within a few days after the meeting. The minutes help to understand the commitments and decisions made during the meeting, therefore the minutes from the previous meeting should be reviewed at the beginning of the meeting.

5.3.2 Project Leaflet

When implementing the landslide management project at the landslide hazard areas, the purpose of the work and its progress should be informed to inhabitants who live in the target areas and related organisations.

Project leaflet is one of the communication tools between the project implementing agency and the public. Information such as progress of the work and the outputs can be explained in the leaflet. Continuous support and cooperation from inhabitants could be also requested in the leaflet.

Although the frequency of issuing the leaflet depends on the progress of the work, the leaflet would be preferably issued every six months at least. In case of the JICA landslide management project, project leaflets were issued three times when the major events of the project happened. The details are shown in Figure 5.3.2.

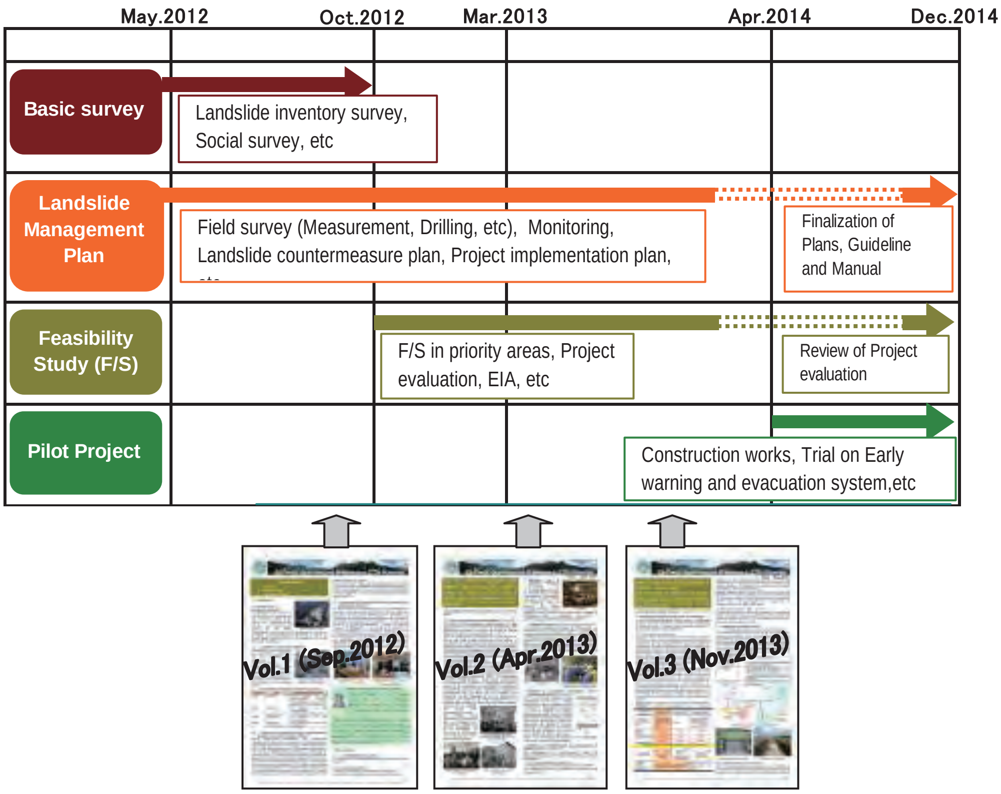


Figure 5.3.2 Schedule of issuing the Project Leaflet (source: JET)

5.3.3 Sensitisation Materials

The primary objective of developing the public awareness raising materials is to sensitise the public in order to take necessary actions for landslide disasters. The appropriate actions protect their lives, properties.

Emergency preparedness is everyone's responsibility, not only the government’s responsibility. The government is required to provide a wide variety of information such as the measures for landslide disaster risk reduction, evacuation rote and shelter, hazardous spots in the residential areas and restrictions on development actions and building construction in the hazard areas to the public. On the other hand, inhabitants should always be aware of the information and take proper actions accordingly.

The JICA Landslide Management Project made a number of materials, which aimed to improve inhabitants’ understanding about landslide management. The automatic alert systems and simple rain gauges were installed at three hazard areas under the Project as supplementary systems to the Landslide Emergency Scheme in the NDS 2015 edition. The installed automatic alert systems will inform inhabitants in the landslide-prone areas as well as the related organisations such as NDRRMC and Mauritius Police Force when the ground movement reaches a warning and evacuation level. The systems are useful for inhabitants to proceed self-evacuation to protect their own lives.

In addition to the automatic alert systems, various materials were developed under the Project and were distributed to the target inhabitants and relevant organisations as shown in Table 5.3.6.

The materials shown in the Table 5.3.6 are for the specific target groups of inhabitants living in the landslide hazard areas, and the relevant organisations of NDRRMC, Mauritius Police Force and Special Mobile Force. These materials were explained in the stakeholder meetings and door-to-door visits in the Previous Project in order to raise awareness of the public.

Similar materials are expected to be developed for the other landslide-prone areas, apart from three priority areas targeted by the following JICA Landslide Management Project. Moreover, a contingency plan for each landslide hazard area is useful.

Table 5.3.6 Sensitisation Materials Made by the Previous Project (source: JET)

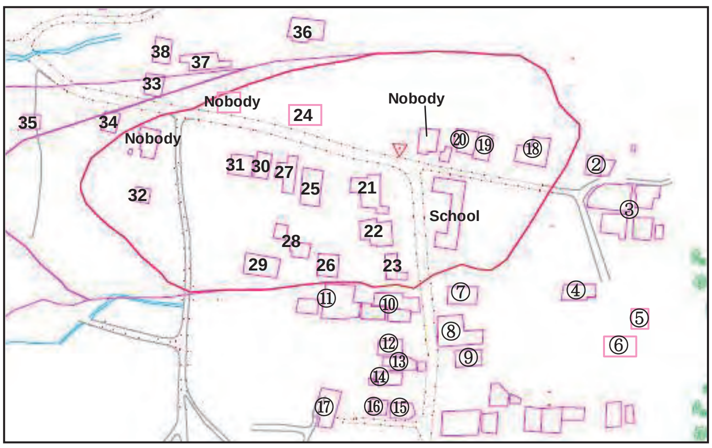
Material		Purpose of the material	Target of distribution	
			Inhabitants	Relevant organizations
(1)	Evacuee list	To list all the names and contact information of inhabitants	-	○
(2)	Location map of evacuators	To identify the location of houses needing to be evacuated	-	○
(3)	Early waning and evacuation system flow	To guide inhabitants how to respond when a landslide occurs	○	○
(4)	Instruction manual of simple rain gauge	To guide how to deal with a simple rain gauge	○ (only inhabitants who own the device)	○
(5)	Communication network	To clearly define who communicates who in case of warning stage based on simple rain gauges and alert system	○	○
(6)	Location map of the designated evacuation centre and its route	To provide information of evacuation centre and its route from inhabitants' houses on a map	-	○
(7)	Protocol on Early Warning Evacuation System (revised Disaster Scheme)	To guide the role and responsibility of each organisation	-	○

Sensitisation materials explained in the Table 5.3.6 are shown below for reference.

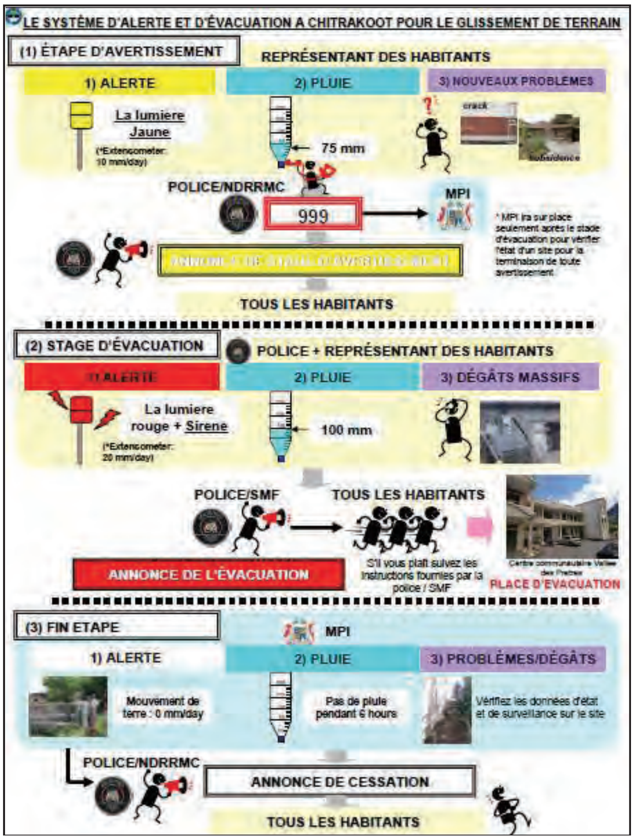
(1) Evacuee List

House No.	Surname	First name	Mobile No.	Location on the map
1				
2				
3				
4				
5				
・ ・ ・				

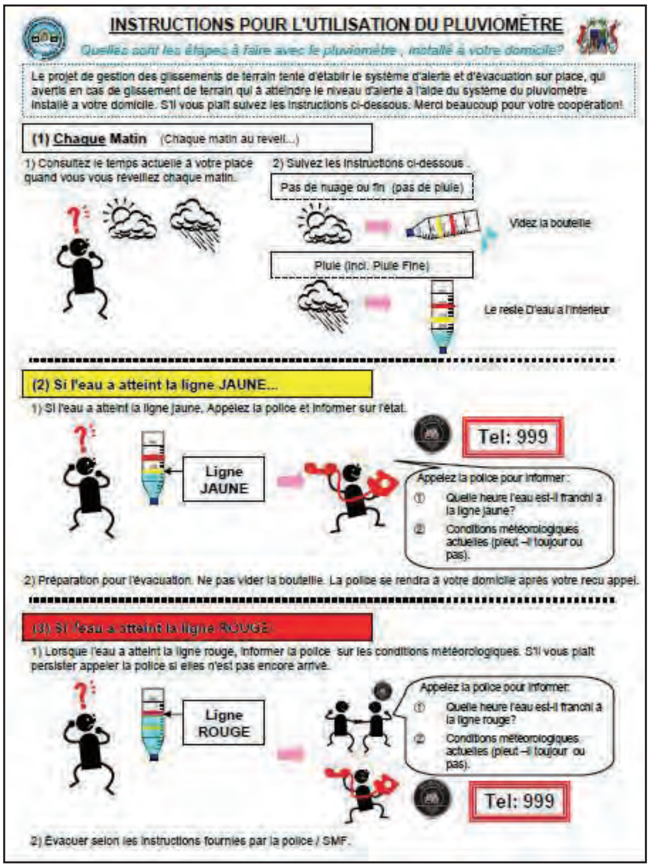
(2) Location Map of Evacuators *(abstract)*



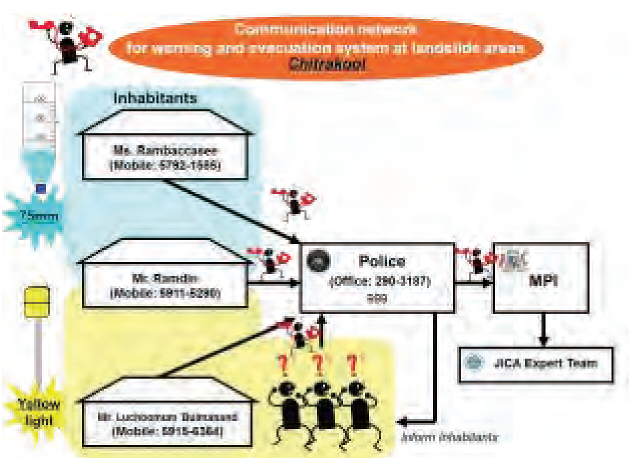
(3) Early waning and evacuation system flow



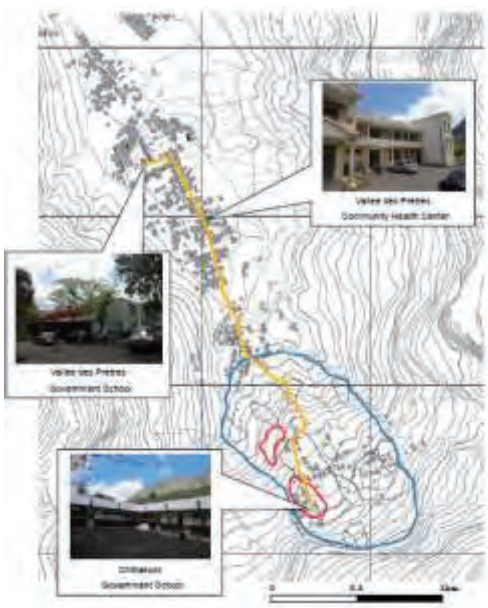
(4) Instruction manual of simple rain gauge



(5) Communication network



(6) Location map of the designed refugee centre and the route



Reference

1. United Nations, 2015, 'Sendai Framework for Disaster Risk Reduction 2015-2030'.

6 Design for Structural Countermeasures

6.1 Principal of Design for Landslide Countermeasures

6.1.1 General

The landslide countermeasures shall be selected in consideration of the impact of the target entity for preservation, the economic efficiency of the countermeasure and the mechanism of landslide movement based on the geology, topography and activity of target landslide, relativity between precipitation and landslide activity, dimension of landslide block, groundwater condition.

The structures for countermeasure shall be in accordance with the appropriate planning with suitable function and safety. The durable materials shall be also considered to secure long term stability of the landslide and as aforementioned, it shall be always examined the effect of the countermeasures and cost effectiveness of the application of measure works.

In a landslide area showing continuous activity under the monitoring, the restraint countermeasure work such as pile work and anchor work cannot be executed when the activity is continuing. The restraint countermeasure works such as pile works can only be conducted when the landslide becomes near stable with landslide control work. If the preservation entity is of high importance, the restraint work such as pile work and anchor works should be examined for installation because they can certainly stabilize the landslide. If the landslide is of large scale, and it is difficult to get enough budget to execute the restraint works such as pile work and anchor works, the plan of the countermeasure works should put more weight on the control works such as groundwater drainage works, and earth removal work. So for the selection of suitable countermeasure works, all of the conditions should be considered.

6.1.2 Classifications of Landslide Countermeasures

Landslide countermeasures are divided into control works and restraint works. The control works mitigate landslide risk by changing natural conditions such as groundwater or topography contributing to the slide; the restraint works directly affect the landslide risk due to partially or wholly stopping landslide activity by deterrent potential of the structural countermeasures.

The classifications of landslide countermeasures are shown in Figure 6.1.1. Feature of each countermeasure work is described below. More detailed description is shown on next sub-clause.

a. Control Work

a.1 Surface drainage work

The surface drainage work prevents rainfall and surface water infiltration into and discharge out of the landslide area. There are several types of drainage work such as ditch work using concrete-masonry or corrugated steel pipe and infiltration prevention work using waterproof sheets. The work is often effective as a landslide countermeasure even though effectiveness of the work cannot be numerically-expressed by stability analysis.

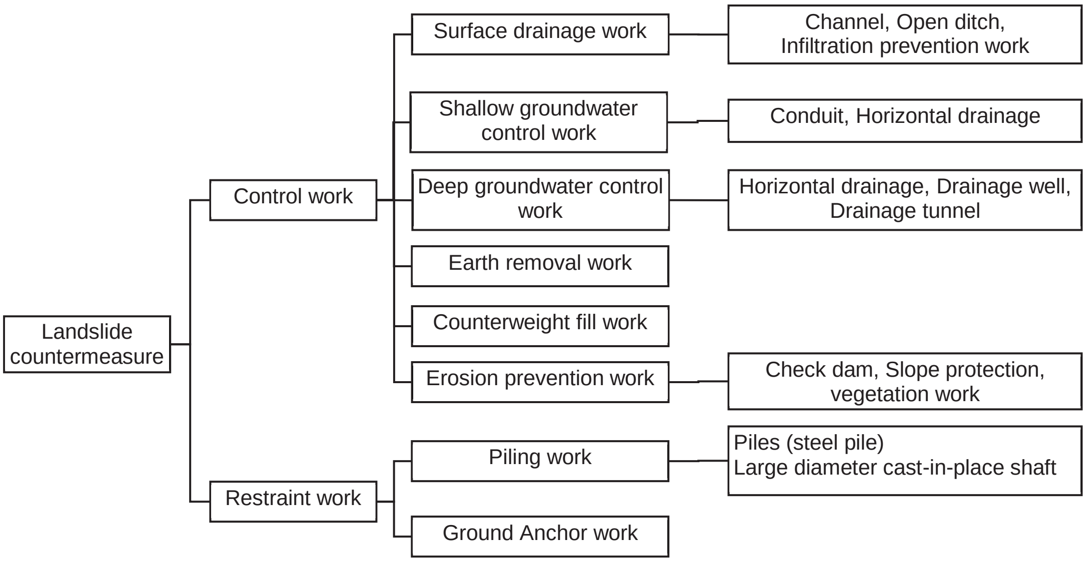


Figure 6.1.1 Classification of Structural Countermeasures for Landslides[1]

a.2 Shallow groundwater control work

The shallow groundwater control work shall be applied when it is confirmed by the investigations that groundwater is contributing to landslide activity. There are following two types of groundwater to discharge.

- Groundwater that exists within the landslide area, and has an effect on landslide stability directly due to making increased pore water pressure and/or moisture content of landslide block.
- Groundwater that exists out of the landslide area, but is a supply resource of groundwater to the area.

The shallow groundwater control work targets shallow groundwater in the above mentioned conditions of groundwater. Conduit, open-blind ditch and horizontal drainage will be categorized as the shallow groundwater control work.

a.3 Deep groundwater control work

Application of the deep groundwater control work shall be considered in case that shallow groundwater control work will not have an effect on the landslide due to groundwater level and slip surface of the landslide located at a deep level. Deep groundwater control work includes horizontal drainage, drainage wells and drainage tunnels.

- Horizontal drainage is often applied to discharge groundwater which distributes around slip surface of landslide at more than 5m deep from ground surface, or that is located along the fault and fracture zone.

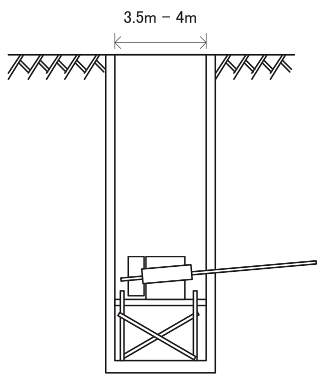


Figure 6.1.2 Schematic Drawing of Drainage Well (source: JET)

- Drainage well is often adopted in case that horizontal drainage shall be installed longer than 60m in accordance with scale of landslide. Diameter of the well is required 3.5m to 4m to install a water collecting drainage pipe in the well.

- Drainage tunnel is often considered in case that target landslide is huge scale, and it will be difficult to apply horizontal drainage or water collecting well due to groundwater distributes deep level. In case that an abundant water vein is found to be contributing landslide activity near the slip surface, the drainage tunnel work will be effective due to discharge deep groundwater through water collecting drainage pipes installed on the tunnel wall.

a.4 Earth removal work

Earth removal work is generally planned in the upper zone of the landslide in order to reduce sliding force. When the earth removal work is planned, volume and area of earth removal shall be decided to achieve the designed factor of safety by the stability analysis based on precise data about scale, area and strengthening of material of landslide block obtained through detailed investigations.

a.5 Counterweight fill work

Counterweight fill work is implemented in the toe zone of the landslide in order to increase resistance to sliding. Since generally a toe zone of a landslide is weak and soft condition due to disturbance by landslide activity, groundwater control work shall be used with counterweight fill work in combination to avoid failure of ground foundation by surcharge filling at the toe zone, or contribution to landslide activity by increasing pore water pressure near the slip surface due to interference with ground water flow by the filling. Additionally, induction of other landslide activity shall be remarked in case that hazard of other landslides at toe part of target landslide can be assumed.

a.6 Erosion prevention work

Erosion by water flow is often direct cause of loosening of landslide stability. The work shall be applied to protect erosion of landslide block. Check dam to raise river bed, retaining wall, slope protection work and vegetation work can be used as the erosion prevention work. Check dam and retaining wall shall be installed on stable and firm ground that does not have an effect on landslide stability.

b. Restraint Work

b.1 Piling work

The piles aimed at restraint of landslide shall be installed certain depth which is deeper than slip surface of landslide using a large diameter drilling machine. The borehole shall be in a vertical direction and should penetrate the slip surface. Steel pile shall be installed in the borehole with grouting clearance between pile and borehole, and generally inside of the pile also is grouted.

Generally, the piles shall be installed in places where soil reaction of ground behind the pile will be positively affected, and installing piles at tension zone of a landslide such as head part of a landslide block shall be avoided to install.

- Large diameter cast-in-place shaft

Shaft piles, mainly large diameter cast-in-place shafts for deep foundation, are vertical shafts with a diameter of 2.5m to 6.5m excavated into the stable bedrock and filled with reinforced concrete.

The piling work shall not be applied for landslide which shows more than 1mm/day movement.

b.2 Ground anchor work

Ground anchor makes increasing resistance force against landslide sliding force using the extension strength of the steel of anchor installed in the stable bedrock. The ground anchor has structure which consists of high-strength tension cable installed borehole reached stable ground and the pressure receiving plate to receive reactive force from the cable. It is an advantage of the work comparison with other restraint works, that planned deterrent force can be obtained before an increase in landslide movement because the anchor exerts an initial pre-stressing force. Decision of required deterrent force for ground anchor, how to make an initial pre-stressing force and long-term stability of anchorage shall be considered carefully. Corrosion prevention for anchor shall be carried out surely and sufficiently to secure performance of the ground anchor work.

6.1.3 Selection of Landslide Countermeasure Work

When planning for countermeasure works, the topographic and geological condition, landslide deformation situation, and the relationship to the rainfall, the safety situation of the planned area should be clarified first. Then, through the investigation on the landslide blocks, the location and shape of the slip surface, groundwater distribution and groundwater level, the landslide mechanism should be certainly understood. Finally, the plan should be made in consideration with the following items.

(a) In case that a relevancy between precipitation and landslide movement is clarified, groundwater drainage works shall be applied to avoid rainfall from infiltrating the ground.

(b) Groundwater can be categorized as shallow groundwater which flows in aquifer in colluvial deposit layer, and deep groundwater which is confined in base rock under a landslide slip surface. Since there are different types of groundwater drainage work depending on the type of the target groundwater, the groundwater drainage work shall be selected based on a study on the influence of groundwater on landslide movement.

(c) In case there is a correlation between long term rainfall such as in the rainy season and occurrence/movement of landslide, it can be recommended to apply countermeasure work focusing around deep groundwater drainage work.

(d) For an active landslide which consists of cohesive soil as highly weathered tuff or mudstone, countermeasure work focusing around shallow groundwater/surface water drainage work shall be selected. In case the landslide consists of very loose cohesive soil, the landslide shall be settled gradually by groundwater block wall or groundwater drainage work to avoid groundwater to flow into the landslide area.

(e) In case the target landslide is independent* and has a circular slip surface, removal soil work at head part of landslide or deep groundwater drainage work will be effective countermeasure. (*: the landslide area where other landslide blocks are not found in its vicinity)

(f) In case the landslide is divided into several blocks and the blocks are neighbouring each other or the slip surface shows nearly linear shape, groundwater drainage work will be effective countermeasure work. On the other hand, in such cases, counterweight filling work and removal work is not recommended to apply because the works are not expected to be effective depending on the location and shape of the works.

(g) The restraint work will be effective countermeasure for a small scale landslide. Even if the target landslide is large scale, the work will be effective for stabilization of part of the landslide block. Also the work can be applied to the cases whereby control works such as groundwater drainage work or soil removal work is difficult to be conducted. Since huge deterrent force will be required against a large scale landslide, a combination of several types of restraint work is often applied. Since each restraint work has a different mechanism of affecting a landslide, acting timing of effectiveness of the countermeasure works, estimated damages for the period and economic effect shall be considered carefully in advance.

(h) Regarding to implementation of countermeasure work, sequence or work progress shall be considered carefully to keep landslide stability because there is a possibility the combination of the countermeasure works will cause instability in the landslide. Selecting condition for countermeasure works and the process.

(i) Generally, maintenance of landslide countermeasure work is necessary to be continued in long term period. Thus it shall be considered maintenance also adequately when the countermeasure work is selected.

Before decision of countermeasure works, Environment Impact Assessment (EIA) shall be carried out. Details about EIA study is described in Chapter 6.3

Countermeasure for landslide shall not select only one work, but often several work to be applied in combination. Generally the control work is selected as primary measure work, and the restraint work is applied in combination with control work depending on the conditions.

The selection of landslide countermeasures can be conducted in reference to Figure 6.1.3.

According to the Figure 6.1.3, examination of landslide countermeasure work can be divided into four (4) stages. In stage 1, the water control works such as surface drainage work and horizontal drainage work shall be considered preferentially. If factor of safety cannot achieve designated value by water control works only, earth works such as soil removal work and counterweight fill work in stage 2 shall be examined. Since natural conditions on the site will be changed by the earth works, further influences as a result of the work shall be examined in advance for not only the target landslide area but also adjacent areas.

When the factor of safety cannot be achieved to the designated value by the countermeasure works in stage 1 and 2, restraint work shall be considered. Even if the factor of safety could be achieved to the designated value by such restraint countermeasure works, evaluation of the effect of the works shall be conducted using landslide monitoring after completion of the works.

If further movements of the landslide are detected, stage 1 countermeasures shall be re-examined to find the most suitable work to be adopted. Landslide deformation monitoring and investigation shall be continued for several years.

If the designated factor of safety planned in stage 2 is very difficult to achieve, then in stage 4, monitoring system on slope should be established, and it is necessary to execute the early warning and evacuation measures.

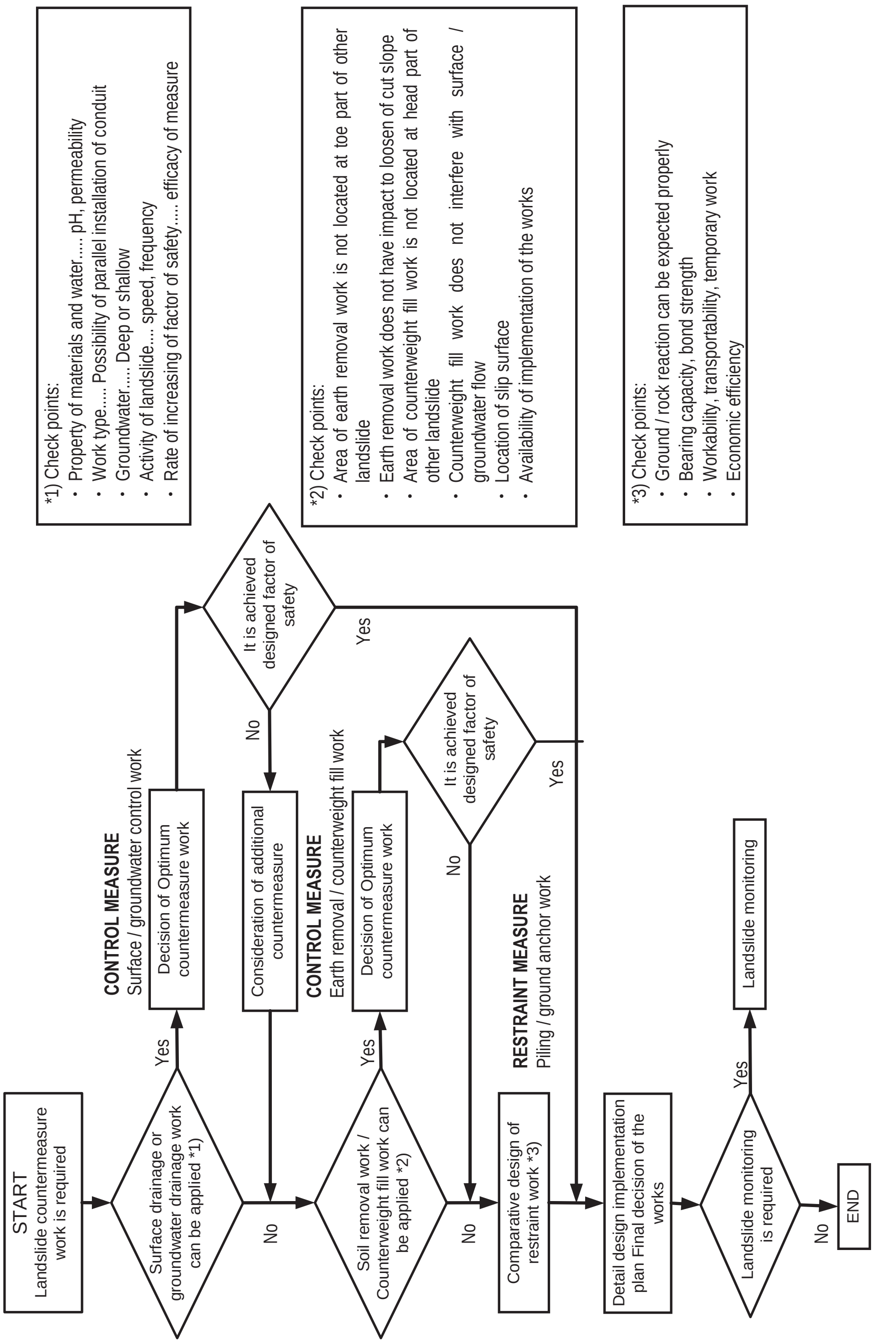


Figure 6.1.3 Flow Chart of Examination of Landslide Countermeasure[2]

Table 6.1.1 Conditions for Countermeasure Work Selection[3]

Countermeasure work			Purpose	Points to consider	Verification of the effect
Control work	Surface drainage work	Infiltration prevention, drainage channel	To collect the rainfall and to drain it out from the landslide, so that the infiltration to the ground can be prevented.	For the drainage channel, the dimension and extent should be large and long enough to drain out all of the water from rainfall through considering water catchment area.	Check the discharged amount, and compare it with the estimated amount for rainfall time.
Control work	Shallow ground-water control work	Conduit, Open-blind ditch	To collect the rainfall / shallow groundwater and to drain them out quickly from the landslide area, so that the infiltration can be prevented.	The dimension and extent of the drainage should be large and long enough to drain out the water on the target area.	Check the discharged amount, and compare it with the estimated amount for rainfall time.
Control work	Shallow ground-water control work	Horizontal drainage	To drain the groundwater directly to order to draw the groundwater level down. The work controls the pore-water pressure especially during a time of groundwater rising due to decreasing groundwater level. It can be used as emergency measure.	The aquifer and groundwater way should be identified by detail investigation at first. The location, alignment and number of the horizontal drainage should be determined in order to the drainage can be effectively based on distribution of target groundwater.	To conduct the monitoring on displacement and groundwater level. Based on the data, effect of the work shall be examined and analysed.
Control work	Deep ground-water control work	Horizontal drainage (Water collecting drainage)	To drain relatively deep groundwater directly in order to draw the groundwater level down. The work controls the pore-water pressure especially during time of groundwater rising due to decreasing groundwater level.	The aquifer and groundwater way should be identified by detailed investigation at first. The location, alignment and number of the horizontal drainage should be determined in order that the drainage can be effectively based on identified distribution of target groundwater.	To conduct the monitoring on movement of landslide and groundwater level. Based on the data, effect of the work shall be examined and analysed.
Control work	Deep ground-water control work	Drainage well	To drain relatively deep groundwater, through the well and water collecting drainage installed on the well wall. The well will be adopted in case that the landslide block is too huge and deep to collect groundwater by horizontal drainage.	The aquifer and groundwater flow paths and locations should be identified by detailed investigation at first. The location and number of the water collecting well should be determined in order to discharge the groundwater effectively based on identified distribution of target groundwater.	To conduct the monitoring on movement of landslide and groundwater level. Based on the data, effect of the work shall be examined and analysed.
Control work	Deep ground-water control work	Drainage tunnel	It is adopted for large scale landslide with thick sliding mass to decrease the ordinary groundwater level, and to decrease the pore-water pressure around slip surface. The tunnel shall be made on stable ground under the slip surface.	The groundwater can be effectively drained out through a combination of water collecting well, drainage tunnel, and water collecting drainages. If the groundwater will be used for other purposes such as irrigation, it shall be considered in the planning stage. The countermeasure work will require sufficient material, machinery engineering technique and budget.	To conduct the monitoring on movement of landslide and groundwater level. Based on the data, effect of the work shall be examined and analysed.
Control work	Earth removal work and Counter-weight fill	Earth removal work	It is adopted to reduce sliding force of landslide by removing head part of landslide block. In case that the cause of landslide is artificial filling at landslide area, the fill material shall be removed to bring it back to	The area and volume of removing earth (soil) shall be decided by stability analysis. Figure of cut slope making by the earth removal work should be decided so as to ensure the slope will be stable. The work cannot be adopted in the cases that a head part of landslide is located at a toe part of another	To check landslide stability by stability analysis based on the landslide figure after the work. To check whether there is crack and bulging on a surface of the cut

Countermeasure work			Purpose	Points to consider	Verification of the effect
	work		the original condition. It can be used as emergency measure also.	landslide, or it can be considered that the slope above the landslide will be unstable by the earth removal work at landslide area. If the distance is reasonable for transportation for disposal of removed debris, counterweight fill work also can be considered to adopt as a set.	slope. , To monitor the deformation of the cut slope to check whether the slope is stable or not.
		Counterweight fill work, soil retaining work	It is adopted to increase resisting force against sliding force of landslide by surcharge at lower part of landslide block. It can be used as an emergency measure also.	Area and volume of the work shall be necessary to examine carefully by stability analysis to have sufficient effect by the counterweight fill work on the lower part of the landslide. Soil retaining work is used for small scale landslide. It shall be applied on/around weak toe part of landslide to prevent the displacement of unstable debris by landslide movement.	To check landslide stability by stability analysis based on the landslide figure after the work. Check the possibility of collapse of the fill part. To monitor the changing of groundwater level caused by rainfall after the work.
Restraint work	Pile work	Steel pile work	It is adopted to increase resisting force against landslide sliding force by shear strength of the pile penetrated until stable ground. Pile shall be installed at gentle slope part to have higher ground reaction force. The bending strength is also expected in case of steel pile depending on the installed part of landslide.	Location and number shall be decided in design stage depending on which type of resisting force such as shear strength and bending strength will be expected for the pile function. The planned location to install the pile shall be secured enough space to set the piling machine.	In recent years after installing piles, it is requested to maintain the pile if some abnormalities are found on the landslide area.
		Cast-in-place concrete shaft work	The shaft work is to construct a reinforced - concrete shaft in large diameter (2.5-6.5m diameter) to obtain greater resisting force than steel pile work. The shaft shall be installed at gentle slope part to have higher ground reaction force.	It shall be considered to apply shaft work in case that enough resisting force against target landslide cannot be expected by the steel pile work. Shaft work requires firm ground for foundation of shaft. Bending pile and rigid pile (flexible pile and stiff pile) can be designed depending on the ground strength. Generally a shaft making by hollow concrete block cylinder is installed into the large diameter pit as water collecting well.	In recent years after installing piles, it is requested to maintain the pile if some abnormalities are found on the landslide area.
	Ground anchor work		It is to fix a landslide body by transferring tension stress of structure to a firm ground. Anchor consists of "Anchor Body" to transfer tension stress to a ground, "Tensile Part" to transfer a tension stress form Anchor Head Part to Anchor Body and "Anchor Head Part" to bind anchor to structure. A high resisting force can be obtained against sliding force of landslide.	It is used for the following cases; ・on steep slope where no ground reaction force can be expected to be obtained, ・in an urgent situation requiring an immediate effect and ・when a local part such as toe part of landslide requires stabilization against collapse.	It is required to conduct lift-off test regularly to check whether the anchor is keeping planned tension stress or not. Measures prevent corrosion of anchor should be taken sufficiently.

6.2 Design of Structural Countermeasure Work for Landslide

The countermeasure works shall be designed so as to ensure that countermeasures have a sufficient impact on the landslide in question.

6.2.1 Control Work

a. Surface Drainage Work

Surface drainage network shall be installed to collect and discharge surface water through a combination of water catchment drainage and discharge ditch in the landslide area in accordance with topographical features (refer to Figure 6.2.1)

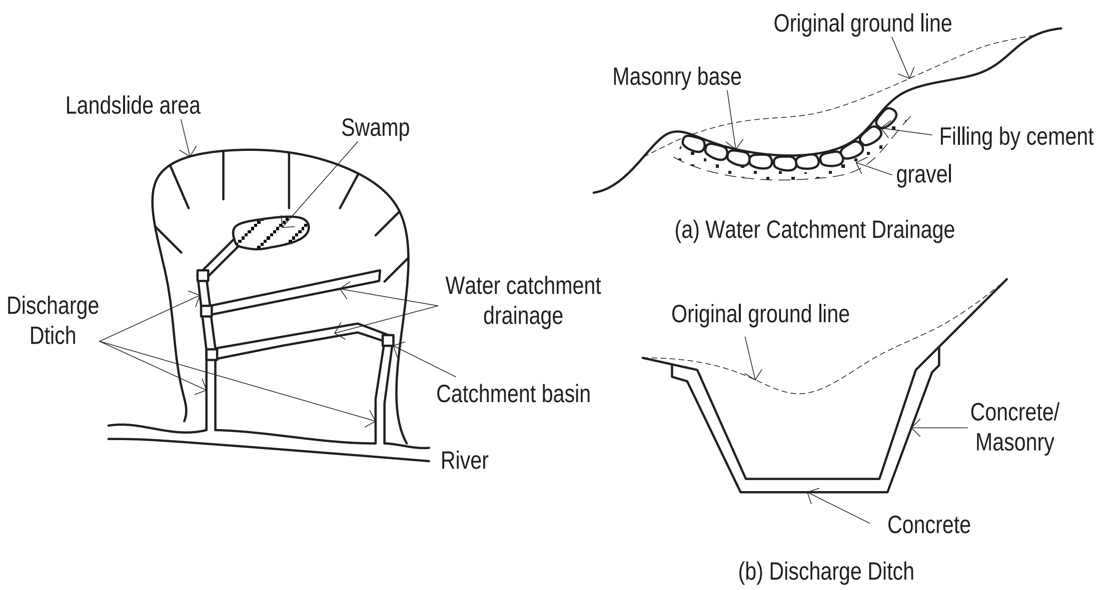
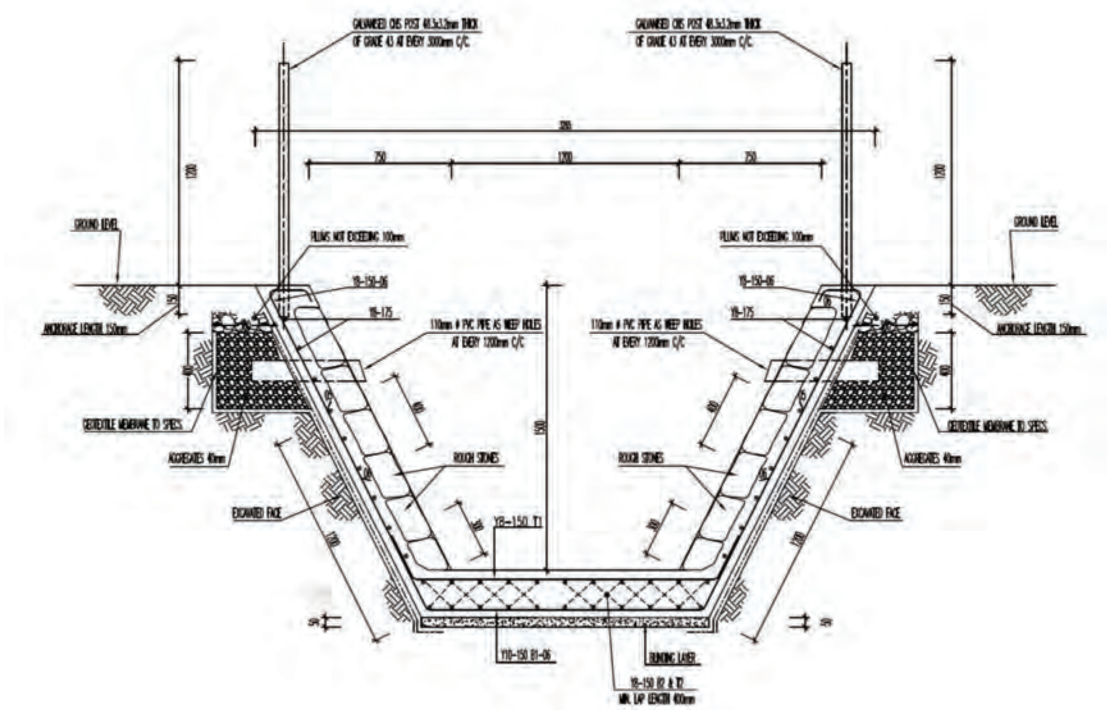


Figure 6.2.1 Example of Surface Drainage Work (source: JET)



SECTION 5-5
UPGRADING OF EXISTING RIVER TYPE 1

Figure 6.2.2 Example of Surface Drainage Work, Chitrakoot (source: MPI)

a.1 Water catchment Drainage and Discharge Ditch

Generally, the water catchment drainages can be made as shallower and wider dimension to collect rain water and surface runoff water. The drainage is installed mainly to cross the slope direction. The drainage shall be paved by masonry, reinforced concrete, PC concrete pipe. In case that the pavement material has high stiffness, each pipe shall be made shorter and supported by simplified pegs to avoid damage by land movement.

$L = \kappa(h_1 + t)$ -- (Formula 6-1)

L: Inside measure (m)
k: 2.5 to 3.0
t: Water depth of ditch (m)
h_1: Gap between Upper and lower ditch
h_2: Water depth of Catchment basin (m) (0.2 to 0.5m)

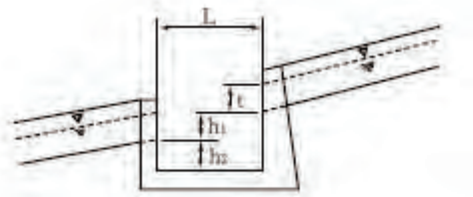


Figure 6.2.3 Side View of Catchment Basin[4]

The discharge ditch is installed to discharge collected water out of a landslide area immediately and completely. The dimension of the drainage shall be decided by the calculation of runoff water volume. The drainage shall be paved masonry, reinforced concrete, PC concrete pipe to avoid erosion of water way and filtration of water into the ground.

a.2 Infiltration Prevention Work

Since it will be difficult to install the infiltration prevention work to whole landslide area, the work shall be installed at the places such as open cracks, areas where water accumulates and swamps which can be assumed to be water supply point to the landslide area. If crack is found on the ground surface, the crack shall be filled by cohesion soil or cement, or covered by plastic sheet. If infiltration can be assumed from swamp or water way, those bottoms shall be paved by impermeable materials.

a.3 Calculation of Runoff Water Volume

The dimension of the drainage shall be decided in accordance with calculation of runoff water volume.

a.3.1 Designed Runoff Water Volume

Runoff volume of surface water can be calculated by using the rational formula)

Q＝1 / 3.6 × f × r × A -- (Formula 6-2)

where,
Q: Runoff volume (m^3/sec)
f: Runoff coefficient
r: Intensity of rainfall (mm/hour)
A: Catchment area (km^2)

- Runoff coefficient: f

The runoff coefficient shall be decided with reference of the table below.

Table 6.2.1 Runoff Coefficient based on Ground Surface Condition[5]

Condition of ground surface			Runoff Coefficient
Road surface	Paved road		0.70 - 0.95
	Gravel road		0.30 - 0.70
Road shoulder, cut slope	Fine grained soil		0.40 - 0.65
	Coarse grained soil		0.10 - 0.30
	Hard rock		0.70 - 0.85
	Soft rock		0.50 - 0.75
Grass on sandy soil	Gradient:	0 ~ 2%	0.05 - 0.10
		2 ~ 7%	0.10 - 0.15
	more than 7%		0.15 - 0.20
Grass on cohesive soil	Gradient:	0 ~ 2%	0.13 - 0.17
		2 ~ 7%	0.18 - 0.22
	more than 7%		0.25 - 0.35
Roof			0.75 - 0.95
Park			0.10 - 0.25
Gentle mountainous land			0.20 - 0.40
Steep mountainous land			0.40 - 0.60
Rice field, Water surface			0.70 - 0.80
Cultivate land			0.10 - 0.30

- Intensity of rainfall: r (mm/hr)

Intensity of rainfall is obtained from the matrix below. Generally a 50-year return period and 15 minutes duration are utilized to estimate intensity of rainfall for design of drainage in Mauritius.

Table 6.2.2 Intensity of Rainfall[6]

		Return Period (years)					
		2	5	10	25	50	100
Duration (min)	5	1.75	2.25	2.65	3.10	3.45	3.75
	10	1.45	1.85	2.15	2.45	2.75	3.05
	15	1.15	1.45	1.65	1.90	2.10	2.30
	30	0.95	1.20	1.40	1.65	1.85	2.05
	45	0.80	1.05	1.25	1.50	1.70	1.85
	60	0.65	0.90	1.10	1.30	1.50	1.70
	120	0.35	0.60	0.75	1.00	1.05	1.25

a.3.2 Drainage Capacity

The designed dimension of the drainage is verified whether it has enough capacity to drain displacement from the drainages.

Drainage capacity shall be calculated using the following formula.

Qa = A × v -- (Formula 6-3)

where,
Qa: Capacity of drainage (m^3/sec)
A: Cross section area of flow (m^2)
v: Mean flow velocity (m/sec)

- Cross section area of flow: A

The cross section area of flow of the designed drainage shall be 80% of the maximum dimension of the drainage.

- Mean flow velocity: v

Mean flow velocity shall be obtained using Manning's formula

$v = 1 / n \times R^{2/3} \times i^{1/2}$ -- (Formula 6-4)

where
v: Mean flow velocity (m/sec)
n: Roughness coefficient ($m^{1/3}$sec)
R: Hydraulic mean depth (m)
(= A/P: A: Cross section area of flow, P: Wetted perimeter）
i: Water slope

✓ Roughness coefficient: n
Roughness coefficient can be obtained from the following table

Table 6.2.3 Manning's Roughness Coefficient[7]

Type of Drainage	Condition of Drainage	Range of n	Average of n
Culvert	Cast-in-place concrete		0.015
	Concrete pipe		0.013
	Corrugated metal pipe		0.024
	P.V.C pipe		0.010
Lining drainage	Steel, no painting, smooth	0.011-0.014	0.012
	Mortal	0.011-0.015	0.013
	Wood, planed finish	0.012-0.018	0.015
	Concrete, trowel finish	0.011-0.015	0.015
	Concrete, gravel bottom	0.015-0.020	0.017
	Mason, filled by mortal	0.017-0.030	0.025
	Dry mason	0.023-0.035	0.032
	Asphalt, smooth	0.013	0.013
No lining drainage	Soil, straight, uniform dimension	0.016-0.025	0.022
	Soil, straight, with grass	0.022-0.033	0.027
	Gravel, straight	0.022-0.030	0.025
	Rock, straight	0.025-0.040	0.035
Natural drainage	Regular dimension	0.025-0.033	0.030
	Irregular dimension, grass and bush	0.075-0.150	0.100

b. Shallow Groundwater Control Work

b.1 Conduit / Open-Blind Ditch

Conduit /Open-Blind Ditch is the most appropriate work to discharge shallow groundwater which is distributed around 3m deep from ground surface. Especially, it can be applied to discharged groundwater which exists void of soil particles in low permeable soil layer. The length of the ditch shall be less than 20m. If the length is more than 20m, catchment basin shall be installed along the ditch path to connect surface drainage or another conduit.

b.1.1 Water Catchment Conduit (Blind Ditch)

The water catchment conduit is planned to collect ground water in the blind ditch (refer to Figure 6.2.4). The conduit consists of the following items.

- ✓ Perforated pipe or gabion shall be put in the trench at a specific depth
- ✓ Waterproof sheet or concrete shall be laid on the bottom of the trench to avoid infiltration
- ✓ The trench shall be filled by the aggregate or crushed run stone to avoid clogging.

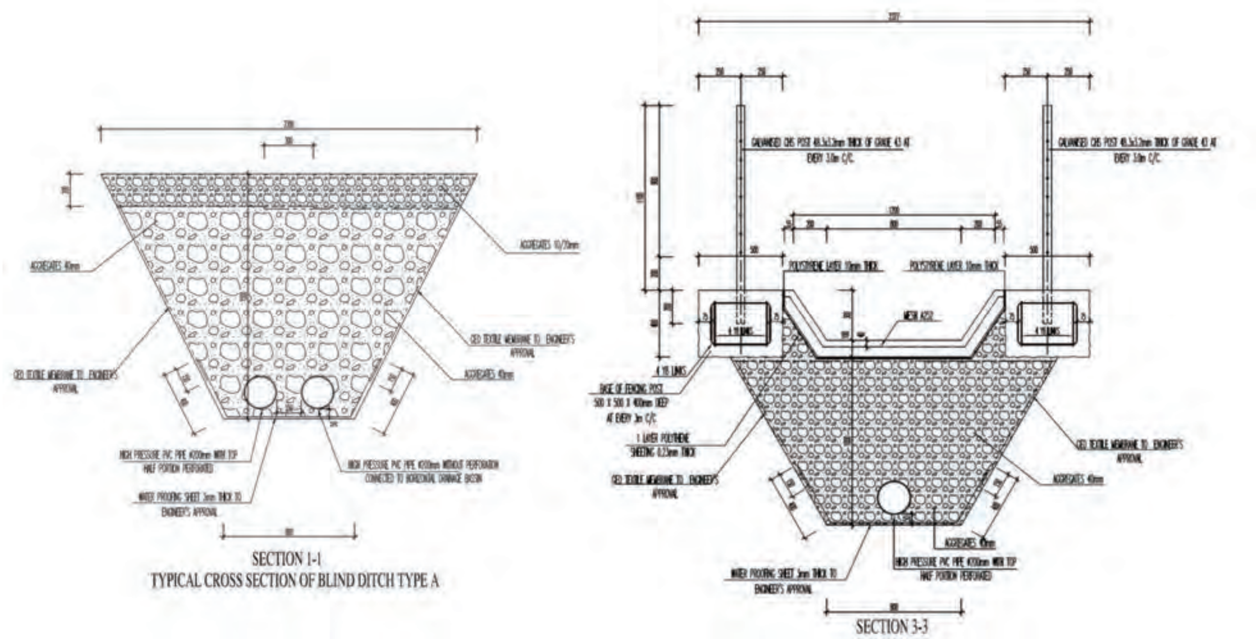


Figure 6.2.4 Example of Blind Ditch, Chitrakoot (source: MPI)

In case that the conduit is planned to installed over a long distance, a catch basin or a man-hole shall be installed every 20 to 30m to avoid re-infiltration of the collected water or clogging of the conduit.

b.1.2 Discharge Conduit

Discharge conduit is installed to discharge the water collected in water conduit. It shall be non-perforated concrete or PVC pipe. The pipe shall be connected to surface drainage at the catchment basin point.

b.1.3 Open-Blind Ditch

Since shallow groundwater can be found at depression or gully part of the topographical feature same as surface water distribution, generally the conduit network has tendency to correspond with surface drainage network. The following figure shows combination open-blind ditch and conduits.

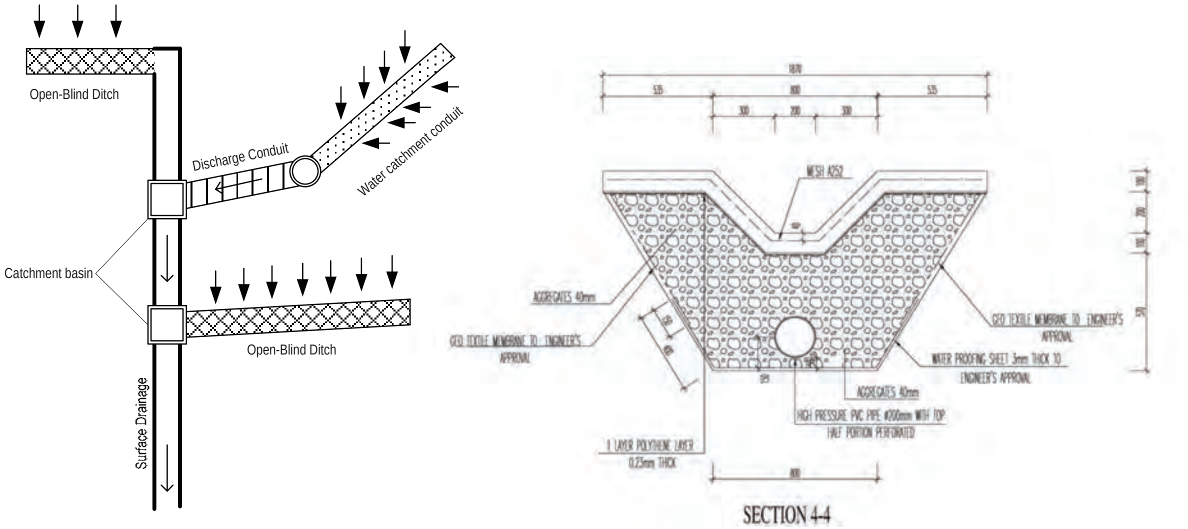


Figure 6.2.5 Example of Open-Blind Ditch (source: JET)

b.1.4 Large scale Blind Ditch

In case that aquifer is located 3 to 5m below the ground surface, blind ditch or conduit will need to be large scale and require a large amount of excavation. Such a large scale ditch shall be installed near the boundary of the target landside to discharge and to block inflow water into the landslide area from out of the area. If a large scale ditch is installed in the lower part of the landslide, the possibility of the excavation for the ditch causing the landslide becomes unstable or active needs to be fully investigated. .

b.2 Horizontal Drainage

In case to discharge of shallow groundwater, generally, the horizontal borehole shall be made 5 degrees upward and 20m to 50m depth. The diameter of the borehole shall be more than 66mm by drilling machine, and perforated PVC pipe / steel pipe shall be installed in the borehole to protect the borehole wall. The outlet of the drainage shall be set on stable ground as far as possible. The drainage pipes shall be aligned in a fan shape (refer to Figure 6.2.6). The slope of outlet of drainage shall be protected by a concrete wall or gabion against erosion (refer to Figure 6.2.7).

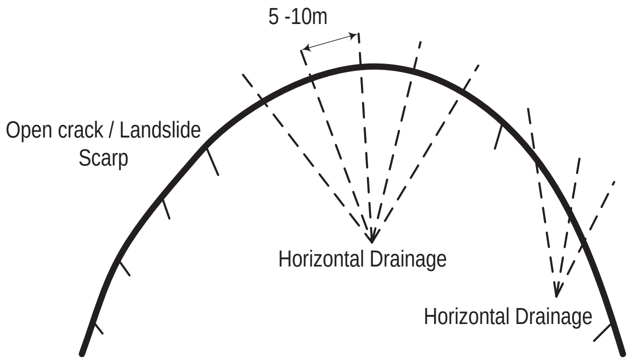


Figure 6.2.6 Example of Alignment of Horizontal Drainage (source: JET)

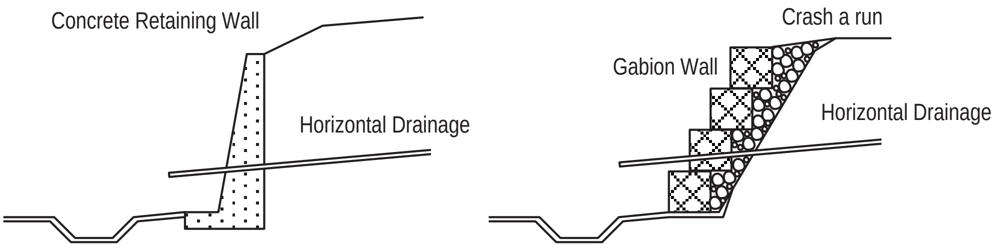


Figure 6.2.7 Example of Slope Protection at Outlet of Horizontal Drainage (source: JET)

Figure 6.2.8 Horizontal Drainage, Chitrakoot (source: MPI)

c. Deep Groundwater Control Work

c.1 Horizontal Drainage (Water Catchment Drainage)

Horizontal drainage of deep groundwater shall be installed 5 degrees upward, and 10m more after penetration of the slip surface or aquifer (refer to Figure 6.2.9). The drainage pipes shall be aligned in a fan shape (refer to Figure 6.2.6). The drainage shall be set at an orthogonal direction (at a right angle) to the sliding direction of the landslide. The tip of each drainage shall be 5 to 10m (refer to Figure 6.2.6). The outlet of the drainage shall be set on stable ground as far as possible. The slope of the outlet of drainage shall be protected by a concrete wall or gabion against erosion (refer to Figure 6.2.7).

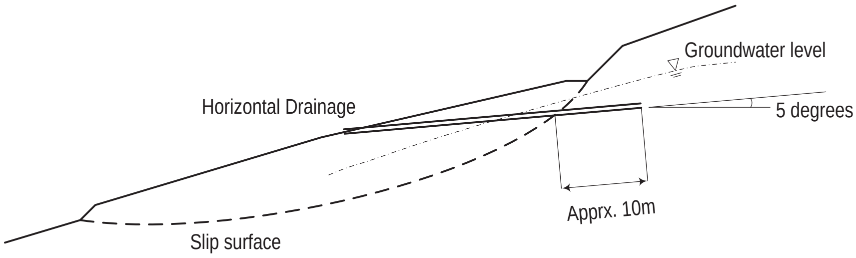


Figure 6.2.9 Depth and Inclination of Horizontal Drainage (source: JET)

An effectively working horizontal drainage can be expected to have a drawdown of 3 m from the original groundwater level in the design stage.

The borehole shall be made with more than 66mm diameter. Perforated rigid PVC pipe or steel pipe to protect the borehole wall shall be installed in the borehole.

In case that a long borehole is required, the drilling work shall be carried out with utmost care and prudent operation is required to reach the planned area because there is possibility of defection of borehole in geological layer with boulder or heterogeneous stratum.

If the target area can be considered to consist of low permeable materials, the strainer can be made on whole stretch of the drainage pipe. The hole of strainer and its interval shall be decided in consideration with avoiding clogging (refer to Figure 6.2.10). In case of making large holes (to avoid clogging), there is a risk of the drainage wall collapsing because the low risk of clogging means the surrounding soils can more easily flow into the pipe with water to be discharged. In case of making the holes small, there is a greater risk of clogging.

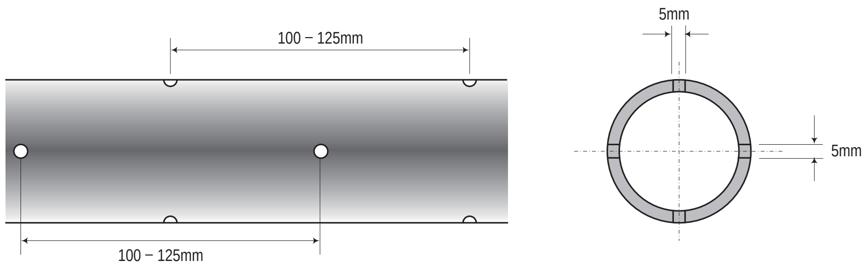


Figure 6.2.10 Example of Horizontal Drainage Pipe (source: JET)

c.2 Drainage Well

The drainage well shall be installed on the stable foundation. The diameter of the well shall be 3.5 to 4.0m. The collected water by water catchment drainage (horizontal drainage) shall be drained by gravity through a discharge pipe (apprx.100m length) from the well or discharge tunnel.

Depth of the well is, generally, more than 2m above the slip surface in case of an active landslide. In case of a dormant landslide or it is outside of a landslide area, the well shall be installed 2m to 3m below the slip surface, and the bottom of the well shall be paved with concrete. Water catchment drainage connected to the well shall be installed in stable ground in case it is outside of a landslide area. Especially, in case that the drainage well is installed in a dormant landslide, installation area shall be decided with utmost care to avoid damaged that may cause re-activation of the landslide.

Water catchment drainage on the well shall be 50m depth generally, and be aligned in a fan shape from the drainage well to penetrate the slip surface. The tip of each drainage shall be 5 to 10 m apart. The position of water catchment drainages shall be planned at several levels depending on the location of aquifer (refer to Figure 6.2.11). Number of the drainage shall be decided in consideration with the result of geological and hydrological investigations, and can be changed depending on the actual condition in the construction stage. If there is the possibility of the drainage being demolished or deformed by landslide activity after installation, the well shall be filled by gravel or rocks. In that case, water catchment drainage cannot be maintained in the well.

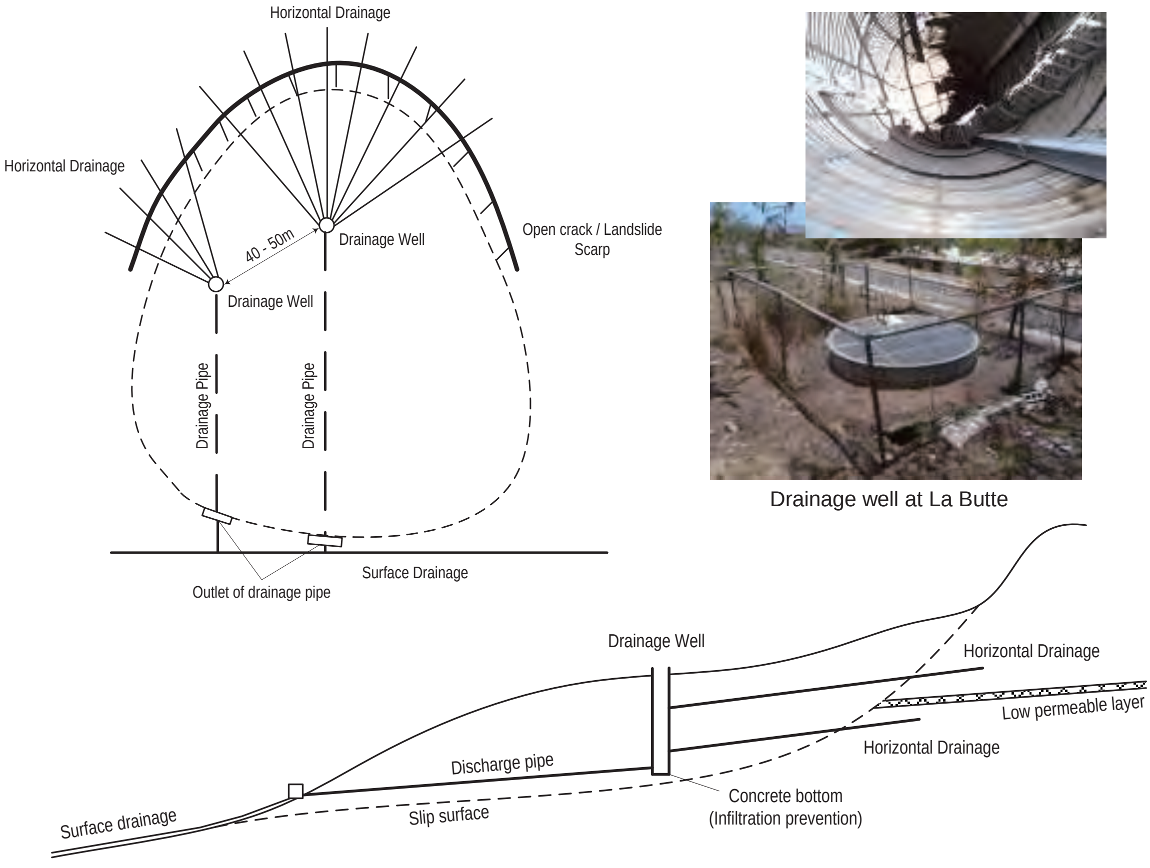


Figure 6.2.11 Example of Drainage Well in Case of an Active Landslide (source: JET)

Generally, drainage wells shall be installed at 40m to 50m intervals laterally. The drainage wells can be considered to be effective when there is a drawdown of groundwater level from original design stage level.

Drainage well shall be made with Reinforced-Concrete or lining plate with galvanization for corrosion protection. In design stage, ancillary facilities such as steel rid or ladder shall be planned to attach for safety and maintenance after completion of the construction. Collected water at the well shall be discharged by gravity through a discharge pipe bored into the bottom of the well in the lower part on the slope. Generally, long distance of discharge pipe is required. Since large drilling machine will not use in the well, drilling shall be carried out with utmost care to avoid jamming of the drilling bit in case of drilling for long distances. Three to four inch steel or PVC pipe can be used for the casing of the discharge pipe. If the length of the discharge pipe will be longer than 100m and the ground condition is not good for the long distance excavation, the installation of a drainage tunnel can be considered instead of a discharge pipe. The diameter of the tunnel excavation should be a minimum of approximately 2m. When the tunnel reaches the target well, the tunnel can be backfilled after a drainage pipe has been installed. In case that it is difficult to excavate the tunnel due to weak ground conditions, another intermediate drainage well shall be installed 70 to 80m from the target well to connect a discharge pipe using a drilling machine.

In case of emergency situation, water in the well can be discharged by a pump temporarily.

d. Earth Removal Work

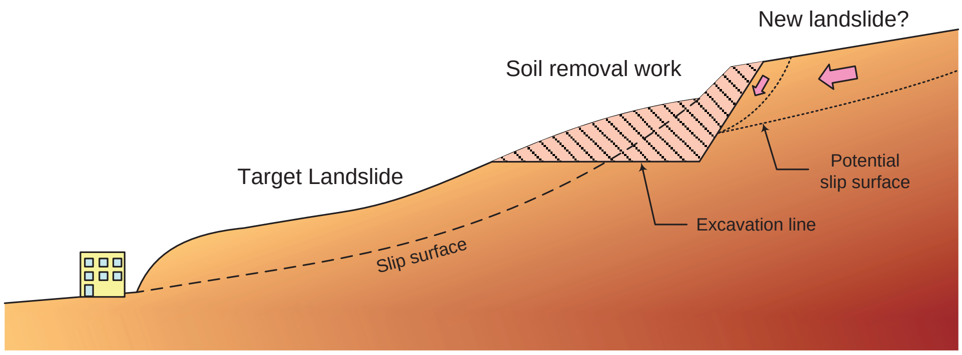
The earth removal work is one of the most reliable countermeasure works. Generally, the work is applied in combination with other control works or groundwater discharge work as a part of restraint works.

The earth removal work shall be designed at head part of landslide block to secure slope stability. Volume and area of earth removal, and height and gradient of cut slope can be decided by slope stability analysis. In a design stage, stability of candidate area for the work and existence of potential landslide shall be studied in advance to avoid destabilization of cut slope behind the work area and activation of another landslide. Sufficient examination shall be carried out to adapt the work to the target site. Protection work for cut slope by the work shall also be considered.

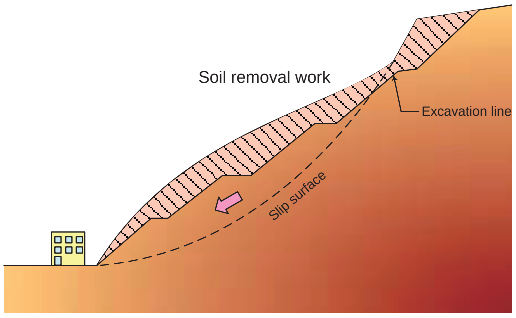
d.1 Methodology

d.1.1 Location of Earth Removal

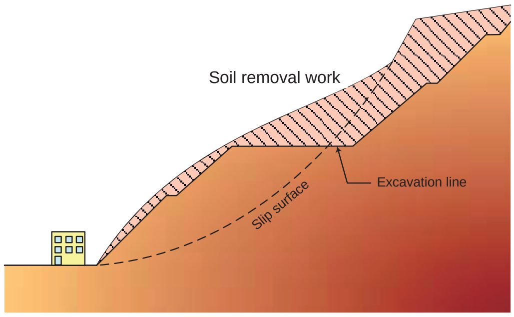
Generally, the earth removal work shall not be adopted at toe part of landslide, but at head part of landslide. In case that toe part of landslide shows loose and weak condition, the toe part shall be removed after first removing part of the head of the landslide to ensure whole landslide block is balanced.



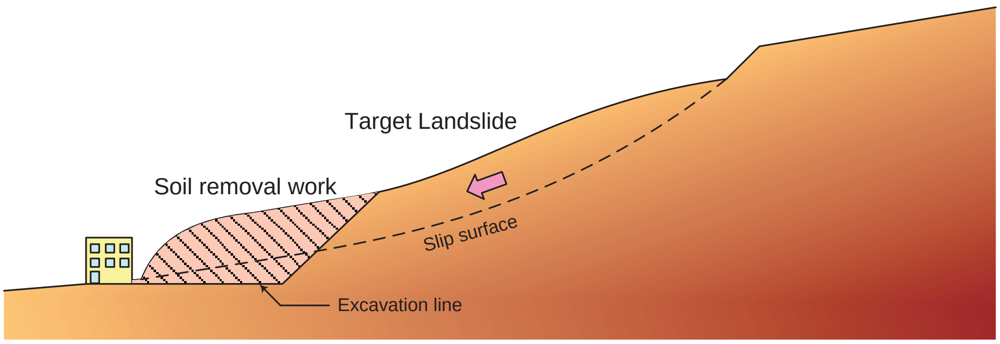
(i) Soil removal work at the head of a landslide will have a good effect on stability itself but it may also trigger a new landslide behind the target landslide.



(ii) Excavation work conducted as shown in the above figure will contribute to the instability of the target landslide due to lack of soil at the lower part of the landslide block[8]



(iii) Excavation at the head of the landslide block with an appropriate slope gradient will contribute to the stability of the target landslide



(iv) Excavation at the toe of a landslide will encourage instability of the target landslide. Therefore, the excavation shall not be conducted at the toe of a landslide even though there is a possibility that houses or public facilities are damaged by further landslide activity.

Figure 6.2.12 Example of Soil Removal Work at the Head and Unstable Part of Target Landslide (source: JET)

d.1.2 Effect of the Work and Shape of Landslide

In case that the target landslide consists of several minor landslide blocks, the earth removal work shall not be adopted at landslide block located in the middle or lower part of the whole landslide block otherwise it will influence the stability of a landslide located in the upper part of the landslide block (refer to Figure 6.2.13). There is considered to be a possibility of triggering a primary landslide as a result of loosening the ground when a large volume of earth is excavated. In case that slip surface of landslide shows circular arc or thickness of head part of landslide block is much bigger than lower part of landslide, the soil removal work at head part can be expected to have a profound effect.

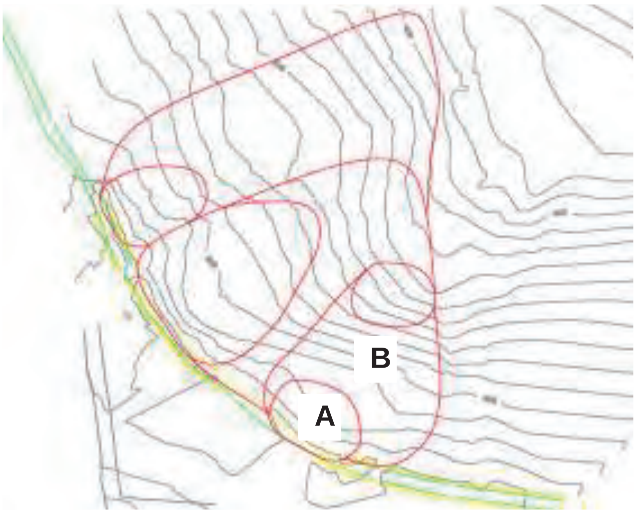


Figure 6.2.13 Example Case that Minor Landslides exist within a Large Landslide Area. If the soil removal work is adopted at head part of landslide A, it will affect the stability of landslide B (source: JET)

d.1.3 Gradient of Cut Slope made by the Work

The soil removal work shall be adopted around upper part of the landslide block. If the area for the work shows gentle slope, the cut slope of the work shall be at an angle of 1:2.0 to 1:4.0. In case that the work will be adopted at a landslide scarp, the cut slop will be relatively steep angle, and the shape of feature after the work will be terraced. Even if the soil removal work area is within the steep slope part of the landslide block, the cut slope of the work shall have the same angle as original or 1:1.0 to 1:1.5.

d.1.4 Point of Consideration

The excavation work shall be carried out from the upper part to the lower part to avoid causing any instability in the landslide block. The work shall be done in dry season, and it shall not be carried out at times of rainfall.

d.2 Surface Treatment on the Cut Slope

Since cut slope just after excavation has, generally, high permeability and the slope can easily become loose or collapse due to rainfall, it is recommended to install a drainage system and slope protection work on the surface of the cut slope.

d.3 Treatment of Excavated Soil

Excavated soil of the work is often used to apply material for counterweight fill work as a landslide countermeasure or fill material for other civil works. However, there is a case that excavated soil is not appropriate material for fill work because generally materials contained in such landslide blocks are cohesive soils comprised of weathered rock. In such cases, utmost attention is required if the excavated soil is to be reused.

e. Counterweight Fill Work

The counterweight fill work is adopted to increase resistant force against sliding force of landslide by installation of fill at toe part of landslide. Volume and position shall be decided according to a stability analysis to obtain an expected resistant force. In design stage of counterweight fill work, the following items shall be considered carefully.

- Stability of foundation ground of the fill
- Treatment of groundwater behind the fill
- Protection of fill slope and toe part of fill slope

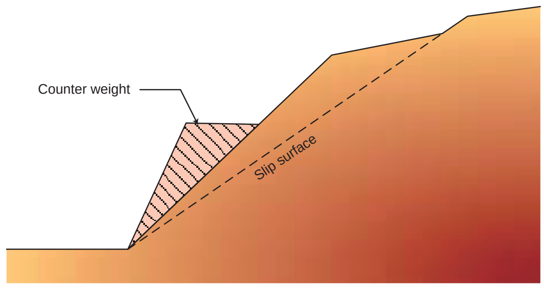
Position and area of counterweight fill work shall be decided carefully to avoid negatively affecting the target landslide stability or adjacent area. Limitation of height of the fill shall be studied in advance based on bearing capacity of the foundation ground by the laboratory test. Generally, average gradient of the fill slope shall be 1:1.5 to 1:2.0, and terraced steps of 1 to 2m width shall be installed every 5m of vertical height on the fill slope. Side ditches shall also be installed on each step.

In case that water spring/seepage is found at toe part of landslide block, the fill work shall be designed to avoid blocking water flow by the work. In case that aquifer of shallow groundwater is found at planned area of the fill work, water treatment work behind of the fill shall be considered to avoid making the landslide unstable as a result of raising the ground water level by blocking the water flow.

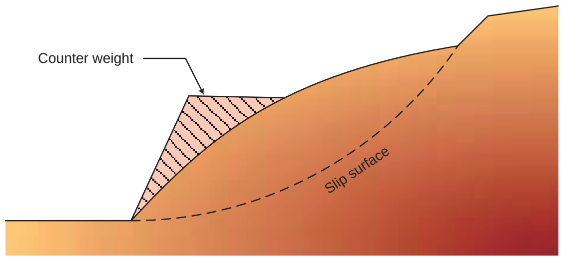
In case that toe part of landslide fronts on a river, it can be expected to have same effect as counterweight fill work by sediments behind check dam when check dam is installed downstream of the river.

Slope protection work shall be adopted on fill slope because fill slopes easily become loose or collapse because of rainfall. To protect the slope vegetation work, gabion work or simplified piling work can be adopted, but solid structures such as concrete walls or masonry walls with concrete are not recommended.

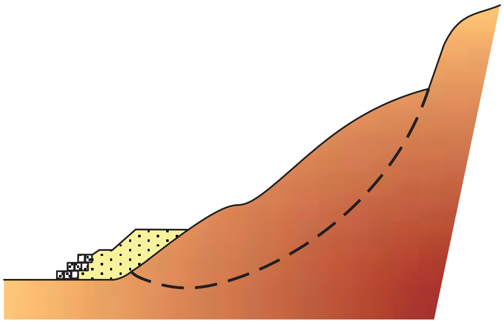
Generally, Gabion wall or Reinforced concrete wall can be adopted as retaining wall at toe part of fill slope. In case of gravity-type concrete retaining wall, it shall be carried out with utmost attention to avoid causing the landslide to become unstable due to excavation for foundation of the retaining wall. Surface of the fill shall be covered by vegetation from an erosion protection, natural environment and landscape points of view.



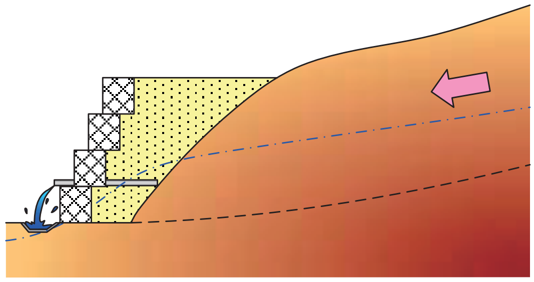
(i) In the case that a slip surface appears straight, the safety factor of the landslide will not be drastically changed by the counter weight work.



(ii) In the case that a slip surface appears curved, an increase in the safety factor of the landslide can be expected by the counter weight work.



(iii) The slope of the counterweight filling work shall be covered by a gabion or sandbags to avoid erosion.



(iv) In the case that a spring or seepage is found at the toe of the landslide, weep holes shall be installed in the filling/embankment to avoid a rise of the groundwater level in the landslide.

Figure 6.2.14 Points of Installation of Counter Weight Work (source: JET)

6.2.2 Design of Restraint Work

a. Pile Work

Piling work shall be carried out at a place which has firm foundation ground and with enough capacity against sliding force of landslide. In case of active landslide which shows more than 1mm/day movement, the piling work will not be suitable countermeasure because piling work will not work properly unless all piles are installed as planned at same time in such landslide case.

Various types of piling materials for landslide countermeasure work can be applied such as steel pipe pile, reinforcement concrete pile and H-shape steel pile. Generally insertion pile method is used for landslide countermeasure. The insertion method shall be carried out as follows,

1. Insert steel pile into large diameter borehole
2. Fill the pile with concrete
3. Grout between pile and borehole

In case that foundation ground is stratum with hard rock boulders, Down-the-Hole Hammer method or the Shaft method shall be applied. Shaft method is to cast reinforcement concrete pile in the well dug with liner plate or steel/RC pipe segments (2.5 to 6.5m diameter). In case of applying the Shaft method, the utmost care shall be taken to avoid rock falls or collapse of well walls because the work such as excavation and removal of debris shall be done in a limited space.

Generally pile work for landslide countermeasures shall be carried out to install pile into vertical borehole, and then grout by concrete between pile and borehole wall. Driving pile will be difficult to be installed up to planned depth in a gravel layer, and driving depth of pile in a rock layer will be limited. Additionally, damaging the rock foundation of the pile as a result of the driving will negatively affect landslide stability. Therefore, driving pile shall not be applied as a permanent landslide countermeasure.

a.1 Steel Piling Work

The steel piling work shall be designed in consideration with topography and geology in the target landslide to obtain planned restraining force. In a design stage of the work, pile stability shall be studied against internal stress under the condition that planned restraining force works on the pile. And also, sliding by passive pressure, destruction of pile foundation and pass-through of soil between piles (refer to Figure 6.2.15).

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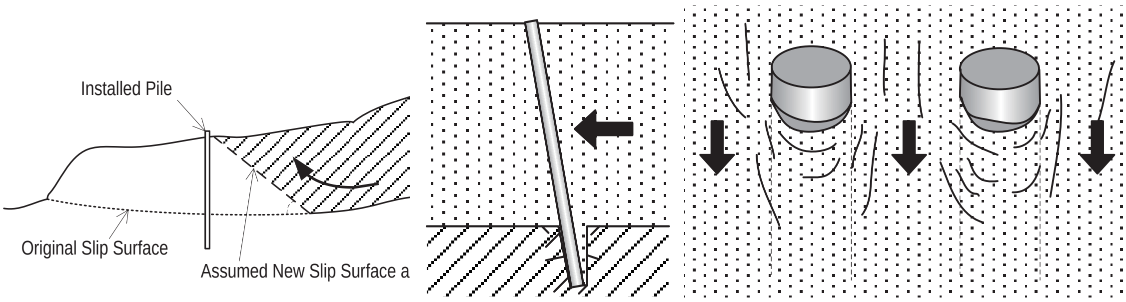


New sliding by passive pressure | Destruction of pile foundation | Pass-through of soil between piles

Figure 6.2.15 Check points when Steel Pile Work is Designed (source: JET)

a.1.1 Applicable Condition of Pile Work

In case of application of the Piling Work, applicable condition shall be considered carefully. According to experience in Japan, the thickness of a landslide block suitable for pile work should be less than 20m. Other applicable conditions of pile work are,

- the work shall not be applied where the ground is soft,
- target landslide shall not be segmentalised by fracture and
- the work shall be carried out in dormant period of the target landslide.

For the design of the pile, it shall be considered as a precondition that a pile is presumed to be an elastic body, and ground reaction around the pile can be expected constantly.

a.1.2 Required Strength of Pile against Lateral Pressure

For calculation of effectiveness of pile, Hennes's Formula (1936) and White's Formula (1946) are known well. Restraining effect found by these formulas is deemed breaking strength of landslide block around piles in case that the pile is rigid body which has infinite strength. However, since in reality the pile does not have infinite strength, one pile cannot bear the entire stress found by the above formula. Thus the number of the pile that suffices for the required restraining stress for each unit width is calculated based on strength of available piles for a site.

Required restraining stress of pile for each unit width: P_r to achieve the Planned Factor of Safety: F_{sp} can be found by the Formula 6-6. The Formula comes from Formula 6-5 which is added restraining stress P_r on the molecule.

$$F_{sp} = \frac{\sum\{c \cdot \ell + (W \cdot \cos\alpha - u) \cdot \tan\phi\} + P_r}{\sum W \cdot \sin\alpha}$$ ------------------------------- Formula 6-5

$$\mathrm{P_r} = F_{sp} \sum W \cdot \sin\alpha - \sum\{c \cdot l + (W - u \cdot b)\cos\alpha \cdot \tan\phi\}$$ ------------ Formula 6-6

where,
- P_r: Required restraining stress of pile for each unit width (kN/m)
- F_{sp}: Planned Factor of Safety
- W: Weight of slice of landslide block (kN/m)
- u: Pore water pressure working on slip surface of slice of landslide block (kN/m)
- ℓ: Length of slip surface of slice of landslide block (m)
- α: Angle of slip surface of slice of landslide block (degree)
- Φ: Friction angle of slip surface (degree)
- c: Cohesion of slip surface (kN/m^2)

In case of adopting jointly with other countermeasure works, the required restraining stress of pile shall be calculated under the conditions that will affect the countermeasures such as pore water pressure (u), weight of slice of landslide block (W) and length of slip surface of slice of landslide block (ℓ) .

a.1.3 Location of Installation of Pile

Location of installation of pile shall be lower part of landslide where the slip surface is a gentle angle and compression part of landslide block. The installation part of landslide block shall be thick relatively, and the place which is low risk of sliding by passive pressure.

If only locations in the upper part of the landslide block are available for the pile work, pile can be installed at tension part of landslide block where slip surface shows relatively steep angle. In that case, since ground reaction cannot be expected due to movement of lower landslide block of the pile, the function of the pile shall be considered as cantilever beam. Thus, the pile shall be designed in consideration that sliding force of landslide works on the pile in the moving landslide block as distribution load or concentric load on cantilever beam.

The compression part shall be identified by Formula 6-7 and Formula 6-8. The compression part shall be sliding force: ΣR_i > resistance force: ΣT_i, and the tension part shall be $\Sigma R_i < \Sigma T_i$. Additionally location of installation of pile shall be the place which can be expected to obtain sufficient back soil pressure.

$$T_i = W_i \cdot \sin\alpha_i \quad \text{---------- Formula 6-7}$$

$$R_i = (W_i \cdot \cos\alpha_i - u_i) \cdot \tan\phi + c \cdot \ell \quad \text{---------- Formula 6-8}$$

where,
- T_i: Sliding force of each slice of landslide block (kN/m)
- R_i: Resistance force of each slice of landslide block (kN/m)
- W_i: Weight of slice of landslide block (kN/m)
- u_i: Pore water pressure working on slip surface of slice of landslide block (kN/m)
- ℓ_i: Length of slip surface of slice of landslide block (m)
- α_i: Angle of slip surface of slice of landslide block (degree)
- ϕ: Friction angle of slip surface (degree)
- c: Cohesion of slip surface (kN/m^2)

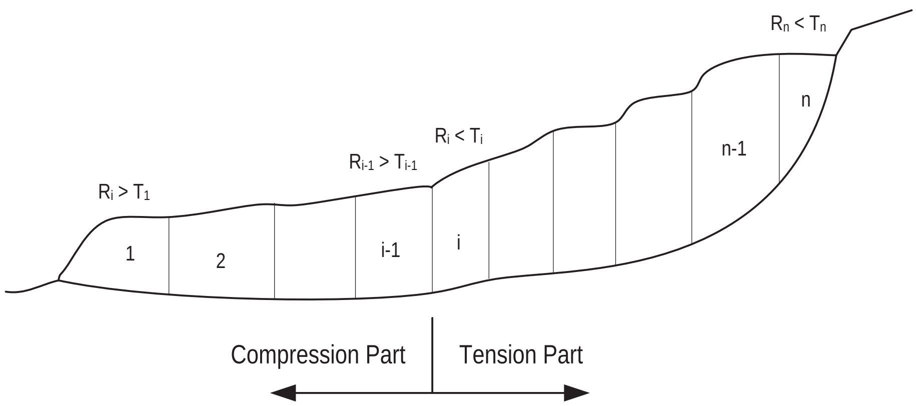


Figure 6.2.16 Compression Part and Tension Part of Landslide Block[9]

In case that pile is installed at toe part of landslide, it shall be considered to avoid occurrence of sliding by passive pressure (refer to Figure 6.2.17). Risk of the sliding by passive pressure shall be examined by using Formula 6-9 and Formula 6-10. F_{sp}' (Formula 6-10) shall be bigger than F_{sp} (Formula 6-9)

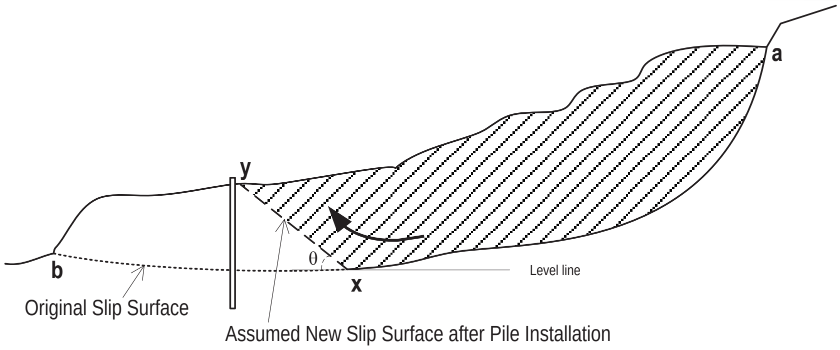


Figure 6.2.17 Schematic Image of Sliding by Passive Pressure[10]

$$F_{sp} = \frac{\sum\{(W_{ab} \cdot \cos\alpha - u_{ab}) \cdot \tan\alpha + c \cdot \ell_{ab}\} + P_r}{\sum W_{ab} \cdot \sin\alpha}$$ ---------------------------- Formula 6-9

where,

- F_{sp}: Factor of Safety of original slip surface after installation of Pile
- P_r: Resistance force of each unit width of pile (kN/m)
- W_{ab}: Weight of slice of landslide block on slip surface **a-b** (kN/m)
- u_{ab}: Pore water pressure of slice of landslide block on slip surface **a-b** (kN/m)
- ℓ_{ab}: Length of slip surface of slice of landslide block on slip surface **a-b** (m)
- α_i: Angle of slip surface of slice of landslide block on slip surface **a-b** (degree)
- ϕ: Friction angle of slip surface **a-b** (degree)
- c: Cohesion of slip surface **a-b** (kN/m^2)

$$F_{sp}' = \frac{\sum\{(W_{ax} \cdot \cos\alpha_{ax} - u_{ax}) \cdot \tan\phi_{ax} + c_{ax} \cdot \ell_{ax}\} + \sum\{(W_{xy} \cdot \cos\alpha_{xy} - u_{xy}) \cdot \tan\phi_{xy} + c_{xy} \cdot \ell_{xy}\}}{\sum W_{ax} \cdot \sin\alpha_{ax} + \sum W_{xy} \cdot \sin\alpha_{xy}}$$

------------------------ Formula 6-10

where,

- F_{sp}': Factor of Safety of assumed new slip surface **a-x-y** after installation of Pile
- W_{ax}: Weight of slice of landslide block on slip surface **a-x** (kN/m)
- W_{xy}: Weight of slice of landslide block on slip surface **x-y** (kN/m)
- u_{ax}: Pore water pressure of slice of landslide block on slip surface **a-x** (kN/m)
- u_{xy}: Pore water pressure of slice of landslide block on slip surface **x-y** (kN/m)
- ℓ_{ax}: Length of slip surface of slice of landslide block on slip surface **a-x** (m)
- ℓ_{xy}: Length of slip surface of slice of landslide block on slip surface **x-y** (m)
- α_{ax}: Angle of slip surface of slice of landslide block on slip surface **a-x** (degree)
- α_{xy}: Angle of slip surface of slice of landslide block on slip surface **x-y** (degree)
- ϕ_{ax}: Friction angle of slip surface **a-x** (degree)
- ϕ_{xy}: Friction angle of slip surface **x-y** (degree)
- c_{ax}: Cohesion of slip surface **a-x** (kN/m^2)
- c_{xy}: Cohesion of slip surface **x-y** (kN/m^2)

$$\theta = 45° - \frac{\phi_{xy}'}{2}$$ --- Formula 6-11

a.1.4 Alignment of Piles

Pile shall be aligned at right angle against landslide movement direction, and the piles shall be installed at regular intervals. Interval of each pile shall be decided in consideration with applied design condition of the pile. Additionally, since there is a risk of loose ground by excavation and movement of soil between piles depending on the aspect of the landslide material, the distance of intervals between piles is shown in Table 6.2.1 can be applied as rough standard. The interval shall be within 8 times of diameter of the pile and more than 1m to avoid disturbance of adjacent ground by excavation. In case the calculation necessitates an interval of less than 1m, the piles shall be aligned in a staggered manner.

Table 6.2.1 Interval of Piles[11]

Thickness of Landslide block at pile installation point	Interval of Pile
0 - 10m	Less than 2.0m
10 - 20m	Less than 3.0m
More than 20m	Less than 4.0m

b. Shaft Work

Caisson pile method (Shaft work) shall be adopted in the following cases.

- Scale of target landslide is large
- Sliding force of the landslide is too big to restraint by pile work
- Ground condition makes it difficult to conduct large diameter boring to install steel piles.

Shaft work is constructed with following procedure.

1. 3.0 to 6.5m diameter vertical shaft is excavated by manual or machinery with liner plate up to stable ground.
2. Reinforcing bar (D32 to D51) is built up in the shaft cylindrically as main reinforcement
3. Concrete casts in the shaft to make a RC caisson.

b.1 Point for Design

b.1.1 Selection of expected function of pile

First of all in design stage of shaft work, expected function of the piles shall be selected, namely whether to use rigid piles (caisson) or flexible piles. A rigid pile is a pile that makes resistance against lateral load without deformation. Structural design of such piles should take into consideration that the pile body is intend to make a stable condition by vertical and horizontal ground reaction (refer to Figure 6.2.18(a)). A flexible pile is a pile that makes resistance against lateral load with deformation (bending). Structural design of the pile should take into consideration that the pile body will bend in the manner of a steel pile even in cases whereby the pile is long such as rigid body RC piles. Such piles act in the manner of flexible piles due to exchange of stress between the piles and ground, and are therefore deemed an elastic body (refer to Figure 6.2.18 (b)).

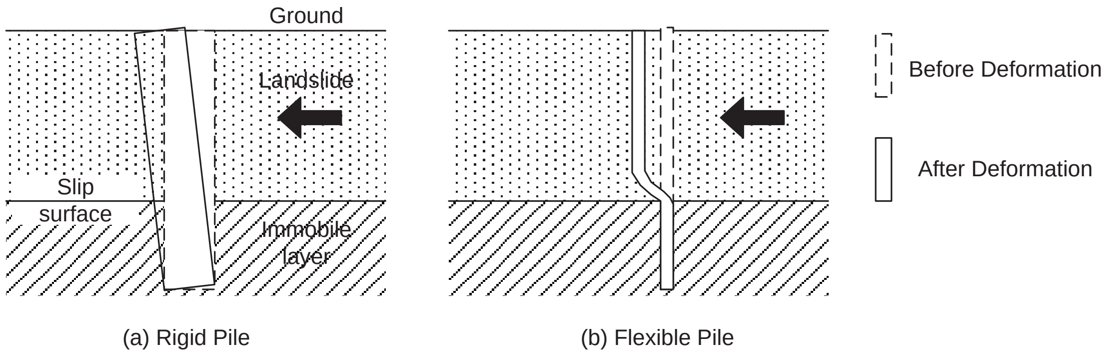


Figure 6.2.18 Schematic Image of Effect of Rigid Pile and Flexible Pile[12]

Selection of rigid pile and flexible pile can be done by using following formula. (Abridgement: The Japanese Ministry of Land, Infrastructure, Transport and Tourism Technical Criteria for River Works: Practical Guide for Design)

In case of $\beta\ell \leq 2$, the pile shall be designed as rigid pile (Caisson)
In case of $\beta\ell \geq 2$, the pile shall be designed as flexible pile

where, $\beta = \sqrt[4]{\frac{Kd}{4EI}}(m^{-1})$ -- Formula 6-12

- K: Lateral ground modulus of foundation of embedment of pile (kN/m^3)
- d: Width of whole outer area of pile (m)
- ℓ: Length of embedment pile from slip surface to the bottom (m)
- E: Elastic modulus of pile (kN/m^2)
- I: Second moment of area of pile (m^4)

Since the scale of landslides on which shaft work is conducted is generally large, and moreover the landslides are generally thick, flexible piles are most often selected.

b.1.2 Differentiation from Design of Steel Pile

Section of the shaft pile is intend to be decided based on shearing unit stress as opposed to steel pile whose section is decided based on tension unit stress. Especially, since shearing stress of concrete often exceeds allowable value around depth of slip surface, some reinforcement of the piles will be required.

b.1.3 Point of Calculation of Sectional Force

Since, generally, shaft work will cost more than steel pile work because the scale of the target landslide will be larger, sectional structure of pile such as arrangement of reinforcement shall be decided in the detail design stage based on not only the main section but several sectional calculations.

c. Ground Anchor Work

Ground anchor work shall be designed to obtain planned restraining force in consideration with topographical and geological conditions at the target landslide area. Also, it shall be designed to secure not only stability of anchor against tensile force, but fixing ground and structure such as pressure plate as well.

Anchor is a part of the countermeasure structure that transfers tensile force from the structure to the ground. The ground anchor consists of "Fixed anchor part (Anchor body and Fixing ground)" which has function to transfer tensile force to the ground, "Tension part" which transfers tensile force from the head part of the anchor, and "Head part including reaction structure" which fixes anchor to structure (refer to Figure 6.2.19).

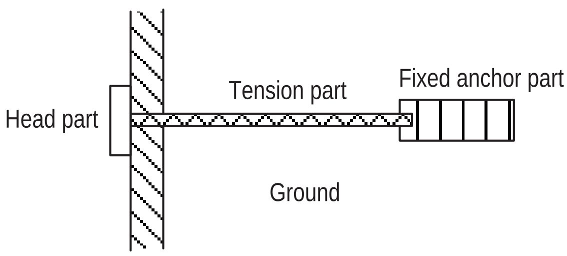


Figure 6.2.19 Basic Element of Ground Anchor (source: JET)

c.1 Structure of the Anchor

c.1.1 Fixed Anchor Part

Fixed anchor part is a resistance part to transfer tensile force from the tension part to ground by frictional resistance and bearing resistance of the ground, and it is constructed by injection of grouting material. Generally, anchor body consists of the Grouting cement materials and the Tendon assembled by Pre-cast steel products.

c.1.2 Tension Part

Tension Part is a part to transfer tensile force from the head part of anchor to the anchor body. This part consists of the Tendon assembled by Pre-cast steel wire and steel bar and the Sheath to equalize elongation of the tendon (refer to Figure 6.2.20).

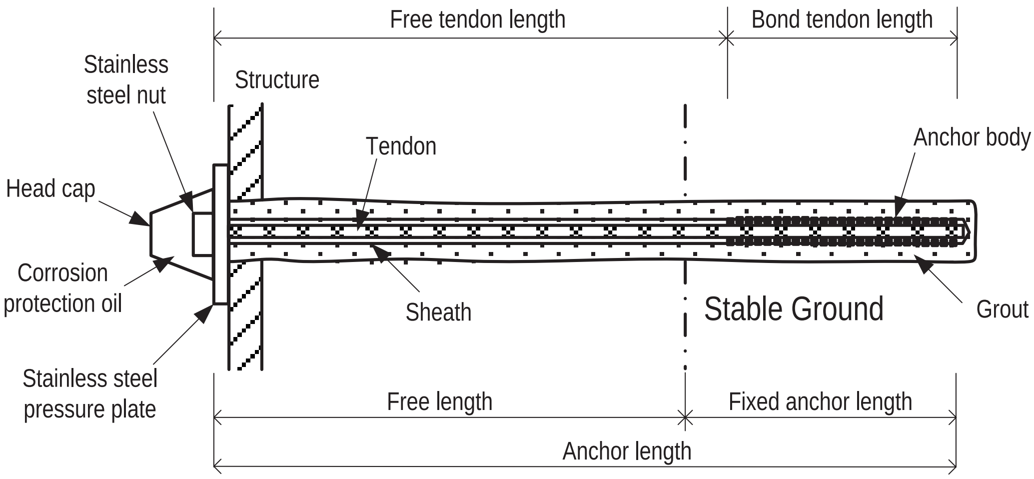


Figure 6.2.20 Structure of Ground Anchor[13]

c.1.3 Head Part of Anchor

Head part of the anchor has function to transfer tensile force generated on the Tendon to the structure. The head part consists of Anchorage such as wedge or nut to constrict and fix the Tendon, the Pressure Plate to disperse bearing load by the Anchorage, and the Pedestal to keep direction of the Tendon perpendicularly to surface of the structure.

c.2 Function of Ground Anchor

Anchor for landslide countermeasure has following functions.

c.2.1 Constriction Effect

It is to increase shearing resistance by increasing of normal stress against slip surface of landslide (refer to Figure 6.2.21). Condition to obtain constriction effect is that the landslide block shall not have compressive or consolidated deformation. Thus, in case that landslide block consists of cohesive soil, colluvial soil or fractured weathered rock, it will be difficult to expect it to have a constriction effect. Additionally, in case a deep landslide slip surface exists, it will also be difficult to have an effect.

c.2.2 Detention Effect

It is to arrest landslide block by component force of the anchor, which is in the direction of the tangent of the slip surface when a landslide moves along slip surface. Since it can achieve a fully tensile resistance force of steel materials, ground anchor work can be used for landslide which has large sliding force, or is difficult to adopt pile work

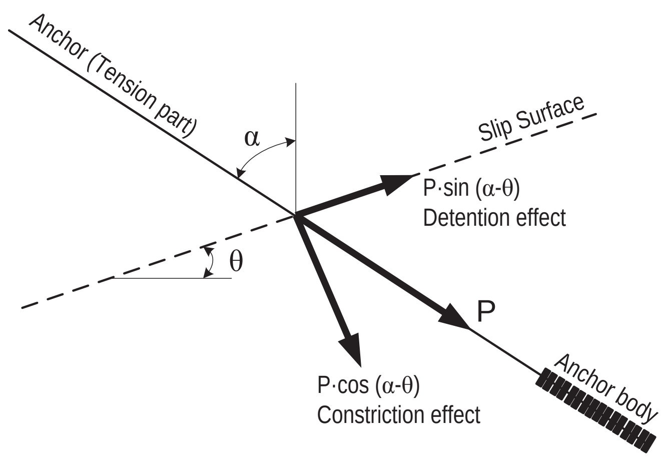


Figure 6.2.21 Schematic Diagram of Function of Ground Anchor[14]

Ground anchor work for landslide countermeasures is often adopted at toe part of landslide block, where it can be most expected to have a detention effect. In design stage, expected effects of the work shall be selected in consideration with angle of anchor, angle and depth of slip surface. Both constriction effect and detention effect can be reflected into the design of the work.

c.3 Calculation of Required Anchor Force

As mentioned above, ground anchor work shall be applied to use effect of constriction and detention. Required anchor force can be found by the following formula depending on expected effects.

- Required anchor force using constriction effect

$$F_{sp} = \frac{\{\sum(W \cdot \cos\theta - u) + p \cdot \cos(\alpha - \theta)\} \tan\phi + c \cdot \sum \ell}{\sum W \cdot \sin\theta}$$ ---------------- Formula 6-13

- Required anchor force using detention effect

$$F_{sp} = \frac{\sum(W \cdot \cos\theta - u) \cdot \tan\phi + c \cdot \sum \ell + P \cdot \sin(\alpha - \theta)}{\sum W \cdot \sin\theta}$$ ---------------- Formula 6-14

Where, F_{sp} : Planned Factor of Safety
W : Weight of slice of landslide block (kN/m)
u : Pore water pressure working on slice of landslide block (kN/m)
P : Required anchor force (kN/m)
ϕ : Internal friction angle of slip surface (degree)
c : Cohesion of slip surface (kN/m^2)
ℓ : Length of slip surface of slice of landslide block (m)
θ : Angle of slip surface at anchor position (degree) refer to Figure 6.2.17
α : Angle of anchor position (degree) refer to Figure 6.2.17

c.4 Alignment of Anchor Position

Ground anchor shall be aligned in consideration with stability of reaction structure, adjacent ground and fixing ground, and influence of neighbouring structures as well. Fixing position, direction and interval of anchor shall be assumed in early stage of design work.

- Planned Position of Ground Anchor Work: In case that anchor intersects at almost right angle with slip surface such as at head part of landslide whose slip surface shows steep angle, anchor may be sheared due to decreasing of detention effect of anchor. Planned position of anchor shall be decided in consideration with the situation mentioned above, and installation in the head part of the landslide shall be avoided.

- Influence of Neighbouring Structures: In case that there are underground facilities, tunnel or piles around planned anchor position, anchor position shall be decided to avoid influence to those structures. Direction of anchor shall conform to direction of landslide movement.

- Inclination of Ground Anchor: Inclination of anchor shall be decided from not mechanical advantage point of view only, but conditions of topography, geology and workability also. In principle, inclination of anchor shall not be in range of -10 degrees to +10 degrees from horizontal-plane to avoid problems of implementation of the work such as residual drilling slime or bleeding of grouting materials.

- Interval of Anchor Position: Interval of anchor position shall be decided in consideration with specification of designed anchor such as designed anchor force, diameter of anchor body or fixed anchor length. In case of Japan, generally, interval of anchor is more than 1.5m and less than 5m.

c.5 Design of Ground Anchor

Regarding to calculation of designed anchor force and specific design of anchor, the general method, standards or procedures which are used in Mauritius can be applied. For reference, example of design standard of the anchor is shown below.

- Designed Anchor Force: Designed anchor force shall be decided in consideration with feature of slip surface, restraining function of anchor and alignment. Designed anchor force is found by the following formula.

$$T_d = \frac{P_r}{\sin\beta \cdot \tan\phi + \cos\beta} \cdot \frac{@}{n}$$ ----------------------- Formula 6-15

T_d : Designed Anchor Force (kN)
P : Required Anchor Force (kN/m)
β : Intersect angle of anchor direction and slip surface = $\theta + \alpha$
θ : Angle of slip surface at anchor position (degree)
ϕ : Internal friction angle of slip surface (degree)
α : Inclination of anchor (degree)
@ : Interval of anchor position(m)
n : Number of steps of anchor

On the section for stability analysis, in case that intersect angle of anchor and slip surface β is uniform, designed anchor force at each anchor will also be uniform. Thus angle of slip surface θ shall be applied average angle in work area in principle. In case that slope angle is changing, inclination of anchor α shall also be uniform.

General target of designed anchor force shall be 150 to 800kN/anchor.

- Free Length of Anchor: In principle, free length of anchor shall be more than 4m. Length of the free length shall be rounded to 0.5m.

- Fixed Length of Anchor: In principle, fixed anchor length shall be more than 3m and less than 10m. The length shall be decided in consideration with pulling force of ground and grouting, and binding force of ground and the tendon. The length shall be rounded in 0.5m

- Excess Length of Anchor: Generally, ground anchor for slope stability shall secure certain excess length from slip surface on the safe side. Purpose of it is to cover uncertainties in assumption of depth of slip surface and fixing ground. Generally, it often takes 1m to 3m.

c.5.1 Passive Pressure Plate

For the ground anchor work for landslide countermeasure, cut slope will be made to install passive pressure plate. In that case, it shall be required to check influence of the cut slope on landslide stability.

The passive pressure plate is the structure to install on slope to fix the anchor to the ground. Therefore, the passive pressure plate shall be designed to have enough endurance against tensile force of anchor. There are several types of plate as a reaction structure such as independent type and successive type with slope-crib work. For the landslide case, independent type is often applied.

- Acting Force for the Passive Pressure Plate: Basically, it shall be the designed anchor force and ground reaction as reaction force of the designed anchor force.

- Sectional Force of the Passive Pressure Plate: In principle, calculation of sectional force of the plate shall be applied beam models analysis. It shall be examined carefully in consideration with condition of background of the plate, whether ground reaction shall be treated as uniformly distributed load, and whether anchor force shall be treated as concentrated load.

- Vegetation on the Slope where the Passive Pressure Plate is installed: The slope where the passive pressure plate is installed shall be planted with vegetation to avoid erosion of the slope and maintain the natural environment and landscape.

c.5.2 Corrosion Protection

In principle, the ground anchor work shall be permanent anchor with definite corrosion protection. Structure of anchor shall be examined in consideration with corrosive environment on the implementation of the work or after completion of the work. It shall take measurement for corrosion protection under the most inconvenient conditions of corrosion.

- For Anchor Body: Anchor body shall be wrapped with anticorrosion material which has a certain thickness and strength, and clearance between anchor body and anticorrosion material shall be filled by anticorrosion grouting material.

- For Tension Part: Tendon shall be wrapped with anticorrosion material which has a certain thickness and strength, and clearance between tendon and sheath shall be filled by anticorrosion material such as anti-rust oil. In case of re-tensioning anchor, the anticorrosion material which does not interfere in tension of tendon shall be applied.

- For Head Part: Head part of anchor shall be treated by head cap and anticorrosion material such as anti-rust oil for corrosion protection.

c.6 Considerable Points for Design of Ground Anchor Work

- Feasibility study for the ground anchor work shall be carried out regarding to aspect of safety, economic and workability comparison with other countermeasure works such as pile work or shaft work.

Reference

[1] Japan International Cooperation Agency, 2011, “Manual for Survey and Analysis on Landslide” modified

[2] Japan Road Association, 2009, Manual for Slope cutting work and slope stability work

[3] Japan International Cooperation Agency, 2011, “Manual for Survey and Analysis on Landslide” modified

[4] Japan Road Association, 2009, Manual for Slope cutting work and slope stability work

[5] Japan Sewage Works Association, 2001, Manual and Guide for design of sewer facility

[6] Irrigation Authority of Mauritius

[7] Japan Society of Civil Engineers, 1999, Collection of Hydraulic Formula

[8] Japan Road Association: Highway Earthwork Series, 2009, Manual for slope protection, p. 435

[9] Public Works Research Institute, 2007, Technical Guideline for Landslide Countermeasure

[10] Ibid.

[11] Ibid.

[12] Ibid.

[13] Public Works Research Institute, 2007, Technical Guideline for Landslide Countermeasure-modified

[14] Public Works Research Institute, 2007, Technical Guideline for Landslide Countermeasure

7 Maintenance after Installation of Countermeasure Works

7.1 Execution Plan

For the economical, speedy, precise and safe execution of countermeasure works for landslides while achieving the required quality, it is essential to prepare an appropriate execution plan prior to execution by fully understanding the contents of the work and the work conditions based on a relevant study.

Planning is determining what needs to be done, by whom, and by when, in order to fulfil one's assigned responsibility. Effective total project planning cannot be accomplished unless all of the necessary information becomes available at work initiation.

The normal procedure for the preparation of an execution plan is the preparation of an overall plan to ensure the completion of the work within a specified work period, followed by the adjustment of various conditions which pose bottlenecks for the progress of the work.

An execution plan incorporates all of the relevant matters for work execution. Execution planning team has to examine and check that the following information is considered and included in the plan, but is not limited to:

1. The statement of work (SOW): The objective of the countermeasure work against landslide, brief description of the work, the funding constraint, and the specification and the schedule (start date, end date, major milestones, etc.)
2. Work specifications
3. Order and timing of execution for each type of work and the overall schedule. The milestone schedule
4. Plan for land-use for the application area. Explanation for landowner and explanatory meeting for local people about the projected countermeasure works against landslide
5. Construction method, plan for use of required construction machinery, work execution speed and required time for each type of work.
6. Plan for scheme of hauling
7. Labour plan and equipment and materials plan
8. On-site execution system and temporary facilities plan
9. Plan for construction of roads and other preparatory work, if necessary
10. Plan for accident prevention, safety and health
11. Plan for conservation of the surrounding environment

7.2 Execution

Special attention should be paid to the following points for the execution of countermeasure work for landslides.

7.2.1 Control Work

- When corrugated pipes etc. are used for channel work, they must firstly be fixed to the ground by wooden stakes or similar to prevent their lifting.
- When a large scale drainage conduit is constructed at the lower part of a slope, careful attention, including execution at a short section at a time, should be paid to not damaging the stability of the landslide mass

Photo 7.2.1 Corrugated Steel Half-Pipe (source: JET)

- For the execution of horizontal drainage, a suitable location according to the geological conditions must be used. In addition, the conformity of the actual geological conditions with the design conditions should be constantly checked. If there is any major discrepancy, a change of the design may be necessary.
- When the length of horizontal drainage becomes quite long, the drilling hole could be bent at a gravelly soil layer or heterogeneous layer. Careful attention is, therefore, required, including confirmation of the frontal position of the borehole using a bending gauge, during the drilling.
- In regard to earth removal work, the earth should, in principal, be removed downwards so as not to damage the stability of the slope. This type of work should be avoided during the rainy season.
- The face of a slope after earth removal generally has a high level of permeability and is prone to softening and even failure due to rainwater. It is, therefore, necessary to implement slope drainage work immediately after earth removal, followed by appropriate slope protection work.

7.2.2 Prevention Work

- In regard to pile work, when landslide movement is serious enough to be clearly visible, piles driven into the ground only function individually unless all of the planned piles are driven at the same time. As the positive effects of piles cannot be expected to materialize, pile work should be avoided under such conditions.
- Piles are usually driven into the ground to avoid harmful vibrations to the ground. When a large quantity of drilling mud is used for the drilling of holes, loosening of the ground and/or the creation of water paths may occur with adverse impacts regarding landslide. Careful attention should be paid to reduce the quantity of drilling mud and to using thicker slurry.
- For the execution of shaft work, excavation and muck haulage are conducted in a narrow place same as in the case of drainage well work, making it essential to pay proper attention to rock falls.
- For the execution of anchor work, the drilling speed and drilling mud, etc. should be checked during the drilling in consideration with the ground condition. In places where the anchor fixing ground is of poor quality, a borehole lateral loading test should be conducted to check the presence of the design ground strength and properties.
- When the compressive strength of the grout for the anchor body exceeds the required value, either a tensile or confirmation test should be conducted for all of the anchors to determine whether or not the design anchor strength can be achieved. After the test, tension and fixing work should be conducted with the predetermined tensile force. In this

case, tension work should be conducted to achieve a good balance of all of the anchors.

7.3 Work Management

7.3.1 Introduction

The work must be properly managed so that the planned and design structures with specific work specifications can be completed at a reasonable cost within a predetermined period while satisfying the required shape, dimensions and quality. Work inspection must be conducted to confirm that the completed structures meet the initial plan and design.

Two types of management are involved in work management. One is the management of "end factors" (schedule, quality and cost) relating to the activity functions of the body which directly conducts the work and the other is the management of "mean factors" as control factors to ensure the smooth performance of the said activity functions. The former is generally called execution management while the latter is called site management.

7.3.2 Execution Management

a. Schedule Control

As earthwork is easily affected by the weather and others, it is not always easy to proceed with the work as initially planned. For this reason, a detailed schedule plan should be prepared in advance and the planned schedule and actual progress should be compared at each stage of the work. Should any delay in the schedule occur, its cause(s) must be analysed with a view to promptly preparing a suitable countermeasure(s) as part of the strict schedule control.

b. Quality and Finished Work Control

b.1 Purposes of Quality and Finished Work Control

In general, it is difficult to readjust inferior work which is discovered by inspection after completion. Even if readjustment is possible, much labour and time are required, resulting in an unfavourable economic performance. It is, therefore, rational to constantly control the quality and finished work during the construction period so that the subject items for construction pass the inspection without fail.

Precise quality control can economically complete the subject items for construction which satisfy the quality standards demanded by the specifications. The minimum dispersion of quality can enhance the reliability of construction work.

b.2 Quality Control Methods

Common quality control techniques involve the execution of various tests designed to objectively evaluate the quality and statistical processing of the test results so that if there is a chance that the work quality upon completion will not meet the predetermined target(s), the necessary measures can be implemented, thereby contributing to improved quality control after these tests. The technique (control method) for the sorting of quality control data is shown in Table 7.3.1.

Table 7.3.1 List of Quality Control Tests (Example of Embankment)[1]

Subject	Item	Qualitative Characteristics	Testing/Measuring Method	Remarks
Filled Up Ground	Material	Natural water content Specific gravity of soil particles Particle size Liquid limit Plasticity Limit Maximum dry density and optimal water content Cone index	Water content test for soil Specific gravity test for soil particles Particle size test for soil Liquid limit test for soil Plasticity limit test for soil Soil compaction test using a rammer Static cone penetration test	Frequency: at the beginning of the work and when the soil properties are changed
	Execution	Water content during construction Dry density Air voidage Degree of saturation Cone index	Water content test for soil In-situ unit volume weight test for soil Static cone penetration test	After rain or when a change of the water content is observed At the rate of one test/1,000 m3; at least three times for work involving an earth volume of less than 5,000 m3

b.3 Finished Work Control Methods

Finished work control means to check whether or not the shape and dimensions of the subject items for construction satisfy the shape and dimensions demanded by the design documents and specifications at predetermined interim stages of the construction work in order to ensure the completion of highly reliable subject items. In the case of those parts which cannot be visually checked after the completion of construction work, photographs, etc. should be used to record the work completed.

Many finished works can be visually checked after the completion of construction work. These include the position, dimensions, gradient and reference height.

7.3.3 Work Inspection

Inspection means to check whether or not the work has been exactly executed according to the contract at the stage of completion or partial completion (or during work progress) by means of visual observation, measurement, testing or other methods with a view to making a verdict on the pass or failure of the inspected work. Recent road work is mainly conducted by contractors and the criterion for pass is the satisfaction of the conditions specified in the contract documents (agreement, specifications and drawings, etc.) Inspection is conducted on the finished works relating to the position, height, width, length, gradient and quantity and also on the quality.

Inspection is conducted at the completion of construction work and also during construction work.

As it is difficult to inspect all of the quantitative items involved in construction work, sampling is usually conducted and is often accompanied by a supplementary method such as visual observation.

a. Finished Work Inspection Methods

Finished work inspection involves such inspection items as the reference height, length (distance, width and slope length) and gradient in addition to confirmation of the cut slope and embankment positions. As far as measuring is concerned, it is time-consuming and not very efficient to conduct measuring at all of the measuring points. The common practice is, therefore, to conduct measuring by selecting more points at sections with many changes of the horizontal alignment as well as longitudinal alignment while selecting fewer points at sections with fewer changes, leaving the remaining points for visual checking. Visual checking is also required at the halfway points between the measuring points as the values demanded by the design drawing must be met at these points as in the case of the measuring points. If visual inspection detects any difference at a point from the preceding or subsequent point, verification with the design drawing is required. In addition, it may also be necessary to conduct measuring in the same manner at measuring points to check for any abnormality.

a.1 Inspection of Reference Height

This inspection uses a level or other suitable tool/equipment to measure the height of the centre line of the measuring point and the top of the slope and the results are compared with the corresponding heights specified in the design drawing.

a.2 Inspection of Length (Distance, Width and Slope Length)

- Inspection along Longitudinal Direction

This inspection involves measuring of the distance between measuring points, distance from a point of change of the horizontal or vertical alignment, distance between a structure and a measuring point and distance between a point of change of a cut slope or embankment and a measuring point and the results are compared with the corresponding distances specified in the design drawing.

- Inspection along Cross-Sectional Direction

This inspection involves measuring of the width, distance from the centre line, width of beam(s), slope length and height of the road surface at measuring points and the results are compared with the corresponding values specified in the design drawing.

a.3 Inspection of Gradient

This inspection involves measuring or calculation of the gradient of the face of a cut slope and/or embankment slope at measuring points based on the horizontal distance, vertical distance, slope length and gradient meter readings and the results are compared with the corresponding values specified in the design drawing.

b. Quality Inspection Methods

The quality inspection of landslide countermeasures practically consists of inspection of the banking material and the degree of compaction. Incidentally, the quality of vegetation work on the face of a slope and of small concrete structures is also inspected. In this section, inspection of the banking material and the degree of compaction is described.

Quality inspection of the banking material commonly involves a judgment on whether or not the quality test results meet the quality set forth in the specifications using the construction management records. Given the extreme difficulty of rectifying the quality of the banking material when it fails inspection, it is essential to confirm the quality of the soil at the initial as well as interim stages of execution in addition to a borrow pit survey.

The practical way to conduct inspection of the degree of compaction is to make a judgment based on the quality control documents recording the measured values. However, inspection can be conducted in the form of the necessary tests. Special attention should be paid to the sufficiency of compaction at the road edges and near structures.

Quality inspection is commonly conducted by the owner using reference data submitted by the contractor in accordance with the specifications. In addition to this, the owner may also conduct his own quality tests as part of the quality inspection process. In any case, the reliability of the tests and measuring which provide reference data is a precondition and these tests and measuring must be properly conducted under the guidance of skilled supervisors.

c. Acceptance Judgment

There are two methods as described below to judge whether or not especially earthwork-related results are acceptable.

c.1 Method using Standard Values

In principle, when all of the measured values of the total inspection satisfy the standard values (within the allowable error of the design values specified in the design documents and specifications), the inspected item is judged to have passed the inspection. This method is commonly used for inspection of the external dimensions of structures.

c.2 Method using Acceptance Values

In regard to sampling inspection, when the measuring results of samples of which the quantity is determined for each lot together with the size of lot satisfy the following equation, the inspected item is judged to have passed the inspection.

Higher acceptance value ≥ mean value of measured values ≥ minimum acceptance value

An acceptance value is commonly set at a level where 95% of the samples meet the standard value. This method is generally used for quality inspection. Finally, constructed figures shall be recorded with the As Built Drawings and registrations.

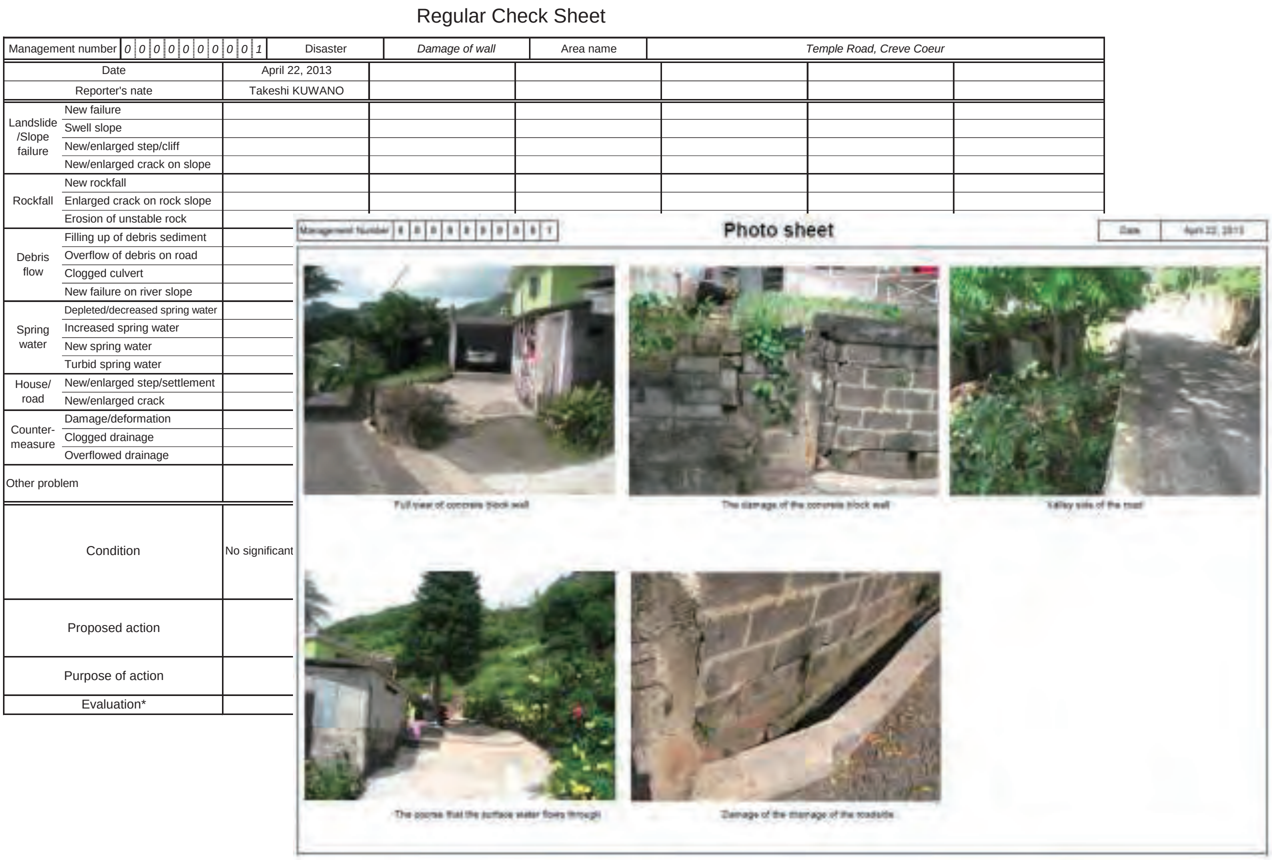
7.4 Maintenance after Installation of Landslide Countermeasure

Even though landslide countermeasure work has been installed, maintenance shall be carried out for not only landslide area but countermeasure facilities also. Since the trigger and movement system of landslide is complex, there are some cases that landslide re-activates even after installation of countermeasure works. Monitoring and inspection for the target landslide area, therefore, shall be carried out regularly to detect potentials of occurrence of landslide early.

7.4.1 Inspection

For the target landslide area which has been installed countermeasure works, inspection shall be carried out regularly as well as in/after abnormal weather conditions such as an earthquake or heavy rainfall. Regular inspection shall be carried out once or twice per year. The inspection is to be visual inspections of changes to the condition of slope surface or water springs during site reconnaissance.

The inspection shall be carried out using an inspection sheet that was prepared by JICA Expert Team in 2013. The inspection sheet consists of 2 sheets, namely, Regular checking sheet and Photo sheet as shown below.



Regular Check Sheet

Management number	0 0 0 0 0 0 0 0 0 1	Disaster	*Damage of wall*	Area name	*Temple Road, Creve Coeur*
Date		April 22, 2013			
Reporter's nate		Takeshi KUWANO			
Landslide /Slope failure	New failure				
	Swell slope				
	New/enlarged step/cliff				
	New/enlarged crack on slope				
Rockfall	New rockfall				
	Enlarged crack on rock slope				
	Erosion of unstable rock				
Debris flow	Filling up of debris sediment				
	Overflow of debris on road				
	Clogged culvert				
	New failure on river slope				
Spring water	Depleted/decreased spring water				
	Increased spring water				
	New spring water				
	Turbid spring water				
House/ road	New/enlarged step/settlement				
	New/enlarged crack				
Counter-measure	Damage/deformation				
	Clogged drainage				
	Overflowed drainage				
Other problem					
Condition		No significant			
Proposed action					
Purpose of action					
Evaluation*					

Figure 7.4.1 Regular Inspection Sheet (source: JET)

After installation of landslide countermeasure works, the existing monitoring devices might be removed or not work properly. In that case, inspection will be the most useful method to evaluate the condition of the landslide area. Additionally, emergency inspections shall be carried out when inhabitants report abnormal conditions at the site.

In the inspection, the following items shall be checked mainly.

- Cracks or gaps on the ground surface
- Damage of facility of countermeasure, house and road
- Changing of hydraulic conditions (water spring, seepage etc.)

The inspection shall be carried out by the authority of landslide in the area. The inspector shall be person who knows the site condition and is trained.

7.4.2 Monitoring

The landslide area which has many preservation targets such as roads, houses, pubic facilities, etc. shall be monitored by not only visual checks, but using mechanical equipment installed in/around landslide area to check the stability conditions of the slope, even after installation of countermeasure works.

When some movement or abnormal conditions are identified visually, equipped monitoring for distance or inclination of the slope shall be carried out to know the actual condition of the landslide.

Monitoring of distance of the slope shall be carried out using surface extensometer, fixed points monitoring or GPS. The common monitoring equipment for landslides are shown in the Table 7.4.1

Table 7.4.1 Target and Method of Landslide Monitoring[2]

Target of Monitoring		Monitoring Method	Monitored Item
Landslide	Ground surface	Extensometer	Ground movement Open crack movement
		Fixed Point Monitoring	Ground movement
		GPS	Ground movement
		Tilt meter	Inclination of ground surface
	Sub-surface	Pipe strain gauge	Strain of sub-ground (landslide)
		Inclinometer	Movement of landslide block
		Borehole extensometer	Movement of landslide block
		Pore pressure meter	Pore water pressure
		Groundwater level meter	Groundwater level
		Load cell	Tension load of ground anchor

7.4.3 Check of Stability

Stability of the landslide shall be checked to confirm effectiveness of the installed countermeasure works after they have been installed/constructed.

The check of the stability shall be carried out using stability analysis with applied calculation model and parameters which reflect the current conditions after installation of the works. The parameters which will be changed after installation of the works for the analysis will be as follows,

- Figure of the calculation model (Cross section of target area): Earth removal work, Counterweight fill work
- Groundwater level: Surface/groundwater drainages works
- Additional resistance force: Restrain works as ground anchor work or piling work

Regarding to the groundwater level, measured groundwater level after installation of the works shall be reflected to the calculation.

The effectiveness of the installed works shall be evaluated according to the changing of the Factor of Safety determined by the stability analysis with corrected parameters after installation of the works.

7.4.4 Maintenance Record

The condition of the landslide shall be managed by using slope inspection sheet (refer to Figure 7.4.1) which shows history of disaster, result of inspection and evaluation result of inspection. Record of inspection or relevant documents, photos or drawings shall be compiled to use the management of landslides.

7.4.5 Reflection for Landslide Prevention Plan (Disaster Scheme and PPG)

When evidence/factor showing possibility of landslide activity are detected according to result of inspection or monitoring, current landslide prevention plan shall be re-examined, and further landslide countermeasures shall be considered necessary.

Especially, the disaster scheme and Planning Policy Guidance (PPG) shall be re-examined based on result of monitoring after installation of landslide countermeasure works. In that case, the monitoring result for the re-examination of the disaster scheme or the PPG is desirable to be measured for 2 years (two rainy seasons).

7.5 Maintenance of Existing Structural Countermeasure Facilities

Maintenance of the facility for landslide countermeasure shall be maintained to be keep its function for the target landslide.

7.5.1 Inspection

The inspection for the countermeasure facility shall also be carried out regularly and in/after abnormal weather conditions such as an earthquake or heavy rainfall. Regular inspection shall be carried out once or twice per year. The inspection is to verify visually on site about the condition of surface/groundwater drainage, cut slope, fill slope, ground anchor, etc.

For inspection in/after abnormal weather condition shall be carried out visually by checking same as the regular inspection.

The check items for the facilities shall mainly be as follows:

a. Surface Drainage

Damage such as cracks on the joints, clogging by debris, sedimentation of debris in water catch basins, deformation of drainage shall be verified.

b. Groundwater Drainage

b.1 Drainage Well

- Damage/deformation, seepage, corrosion of well body
- Corrosion, clogging of drainage pipe, actual condition of discharging capacity
- Corrosion, clogging of discharge pipe, actual condition of discharging capacity
- Damage/deformation, corrosion of ancillary facilities such as lid, safety fence, ladder)
- Collapse, crack or subsidence around the well

b.2 Horizontal Drainage

- Damage/deformation of protection facility for outlet of the drainage pipes.
- Corrosion or clogging of drainage pipe

c. Cut slope / Fill slope

- Water seepage/spring from the slope
- Surface collapse on the slope

d. Ground Anchor

- Head part of an anchor (Fracture, corrosion, loss of head cap)
- Damage of Pressure plate (Crack, deformation)

7.5.2 Monitoring

The countermeasure facilities at landslide area which has many preservation targets shall be monitored by not only visually, but by mechanical equipment installed in/around landslide area to verify the stability conditions of the slope. The monitoring results shall be checked regularly.

Monitoring devices for the facility are shown in the Table 7.5.1. If evidence would be detected by the inspection, the condition of the facility shall be monitored by the devices. Effectiveness of the drainage well or the horizontal drainage shall be verified based on lowering of groundwater level, range of drawing down of groundwater level and amount of discharge from the drainage facility. Therefore, data of pore water pressure, groundwater level discharge volume will be required for the verification.

Table 7.5.1 Target and Method of Monitoring for Facility[2]

Target of Monitoring	Monitoring Method	Monitored Item
Surface Drainage	Discharge meter	Discharge volume
	Groundwater level meter	Groundwater level
Horizontal Drainage	Discharge meter	Discharge volume
	Groundwater level meter	Groundwater level
Drainage Well	Discharge meter	Discharge volume
	Groundwater level meter	Groundwater level
Pile	Inclinometer	Deformation of pile
Ground Anchor	Load cell	Loading on pressure plate

7.5.3 Ancillary Facility

For maintenance of landslide countermeasure facility, ancillary facility such as ladder, lid or safety fence shall be installed as necessary.

a. Surface Drainage

- Safety fence to prevent residents from entering the drainage
- Bridge to access the land which is divided by the drainage
- Ladder to access bed of the drainage as necessary
- Lid or ladder to enter the water catch basin

b. Drainage Well

- Stair or ladder shall be installed in the well to access bottom of the well. Stair landing shall be installed every 5m of direct height.
- Lid of reinforced concrete or steel shall be installed on top of the well to avoid anyone falling in.
- Safety fence which has a doorway with a lock shall be installed around the well to prevent outsiders from entering the area.

7.5.4 Maintenance Record

The results of monitoring and inspection for the landslide countermeasure facility shall be compiled in the inventory. Location map of the facility, year of installation, structure drawings of the facility shall be shown in the inventory. Record of inspection or relevant documents, photos or drawings shall be compiled to use for the management of landslides.

7.5.5 Evaluation of Function of Landslide Countermeasure Facility

For the evaluation of function of groundwater drainage facility, correspondence between groundwater level in expected lowering range and discharge volume of the facility shall be compared. It will be better to compare the discharge volume at same groundwater by using the h-Q curve shown on Figure 7.5.1 year by year. As the result, if the discharge volume is decreased, it can be considered functional decline of the drainage by clogging of pipe screen. For the landslide which has not been installed monitoring devices, visual inspections to check the function of landslide countermeasure facility(s) shall be carried out. If the result of the evaluation shows functional decline of the facility, maintenance shall be carried out immediately.

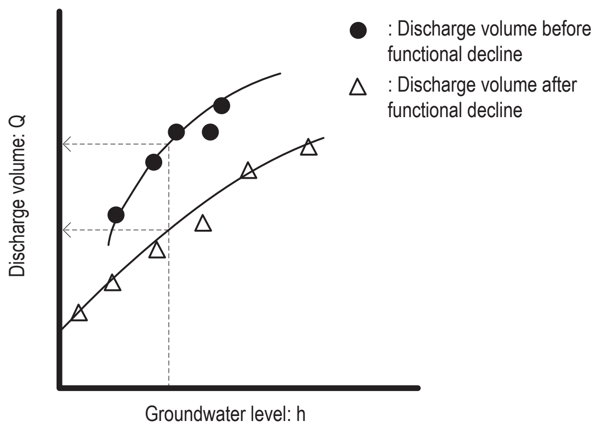


Figure 7.5.1 h-Q curve diagram[2]

If landslide activity is detected by the monitoring, further countermeasures shall be installed.

7.5.6 Repair

According to result of the inspection or monitoring, the countermeasure facility shall be repaired as necessary.

If it can be assessed that the facility will not be recovered by repair as the result of inspection or monitoring, further landslide countermeasures shall be considered to be installed after detailed investigation.

a. Maintenance and Repair for Control Countermeasure Work

a.1 Drainage

As the result of regular inspection, the following repair works shall be carried out to avoid decline in the function of drainage.

- Clearance of debris, trees or branches which are deposited on the drainage to avoid clogging of the drainage
- Maintenance of damaged joint or lid to avoid leakage or hydraulic jump from the drainage
- Repair of damage to the drainage caused ground movement of a landslide

a.2 Horizontal Drainage

Generally, collecting water from drainage facilities such as horizontal drainage shows trend of decreasing over time after its installation. Two reasons of the phenomena can be considered as the effect of groundwater drainage work and the decline in function of the facility. Cause of the latter reason is clogging of screen of pipe by adhesion of fine grain materials. If functional decline of horizontal drainage is detected or damaged facility are found by inspection, the following maintenance shall be carried out according to the actual conditions. Additionally, since outlet of horizontal drainage will be difficult to find due to thick growing of plants, some markers such as poles shall be put near the horizontal drainage facility to show the location.

- Cleaning of the pipe to remove fine grain material on the screens (refer to a.3.1).
- Repair of facility of outlet of the drainage
- Removal of debris and repair of damaged facility to discharge water accumulated in the drainage out of the landslide area immediately.
- Installation of new horizontal drainage in case that the existing drainage are damaged or corrosion seriously.

a.3 Drainage Well

If functional decline (discharge volume of groundwater) or damaged facility is detected by the inspection, the following maintenance works shall be carried out immediately. The maintenance work in the well shall be conducted with air ventilation and checking of consistency of oxygen or toxic gas constantly.

- Since the wells consist of sunk well and reinforced soil, maintenance of sunk well is important to secure of function of collecting groundwater and possibility of repair work of the well. Thus repair work shall be carried out immediately when deformation of damages of the sunk well or reinforce soil are found. If repair work is not possible, the well shall be filled by rubble stones or gravel to maintain the function of the drainage well.
- If the well is disconnected by landslide activity, a new well shall be re-constructed.
- The water collecting pipe (drainage pipe) in the well shall be cleaned to remove fine grain materials on the screen (refer to a.3.1)
- In case that the discharge pipe from the well is disconnected by landslide activity, the accumulated water in the well shall be discharged by a pump to avoid leakage to landslide block, and a new discharge pipe shall be installed immediately.

- Ancillary facilities are installed for safety control and maintenance of the well. If there is any damage or corrosion of the ancillary facilities such as ladder, lid or safety fence, repair work shall be conducted immediately.

a.3.1 Pipe Cleaning

Clogged screen of a drainage pipe shall be washed and its function restored by high-pressure water. Since there is possibility that high-pressure water may cause the borehole wall of the pile to become wider or cause a large volume of water to flow into landslide block during the washing of pipe, therefore the method of cleaning using high-pressure water shall be selected carefully.

In case of corroded steel drainage pipe, there is possibility that the screen mesh will be made bigger due to breaking of the pipe or its screen by the high-pressure water. Additionally, there is also possibility of clogging of the screen by the debris due to washing away the soil around the pipe if the mesh of the screen is larger than necessary.

Generally, the capacity of the compressor and engine for cleaning the pipes needs to be 35～70ℓ/min and 14.7MPa. For high angle (more than 45 degrees) of the drainage pipe such as drainage in a drainage tunnel, an engine capacity of 20MPa will be required.

Evaluation of effect of pipe cleaning shall be done by measurement of discharge volume before and after pipe cleaning. The measurement shall be conducted at a later date to avoid influence of remaining water by the cleaning.

Main cause of clogging of pipe is fine grain material (soil) and slime (refer to Photo 7.2.1). In many cases, the adhesion of slime to the pipe goes along from around outlet of the pipe and gradually back into the pipe from there. The slime consists mainly of ferric oxide, and iron bacteria exist in the slim. In case that a groundwater drainage facility which has possibility of adhesion of slime to the drainage pipe, all iron contents in groundwater will be more than 1mg/ℓ. It can be assessed as high potential of adhesion of slime if all iron contents in groundwater shows more than 4 mg/ℓ.

Photo 7.5.1 Slime in the Drainage Pipe[3]

a.4 Earth Removal and Counterweight Fill Work

The following works shall be carried out to maintain the cut slope and the fill slope.

- If volumes of water can be found on the slope, the slope shall be protected by gabion or concrete wall to prevent the slopes from being eroded.
- If the slope is failed, facility which has flexible and permeable functions shall be installed to avoid expanding of failure.
- If some indications of failure such as cracks are found on slope, counterweight shall be adapted at toe part of the slope to prevent slope failure.

b. Maintenance and Repair for Restraint Countermeasure Work

b.1 Pile/Shaft Work

Deformation of pile/shaft and ground movement around the pile/shaft shall be monitored continuously to examine whether those facilities maintain their designed effectiveness at the place where pile/shaft has been installed. Deformation of pile/shaft can be monitored by inclinometer which has been installed into the pile, and movement of the pile head can be monitored by fixed point monitoring by survey equipment.

Since landslide has trend to be activated by heavy rain generally, timing of inspection or monitoring shall be before/after rainy season. Basically repair of existing pile/shaft is difficult to be conducted due to such facilities being installed underground. If deformation or damage of pile/shaft are detected by inspection or monitoring, stability of the target landslide shall be examined by stability analysis based on current conditions, and additional countermeasure(s) shall be installed as necessary.

b.2 Ground Anchor Work

Regular inspection and/or monitoring shall be carried out to examine whether the installed ground anchor keeps an expected function as the design. The inspection to examine current condition of a ground anchor shall be carried out according to following methods.

- To inspect corrosion of head part of ground anchor or cracks on the concrete regularly. The head part of the anchor shall be protected to avoid damaging of the part. If some damages are found at the part, it will be required that repair the part or installation of additional ground anchor according to the situation.
- To monitor changing of tension stress of a ground anchor. Parts of the fixed anchor length and the free length cannot be confirmed by visual check due to the parts being in the ground. Thus, condition of the anchor shall be examined by load cell which is installed at head part of the anchor to monitor the tension stress of the anchor.
- Frequency of inspection and monitoring shall be determined in consideration with strengthening of fixing ground or degree of incidence for preservation target. Generally, inspection and monitoring shall be carried out at a high frequency just after installing the ground anchor. After the tension stress has become stable, it can be done at a low frequency.
- If decline of tension stress of the ground anchor is detected by the monitoring, current stability of the target landslide shall be examined by stability analysis whether repair or maintenance of the anchor can be available. And additional ground anchor shall be installed as necessary.

Reference

[1] Public Works Research Institute, 2004, Manual for Highway Earthwork in Japan: Modified
[2] Public Works Research Institute, 2007, Technical Guideline for Landslide Countermeasure
[3] Ministry of Agriculture, Forestry and Fisheries of Japan ,2008, Cause and Measure for Clogging of Horizontal Drainage

8 Initial Survey and Emergency Response

8.1 General

This Chapter summarises what actions should be taken in the event of a landslide disaster, and includes the procedures the Ministry of Public Infrastructure and Land Transport (MPI) should implement in such an event. The procedures are composed of a literature survey, an initial site survey, emergency response, a detailed survey plan etc. The scope of application of this chapter is indicated in the following figure.

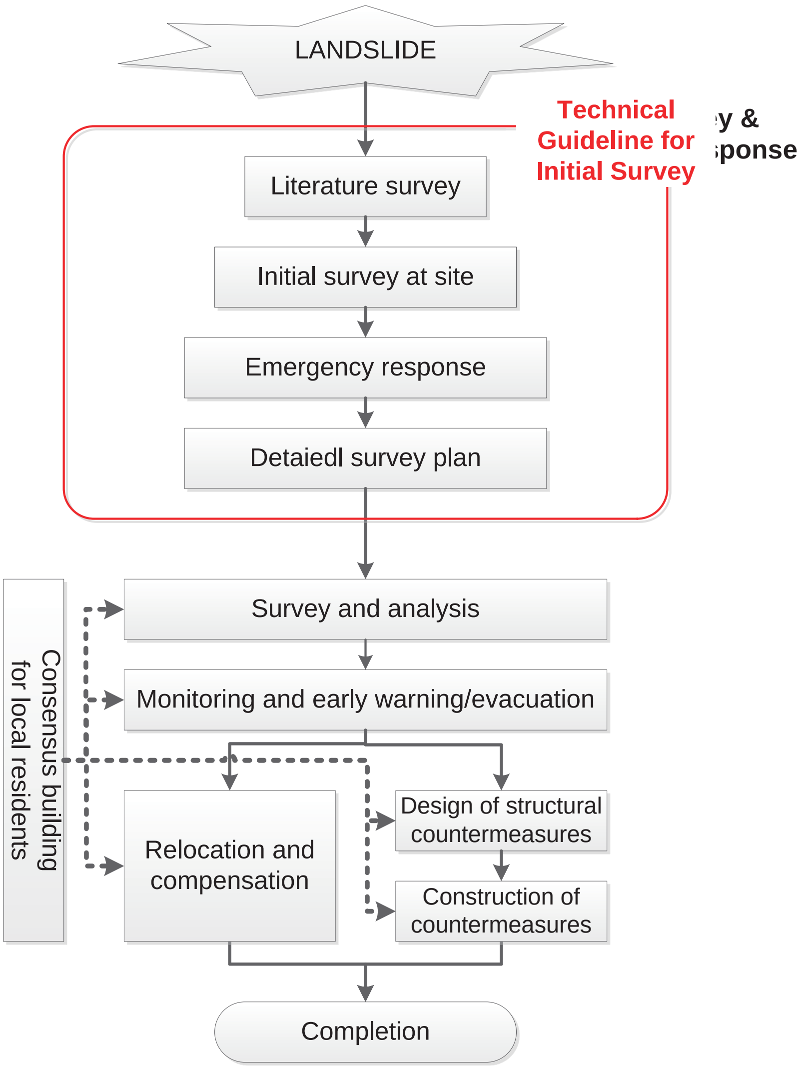


Figure 8.1.1 The Scope of Initial Survey and Emergency Response (source: JET)

8.2 Literature Survey

In case of an emergency landslide disaster, literature survey is necessary to understand the rough outline and general information of the landslide before visiting the landslide site. The literature survey is mainly composed of 1) data collection and 2) confirmation of related laws and regulations on landslides.

8.2.1 Data Collection and its Utilization

The data to be collected are geomorphology, geology, vegetation, meteorology, hydrology, landslide history and disaster records in the area. The necessary information on the landslide should be extracted from the collected data. The following table indicates the data to be collected as a preliminary survey of the landslide.

Table 8.2.1 List of the Data to be Collected (source: JET)

Data classification	Items
Geomorphology and geology	➢ Topographic map (Scale= 1/1,000-1/5,000) ➢ Aerial photo (Scale= 1/8,000-1/40,000) ➢ Geological map (Scale= 1/50,000-1/200,000) ➢ Land use map ➢ Landform classification map
Landslide history and disaster records	➢ Report on geotechnical investigation/analysis ➢ Report on construction (road, house, bridge etc.) ➢ Report on disaster record and landslide history ➢ Thesis, paper, note on landslide ➢ Newspaper
Meteorology and hydrology	➢ Rainfall data (hourly, daily, monthly) ➢ Data on water level and river flow ➢ Data on ground water level

Interviews of local residents and local municipalities are able to provide useful and practical information on the landslide disaster as well as the data collection. The following items should be confirmed in the interview survey:

- Location/degree/volume of abnormalities on landslide
- Volume/direction/speed of mass movement
- Condition of surface water flow/groundwater/spring water
- Condition of rainfall
- Location/degree/volume of damage (houses, buildings, roads, other infrastructure etc.)
- Disaster records in the past
- Social condition, geographic condition and law/regulations of the area

8.2.2 Aerial Photograph (geomorphological) Interpretation

Landslide prone areas are areas likely to have active landslides and are associated with certain types of micro landforms in Figure 8.2.1; therefore topographical and geomorphological interpretation is important for landslide identification. Geomorphologic interpretation is implemented with aerial photographs and topographic maps to identify landslide forms and potential landslide areas.

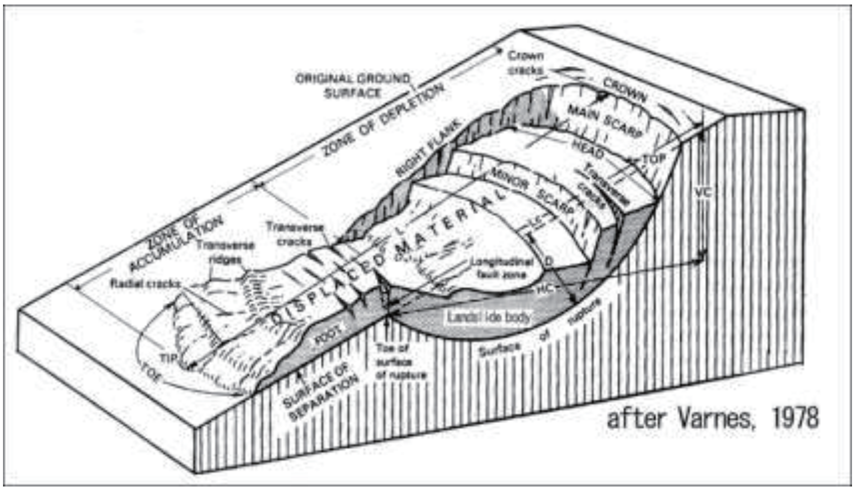


Figure 8.2.1 Micro Landforms in a Landslide[1]

Micro landforms, historical landslide formations, land use and vegetation are identified with aerial photograph interpretation. The micro landforms caused by landslide movement are interpreted using a large-scale aerial photograph such as 1:10,000 or larger. Aerial photograph interpretation is a useful method of finding several causes of landslides over a wide area. In case that it is impossible to obtain the stereo images of an aerial photograph, a topographic map can be substituted for the aerial photograph.

Stereoscopic images are obtained from stereo type photographs using a stereoscope. The micro landforms and the geomorphologic features caused by landslide movement are identified with the stereo image.

Table 8.2.2 shows the classification of landslides. Landslides are classified into several types by topographic and geological characteristics. The table classifies the type of landslide based on topographic and geological features, most of which are able to be identified with aerial photograph (geomorphological) interpretation.

Table 8.2.2 General Classification of Landslides[2]

Type / Feature	Rock block slide	Weathered rock slide	Colluvium slide	Strongly-weathered rock slide
Planar shape	Horseshoe-shaped, Square-shaped	Horseshoe-shaped, Square-shaped	Horseshoe-shaped, Square-shaped, Bottleneck-shaped Valley-shaped	Bottleneck-shaped, Valley-shaped
Micro topography	Convex and ridge -shape	Convex and mono terrace -shape	Convex and multi-terrace shape	Concave and gentle slope-shape
Shape of slip surface	Chair like, Ship like shape	Chair like, Ship like shape	Stepwise, Laminar	Stepwise, Laminar
Ex-name	New born stage	Immature stage	Mature stage	Elder stage
Material (Head part)	Bedrock or Gentle-weathered rocks	Weathered rock (Many clacks)	Earth and sand including rocks	Boulder or Earth and sand including rocks
Material (Toe part)	Weathered rocks	Earth and sand including boulder	Earth and sand including rocks, clay	Clay, Clay including rocks
Movement velocity	Over 2cm/day	Around 1.0~2.0cm/day	0.5~1.0cm/day	Under 0.5cm/day
Movement continuity	Short and sudden event	Intermittent (Once from decades to centuries)	Intermittent (Once 5-20 years)	Intermittent (Once 1-5 years)
Figure of slip surface	Flat (Chair like shape)	Flat (Head and toe parts: a bit circular slips)	Circular slip and linear shape, Fluidized toe	Head part: Circular slip Most part: flow condition
Number of blocks	Normally, 1 block	Generating secondary-derived landslides on side and toe of landslide	Upper slope of landslide can be divided into 2-3 blocks.	Whole slope of landslide can be divided into many blocks. Their movement links each other.
Difficulty level of prediction	Quite difficult Needed detailed exploration and analysing	Possible Using topographic maps (1/3,000~1/5,000) or aerial photographs	Possible Using topographic maps (1/5,000~1/10,000) or door-to-door investigation	Easy Site investigation
General slope shape	Unclear terrace, Convex slopes, Generating from saddleback	Clear scarp, A band of depression and terrace. Concave in macro point of view but generally convex	Main scarp, Pond, Swamp, Depression, Concave slopes.	Unclear terrace on upper slope, Uniform gentle slope, Valley shape
Main causes	Massive construction, Sunken slope, Earthquake, heavy rainfall	Torrential rainfall, Exceeding snow melting and washout, Earthquake, Mid-scale constructions	Snow melting, Typhoon, Torrential rainfall, construction	Heavy rainfall, Snow melting, Snow cover, River-erosion, Small-scale construction
Main geology and the structure	Effects of fault and fracture zone	A wide distribution of crystalline schist area, Neogene stratigraphy, Effects of fault and fracture zone	A wide distribution of crystalline schist area, Neogene stratigraphy	Distribution of Neogene, fracture zone

8.2.3 Confirmation of the Cyclone and Other Natural Disasters Scheme

The schemes of emergency response for cyclones, torrential rain, tsunamis, high waves and landslides are indicated in Cyclone and Other Natural Disasters Scheme (hereinafter Disasters Scheme) in Mauritius. The chapter on landslides in the scheme contains monitoring, actions by Local Authorities, response by related ministries/agencies and warning/evacuation system. The section on warning/evacuation systems has five stages based on monitoring data of rainfall and displacement.

When a landslide occurs or a landslide disaster is a concern at a site, it should be checked whether the site is on the list in the Disasters Scheme. If the site is on the list, the relevant information such as disaster records, detailed topographic map, drawings of construction works for development in/surrounding the site, reports and others might be available from related ministries/agencies/local authorities. The information will be useful for the investigation of the landslide block, estimation of damage area, examination of the critical value of displacement, consideration of emergency countermeasures, etc. Therefore, the landslide-prone regions in the Disaster Scheme should be checked.

8.2.4 Confirmation of the Landslide Hazard Zone and Landslide Special Hazard Zone

Landslide Hazard Zone and Landslide Special Hazard Zone are proposed to identify specific landslide affected areas for concrete and effective structural/non-structural countermeasures, even as the technical transfer for the identification and making a map which includes the information of the Zones has been conducted in the Landslide Management Unit (hereinafter LMU) of MPI.

Landslide Hazard Zone (Yellow Zone)

- A landslide hazard zone (yellow zone) is the area where inhabitants and buildings may be damaged when a landslide occurs. At present, it is not an active area, however, it is an area where a landslide has been active in the past, or it is the area with the possibility of landslide activity in the future.
- No new development is permissible in this area, and the information of disaster prevention should be shared with the inhabitants.

Landslide Special Hazard Zone (Red Zone)

- A landslide special hazard zone (red zone) is an area where inhabitants and buildings are expected to sustain heavy damage when a landslide occurs.
- It is designated by the following criteria: Active landslide block and an area below the bottom end of the landslide block that will be impacted by the landslide activity.
- No new development is permissible in this area, and the information of disaster prevention should be shared with the inhabitants.
- Landslide countermeasures or relocation of the houses should be carried out immediately. An early warning and evacuation system is required until a countermeasure is completed.

When a landslide occurs or there is concern of a landslide disaster occurring at a site, it should be checked whether the site is in a Landslide Prevention Areas to confirm the existing landslide block, affected area and others.

8.2.5 Confirmation of Development Restrictions/Land-use Controls

- Settlement Boundary
- Protection of National Parks

- Protection of Nature Reserves
- Protection of River Valley
- Conservation of Environmentally Sensitive Areas
- Conservation of Water Resources

8.3 Initial Survey at Site

The purpose of the initial site survey is to recognise the **area**, **cause** and **activity** of a target landslide as soon as possible. The results of the initial site survey are used for the emergency response, which are a structural measure, evacuation and early warning.

8.3.1 Setting of Target Landslide Areas

The flowchart for determining the target landslide area is shown below.

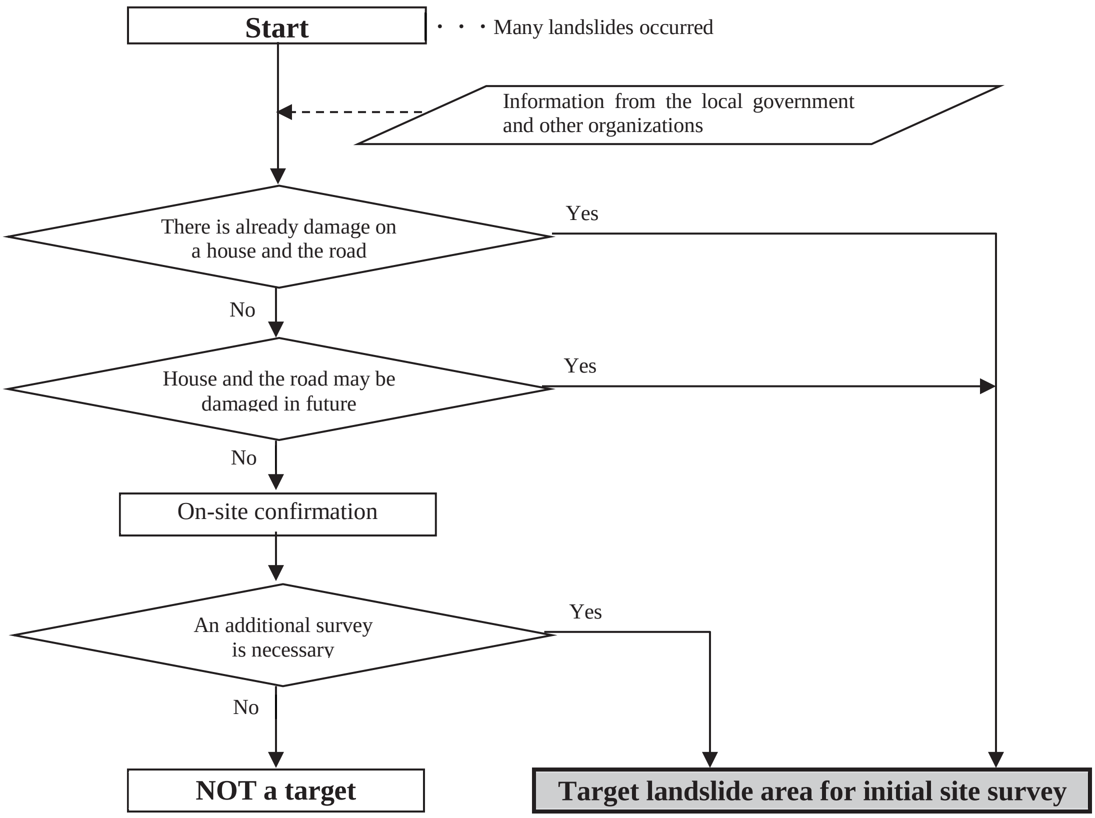


Figure 8.3.1 Flowchart for Determining the Target Landslide Area (source: JET)

8.3.2 Site Survey and Analysis

During the initial site survey, the following items are investigated. These items are listed in the order they are usually carried out. However, in an emergency situation, they should be carried out in parallel.

1) Confirmation of the landslide area and the movement direction
2) Emergency monitoring for landslide

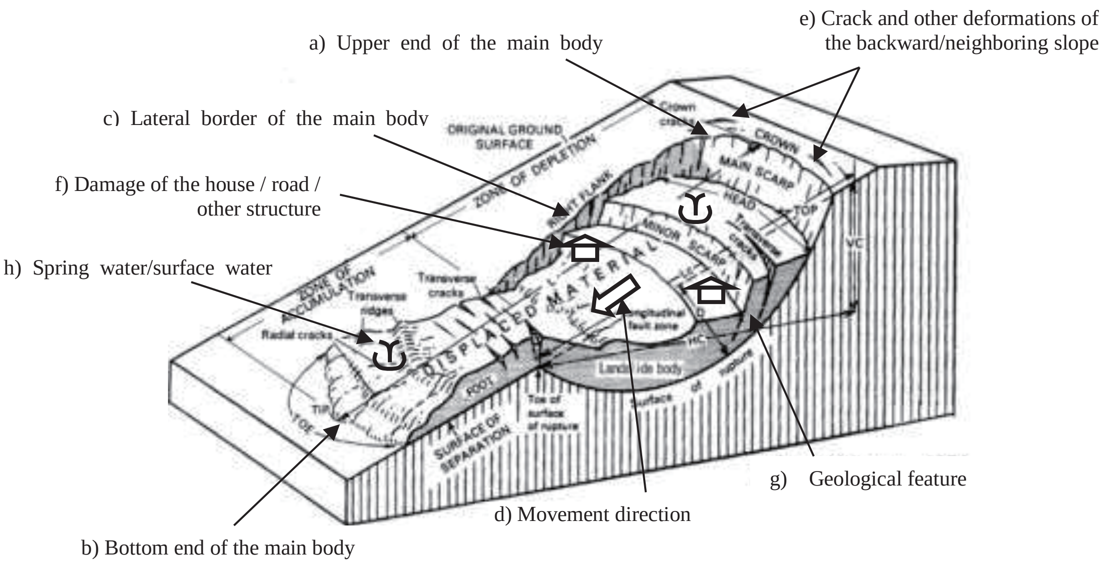
3) Estimation of the cause of the landslide occurrence

4) Prediction of landslide activity

5) Estimation of the influence area

8.3.3 Confirmation of the Landslide Area and the Movement Direction

When confirming the landslide area, it is important that the neighbouring landforms and deformations are investigated as well as the main landslide body. Therefore, the backward and neighbouring slopes of the landslide body should be investigated carefully.



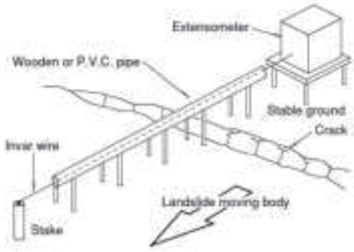
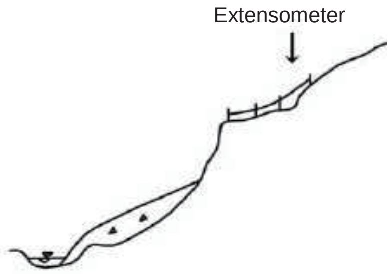
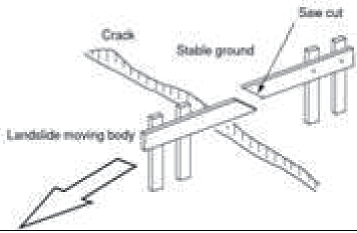
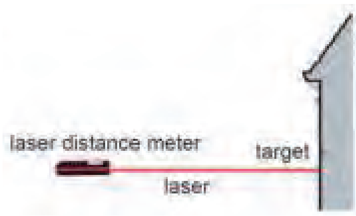
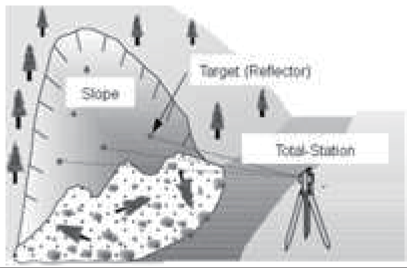
* It is modified by Varnes, D. J. (1978)

Figure 8.3.2 Viewpoints of the Investigation (source: JET)

8.3.4 Emergency Monitoring for Landslide

In an emergency situation, it is not possible to carry out monitoring by drilling from the viewpoint of the time and security of the work. Therefore, for emergency monitoring, measurement of the ground surface displacement of the landslide is effective. The method for monitoring the landslide earth surface displacement is shown below.

Table 8.3.1 Emergency Monitoring Types and Equipment (source: JET)

type	Equipment	
Extensometer	Measuring the amount of movement, recording data continuously 	* It is effective for monitoring the upper part of the landslide where the deformations are not seen from the ground surface. 
Simplified extensometer	Simple deformation detection board, easy, and many can be set up. 	Laser Extensometer 
Others	Crack monitoring with Vernier Caliper on concrete wall. 	Using a Total-Station, the displacement of the landslide is measured from a distance. 

8.3.5 Estimate of the Cause of the Landslide Occurrence

It is very important that the cause of the landslide occurrence is estimated in predicting future landslide activity. The cause of the landslide occurrence is divided into a basic factor and an exciting cause (trigger).

- Basic factor: Topography / Geological feature
- Exciting cause (Trigger): Rain / Groundwater / Artificial topography modification

The examples in the study of the cause of the landslide is shown below. Because a method to remove an exciting cause (trigger) is effective for an emergency countermeasure, the estimate of the exciting cause is extremely important.

Table 8.3.2 Examples in the Study of the Cause of the Landslide (source: JET)

Courses	Items	Examples
Basic factor	Topography	Characteristic landslide shape, Scarp, Cliff, Slope angle, Steps, Uplift, Subsidence, Bulging at lower part
	Geological feature	Soil, Rock, Colluvium, etc.
Exciting cause (Trigger)	Rain	Rain data (Meteorological Agency / field observation)
	Groundwater	Spring water, Pond, the quantity of water Surface water, Drainage (damage)
	Artificial topography modification	Cut slope (Excavation at toe part of a landslide) Embankment, (Filling at top/middle of a landslide)

8.3.6 Initial Survey at Site

a. Prediction Form the Landform and Deformation

1) The case that landslide mass completely slides down has low activity in future, and the stability is relatively high.
2) As for the case that a distal end of landslide mass rises, the landslide activity often becomes dormant, because it is estimated that the sliding surface is a horizontal or reverse incline.
3) The case that the inclination of the downward slope is gentle, the landslide activity often becomes dormant for a reason same as case 2.
4) The case that the inclination of the downward slope is steep, the landslide does not stop easily.

b. Prediction Form the Landform and Deformation

Generally, because the displacement of the landslide suddenly accelerates just before collapse, the activity of the future landslide is estimated by monitoring landslide displacement. It is necessary to be careful about future sudden displacement increase even if there is not the movement of the landslide at present.

8.3.7 Estimate of the Influence Area

When a landslide area spreads, there is the risk that heavy damage will occur. The possibility of the landslide area expanding should be sufficiently considered in the initial site survey.

If a landslide movement area is identified, the danger zone where a landslide mass will reach must be estimated. As a result of a study of landslide disasters in Japan, in 95% of landslides, the danger zone where the landslide mass reached was less than two times the length and width of the landslide body. Therefore, the danger zone shown below should be referred to when an early warning and/or evacuation is considered.

8.4 Emergency Response

8.4.1 Structural Countermeasure Work

The aim of the emergency structural countermeasure is to mitigate landslide activity, to minimise damage by landslide disaster and to release the warning status at an early stage. As there are cases where premature measure work may foment landslide activity, the type and layout of the emergency measure shall be decided carefully in consideration of the cause of the landslide and actual site conditions. Otherwise, the result of the work will have insufficient effect or even worse conditions. At the very least, before consideration of countermeasure works, the area and cause of the target landslide shall be recognised.

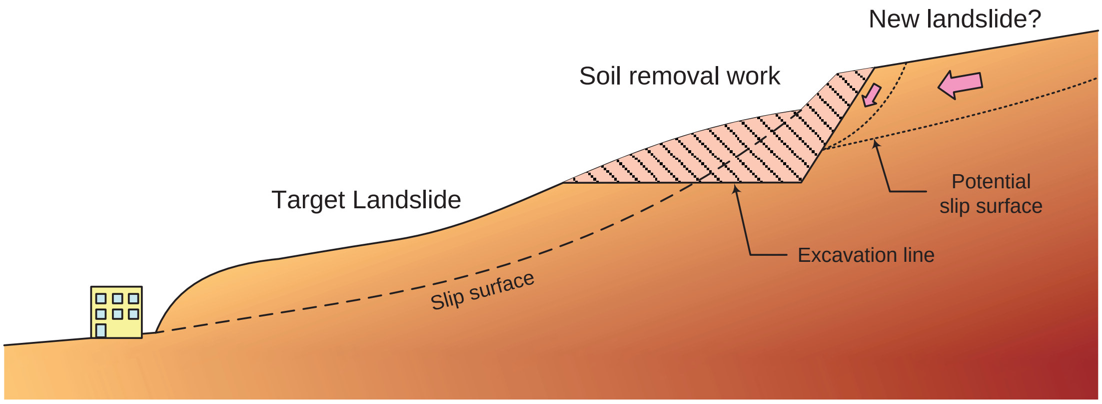
Generally, structural countermeasure work in an emergency shall be applied control works because control works can be conducted in a short time. The control works below can be considered as emergency countermeasure work for landslides.

It is thought that the main causes of landslides in Mauritius are artificial topographical changes by excavation work or soil filling work and hydraulic environment changes by runoff water or the rising groundwater level in the rainy season.

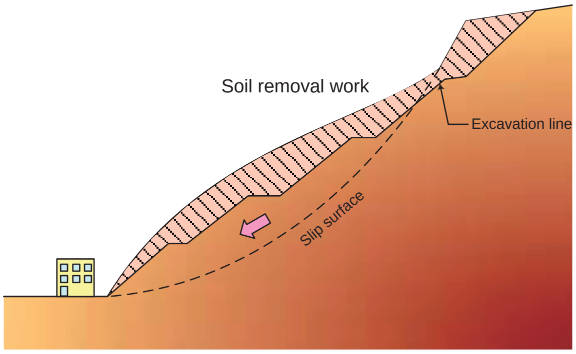
In the case of landslides caused by artificial topographical changes, the site shall be rehabilitated to its original condition as far as possible. If the rehabilitation of site conditions is difficult or the landslide occurred due to natural causes such as changes in hydraulic conditions, the following works can be considered as emergency countermeasure work:

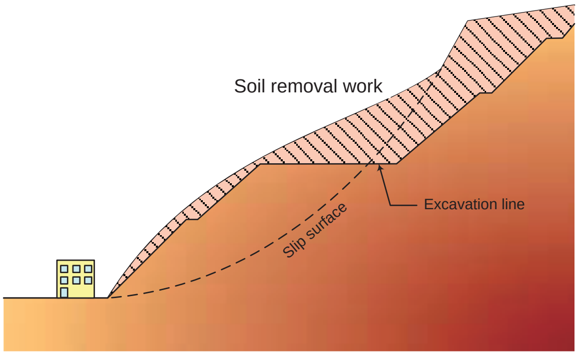
- Soil removal work (Excavation work)
- Counter weight work
- Drainage work
- Detours

These countermeasures are works just for emergency situations and to mitigate damage by landslide provisionally. It is recommended that expected the factor of safety shall be secured at 1.05 by the emergency countermeasure works. After installation of the works, permanent countermeasures shall be examined and installed based on the results of a detailed investigation.



(i) Soil removal work at the head of a landslide will have a good effect on stability itself but it may also trigger a new landslide behind the target landslide.

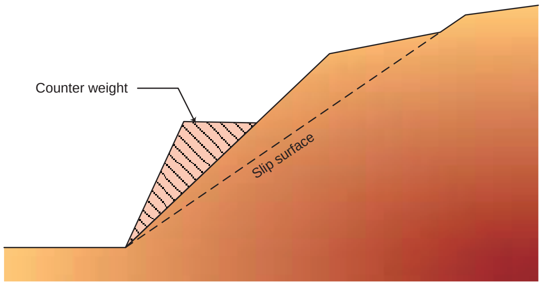


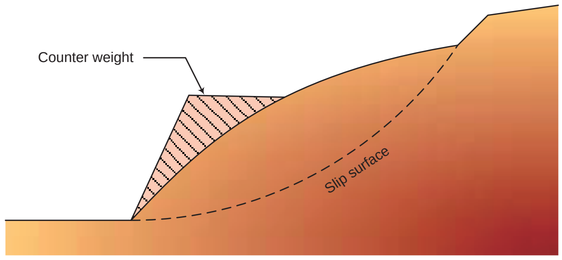


(ii) Excavation work conducted as shown in the above figure will contribute to the instability of the target landslide due to lack of soil at the lower part of the landslide block *[1]

(iii) Excavation at the head of the landslide block with an appropriate slope gradient will contribute to the stability of the target landslide[1]

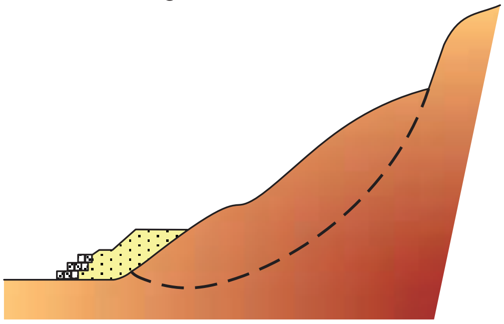
Figure 8.4.1 Example of Soil Removal Work at the Head and Unstable Part of Target Landslide (source: JET)

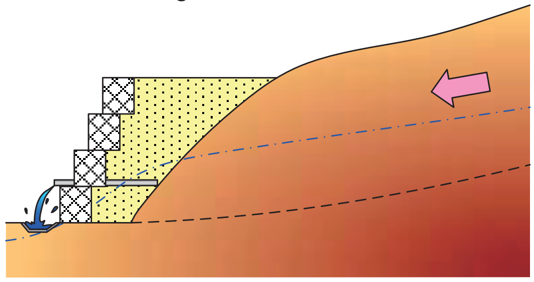




(i) In the case that a slip surface appears straight, the safety factor of the landslide will not be drastically changed by the counter weight work.

(ii) In the case that a slip surface appears curved, an increase in the safety factor of the landslide can be expected by the counter weight work.





(iii) The slope of the counterweight filling work shall be covered by a gabion or sandbags to avoid erosion.

(iv) In the case that a spring or seepage is found at the toe of the landslide, weep holes shall be installed in the filling/embankment to avoid a rise of the groundwater level in the landslide.

Figure 8.4.2 Points of Installation of Counter Weight Work (source: JET)

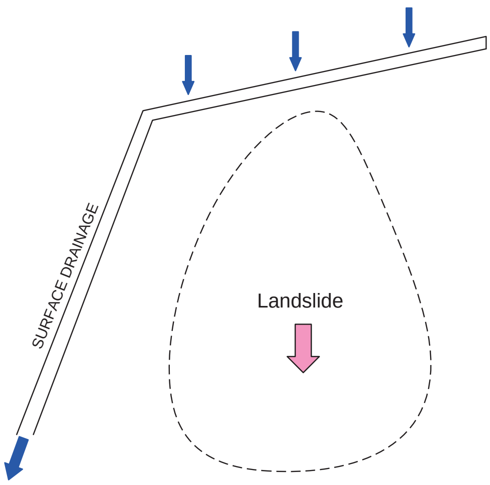


Figure 8.4.3 Example of Arrangement of Surface Drainage (source: JET)

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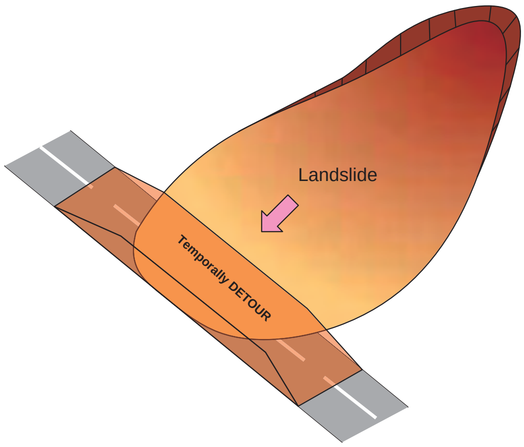


Figure 8.4.4 Detour on the Original Road (source: JET)

8.4.2 Evacuation and Relocation Support

a. Evacuation

The contingency plan contains the followings (for details of the below, refer to the end of this guideline.)

- Location map of evacuators
- Evacuee list:
- Early waning and evacuation system flow
- Instruction manual of simple rain gauge
- Communication network
- Location map of the designed refugee centre and the route

b. Relocation Support

In the initial survey, the information will be collected through an interview survey of inhabitants and reconnaissance of a site. Based on the survey result, the basic policy of the response to the landslide disaster damage area such as countermeasure works, non-structural countermeasure and necessity of the relocation is considered by the related ministries/ agencies.

In case the deliberation reaches a conclusion that relocation is necessary, the explanation of the relocation project will be conducted for the inhabitants (explanation of the survey result, the purpose of the relocation project and its schedule; as well as to obtain consent of detailed survey, etc.)

The information regarding the right of the land, buildings and others should be confirmed to implement the appropriate and effective work for relocation. In the detailed survey, the information which is shown on the following table will be collected through an interview survey of inhabitants, reconnaissance of a site, investigation of cadastral data/registration records, land survey and investigation of the buildings.

Table 8.4.1 Items and Content of the Detailed Survey for Relocation (source: JET)

Category	Item	Content
Detailed information of the victims	List of the victims (entire family)	Name, Address, Age, Contact information, Occupation, Relationship in family structure, Amount of revenue
	Situation of land acquisition for the relocation	Acquired (own land, lease) or Not acquired. (In case of acquired, address: ___)
	Situation of building acquisition for the relocation	Acquired (own building, lease) or Not acquired. (In case of acquired, address: ___)
	Necessity of the relocation	
	Conditions of a location for the relocation	
Detailed information of the damage about the land	Name of owner/lessee	
	Address of the land	(plot on a map)
	Address of the owner	
	Date and time of disaster damage occurrence	year-month-day-time format
	Condition of the damage	Buried in the ground, Swept away, other ( )
	Area of the land	
	Use	Residential, Commercial, Agricultural, Industrial, Forestry, Other ( )
	Photo of the damage	
	In case of own land, situation of a loan	Date of borrowing, Debt balance, Lender, Borrowing period
	In case of leased land	private-owned or nationally-owned, Name/address of lessor, Lease period, Rent, Other conditions
Detailed information of the damage about the building	Name of owner/lessee	
	Address of the building	(plot on a map)
	Address of the owner	
	Date and time of disaster damage occurrence	year-month-day-time format
	Structure of the building	Concrete block, Reinforced concrete, Steel, Steel framed reinforced concrete, Wooden, Other ( )
	Condition of the damage	Complete destruction, partial destruction, buried in the ground, swept away, other ( )
	Area of the building	Total ___m2 (1st floor ___m2, 2nd floor ___m2, 3rd floor ___m2, other ___m2)
	Use	Residential, Shop, Storage, Office, Workshop, Other ( )
	Damage in parts and hazardous situation	Roof ( ), Frame structure ( ), Wall ( ), Fittings ( ), Floor ( ), Foundation ( ), Other ( )
	Photo of the damage	
	In case of own house, situation of a loan	Date of borrowing, Debt balance, Lender, Borrowing period
	In case of leased house	private-owned or nationally-owned, Name/address of lessor, Lease period, Rent, Other conditions

The confirmation of the possessor, right holder and other stakeholders is required through the clarification of the location of the land/building and the registration record based on the investigation of the cadastral map of Ministry of Housing and Lands. The collected data and materials by the investigation of the cadastral map and registration record contain the personal information. The information must not be used for anything besides the intended purpose and the information must be managed carefully.

The land survey will be conducted after the location of the subject land of relocation, detailed address, cadastral data, possessor, right holder and other stakeholders are confirmed based on the investigation result of the cadastral map and registration record. The surveyors have to enter the land of the stakeholders to conduct the land survey. It is needed to obtain the stakeholder's consent for and notify them of the intention to enter their land for the survey.

For the investigation of the buildings the consent of the stakeholders needs to be obtained in order to enter their buildings to conduct the investigation. The objects of the investigation are building, machinery, productive facility, barn, plumbing, garden tree, farm product and others.

When the land survey and investigation are finished, the record for each land/building stakeholder should be prepared. And the records are required to be confirmed by stakeholders with their signature.

The landslide area (includes areas of landslide activity and/or extremely high risk of landslide damage) and areas adjacent to a landslide area (has a possibility of triggering a landslide or to have a negative effect on the landslide area) will be examined by the related ministries/agencies based on the survey result to consider the implementation of the relocation.

8.4.3 Landslide Warning Systems

a. Information for Landslide Warning

Prediction of the landslide disaster
To predict a landslide disaster, we must identify small phenomena caused by landslide. Generally, small phenomena such as cracks or deformation of the ground and structures can be seen prior to a landslide disaster. We must identify the small phenomena and monitor whether they are getting worse or not using tools or instruments.

Location of the landslide risk areas
A landslide warning system is used to warn the residents in a landslide risk area to evacuate when necessary. Therefore, the houses in landslide risk areas must be identified to conduct a landslide warning. Landslide risk areas shall be identified by detailed investigations prior to establishing the landslide warning system. A landslide risk area is both the area of a landslide block and the surrounding area that can be affected. Landslide blocks can be confirmed by the inventory survey and detailed investigations.

Information Transfer
Once we predict the landslide disaster, the information must be transferred from the tools or instruments to all residents in the landslide risk area. Therefore, a person to receive the information from the tools or instruments and a person to transfer the information to all residents must be appointed.

b. Phenomenon Initiate the Warning and Sensors

To issue a warning, we must find where the landslide risk areas are and predict when the landslide disaster will occur. Once the location of the landslide had been identified and a landslide warning system is established, the landslide warning system must predict the timing of the landslide disaster. In order to predict the timing of the landslide disaster, we should find and monitor the small phenomena which arise prior to the landslide There are two kinds of phenomena in landslide risk areas we have to keep our eyes: a) small phenomena such as cracks or deformation on the ground surface or structures caused by landslides and b) phenomena which can cause landslides.

a) Small phenomena which can be seen everywhere in a landslide area should be found and monitored. The movement of the ground surface, cracks on the ground, cracks on a structure and movement of the subsurface are all possible phenomena caused by landslide.

b) In Mauritius, only an increase in groundwater level can cause landslides. As monitoring of the groundwater level is sometimes difficult, precipitation monitoring can be performed as an easy way to determine an increase in the groundwater level.

c. Criteria of Warning

The most important thing to establish the criteria of warning is to recognize the limit of landslide movement or the limit of precipitation to keep the people secure. "People in danger" means that houses are being destroyed by the landslide. The warning to evacuate the houses must be issued a few hours before destruction by the landslide. In order to determine the timing of when the houses are destroyed in the landslide, we must find the relationship between the deformations recorded by the extensometers and the destruction of houses or precipitation and the destruction of houses.

d. Warning

<u>Warning with Alarm Devices</u>

There are two ways to emit the warning, by in-situ alarm or by remote alarm. Although there are many types of in-situ alarm devices, sound and light are the most popular for landslide warning systems. Sirens are mostly used for sound alarms, but horns, bells and loud speakers can also be used. For light alarms, beacons are mostly used but light bulbs and flushes are sometimes used. In order to transfer the sound and light warning to all of the residents in the area, a watchman must be assigned to monitor the light and sound devices. Therefore, the light and sound devices must be installed in a place where the watchman can see and hear the alarm. The sound alarm in a warning system emits a loud sound to warn all people in the area like a fire alarm system in a building. As the sound is expected to warn all people in the area, a number of sound alarms should be installed. When installing the sound system, all people in the area must be able to recognize the alarm system. Communication among residents is even more important to help warn people in the area who may not hear the alarm due to bad ears or because they are listening to music with head phones.

With a remote alarm system, data and warning signals from the instruments are sent by cable or radio to a remote control office. The advantages of this system are that it is easy to control a number of instruments and because some landslides occur simultaneously in one place. Also, a landslide expert can access the data easily and judge the seriousness of the situation immediately based on the data sent from the site.

<u>Warning with Simple Devices</u>

Without an automatic warning system, someone must always watch devises such as the extensometers and rain gauges and once the reading reaches the warning level, he must send out a warning immediately. It is necessary to decide who the watchman will be, how the instruments will be monitored and how the warning will be sent. Someone must be appointed to watch the devices 365 days a year and there should be more than one watchman. Regular monitoring such as hourly and daily should be carried out every day by the watchman. The interval of monitoring depends on the landslide activity but monitoring is usually once a day and becomes more frequent if the landslide is more active.

e. Transmission of Warning

Transmission of the landslide warning can be considered as a fire alarm system. In a fire alarm system, a warning is transferred to all people in the building and building management by the sound of a fire alarm. The information is transferred to a fire station directory from the alarm system or through building management. When we adapt the fire alarm system to the landslide warning system, the people in the building are the people in the landslide risk area, building management is MPI, and the fire station is the police station. In the case of a fire, the fire fighters must arrive as soon as possible to put out the fire while in the case of a landslide, the police must warn all the residents and guide them to a safe place.

Since the police are concerned with the evacuation of residents in Mauritius, the police should receive the warnings of the landslides and transfer the warning to all the residents in the area. MPI who manages all landslides in Mauritius must receive all the warnings from the instruments and watchmen and transfer the warnings to the police.

f. Evacuation

Instruction to residents about evacuation should be done by the police, not by MPI. However, MPI should explain the following technical matters about landslides to the people.

- Boundary of the landslide risk area
- Confirmation of residential houses in the landslide risk area
- Notification to the residents of houses in the landslide risk area
- Danger in the landslide risk area
- Warning system installed in the landslide risk area
- Management of simple devices
- Appointment of the watchman

8.5 Detailed Survey Plan

8.5.1 Flow of Landslide Survey

A survey and analysis on landslides should be implemented to establish preventive plans and to discuss countermeasures for landslides. The survey is generally divided into two stages: a preliminary survey and a main survey.

The preliminary survey is composed of the collection of documents, data and maps and the searching and analysis of related literature.

The main survey for landslides chiefly consists of a hydrological survey, geomorphologic survey, geological survey, drilling and slip surface surveys, physical testing, monitoring and geophysical exploration. The analysis of landslides, such as the preparation of geological cross sections, establishment of the safety factor and stability analysis, should be implemented based on the specific results of the above mentioned surveys. The following figure summarizes the flow of the survey and analysis of landslides and the scope which is described in this manual. The survey items and survey methods are shown in following table. In order to properly examine the items listed in the table, a detailed survey which will satisfy the study objectives should be planned by selecting appropriate survey methods and instruments described in the table.

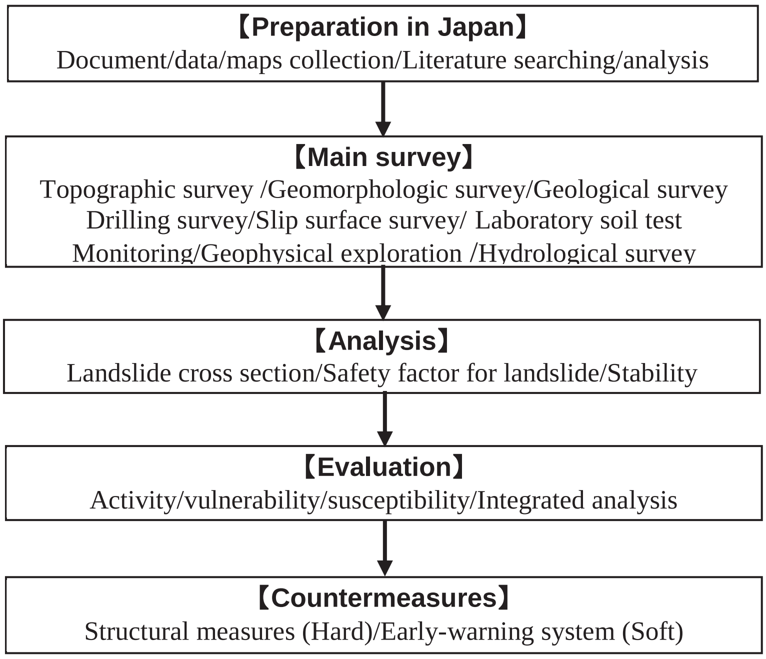


Figure 8.5.1 Flowchart Summarising Survey/Analysis for Landslides (source: JET)

Table 8.5.1 Survey Items and Survey Method for Landslides[3]

Investigation items		Interpretation of aeral photographs	Literature research	Topographic survey	Topographic investigation	Surficial geologic investigation	Subsurface exploration by borings	Test adit	Geophysical exploration	Soil tests	Groundwater tests	Investigation of slip surface	Investigation of land deformation	Notes
Topography	slope form	○		◎	○									
	slope inclination			◎	○									
	slope height, location of safety objective	△		○	○									
	formational process of slope	○	△		△									
	landslide topography (areal extact, moving blocks, direction of movement)	◎		◎	◎									
	knick line (yes or no)	◎		○	○									
	micro topography of slope	△			◎									
Geology and geologic structure	rock type and rock quality	△	○			◎	◎	◎	○	△	△			composition of rocks and hardness
	degree of weathering and level of relaxation					△	○	◎	◎		△			
	density of rock formation						△	◎		◎				
	distribution of faults and fracture zones	○	△			◎	◎	◎	○					
	distribution and depths of slip surface	△				○	◎	◎	○			◎		continuity
	inclination of slip surface					○	◎	◎				◎		
	quality of slide mass, composition of slip surface materials					○	◎	◎			○			filling
	mechanical coefficient of slip surface									◎				
	deformation conditions of slip surface											◎		
Deformation condition of ground surface					△								◎	
Conditions of groundwater and springs						△	○				○			
Estimation of pore-water pressure							△				◎			
Existing conditions and warning signs	history of past disasters	○	◎		△									
	existence and conditions of scarps	○			◎									
	secondary failures and rock falls	△			○									
	conditions of toe area and uplift	○			◎									
	existence of extremely relax beds and rocks				△									
	deformation of structures				◎									

◎ : very effective investigation method
○ : effective investigation method
△ : depending on the situation, may be effective method

8.5.2 Outline of Countermeasure Policy

Generally, an area or place which has the potential of landslide or large scale slope problems shall not be used for housing or road development. In the case that landslide or slope problems exist or have an impact on a residential area or road, the countermeasure shall be applied substantially based on the required investigations.

The countermeasure shall be planned after the evaluation of landslide hazard based on the hazard rank in the table below.

Table 8.5.2 Evaluation Sheet of Landslide Stability[4]

Hazard Rank	Deformation and Topographical feature of landslide	Activation Rank
A	Cracks, subsidence, collapse and uplift caused by landslide are found on the slope. Deformation caused by landslide is found on an existing facility such as a side ditch. No landslide countermeasure works have been installed even though there is a history of previous landslides. It has a high potential for landslide hazard to the road directory despite no artificial landform changes.	Condition a Condition b
B	Clear landslide characteristic features are found even though evidence of landslide activity is not clearly recognised. It has high potential for landslide hazard to the road directory by artificial landform changes.	Condition c
C	The slope shows landslide characteristic features but they are not clear. Even if landslide occurs due to large-scale changing of environment conditions, the possibility for expansion of damage is low and treatment of the landslide damage can be done promptly at that moment.	There is possibility to be condition c

The activation rank is shown in the table below.

Table 8.5.3 Displacement Monitoring by Extensometer[5]

Activation Rank	Daily displacement (mm/day)	Accumulated displacement (mm/month)	Activation
Rank a	More than 1	More than 10	Active movement t
Rank b	0.1 - 1	2 - 10	Sluggish movement
Rank c	0.02 - 0.1	0.5 - 2	Intermittent movement (Further monitoring is required)
Rank d	More than 0.1	Less than 0.5	Partial movement

8.5.3 Structural countermeasure Work

The structural landslide countermeasure work can be divided into control work and restraint work. The control work is the work to stop or mitigate landslide movement by improvement of natural conditions such as topographical and hydrological aspects. The restraint work is the work to stop a part or the entire landslide block by the restraint force of structures installed in the landslide area.

It is not necessarily the case that only one type of countermeasure is installed. Rather, several types of structural landslide countermeasures are applied in combination. The general types of structural countermeasures are shown below.

Control Work

- Surface drainage work (drainage work, infiltration prevention work)
- Groundwater drainage work
  - Shallow groundwater drainage work
    - (conduit work, open-blind ditch, horizontal drainage work)
  - Deep groundwater drainage work
    - (infiltration well, drainage tunnel work, horizontal drainage work)
- Soil removal work
- Counter weight work
- River structural facility (dam, consolidation work, water control work, revetment work)

Restraint Work

- Pile work
  - Pile work (steal pipe pile work)
  - Shaft work
- Ground anchor work

In the case that the landslide is active, the restraint work will not have the expected proper effect and the construction work will also be extremely dangerous. Therefore, in such a situation, the restraint work shall be installed at an appropriate time after mitigating the landslide movement by control work. Selection of the structural countermeasure can be done according to the flowchart below.

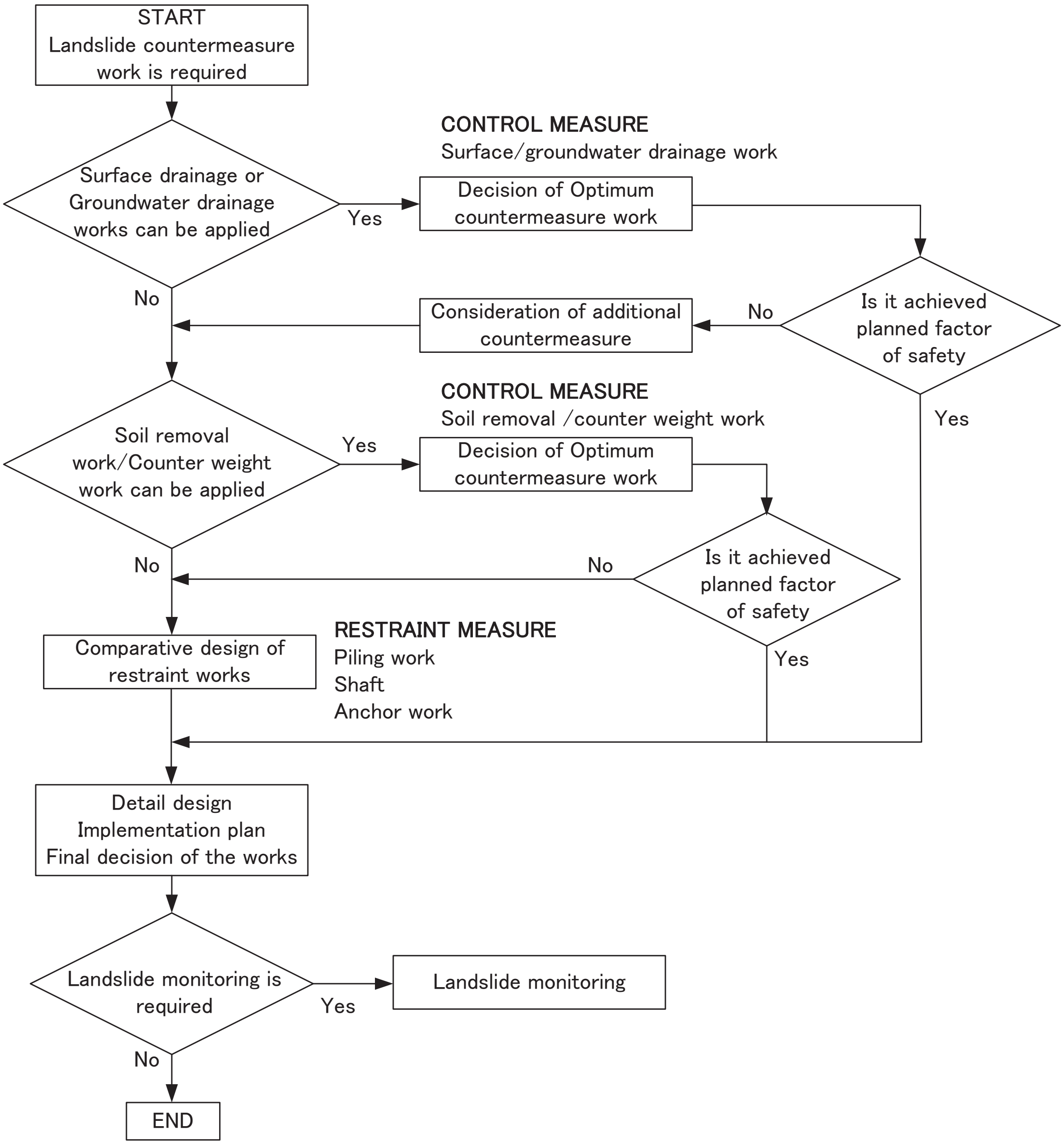


Figure 8.5.2 Flowchart for the Selection of Landslide Countermeasure Work[6]

8.5.4 Confirmation of Regulations and Laws

a. Development Restriction and Land-use Control

If there is no development restriction or land-use control in a landslide site, activities for review of the development restriction/land-use control will be required to avoid the landslide disaster risk by development in the future. If a development restriction/land-use control is available in a landslide site, reconfirmation and coordination with related authorities will be needed for thorough investigation and approval of the development application. The confirmation of development restriction/land-use control should be conducted for the above. It will be also required to refer the following information for review of the development restriction/land-use control. If the following information regarding the landslide site is available, the data collection and confirmation should be conducted.

- Disaster record

- Risk map
- Hazard map
- Research/study regarding the disaster risk management

b. Legal Systems and Schemes

It is required to comprehend the basis acts of legal systems and schemes regarding the development restriction and land-use control to coordinate with related authorities and review existing regulation.

The following figure shows legal systems/schemes which have a relationship with landslide disaster risk management (hereinafter LDRM) in Mauritius. The existence of the relevant legal systems/schemes in the object area should be confirmed for each site.

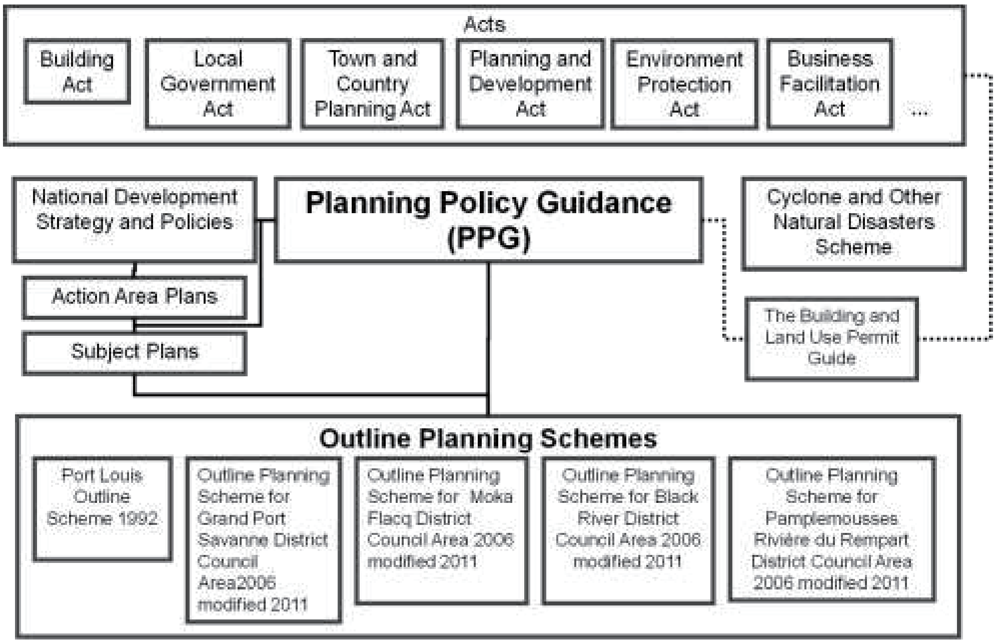


Figure 8.5.3 Acts and Schemes Related with LDRM (source: JET)

c. Development Restriction by PPG

If a landslide site is not applicable development restriction for sloping site by Planning Policy Guidance (hereinafter PPG), activities for review of the development restriction/land-use control will be required to avoid the landslide disaster in the future. If a landslide site is applicable the PPG’s development restriction for sloping site, reconfirmation and coordination with related ministries/agencies/local authorities will be needed for thorough investigation and approval of the development application. Therefore, the confirmation of the PPG’s development restriction for sloping site which is shown below should be conducted.

In the PPG existing as of December 2013, it has the following regulations such as Landslide Disaster Risk Management. Once the initial survey is conducted, the following points should be kept in mind:

- ➢ Development will not normally be permitted on slopes steeper than 1:5 (20%).

- Above slopes of 1:10 (10%) and in areas of poor load-bearing capacity, the ground conditions should be checked and proposed structures certified by a qualified engineer. A Site Constraint Analysis and written statement detailing all proposed mitigation measures should be submitted to and approved by the Permit Authority prior to the commencement of any on-site works.
- As a general guide, development should not be any higher than 45 meters above the mountain base or, in the case of slopes facing the sea, 45 meters above Mean Sea Level.
- Buildings and structures should be set back far enough from ridges and cliff edges so that the structure does not appear to be perched on the edge.

d. Confirmation of the Development Plan Regarding the Landslide Site

The development record regarding a landslide site will be useful for identification of the cause of the landslide, examination material for emergency countermeasure and others. And, the confirmation of the development plan in the future is important to consider the disaster prevention measures. When the development record/plan will be confirmed, it will be required to refer the following information. If the following information regarding the landslide site is available, the data collection and confirmation should be conducted.

Natural Conditions
- Meteorological condition
- Topography
- Geology/Soil
- Land-use
- River/Basin
- Drainage
- Environment
- Cultural assets

Social Conditions
- Population
- Road network
- Bus system
- Water facility
- Drainage facility
- Park
- Public utility

Land-use Planning Conditions
- Settlement boundary
- Zoning (use district, scenic zone, etc.)
- District planning
- Land-use planning for public facility
- Term/Condition by the Building Act

Reference

[1] Varnes, D. J., 1978, Slope movement 43. types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides—Analysis and control: Transportation Research Board Special Report 176, National Research Council, Washington, D. C., pp. 11-23.
[2] JASDM & JCTC: Japan Association for Slope Disaster Management and Japan Construction Training Centre, 1995, Textbook of landslide prevention technical training.
[3] Japan Landslide Society, 2002, Landslides in Japan (The Sixth Revision), p. 21
[4] Japan Road Association, 1999, Road Earthwork Manual -Cut slope and Slope Stability-, p. 340, modified
[5] Japan Road Association, 1999, Road Earthwork Manual -Cut slope and Slope Stability-, p. 116
[6] Ibid, p. 355

APPENDIX 1

Designation of the Landslide Prevention Area

A landslide prevention area is the landslide hazard zone (yellow zone) and the landslide special hazard zone (red zone).

Landslide Hazard Zone (Yellow Zone)

- A landslide hazard zone (yellow zone) is the area where inhabitants and buildings may be damaged when a landslide occurs. At present it is not an active area, however, it is an area where a landslide have been active in the past, or it is the area with the possibility of landslide activity in the future.
- No new development is permissible in this area, and the information of disaster prevention should be shared with the inhabitants.

Landslide Special Hazard Zone (Red Zone)

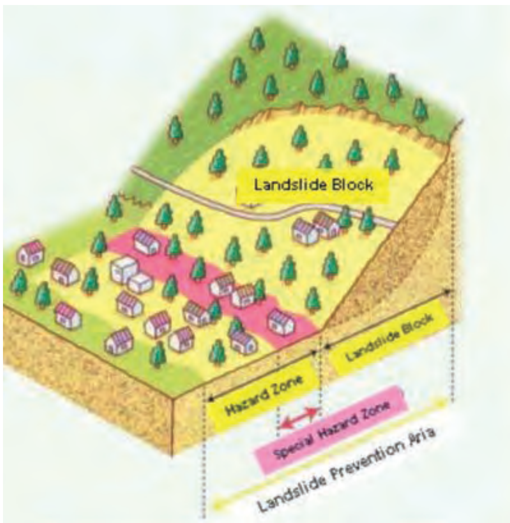
- A landslide special hazard zone (red zone) is an area where inhabitants and buildings are expected to sustain heavy damage when a landslide occurs.
- It is designated by the following criteria: Active landslide block and an area below the bottom end of the landslide block that will be impacted by the landslide activity.
- No new development is permissible in this area, and the information of disaster prevention should be shared with the inhabitants.
- Landslide countermeasures or relocation of the houses should be carried out immediately. An early warning and evacuation system is required until a countermeasure is completed.

＜Setting of the Landslide Hazard Zone : According to an example of Japan＞

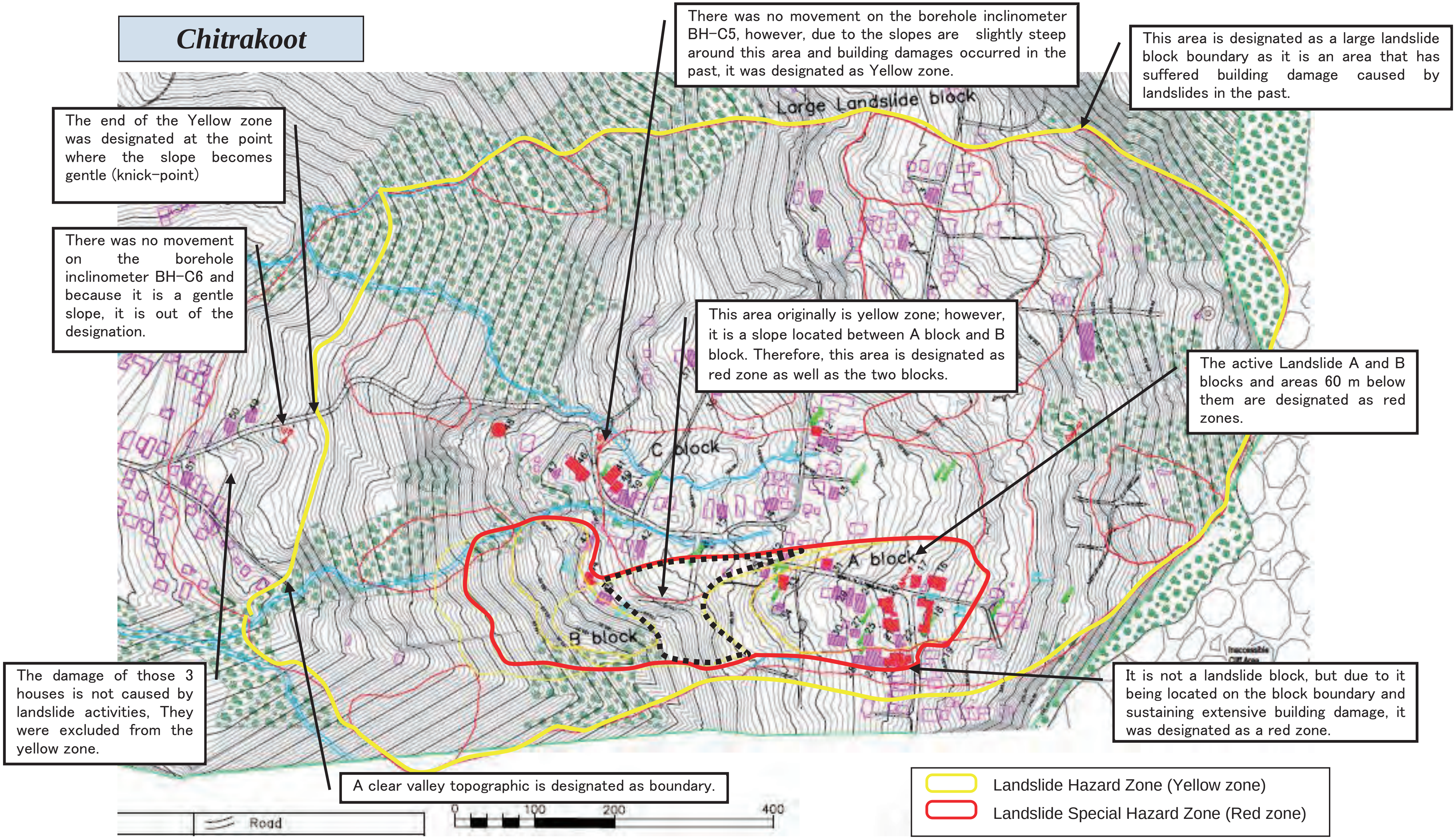
Special Hazard Zone (red zone): an area within 60 m from the bottom end of the landslide block.

Hazard Zone (yellow zone): an area within a distance equivalent to the length of the landslide mass from the bottom end of the landslide block (250m if the length of the landslide mass is longer than 250m).

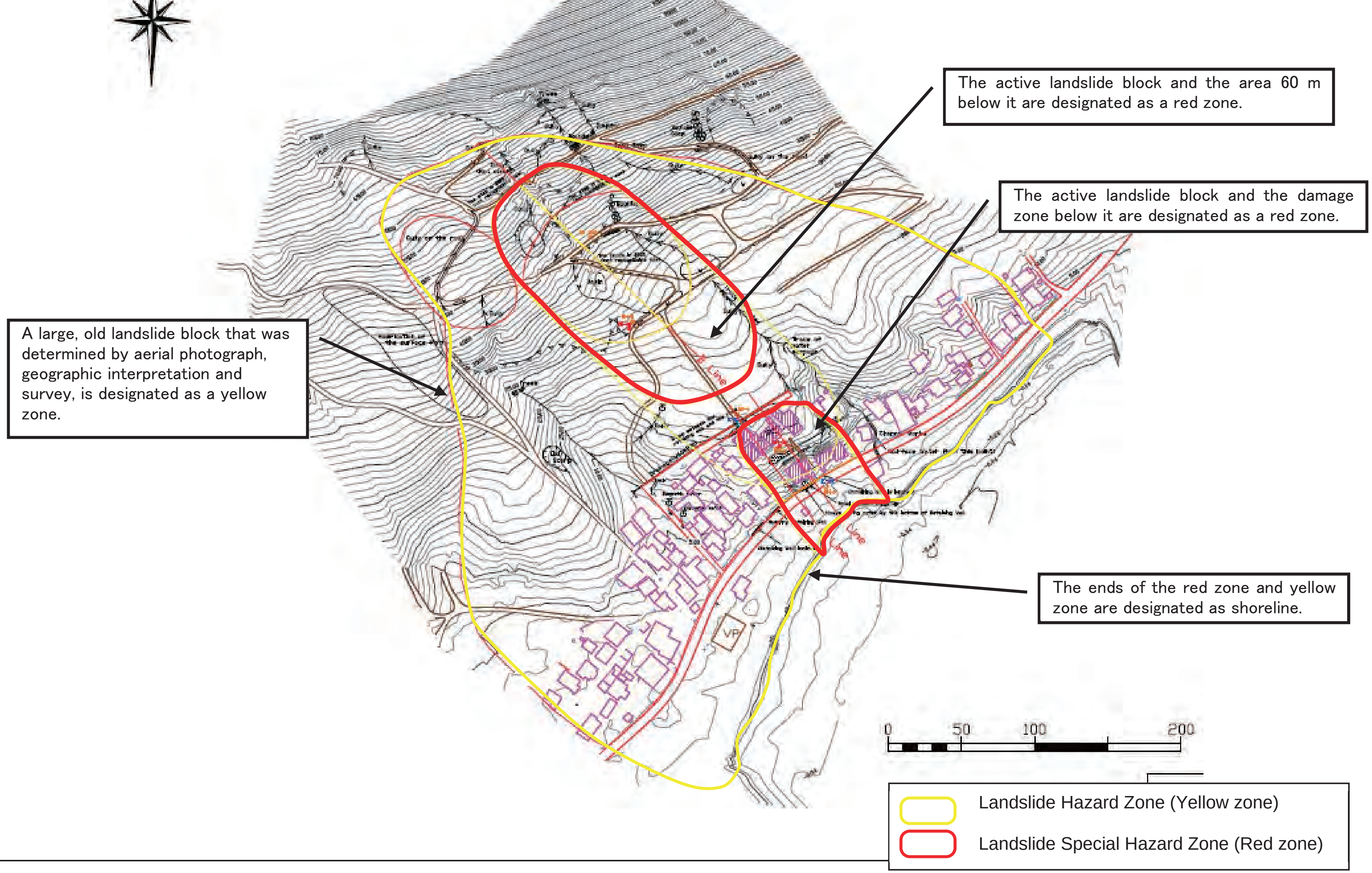
But, depending on the site conditions such as the topography or the geological features, the area of the red zone and yellow zone should be set using technical judgment as appropriate.



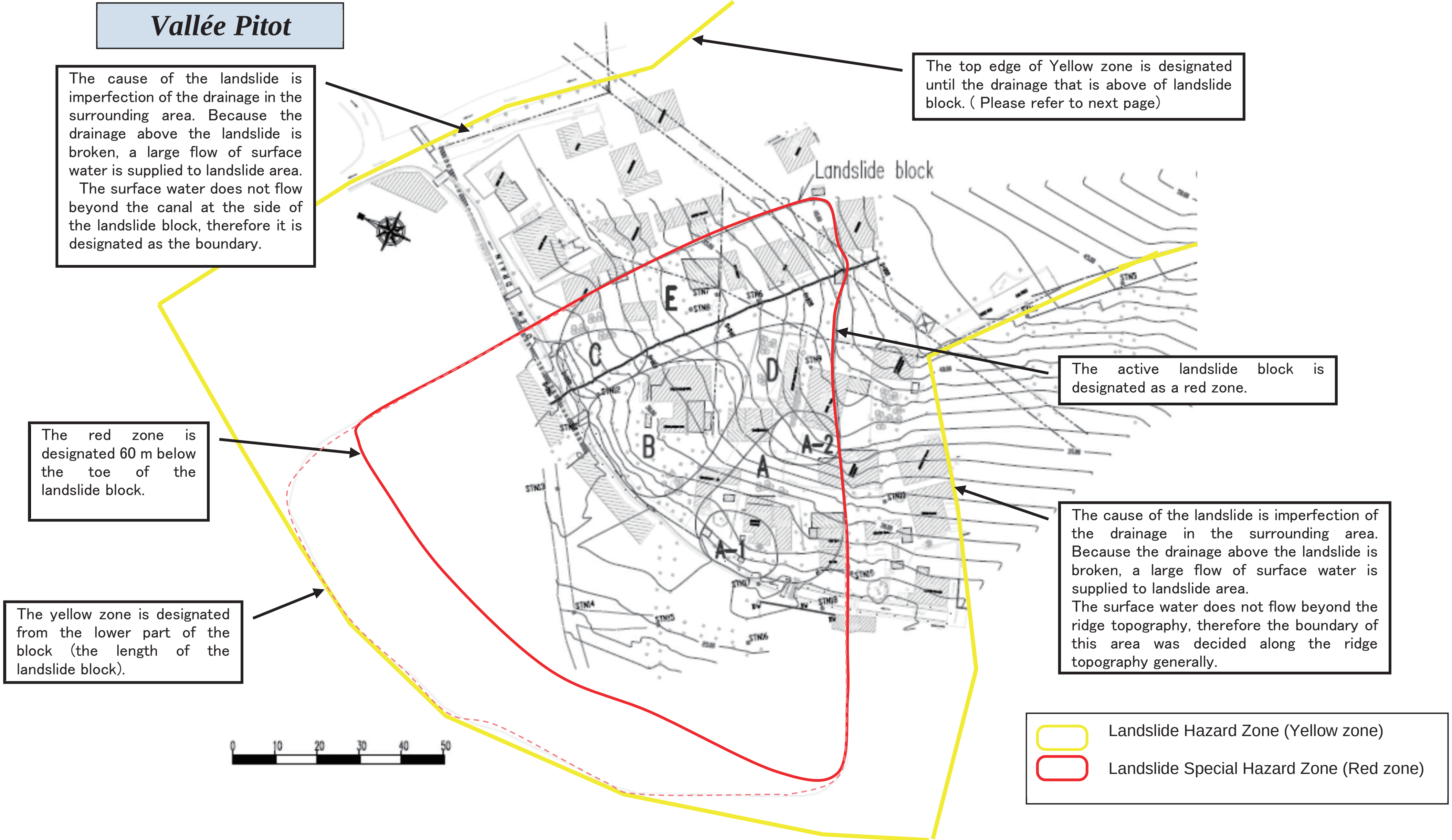
Chitrakoot


There was no movement on the borehole inclinometer BH-C5, however, due to the slopes are slightly steep around this area and building damages occurred in the past, it was designated as Yellow zone.
This area is designated as a large landslide block boundary as it is an area that has suffered building damage caused by landslides in the past.
Large Landslide block
The end of the Yellow zone was designated at the point where the slope becomes gentle (knick-point)
There was no movement on the borehole inclinometer BH-C6 and because it is a gentle slope, it is out of the designation.
This area originally is yellow zone; however, it is a slope located between A block and B block. Therefore, this area is designated as red zone as well as the two blocks.
The active Landslide A and B blocks and areas 60 m below them are designated as red zones.
C block
A block
B block
It is not a landslide block, but due to it being located on the block boundary and sustaining extensive building damage, it was designated as a red zone.
The damage of those 3 houses is not caused by landslide activities, They were excluded from the yellow zone.
A clear valley topographic is designated as boundary.
Road
0
100
200
400
Landslide Hazard Zone (Yellow zone)
Landslide Special Hazard Zone (Red zone)

Quatre Soeurs



Vallée Pitot




Vallée Pitot
Google Maps
The canal at the side of the landslide block is designated as the boundary.
The yellow zone is designated as the area up until the drainage above it.

APPENDIX 2

Points of Note for Execution of Horizontal Drainage Work

Special attention should be paid to the following points for the execution of horizontal drainage work for landslide countermeasures.

The horizontal drilling machine is not so familiar like dozer, shovel excavator, that can be drilled a deep hole into the earth, making an artificial spring, therefore there are some local people who were beset with doubt and fear. The person who is in charge of this execution planning prior to commencement of the work shall have sufficient understanding of the work so as to be able to carry out an explanation meeting regarding the purpose of landslide countermeasure works and its influence of groundwater by the works to the local community and its representative to garner their cooperation with the local government officer(s).

The collected drain water from the pipes which were installed horizontal drilling work shall be immediately discharged through the discharge channel to outside of the slope/landslide area. The order of work, the construction of discharge channel should be commenced prior to the horizontal drilling work. At least when starting the work for horizontal drilling, the site for discharge channel should be completed for right of way procedure, and to commence the execution of channeling work.

The location of horizontal drilling work shall be selected at stable ground and by keeping in mind the discharged groundwater shall not be concentrated the flow into the soft soil/ground place. It is also necessary to avoid the soil flow and suction near the mouth of drainage to put gabions or to install the water-permeable canvas sheet around 50 cm inner part of drilled hole mouth.

The time of starting horizontal drilling work is better to be in the dry season when landslide activity is likely to be lower. Movement of landslide mass continues for some time even after the end of the rainy season. The drilling operator shall make the judgment of whether to halt work to avoid trouble if he/she suspects bending of the drilling rods during the work. The reason is this will lead to jamming or breakage of drilling rods from deformation of the drilled hole because movement of landslide mass not yet stopped.

For the execution of horizontal drilling work, a suitable bit for the geological conditions must be used. In addition, the conformity of the actual geological conditions with the design conditions should be constantly checked. If there are any major discrepancies, a change of the design may be necessary.

The work specifications, such as the location of drilling, length and number of the drainages, direction and angle of inclination of horizontal drilling shall be prepared using design drawings and instructions of an engineer based on the site survey results.

The survey equipment such as Total Station or GPS device can be used for positioning of the drilling machine, either positioning of the direction for horizontal drilling can be decided using a tape measure. The angle of inclination of drilling rod shall be checked using slant ruler.

The procedures of the main horizontal drilling works are outlined below.

① Preliminary topographic positioning and preparation. Permission to use the land, land-use rights, shall be obtained from the Land-Owner/Users with the cooperation of the Service Contract Office and Local Government Office.

② Mobilization of machineries and equipment from the garage

③ Topographic measurement (Photo-A-1)

④ To prepare the work platform with access road by the excavator to mobilize/set the machineries.

⑤ Installation of machine (Photo-A-2)

⑥ Drilling work (Photo A-3, Photo A-4)

⑦ Installation of drainage pipe

⑧ Installation of drainage ditch and protection of mouth of pipes by retaining/gabion wall (See Photo A-5)

Photo A-1 Positioning of drilling points by GPS (Source: JET)

Photo A-2 Adjustment of drilling direction (Source: JET)

Photo A-3 Setting of drilling machine in the direction of the marked points (Source: JET)

Photo A-4 Checking the inclination of drilling rod (Source: JET)

Photo A-5 Retaining wall for protection of mouth of drainage pipes and discharging channel (Source: JET)

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
MINISTRY OF PUBLIC INFRASTRUCTURE AND LAND TRANSPORT (MPI)

Technical Guideline for Initial Survey

December 2014

(Revised in September 2017)

KOKUSAI KOGYO CO., LTD.

NIPPON KOEI CO., LTD.

CENTRAL CONSULTANT INC.

FUTABA INC.

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0 Preface

0.1 Definition of Landslides

The term “Landslide” is defined variously in different literature. For example, United States Geological Survey (USGS) defines “Landslide” referring to Cruden, 1991, and Varnes 1996 as follows:

A landslide is defined as "the movement of a mass of rock, debris, or earth down a slope" (Cruden, 1991). Landslides are a type of "mass wasting" which denotes any down slope movement of soil and rock under the direct influence of gravity. The term "landslide" encompasses events such as rock falls, topples, slides, spreads, and flows, such as debris flows commonly referred to as mudflows or mudslides (Varnes, 1996). Landslides can be initiated by rainfall, earthquakes, volcanic activity, changes in groundwater, disturbance and change of a slope by man-made construction activities, or any combination of these factors.

- Cruden, D. M., 1991. A Simple Definition of a Landslide. Bulletin of the International Association of Engineering Geology, No. 43, pp. 27-29.
- Varnes, D. J., 1996. Landslide Types and Processes, in Turner, A. K., and Schuster, R. L., Landslides: Investigation and Mitigation, Transportation Research Board Special Report 247, National Research Council, Washington, D.C.: National Academy Press.

The classification by Varnes, 1978 through USGS is widely adopted worldwide. Table 0.1.1 presents the updated classification.

Table 0.1.1 Classification of Types of Landslides[1modified]

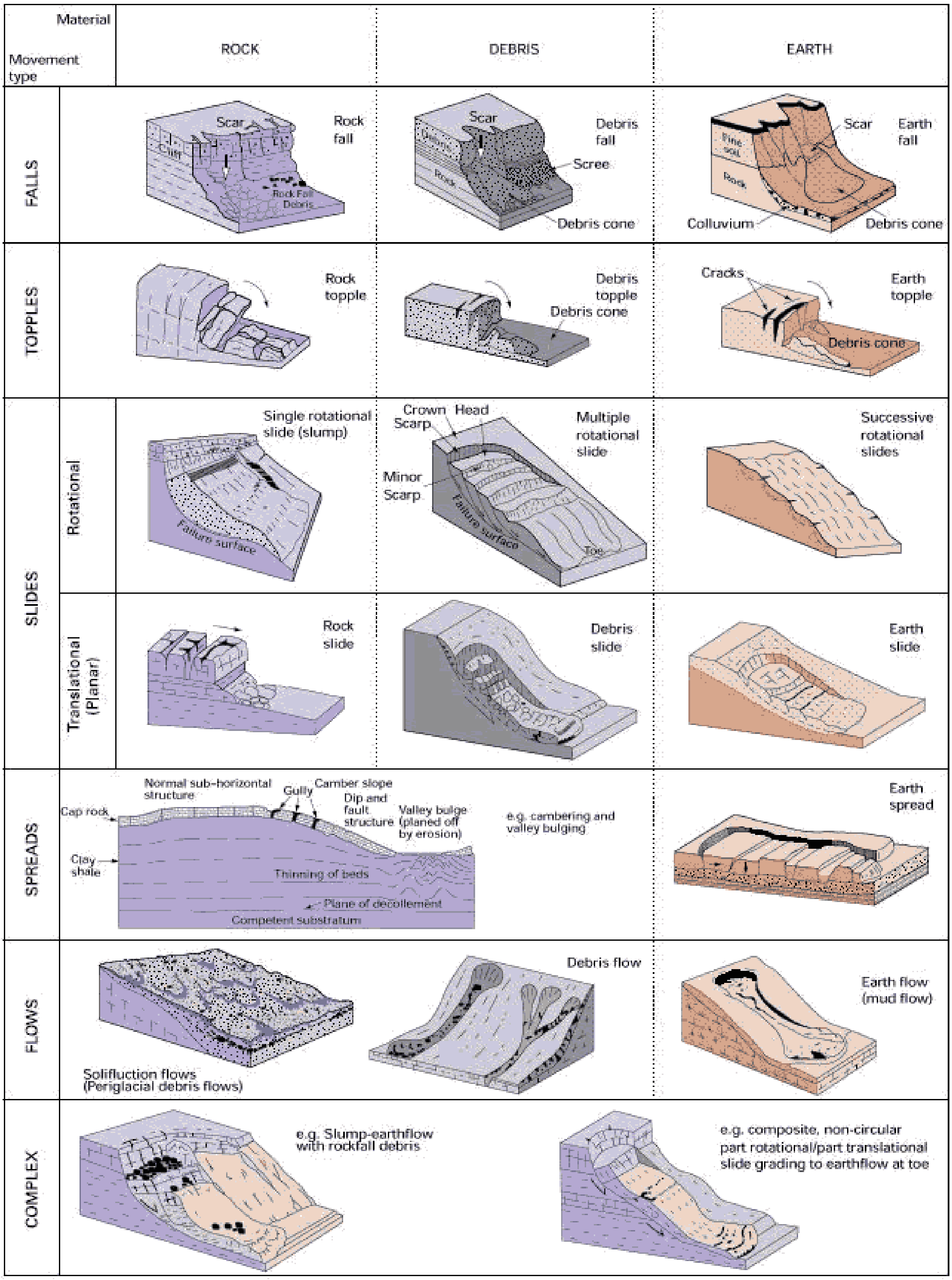


Figure 2 Classification of type of landslip (modified after Varnes, 1978 and DoE., 1990).

Falls mass detached from steep slope/cliff along surface with little or no shear displacement, descends mostly through the air by free fall, bouncing or rolling.
Topples forward rotation about a pivot point.
Rotational slides sliding outwards and downwards on one or more concave-upward failure surfaces.
Translational (planar) slides sliding on a planar failure surface running more-or less parallel to the slope.
Spreads fracturing and lateral extension of coherent rock or soil materials due to liquefaction or plastic flow of subjacent material.
Flows slow to rapid mass movements in saturated materials which advance by viscous flow, usually following initial sliding movement. Some flows may be bounded by basal and marginal shear surfaces but the dominan movement of the displaced mass is by flowage.
Complex slides slides involving two or more of the main movement types in combination.

Generally speaking, a landslide is classified as follows, when you take countermeasures for each phenomenon.

(1) Landslide

A landslide is equivalent to mainly “SLIDES” in the Table 0.1.1. A landslide is a phenomenon where the soil mass on one or more failure (slip) surfaces deep in the ground gradually shifts downward, triggered by heavy rain or earthquake, river erosion, earthworks. Landslide sites tend to be concentrated in areas with specific geology or geological structure. Compared to slope failure, the gentler slope moves on a large-scale, forming specific topography (landslide topography), the inclination angle of the landslides slope is a relatively low angle (about 5-20 degrees).

(2) Slope Failure

A slope failure is equivalent to “FALLS” of debris and earth material in the Table 0.1.1, but it does not include “Rock fall”. The slope failure mass detaches from a steep slope/cliff along a surface with little or no shear displacement. It may be called a “Surface Failure“. Compared to landslides, the slope failure moves quickly on a small-scale and the inclination angle is relatively high (over 20 degrees).

(3) Debris Flow

A debris flow is equivalent to “FLOWS” of debris and earth material in the Table 0.1.1. A debris flow is a phenomenon where soil and boulders are liquefied by surface water or groundwater and tend to flow downward rapidly through a mountain torrent. It usually has huge energy and destructive force. Debris flows tend to occur in places where there is a massive amount of unstable sediment along a steep torrent, or a large risk of slope failure due to heavy rain in the catchment basin.

(4) Rock fall

A rock fall is equivalent to “FALLS” and “TOPPLES” in Table 0.1.1. A rock fall is a phenomenon where foliated rocks and gravel due to enlarged cracks in the bedrock or outcropped rocks start to fall down a slope.

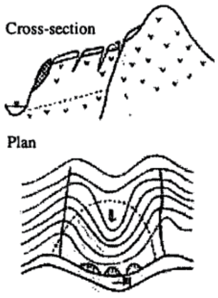
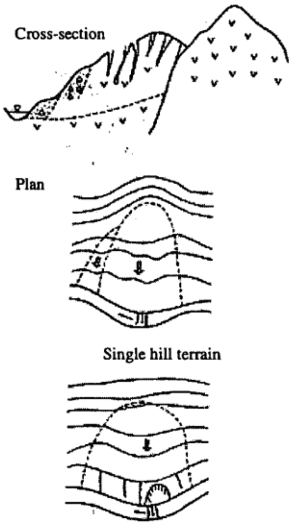
In this manual, “a slope disaster” is defined as the four (4) above mentioned types of natural disasters.

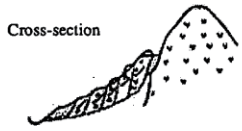
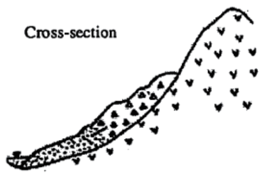
0.2 Classification and Mechanisms of Landslides

0.2.1 Classification of Landslides

Table 0.2.1 shows type classification of landslides which have slip surfaces and repeated activity. Landslides are classified into several types by the topographic and geological characteristics. This classification makes it possible to estimate the cross-section, longitudinal profiles and depths of landslides. As a result, the estimations are used as significant information to plan landslide surveys.

Table 0.2.1 Classification of the Landslide type[2]

Category	Description	Schematic Drawing	Typical Geological Features	Remarks
(1) Bedrock Landslide	1) Convex ridge terrain with a chair or boat-type sliding surface; often starts at a saddle section 2) Bedrock or lightly weathered at the head and weathered rock at the bottom 3) Sudden occurrence makes its prediction very difficult; careful reconnaissance and a detailed survey are required	 Convex ridge terrain	Often affected by a fault or fracture zone; Tertiary formations, crystalline schist and Mesozoic and Paleozoic formations	Triggered by large-scale earthworks, submersion of part of the slope, earthquake or heavy rain
(2)Weathered Rock Landslide	1) Convex plateau terrain, single hill, concave plateau terrain with a chair or boat-type sliding surface 2) Weathered rock with many cracks at the head and sediment mixed with boulders at the bottom	 Single hill terrain Concave plateau	Crystalline schist, Mesozoic/Paleozoic formations or Neogene formation affected by a fault or fracture zone	Triggered by a downpour, abnormal thawing, earthquake or medium-scale earthworks
(3) Colluvial Deposit Landslide	1) Multiple hill or concave plateau terrain with a stair or layer-type sliding surface which can be divided into 2 – 3 blocks 2) Mainly consists of sediment		Colluvial deposit from crystalline schist, Mesozoic/Paleozoic formations, Neogene formation or serpentinite	Triggered by thawing, typhoon, downpour or medium-scale earthworks

	containing gravel and becomes clay at the bottom 3) Intermittent activity repeated every 5 – 20 years; landslide hysteresis is clear from the topographical point of view and can be checked with a topographical map of 1 to 5,000 or 1 to 10,000; interviews with local people are also useful	  Multiple hill terrain		
(4) Clayey Soil Landslide	1) Gently sloping concave terrain with a multi-blocked stair or layer type sliding surface; closer relation between the blocks than (3) 2) Mainly consists of clay or clay containing gravel 3) As landslide movement is semi-continuous with a recurrence every 1 – 5 years, its presence is well-known locally.	  Gently sloping concave terrain	Neogene formation, fracture zone and solfataric soil	Easily activated by a downpour, thawing, river erosion or small-scale earthworks

0.2.2 Mechanisms of Landslides

A landslide is a phenomenon where the soil mass on one or more slip (failure) surfaces deep in the ground gradually shifts downward (Figure 0.2.1). As one of the characteristics, the inclination angle of the landslide slope is a relatively low angle (about 5-20 degrees). Mechanism and movement direction of landslides are able to be estimated by checking the following points:

- Small deformations and surface anomalies such as steps, subsidence or heaving
- Main scarp, tension crack, compression crack, radial crack, lateral crack
- Deformation of artificial building such as house or stone wall
- Anomaly of vegetation such as bending of tree root.

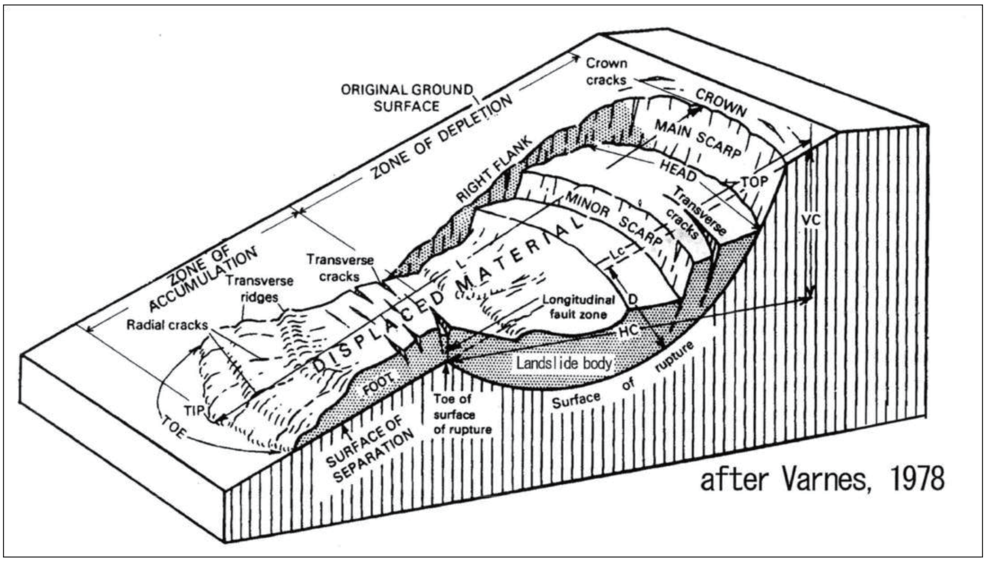


Figure 0.2.1 Structure of Typical Landslide[1]

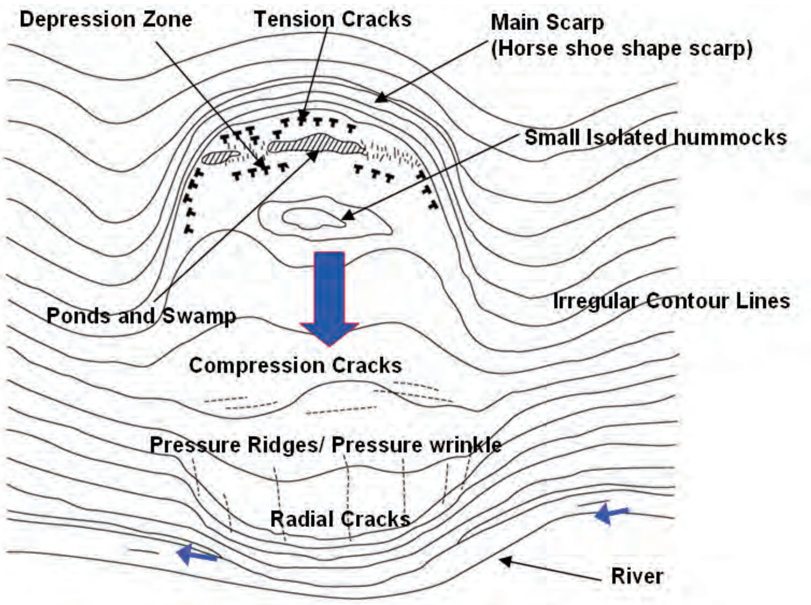


Figure 0.2.2 Schematic Diagram of Landslide Landforms[3]

0.2.3 Factor of Landslide

Basic factor (Mechanical factor): In general, landslides occur frequently in a landslide area that has its own natural characteristics as basic factors. Most basic factors are natural even when the inducing factor is artificial. The basic factors are: topographical (water collecting nature), geological (nature of creation of slip surface such as bedded structure, mud-clay layer, tuff etc., and thick loose formations on an unstable slope), geological structure (faults, anticline, syncline, etc., which will become a factor of the landslide), the condition of groundwater and so on.

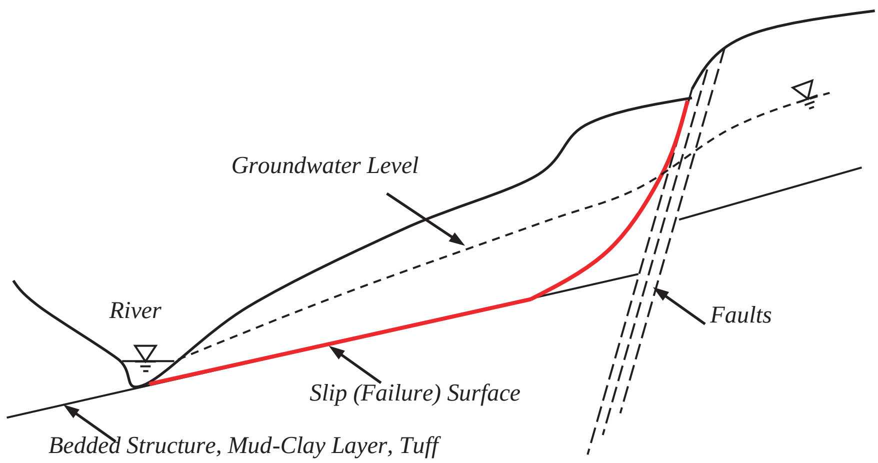


Figure 0.2.3 Schematic Cross Section of Basic Factors of Landslides (source: JET)

Inducing factors: In areas prone to the basic factors of landslides, floods during the rainy season, and other changes to the natural environment (wash out of the slope toe by rivers, formation or blockage of new waterways at surface and subsurface) are triggers of landslides (inducing factors).

Artificial cause: such as embankment at the upper landslide mass, cut slope at the toe of a landslide, slope submersion under water and blockage of surface drainage.

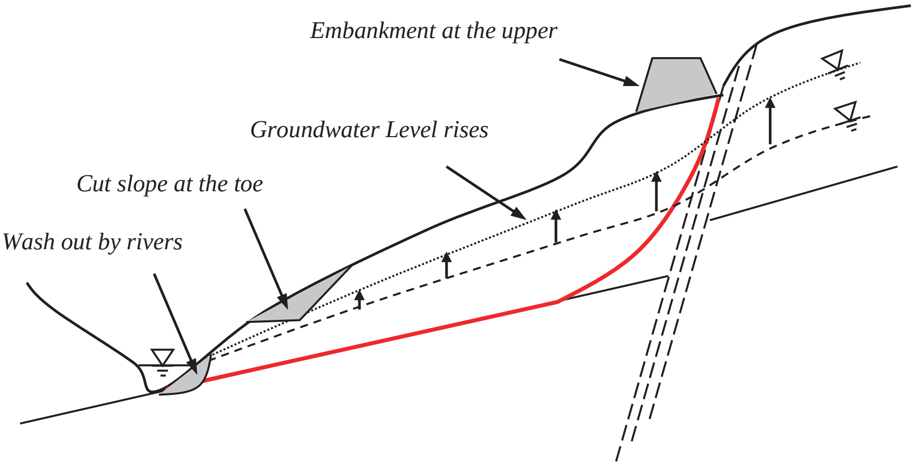


Figure 0.2.4 Schematic Cross Section of Inducing Factor and Artificial Cause (source: JET)

0.3 Outline of Landslides in Mauritius

0.3.1 Classification of Hazard Area in Mauritius

The 37 landslide hazard areas, selected based on the "Cyclone and Other Natural Disasters Scheme 2011-2012", includes several disaster forms besides landslides. Therefore the 37 hazard areas are classified into nine (9) kinds of disasters, given in Table 0.3.1, while Table 0.3.2 gives a description of nine (9) kinds of disasters.

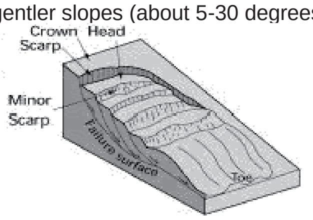
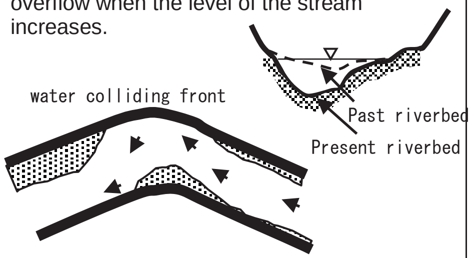
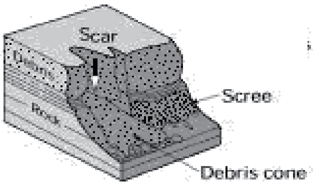
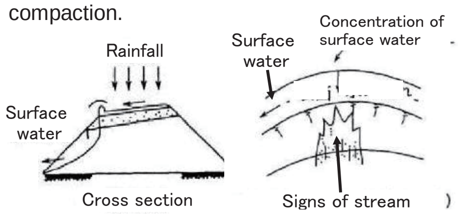
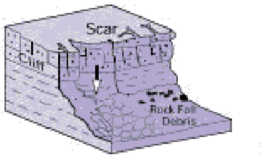
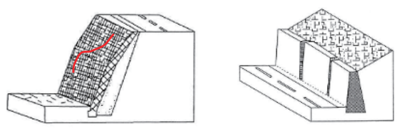
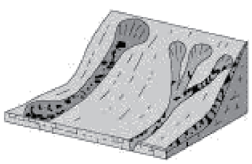
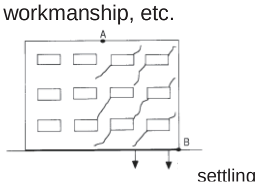
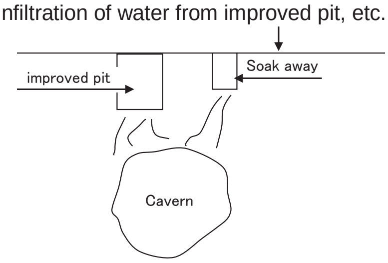
General classification : At first, the 37 hazard areas selected based on the "Cyclone and Other Natural Disasters Scheme 2011-2012" are classified into two kinds of disaster, Slope disasters and Other disasters.

Sub classification : Then, Slope disasters are classified into Landslide, Slope failure, Rock fall, and Debris flow. Other disasters are classified into Stream erosion, Damage of embankment, Damage of wall, Damage of house, and Cavern.

Table 0.3.1 Classification of Hazard Area in Mauritius (source: JET)

General classification			Sub classification		Summary
Disaster	Slope	15 areas	Landslide	6 areas	Can be classified as a Landslide Hazard Area
			Slope failure	7 areas	Because it is not a "Landslide", it cannot be classified as a Landslide Hazard Area
			Rock fall	1 areas	
			Debris flow	1 areas	
	Other	22 areas	Stream erosion	10 areas	
			Damage of Embankment	4 areas	
			Damage of wall	5 areas	
			Damage of house	1 areas	
			Cavern	2 areas	
			Total	37 areas	

Table 0.3.2 Description of the Disaster Type in Mauritius (source: JET)

Slope disaster		Other disaster	
Landslide	A landslide is a phenomenon where the soil mass on failure surfaces deep in the ground gradually shifts downward, triggered by heavy rain, an earthquake, river erosion or earthworks. Compared to slope failure, landslides are generally on a larger scale and occur on gentler slopes (about 5-30 degrees).  	Stream erosion	Stream erosion is the phenomenon where the soil of the bank is removed by the flow of the river. It occurs in riverbanks where the flow of the river hits with the most force. Water might overflow when the level of the stream increases. 
Slope failure	A slope failure is a mass becoming detached from a steep slope/cliff along surface with little or no shear displacement. Compared to landslides, the failure is rapid and on a small-scale, the inclination angle is a relatively high (over 30 degrees).  	Damage of embankment	The collapse of the road embankment is often triggered by rainfall, infiltration of underground water, erosion by surface water, or a partial catchment. It can be caused by weak embankment material or by lack of soil compaction. 
Rock fall	A rock fall is a phenomenon where foliated rocks and gravel start to fall down a slope as a result of enlarged cracks in the bedrock or outcropped rocks.  	Damage of wall	The disaster of a retaining wall doesn't occur suddenly as with a rock fall etc., rather the deformation occurs over a comparatively long time. The survey should investigate: ・ condition around the retaining wall ・ main body of the retaining wall ・ history of the retaining wall 
Debris flow	A debris flow is a phenomenon where soil and boulders are liquefied by surface water or groundwater and tend to flow downward rapidly through a mountain torrent. 	Damage of house	A crack that occurs on the wall of a house may be caused by: ・ Lack of bearing capacity ・ Subsidence of foundation ground ・ Shoddy workmanship, etc. 
		Cavern	A cavern may be caused by: ・Infiltration of water from soak away ・Infiltration of water from improved pit, etc. 

0.3.2 Location Map and Inventory

The landslide location map in Mauritius is indicated in Figure 0.3.1 and the characteristics are compiled in Table 0.3.3.

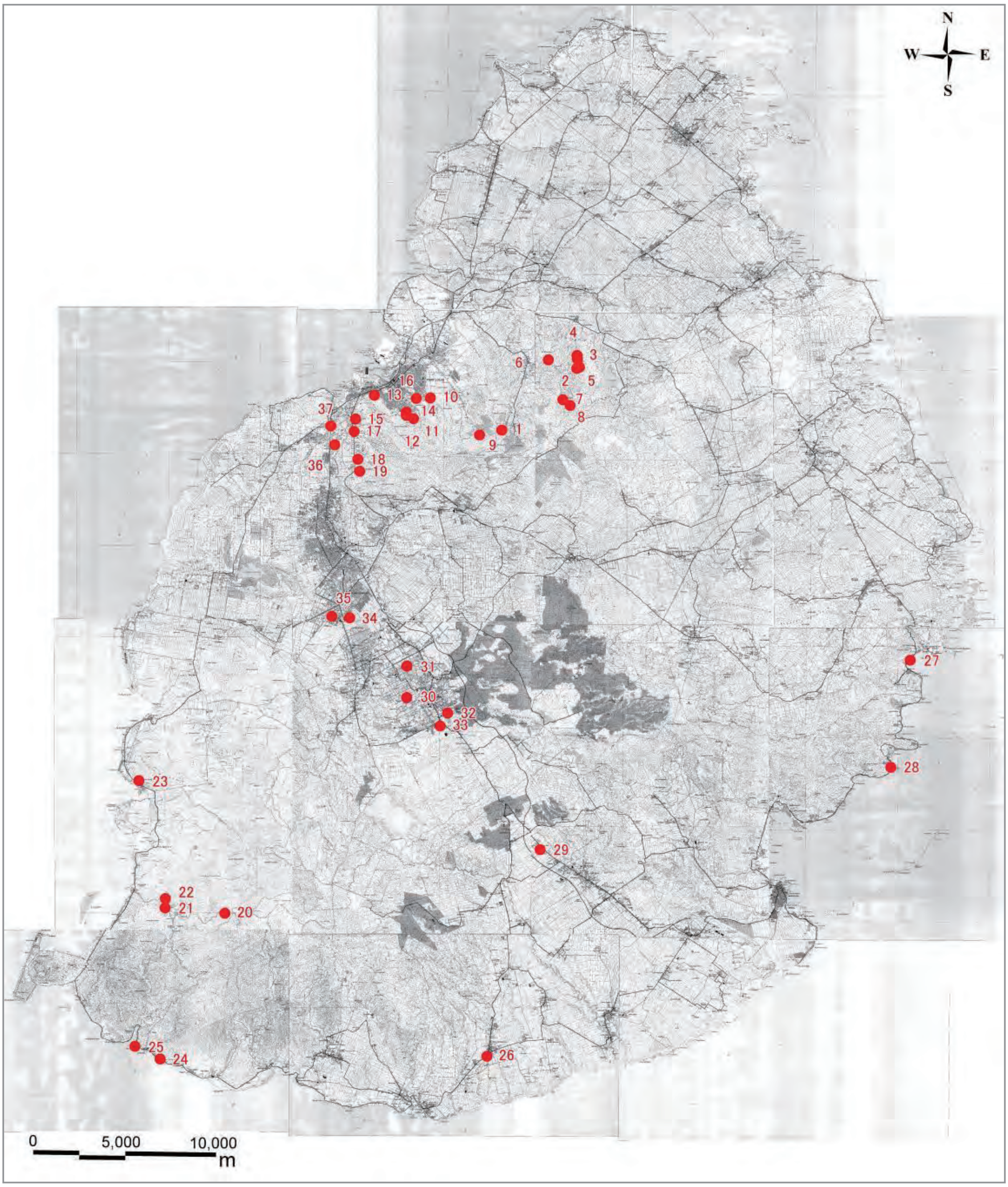


Figure 0.3.1 Landslide Location Map in Mauritius (source: JET)

Table 0.3.3 Landslide Inventory in Mauritius (source: JET)

no.	Area name	Summary of the field investigation and interview	Kind of the disaster	
			General	Sub
1	Temple Road, Creve Coeur	Deformation on the concrete block wall and house caused by embankment deformation at the front yard (parking area) was confirmed. Another problem was inadequate surface drainage causing surface water from mountains to flow directly at houses during heavy rain.	Other	Damage of wall
2	Congomah Village Council (Ramlakhan)	A small stream flows under the road through a concrete pipe culvert, however, because it is too small it causes flooding and bank erosion during heavy rain.	Other	Stream erosion
3	Congomah Village Council (Leekraj)	A 1m high retaining wall that was constructed to build the road was reported to be leaning but it was found to be stable and no slope failure was observed.	Other	Damage of wall
4	Congomah Village Council (Frederick)	The 1m high retaining wall along the road was found to have collapsed due to erosion by surface water flow during rainy season.	Other	Damage of wall
5	Congomah Village Council (Blackburn Lanes)	A slope failure was confirmed on the side of the road.	Other	Damage of Embankment
6	Les Mariannes Community Centre (Road area)	There are a few slope failures and a landslide in this site. The slope at the roadside collapsed during heavy rain in 2010 and a section of road was washed away. Since then, a retaining wall has been constructed and the site is currently stable.	Slope	Slope failure
7	Les Mariannes Community Centre (Resident area)	There appeared to be bank erosion on the left bank above the bridge.	Other	Stream erosion
8	L'Eau Bouillie	The cracks have been spotted on the road surface due to the deterioration of bearing capacity of the roadbed. However, the cracks have been repaired.	Other	Damage of Embankment
9	Chitrakoot, Vallee des Pretres	A clear landslide was confirmed. A landslide was reported to have damaged houses and a school after heavy rain in 2005. Drilling investigation and monitoring have been carried out, but not sufficiently. No countermeasures have been implemented. Therefore, a detailed investigation and monitoring are necessary while the countermeasures are expected in future.	Slope	Landslide
10	Vallée Pitot (near Eidgah)	Lately, housing developments are growing rapidly in this area. A landslide boundary of 35m x 20m was clearly detected. Several houses have been damaged and some cracks were observed. The situation of the damage was also reported in the newspaper.	Slope	Landslide
11	Le Pouce Street	Insufficient surface drainage means rain water concentrates in low area and erodes roads and houses in its path. Damage is negligible at present, although the maintenance of the surface drainage will be necessary.	Other	Stream erosion
12	Justice Street (near Kalimata Mandir)	An embankment has been constructed to build up the road, which caused an adjacent retaining wall to be pushed out and deformed. Insufficient surface drainage causing accumulation of groundwater could also be a factor causing this deformation.	Other	Damage of wall
13	Mgr. Leen Street and nearby vicinity, La Butte	The landslide of La Butte occurred in 1986, and many houses and a school were damaged. As for this landslide, countermeasures were carried out in 1998, therefore further investigation of the landslide is unnecessary. However, Port Louis City wants to continue the monitoring on this landslide in the future.	Slope	Landslide
14	Pouce Stream	Every side of the channel is covered by concrete. The water level rises until the upper edge of the channel and erodes beyond this point in the rainy season. The gabion has been set up at the lower part of slope at the channel and no damage has been reported yet. However, the deterioration of the concrete wall is remarkable and the extension of the wall height will be necessary. Therefore, further investigation and countermeasures are advisable.	Other	Stream erosion
15	Old Moka Road, Camp Chapelon	The landslide topography is not clear, but five houses and two retaining walls were damaged while the spring water was spotted in two places. There are two possible causes of this, creep transformation of weak surface soil or a shallow landslide. Therefore, landslide investigation and monitoring are necessary while the countermeasures are expected in future.	Slope	Landslide
16	Boulevard Victria, Montague Coupe	The gabion was installed on the cut-slope when the road was constructed. There is no record of damage for this site but the angle of the wall is steep. Therefore, the observation of this wall is advisable.	Other	Damage of wall
17	Pailles: (i) access road to Les Guibies and along motorway, near flyover bridge	The slope failure has been spotted along the cut-slope (5m height) at the roadside of highway. The surface of the cut-slope has been weathered, and it is eroded by rain.	Slope	Slope failure

18	Pailles: (ii) access road Morcellement des Aloes from Avenue M. Leal (on hillside)	Insufficient drainage is causing erosion at the base of the water tank. Immediate remedial work is needed.	Other	Stream erosion
19	Pailles: (iii) soreze region	Falling rocks at the upper slope and shallow slope failure at the middle and lower slope occurred in an area of housing. There is only slight damage for now, although shallow slope failure and cracks have been confirmed.	Slope	Slope failure
20	Plaine Champagne Road, opposite "Musee Touche Dubois"	Retaining walls have been constructed as countermeasures where the slope failure has been confirmed. It is currently stable, although there were a few cracks spotted in the retaining walls which are believed to be due to substandard construction.	Slope	Slope failure
21	Chamarel: (i) near Restaurant Le Chamarel	Cracks in the road shoulder have occurred due to a lack of bearing capacity. It is caused by insufficient soil compaction.	Other	Damage of Embankment
22	Chamarel: (ii) Roadside	Deformation of the road has been confirmed at the shoulder of the road due to a lack of bearing capacity. The embankment of stone masonry wall and retaining wall were constructed but it is insufficient.	Other	Damage of Embankment
23	Gremde Riviere Noire Village Hall	The crack at the base of village hall area and edge of concrete basketball court has been confirmed. However, the surrounding structures are not affected, therefore it is considered unlikely this damaged was caused by landslides. Rather it is likely to be caused by lack of bearing capacity of the ground or a problem with the structure itself.	Other	Damage of house
24	Baie du Cap: (i) Near St Francois d'Assise Church	A debris flow has occurred in the past and a block wall has since been constructed. Also, small surface failures have been observed frequently in this area.	Slope	Debris flow
25	Baie du Cap: (ii) Maconde Region	A new road was built to reduce the damage from rock falls. However, rock falls and small rock failures are also a frequent occurrence along the new road. The rocks are weathered, and there is a high possibility of rock fall in future.	Slope	Rock fall
26	Riviere des Anguilles, near the bridge	There are many houses built on the cliff here. The cliff is weathered severely and stream erosion occurs frequently. Therefore, the house will need to be relocated.	Other	Stream erosion
27	Quatre Soeurs, Marie Jeanne, Jhummah Streert, Old Grand Port	Landslide activity has been confirmed at the Quatre Soeurs area where many houses have been damaged. The groundwater level at the lower part of the landslide is high and is causing instability in the landslide. Drilling investigation and monitoring have been carried out, but not sufficiently. Further investigation and monitoring are necessary while the countermeasures are expected in future.	Slope	Landslide
28	Bambous Virieux, Rajiv Gandhi Street (near Bhavauy House), Impasse Bholoa	Slope failure was confirmed at the backyard of the house. No damage on the house was reported although the soil of the slope approached near the house. A retaining wall has been constructed independently.	Slope	Slope failure
29	Cave in at Union Park, Rose Belle	A cavity (4m x 4m x 3m depth) due to land subsidence was observed in the residential area. No damage was caused to the houses and the cavity was filled in with soil. Similar situation was confirmed nearby.	Other	cavern
30	Trou-AUX-Cerfs	The slope failure in the crater of the volcano occurred during heavy rainfall in 2005. The possibility of slope failure on the rear side is low. However, the slope failure on both sides can be expected.	Slope	Slope failure
31	River Bank at Cite L'Oiseau	Bank erosion and flooding is common in the rainy season when the river water level rises. There are more damage on the left side of the riverbank due to the strong collision of water. However, past damage has been restored by constructing a retaining wall.	Other	Stream erosion
32	Louis de Rochecouste (Riviere Seche)	The bank erosion and flood are common in the rainy season. The base of the houses has been eroded and the retaining walls of the houses are inclined.	Other	Stream erosion
33	Piper Morcellement Piat	The bank erosion and flood are remarkable in the rainy season. However, the past damage has been restored by constructing the retaining wall.	Other	Stream erosion
34	Candos Hill at LallBahadoor Shastri and Mahatma Gandhi Avenues	A clear landslide site was confirmed at the backyard of the house. The landslide topography and slope are clear while the spring water has been observed. The scale of this landslide is small (40m x 35m) and no house on the landslide area. Only slight crack has been confirmed on the retaining wall.	Slope	Landslide
35	Cavernous Area at Mgr Leen Avenue and Bassin	A cavity was reported during the house construction but it was filled with concrete. There is no further danger at this site.	Other	cavern
36	Morcellement Hermitage, Coromandel	At this slope, slope failure occurred in 2010, and a road was destroyed. After a retaining wall was made as a countermeasure, large-scale slope failures have not been found. However, the stone blocks from on top of the retaining wall have fallen down. This is likely caused by the ground behind the retaining wall sinking due to lack of compaction of the backfilling soil.	Slope	Slope failure
37	Montee S, GRNW	Weathered outcrops were detected on both sides of the bank. The erosion is remarkable in the rainy season.	Other	Stream erosion

Reference

[1] Varnes, D. J., (1978, Slope movement 43. types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides—Analysis and control: Transportation Research Board Special Report 176, National Research Council, Washington, D.C., pp. 11-23.

[2] Public Works Research Institute, 2004, Manual for Highway Earthworks in Japan Technical Memorandum of Public Works Research Institute, No.3924-2

[3] Fujiwara, A., 1979, Analysis and Prevention Plan of Landslides, Rikoh Pub. Co., Tokyo. (in Japanese)

1 Introduction

"Technical Guideline for Initial Survey (hereinafter the Guideline)" has been prepared as a procedure guideline for landslide survey/countermeasures on emergency landslide disasters. The Guideline is specialized for landslide disasters in Mauritius.

The Guideline covers what actions should be taken in the event of a landslide disaster, and includes the procedures the Ministry of Public Infrastructure and Land Transport (MPI) should implement in such an event. The procedures are composed of a literature survey, an initial site survey, emergency response, a detailed survey plan etc. The detailed survey/analysis/monitoring and the design/construction after the discussion of the survey plan are described in "Procedure Manual for Landslide".

The scope of application of the Guideline is indicated in the following figure and the contents of it are in the table on the following page.

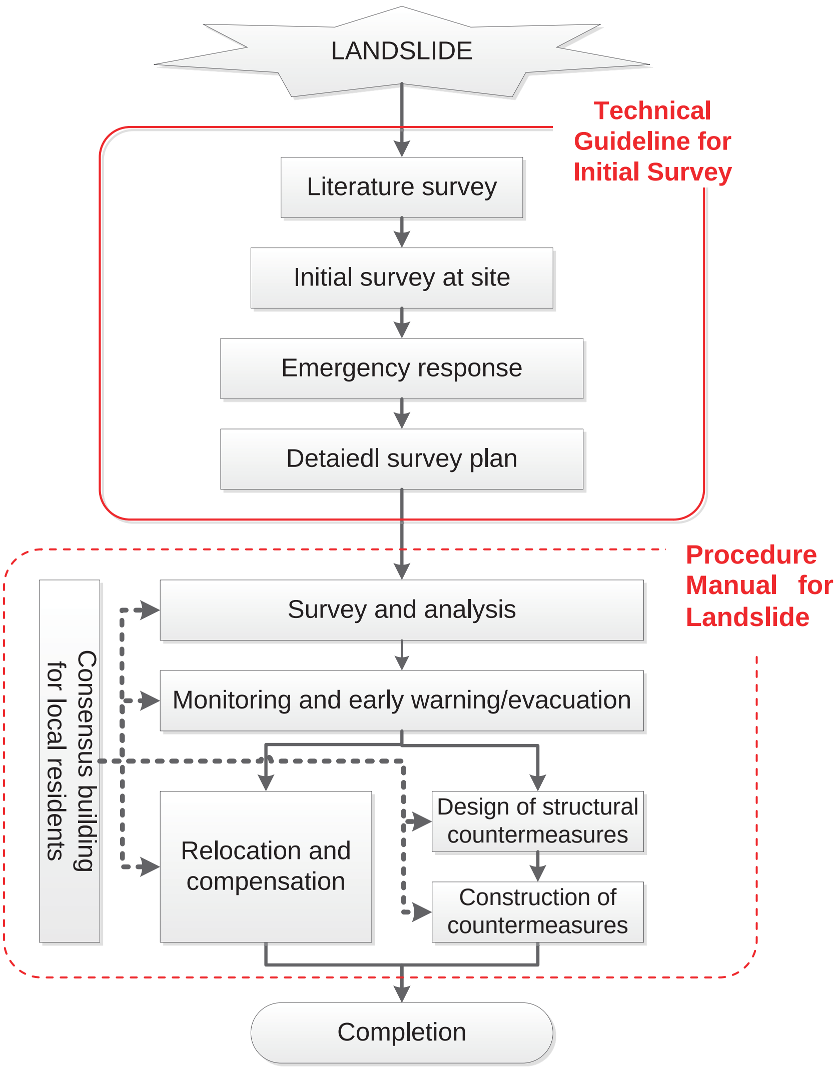


Figure 1.1.1 The scope of Application of the Technical Guideline for Initial Survey

(source: JET)

Table1.1.1 The contents of the Technical Guideline for Initial Survey (source: JET)

Cp.	Title	Contents
1	Introduction	- Contents, objectives, flow of the guideline - Outline of landslides in Mauritius - Workflow of initial survey
2	Literature survey	- Data to be collected and data utilization - Regulation of laws and land-use
3	Initial survey at site	- Setting of target areas - Site survey and analysis - Monitoring for initial survey
4	Emergency response	- Structure measures - Evacuation and relocation - Early warning system
5	Detailed survey plan	- Outline of detailed survey - Outline of countermeasure policy

The Landslide Management Unit (LMU) of MPI should renew appropriately the contents of the Guideline to make it more usable and rational based on the case examples and issues in Mauritius.

2 Literature Survey

In case of an emergency landslide disaster, literature survey is necessary to understand the rough outline and general information of the landslide before visiting the landslide site. The literature survey is mainly composed of 1) data collection and 2) confirmation of related laws and regulations on landslides. In this chapter, the methods and the significance of the literature survey are elaborated.

2.1 Data Collection and its Utilization

2.1.1 Data Collection

The objectives of data collection are to grasp the features and characteristics of the targeted landslide before visiting the landslide site. The data to be collected are geomorphology, geology, vegetation, meteorology, hydrology, landslide history and disaster records in the area. The necessary information on the landslide should be extracted from the collected data. The following table indicates the data to be collected as a preliminary survey of the landslide.

Table 2.1.1 List of the Data to be Collected (source: JET)

Data classification	Items
Geomorphology and geology	➢ **Topographic map (Scale= 1/1,000-1/5,000)** ➢ **Aerial photo (Scale= 1/8,000-1/40,000)** ➢ Geological map (Scale= 1/50,000-1/200,000) ➢ Land use map ➢ Landform classification map
Landslide history and disaster records	➢ Report on geotechnical investigation/analysis ➢ Report on construction (road, house, bridge etc.) ➢ Report on disaster record and landslide history ➢ Thesis, paper, note on landslide ➢ Newspaper
Meteorology and hydrology	➢ Rainfall data (hourly, daily, monthly) ➢ Data on water level and river flow ➢ Data on ground water level

Interviews of local residents and local municipalities are able to provide useful and practical information on the landslide disaster as well as the data collection. The following items should be confirmed in the interview survey:

- Location/degree/volume of abnormalities on landslide
- Volume/direction/speed of mass movement
- Condition of surface water flow/groundwater/spring water
- Condition of rainfall
- Location/degree/volume of damage (houses, buildings, roads, other infrastructure etc.)
- Disaster records in the past
- Social condition, geographic condition and law/regulations of the area

2.1.2 Aerial Photograph (geomorphological) Interpretation

Landslide prone areas are areas likely to have active landslides and are associated with certain types of micro landforms in Figure 2.1.1; therefore topographical and geomorphological interpretation is important for landslide identification. Geomorphologic interpretation is implemented with aerial photographs and topographic maps to identify landslide forms and potential landslide areas.

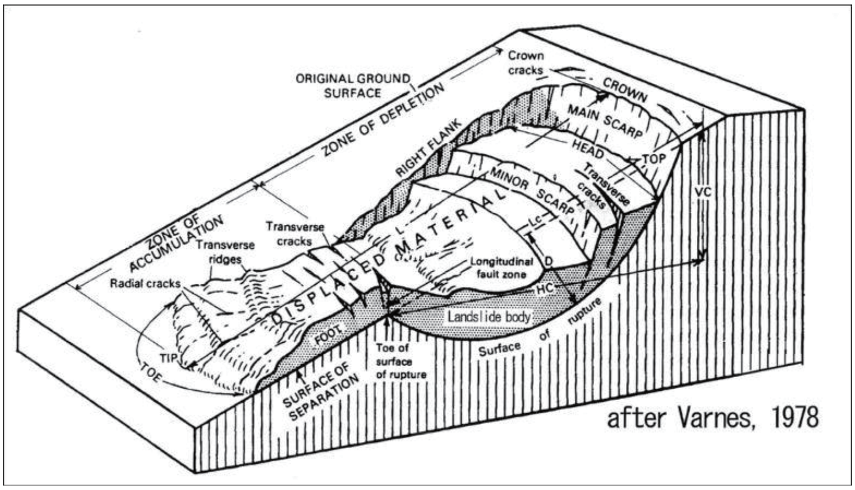


Figure 2.1.1 Micro Landforms in a Landslide[1]

Micro landforms, historical landslide formations, land use and vegetation are identified with aerial photograph interpretation. The micro landforms caused by landslide movement are interpreted using a large scale aerial photograph such as 1:10,000 or larger. Aerial photograph interpretation is a useful method of finding several causes of landslides over a wide area. In case that it is impossible to obtain the stereo images of an aerial photograph, a topographic map can be substituted for the aerial photograph.

Stereoscopic images are obtained from stereo type photographs using a stereoscope. The micro landforms and the geomorphologic features caused by landslide movement are identified with the stereo image.

Figure 2.1.2 Aerial Photo Interpretation using a Stereo Scope (source: JET)

Characteristics of the conditions which may cause landslides are shown below:

A topographic map also provides information of the slope conditions which may be related to landslide movement. Larger scale of topographic map, 1/10,000 or larger, is preferable for the interpretation with topographic maps. Characteristics of the conditions which may cause landslides are shown below:

- Irregular and winding contour lines
- Scarps, steps, cracks, depressions, ponds and swamps on gentle slopes
- No major or visible stream lines

The topographic characteristics of landslides that aid in interpretation are summarised in Figure 2.1.3 and 2.1.4.

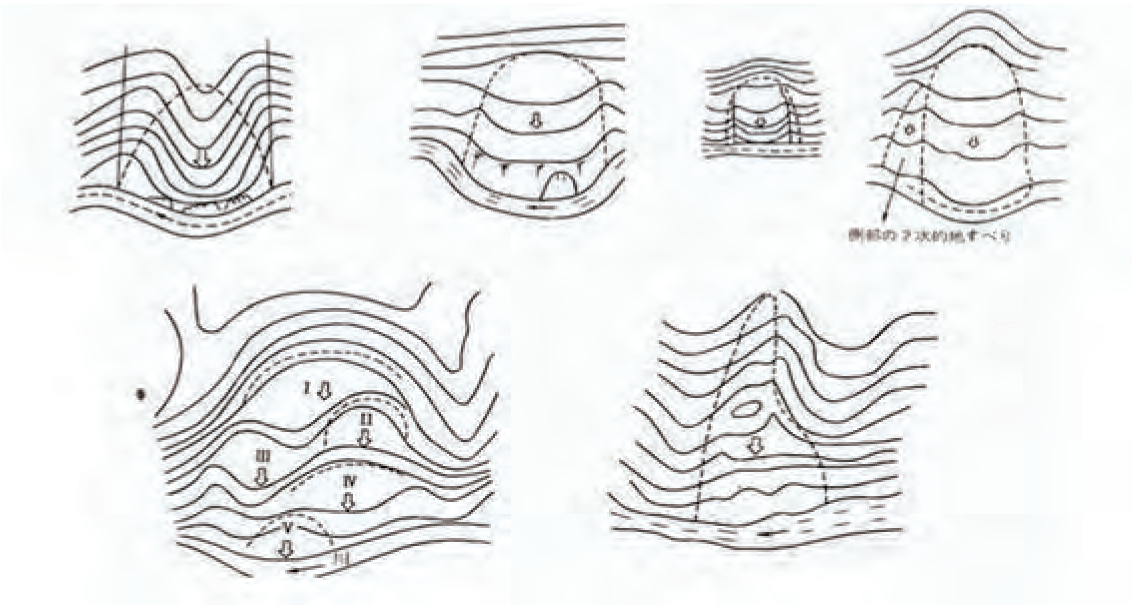


Figure 2.1.3 Characteristics related to Landslides[2]

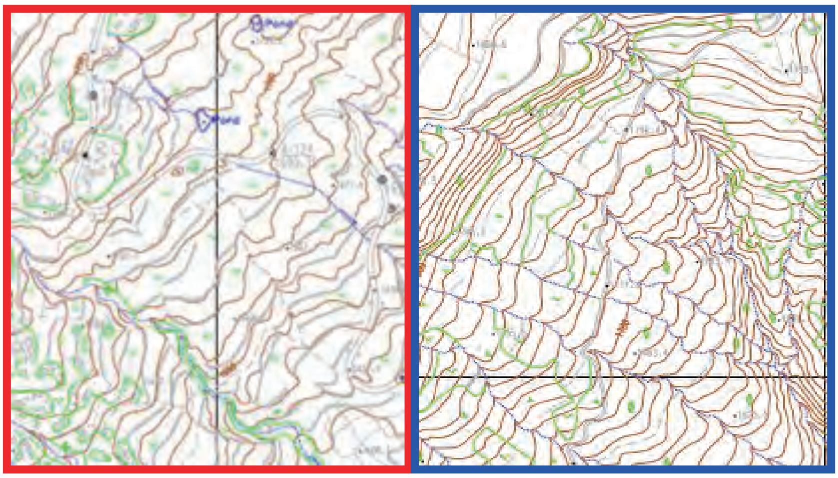


Figure 2.1.4 Comparison of Contour Lines in a Landslide Area (left) and Area with no Landslides (right) (source: JET)

The result of the interpretation is compiled as a landslide distribution map. An example of a legend used in the interpretation of landslides is shown in the following figure.

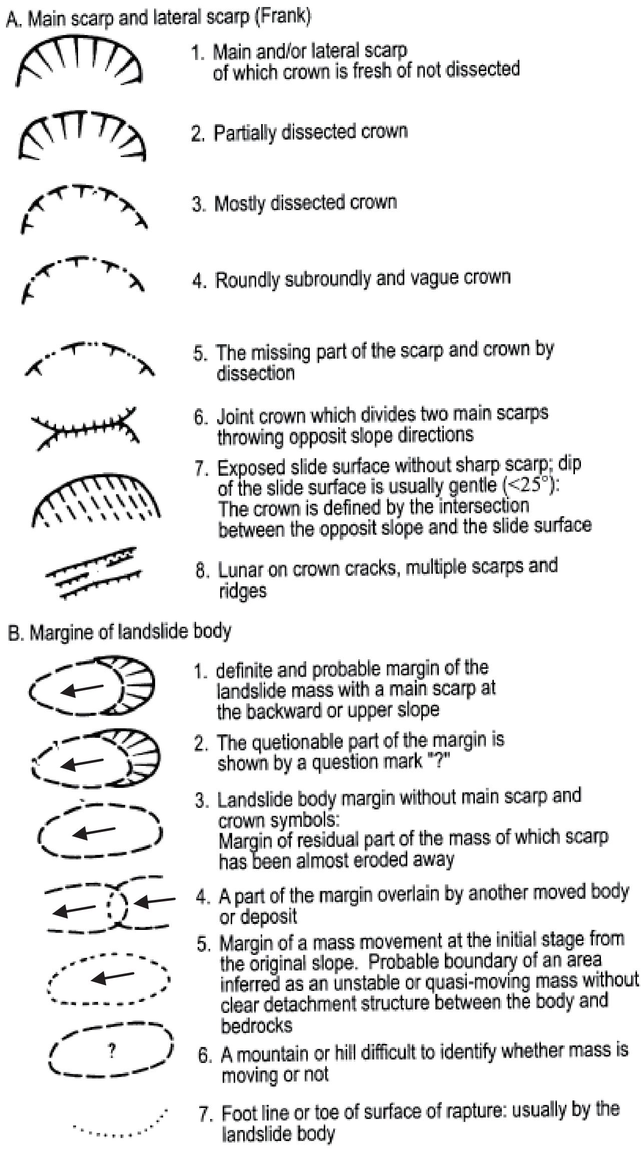


Figure 2.1.5 An Example of a Legend for Interpreting Landslides (source: JET)

Table 2.1.2 shows the classification of landslides. Landslides are classified into several types by topographic and geological characteristics. The table classifies the type of landslide based on topographic and geological features, most of which are able to be identified with aerial photograph (geomorphological) interpretation.

Table 2.1.2 General Classification of Landslides[2]

Type / Feature	Rock block slide	Weathered rock slide	Colluvium slide	Strongly-weathered rock slide
Planar shape	Horseshoe-shaped, Square-shaped	Horseshoe-shaped, Square-shaped	Horseshoe-shaped, Square-shaped, Bottleneck-shaped Valley-shaped	Bottleneck-shaped, Valley-shaped
Micro topography	Convex and ridge -shape	Convex and mono terrace -shape	Convex and multi-terrace shape	Concave and gentle slope-shape
Shape of slip surface	Chair like, Ship like shape	Chair like, Ship like shape	Stepwise, Laminar	Stepwise, Laminar
Ex-name	New born stage	Immature stage	Mature stage	Elder stage
Material (Head part)	Bedrock or Gentle-weathered rocks	Weathered rock (Many clacks)	Earth and sand including rocks	Boulder or Earth and sand including rocks
Material (Toe part)	Weathered rocks	Earth and sand including boulder	Earth and sand including rocks, clay	Clay, Clay including rocks
Movement velocity	Over 2cm/day	Around 1.0~2.0cm/day	0.5~1.0cm/day	Under 0.5cm/day
Movement continuity	Short and sudden event	Intermittent (Once from decades to centuries)	Intermittent (Once 5-20 years)	Intermittent (Once 1-5 years)
Figure of slip surface	Flat (Chair like shape)	Flat (Head and toe parts: a bit circular slips)	Circular slip and linear shape, Fluidized toe	Head part: Circular slip Most part: flow condition
Number of blocks	Normally, 1 block	Generating secondary-derived landslides on side and toe of landslide	Upper slope of landslide can be divided into 2-3 blocks.	Whole slope of landslide can be divided into many blocks. Their movement links each other.
Difficulty level of prediction	Quite difficult Needed detailed exploration and analysing	Possible Using topographic maps (1/3,000~1/5,000) or aerial photographs	Possible Using topographic maps (1/5,000~1/10,000) or door-to-door investigation	Easy Site investigation
General slope shape	Unclear terrace, Convex slopes, Generating from saddleback	Clear scarp, A band of depression and terrace. Concave in macro point of view but generally convex	Main scarp, Pond, Swamp, Depression, Concave slopes.	Unclear terrace on upper slope, Uniform gentle slope, Valley shape
Main causes	Massive construction, Sunken slope, Earthquake, heavy rainfall	Torrential rainfall, Exceeding snow melting and washout, Earthquake, Mid-scale constructions	Snow melting, Typhoon, Torrential rainfall, construction	Heavy rainfall, Snow melting, Snow cover, River-erosion, Small-scale construction
Main geology and the structure	Effects of fault and fracture zone	A wide distribution of crystalline schist area, Neogene stratigraphy, Effects of fault and fracture zone	A wide distribution of crystalline schist area, Neogene stratigraphy	Distribution of Neogene, fracture zone

2.2 Confirmation of the Legal Systems/schemes and Development Restriction/Land-use Control

2.2.1 Confirmation of the Cyclone and Other Natural Disasters Scheme

The schemes of emergency response for cyclones, torrential rain, tsunamis, high waves and landslides are indicated in National Disaster Scheme (NDS) 2015 in Mauritius.

The chapter on landslides in the scheme contains monitoring, actions by Local Authorities, response by related ministries/agencies and warning/evacuation system.

The warning/evacuation system has three stages based on monitoring data of rainfall and displacement.

There is a list of landslide-prone areas in the NDS which is shown below.

Table 2.2.1 List of Landslide-prone Areas in Mauritius[3]

No	District Council/ Municipality	Area Name
1	City Council of Port Louis	Chitrakoot, Vallée des Prêtres
2		Vallée Pitot (near Eidgah)
3		Mgr. Leen Street and nearby vicinity, La Butte
4		Old Moka Road, Camp Chapelon
5	Grand Port District Council	Quatre Soeurs, Marie Jeanne, Khummah Street, Old Grand Port
6	Municipality of Quatre Bornes	Candos Hill at Lall Bahadoor Shastri and Mahatma Gandhi Avenues

When a landslide occurs or a landslide disaster is a concern at a site, it should be checked whether the site is on the list. If the site is on the list, the relevant information such as disaster records, detailed topographic map, drawings of construction works for development in/surrounding the site, reports and others might be available from related ministries/agencies/local authorities. The information will be useful for the investigation of the landslide block, estimation of damage area, examination of the critical value of displacement, consideration of emergency countermeasures, etc. Therefore, the landslide-prone regions in the Disaster Scheme should be checked.

2.2.2 Confirmation of the proposed Landslide-Prone Areas and Landslide Hazard Zones

In the Project of Landslide Management in the Republic of Mauritius by JICA (hereinafter the Project), Landslide-Prone Areas and Landslide Hazard Zones are proposed to identify specific landslide affected areas for concrete and effective structural/non-structural countermeasures, even as the technical transfer for the identification and making a map which includes the information of the Landslide-Prone Areas and Landslide Hazard Zones has been conducted in the Landslide Management Unit (hereinafter LMU) of MPI.

< Landslide-Prone Area>

- There is a possibility of occurrence of landslide disaster by development, climate change and others.
- Landslide-Prone Area is less active compared with a Landslide Hazard Zone.

< Landslide Hazard Zone >

- An area which poses a danger to the lives/bodies of the residents and building damage when a landslide disaster occurs in a Landslide-Prone Area.

- Area within a distance equivalent to the length of the landslide mass from the bottom end of the landslide area (250 m if the length of the landslide mass is longer than 250 m)

- Landslide area (area which is currently prone to landslides or possibly vulnerable to landslides in future)

The following figure shows an example of sample image of a Landslide-Prone Area and Landslide Hazard Zone.

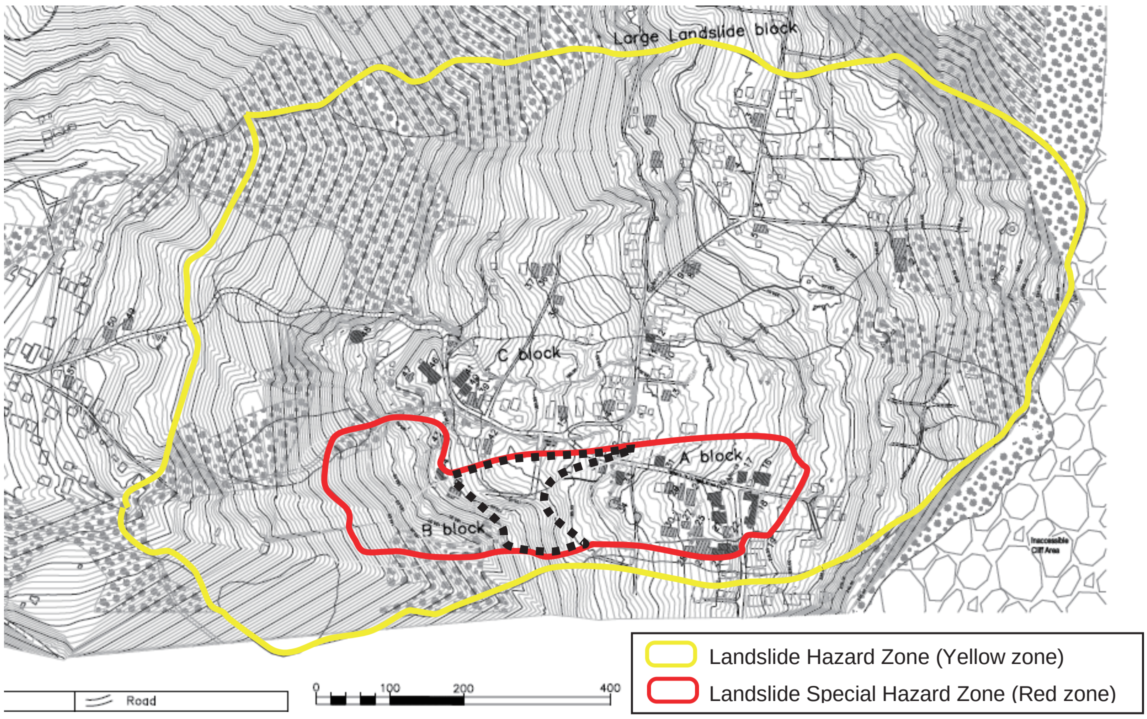


Figure 2.2.1 Example of a Landslide-Prone Area and Landslide Hazard Zone[4]

When a landslide occurs or there is concern of a landslide disaster occurring at a site, it should be checked whether the site is in a Landslide-Prone Area or a Landslide Hazard Zone to confirm the existing landslide block, affected area and others.

2.2.3 Confirmation of Development Restrictions/Land-use Controls

(1) Settlement Boundary

Following figure shows an example of the settlement boundary and a landslide prone area. According to the Outline Planning Scheme (hereinafter OPS), which covers areas that are prone to landslides, such areas are designated as developable land upon gaining approval for development from the Local Authority (see figure below, orange coloured boundary shows the developable area and black frame shows the landslide prone area).

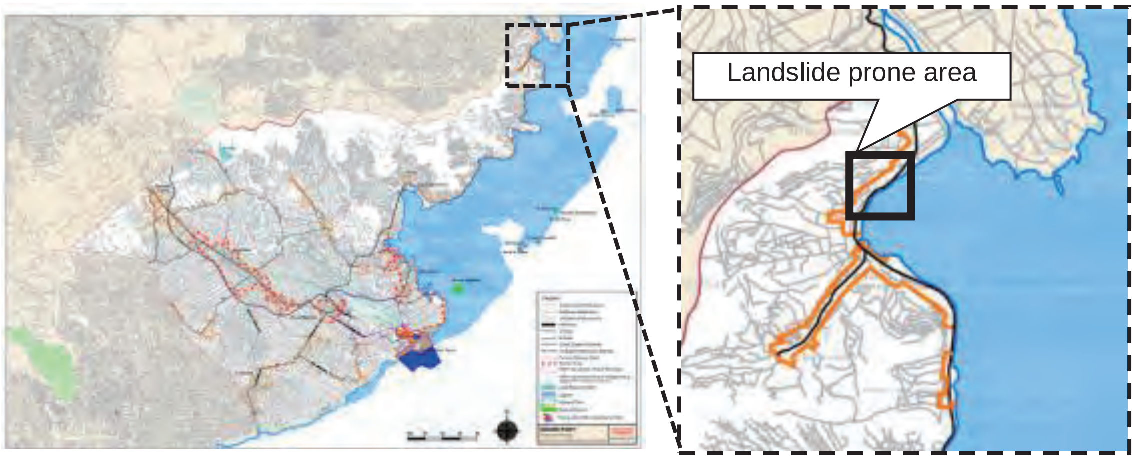


Figure 2.2.2 Example of a settlement boundary[5]

If the landslide site is within a settlement boundary, a review of the boundary will be required to avoid the landslide disaster risk by development in the future.

(2) Protection of National Parks

National Parks should be protected from development except as allowed under the National Parks and Wildlife Act and are shown on the Development Strategy Map and Development Management Map in OPS, conservation management plans prepared or being prepared by the Ministry responsible for Agro-Industry, Food Production and Security and Fisheries' National Parks and Conservation Service, or for educational purposes, visitor facilities or in the national interest. Development in National Parks which would destroy or adversely affect the area's natural environment should not normally be permitted.

If the landslide site is in a National Park, a landslide countermeasure plan should be prepared and assessed in conjunction with the Ministry responsible for Agro-Industry and Fisheries, Ministry responsible for Environment and Ministry responsible for Housing and Lands.

(3) Protection of Nature Reserves

All Nature Reserves designated under the Forests and Reserves Act and shown on the Development Management Maps in OPS should be protected from development except as allowed under the said Act, or for educational purposes, visitor facilities or in the national interest or are being prepared by the Ministry responsible for Agro-Industry and Fisheries' National Park Conservation Service. Development in protected Nature Reserves which would destroy or adversely affect the area's natural environment should not normally be permitted unless supported by an approved environmental management plan and an Environmental Impact Assessment in accordance with the EPA (Amendment of Schedule) Regulations.

If the landslide site is in a Nature Reserve, a landslide countermeasure plan should be prepared and assessed in conjunction with the Ministry responsible for Agro-Industry and Fisheries, Ministry responsible for Environment and Ministry responsible for Housing and Lands.

(4) Protection of River Valley

All River Reserves should normally be protected from development by the Forests and

Reserves Act. Exceptions may be made for works deemed essential for water abstraction, flow regulation, flood control and for road crossings. Clearing and replanting of river reserves shall only be carried out with authorization from the Conservator of Forests.

If the landslide site is near a river, a landslide countermeasure plan should be prepared and assessed in conjunction with the Ministry responsible for Agro-Industry and Fisheries, Ministry responsible for Environment and Ministry responsible for Housing and Lands.

(5) Conservation of Environmentally Sensitive Areas

Further to more detailed identification, mapping and classification of Environmentally Sensitive Areas (hereinafter ESAs) by the Ministry responsible for Environment and in addition to any requirements under the Environment Protection Act, the natural functions, biodiversity, habitat and amenity of ESAs should be protected from adverse effects of development.

Where the ESAs are indicated on the Development Management Maps in OPS there should be a general presumption against development other than for educational or environmental management purposes or in order to sustain local economies or where development is deemed to be in the national interest and is acceptable on planning and environmental grounds. In case of discrepancy between the ESAs shown on the Development Management Maps and the ESA map at the Ministry of Environment, the project proponent should consult the Ministry of Environment.

If the landslide site is within an ESA, a landslide countermeasure plan will be required to first obtain an Environmental Impact Assessment license under the Environment Protection Act as subsequently amended, prior to seeking a building and land use permit.

(6) Conservation of Water Resources

The existing and proposed dams/reservoirs and their catchment areas and the rivers that supply water into them should be safeguarded against pollution, erosion and deforestation. Development within thirty metres of the high water level of the dams and adjacent to rivers, rivulets and streams, open canals or within the catchment areas should not normally be permitted, unless the developer has obtained written agreement from the Water Resources Unit/Ministry of Public Utilities and the Sanitary Authority that the proposals do not pose a threat to the quality or quantity of surface or groundwater resources. A passage one meter wide shall be left along one or other side of every canal along its whole length and kept free from obstruction. No development should be permitted within a two hundred metres radius of a borehole or spring without consultation and prior written approval of the Water Resources Unit/Ministry of Public Utilities.

If the landslide site is near a water resource, a landslide countermeasure plan should be prepared and assessed in conjunction with Water Resources Unit/Ministry of Public Utilities and the Sanitary Authority.

Reference

[1] Varnes, D. J., 1978, Slope movement 43. types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides—Analysis and control: Transportation Research Board Special Report 176, National Research Council, Washington, D.C., pp. 11-23.

[2] JASDM & JCTC, 1995, Japan Association for Slope Disaster Management and Japan Construction Training Centre. Textbook of landslide prevention technical training.

[3] Ministry of Environment, Sustainable Development, and Disaster and Beach management, 2015, National Disaster Scheme (NDS) 2015 edition

[4] JICA Study Team, 2013

[5] Ministry of Housing and Lands on behalf of the Town and Country Planning Board, 2006, Outline Planning Scheme for Grand Port Savanne District Council Area (as subsequently modified in November 2011)

3 Initial Survey at Site

The purpose of the initial site survey is to recognize the **area**, **cause** and **activity** of a target landslide as soon as possible. The results of the initial site survey are used for the emergency response, which is a structural measure, evacuation and early warning (Chapter4).

3.1 Setting of Target Landslide Areas

Because a landslide may occur in a large number of areas in the case of cyclones and the heavy rains of the rain season, it may be necessary to select the target landslide area from a large number of landslide areas to take precedence for the initial site survey. When there is a report that multiple landslides have occurred, the target landslide area for the initial site survey shall be chosen promptly based on the information from the local government and other organizations concerned. However, if it is not possible to determine the target landslide area from the information provided, site confirmation by the engineer is necessary.

The flowchart for determining the target landslide area is shown below.

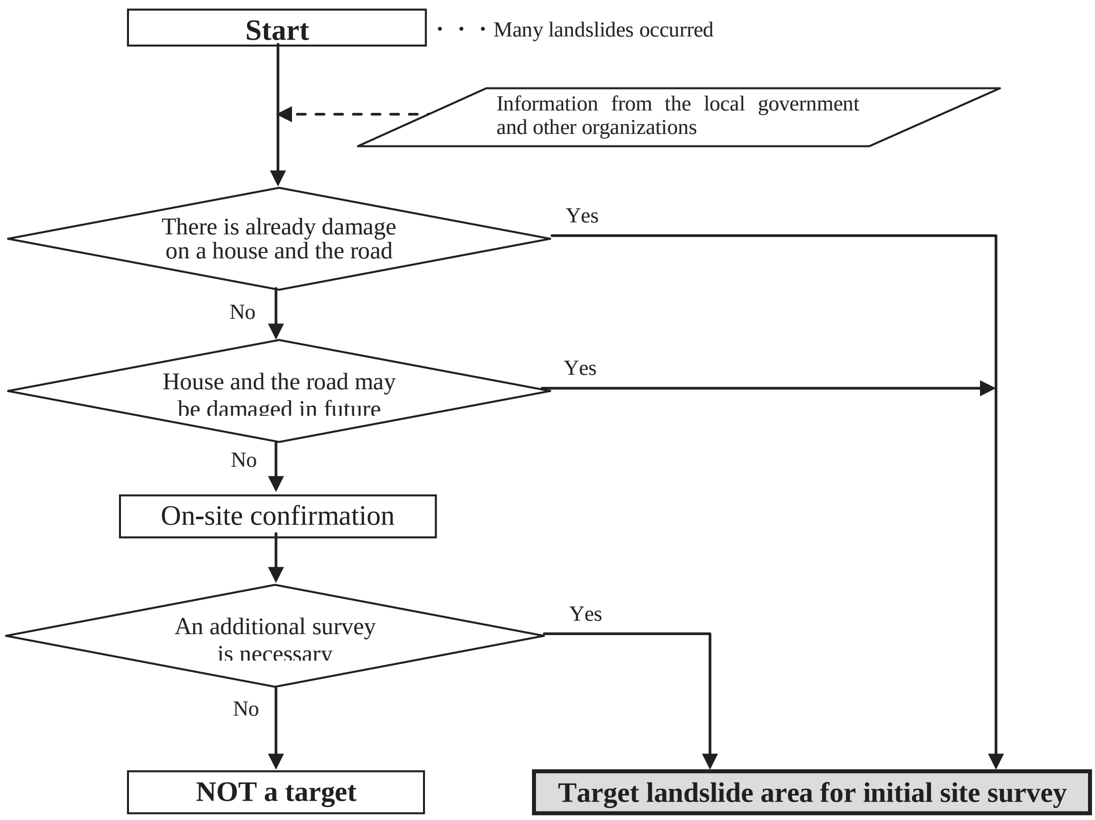


Figure 3.1.1 Flowchart for Determining the Target Landslide Area (source: JET)

3.2 Site Survey and Analysis

During the initial site survey, the following items are investigated. These items are listed in the order they are usually carried out. However, in an emergency situation, they should be carried out in parallel.

1) Confirmation of the landslide area and the movement direction
2) Emergency monitoring for landslide
3) Estimation of the cause of the landslide occurrence
4) Prediction of landslide activity
5) Estimation of the influence area

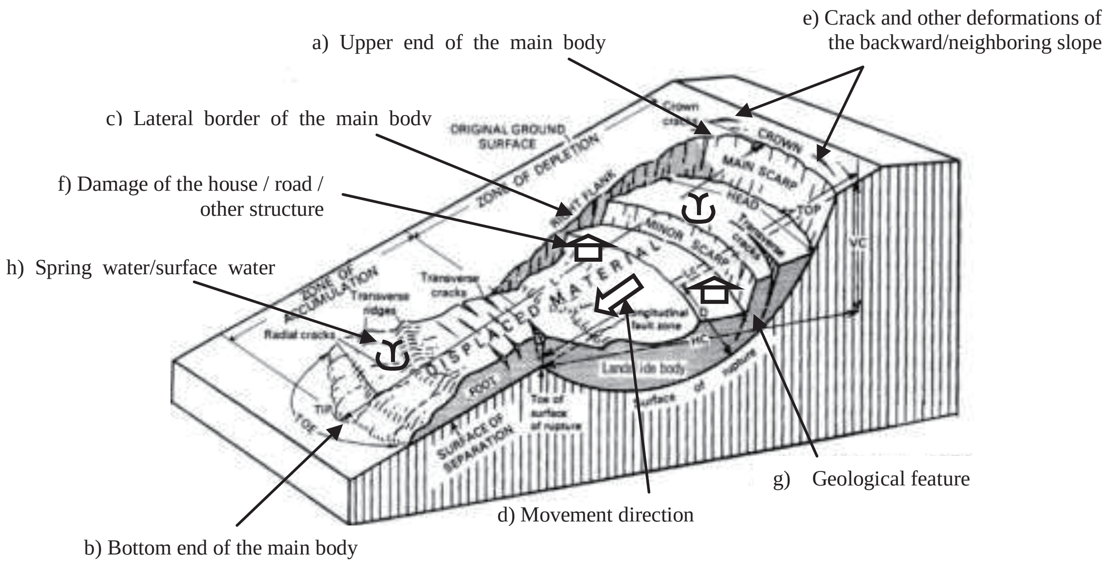
3.2.1 Confirmation of the Landslide Area and the Movement Direction

When a landslide occurs, the first item performed is to confirm the landslide area and movement direction.

When confirming the landslide area, it is important that the neighbouring landforms and deformations are investigated as well as the main landslide body. Therefore, the backward and neighbouring slopes of the landslide body should be investigated carefully. The viewpoints of the investigation are as follows:

Table 3.2.1 Viewpoints of the Investigation (source: JET)

a) Upper end of the main body	b) Bottom end of the main body
c) Lateral border of the main body	d) Movement direction
e) Crack and other deformations of the backward/neighbouring slope	
f) Damage to a house / road / other structure	
g) Geological features	h) Spring water/surface water



* It is corrected Varnses, D. J. (1978)

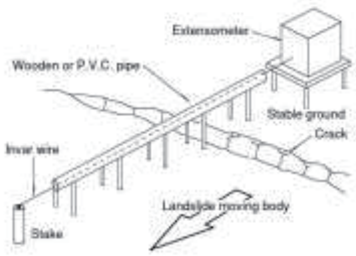
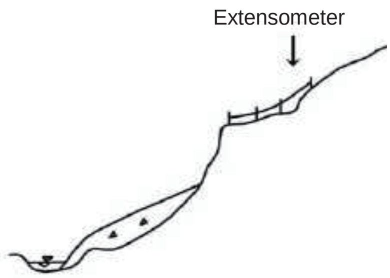
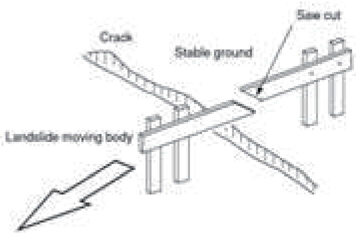
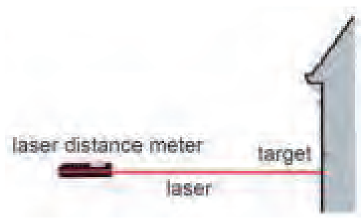
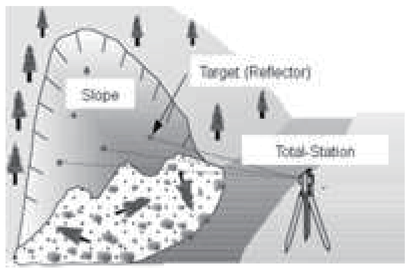
Figure 3.2.1 Viewpoints of the Investigation (source: JET)

3.2.2 Emergency Monitoring for Landslide

In an emergency situation, it is not possible to carry out monitoring by drilling from the viewpoint of the time and security of the work. Therefore, for emergency monitoring, measurement of the ground surface displacement of the landslide is effective. The method for monitoring the landslide earth surface displacement is shown below.

A scalp (cliff) of the landslide head and the cracks are monitored by an extensometer and/or simplified extensometer. Cracks on buildings and roads are monitored by vernier calipers and/or a laser distance meter. The results of the monitoring are used to estimate the landslide cause and the activity, as well as for early warning and evacuation.

Table 3.2.2 Emergency Monitoring Types and Equipment (source: JET)

type	Equipment	
Extensometer	Measuring the amount of movement, recording data continuously 	* It is effective for monitoring the upper part of the landslide where the deformations are not seen from the ground surface. 
Simplified extensometer	Simple deformation detection board, easy, and many can be set up. 	Laser Extensometer 
Others	Crack monitoring with Vernier Caliper on concrete wall. 	Using a Total-Station, the displacement of the landslide is measured from a distance. 

3.2.3 Estimate of the Cause of the Landslide Occurrence

It is very important that the cause of the landslide occurrence is estimated in predicting future landslide activity. The cause of the landslide occurrence is divided into a basic factor and an exciting cause (trigger).

- Basic factor: Topography / Geological feature
- Exciting cause (Trigger): Rain / Groundwater / Artificial topography modification

The examples in the study of the cause of the landslide are shown below. Because a method to remove an exciting cause (trigger) is effective for an emergency countermeasure, the estimate of the exciting cause is extremely important.

Table 3.2.3 Examples in the Study of the Cause of the Landslide (source: JET)

Courses	Items	Examples
Basic factor	Topography	Characteristic landslide shape, Scarp, Cliff, Slope angle, Steps, Uplift, Subsidence, Bulging at lower part
	Geological feature	Soil, Rock, Colluvium, etc.
Exciting cause (Trigger)	Rain	Rain data (Meteorological Agency / field observation)
	Groundwater	Spring water, Pond, the quantity of water Surface water, Drainage (damage)
	Artificial topography modification	Cut slope (Excavation at toe part of a landslide) Embankment, (Filling at top/middle of a landslide)

3.2.4 Prediction of the Landslide Activity

a. Prediction Form the Landform and Deformation

1) The case that landslide mass completely slides down has low activity in future, and the stability is relatively high.

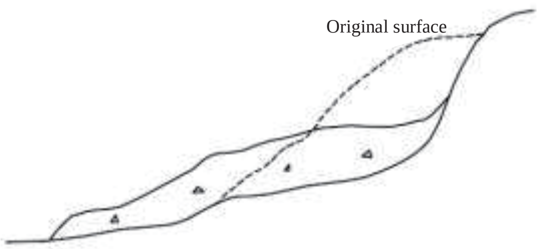


Figure 3.2.2 Case 1: Landslide Mass Completely Slides Down[1]

2) As for the case that a distal end of landslide mass rises, the landslide activity often becomes dormant, because it is estimated that the sliding surface is a horizontal or reverse incline.

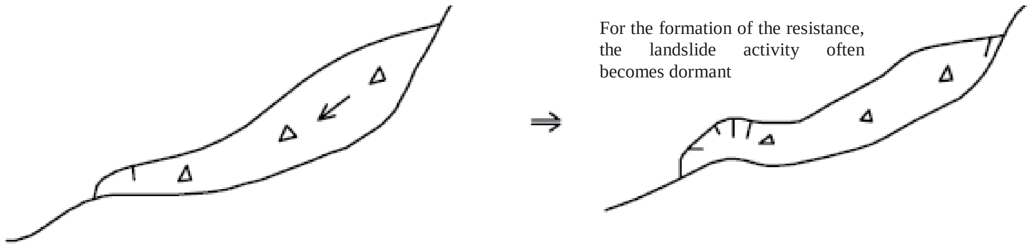


Figure 3.2.3 Case 2: Distal End of Landslide Mass Rises[1]

3) The case that the inclination of the downward slope is gentle, the landslide activity often becomes dormant for a reason same as case 2.

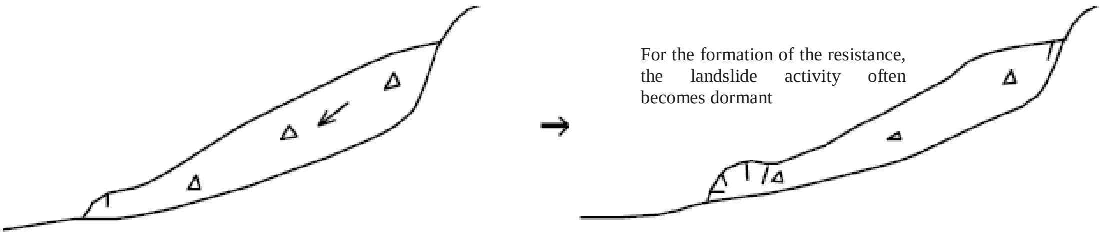


Figure 3.2.4 Case 3: Inclination of the Downward Slope is gentle[1]

4) The case that the inclination of the downward slope is steep, the landslide does not stop easily.

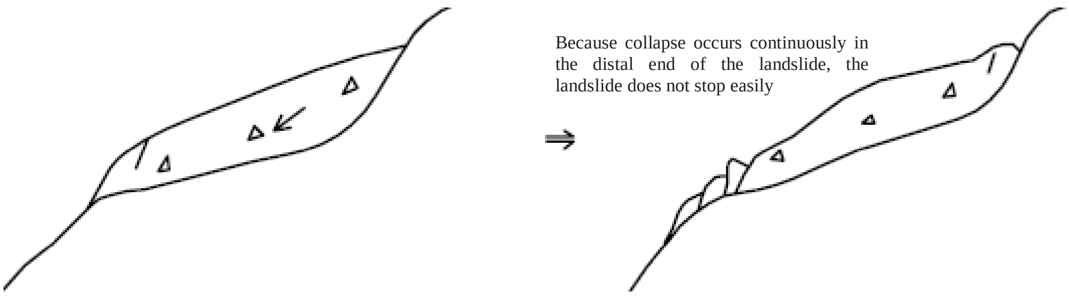
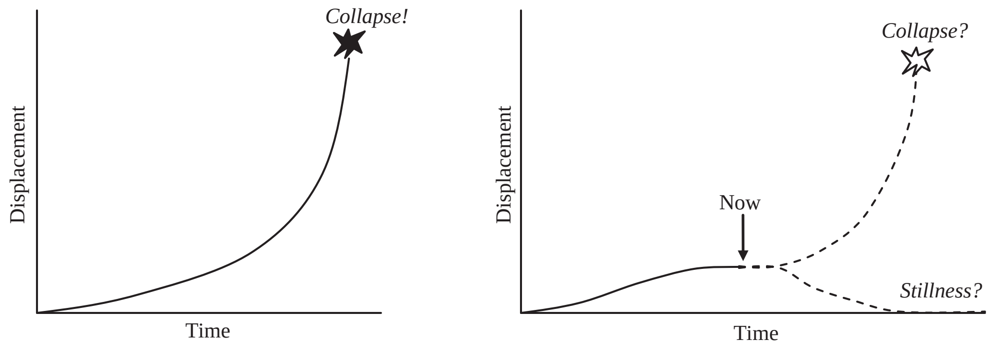


Figure 3.2.5 Case 4: Inclination of the Downward Slope is Steep[1]

b. Prediction Form the Landform and Deformation

Generally, because the displacement of the landslide suddenly accelerates just before collapse, the activity of the future landslide is estimated by monitoring landslide displacement. It is necessary to be careful about future sudden displacement increase even if there is not the movement of the landslide at present.



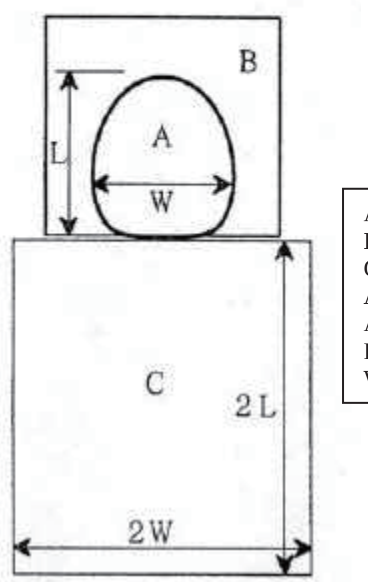
a) Case of collapses b) Case before the collapse

Figure 3.2.6 Change Pattern of the Landslide Displacement (source: JET)

3.2.5 Estimate of the Influence area

When a landslide area spreads, there is the risk that heavy damage will occur. The possibility of the landslide area expanding should be sufficiently considered in the initial site survey.

If a landslide movement area is identified, the danger zone where a landslide mass will reach must be estimated. As a result of a study of landslide disasters in Japan1), in 95% of landslides, the danger zone where the landslide mass reached was less than two times the length and width of the landslide body. Therefore, the danger zone shown below should be referred to when an early warning and/or evacuation is considered.



A: Landslide block
B: Zone with a basic factor same as A
C: Danger zone where a landslide mass reaches
A+B: Landslide hazard zone
A+B+C: landslide prone area
L: Length of landslide block
W: Width of landslide block

Figure 3.2.7 Landslide Danger Zone[1]

Reference

[1] Public Works Research Institute, 2007, A guidance and commentary of the prevention technology of the landslide, Japan

4 Emergency Response

4.1 Structural Countermeasure Work

The aim of the emergency structural countermeasure is to mitigate landslide activity, to minimise damage by landslide disaster and to release the warning status at an early stage. As there are cases where premature measure work may foment landslide activity, the type and layout of the emergency measure shall be decided carefully in consideration of the cause of the landslide and actual site conditions. Otherwise, the result of the work will have insufficient effect or even worse conditions. At the very least, before consideration of countermeasure works, the area and cause of the target landslide shall be recognised.

Generally, structural countermeasure work in an emergency shall be applied control works because control works can be conducted in a short time. The control works below can be considered as emergency countermeasure work for landslides.

It is thought that the main causes of landslides in Mauritius are artificial topographical changes by excavation work or soil filling work and hydraulic environment changes by runoff water or the rising groundwater level in the rainy season.

In the case of landslides caused by artificial topographical changes, the site shall be rehabilitated to its original condition as far as possible. If the rehabilitation of site conditions is difficult or the landslide occurred due to natural causes such as changes in hydraulic conditions, the following works can be considered as emergency countermeasure work:

- Soil removal work (Excavation work)
- Counter weight work
- Drainage work
- Detours

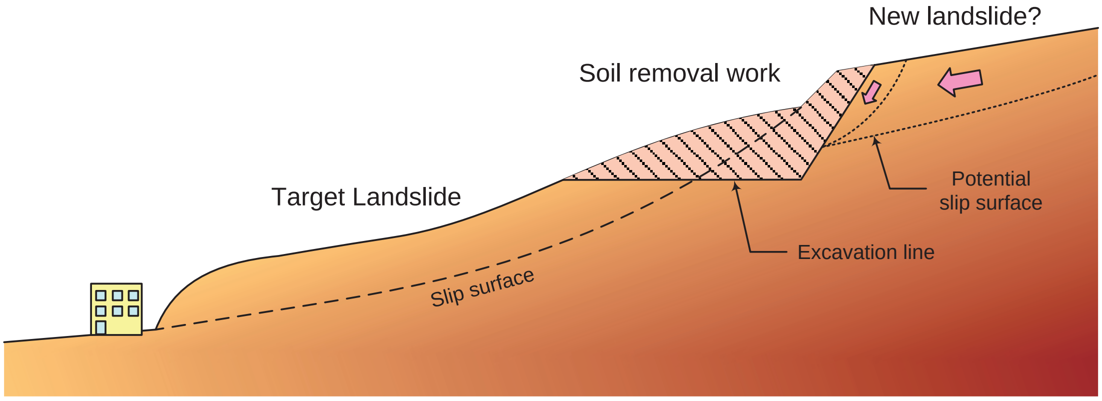
These countermeasures are works just for emergency situations and to mitigate damage by landslide provisionally. It is recommended that expected the factor of safety shall be secured at 1.05 by the emergency countermeasure works. After installation of the works, permanent countermeasures shall be examined and installed based on the results of a detailed investigation.

The points of the emergency countermeasure works are described below.

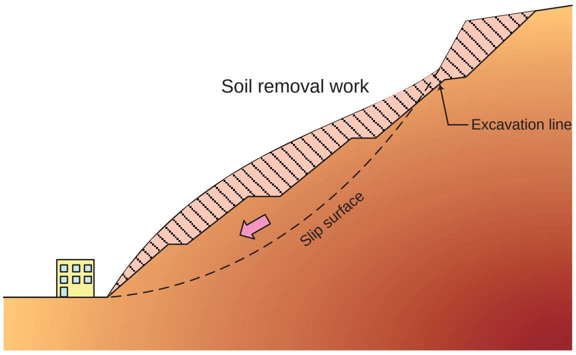
4.1.1 Soil Removal Work

The aim of the work is to increase the stability of the landslide block by removing soil at the head of the landslide. The work is simple earth work and has high workability. However, there are cases where the landslide itself or another slope behind the landslide might become unstable depending on the location of the applied work (refer to (i) and (ii) in the figure below). Therefore, the location of the applied work shall be considered and decided on carefully. Additionally, debris at the toe of the landslide shall not be removed rashly (refer to (iv) in the figure below). Otherwise, it will encourage further landslide activity.

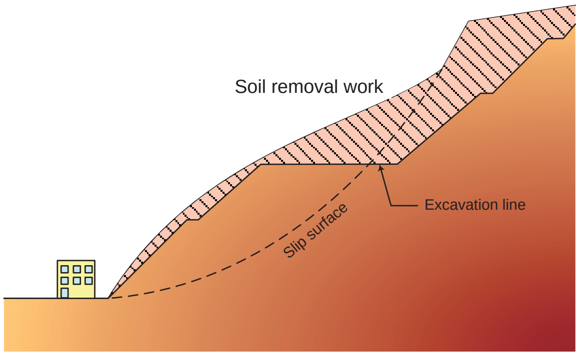
It will be difficult to apply the work in residential areas or on private land because the work will change the environmental conditions at the work site. According to the impact on environmental conditions at the site, the area of excavation shall be minimal. It is recommended that the area of excavation be decided based on the results of simple stability analysis to achieve the planned factor of safety.



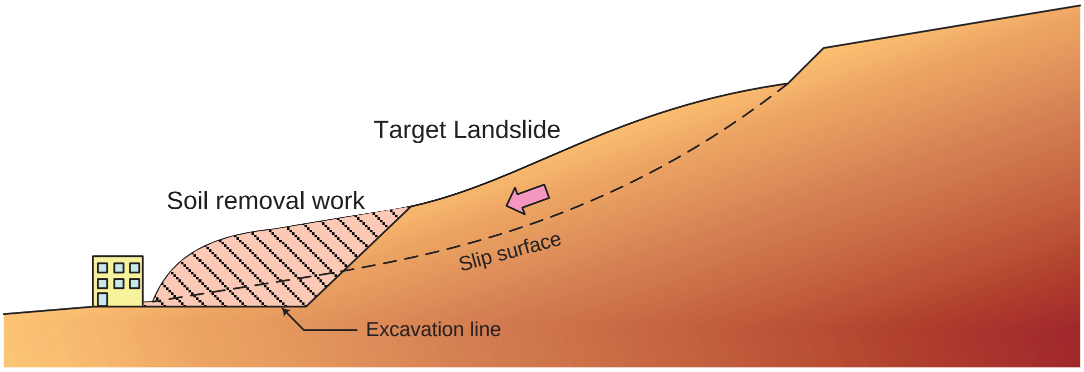
(i) Soil removal work at the head of a landslide will have a good effect on stability itself but it may also trigger a new landslide behind the target landslide.



(ii) Excavation work conducted as shown in the above figure will contribute to the instability of the target landslide due to lack of soil at the lower part of the landslide block[1]



(iii) Excavation at the head of the landslide block with an appropriate slope gradient will contribute to the stability of the target landslide



(iv) Excavation at the toe of a landslide will encourage instability of the target landslide. Therefore, the excavation shall not be conducted at the toe of a landslide even though there is a possibility that houses or public facilities are damaged by further landslide activity.

Figure 4.1.1 Example of Soil Removal Work at the Head and Unstable Part of Target Landslide (source: JET)

4.1.2 Counter Weight Work

The aim of the work is to increase the load of the lower part of the landslide block and shear resistance force by installation of filling at the toe of the landslide.

In the case that bulging at the lower part of a landslide block is found, the counter weight work will be quite an efficient countermeasure against landslide. However, there is a possibility that the foundation of the embankment will fail if the lower part of the landslide becomes loose due to disturbance by landslide activity, and also another landslide block may potentially exist below the location of the embankment.

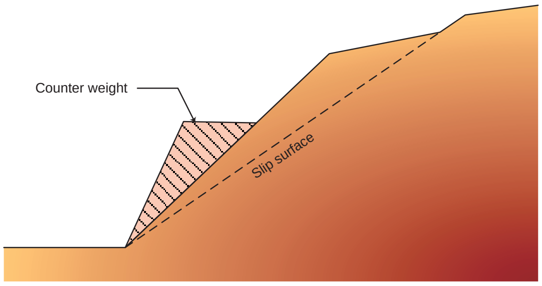
The surface of the embankment slope shall be covered with a gabion or sandbags to avoid erosion of the embankment soil.

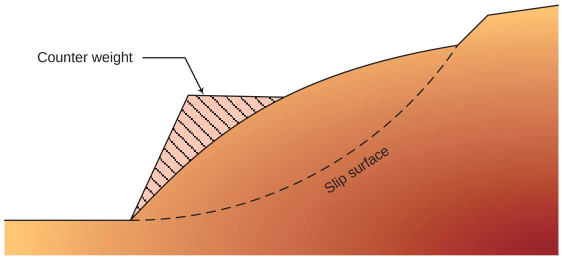
It shall be noted that there may be cases where the effect of the work will not be as expected according to shape of the slip surface (refer to (i) and (ii) of the figure below).

Generally, water springs or seepage are found at the toe of landslides. In that case, counter weight work may cause the groundwater level in the landslide block to rise as a result of blocking the discharge of spring water. Therefore, in the case that the counter weight work is installed where there is a spring or seepage, highly permeable material shall be used for the work with a gabion or drainage pipes shall be installed to discharge spring water properly.

It is recommended that the location, figure and volume of the embankment are decided based on the results of simple stability analysis.

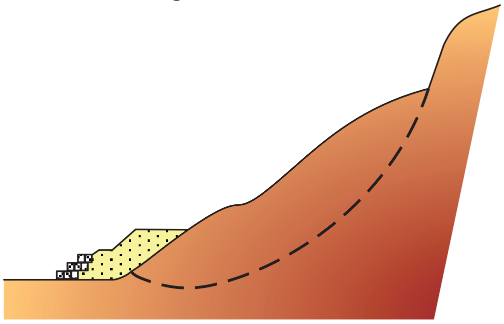
Since a huge space of land will be required for the work, it might be difficult to apply the work in residential areas or on private land.

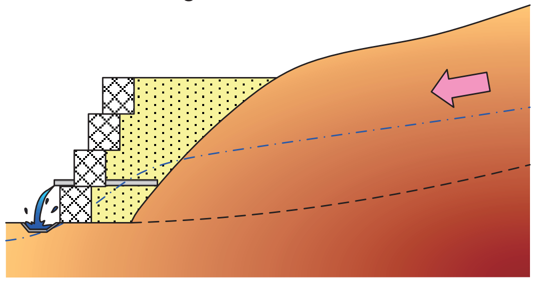




(i) In the case that a slip surface appears straight, the safety factor of the landslide will not be drastically changed by the counter weight work.

(ii) In the case that a slip surface appears curved, an increase in the safety factor of the landslide can be expected by the counter weight work.





(iii) The slope of the counterweight filling work shall be covered by a gabion or sandbags to avoid erosion.

(iv) In the case that a spring or seepage is found at the toe of the landslide, weep holes shall be installed in the filling/embankment to avoid a rise of the groundwater level in the landslide.

Figure 4.1.2 Points of Installation of Counter Weight Work (source: JET)

Figure 4.1.3 Large-sized Sandbags[2]

Figure 4.1.4 Gabion wall for Counter Weight (source: JET)

4.1.3 Drainage Work

In the case that a pond or swamp is found at the upper part of the landslide, the pond shall be cut drainage to discharge as much as possible. The opened crack shall be covered by a plastic sheet to avoid intrusion into the landslide block. A plastic pipe shall also be provisionally installed at the water spring and existing water course.

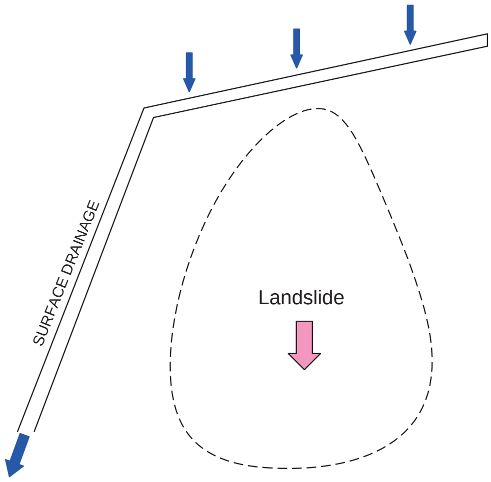


Figure 4.1.5 Example of Arrangement of Surface Drainage (source: JET)

Drainage shall be installed outside the landslide block. Drainage in the landslide block is at risk of being damaged by landslide activity. In the case that drainage is damaged, water will infiltrate the landslide block through the damaged drainage and encourage landslide activity. Therefore, drainage shall not be installed in the landslide block whenever possible. If drainage has to be installed in the landslide block, the drainage shall have a flexible structure to follow the changes in topographical features due to landslide activity.

4.1.4 Detour

In the case that a lifeline such as a national road is damaged by landslide, a detour shall be made to secure the traffic route temporarily. The detour shall be made out of the landslide block. After stopping landslide activity by installation of a permanent countermeasure, the damaged road can be rehabilitated and used on the original route.

When the detour route is planned, the possibility of another landslide occurring due to construction of the detour shall be examined.

In the case that there is no space to make a safe detour, a temporary detour shall be made on the original road even if the gradient of the road is steep to avoid encouraging landslide activity.

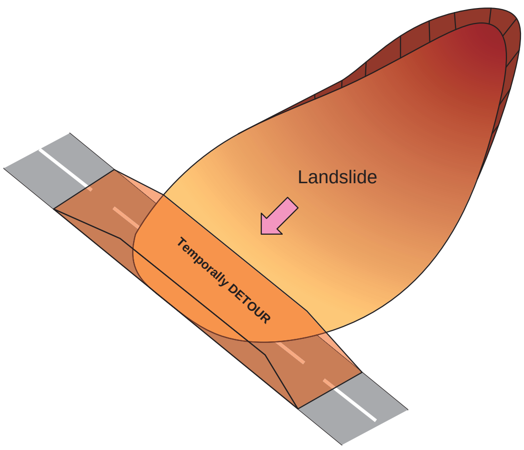


Figure 4.1.6 Detour on the Original Road (source: JET)

4.2 Evacuation and Relocation Support

4.2.1 Evacuation

(1) In case of the pilot sites by the Project

In the Project of Landslide Management in the Republic of Mauritius (hereinafter the Project), the draft contingency plan has been made for the three pilot sites which are Chitrakoot, Quatre Soeurs and Vallée Pitot (hereinafter CK: Chitrakoot, VP: Vallée Pitot, QS: Quatre Soeurs). The contingency plan contains the followings (for details of the below, refer to the end of this guideline.)

- Location map of evacuators: it is a map which has information of location of houses evacuators live.
- Evacuee list: it is a list of all evacuees in a landslide site which have the name and contact of inhabitants.
- Early waning and evacuation system flow: it is a guide for how to response when landslide occurs.
- Instruction manual of simple rain gauge: it is a guide for how to deal with a simple rain gauge.
- Communication network: it is made to clearly define from WHO to WHO to communicate in case of warning stage based on simple rain gauges and alert system.
- Location map of the designed refugee centre and the route: it has information of refugee centre and the route from residence on a map

If a landslide occurs in the pilot sites, the above contingency plan can be utilized. Table 4.2.1 shows the flow of early waning and evacuation in the pilot sites. And Figure 4.2.1 shows task flow of related ministries/agencies for early waning and evacuation in the pilot sites.

Table 4.2.1 Early Waning and Evacuation in the Pilot Sites (source: JET)

Category	Content
Information collection	MPI will collect the following information. - Displacement - Rainfall (by MMS) - Anomalies (cracks, subsidence, etc.), However, under the situation of Cyclone/Torrential Rain which is described in the disaster scheme, the Special Mobile Force will take readings of extensometers on hills and will communicate the information to the MPI and the MMS.
Information provision regarding the stage 1 (waning stage)	Based on the above information collection, if one of the following conditions is confirmed, MPI informs the observation result to NDRRMC - MMS and MPI observes rainfall 75 mm (CK, VP)/100mm (QS), or - MPI confirms that the yellow light revolves, which means the extension on ground is over 10 mm/day (CK, VP) , or - MPI confirms minor anomalies (cracks, small substances, etc.)
Information provision regarding the stage 2 (evacuation stage)	Based on the above information collection, if one of the following conditions is confirmed, MPI inform the observation result to NDRRMC - MMS and MPI observe rainfall 100 mm (CK, VP)/200mm (QS), or - MPI confirms that the red light revolves and/or the sound beeps, which means the extension on ground is over 20 mm/day (CK, VP) , or - MPI confirms the heavy damage to buildings.
Information provision regarding the stage 3 (Termination stage)	Based on the above information collection, if all of the following conditions is confirmed, MPI inform the observation result to NDRRMC - No rainfall of 0 mm in 6 hours (CK, VP, QS), and - No ground displacement of 0 mm being recorded (CK, VP), and - No new anomalies being confirmed
In case of sudden landslides	If the designated inhabitants obtain information regarding a sudden landslide occurrence, the information will be transferred to police and NDRRMC to issue the stage 2 (evacuation stage)
In case of landslides during Cyclone Warning/Torrential Rain Warning	When MMS observes the designated threshold which is shown the above under the situation of the issue of a Cyclone Warning Class/Torrential Rain Warning, MMS inform the observation result to NDRRMC.

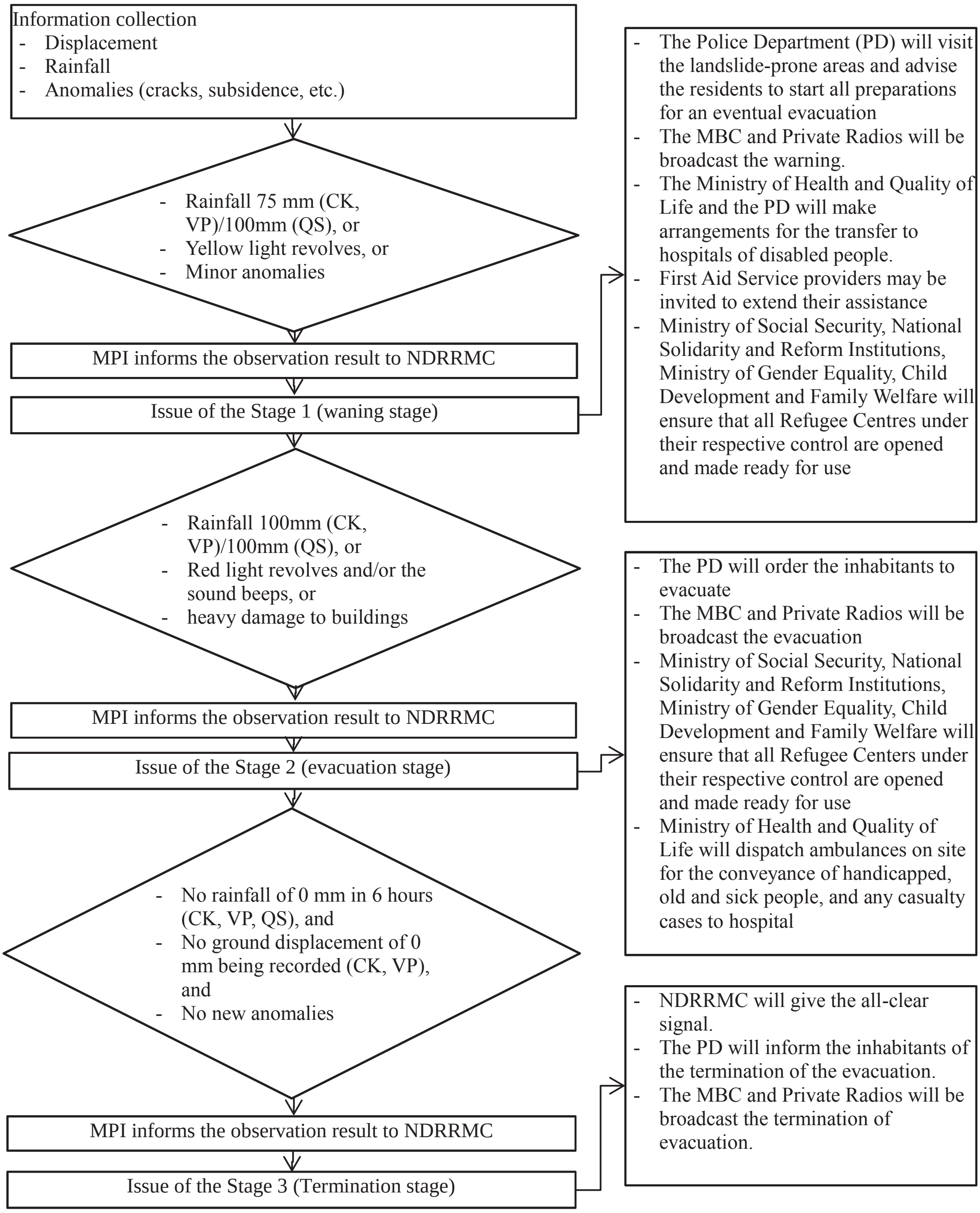


Figure 4.2.1 Task Flow of Related Ministries/Agencies for Early Waning and Evacuation in the Pilot Sites (source: JET)

(2) In case of landslide site other than pilot sites by the Project

If a landslide occurs in a site other than the pilot sites by the Project which are Chitrakoot, Vallée Pitot, the following task shown on Table 4.2.2 by MPI will be required. And Figure 4.2.2 shows the task flow of MPI related ministries/agencies.

Table 4.2.2 MPI's Task for Early Waning and Evacuation in a Site Other than Pilot Sites by the Project (source: JET)

Category	Content
Information collection	On being informed that the 30mm rainfall in 12 hours has been recorded, MPI will start taking daily readings of extensometers to measure ground displacement. MPI will also collect the following information. - Displacement - Anomalies (cracks, subsidence, etc.), - Other related information (such as date and time of occurrence of landslide, location information of the landslide, scale/extent of the landslide, degree of landslide disaster damage) However, under the situation of Cyclone/Torrential Rain which is described in the disaster scheme, the Special Mobile Force will take readings of extensometers on hills and will communicate the information to the MPI and the MMS.
Information provision regarding the stage 1 (waning stage)	If MPI confirms ground displacement of 1cm in 24 hours, MPI inform the observation result to NDRRMC
Information provision regarding the stage 2 (evacuation stage)	If MPI confirms ground displacement of 2mm in an hour, MPI inform the observation result to NDRRMC
Information provision regarding the stage 3 (termination stage)	If MPI confirms no ground displacement and no new anomalies, MPI inform the observation result to NDRRMC
In case of sudden landslides	If MPI obtains information regarding a sudden landslide occurrence, the information will transfer to NDRRMC to issue the stage 2 (evacuation stage)
In case of landslides during Cyclone Warning/Torrential Rain Warning	When MPI observes the designated threshold which is shown the above under the situation of the issue of a Cyclone Warning Class/Torrential Rain Warning, MPI inform the observation result to NDRRMC.

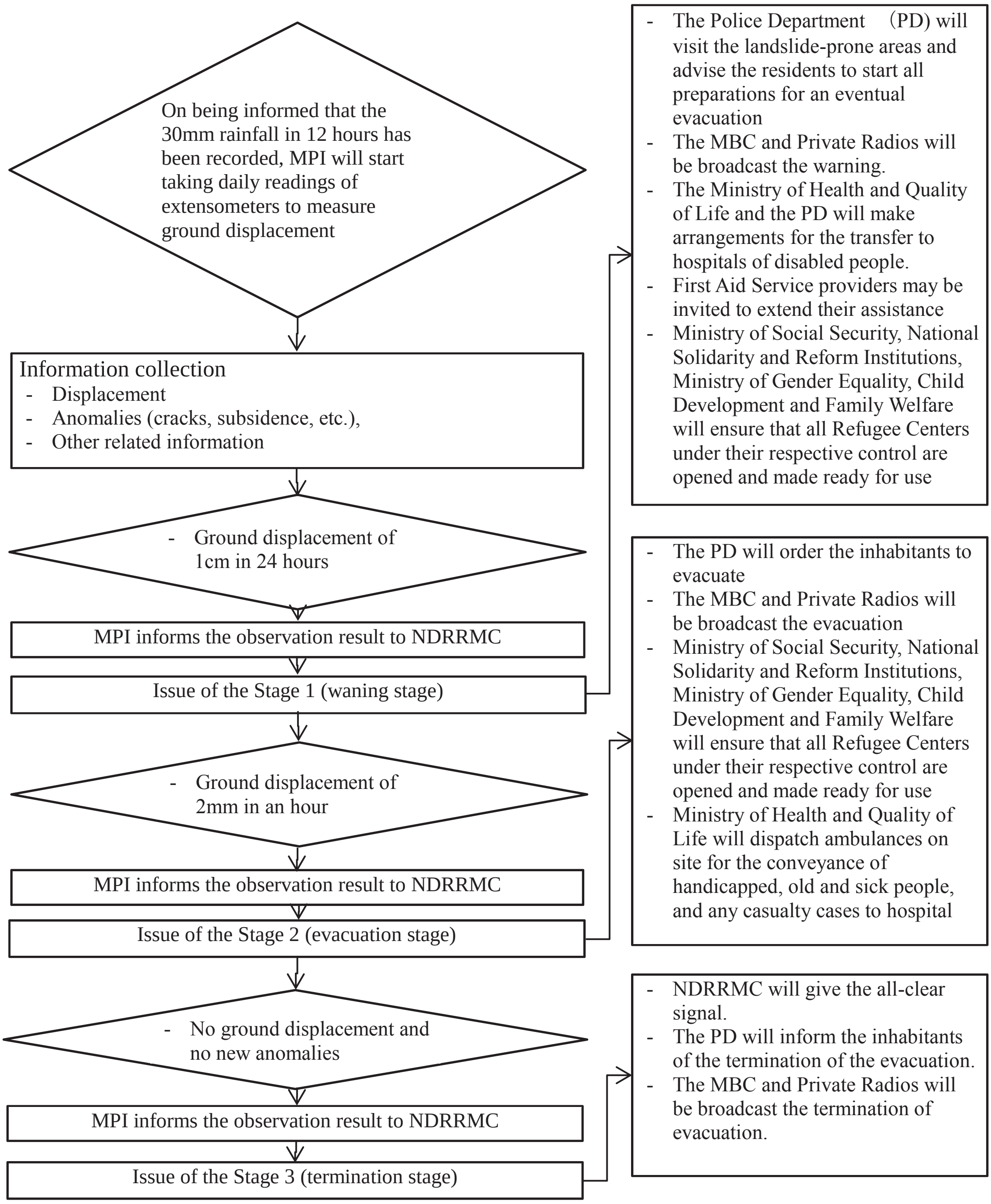


Figure 4.2.2 Task Flow of Related Ministries/Agencies for Early Warning and Evacuation in a Site Other than Pilot Sites by the Project (source: JET)

4.2.2 Relocation Support

(1) Initial Survey for Relocation

In the initial survey, the information which is shown on the following table will be collected through an interview survey of inhabitants and reconnaissance of a site. Based on the survey result, the basic policy of the response to the landslide disaster damage area such as countermeasure works, non-structural countermeasure and necessity of the relocation is considered by the related ministries/agencies.

In case the deliberation reaches a conclusion that relocation is necessary, the explanation of the relocation project will be conducted for the inhabitants (explanation of the survey result, the purpose of the relocation project and its schedule; as well as to obtain consent of detailed survey, etc.)

Table 4.2.3 Items and Content of the Initial Survey for Relocation (source: JET)

Category	Item	Content
Basic information of the affected area	Date and time of occurrence	year-month-day-time format
	Address, place name	
	Number of the victims	Total ___ persons (adult__, children__, vulnerable people)
	Class of disaster	Landslide, Slope failure, other (　)
	Number of damaged buildings	Total ___ buildings (houses ___, other ___)
	Extent of disaster damage	East to west ___m x North to south ___ m (___m2)
Basic condition of the affected area	Name of the hazard area	_____ Landslide Area
	Type of the hazard	Landslide-Prone Area, Landslide Hazard Zone, other (　)
	Designation date of the hazard area	
	Current situation of the disaster measures	Complied with, in operation, under review, other (　)
Basic information of the victims (head of the household)	Name	
	Address	(plot on a map)
	Age	
	Contact information	
	Occupation	
	Family structure	
Basic information regarding the affected lands	Name of owner/lessee	
	Date and time of disaster damage occurrence	year-month-day-time format
	Address	(plot on a map)
	Area	___m2
	Use	Residential, Commercial, Agricultural, Industrial, Forestry, Other (　)
	Possession type	Private, leased (private-owned, nationally-owned)
Basic information regarding the affected buildings	Name of owner/lessee	
	Date and time of disaster damage occurrence	year-month-day-time format
	Address	(plot on a map)
	Area	___m2
	Use	Residential, Commercial, Agricultural, Industrial, Forestry, Other (　)
	Possession type	Private, leased (private-owned, nationally-owned)

(2) Detailed Survey of the Land, Building and Others for Relocation

The information regarding the right of the land, buildings and others should be confirmed to implement the appropriate and effective work for relocation. In the detailed survey, the information which is shown on the following table will be collected through an interview survey of inhabitants, reconnaissance of a site, investigation of cadastral data/registration records, land survey and investigation of the buildings.

Table 4.2.4 Items and Content of the Detailed Survey for Relocation (source: JET)

Category	Item	Content
Detailed information of the victims	List of the victims (entire family)	Name, Address, Age, Contact information, Occupation, Relationship in family structure, Amount of revenue
	Situation of land acquisition for the relocation	Acquired (own land, lease) or Not acquired. (In case of acquired, address: ___)
	Situation of building acquisition for the relocation	Acquired (own building, lease) or Not acquired. (In case of acquired, address: ___)
	Necessity of the relocation	
	Conditions of a location for the relocation	
Detailed information of the damage about the land	Name of owner/lessee	
	Address of the land	(plot on a map)
	Address of the owner	
	Date and time of disaster damage occurrence	year-month-day-time format
	Condition of the damage	Buried in the ground, Swept away, other ( )
	Area of the land	
	Use	Residential, Commercial, Agricultural, Industrial, Forestry, Other ( )
	Photo of the damage	
	In case of own land, situation of a loan	Date of borrowing, Debt balance, Lender, Borrowing period
	In case of leased land	private-owned or nationally-owned, Name/address of lessor, Lease period, Rent, Other conditions
Detailed information of the damage about the building	Name of owner/lessee	
	Address of the building	(plot on a map)
	Address of the owner	
	Date and time of disaster damage occurrence	year-month-day-time format
	Structure of the building	Concrete block, Reinforced concrete, Steel, Steel framed reinforced concrete, Wooden, Other ( )
	Condition of the damage	Complete destruction, partial destruction, buried in the ground, swept away, other ( )
	Area of the building	Total ___m2 (1st floor ___m2, 2nd floor ___m2, 3rd floor ___m2, other ___m2)
	Use	Residential, Shop, Storage, Office, Workshop, Other ( )
	Damage in parts and hazardous situation	Roof ( ), Frame structure ( ), Wall ( ), Fittings ( ), Floor ( ), Foundation ( ), Other ( )
	Photo of the damage	
	In case of own house, situation of a loan	Date of borrowing, Debt balance, Lender, Borrowing period
	In case of leased house	private-owned or nationally-owned, Name/address of lessor, Lease period, Rent, Other conditions

The confirmation of the possessor, right holder and other stakeholders is required through the clarification of the location of the land/building and the registration record based on the investigation of the cadastral map of Ministry of Housing and Lands. The collected data and materials by the investigation of the cadastral map and registration record contain the personal information. The information must not be used for anything besides the intended purpose and the information must be managed carefully.

The land survey will be conducted after the location of the subject land of relocation, detailed address, cadastral data, possessor, right holder and other stakeholders are confirmed based on the investigation result of the cadastral map and registration record. The surveyors have to enter the land of the stakeholders to conduct the land survey. It is needed to obtain the stakeholder's consent for and notify them of the intention to enter their land for the survey.

For the investigation of the buildings the consent of the stakeholders needs to be obtained in order to enter their buildings to conduct the investigation. The objects of the investigation are building, machinery, productive facility, barn, plumbing, garden tree, farm product and others.

When the land survey and investigation are finished, the record for each land/building stakeholder should be prepared. And the records are required to be confirmed by stakeholders with their signature.

The landslide area (includes areas of landslide activity and/or extremely high risk of landslide damage) and areas adjacent to a landslide area (has a possibility of triggering a landslide or to have a negative effect on the landslide area) will be examined by the related ministries/agencies based on the survey result to consider the implementation of the relocation.

4.3 Landslide Warning Systems

4.3.1 Outline of Landslide Warning Systems

a. Definition of Landslide Warning

A landslide warning system is a system which predicts landslide disasters and allows people in landslide risk areas to escape from the disaster. A landslide warning system cannot protect the property of the people in a landslide risk area. It can only protect the lives of people in the area from the landslide. A landslide warning system can be a temporary measure. This is the most important matter when we consider landslide disaster management. To implement a landslide warning system, we must find where the landslide risk areas are and predict when the landslide disasters will occur.

b. Information for Landslide Warning

Prediction of the landslide disaster
To predict a landslide disaster, we must identify small phenomena caused by landslide. Generally, small phenomena such as cracks or deformation of the ground and structures can be seen prior to a landslide disaster. We must identify the small phenomena and monitor whether they are getting worse or not using tools or instruments.

Location of the landslide risk areas
A landslide warning system is used to warn the residents in a landslide risk area to evacuate when necessary. Therefore, the houses in landslide risk areas must be identified to conduct a landslide warning. Landslide risk areas shall be identified by detailed investigations prior to establishing the landslide warning system. A landslide risk area is both the area of a landslide block and the surrounding area that can be affected. Landslide blocks can be confirmed by the inventory survey and detailed investigations.

Information Transfer

Once we predict the landslide disaster, the information must be transferred from the tools or instruments to all residents in the landslide risk area. Therefore, a person to receive the information from the tools or instruments and a person to transfer the information to all residents must be appointed.

c. Evacuation

Injuries to people in a landslide disaster are mostly due to being buried under the debris of the houses destroyed. The victims of landslide disasters are usually only the people in residential houses in the landslide risk areas. Therefore, when a landslide warning is issued, the residents in the landslide risk area should escape to a place away from the landslide risk area or at least from their houses. It is not necessary for the people in the area to go to a refuge.

4.3.2 Warning

a. Phenomenon Initiate the Warning and Sensors

To issue a warning, we must find where the landslide risk areas are and predict when the landslide disaster will occur. Once the location of the landslide had been identified and a landslide warning system is established, the landslide warning system must predict the timing of the landslide disaster. In order to predict the timing of the landslide disaster, we should find and monitor the small phenomena which arise prior to the landslide There are two kinds of phenomena in landslide risk areas we have to keep our eyes: a) small phenomena such as cracks or deformation on the ground surface or structures caused by landslides and b) phenomena which can cause landslides.

a) Small phenomena which can be seen everywhere in a landslide area should be found and monitored. The movement of the ground surface, cracks on the ground, cracks on a structure and movement of the subsurface are all possible phenomena caused by landslide.

b) In Mauritius, only an increase in groundwater level can cause landslides. As monitoring of the groundwater level is sometimes difficult, precipitation monitoring can be performed as an easy way to determine an increase in the groundwater level.

b. Instruments

The instrumentation for the landslide warning system generally consists of a sensor, a logger and an alarm devise. An extensometer which can detect small movements of the ground surface is often employed as an instrument for detecting small phenomena in a landslide. Because it is easy to install, less trouble with a simple structure, easy to monitor automatically and easy to attach a warning devise to, the extensometer is especially popular in Japan where less protection barrier is required, as there are fewer burglars.

Other than extensometers, tiltmeters and crack gauges are employed for the monitoring of landslides. However, they are not so popular compared with extensometers because they cannot obtain the absolute value of the movement of a landslide.

Because rain gauges are also easy to handle and easy to install, rain gauges can be employed for the landslide warning system in order to detect an increase in groundwater level indirectly.

The advantages of a rain gauge are that it does not require construction works such as drilling works and can be installed anyplace where there is open air around the landslide area.

Extensometer
Extensometers should be installed at the top centre or bottom centre of the landslide block where it can detect the movement of the landslide precisely.

Rain Gauge
A rain gauge can be installed in any open area around the landslide because precipitation does not very much in a limited area. The rain gauge should be installed in a place away from trees and buildings which can obstruct the rain falling on the rain gauge. Also, the rain gauge should be at the height of one meter (1m) or more from the ground surface to prevent water and mud splashing up from the ground surface.

Simple Devices
Simple devices such as an extensometer, a tiltmeter and a rain gauge can be used to monitor the small phenomena which arise prior to a landslide in order to predict the timing of the landslide disaster. Since these simple devices do not have either a logger or an alarm, someone must always watch them.

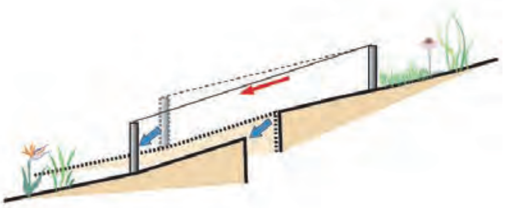


Figure 4.3.1 Wire Extensometer
(source: JET)

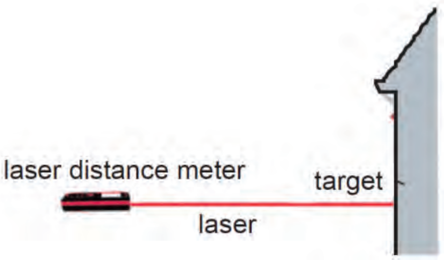


Figure 4.3.2 Laser Extensometer
(source: JET)

Figure 4.3.3 Laser Extensometer, Vallée Pitot (source: JET)

A simple rain gauge consists of a funnel, a bottle (or cylinder) and a hose. All materials can be easily obtained in Mauritius.
The diameter of the funnel used for the simple rain gauge installed in Chitrakoot is 128 mm.
The precipitation is as follows:

50 mm of precipitation =	643 cc
75 mm of precipitation =	965 cc
100 mm of precipitation =	1286 cc
200 mm of precipitation =	2572 cc

$* V = \pi R^2 H / 1000$

V : volume of precipitation (cc)
R : diameter or the funnel (mm)
H : precipitation (mm)

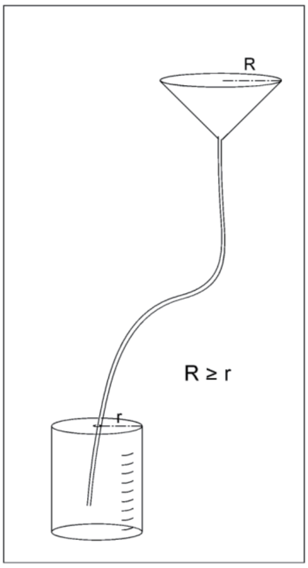


Figure 4.3.4 Rain Gauge
(source: JET)

c. Criteria of Warning

The most important thing to establish the criteria of warning is to recognize the limit of landslide movement or the limit of precipitation to keep the people secure. “People in danger” means that houses are being destroyed by the landslide. The warning to evacuate the houses must be issued a few hours before destruction by the landslide. In order to determine the timing of when the houses are destroyed in the landslide, we must find the relationship between the deformations recorded by the extensometers and the destruction of houses or precipitation and the destruction of houses. However, there are no such records in Mauritius so we need to accumulate such data to improve the landslide warning system.
The following are examples of establishing the criteria of warning in Chitrakoot and Vallée Pitot in Mauritius.

Example of the criteria of warning on extensometers in Mauritius

There are three ways of using the displacement of extensometers for the landslide warning system: total displacement, daily displacement and hourly displacement. Small landslides, which account for most of the landslides in Mauritius, move fast immediately after they are activated and their moving speeds are not constant. A short period of displacement of the extensometer such as an hourly displacement is not suitable for the warning system in Mauritius. The total displacement of the extensometer is not suitable in Mauritius either because many landslides in Mauritius are constantly moving, even in the dry season. Therefore, landslide management based on the daily displacement is the best way in Mauritius.

Automatic wire extensometers were installed in two landslide risk areas, Chitrakoot and Vallée Pitot. The criteria are obtained based on the relationship between the displacement of the extensometer and the landslide disaster. A landslide disaster occurred in Vallée Pitot on February 25, 2013, and a house was partially destroyed. The extensometer (EV1) had been installed near the site of the disaster, and it recorded a big displacement of the landslide. The start of the displacement was recorded by the extensometer three days before the disaster. The total displacement in the three days leading up to the disaster was 54.2mm, the maximum daily displacement recorded two days before the disaster was 30.7mm, and the maximum hourly displacement was 1.9mm, as shown in Figure 4.3.4. The daily displacement of 30.7mm was the biggest daily displacement recorded by all extensometers installed in the project. Based on the relationship between the landslide disaster and the records of the extensometer in Vallée Pitot, a displacement of 30.4mm/day is the critical value to be evacuated. For the criteria for evacuation and warning, we decided that a 20mm/day displacement of the extensometer is the criterion for evacuation with a safety factor of 50%. A 10 mm/day displacement of the extensometer, which is half of the evacuation criterion, is the criterion for warning. These criteria have been decided based on only one landslide disaster. They may be reconsidered with the accumulation of records by the extensometers and on landslide disasters.

Criterion for Evacuation: 20mm/day
Criterion for Alert Warning: 10mm/day

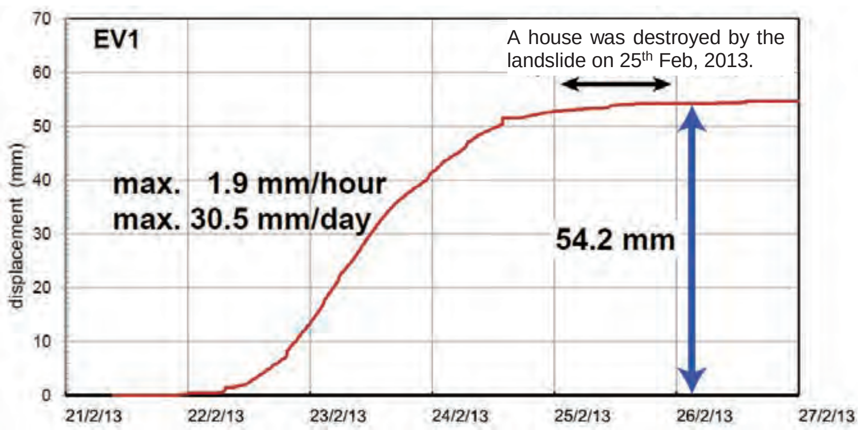


Figure 4.3.5 Record of the Extensometer on the Event of Disaster in Vallée Pitot (source: JET)

Example of the Criteria of warning on rain gauges in Mauritius

As there are not many records of the hourly precipitation at landslide disasters in Mauritius, the accumulated rainfall method is the best method in Mauritius. Figure 4.3.5 shows the relationship between precipitation and disasters in Chitrakoot and Vallée Pitot in Mauritius.

In Chitrakoot in 2005, landslides damaged houses with 376mm of accumulated rainfall. However, there was no damage to houses with 167mm of accumulated rainfall. In 2008 in Chitrakoot, landslides damaged houses with 117mm and 176mm of accumulated rainfall. In 2013, the extensometer recorded big displacements with over 100mm of accumulated rainfall. Although there are some exceptions, displacements of the ground increased in over 100mm of accumulated rainfall and landslide disasters occurred in over 120mm of accumulated rainfall. Therefore, the criteria for evacuation in Chitrakoot can be 100mm of accumulated rainfall.

In Vallée Pitot in 2007, landslides damaged houses with 385mm of accumulated rainfall. In 2013 in Vallée Pitot, a landslide damaged a house with 100mm of accumulated rainfall and the extensometer recorded big displacements.

The criterion for the risk level of landslides in Vallée Pitot is 100mm of accumulated rainfall.

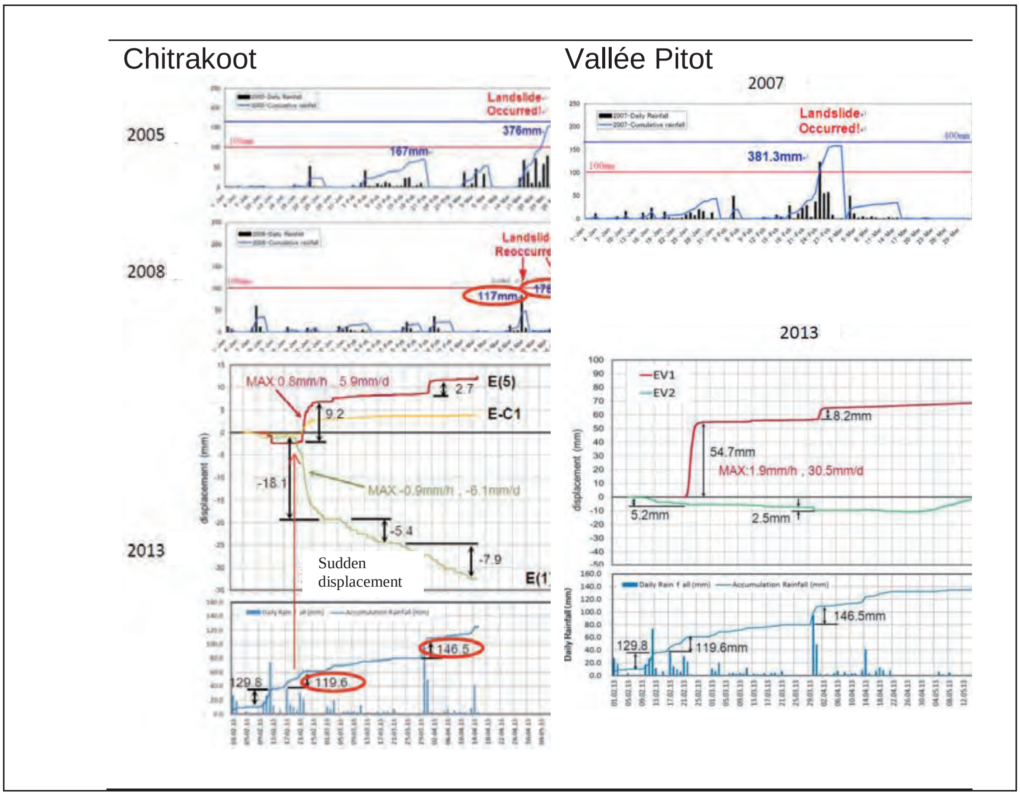


Figure 4.3.6 Relation between Precipitation and Disasters (source: JET)

Proposed criteria of warning by extensometers and rain gauges

Based on the results of the extensometers and rain gauges and the records of disasters in Mauritius, the criteria for the risk levels of landslides were determined. Table 4.3.1 shows the proposed criteria for the risk levels of landslides determined based on the monitoring records in this project and the disaster records.

Table 4.3.1 Proposed Criteria of Risk Levels in 3 Areas (source: JET)

Stage		Monitoring	Criterion
Stage 1	Alert	Accumulated rain fall Ground displacement	75 mm 10 mm / day
Stage 2	Evacuation	Accumulated rain fall Ground displacement	100 mm 20 mm / day
Stage 3	Termination	Accumulated rain fall Ground displacement	No precipitation for 6 hours 0 mm/ 6 hours

d. Warning

Warning with Alarm Devices

There are two ways to emit the warning, by in-site alarm or by remote alarm. Although there are many types of in-site alarm devices, sound and light are the most popular for landslide warning systems. Sirens are mostly used for sound alarms, but horns, bells and loud speakers can also be used. For light alarms, beacons are mostly used but light bulbs and flushes are sometimes used. In order to transfer the sound and light warning to all of the residents in the area, a designated inhabitant must be assigned to monitor the light and sound devices.

Therefore, the light and sound devices must be installed in a place where the designated inhabitant can see and hear the alarm. The sound alarm in a warning system emits a loud sound to warn all people in the area like a fire alarm system in a building. As the sound is expected to warn all people in the area, a number of sound alarms should be installed. When installing the sound system, all people in the area must be able to recognize the alarm system. Communication among residents is even more important to help warn people in the area who may not hear the alarm due to bad ears or because they are listening to music with head phones.

With a remote alarm system, data and warning signals from the instruments are sent by cable or radio to a remote control office. The advantages of this system are that it is easy to control a number of instruments and because some landslides occur simultaneously in one place. Also a landslide expert can access the data easily and judge the seriousness of the situation immediately based on the data sent from the site.

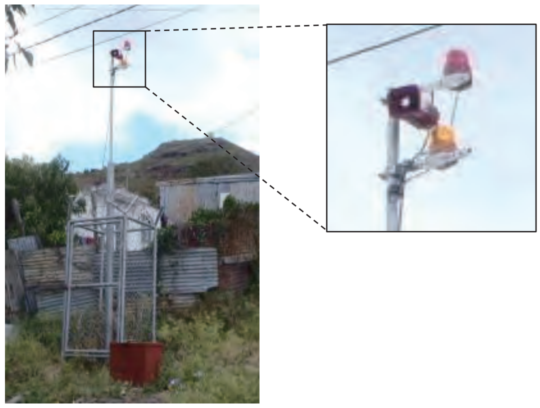


Figure 4.3.7 The in-site alarm devices, sound and light, Vallée Pitot (source: JET)

Warning with Simple Devices

Without an automatic warning system, someone must always watch devises such as the extensometers and rain gauges and once the reading reaches the warning level, he must send out a warning immediately. It is necessary to decide who the designated inhabitant will be, how the instruments will be monitored and how the warning will be sent. Someone must be appointed to watch the devices 365 days a year and there should be more than one designated inhabitant. Regular monitoring such as hourly and daily should be carried out every day by the designated inhabitant. The interval of monitoring depends on the landslide activity but monitoring is usually once a day and becomes more frequent if the landslide is more active.

The following is an example of the instructions given to a watchman who monitors a simple rain gauge in Chitrakoot. Monitoring of a simple extensometer can also be done this way.

Instructions for Simple Rain Gauge

Please measure the volume of water in the bottle every morning. Please throw away the water of the bottle, if it does not rain currently. Please watch the rain gauge sometimes in heavy rain.

I-1 When the volume of water in the bottle reaches 600 cc

Call MPI and inform the following.-
- the time when the volume of water reached 600 cc,
- current volume of the water in the bottle,
- the time when it started rain.
- current weather

If possible, call MPI every 3 hours after that and inform whether the volume of water in the bottle reaches 900cc or not.

Do not throw away the water in the bottle until MPI instruct you.

I-2 When the volume of water in the bottle reaches 900 cc

Call MPI and inform the following. -

- the time when the volume of water reached 900 cc,
- current volume of the water in the bottle,
- current weather

And call MPI every 3 hours after that and inform whether the volume of water in the bottle reaches 1200cc or not.
Do not throw away the water in the bottle until MPI instruct you.
Please prepare for evacuation from your house.
(MPI will inform the police that the rain fall reached 900 cc.)

I-3 When the volume of water in the bottle reaches 1200 cc

Call MPI and inform the following. -

- the time when the volume of water reached 1200 cc,
- current volume of the water in the bottle,
- current weather

After the call, please evacuate according to the instruction of the police. Do not throw away the water in the bottle until MPI instruct you.
(MPI will inform the police that the rain fall reached 900cc.)

II-1 in case if the volume of water in the bottle reaches 600 cc when you are going to sleep and still it is raining.

Call MPI and inform the following.-

- the time when the volume of water reached 600 cc,
- current volume of the water in the bottle,
- the time when it started rain.
- current weather

If possible, call MPI in that night and inform whether the volume of water in the bottle reaches 900cc or not.
In the next morning, call MPI and inform the following.-

- current volume of the water in the bottle,
- current weather

Do not throw away the water in the bottle until MPI instruct you.

II-2 in case if the volume of water in the bottle reaches 900 cc when you are going to sleep and still it is raining.

Call MPI and inform the following.-

- the time when the volume of water reached 900 cc,
- current volume of the water in the bottle,
- the time when it started rain.
- current weather

And call MPI every 3 hours after that and inform whether the volume of water in the bottle reaches 1200cc or not.
Do not throw away the water in the bottle until MPI instruct you.
Please prepare for evacuation from your house.
(MPI will inform the police that the rain fall reached 900 cc.)

4.3.3 Transmission of Warning and Evacuation

a. Transmission of Warning

Transmission of the landslide warning can be considered as a fire alarm system. In a fire alarm system, a warning is transferred to all people in the building and building management by the sound of a fire alarm. The information is transferred to a fire station directly from the alarm system or through building management. When we adapt the fire alarm system to the landslide warning system, people in the building are people in the landslide risk area, building management is MPI, and the fire station is the police station, In the case of a fire, the fire fighters must arrive as soon as possible to put out the fire whole in the case of a landslide, the police must warn all the residents and guide them to a safe place.

Since the police is concerned with the evacuation of residents in Mauritius, the police should receive the warnings of the landslides and transfer the warning to all the residents in the area. MPI who managements all landslides in Mauritius must receive all the warnings from the instruments and watchmen and transfer the warnings to the police. Figure 3.1.1 shows the recommended flow of a warning in the landslide warning system in Mauritius. All the warnings and information from the warning devices and watchmen should be concentrated to MPI because the warning system and instruments are installed and maintained by MPI and are MPI's responsibility. Therefore, all the information from the instruments, devices and watchmen must be transferred to MPI.

The role of MPI is very important in landslide management. MPI should be responsible for the following matters:

In ordinary times

Install and manage the instruments for landslide management
Explain the landslide warning system to people in the landslide risk area
Observe and inspect the landslides regularly

In an emergency or imminent situation

Receive the warning from the instruments or the watchmen
Transfer the warning to the police
Observe site as soon as receiving the warning

Inspecting the landslide area for new cracks, the opening of old cracks and deformation to confirm whether the landslide disaster is serious (For all of our sleep in peace, MPI must make people in the landslide risk area relocate as soon as possible instead of the landslide warning system).

<u>Role of MPI for the moment</u>

MPI does not have sufficient capacity to respond to an emergency as of early 2014. Therefore, the police receives the warning from the landslide risk area and respond to the emergency for the moment. Even so, MPI must go to the site immediately after receiving the warning from the police. MPI must also establish the necessary organisation to respond to emergencies as soon as possible.

b. Evacuation

Instruction to residents about evacuation should be done by the police, not by MPI. However, MPI should explain the following technical matters about landslides to people:

- The boundary of the landslide risk area
- Confirmation of residential houses in the landside risk area
- Notification to the residents of houses in the landslide risk area
- The danger in the landslide risk area
- The warning system installed in the landslide risk area
- Management of simple devices
- Appointment of the watchman

4.3.4 Landslide Warning without Instruments

Landslide disasters are caused by only the motion of the ground. Even with heavy rain, a landslide disaster would not arise without ground deformation. On the other hand, without rainfall, a landslide could be activated by an increase in groundwater pressure caused by water from out of the landslide other than rainwater or by human activity. In this sense, a warning by the extensometer may be more accurate than by the rain gauge. However, the extensometer cannot cover the entire landslide risk area if the landslide consists of a number of blocks. Even if the extensometer of the warning system is not issuing a warning, a landslide disaster at another landslide block could arise. In other words, the rain gauge can cover a wide area but is not so accurate while the extensometer is accurate but can only cover a limited area.

Since the residents normally do not have professional knowledge of landslides, anomalies the residents find may not be caused by a landslide. MPI must confirm the cause of the anomalies the residents find. MPI should also educate the residents in the landslide risk area about landslides (i.e. what are the signs of landslides). MPI should request the residents to inform MPI any signs of landslide immediately after they are found, and MPI should inspect the signs of landslide immediately after receiving the information from the residents.

The signs of a landslide are listed as follows by the United States Geological Survey (USGS).

- Springs, seeps, or saturated ground in areas that have not typically been wet before.
- New cracks or unusual bulges in the ground, street pavements or sidewalks.
- Soil moving away from foundations.
- Ancillary structures such as decks and patios tilting and/or moving relative to the main house.
- Tilting or cracking of concrete floors and foundations.
- Broken water lines and other underground utilities.
- Leaning telephone poles, trees, retaining walls or fences.
- Offset fence lines.
- Sunken or down-dropped road beds.
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content).
- Sudden decrease in creek water levels though rain is still falling or just recently stopped.
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb.
- A faint rumbling sound that increases in volume is noticeable as the landslide nears.
- Unusual sounds, such as trees cracking or boulders knocking together, might indicate moving debris.

Reference

[1] Japan Road Association, 2009, Highway Earthwork Series: Manual for slope protection, p. 435
[2] <http://shear.nagaokaut.ac.jp/Information/Niigata716earthquake/Niigata070802/Niigata0 70802.html>

5 Detail Survey plan

5.1 Outline of Detail Survey

5.1.1 Flow of Landslide Survey

A survey and analysis on landslides should be implemented to establish preventive plans and to discuss countermeasures for landslides. The survey is generally divided into two stages: a preliminary survey and a main survey.

The preliminary survey is composed of the collection of documents, data and maps and the searching and analysis of related literature.

The main survey for landslides chiefly consists of a hydrological survey, geomorphologic survey, geological survey, drilling and slip surface surveys, physical testing, monitoring and geophysical exploration. The analysis of landslides such as the preparation of geological cross sections, establishment of the safety factor and stability analysis should be implemented based on the specific results of the above mentioned surveys. Figure 5.1.1 below summarizes the flow of the survey and analysis of landslides and the scope which is described in this manual. The survey items and survey methods are shown in Table 5.1.1. In order to properly examine the items listed in the table, a detailed survey which will satisfy the study objectives should be planned by selecting appropriate survey methods and instruments described in the table.

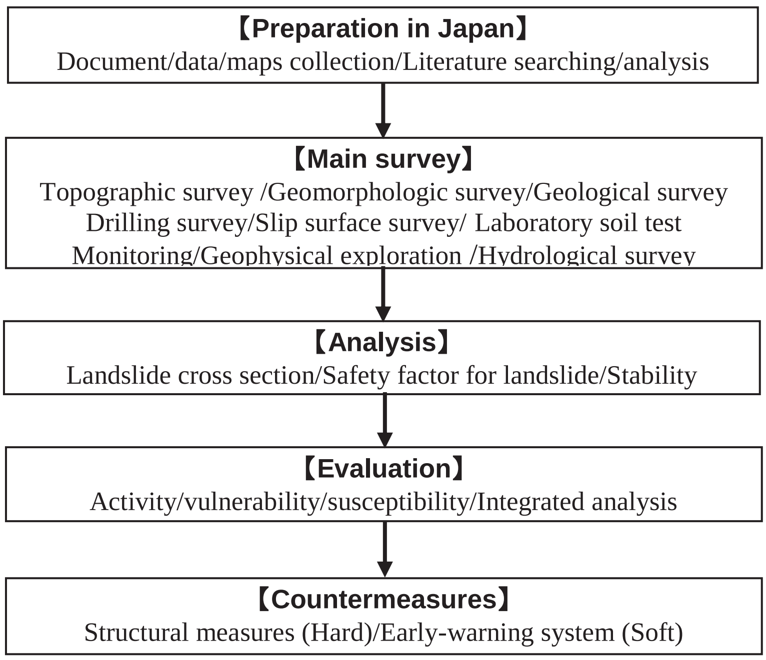


Figure 5.1.1 Flowchart Summarising Survey/Analysis for Landslides (source: JET)

Table 5.1.1 Survey Items and survey Method for Landslides[1]

Investigation items \ Invenstigation methods		Interpretation of aeral photographs	Literature research	Topographic survey	Topographic investigation	Surficial geologic investigation	Subsurface exploration by borings	Test adit	Geophysical exploration	Soil tests	Groundwater tests	Investigation of slip surface	Investigation of land deformation	Notes
Topography	slope form	○		◎	○									
	slope inclination			◎	○									
	slope height, location of safety objective	△		○	○									
	formational process of slope	○	△		△									
	landslide topography (areal extact, moving blocks, direction of movement)	◎		◎	◎									
	knick line (yes or no)	◎		○	○									
	micro topography of slope	△			◎									
Geology and geologic structure	rock type and rock quality	△	○			◎	◎	◎	○	△	△			composition of rocks and hardness
	degree of weathering and level of relaxation					△	○	◎	◎		△			
	density of rock formation						△	◎		◎				
	distribution of faults and fracture zones	○	△			◎	◎	◎	○					
	distribution and depths of slip surface	△				○	◎	◎	○			◎		continuity
	inclination of slip surface					○	◎	◎				◎		
	quality of slide mass, composition of slip surface materials					○	◎	◎			○			filling
	mechanical coefficient of slip surface									◎				
	deformation conditions of slip surface											◎		
Deformation condition of ground surface					△								◎	
Conditions of groundwater and springs						△	○				○			
Estimation of pore-water pressure							△				◎			
Existing conditions and warning signs	history of past disasters	○	◎		△									
	existence and conditions of scarps	○			◎									
	secondary failures and rock falls	△			○									
	conditions of toe area and uplift	○			◎									
	existence of extremely relax beds and rocks				△									
	deformation of structures				◎									

◎ : very effective investigation method
○ : effective investigation method
△ : depending on the situation, may be effective method

5.1.2 Preliminary Survey

The preliminary survey is composed of the collection of documents, data and maps and the searching and analysis of related literature. In the initial survey to be carried out just after the landslide occurrence, the above should be performed, although it will be difficult to complete due to time limitations. Therefore, it is necessary to collect as much data as possible in the detailed survey. (Refer to Chapter 2, Table 2.1.1)

5.1.3 Main Survey

a. Topographic Survey Plan

Ahead of all site investigations, the topographic survey should be carried out. The area of the plane survey should be established in an area that sufficiently covers the landslide activity area, and the cross section survey is planned so that it is carried out on the main-line of the target landslide. In addition, in the case that a landslide area is large and/or consisting of multiple landslides, several cross section lines (sub-lines) should be established. Because geophysical exploration and the drilling survey are carried out on the main-line and sub-lines, the topographic survey plan must consider the contents of the other surveys.

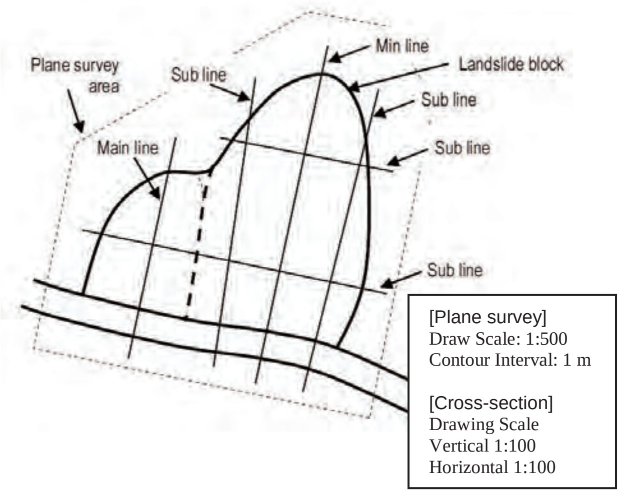


Figure 5.1.2 Image of topographic survey plan (source: JET)

b. Geomorphologic Survey Plan

As a geomorphologic survey, topographic map reading and aerial photo interpretation are carried out, the results shall be compiled into the landslide distribution maps. Then, the map shall be used for the field survey. **The geomorphologic survey should be carried out in the area that is bigger than active landslide block and topographic survey area**, and the topographical characteristic is confirmed in the wide area including the landslide block.

c. Field Survey Plan /Geological Survey Plan

The field investigation can provide more detailed information such as geological structures, causes of landslide, and possible landslides for the assessment. The field investigation should include areas where aerial photographs are not available or are unclear. It shall also include areas where it could help in understanding the particular geo-morphological features and characteristics.

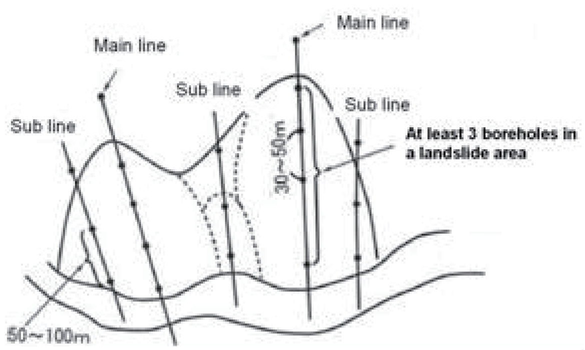


Figure 5.1.3 Location of drilling survey (source: JET)

d. Drilling Survey

Borehole points should be located along the centre line of the direction of landslide movement, at least 3 boreholes in the landslide area and 1 borehole in the upper part of the landslide at 30-50m intervals in principal (Figure 5.1.3). Additional boreholes should be implemented along sub-lines which run parallel at 30-50m intervals when the landslide area is larger. In the case that the landslide area is small, two or more drillings are needed along the movement direction to understand the geology of the area. When there are faults, fracture zones and/or complicated structures in the landslide area, supplemental drillings are preferable. It is desirable for the standard penetration test (SPT) to be carried out every 1m. Because the boreholes are used for the installation of the monitoring devices, the contents of the landslide monitoring should be considered when deciding on the placement and depth of the drilling.

e. Laboratory Soil Testing

Laboratory soil testing basically consists of two major soil tests: 1) physical tests, and 2) dynamic tests. Both kinds of tests tests are performed to review the stability of the landslide. The shear strength parameter of the slip surface provided by the dynamic test shall be applied for landslide stability analysis. Therefore, test samples for the dynamic tests shall be taken from the slip surface layer that is undisturbed by drilling. The physical test can use disturbed samples, which a standard penetration test provides.

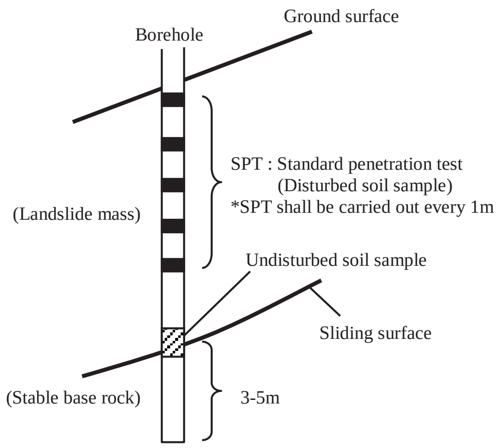


Figure 5.1.4 Conception diagram of the drilling and soil sampling (source: JET)

f. Geophysical Exploration

The geophysical exploration applied to the landslide investigation is primarily seismic exploration and electrical prospecting. These geophysical explorations are conducted together with the drilling survey in order to understand the scale and shape of the landslide moving bed and groundwater availability. The geophysical exploration carried out on the landslide's main-line and some sub-lines, investigates the 3-dimensional structure of the landslide.

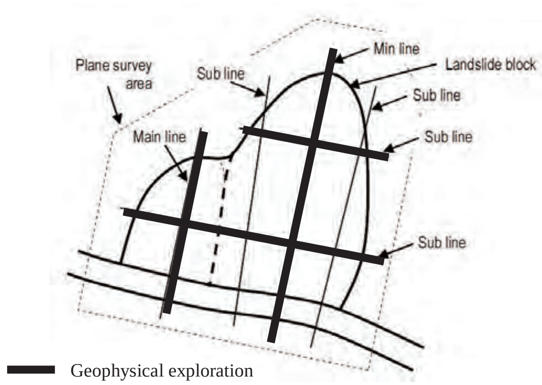


Figure 5.1.5 Location of Geophysical exploration (source: JET)

g. Monitoring

[Movement of a landslide] Extensometers are installed over cracks and/or gaps to measure movement and stress in an active sliding mass. Because the movement of the landslide is the biggest in the main scarp of the head part, it is required that the extensometer be installed in the main scarp.

[Slip surface survey] The borehole inclinometer and the pipe strain gauge investigate the position of a slip surface, and measure the amount of landslide movement on the slip surface. Though the borehole inclinometer has high precision, it cannot be used for active landslides. The pipe strain gauge records data continuously and is durable (1-2 years). These devices are chosen (or combined) in consideration of the activity of the landslide and shall be installed in combination in the boreholes.

[Hydrological survey] The aim of the survey is to judge the correlation between precipitation and changes in groundwater by measuring the precipitation which is a source of the supply of groundwater. The water level meter is installed in multiple boreholes and monitors the change in the groundwater level in the landslide area. The rainfall data are observed in a rain gauge set in the landslide area or the neighbourhood.

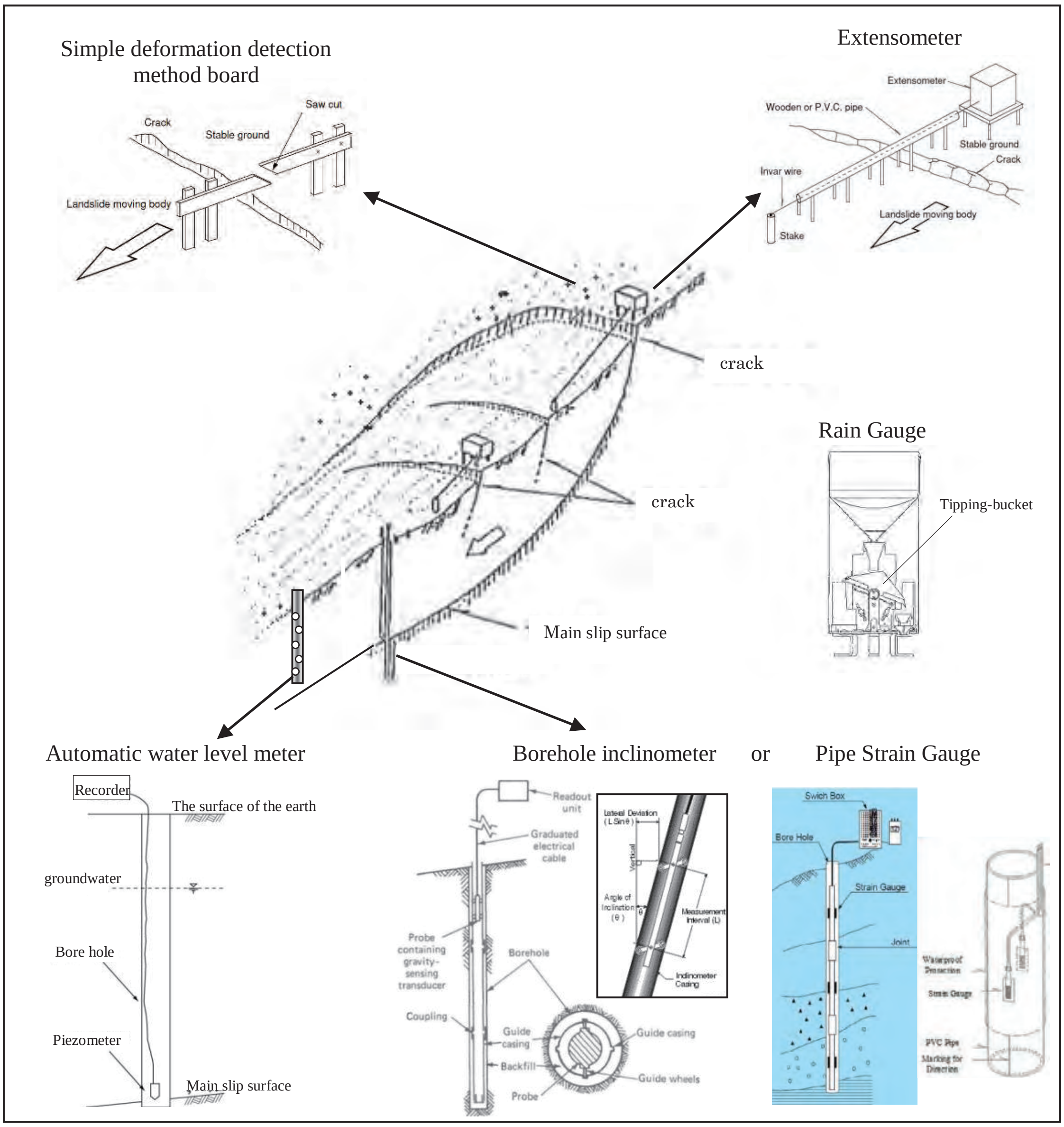


Figure 5.1.6 Setup Images of General Monitoring (source: JET)

5.2 Outline of Countermeasure Policy

Generally, an area or place which has the potential of landslide or large scale slope problems shall not be used for housing or road development. In the case that landslide or slope problems exist or have an impact on a residential area or road, the countermeasure shall be applied substantially based on the required investigations.

The countermeasure shall be planned after the evaluation of landslide hazard based on the hazard rank in the table below.

Table 5.2.1 Evaluation Sheet of Landslide Stability[2] modified

Hazard Rank	Deformation and Topographical feature of landslide	Activation Rank
A	Cracks, subsidence, collapse and uplift caused by landslide are found on the slope. Deformation caused by landslide is found on an existing facility such as a side ditch. No landslide countermeasure works have been installed even though there is a history of previous landslides. It has a high potential for landslide hazard to the road directory despite no artificial landform changes.	Condition a Condition b
B	Clear landslide characteristic features are found even though evidence of landslide activity are not clearly recognized. It has high potential for landslide hazard to the road directory by artificial landform changes.	Condition c
C	The slope shows landslide characteristic features but they are not clear. Even if landslide occurs due to large-scale changing of environment conditions, the possibility for expansion of damage is low and treatment of the landslide damage can be done promptly at that moment.	There is possibility to be condition c

The activation rank is shown in the table below.

Table 5.2.2 Displacement Monitoring by Extensometer[3]

Activation Rank	Daily displacement (mm/day)	Accumulated displacement (mm/month)	Activation
Rank a	More than 1	More than 10	Active movement t
Rank b	0.1 - 1	2 - 10	Sluggish movement
Rank c	0.02 - 0.1	0.5 - 2	Intermittent movement (Further monitoring is required)
Rank d	More than 0.1	Less than 0.5	Partial movement

5.2.1 Decision of Policy of Countermeasure

Landslide countermeasure work can be divided into structural countermeasures and non-structural countermeasures. Generally, structural countermeasure work can be applied for landslide problems. However, in the case that installation of the structural measures is difficult due to topography or environmental conditions or the measures are not a sufficient deterrence force against landslide movement, non-structural countermeasures shall be considered. The policy of countermeasure work shall be decided according to the feasibility study and EIA study results. In some cases, combining structural countermeasures and non-structural countermeasures shall be considered.

For the non-structural countermeasure work, an early warning system using monitoring instruments or relocation can be considered. Regarding non-structural countermeasures, refer to the Manual for Landslides prepared in the Project.

5.2.2 Structural Countermeasure Work

The structural landslide countermeasure work can be divided into control work and restraint work. The control work is the work to stop or mitigate landslide movement by improvement of natural conditions such as topographical and hydrological aspects. The restraint work is the work to stop a part or all of the landslide block by the restraint force of structures installed in the landslide area.

It is not necessarily the case that only one type of countermeasure is installed. Rather, several types of structural landslide countermeasures are applied in combination. The general types of structural countermeasures are shown below.

Control Work

- Surface drainage work (drainage work, infiltration prevention work)
- Groundwater drainage work
  - Shallow groundwater drainage work
    (conduit work, open-blind ditch, horizontal drainage work)
  - Deep groundwater drainage work
    (infiltration well, drainage tunnel work, horizontal drainage work)
- Soil removal work
- Counter weight work
- River structural facility (dam, consolidation work, water control work, revetment work)

Restraint Work

- Pile work
  - Pile work (steal pipe pile work)
  - Shaft work
- Ground anchor work

In the case that the landslide is active, the restraint work will not have the expected proper effect and the construction work will also be extremely dangerous. Therefore, in such a situation, the restraint work shall be installed at an appropriate time after mitigating the landslide movement by control work. Selection of the structural countermeasure can be done according to the flowchart below.

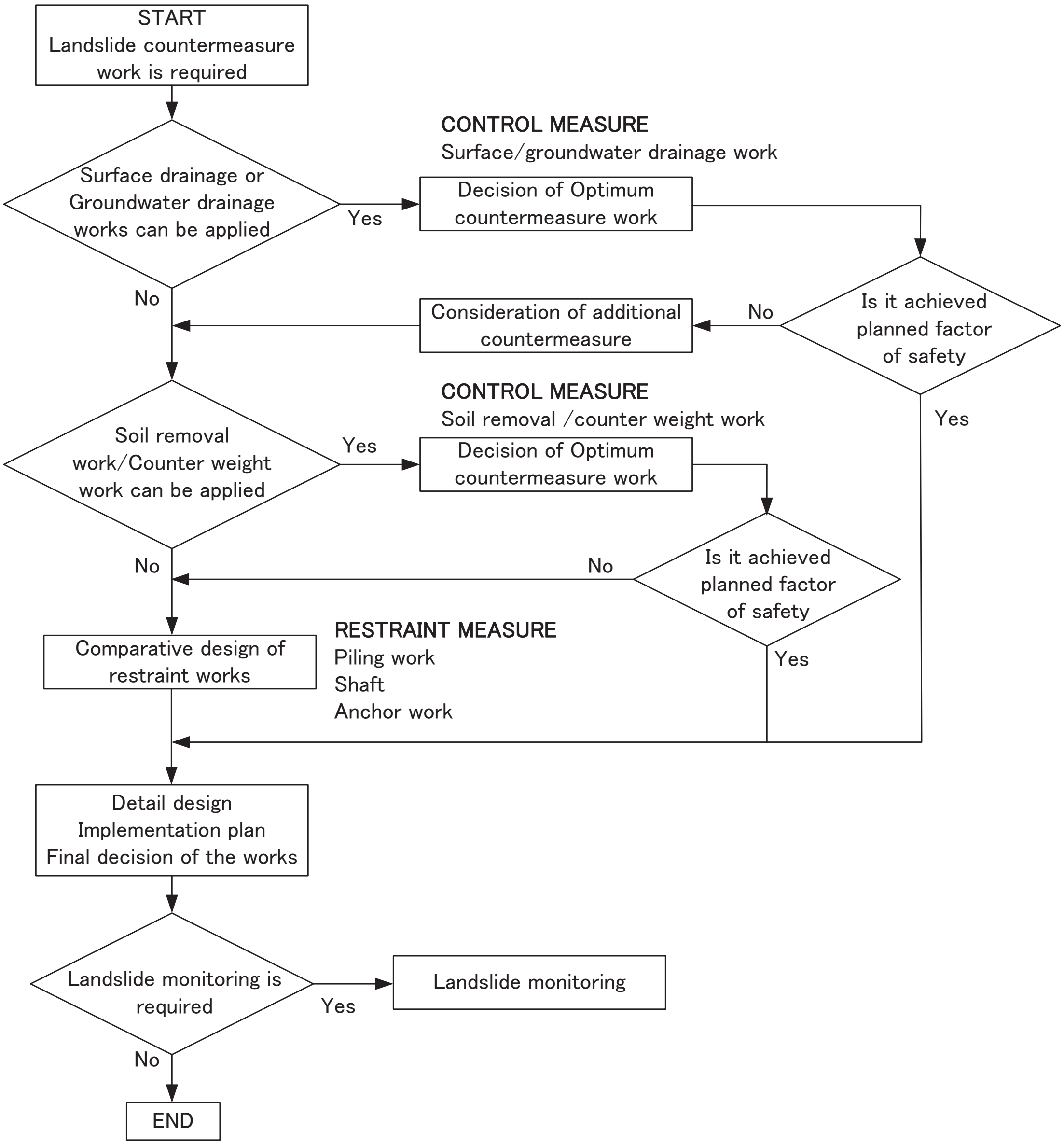


Figure 5.2.1Flowchart for the Selection of Landslide Countermeasure Work[4]

The topographical, geological, and landslide activity conditions, relevancy between rainfall and landslide movement, and safety of the target area shall be clarified when countermeasure work is planned. Furthermore, the mechanism of the landslide shall be clarified based on the figure or landslide block, the figure and depth of the slip surface and the distribution of groundwater. In particular, countermeasures shall be planned according to the following issues.

1. In the case that a relationship between precipitation and landslide movement is found, groundwater drainage works shall be applied to prevent rainfall from infiltrating into the ground.

2. Groundwater can be categorized as shallow groundwater, which flows in an aquifer in the colluvium layer, and deep groundwater, which is confined in base rock under a landslide slip surface. Since there are different types of groundwater drainage work depending on

the type of groundwater, the groundwater drainage work shall be selected based on a study of the influence of the target groundwater on landslide movement.

3. In the case that a relationship between long-term rainfall and the occurrence/movement of landslide is found, it is recommended to apply countermeasure work focusing on deep groundwater drainage work.

4. For an active landslide which consists of cohesive soil such as highly weathered tuff or mudstone, countermeasure work focusing on shallow groundwater/surface water drainage work shall be selected. In the case that the landslide consists of very loose cohesive soil, the landslide shall be settled gradually by a groundwater block wall or groundwater drainage work to prevent groundwater from flowing into the landslide area.

5. In the case that the target landslide is individual* and has a circular slip surface, removal soil work at the head of the landslide or deep groundwater drainage work will be an effective countermeasure. (* A landslide area where other landslide blocks are not found around it.)

6. In the case that the landslide is divided into several blocks and the blocks are neighbouring each other or the slip surface shows a nearly linear shape, groundwater drainage work will be an effective countermeasure work. However, in such cases, counterweight filling work and removal work is not recommended because the works will not have proper effectiveness depending on the location and shape of the works.

7. The restraint work will be an effective countermeasure for a small-scale landslide. Even if the target landslide is large-scale, the work will be effective for stabilization of part of the landslide block. In addition, the work can be applied in cases where control works such as groundwater drainage work or soil removal work are difficult to apply. Since a huge deterrent force will be required against a large-scale landslide, restraint work is often applied in combination with several types of restraint works. Also, as each restraint work has a different mechanism to exert its effectiveness, the acting timing of effectiveness of the countermeasure works, the estimated damage for the period and the economic effect shall be considered carefully in advance.

8. Regarding implementation of the countermeasure work, the sequence or work progress shall be considered carefully to maintain landslide stability because there is a possibility that the landslide may become less stable due to the combination of countermeasure works.

5.3 Confirmation of Development Restriction/Land-use Control and Legal Systems/Schemes

5.3.1 Confirmation of Development Restriction and Land-use Control

If there is no development restriction or land-use control in a landslide site, activities for review of the development restriction/land-use control will be required to avoid the landslide disaster risk by development in the future. If a development restriction/land-use control is available in a landslide site, reconfirmation and coordination with related ministries/agencies/local authorities will be needed for thorough investigation and approval of the development application. The confirmation of development restriction/land-use control should be conducted for the above. It will also require to refer the following information for review of the development restriction/land-use control. If the following information regarding the landslide site is available, the data collection and confirmation should be conducted.

- Disaster record
- Risk map
- Hazard map
- Research/study regarding the disaster risk management

5.3.2 Confirmation of the Legal Systems and Schemes

It is required to comprehend the basis acts of legal systems and schemes regarding the development restriction and land-use control to coordinate with related ministries/agencies/local authorities and review existing regulation.

The following figure shows legal systems/schemes which have a relationship with landslide disaster risk management (hereinafter LDRM) in Mauritius. The existence of the relevant legal systems/schemes in the object area should be confirmed for each site.

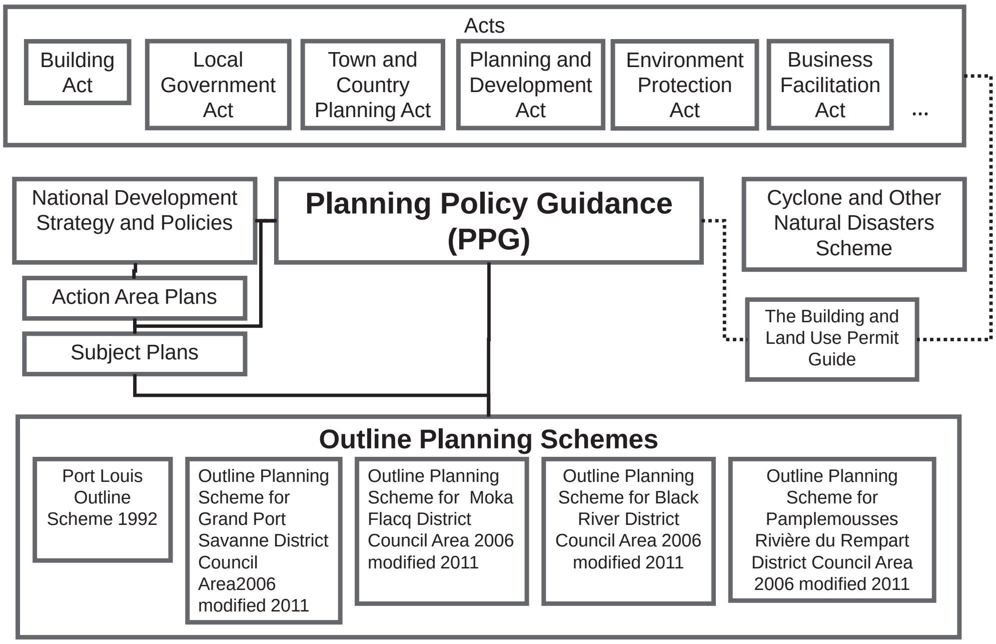


Figure 5.3.1 Acts and Schemes Related with LDRM (source: JET)

The following table shows the detailed content of the principal legal systems/schemes related to LDRM.

Table 5.3.1 The Existing Mauritian Legal Systems/Schemes for LDRM (source: JET)

Legal system/scheme	Content
Planning and Development Act (PDA)	• The Planning and Development Act (PDA) is a new and modern piece of legislation enacted to bring the planning exercise more in line with the requirements of today's changes and challenges (globalization, structural changes in the economy, the need to provide for new sectors of activities). • It gives legal status to the National Development Strategy which had

	remained as a vision document only. ・ However, only a few sections of the PDA 2004 have been proclaimed to date. ・ The objectives of PDA: Sustainable development considering ecological systems; to provide for the appropriate sharing of responsibility for planning and development between the different levels of government; to establish appropriate institutions, structures and processes to achieve effective planning and development; to encourage appropriate private sector participation in planning and development, etc. ・ The Minister of the Ministry of Housing and Lands (MHL) is able to issue Planning Policy Guidance (PPG) regarding development and land use planning to the Local Authorities based on this Act (Article 13 of PDA).
Local Government Act (LGA)	・ The Local Government Act (LGA) is very closely related to the Local Authorities' jurisdiction over development plans. In particular, it covers decentralization, appropriate financial and administrative operation, procedures for development permission, property taxation etc. ・ The LGA also contains the powers and functions of the Permits and Licences Committee, applications for permits, examination of applications for permits and licences by the committee, application to Judge in Chambers, etc.
National Development Strategy (NDS)	・ National Development Strategy (NDS) aims to adopt strategic guidance for the economic infrastructure development of government and local authorities with the goal of achieving development in a planned manner. ・ NDS is made up of two volumes: Volume 1, National Development Strategy & Policies, and Volume 2, Institutional and Legislative Aspects. ・ Volume 1 contains the introduction, context, vision and key development principles, core strategy for conurbation, countryside and coast, housing, social and community facilities, industry and commerce, tourism, agriculture, forestry, natural resources, environment and fisheries, transport, physical infrastructure. In the contents of the core strategy for conurbation, countryside and coast, the PPG is defined as a translated national strategy, namely, made easier to understand, for Local Authorities to actually achieve NDS implementation. ➢ Guidance notes are intended for use by officers involved in development control activities at central and local levels. ➢ It is expected that PPG will be an important element in preparing Local Councils' revised Local Plans and Action Area Plans by translating the NDS policies and principles for application at the local level. ➢ To provide this bridge between policy and implementation, a series of PPG notes has been prepared consistent with the NDS and policies and relevant Local Development Plans (Outline Planning Schemes) as revised.
Planning Policy Guidance (PPG)	・ PPG is a scheme which has legal binding force for land-use policy/planning and can contribute to LDRM in Mauritius. ・ The objective is to create a set of performance criteria and design standards that are applicable to most forms and scales of development for use by individual site owners, developers of large schemes, and assist Government and Local Authorities when considering permit applications. ・ This guidance should be considered with the NDS, Outline Planning Schemes/Local Plans, Action Area Plans and Subject Plans. ・ PPG was established in 2004 and it is revised for commercial

	development, cultural landscape, place of worship, industrial commercial development and small firms, urban heritage areas, radio telecommunication equipment, hotel/resort development and petrol filling stations, etc. ・ PPG has a total of six hundred pages composed of A) introduction and design principles, B) design sheets and C) technical sheets. The design sheets contain commercial development, hotels and resort development, industrial development and residential development. The section on residential development covers design for sloping sites. The design for sloping sites has the following design standards: ➢ Development will not normally be permitted on slopes steeper than 1:5 (20%). ➢ Above slopes of 1:10 (10%), and in areas of poor load-bearing capacity, the ground conditions should be checked and proposed structures certified by a qualified engineer. A Site Constraint Analysis and written statement detailing all proposed mitigation measures should be submitted to and approved by the Permit Authority prior to the commencement of any on-site works. ➢ As a general guide, development should not be any higher than 45 meters above the mountain base or, in the case of slopes facing the sea, 45 meters above Mean Sea Level.
Outline Planning Schemes (OPS)	Outline Planning Schemes (OPS) were legally established based on the TCPA. They are planned for each Local Authority. OPS have three functions: ・ To provide guidance to scheme promoters, developers and individuals contemplating a development project and the subsequent submission of a building and land-use permit application; ・ To assist Government officers at Ministry and Local Authority levels when offering advice to developers and when subsequently assessing permit applications; and ・ To provide the physical development focus for programmes and projects for the variety of Ministries and agencies, as well as the private and non-governmental sectors which have an interest in land development. The Outline Planning Schemes are in two parts: ➢ The Text section which includes: ✧ The Development Context for the Scheme which outlines key development trends, constraints, issues and objectives, and ✧ The Policies and Proposals, which are written in bold, followed by their reasoned justification. The policies are grouped together according to particular subject matter or by land-use type. ➢ The Map section which includes: ✧ The Development Strategy Map, covering major proposals for the whole of the District, and ✧ The Development Management Map, which shows settlements and zones where development is likely to be permitted and other areas where there are various constraints to development.

5.3.3 Confirmation of the Development Restriction by PPG

If a landslide site is not applicable development restriction for sloping site by Planning Policy

Guidance (hereinafter PPG), activities for review of the development restriction/land-use control will be required to avoid the landslide disaster in the future. If a landslide site is applicable the PPG's development restriction for sloping site, reconfirmation and coordination with related ministries/agencies/local authorities will be needed for thorough investigation and approval of the development application. Therefore, the confirmation of the PPG's development restriction for sloping site which is shown below should be conducted.

In the PPG9 existing as of March 2016, it has the following regulations such as Landslide Disaster Risk Management. Once the initial survey is conducted, the following points should be kept in mind:

- Development will not normally be permitted on slopes steeper than 1:5 (20%).
- Above slopes of 1:10 (10%) and in areas of poor load-bearing capacity, the ground conditions should be checked and proposed structures certified by a qualified engineer. A Site Constraint Analysis and written statement detailing all proposed mitigation measures should be submitted to and approved by the Permit Authority prior to the commencement of any on-site works.

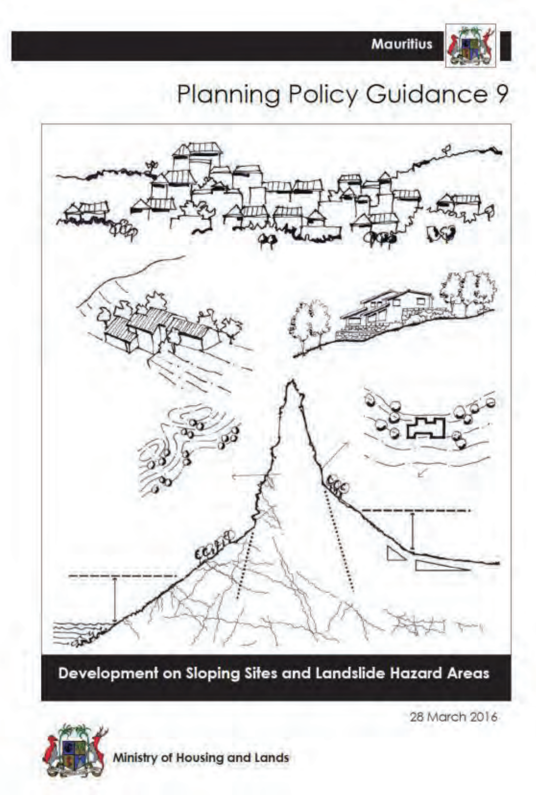


Figure 5.3.2 Revised PPG 9 (source: MHL)

- As a general guide, development should not be any higher than 45 meters above the mountain base or, in the case of slopes facing the sea, 45 meters above Mean Sea Level.
- Buildings and structures should be set back far enough from ridges and cliff edges so that the structure does not appear to be perched on the edge.
-

Table 5.3.2 The Design Guidance for Sloping Sites in the PPG 9 (source: MHL)

Slope height	General guidance development should not be any higher than 45m above the mountain base, or in the case slopes facing the sea above the Mean Sea Level.
Slope gradient: 0% to 3%	Generally suitable for Generally suitable for all development and uses.
Slope gradient: 3% to 8%	Suitable for medium density residential development, agriculture, industrial and institutional uses.
Slope gradient: 8% to 20%	Suitable for moderate to low-density residential development, but great care should be exercised in the location of any commercial, industrial or institutional uses.
Slope gradient: Over 20%	Only used for open space, limited agricultural and certain recreational uses.

Additionally the following information should be considered, if the object area is applicable with the disaster record/hazard map, and if there is an applicable area with the above regulation in/around the object area. Furthermore, it is required attention for location/position, extent, degree of risk and other factors in the record/hazard map.

- Landslide disaster damage record/map
- Topographical/geological condition map
- Flood disaster damage record/map
- Assumed flood area map
- Hazard map of landslides, slope failure, floods, etc.

The examination of problems regarding the development restriction/land-use control is required through the evaluation of the existing study/project, the data collection and hearing investigations/meetings with related ministries, agencies and local authorities.

5.3.4 Confirmation of the Development Plan regarding the Landslide Site

The development record regarding a landslide site will be useful for identification of the cause of the landslide, examination material for emergency countermeasure and others. Also, the confirmation of the development plan in the future is important to consider the disaster prevention measures. When the development record/plan will be confirmed, it will be require to refer the following information. If the following information regarding the landslide site is available, the data collection and confirmation should be conducted.

Natural Conditions
- Meteorological condition
- Topography
- Geology/Soil
- Land-use
- River/Basin
- Drainage
- Environment
- Cultural assets

Social Conditions
- Population
- Road network
- Bus system
- Water facility
- Drainage facility
- Park
- Public utility

Land-use Planning Conditions
- Settlement boundary
- Zoning (use district, scenic zone, etc.)
- District planning
- Land-use planning for public facility
- Term/Condition by the Building Act

Reference

[1] Japan Landslide Society, 2002, Landslides in Japan (The Sixth Revision), p.21.
[2] Japan Road Association, 1999, Road Earthwork Manual -Cut slope and Slope Stability- , p. 340
[3] Ibid, p. 116
[4] Ibid, p. 355