CHAPTER 3

HAZARD AND RISK ASSESSMENT ON SLOPE DISASTERS

3.1 Slope Disaster Types along Narayangharh – Mugling Highway

Hazard and risk assessment was conducted considering the following:

A. Qualitative assessment of the stability of slopes

B. Risk assessment for selected slopes along the road applying the evaluation method proposed by the Team.

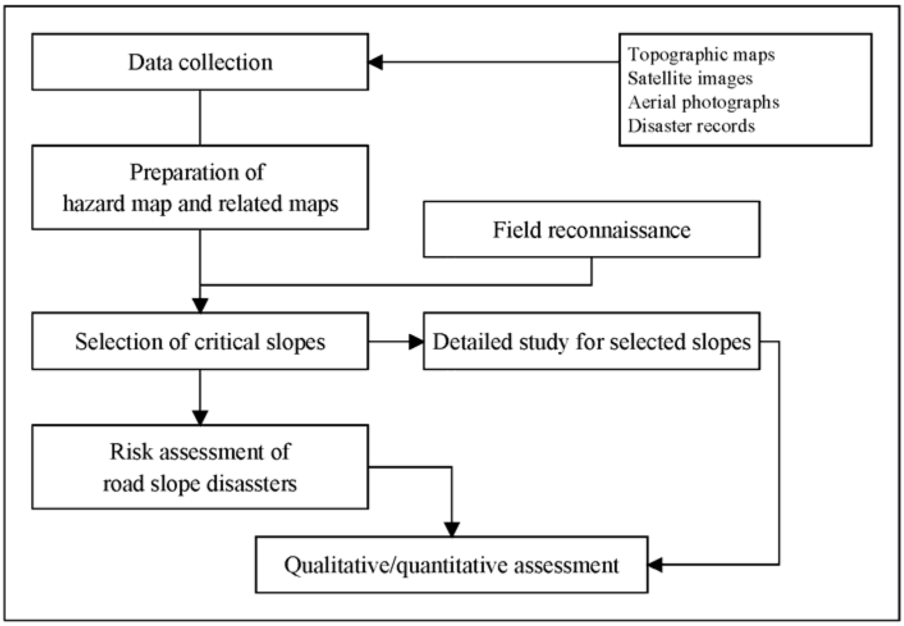


Figure 3.1.1 Flow of Slope Hazard/Risk Assessment

3.1.1 Possible Slope Disasters along Narayangharh – Mugling Highway

(1) Hazard Map and Thematic Maps for Hazard/Risk Assessment

(a) Preparation of Hazard Map

The Team prepared a hazard map and other related thematic maps. These maps were used to assess hazard and risks for the highway.

The hazard map was prepared using various available data and information.

The Team processed the DEM to prepare the slope gradient map (Figure 2.1.3) and the slope aspect map (Figure 2.1.4).

Aerial photographs and high-resolution satellite images were interpreted stereographically to identify landslide potential, debris flows, and slope failures.

Major geological structures were interpreted from existing small scale geological maps.

Finally, locations of major slope hazards (and potential areas) were plotted comprehensively on topographic maps with a nominal scale of 1:25,000.

(b) Interpretation of Hazard Map

There are about 30 slopes having slide potential along the highway as shown in Figure 3.1.2. It means that most of 26 km (CH 10 – CH 36) section of the highway is adjacent to slide potential zones. Finally, locations of major slope hazards (and potential areas) were plotted comprehensively on topographic maps with a nominal scale of 1:25,000.

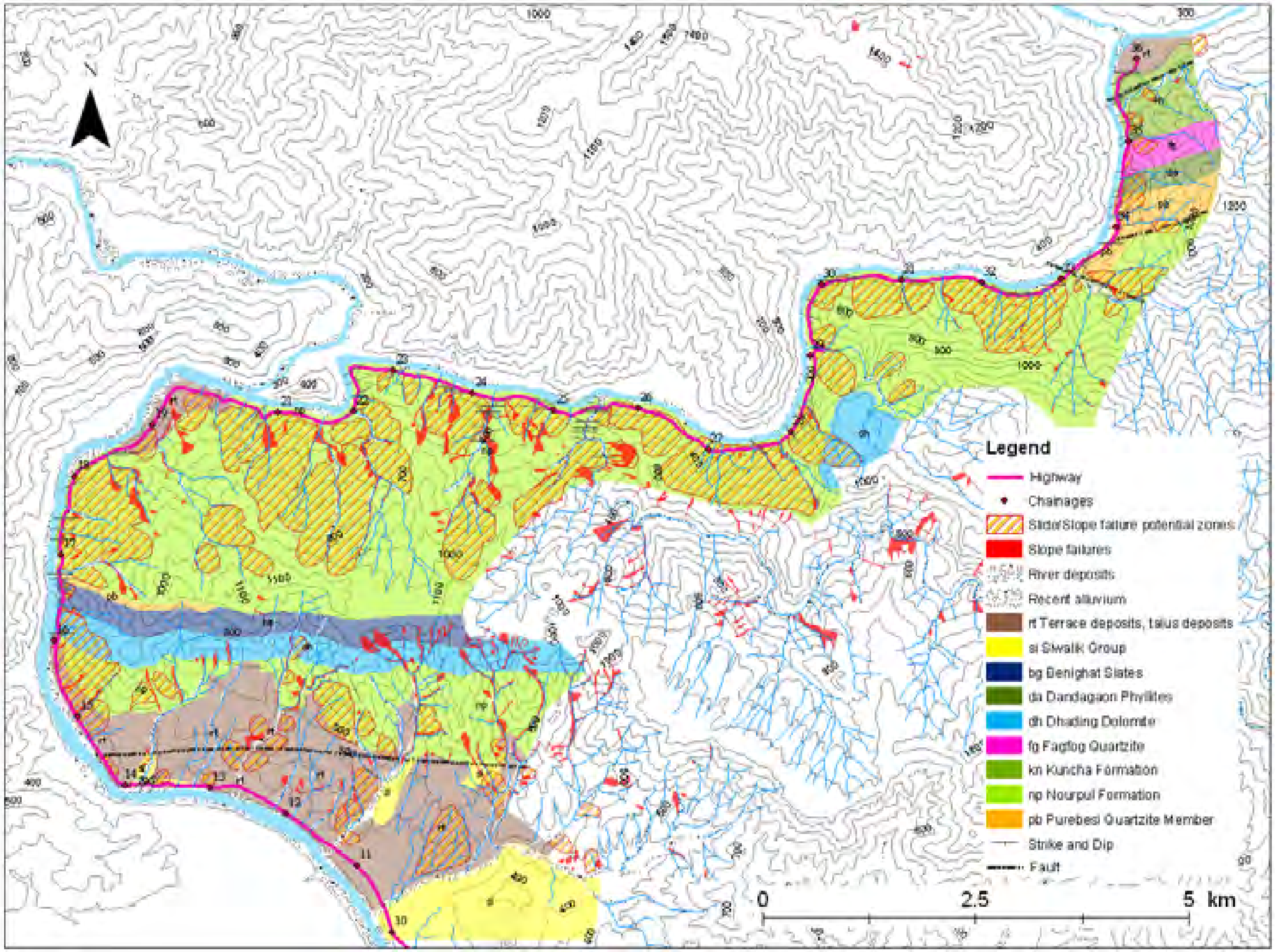


Figure 3.1.2 Hazard Map for CH 10 – CH 36 of N-M Highway

There are about 15 photo-interpreted lineaments along the highway. Some of the lineaments seem to coincide with the major faults such as the MBT. The interpreted lineaments are considered to imply boundaries of rocks, cracks related to slides, and other active/inactive (historic) faults, too.

Various sizes of slope failures are recognized on high resolution satellite images at nominal scales of 1:5000 – 1:10,000. Many locations of slope failures are located in both sides of landslide potential slopes (both sides of mountain streams).

Many of slope hazards, especially landslides and slope failures are considered to be related to bedrock geology and geological structures, e.g., faults, foliations, bedding planes, and folds.

(2) Field Reconnaissance and Observation in Site

Field reconnaissance and observation in the field brought additional and real knowledge to the Study.

(a) Geological Mapping at 1:25,000

The geologist of the Team mapped bedrock geology along the highway section (CH 10 – CH 36) at a scale of 1:25,000. Slope geology along chainage is mentioned in Chapter 2.

(b) Slope Inventory Survey

Critical road slopes were selected through the preliminary field reconnaissance. And the selected road slopes were studied and reviewed with the Road Slope Inventory Sheets proposed by the Team. Results of the slope inventory survey and review and estimation for each slope are mentioned in the later section 3.3.

(3) Geometrical Slope Classification

Through the field reconnaissance by the geologist, typical slope hazards that might affect the highway were recognized. Typical slope hazards with chainage are mentioned in this section.

Through the field reconnaissance, the geologist of the Team recognized that combination of slope position and geology is important to understand the slope hazards for the highway.

In between CH 10 – CH 36, road slopes can be classified into eight aspect groups that are north-facing slope, northeast-facing slope, east-facing slope, southeast-facing slope, south-facing slope, southwest-facing slope, west-facing slope and northwest-facing slope as shown in Figure 2.1.4.

According to slope aspects, road/natural slopes along the highway can be classified into three categories, which are dip-slip slopes, reverse-slip slopes and transverse slopes.

Figure 3.1.3 below shows a schematic diagram geometrically explaining slopes of dip-slip, reverse-slip and transverse-slip.

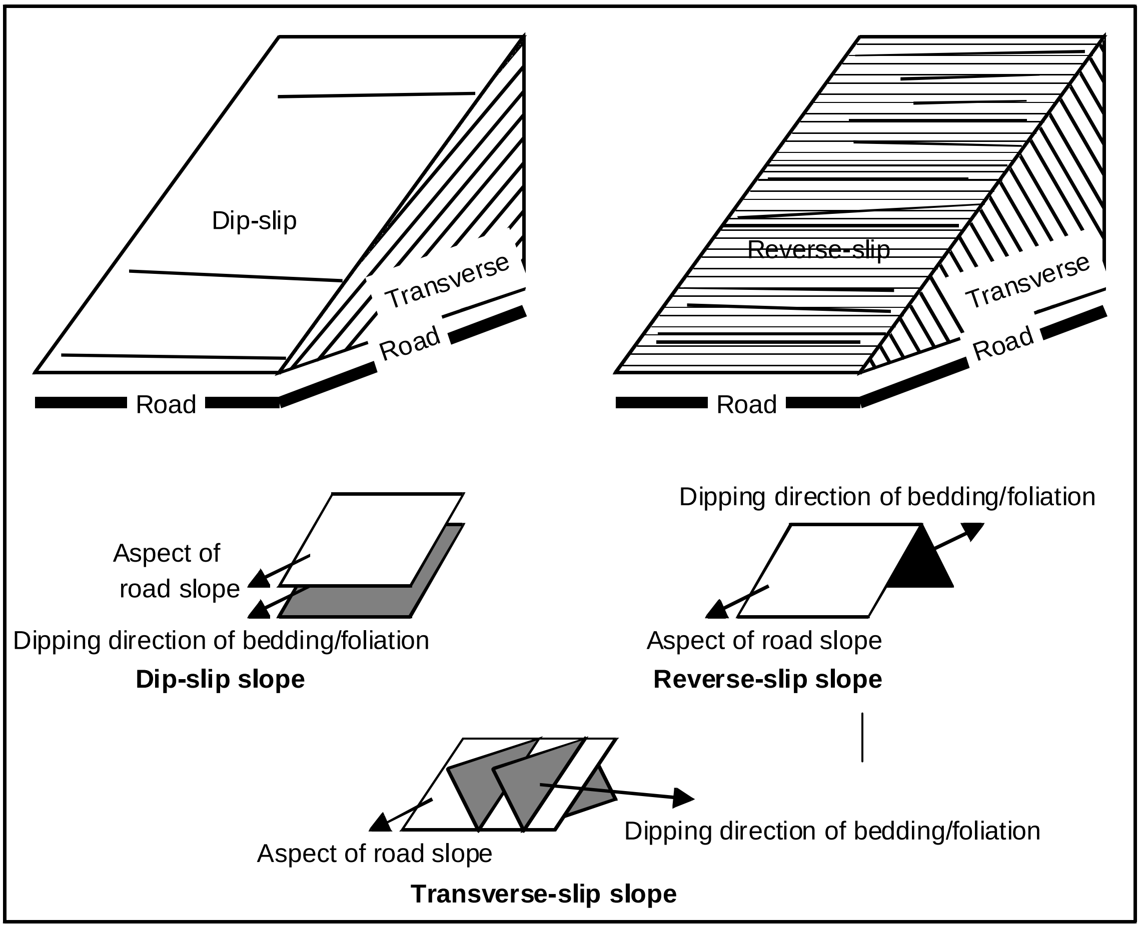


Figure 3.1.3 Geometric Classification of Road Slopes

Table 3.1.3 shows a slope classification by slope aspect and geological structure. As shown in Table 3.1.3, road slopes generally face toward north, southwest, west, and northwest. Northeast-/East-/South-/Southeast- facing slopes are limited and minor groups along the highway.

Major planar geological structures (bedding planes and foliations) in the study area strike in directions of NE-SW and/or E-W, and dip with various angles and directions.

Table 3.1.1 below also shows geometrical slope classification of road sections. Each geometrical slope can be categorized into one of dip-slip, transverse-slip or reverse-slip.

Table 3.1.1 Slope Type Classification with Chainage

Chainage	Aspect	Slope Class	Major Potential Hazard
10+100 – 14+100	SW and S	Reverse-slip	DF, RF
14+100 – 15+600	SW	Transverse-slip	SF, DF
15+600 – 16+800	W	Transverse-slip	SF, DF
16+800 – 17+900	W	Transverse-slip	SF, DF
17+900 – 19+500	NW	Dip-slip	DF, SF
19+500 – 22+000	N	Dip-slip	SF, SL, DF, RF
22+000 – 22+500	W and NW	Transverse-slip	SF, RF
22+500 – 23+000	N	Dip-slip	SF, SL, DF, RF
23+000 – 27+900	N	Dip-slip	SF, SL, DF, RF
27+900 – 29+500	W and N	Transverse-slip	SF, SL, DF, RF
29+500 – 30+100	W	Dip-slip	SF, RF
30+100 – 33+200	N	Reverse-slip	SF, RF, DF
33+200 – 36+000	W and NW	Transverse-slip	RM, SF, RF

DF: Debris flow, RF: Rock Fall, RM: Rock Mass Fall, SF: Slope Failure, SL: (Land) Slide
N: North, W: West, NW: Northwest, SW: Southwest, S: South

Figure 3.1.4 below shows simply strikes of dips of bedrocks in the study area.

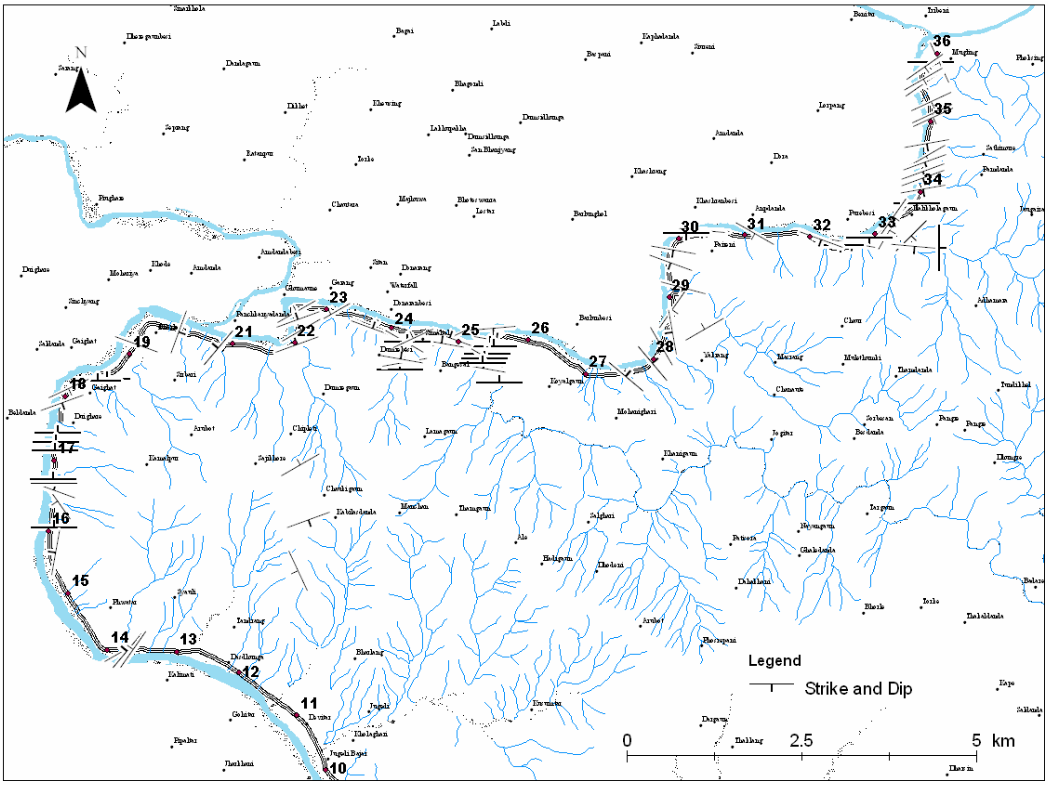


Figure 3.1.4 Strikes and Dips of Bedrock along the Highway

(4) Overview of Existing Slope Hazards

(a) CH 10+100 – CH 14+100

A section of CH 10+100 – 14+100 is located on horizontal/very gentle slopes. Road slopes within this section generally face southward or southwestward.

Road slope geology is mainly the Quaternary unconsolidated deposits forming river terraces along the Trishuli River and its tributaries.

Here, relatively big streams cross the highway. The highway meets the Das Khola at CH 12+600, the Khare Khola at CH 11+300, and the Jugedi Khola at 10+300.

Each stream (khola) has generally big watershed (3 – 5 km^2 or more), and reaches at an elevation of 1000 m. In upstream areas composed of rock slopes, many big slope failures had occurred near the ridges. In downstream areas, a number of slope failures have been observed on river terrace slopes. Such a big amount of slope failure materials are potential source of debris flows to rush into the Trishuli River.

Figure 3.1.5 below shows a schematic illustration of debris flows for the section CH 10 + 100 – CH 14+100.

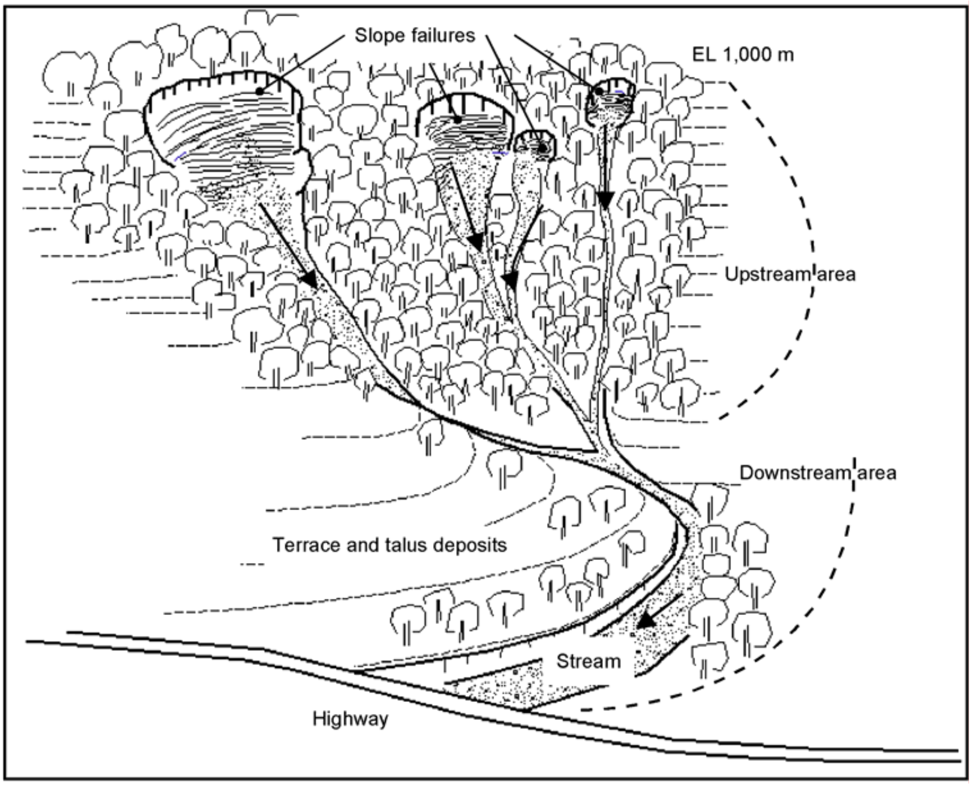


Figure 3.1.5 Schematic Illustration of Slope Failure – Debris Flow Succession

(b) CH 14+100 – CH 15+600

A section of CH 14+100 – CH 15+600 is located on southwest-facing slopes. Road slope geology of this section is mainly the Quaternary unconsolidated deposits (terrace deposits, talus deposits, and recent deposits).

The bedrock comprises of sandstone and mudstone of the Siwalik Group that is covered by the Quaternary deposits. Road slopes of the section are categorized into the transverse slope.

Within this section, large-scale slope hazards cannot be seen. However, small-scale slope failures or debris flows are common.

(c) CH 15+600 – CH 16+800

A section of CH 15+600 – CH 16+800 is located on west-facing slopes. Road slope geology of this section mainly comprises of the Nourpul Formation, the Dhanding Dolomite, the Benighat Slates, and the Purebesi Quartzite Members from the south. These rocks are covered by loose talus deposits.

The slopes are categorized into transverse-slip slip. Within this section, large-scale slope failures are often observed around an elevation of 700 m. And rock falls or rock mass falls from dolomite cliffs frequently occur. Dolomite is usually hard and massive. Therefore dolomite rock falls can easily reach near to the highway. Small-scale debris flows are observed commonly. Source material of debris flows are mainly collapsed bedrocks fallen down from its original positions. Figure 3.1.6 shows typical slope hazards in this section.

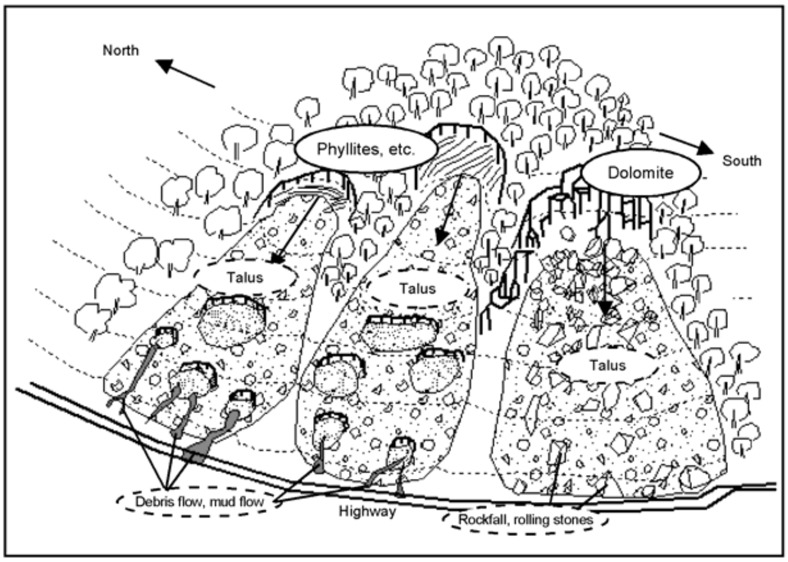


Figure 3.1.6 Schematic Illustration of Slope Failure – Debris Flow Succession

(d) CH 16+800 – CH 17+900

A section of CH 16+800 – CH 17+900 is located on west-facing transverse-slip slopes. Road slope geology of this section comprises of phyllites and sandstone of the Nourpul Formation. Generally these bedrocks are covered by thin soil covers and talus deposits.

In this section, slope failure and landslide are common hazards. Small-scale debris flows are observed commonly, too (See Figure 3.1.6 above).

(e) CH 17+900 – CH 19+500

A section of CH 17+900 – CH 19+500 is located on northwest-facing and dip-slip slopes. Road slope geology of this section comprises of phyllites and sandstone of the Nourpul Formation. Adjacent to the highway, river terrace deposit covers the bedrocks between CH 18+500 and CH 19+500.

This section of 1.6 km has relatively low slope hazard potential to the highway. However debris flows along mountain streams are frequently observed.

(f) CH 19+500 – CH 22+000

A section of CH 19+500 – CH 22+000 is located on north-facing and dip-slip slopes (See Figure 3.1.7). Road slope geology of this section comprises of phyllites and sandstone of the Nourpul Formation.

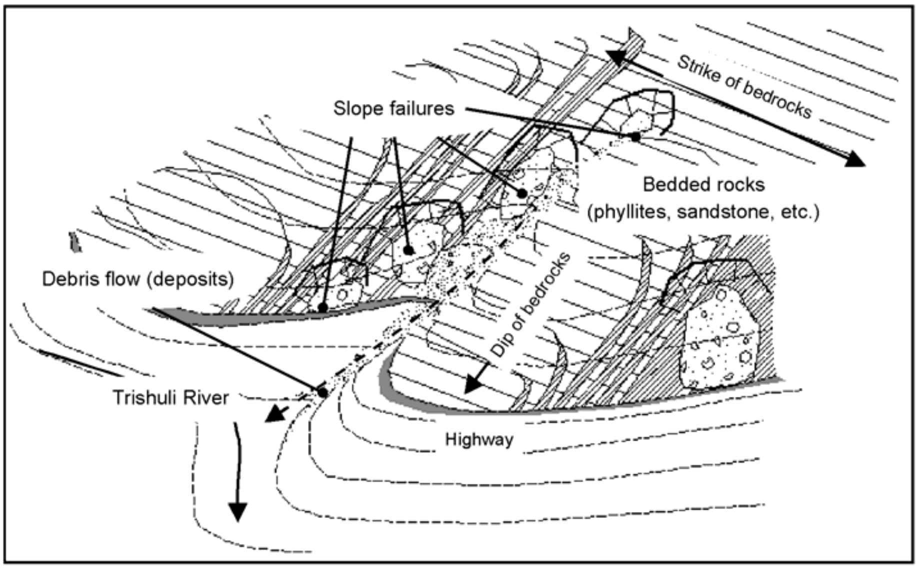


Figure 3.1.7 Schematic Illustration of Dip-Slip Slope

This section of 2.5 km is one of hazardous sections of the highway. Slope failures and landslides are often recognized along the road, and also debris flows have affected the road, too.

Within the section, a big landslide is recognized on a slope at CH 21+750 m approximately. This landslide named SL-1 was selected for a F/S site and surveyed in detail by the Team as mentioned below section.

(g) CH 22+000 – CH 22+500

A section of CH 22+000 – CH 22+500 is located on west and northwest-facing and transverse-slip slopes. Road slope geology of this section comprises of phyllites and sandstone of the Nourpul Formation.

Within this section of 500 m, typical slope hazard is slope failure as shown in Figure 3.1.8 and Figure 3.1.9 below.

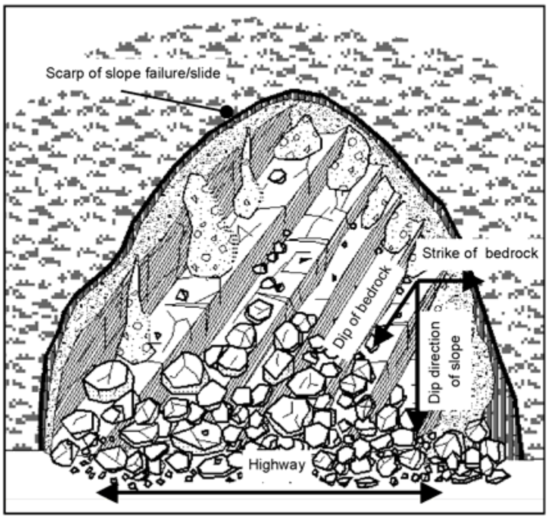


Figure 3.1.8 Typical Slope Failure in between CH 22 – 22+500

Wedge-shape rock slides are also observed.

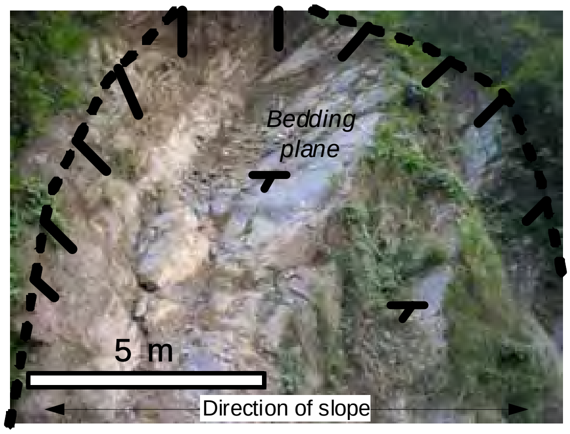


Figure 3.1.9 Wedge-shaped Rock Slides forming a Slope Failure

(h) CH 22+500 – CH 23+000

A section of CH 22+500 – CH 23+000 is located on north-facing and dip-slip slopes. Road slope geology of this section comprises of phyllites and sandstones of the Nourpul Formation.

Small-scale slope failures and landslides are common within this section of 500 m.

Figure 3.1.10 North-facing Dip-slip Slope and Highway along Trishuli River

(i) CH 23+000 – CH 27+900

A section of CH 23 – CH 27+900 is located on north-facing and dip-slip slopes. This section of 4900 m is one of hazardous sections of the highway.

There are many landslides, slope failures, and debris flows along the highway, and with various scales. Especially, debris flows have frequently occurred and disturbed highway transportation. Big landslides and slope failures that directly affect the highway is not so common. However, such kinds of slope hazards are very active within mountain streams that are crossing the highway, and supplying source material of debris flows.

Within this section, there are three slopes having landslide potential. They are named SL-2, SL-3, and SL-4 respectively, and studied in detail as the F/S sites as well as SL-1. Excluding these selected sites, there are many bedding-slip landslides (rock slides) and can be observed along the highway as shown in Figure 3.1.11 and Figure 3.1.12.

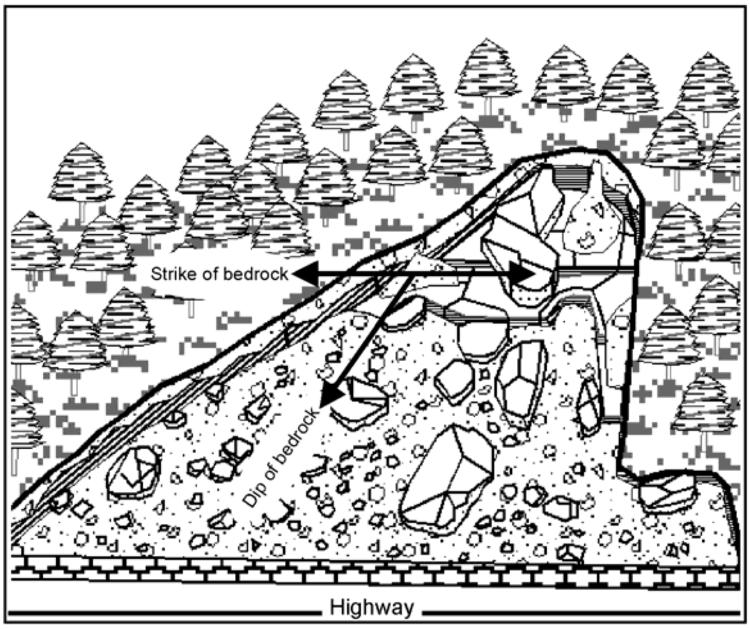


Figure 3.1.11 Schematic Illustration of Bedding-parallel Slip along Highway

Figure 3.1.12 Typical Dip-slip Slope formed by Bedding-parallel slip of bedded rock (CH 25+500, near the Rigdi Khola)

The bedrocks are mainly alternating beds of phyllite and sandstone (sometime quartzite). Weathering seems to penetrate deeply into the rocks there. The rocks have many non-tectonic deformation suggesting gravity creeps, and frequently sheared tectonically. Low-angle joints are developed through phyllites as shown in Figure 3.1.13 below.

Figure 3.1.13 Non-tectonic deformations of phyllites of the Nourpul Formation (Left: road side-dipping joints, Right: gravitational fold of phyllites)

(j) CH 27+900 – CH 30+000

A section of 2100 m between CH 27+900 and CH 30 is divided into the following short sections.

A section of CH 27+900 – CH 29 is located on west-facing and transverse-slip slopes. A section of CH 29 – CH 29+100 is located on north-facing and reverse-slip slopes. A section of CH 29+100 – CH 29+200 is located on south-facing and dip-slip slopes. Remaining section is west-facing transverse-slip slopes.

Bedrock of the section of 2100 m is of the Nourpul Formation. Slope failures are common hazards.

(k) CH 30+000 – CH 33+200

A section of CH 30+100 – CH 33+200 is located on north-facing and reverse-slip slopes. Bedrock is of the Noupur Formation.

Rock fall and slope failures are typical slope hazards. At streams, debris flows are observed.

(l) CH 33+200 – CH 36+000

A section of CH 33+200 – CH 36 (Mugling) is mostly located on west-facing and transverse-slip slopes.

Bedrocks comprises of south-dipping meta-sedimentary rocks of the Purebesi Quartzite, the Dandagaon Phyllites, the Fagfog Quartzite, and the Kuncha Formation.

Typical slope hazards within this 2800 m section are rock fall from quartzite slopes, and slope failures on other meta-sedimentary rock slopes.

Large-scale landslide is not recognized.

Steep cut-slope of the Fagfog Quartzite seems to be stable. However it might be collapsed toward the highway in case of a big earthquake.

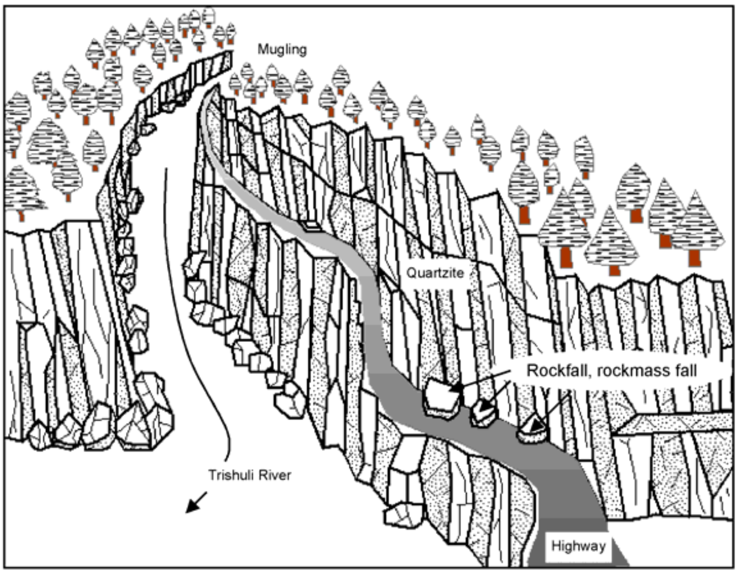


Figure 3.1.14 Schematic Illustration of Rock fall from Cut-Slope of Quartzite

3.1.2 Classification of Slope Disasters on Narayangharh – Mugling Highway

Typical slope disaster types in the region are divided on the basis of the geometrical slope classification as shown in the preceding section. In this section, general classification of the slope disaster type is reviewed at first, then the characteristic and conceptualistic hazard type along the N-M Highway is re-arranged to assess the slope risk appropriately.

(1) General Classification

Classification and terminology for slope hazards have to be defined clearly to facilitate understanding among the persons and the organizations involved in the Study. The slope hazards here indicate “landslide” in general terminology. The term landslide denotes “the movement of a mass of rock, debris or earth down a slope” (Cruden, 1991), and snow avalanches and ice falls are excluded.

In general, landslides are classified by type of movement and material (Varnes, 1958; Varnes, 1978). Types of movement are divided into five (5) main groups: FALL, TOPPLE, SLIDE, SPREAD, and FLOW. A sixth group, complex slope movements, includes combinations of two or more of the other five (5) types. The classification for landslides has been widely adopted. The most common types of landslides are described as follows (Cruden and Varnes,

1996) and are illustrated in Figure 3.1.15 (U.S. Geological Survey, 2004).

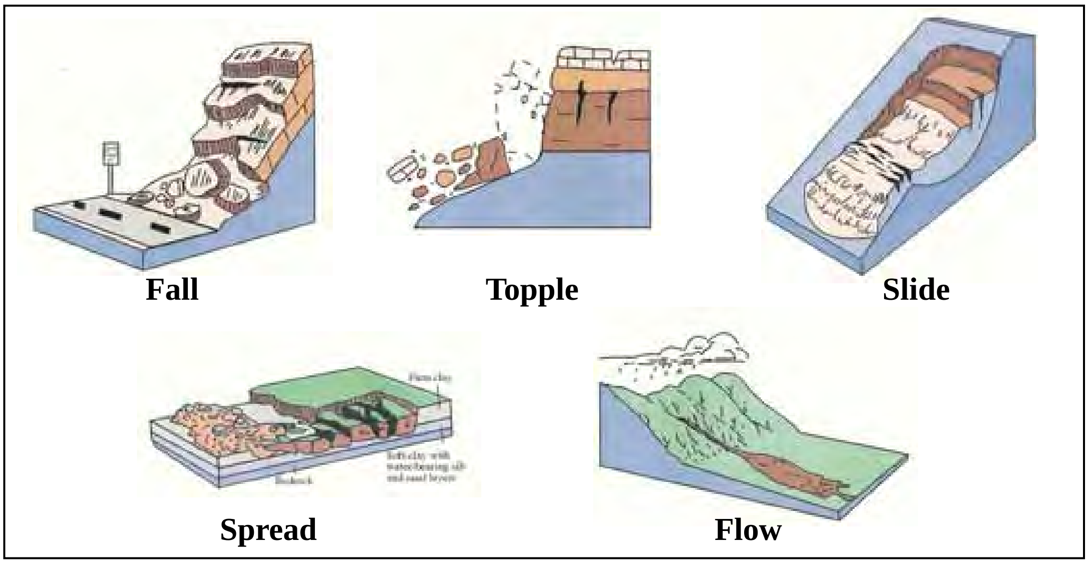


Figure 3.1.15 Schematic Illustrations of the Major Types of Landslide Movement

<u>Fall</u>: A fall starts with the detachment of rock from a steep slope along a surface on which little or no shear displacement takes place. The material then descends largely through the air by falling, saltation or rolling. Movement is very rapid to extremely rapid.

<u>Topple</u>: A topple is the forward rotation out of the slope of a mass of soil or rock about a point or axis below the center of gravity of the displaced mass. Toppling is sometimes driven by gravity exerted by material upslope of the displaced mass and sometimes by water or ice in cracks in the mass. Topples range from extremely slow to extremely rapid, sometimes accelerating throughout the movement.

<u>Slide</u>: A slide is a downslope movement of a soil or rock mass occurring dominantly on surface of rupture or on relatively thin zones of intense shear strain. Movement does not initially occur simultaneously over the whole of what eventually becomes the surface of rupture; the volume of displacing material enlarges from an area of local failure.

<u>Spread</u>: Spread is defined as extension of a cohesive soil or rock mass combined with a general subsidence of the fractured mass of cohesive material into softer underlying materials. The surface of rupture is not a surface of intense shear. Spreads may result from liquefaction or flow of the softer material.

<u>Flow</u>: A flow is a spatially continuous movement in which surfaces of shear are short-lived, closely spaced, and usually not preserved. The distribution of velocities in the displacing mass resembles that in a viscous liquid.

(2) Terminology in the Study

In this Study, a unique classification that is more practicable and more suitable planning countermeasures of road disasters, referring only to Varnes' classification. The proposed classification is composed of the mode that is based on the review of slope disasters in N-M Highway, especially the catastrophic disasters in 2003. The proposed classification for landslides should be discussed with the scientists and the geologists in Nepal. The classification in the Study and their characteristics are shown in Table 3.1.2, and each type is described as follows and is schematically illustrated in Figure 3.1.16.

(a) Rock fall

A rock fall is a very rapid detachment from hard rock slopes or soil slopes including boulders and rock with gradients over 50 degrees, and is influenced by the distribution of cracks and fractured bedrocks. Rock falls are usually below dozens of cubic meters, and might occur simultaneously with slope failures. The modes are free fall, saltation or rolling down of the rock.

(b) Rock mass fall

A rock mass fall is a very rapid detachment from hard rock slopes in escarpment, and is influenced by the distribution of cracks and fractured bed rocks. The rock mass fall is distinguished from rock falls according to the scale. The scale of rock mass fall is a hundred cubic meters or more, and its damage to roads can be considerable.

(c) Slope failure

A slope failure is a very rapid soil slope failure in high cut or natural slopes with gradients of over 50 degrees, and is triggered mostly by heavy rain infiltration and saturation. The slope failure is divided into a shallow failure and a deep failure. Material of shallow failures is generally residual soil produced by weathering of rocks or detritus soils hanging in steep slopes. Generally, the volume involved in shallow failure is rather small, ranging from dozens to several hundreds of cubic meters. The characteristics of deep failure resemble that of large slide, and the scale is comparatively large to moderate. Many shallow failures in the 2003 disaster are distributed in the Study area.

(d) Slide

A slide is a mass movement with slow rate of the movement, including soil mass slide, rock wedge block slide, and rock slope toppling or spreading. Slides are activated not only on an upper slope above the road but also on a lower slope below the road. Some upheaval or subsidence of part of the road might occur due to the sliding. The slides are divided into three groups: 1) a slide that clearly has sliding features with gentle slopes, 2) a slide that clearly has no sliding feature, and 3) a deep slide whose characteristics resemble that of deep failures with steep slopes. Group 2) is predominantly distributed in the Study area during the 2003 disaster. The slide is prone to occur on slopes of earth and highly weathered rocks, and is activated mostly by rainfall infiltration. The movement is slow to extremely slow. Many people live on a gentle slope in the upper part of “huge slide” in the Study area.

(e) Road foundation failure

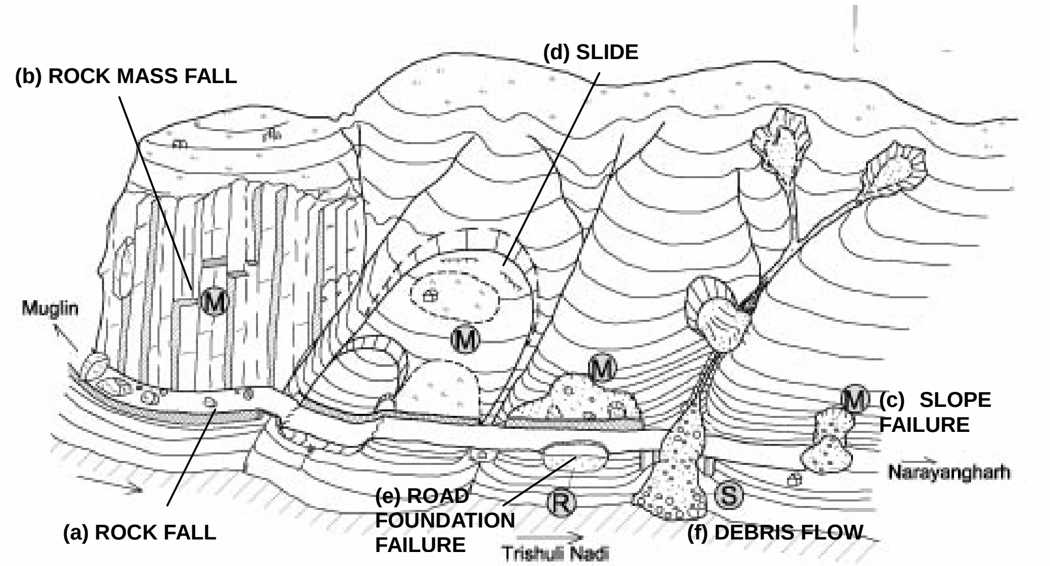
A road foundation failure is a failure, slide, erosion and settlement mainly on the road foundation or some parts of the valley-side slope, which is mainly induced by leakage of surface water. It includes river erosion that erodes or scours the river-side slope of the road, which is caused by flooding. The occurrence might be done by earthquakes or artificial constructions. The rate of movement is very rapid, and its scale is small to moderate. The failure is prone to occur in embankments, natural soil slopes and highly weathered rock slopes. Many road foundation failures in the 2003 disaster are distributed in the Study area.

(f) Debris flow

A debris flow is the rapid flow of boulders, sand, silt and tree mixed with a large quantity of water, and in which occurrence points are in valleys and torrents of mountainside slopes above the road. It flows rapidly down to the riverbed with slope of over 20 degrees, and stops to deposit the debris in the riverbed where the gradient is less than 10 degrees. The scale is moderate to large. Debris flows are mainly generated by 1) slope failure of riversides, 2) abrupt re-movement of deposits in torrents and 3) failure of nature-made dams, which are mostly caused by heavy rainfall as a trigger. Group 1) is predominantly distributed in the Study area during the 2003 disaster.

Table 3.1.2 Classification and Characteristics of Slope Hazard Type in the Study

Slope type	Slope hazard type	Main material	Rate of movement	Predominately scale	Main trigger
Mountainside slope	(a) ROCK FALL	bed rock (fresh)	very rapid	small	rainfall, earthquake
	(b) ROCK MASS FALL	bed rock (fresh)	very rapid	moderate - large	rainfall, earthquake, artificial construction
	(c) SLOPE FAILURE	weathered rock, residual soil, debris	rapid - very rapid	Small - moderate - large	rainfall, earthquake, artificial construction, riverside erosion
Mountainside slope / Road and riverside slope	(d) SLIDE	bed rock, weathered rock, soil (produced by repeat of sliding), debris	slow -very slow, very rapid	moderate - large	rainfall, earthquake, artificial construction, riverside erosion
Road and riverside slope	(e) ROAD FOUNDATION FAILURE	embankment material	rapid - very rapid	small - moderate	rainfall, earthquake, artificial construction, riverside erosion
Crossing stream	(f) DEBRIS FLOW	weathered rock, debris, residual soil	very rapid	moderate - large	rainfall



M: Mountainside slope, R: Road and riverside slope, S: Crossing stream

Figure 3.1.16 Schematic illustrations of slope hazard type in the Study

3.2 Stability Assessment of Selected Landslide Sites

3.2.1 Selected Sites

The Team selected four sites (hereinafter described as SL) that are considered as large-scale landslides adjacent to the highway. The sites were initially identified based on preliminary field reconnaissance jointly carried out by the DWIDP and the Team on August 2 and August 3, 2007. After selection of the sites, the Team planned the survey items and quantities of the work to be executed by a Nepalese local consultant firm. The survey items and quantities of the work are shown in Appendix (See Appendix-2).

The work above included topographic survey for other critical sites too.

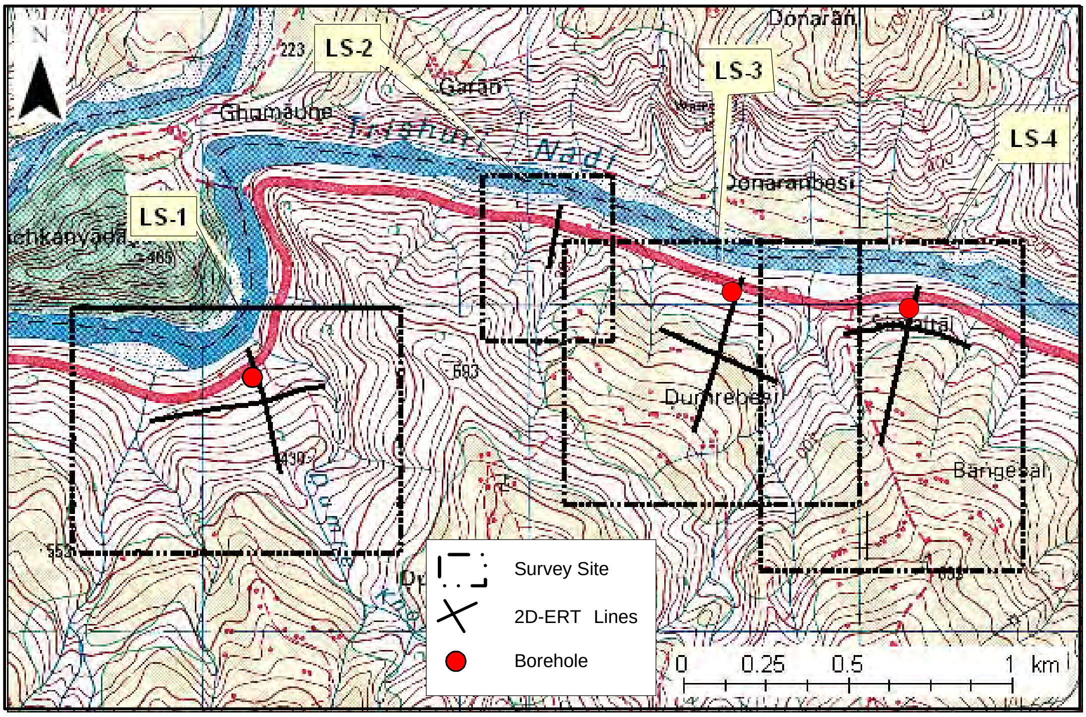


Figure 3.2.1 Location of selected survey sites for Narayangharh-Mugling Highway

3.2.2 Site Conditions

The selected four sites are north-facing and dip-slip slopes as mentioned in Section 3.2.1. Bedrock of the sites comprises meta-sedimentary rocks of the Nourpul Formation.

Table 3.2.1 below summarizes the existing site conditions of the selected sites.

Table 3.2.1 Condition of Selected Sites

Site	Conditions
SL-1	SL-1 is a north-facing and dip-slip slope. Many deformations related to landslide could be identified, e.g., open cracks of the road-side retaining walls, spring water, rotation of gabion walls, and rock falls. The site shows a typical topographic shape of a landslide. Bedrocks comprise meta-sedimentary rocks of the Nourpul Formation and unclassified intrusive basic rock that forms a steep cliff around an elevation of 380 m.
SL-2	SL-2 is a north-facing and dip-slip slope, located approximately at CH 23+600 m. Currently an unstable rock mass have been sliding toward the highway. Masonry road-side retaining wall below the unstable rock mass had been deformed due to rock mass sliding. The cracks on the masonry wall were visible in early of August 2007. The cracks had been widened gradually during the monsoon in 2007, and finally it was collapsed due to heavy rainfall on September 17 in 2007. Bedrocks of the site are of the Nourpul Formation. Slope surrounding this unstable rock mass is at risk of sliding. The unstable rock mass had remained on the slope above the road.
SL-3	SL-3 is a north-facing and dip-slip slope located at CH 24 approximately. At the riverside slope of the site, a concrete wall with anchoring was constructed as countermeasure. Furthermore, concrete blocks have been placed on the riverbed to protect riverside slope from river water erosion. Similar to SL-2, there is an unstable rock mass sliding towards the highway. The road-side retaining masonry wall had been deformed and cracked. Finally. it failed on September 4, 2007, due to the heavy rain fall on September 3, 2007. The unstable rock mass had remained on the slope above the road. Slope including the unstable rock mass has many deformation suggesting landslide, e.g., open cracks, scarps of slope failures, spring water from cracks of the bedrocks, kink bands and micro-folds of foliations, disturbance of foliations and bedding planes. Around an elevation of 350 m, contour lines show a convex shape suggesting a scarp of a landslide.
SL-4	SL-4 is a north-facing and dip-slip slope, similar to other selected sites, and located at CH 24+500 approximately. There were few positive indicators suggesting active landslides. However the slope seemed to show a typical shape of a large-scale landslide based on the topographic map or a high-resolution satellite image. Geometrically this site is projecting towarda the Trishuli River, and it was considered to be formed by landslide movement. Bedrocks of SL-4 are phyllites with sandstones of the Nourpul Formation, often intercalates quartzite beds. There is a retaining-concrete wall along the river-side slope of the road, and concrete blocks have been placed on the riverbed to protect the foot of the slope from river water erosion similar to SL-3.

As shown in Table 3.2.1, bedrocks of the selected four sites generally consist of alternating beds of phyllite and sandstone of the Nourpur Formation. Moreover, all sites are facing north and of dip-slip slope. Results of geological studies are summarized below.

3.2.3 Study Results

(1) SL-1

Topography

Figure 3.2.2 shows a plan view and a cross section of the SL-1 slope respectively, as a result of comprehensive study. As shown in Figure 3.2.2, a continuous scarp existing along contour lines of E.L. 230 m – 250 m. The scarp is the top portion of slope failure facing the highway. Above the scarp, topographic features suggesting landslides are interpretable. Especially, the most visible landslide block is shown as Block 1A in Figure 3.2.2 which should be targeted.

Geological Condition

A landslide block (1A) comprises of talus/colluvial deposits and loosened phyllites, and has dip-slip structure. These unconsolidated deposits and loosened bedrock have landslide potential material. Fresh and hard rocks seem to lie approximately 10 m under the ground.

Groundwater/spring water

Average groundwater level is around GL -3 m in the Borehole BH-1. This level almost coincides with a mountain stream located in right side of SL-1. Many points of spring water were found in 2007 monsoon season.

Strain

The pipe strain meter has shown a deformation around GL -7 m at the borehole BH-1 (See Figure 3.2.3). The deformation slightly accelerated in rainy season (June – September). However, it does not seem to be serious deformation.

Potential Hazard

The landslide (Block 1A) is related to a dip-slip structure. Loose material of lower slope has been pushed by material of upper slope towards the road.

Landslide at SL-1 was originally caused by a bank erosion at the Trishuli River. Consequently, the landslide and related slope failures are considered to have been activated by the cutting of the landslide potential slope (Block 1A) during the construction of the highway. Once Block 1A starts sliding down to the highway, sliding of block (Block 1B) is expected to occur.

For preventing hazard, groundwater should be drained appropriately with suitable countermeasure, e.g., provision of additional horizontal drain holes.

Among the selected sites, SL-1 has the highest hazard potential, and is a typical landslide site.

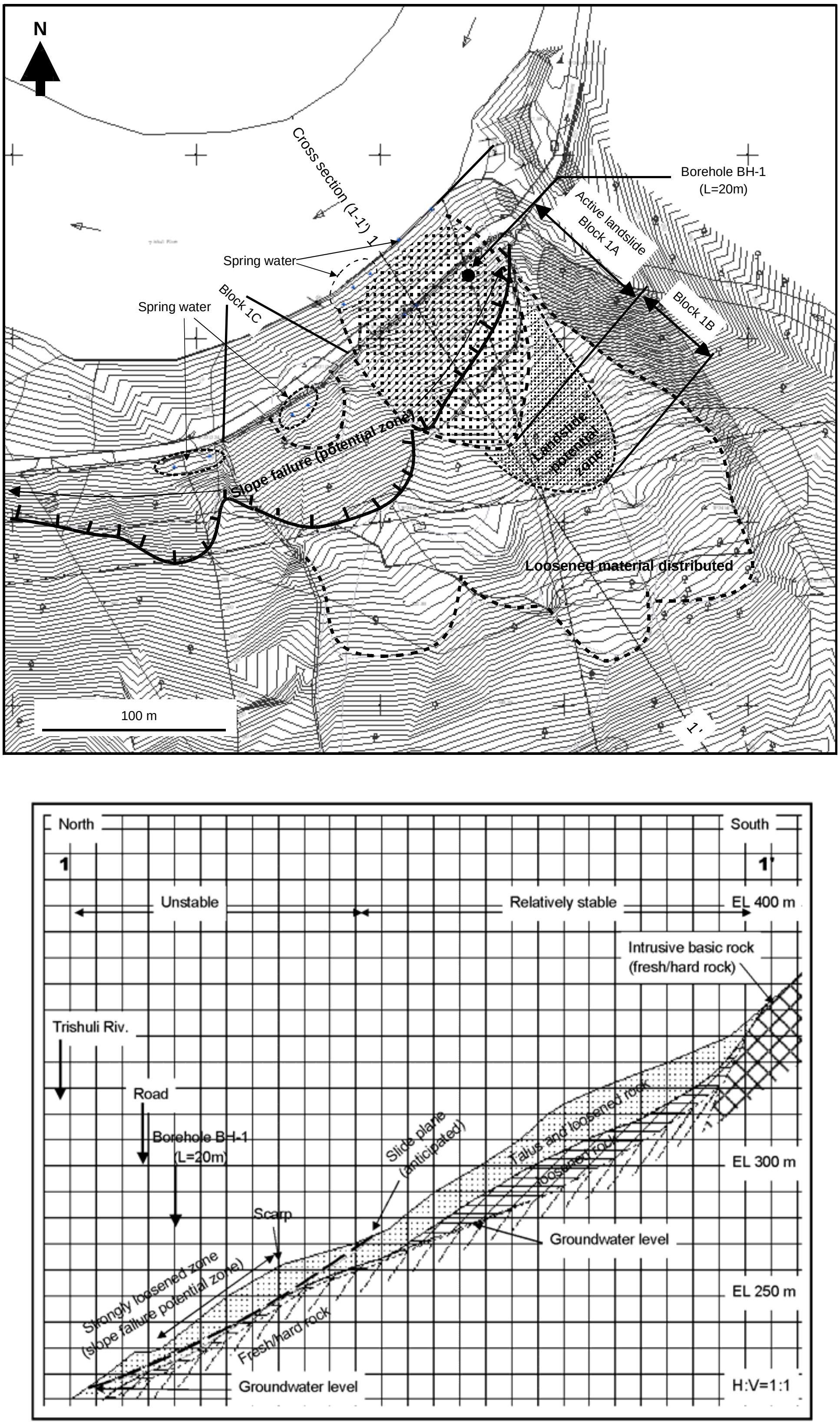


Figure 3.2.2 Plan View and Cross Section of SL-1

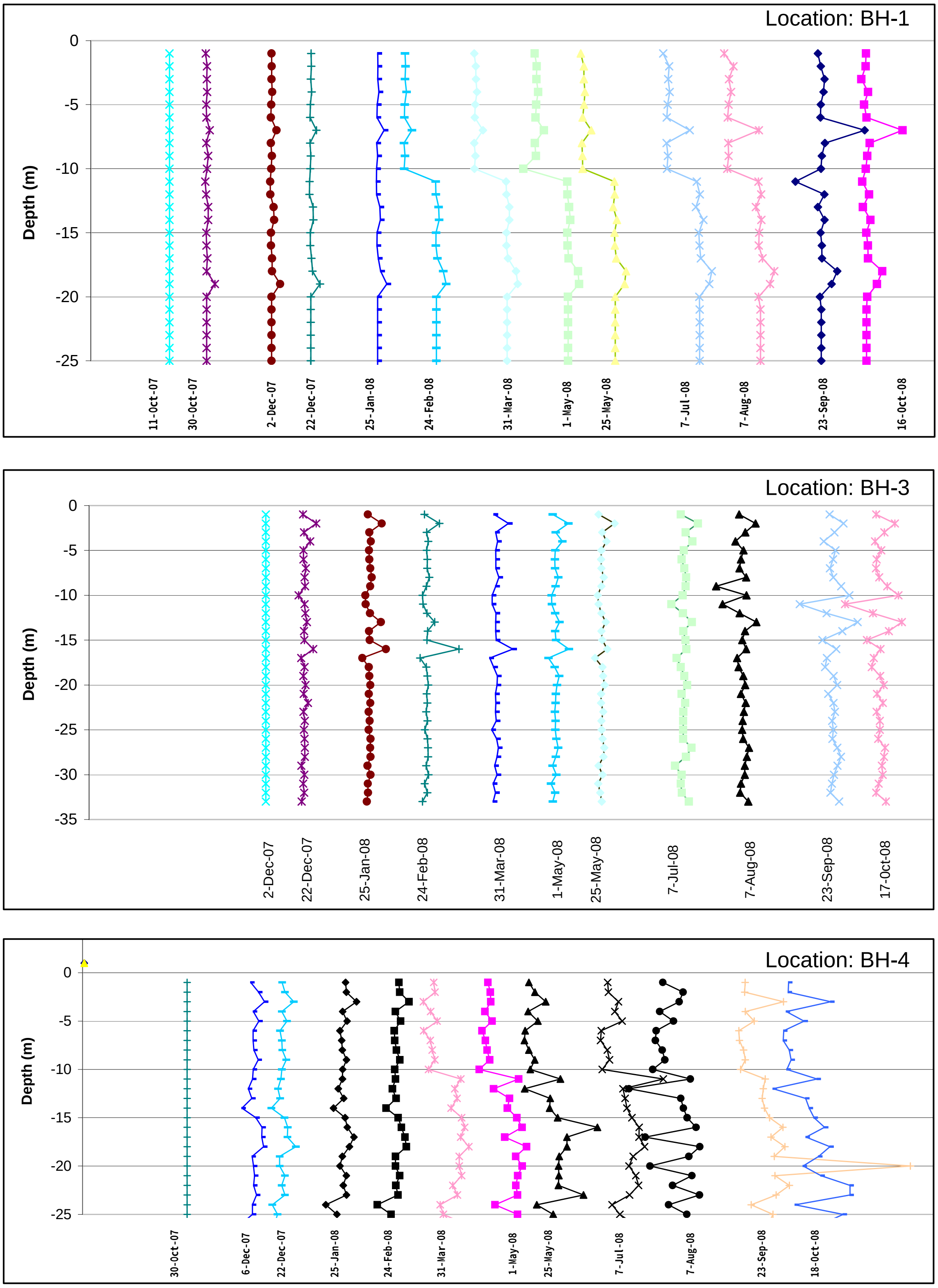


Figure 3.2.3 Pipe Strain Measurement Records of BH-1, BH-3, and BH-4

(2) SL-2

Topography

Figure 3.2.4 shows a plan view and a cross section of the SL-2 slope respectively. As mentioned in Table 3.2.1, there is an unstable rock mass sliding toward the road (Block 2A in Figure 3.2.4). Another Block 2B is positioned behind the Block 2A (See Figure 3.2.4).

Contour lines represent the bedrock structure well.

Geological Condition

The slope is thinly covered with talus deposits, and bedrocks are often exposed on the slope, and partly weathered and loosened.

The slope including the blocks (2A and 2B) is a dip-slip slope. River-side slope of the highway is formed of relatively thick talus deposits and there is no exposure of bedrock.

Groundwater/spring water

Groundwater has not been confirmed in the study. Spring water from a joint of the bedrock was sometime observed in the rainy season in 2007.

Strain

A pipe strain meter was not installed in this study. However, deformation and failure of a road-side retaining (masonry) wall suggests that there has been a certain level of downward movement of the block 2A (See Figure 3.2.3 above).

Potential Hazard

It is considered that the movement of the Block 2A was initiated during the slope-cutting prior to opening of the highway. The unstable rock mass movement is related to geological structure, i.e., dip-slip structure. An assumed sliding plane is a bedding plane of the bedrock (probably made up of sandstone). Once Block 2A collapses, Block 2B will move towards the road.

However, the size of Block 2A is only about 600 m2, which is considered relatively small for a landslide. Such occurrence is common along the highway, but not considered serious. For the mountain-side slope, loose rocks (shown in Figure 3.2.4) beneath the ground surface should be retained with suitable countermeasures. On the other hand, the river-side slope below the road seems to be currently stable. The target for countermeasures is the road-side slope as shown in Figure 3.2.4.

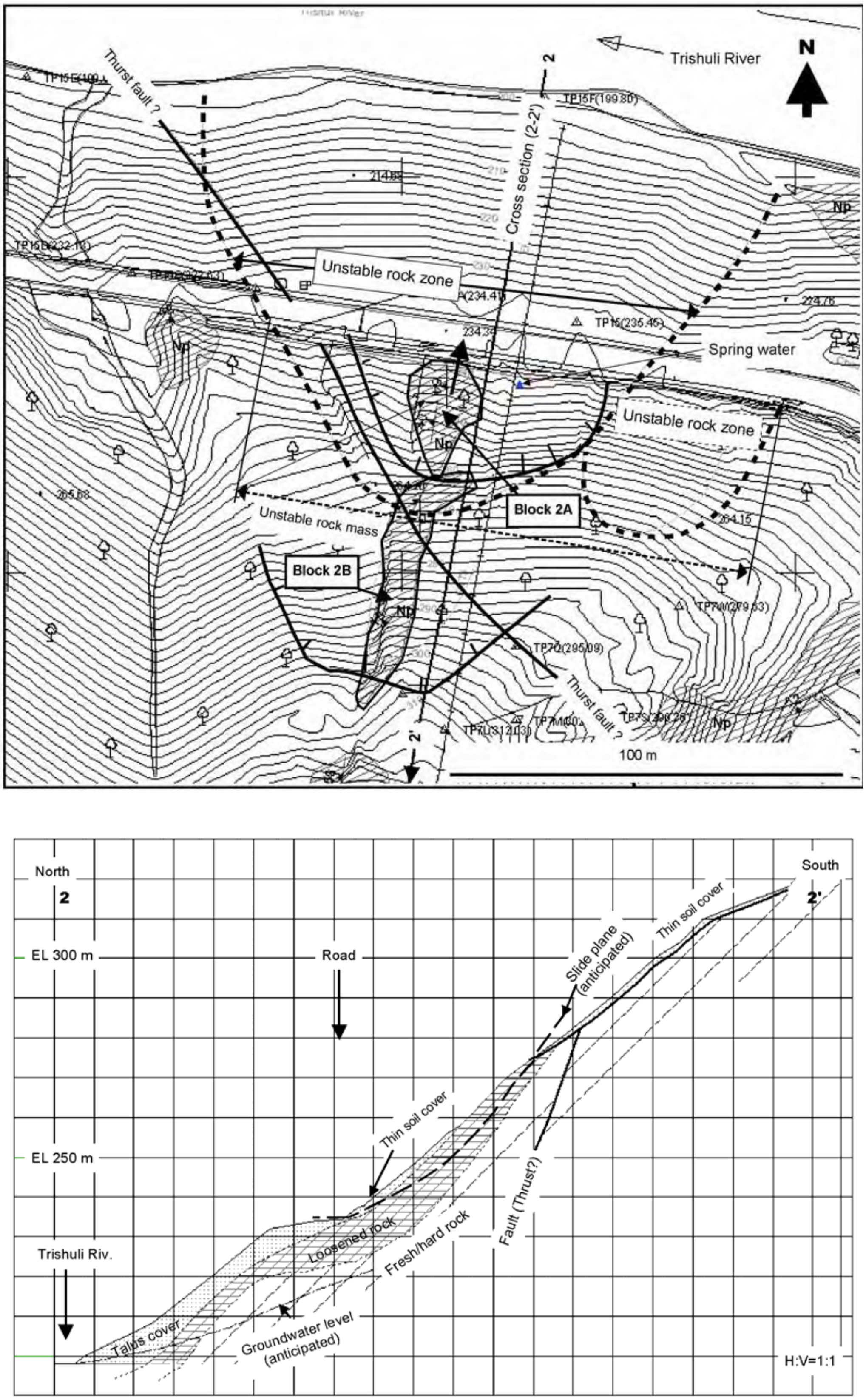


Figure 3.2.4 Plan View and Cross Section of SL-2

(3) SL-3

Topography

Figure 3.2.5 shows a plan view and a cross section of the SL-3 slope respectively. A typical topographic feature suggesting a landslide is recognized between E.L. 200 m and E.L. 320m along a cross section line 3 – 3' shown in a plan view (See Figure 3.2.5 upper).

Scarps of slope failures exist along a contour line of E.L. 260 m.

Geological Condition

The slope is facing north and has dip-slip structure as shown in Figure 3.2.5 lower. At the borehole BH-3, loosened material (composed of talus and weathered/loosened bedrock) lies up to a depth of 13 m. Phyllites in the SL-3 site shows green or greenish-gray. At the mountainside of the road, these rocks have many open-cracks or joints. In the rainy season in 2007, many points of spring water could be observed on these cracks and joints.

Groundwater/spring water

Average groundwater level is around GL -25 m in the Borehole BH-3. This level is 5 m above a water level of the Trishuli River below the site. Many points of spring water were found in 2007 monsoon season as mentioned above.

Strain

The pipe strain meter installed in the BH-3 has not shown any kinds of hazardous movement (See Figure 3.2.3). However, an unstable rock mass (Block 3B) has been pushing a masonry wall by the road that was collapsed in 2007.

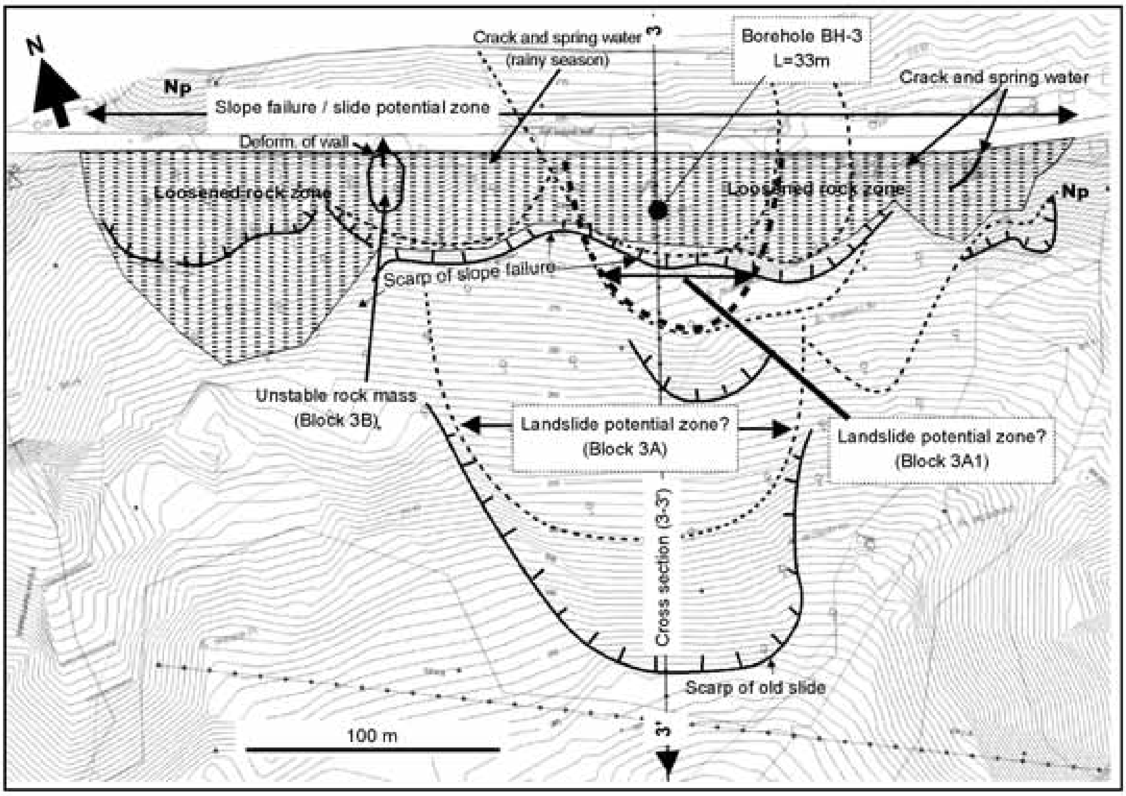
Potential Hazard

Landslide movement of Block 3A and Block 3A1 seemed not active. However during rainy season, it could be activated if heavy rain occurs.

Firstly, the landslides Block 3A and Block 3A1 had been initiated due to bank erosion at the Trishuli River. Subsequently, slope cut during the opening of the road had accelerated the landslide-related movement.

On the other hand, rock-sliding along bedding planes or slope failures within shallower depths (up to 5 m depth) of the cut slope are more active than the big landslides (Block 3A including Block 3A1). Such current slope behavior is considered as a landslide-related movement. Furthermore, slope failures on the cut slope below E.L. 260 m seem to extend to both sides of the Block 3A1 along the road.

The countermeasure should be planned with reviews mentioned above.



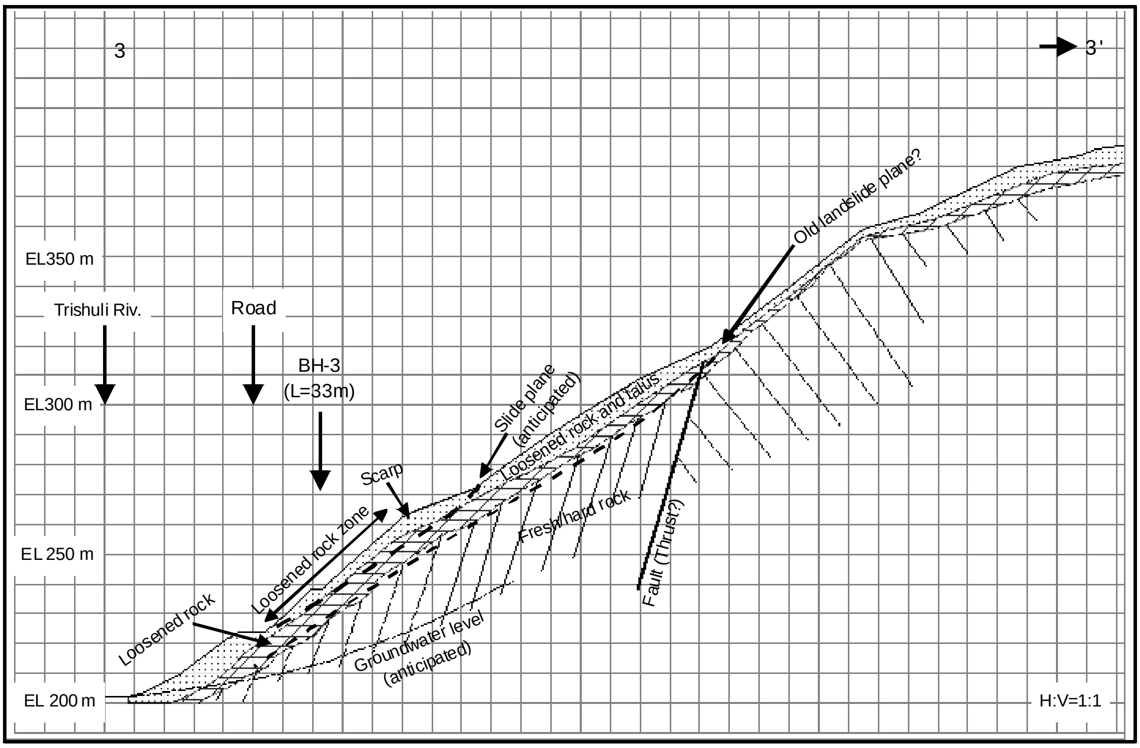


Figure 3.2.5 Plan View and Cross Section of SL-3

(3) SL-4

Topography

Figure 3.2.6 shows a plan view and a cross section of SL-4 slope respectively. Firstly this slope had been considered as a big landslide because contour lines show a typical topographic feature (convex shape toward the Trishuli River) suggesting a landslide.

However it is considered that such shape represented by contour lines suggests just a slope formed of talus/colluvial deposits.

On the other hand, scarps of slope failures exist along a contour line of E.L. 300 m.

Geological Condition

The slope is facing north and has dip-slip structure as shown in Figure 3.2.6 lower. At the borehole BH-4, bedrocks are loosened deeply, and the borehole wall had been collapsed at about a depth of 24 m many times when drilling. Any positive evidences suggesting that this site is a landslide are not recognized in the field reconnaissance.

However the slope above the mountain side retaining wall, loosened and unstable rocks and rolling stones of phyllites are often observed. This condition is considered to suggest slope failures. They are often observed on the natural slope located between E.L. 230 and E.L. 300

Groundwater/spring water

Average groundwater level is around GL -25 m in the Borehole BH-3. This level is 5 m above a water level of the Trishuli River below the site. Spring water from joints of the bedrocks was found on the Block 4A only in rainy season.

Strain

The pipe strain meter installed in the BH-4 has not shown any kinds of hazardous movement (See Figure 3.2.3). Retaining walls were not damaged.

Potential Hazard

Risk of a big landslide moving towards the highway is low. Potential hazards to the highway are slope failures and rock falls from Block 4A and its adjacent slopes. These slope failures seem to be initiated by the cutting of the slope during the opening of the road.

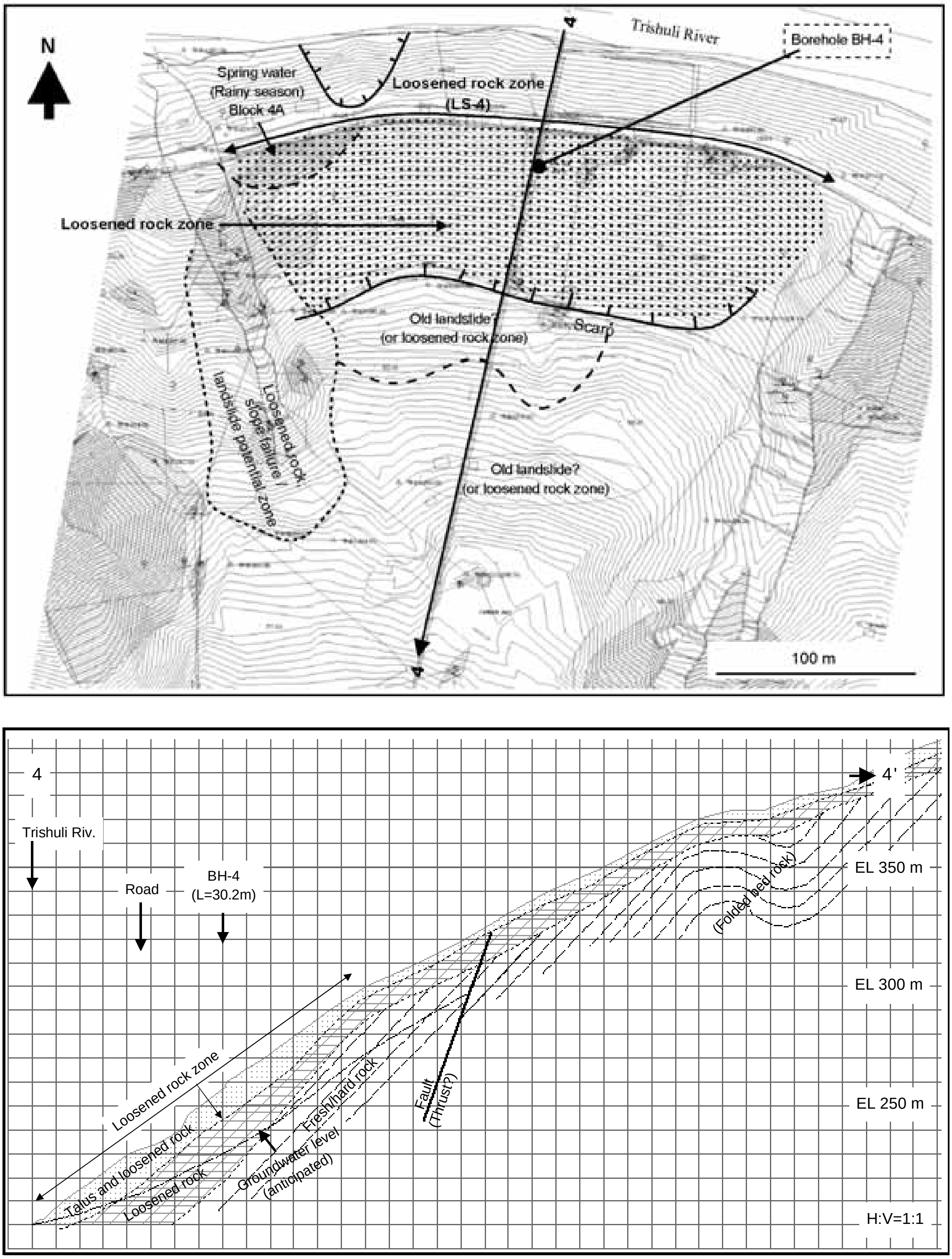


Figure 3.2.6 Plan View and Cross Section of SL-4

3.2.4 Potential of Big Landslides along Highway

Table 3.2.2 summarizes the landslide potential assessment results for SL-1, SL-2, SL-3, and SL-4.

In this study, four slopes having landslide potential were selected and geologically studied in detail. Consequently the slope SL-1 has a high potential of landslide because it is featured with a typical landslide shape on a topographic map, many deformations on the slope and road-related structures, and a high level of groundwater and many spring water.

And, the slope SL-3 has also a land slide potential block that is considered to be an old landslide.

Many landslide-related slope failures have occurred in the SL-1 site and the SL-3 sites. However activeness of landslide main bodies in both sites cannot be recognized currently, based on pipe-strain measurement as shown in Figure 3.2.3.

The slope SL-2 has unstable bedded rock block (400 m^2) sliding gradually toward the road. This unstable block does not seem to be a landslide that has potential of serious damages to the road. However, if the unstable block begins to move, deeper parts of loosened bedrock below the block will have potential of deformation.

Before the study, the slope SL-4 was considered to be one of the biggest landslides along the highway. However, there were few positive evidences showing existence of a landslide affecting the road.

Through the study, it has been found that large-scale landslide potential zones shown in the hazard map in this report are not always actual landslides. Landslide potential slopes interpreted on topographic maps or satellite/airborne images are actual landslides or either of natural slopes (not landslides) tracing bedrock structures, e.g., the SL-4.

Especially, landslide potential zones on north-facing slopes are dip-slip slopes and formed of layered rocks.

Big landslides with big slope failures have occurred within tributary valleys crossing the highway, rather than the road-side slope. Collapsed materials deposited in the valleys are potential source of big debris flows. In actual, debris flows are always the most serious slope hazards for the N-M Highway.

Debris flows and slope failures from the mountain side are more hazardous for the highway transportation than landslide hazards.

Table 3.2.2 Evaluation of Landslide Hazard Potential for SL-1, SL-2, SL-3 and SL-4

Site		SL-1	SL-2	SL-3	SL-4
Landslide Hazard	Topography	Visibly recognized	Visibly recognized	Visibly recognized	Not visible
	Mass, body	Recognized	Recognized	Recognized	Not recognized
	Size (approx.)	Block 1A: 100 m (w) x 120 m (L) Block 1C: 100 m (w) x 75 m (L)	Block 2A: 20 m (w) x 30 m (L)	Block 3A: 150 m (w) x 150 m (L) Block 3A1: 75 m (w) x 70 m (L)	–
	Depth (thickness)	7 – 15 m	3 – 5 m	10 m	–
	Geological mechanism	Bedding-slip of loosened bedrocks with talus deposits (Dip-slip structure)	Bedding-slip of thin bedrock blocks (Dip-slip structure)	Bedding-slip of loosened bedrock with talus deposits (Dip-slip structure)	–
	Groundwater	GL -3 m	GL -20 m (or below)	GL -25 m	GL -30m (or below)
	Spring water	Much in rainy season	Rare	Much in rainy season	Partially in rainy season
	Visible Deformation	Many confirmed	Unstable rock mass	Many confirmed	Partly confirmed* * It is unknown whether the deformations occurred due to a landslide or not.
	Possible trigger	Heavy rain, earthquake	Heavy rain, earthquake	Heavy rain, earthquake	–
	Strain Measurement	Slightly active around GL -7 m (as of May 25, 2008)	–	Not active (as of Jan 25, 2008)	Not active (as of Jan 25, 2008)
Related hazards		Slope failure on cut slope (frequent)	Rock fall (sometimes)	Slope failure on cut slope (sometimes)	Slope failure on cut slope (Block 4A) (rare – sometimes)
Evaluation (Impact to Highway)		High* *Most dangerous landslide	Low* *Size is small. However the slope has to be stabilized.	Moderate* *Slope failures widening	Low* *Seems to be stable
Target of countermeasures		Block 1A (Landslide/Slide)	Topographically lower part of Block 2A and adjacent slopes (Rock fall and rock mass slide)	Lower part of Block 3A1 and adjacent slopes (Slope failures)	Block 4A

L: length, w: width. The evaluation is based on a study results as of February 18, 2008.