CHAPTER 4

RECOMMENDATION

4. Recommendation

4.1 Recommendation about mitigation measures against landslide hazards along the national highway near the Jhelum River

4.1.1 Characteristics of landslides and basic approaches to countermeasure planning

A large number of landslides were triggered by the 2005 Northern Pakistan Earthquake and they are mostly observed still in unstable condition throughout roadsides along the Jhelum River. After several investigations, Japanese scientists and engineers pointed out certain difficulties in planning countermeasures against those landslide hazards. As mentioned in the previous chapter, there are various types of landslides occurred under various geological/geophysical conditions in the target area. The difficulties are caused by a complex variety of the characteristics of the landslides. It is therefore very important to pay attentions to these various conditions to design appropriate countermeasures.

(1) Geological characteristics

From the investigation results three types of geological characteristics which cause quite different stabilities in slopes were identified as shown bellow. In the areas where gravel bed and crack rich sandstone are distributed, steep outcrops can be observed remarkably. Toppling and rock falls occurred there frequently. Concrete crib work with anchor is effective to attain sufficient stability in those areas. Soil removal work and vegetation work are also effective to increase slope stability. In the area with thick debris on a steep slope, a risk of debris slide is extremely high.

(A) Gravel bed of river terrace

Photo 4.1.1 Roadside slope gravel bed near Dhanni

(B) Crack rich sandstone

Photo 4.1.2 Crack rich sandstone near Dhanni

(C) Thick debris on a steep slope

Photo 4.1 3 Debris slide near Dhellan

Photo 4.1.4 Active middle size landslide near Dhellan

(2) Activeness and scale of landslides

In general, activeness and scale of landslides are closely related. Large scale of landslides moves slowly. The risk of catastrophic collapse of such large landslides is not so high and an enormous cost is required to stabilize them. Middle size landslides usually move actively and the risk of sudden collapse is moderately high. Small size landslides easily collapse during the heavy rainfall because surface water and intermediate ground water often induce the collapses. The occurrence risk of small landslides is very high. Accordingly high priority should be given to implementation of countermeasures against those landslides. Photo 4.1.4 shows a toe part of a middle size debris slide. The slide actively moved during the 2005 Northern Pakistan Earthquake.

(3) Locations of landslides in slopes

The Jhelum River flows from the Himalayan Mountains and its discharge volume is extremely large. The agency of erosion causing lateral erosion to the riversides is therefore very strong. The national highway stretches through the slopes of the left side of the Jhelum River. Undercut slopes are always attacked by the river water and prone to be unstable. In order to stabilize the undercut slopes, it is necessary to install concrete revetment work along the riversides. Photo 4.1.5 shows gabions type revetment work installed to protect the riverside from erosion by the running water.

For road constructions, careful attention should be paid to locations of soil removal work in slopes. If soil removal work is carried out on a head of a landslide, it is effective stabilizing the landslide. On the contrary, soil removal work during road construction is carried out of roads on foot of a landslide, it may reduce its stability. In such case, concrete retaining walls are effective to compensate for the decrease of slope stability caused by the soil removal work.

Photo 4.1.6 shows a right flank toe part of a landslide. The landslide was induced by unloading at the toe part that was caused by cutting work for road construction.

Photo 4.1.5 Gabion type revetment works near Supdgiran

Photo 4.1.6 A Right flank of a landslide induced by a road construction near Jaskool

Locations of landslides in slopes

(A) Influences of the Jhelum River to landslides

(B) Relations between the road construction works and landslides

4.1.2 Effective countermeasures against landslides in steep slopes

A large number of slope failures occurred in the left side slope of the Jhelum River. Among the slopes, three types of geological characteristics are observed as described in 4.1.1. It was also observed that slopes in the bedrock strata of the Murree Formation are resistant enough against slope failures in spite of their steepness. These strata consist of alternation of sandstone and mudstone and incline to the SW40° by 60°. The inclination of the strata in reverse to the mountain slopes. In this Therefore it may be concluded that the occurrence risk of landslides in the area is not so high unless external forces such as lateral erosion and earthquake affect slopes.

In order to stabilize riverside slopes along the Jherum River, revetment work is effective to protect toe parts of slopes from lateral erosion. Also removal work to eliminate unstable rock mass and vegetation work are effective to stabilize slope surfaces in such the area.

Planning of countermeasures with consideration of resistance forces against earthquakes is generally not practical, because it requires extremely high costs and their duration periods are ambiguous due to the uncertainty of the timing of the next possible earthquake.

The following are some examples of designing removal and greening works in Japan. Photo 4.1.7 shows a case installed removal and greening works in Japan (Tough greening method).

Photo 4.1.7 Greening works on steep rock slope

(1) Design of removal works

Removal work to cut soil mass in the upper part of a landslide slope is quite effective to increase stability of the slope. It is especially effective in steep slopes. Installation of removal work not only in a wide area but also in a limited area shows drastic increase of slope stability.

Table 4.1.1 shows the standards of slope inclinations for design of cut slopes along roadsides published by the Japan Road Association. In the table, relationships among geological/geophysical types, height of cut slopes and corresponding standard inclinations are indicated. As mentioned before, the areas the bedrock strata of which consist of alternation of sandstone and mudstone are basically resistant enough against slope failures. Accordingly the standard inclination for hard rock (1:0.3～1:0.8) shall be applicable for planning cut slopes in such areas.

Table 4.1.1 Standard inclinations for various ground types and height of cut slopes in Japan

Geological/Geophysical types		Height of cut slopes	Inclinations
Hard rock			1：0.3～1：0.8
Soft rock			1：0.5～1：1.2
Sand	Loose and bad grain size distribution		1：1.5～
Sandy soil	Tight	h≦5m	1：0.8～1：1.0
		5m＜h≦10m	1：1.0～1：1.2
	Loose	h≦5m	1：1.0～1：1.2
		5m＜h≦10m	1：1.2～1：1.5
Gravelly sandy soi	Tight and good grain size distribution	h≦10m	1：0.8～1：1.0
		10m＜h≦15m	1：1.0～1：1.2
	Loose and bad grain size distribution	h≦10m	1：1.0～1：1.2
		10m＜h≦15m	1：1.2～1：1.5
Clayey soil		h≦10m	1：0.8～1：1.2
Gravelly clayey soi		h≦5m	1：1.0～1：1.2
		5m＜h≦10m	1：1.2～1：1.5

(2) Design of vegetation works.

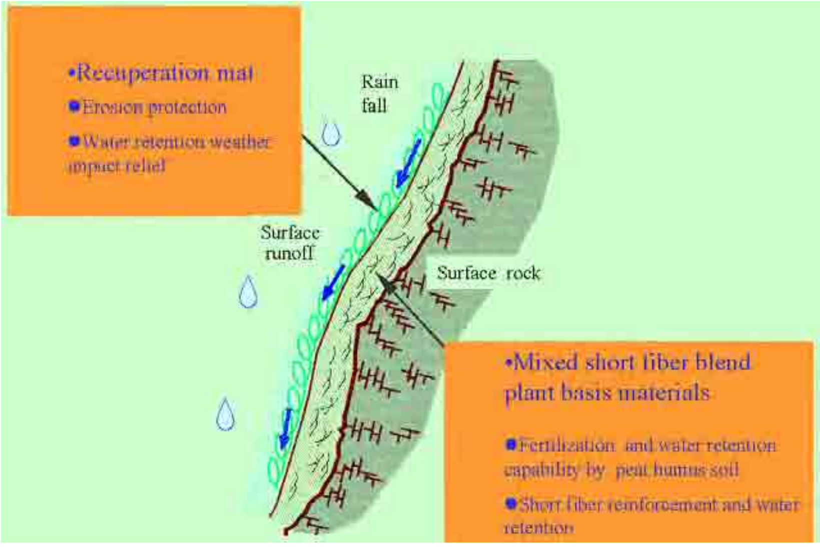
It is very difficult to install vegetation works in steep rock slopes, and it requires advanced technologies. The following are main technical problems:

- Steep slopes: It is difficult for plants to grow in steep slopes because their surface soil is unstable by the strong disturbance through erosion. Accordingly plants cannot germinate and stay in the slopes.
- Poor surface soil: Nutritional and moisture conditions of soil in steep slopes are so poor that root development of plants is extremely limited. Recently a number of vegetation methods in steep rocky slopes are developed and used in Japan. These methods are categorized into the following three types:

A. Improvement of plant base materials with simple protective functions from erosion and weathering (vegetation mat, etc)

[**Example 1: Tough Greening Method**]

Photo 4.1.8 Tough greening method



- Three layers structure of peat humus soil + bark + short nylon fiber
- Without lath net
- Recuperation mat layer: effective for filtering and mulching functions
- Composite materials/ functions of vegetation method

Figure 4.1.1 Schematic diagram about the restraint mechanism of tough greening method

B. Improvement of securing space for plant base materials

[Example 2: Bio-organic Method]

- Mats like Sandbag are fixed by anchor pins
- Mats are filled with muddy soil made from special organic fertilizer, microbial materials, plants growth base materials and water

Photo 4.1.9 Bio-organic method

C. Improvement of surface soil for plant base preventing from erosion by using relatively hard structure

[**Example 3: Special mixture mortal spraying method]**

- Under spraying layer is made from 3〜7cm thickness
- Upper spraying layer is made from vegetation nets and wire nets
- Surface layer is sprayed special mortar

4.1.3 Design procedures and priorities of countermeasures against various types of landslides

Table 4.1.2 shows recommendable priorities of countermeasures against various types of landslides occurred under a complex variety of conditions. Basically it is effective for all types of landslides to carry out soil removal work. Soil removal work for large scale landslides, however, is prone to be very costly. It is therefore more practical to give a priority to monitoring without any mitigation measures using engineering works against large scale landslides. After soil removal work is operated, vegetation work shall be usually installed for a rock fall type of landslides.

Slope stability is generally shown by the ratio of a resistant force to a driving force. Collapses in steep slopes are prone to have larger driving forces in slope stabilities compared with gentler slopes. It is therefore necessary to install concrete crib work with anchoring as countermeasures against those collapses to increase resistant forces. Rock bolt work is also available if sandstone mass is not severely weathered.

Small size landslides move more frequently and have higher occurrence risks than middle and large sizes of landslides. It is therefore necessary to consider installing restraint work, such as anchoring work and pile work, against the small landslides in order to secure sufficient stability of a slope. As anchoring work is able to mobilize all resistant forces at once against the driving force of a landslide after completion of the work, it is applicable also for active landslides. On the contrary, as pile work cannot be charged for resistant forces at once, piles may be damaged inevitable if slide movements occur before all piles are installed.

In general cases, drainage works are installed after construction of restraint works. However it is practical to install drainage works in active middle size landslides in order to maintain safety during constructing restraint works.

Small size landslides are prone to easily lose their slope stability by heavy precipitation. Slope stability of those landslides however is relatively high and they are relatively stable during low rainfall periods. Restraint works against these landslides thus can be installed before construction of drainage works and retaining walls except the rainy seasons.

Table 4.1.2 Priority of main measures

Geological types	Landslide types		Priority of main measures						
Grabel bed of river terrace	Rockfall		Removal	→	Greening				
	Collapse		Removal	→	Concrete crib	→	Anchoring		
Crack rich sandstone	Rockfall		Removal	→	Greening				
	Collapse		Removal	→	Concrete crib	→	Anchoring	or	Rock bolts
Debris and Rock slide	Huge	Active	Removal	→	Drainage				
		moderate	Monitoring						
	middle	Active	Removal	→	Drainage	→	Anchoring	or	Piling
		moderate	Removal	→	Drainage				
	small	Active	Removal	→	Anchoring	→	Drainage	→	Retaining wall
		moderate	Removal	→	Piling	→	Drainage	→	Retaining wall

(a) After collapse (b) After installation of measures

Photo 4.1.10 Example of mitigation measures in Japan*[1)]

4.1.4 Recommendation of countermeasures for typical slope failures

The investigated area covers heavily damaged section of the highway and adjacent slopes. The investigation results for the candidate sites of planned satellite cities are summarized in a separate chapter. The heavily damaged areas along the Jhelum River are Jaskool, Naili and Dannie areas, which will be described in the following pages with some additional locations (Figure 4.1.2).

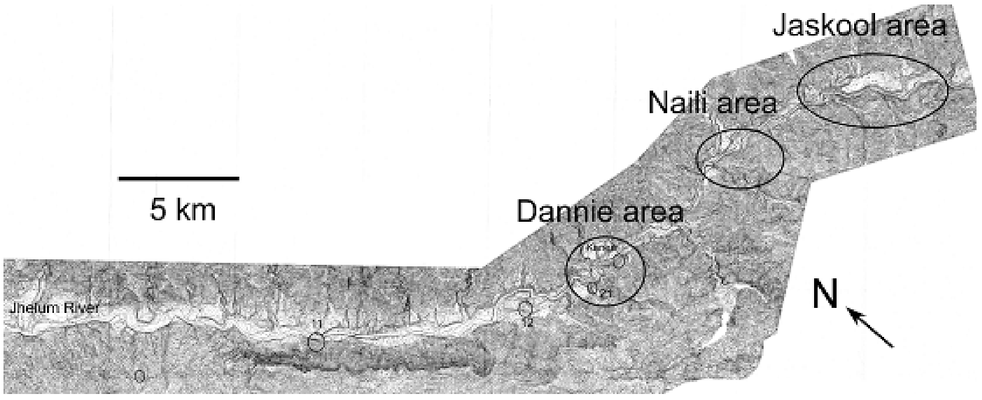


Figure 4.1.2 Location map along the Jhelum River

* Base map was made from IKONOS images

(1) Jaskool area

A. General geology and geomorphology

The highway in Jaskool area strerches along the left side of the river and the damaged slopes strike NW-SE. This direction is almost parallel to the strike of the bedding of the Murree Formation there (Figure 4.1.3). The bedrock strata of the Murree Formation consisting of alternation of sandstone and mudstone mostly dip to the SW 40° to 60° reverse to the mountain slope. However, almost all of the strata near the slope surface have been toppled downward and fractured. As a result, debris materials failed down at many location and formed talus cones. Geomorphologically, this type of gravitational deformation is expressed as downslope-facing scarps along the ridge tops (Figure 4.1.4). Within the deformed slopes, we see several slide bodies with a slide scarp upslope can be seen (Figure 4.1.4). Another typical type of gravitational deformation, namely buckling, was observed near the confluence with Kathal Nara near Chinari.

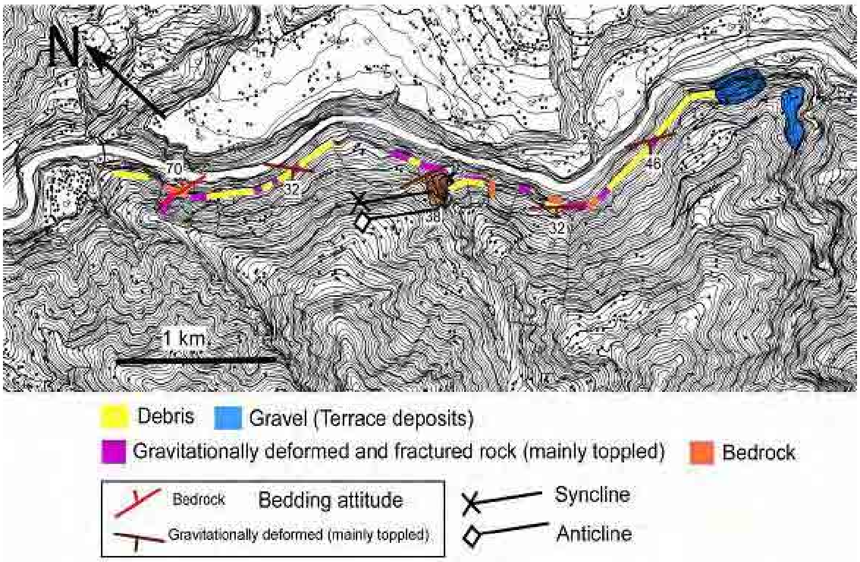


Figure 4.1.3 Geological sketch map in the Jaskool area

Rock masses that have been loosened by toppling, buckling and other type of gravitational deformation have generally high permeability, so groundwater level might not ascend by moderate precipitations

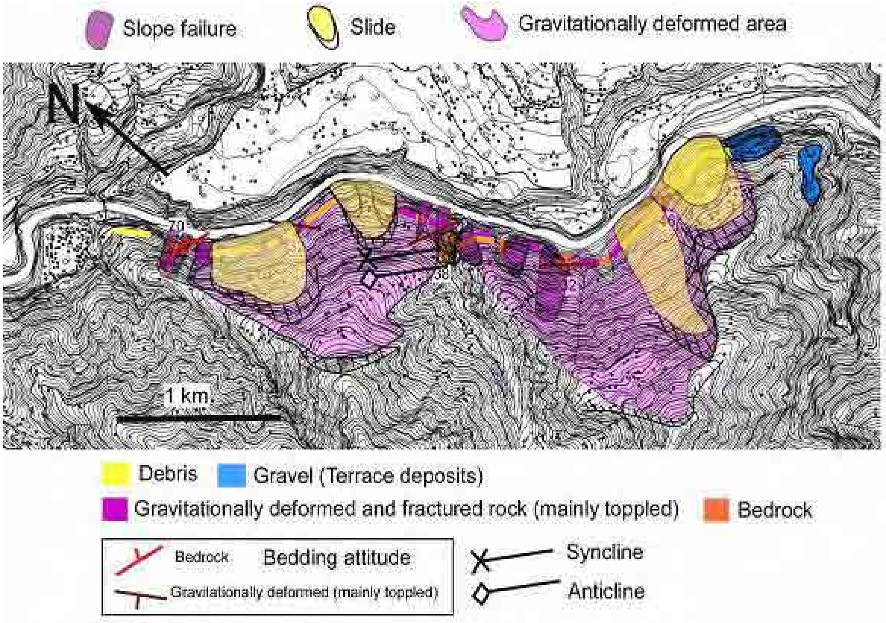


Figure 4.1.4 Distribution map showing the slope deformation, slides and slope failure in the Jaskool area

B. Slope failures of toppled rock mass and overlying debris

Slope failures occurred mostly in the lower part of the gravitationally deformed slopes (Figure 4.1.4) and the displaced soil masses consist of toppled rock mass and overlying debris. Toppled rock mass is more or less fractured, fragmented and loosened (photo 4.1.11), but these fragments still keep their interlocking. The topography can therefore keep steep slopes in comparison with common depositional debris. However, if the toe of the slope of toppled rock mass is removed, the slope will be destabilized. Finally, in addition to the conditions mentioned above, earthquake shaking triggered failure of the surface parts of the slopes.

Photo 4.1.11 Typical flexural toppling and failure of alternating beds of sandstone and mudstone in Jaskool

Recommendation:

Toppled rock mass generally sustain large strain in its inside, so it is to be recommended to remove unstable part of rocks and construct some retaining wall at the toe of the slopes (Figure 4.1.5). However, toppling is expected to continue slowly in general and temporarily accelerated by earthquake shaking, so it is necessary to pay attention to the slope condition. Traffic control according to slope deformation and rainfall should be arranged in case of necessity.

Figure 4.1.5 Recommendation of countermeasures against slope failures of toppled rock mass and overlying debris

Block topple near Dhanni (Length: 16m, Width: 150m, Dip: 75°). This area is located in the undercut slope of the Jhelum River. Rock falls frequently occur from the extremely steep cute structure with overhangs. The risk of rock fall is extremely high.

C. Slope failure preceded by buckling

Two high slopes failed near Chinari Failed slope No.37 in Yagi and Mayumi's report. These slope failures were accompanied by buckling of strata, as shown in Figure 4.1.6 The displaced rock mass removed was a long slab of beds dipping steeply downward; lower part of the bed was buckled. The strata just above the road are still steeper than the strata in the upslope by buckling and fracture, but still hard and not so much loosened. Therefore, the upslope strata now exposed would not fail soon, but if the steeper strata at the foot slope would fail, the whole upslope strata should slide down and similar buckling structure should be newly exposed.

Figure 4.1.6 Slope failure with buckling of beds in the north of Jaskool: Buckled part 10 m above the road (upper right and lower photos).

Recommendation:

It is to be recommended to monitor the deformation of the strata exposed by the road and to pay attention to adjacent slopes and the road surface after execution of partial soil removal works and vegetation works. If significant movement is observed, traffic control should be arranged.

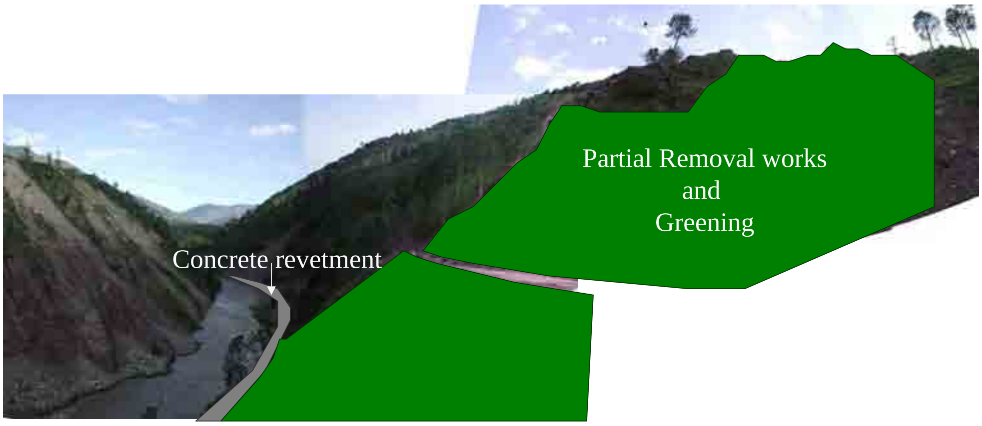


Figure 4.1.7 Recommendable countermeasure against slope failure preceded by buckling

D. Subsidence of roads underlain by debris or toppled rock mass

Road subsidence of less than 1 meter occurred in debris or toppled and loosened rock mass was observed at many locations. Settlement in several locations occurred within previous slide bodies (topographically identified) or along their peripheries which were accompanied by well-defined cracks separated from the adjacent stationary slopes (Figure 4.1.4). These may suggest future reactivation of the slides, but in most case such phenomena would not change to catastrophic slide.

Recommendation:

It is to be recommended to motion the displacement along the cracks, and if displacement accelerates traffic control should be arranged. Moreover, in case definite stability of slope is needed, anchoring works, drainage boring and hillside channel works should be installed after installation of soil removal works and vegetation works (Figure 4.1.8)

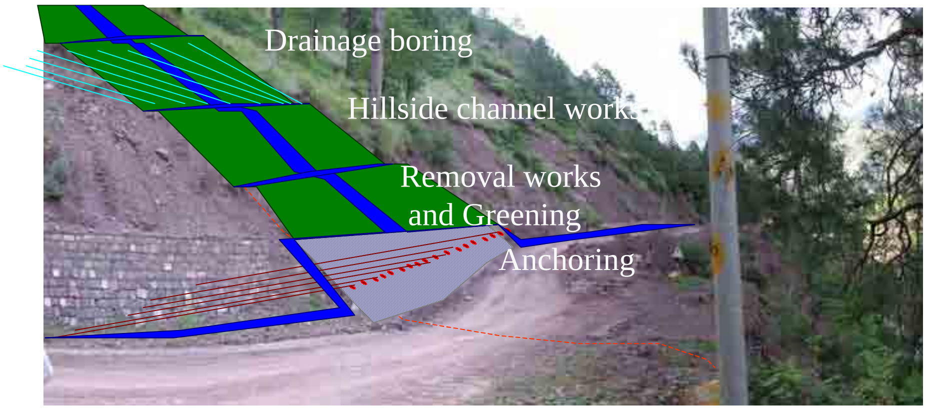


Figure 4.1.8 Typical counter measures against landslides in order to secure the definite stability

For one of landslides at Jaskool area, slope stability is examined for planning of. If the safety factor of original state is assumed to be 1.0, the safety factor after operation of head cutting works is calculated to be 1.0181. Although middle part cutting works bring decrease of slope stability (-1.15%), the driving force of the reshaped landslide mass decreases remarkably. If a part of the cutting mass is removed to the toe area for the embankment works, the safety factor increases to be 1.0319. After those operations, if the drainage wells and boring are installed additionally, the safety factor increases to be 1.0636. If anchor works are also installed, the slope stability increases to be 1.10 of the targeted value. Figure 4.1.8 shows the schematic cross section including results of slope stability analysis and designed counter measures.

However, it requires huge total costs to carry out the whole stages of the countermeasures described above. It is practically not realistic to carry out this kind recommendation even in Japan (Figure 4.1.9).

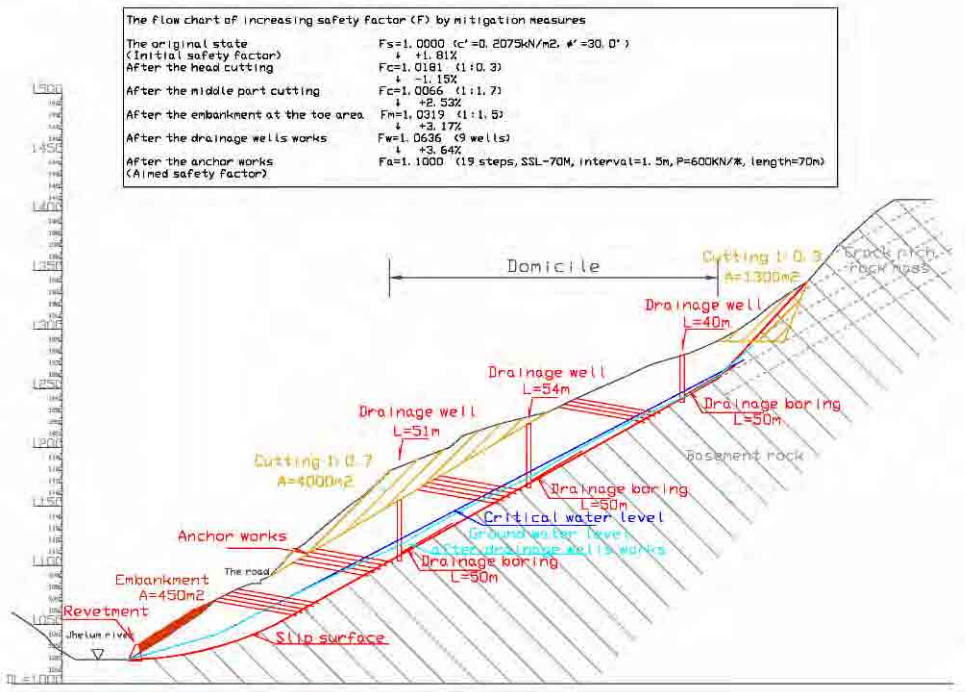


Figure 4.1.9 Schematic cross section of Jaskool landslide

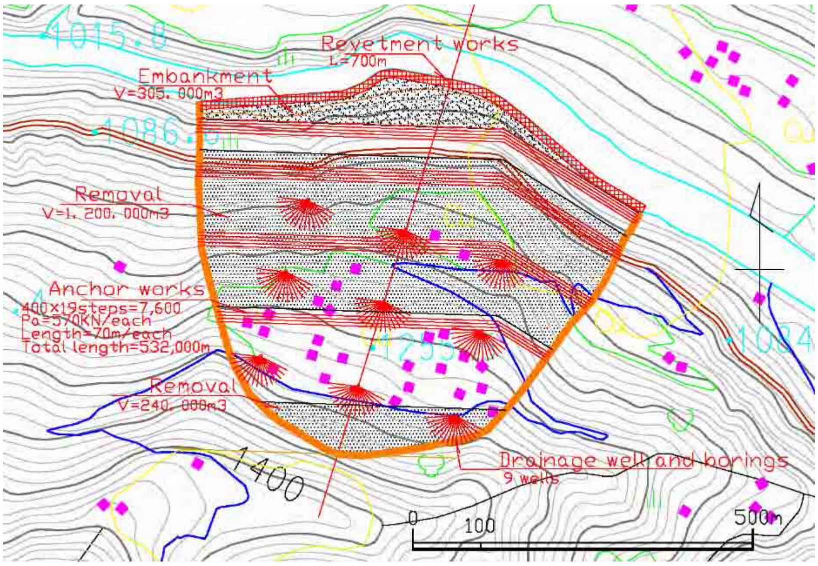


Figure 4.1.10 Recommendation of measures against Jaskool landslide

(2) Naili area

A. General geomorphology and geology

The slope of the south Naili trends NE-SW and inclines to the NE. The morphological features of this slope indicate that this whole slope experienced long-term gravitational deformation, which is represented by a scarplet along the ridge at the top of the slope (Figure 4.1.11 and 4.1.12). This gravitational deformation forms the background of this slope. Within the slope, many horizontally long but narrow gentle slopes, which seem to be made by slope deformation including slide, were observed. Narrow gentle slopes about 100 m high from the river bed accompany boulders, so they are terraces, but gentle slopes in higher elevations do not have boulders, so they are estimated to be made by gravitational deformation.

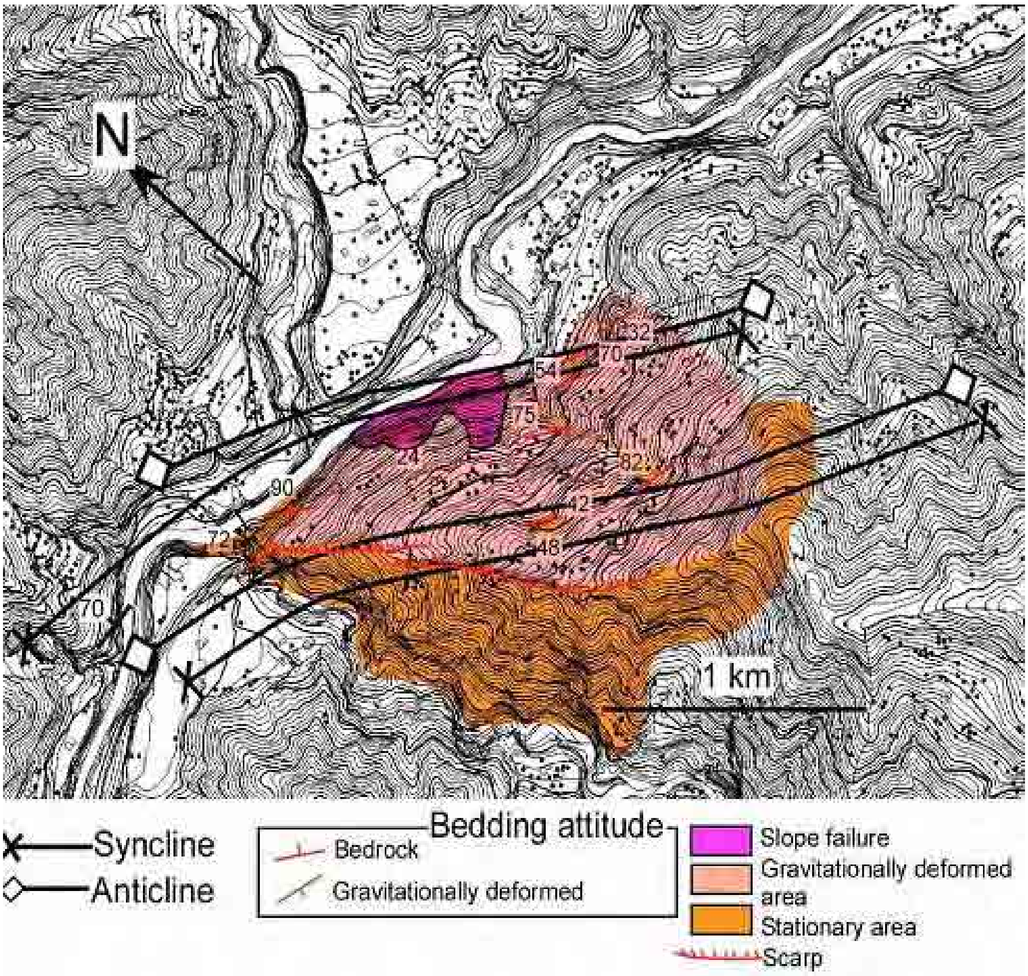


Figure 4.1.11 Geological sketch map of the Naili area

The strata underlie this slope is the Muree Formation consisting of alternating sandstone and mudstone, which are folded with anticlines and synclines. The major portion of the slope is located in the northeastern limb of an anticline, in which bed rock strata trends NW-SE parallel to the slope and dip steeply to NE or nearly vertical (cross section in Figure 4.1.12). Four slope failures (numbers 29-A, B, C, and 30 by Yagi and Mayumi’s report) are located in this limb（Figure 4.1.13）. Almost all of the strata at least in and around the failures are flexurally toppled near the surface presumably to a depth of tens of meters

Figure 4.1.12 Slope deformation in Naili, looking upstream

Ridge-top scarp, which indicate the deformation of whole slope on its left, is clearly seen

Schematic sketch of this slope deformation is shown in Figure 4.1.12. Ridge-top scarplet indicates that sliding occurs there, but the morphology and geologic structures downslope indicate that this sliding does not extend to the foot of the slope. So, this slope deformation seems to be complex, including sliding upslope and toppling downslope.

Figure 4.1.13 Slope failures at the Naili area;

Slope failures 30-A (left) and 29-A (right) are seen in the left photo. Right phopto is the upper part of 29-A, where alternating beds of sandstone and mudstone are toppled and fractured.

B. Slope failures of 29-A, B, C, and 30

These slope failures have similar geologic features. The strata in the slopes are toppled and intensively fractured, providing debris for near surface (Figure 4.1.13). The loosened rock mass and debris failed during the earthquake. Important point is that the failed slopes have narrow but horizontally long gentle slopes on top of them and they are the result of gravitational flexural toppling. Toppled rock mass is exposed along the highway almost continuously. They are fractured but still hard and keep interlocking. Therefore, they would not fail suddenly. However, the toppling deformation would continue for a long time, even slowly.

Recommendation:

Rerouting is recommended if it is possible, because the deformation would continue for long time and the maintenance cost may not decrease. If it is not possible soil, removal works and vegetation with partial grating crib works should be installed to the slope where a risk of rock fall is extremely high. Monitoring of the failure scars and traffic control should be arranged (Figure 4.1.14).

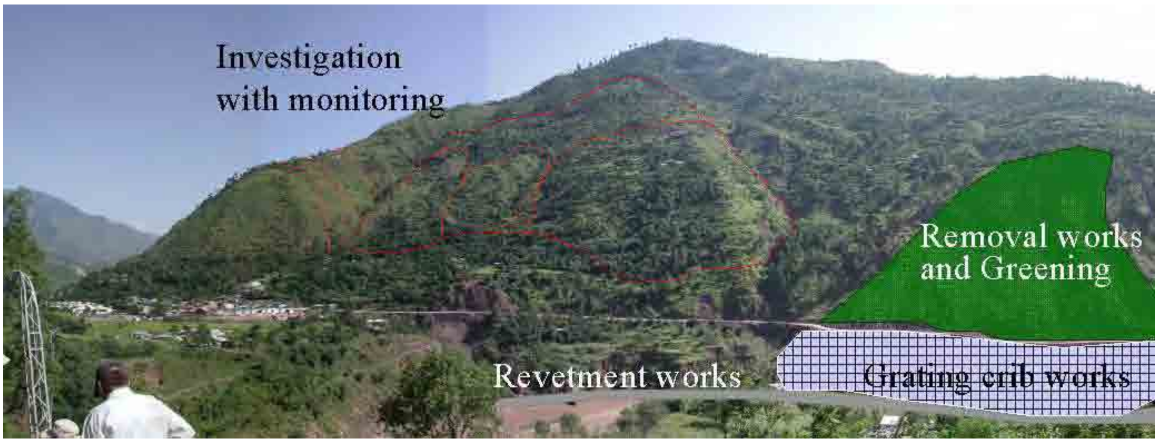


Figure 4.1.14 Counter measures against slope failures at the Naili area;

For the left side landslides it is efficient to investigate and monitor an activeness of landslides before execution of practical measures

(3) Dannie area

A. Slop failure No.21

Road subsidence and slope failures occurred on the western slope of an N-S trending ridge, which is the remnant of a terrace (Figure 4.1.2). The terrace deposits that cover the Murree Formation consist of subrounded to subangular gravels, sand and silt. The road stretching 55 m below the ridge top near the basal unconformity of the terrace deposits subsided a few tens of centimeters. The unconformity seems to be along the bedding plane, which is folded to form a syncline with a NW-SE axis (Figure 4.1.15B, C). The subsidence and slope failures occurred in the terrace deposits burying the depression of the bedrock surface. The depositional surface of the terrace is now forming a N-S trending ridge-top, which has a several meters high step trending E-W. This step is on the upper extension of the high-angle abutment and is likely a displacement step made by previous subsidence of the deposit. The earthquake formed a crack with a maximum vertical separation of 1.5 m at the base of this step (Figure 4.1.15A), suggesting that this crack is also the result of sediments subsidence.

The ridge-crossing crack bounded the south of a slope failure on the west-facing slope, but disappeared on the east-facing slope of the ridge (Figure 4.1.15C). Therefore, the crack does not indicate the sliding of the whole ridge, but indicates that the deposits below the western slope, which is a free face to a river, subsided more than in the eastern slope.

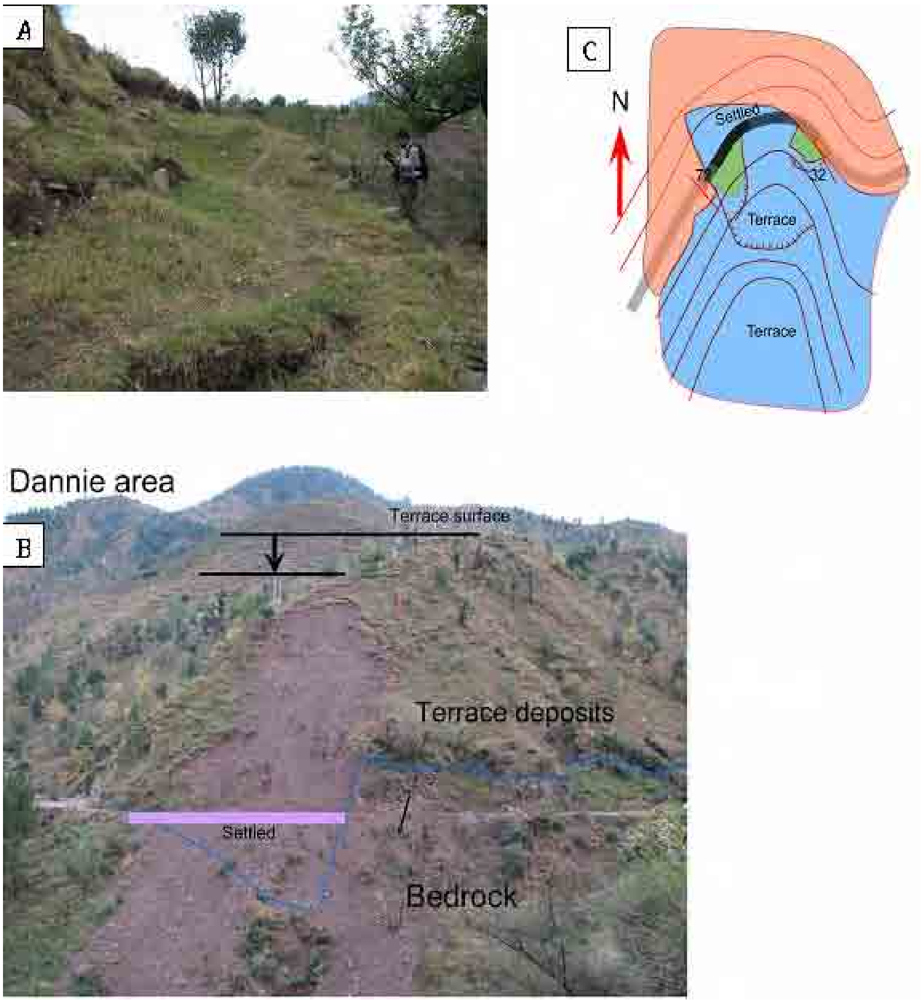


Figure 4.1.15 No. 21 Slope failure at the Dannie area

“A” shows cracks crossing the ridge top in “B” “C” is a plan view. Note that the crack terminates in the middle of east-facing slope.

Slope failure of the terrace deposits, cracks on the road, and bumpy deformation of the road are due to the subsidence described above. Unstable materials still remain on the upper part of the scar and would slide down.

Recommendation:

Removing the unstable materials and vegetation works are recommended. If possible, grating crib works at the lower parts of landslide is effective for increase of stability. After then monitoring the cracks and traffic control should be arranged.

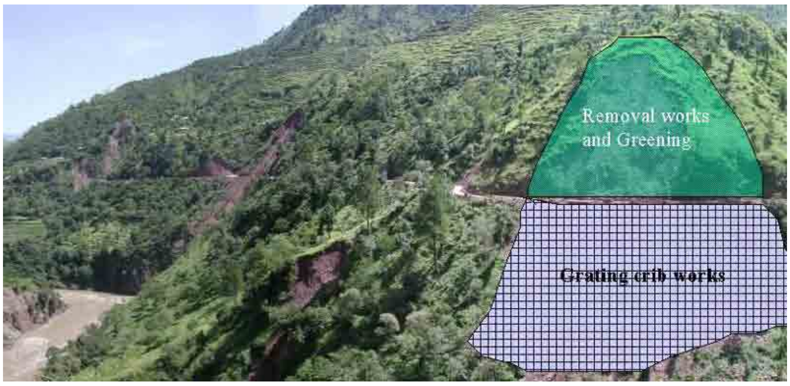


Figure 4.4.16 Recommendation on No.21 slope failure

Retaining wall should be avoided so as not to decrease slope stability on failure.

4.2 Application of the slope inspection guideline prepared by the Study Team for rehabilitation of the roadside slope damaged by the earthquake

In Pakistan, road maintenance works to safeguard against landslides have been conducted on a routine or a periodic basis and the knowledge of slope protection techniques has been accumulated accordingly. However, there is no manual or standards for slope inspections. Insufficient measure against a landslide due to the lack of necessary field data causes frequent landslides, which consequently impose financial strain in road maintenance.

Based on the perspective, the Guide attached in Appendix A has been prepared for the purpose of the risk reduction of landslides through the development of the slope inspection for road maintenance. In view of circumstances in the lack of specialized engineers for slope stability, the Guide emphasizes the dissemination of an essential knowledge to the staff in charge of the road maintenance in Pakistan. Furthermore, the Guide also covers emergency measures in a response to the urgent need of landslide risk reduction, since an appropriate and timely measure can prevent recurring landslides and help in the rehabilitation procedure.

In general, the word “Landslide” includes various types of slope failures, and also has a regional variety in geological condition. Moreover, it should be recognized that physical and mechanical characteristics of the article slopes shall worsen slowly over time. The lessons mentioned in the Guide might include some exceptional cases due to these uncertainties.

Therefore, we hope the Guide will prove appropriable through actual slope inspections and new knowledge of slope stability will be accumulated in the due course of new findings.

4.3 Effective use of the five bridges reconstructed

It shall be pertinent to mention that the construction process of the five bridges has been achieved on fast-track footings within the scheduled shortest possible time period. The entire construction process was a judicious combination of sustainable work in an appropriate chronological sequence which just to implementation through field efforts by the contractor and supervision by the Study Team together with incorporation of quality component materials procured from the best available sources.

The five bridges have been reconstructed as an important and essential facility to mitigate the suffering of the people of the surrounding difficult areas to provide them ease of transportation. It is therefore recommended that the Government of Pakistan shall hence forth make necessary arrangements and undertake appropriate measures to maintain this facility for its long term and efficient utilization as a general public facility.