It should also be mentioned here that in view of the nature of the mission of the Team, this chapter is limited to technical aspects, and economic feasibility is not dealt with.

Considerable expenditures will be required to implement measures proposed in this chapter. These measures to protect infrastructures will be well taken into account in the reconstruction of such structures with possible assistance from foreign donors, however, the question is in the very limited resources for those to protect villages: in Nepal such works should be, in principle, under the responsibility of villagers, but it is obvious that the required resources are far beyond the capability of the villagers both financially and technically.

In view of the heavy damage caused by the disaster it is hoped that HMG will take appropriate actions so that proposed countermeasures, especially those to protect villages, may be implemented as much as possible with more input from HMG, more assistance from foreign donors and of course full participation of the villagers.

Investigations were conducted at the following six locations: ① the upper reach of the Rapti River, ② the Mandu Khola basin, ③ the downstream area of the Mandu Khola basin, ④ the Khani Khola near the confluence with the Rapti River, ⑤ the upper stream of the Palung Khola, and ⑥ the Kitini Khola, as marked with a circle in Fig. 6.2.1. All these sites are situated in the southwest areas 20 to 30 km away from Kathmandu.

6.2.2 Debris flow situation and countermeasures

(1) Upper reach of Rapti River (Bhimphedi-Bhainse)

1) General situation of debris flows (Fig. 6.2.2)

In the upper most reaches of the Rapti River from Bhimphedi to Bhainse, a number of debris flows occurred in almost all tributaries as a combined effect of mountain slope collapses, river bank erosion and discharge of old deposits on the river bed in the upstreams.

Near the confluence between Bhimphedi River and Lam in the upstream of Bhimphedi VDC, an alluvial fan of the volume of approximately 20,000 m^3 was formed by debris flows. The depth of the debris flow is assumed to have been 2.0 m to 2.5 m judging from damages to trees. The gradient of sedimentation is about 10 degrees. The representative grain-size is relatively small (20-30 cm) and accordingly the mode of sediment transport is assumed to have been a mud-flow rather than a debris flow.

In Chisapani valley located in front of Bhimphedi an alluvial fan was formed as a result of a similar mode of sediment transport. The volume of the deposit is about 75,000 m^3 with the depth of 1 m and the surface gradient is 10 degrees. The revetment protecting Bhimphedi was damaged by a length of about 50 m due to the sediment flow from this valley.

Therefore, the existing houses on this terrace can be damaged unless some measures are provided to protect the banks from subsequent erosion.

2) Basic concept of measures

As for the deposits near the confluence between Bhimphedi River and Lam Khola in the upstream of Bhimphedi, no immediate measures might be necessary. Because the river course of Bhimphedi River just in the downstream of the confluence is wide (B 40 m, L ≒ 1,000 m), therefore sediment discharge from the two rivers will be retained for a certain period at this portion and will not flow down immediately. But excavation of deposits will be required according to the volume of discharge vis-a-vis the retaining capacity of the wide portion.

The alluvial fan of Chisapani valley will continue to expand downwards as the catchment has been devastated. In order to restrict expansion of the fan downwards it is proposed that:

① as an immediate measure, a check dam should be constructed at the top of the fan to retain sediment discharge and to restrict the meandering on the fan. A series of consolidations groundsels are indispensable on the fan in order to control development of the fan by dispersing sediment flow overflowed from the check dam and to restrict secondary movement of the sediment due to erosion.

② as future measures, a series of check dams should be constructed in the upstream of the fan, together with hillside work on the collapsed slopes.

The restriction of expansion of the fan will be effective, to some extent, for controlling the meandering in the downstream.

In Bhimphedi, the terrace on which the town is located is composed of unstable river deposits. Therefore a revetment with a strong foundation should be constructed along the foot of the terrace in order to protect the terrace from scouring. Shifting the road from the terrace slope to the terrace surface might be a viable idea, which is free from any damage from the river.

Consolidation work is necessary at the downstream end of the wide portion, where the river becomes narrow and the increased tractive force may cause heavy erosion resulting in abrupt discharge of massive sediment and scouring of the foundation of the revetment. It will be necessary to excavate sediment deposited and reuse them for construction.

(2) Mandu Khola Basin (Jurikhet Khola)

1) General situation of debris flows (Fig. 6.2.3)

Jurikhet Khola is a tributary of the Mandu Khola. In Jurikhet Khola, some check dams, a headrace steel pipe (penstock) of power station etc. were destroyed by the strong shearing stress of debris flows which contained big boulders with a diameter of several meters.

The sources of the debris flows are assumed to be both mountain slope collapses and torrent erosions, judging from the deposits (newly produced granite and old river deposits). Especially in the granite regions, massive collapses due to deep weathering were seen here and there, the ratio of collapsed areas reaching nearly 2-3 percent in upstream areas. The volume of debris flow deposits is estimated at about 25,000 m^3, the representative grain-size is 20-30 cm with the maximum diameter of 10 m and the surface gradient of the sedimentation is 10 degrees.

The penstock was located at the bent portion of the river. The bent flow of the debris flow with 5 m difference in height between the two banks heavily eroded the left bank by about 15 m.

2) Basic concept of measures

Measures against debris flows with big boulders of the diameter of several meters should be, among other things, the key measures to be adopted in this river.

Since a large volume of sediment was yielded and deposited in this stream during these rainfalls, it is presumed that debris flows can occur again in the future. If any debris flows occurs, the mainstream of the Rapti River can be affected by the debris flow deposits which would result in raising the Riverbed and flooding areas downstream. Therefore, measures must be taken to protect this stream from the sediment flows.

Where the power generation pipeline is to be restored at existing location, it should be protected from the direct shock of debris flows. The pipeline should be buried either in the riverbed or in the pocket of check dam with mud.

The wing portions of the check dams were destroyed by big boulders with diameters of more than 3 m. Therefore it is necessary to adopt a shock absorbing method in combination of earth filling and gabions behind the wing. The width of the crown of dam is 2 m which is too thin to withstand the impact of debris flows. The dams should be raised and the width of the crown should be wider (at least 3 m according to the Japanese criteria).

In the sedimentation area, consolidation works are necessary to consolidate the river bed after big boulders are taken out.

The penstock is located at the bent portion of Juriket Khola River. Construction of the revetment with the height determined taking into account of the rise in the water level at the outer bend is considered indispensable.

(3) Mandu Khola near the confluence with the Rapti River

1) General situation of debris flows (Fig. 6.2.4)

As in other areas, debris flows with big boulders with diameter of several meters (maximum 20 m) flowed down and were deposited. An intake for the power station was completely destroyed (Photo. 6.2.7). The volume of the deposit is estimated at 50,000 m^3, the representative grain-size is 2-3 m and the gradient of the deposit is 10-15 degrees. The river section where the intake was located has been heavily eroded by about 200 m as it is the bent portion of the river.

2) Basic concept of measures

If the intake is reconstructed again at a site which is prone to debris flows of big boulders measuring several meters, a number of measure works will be needed to protect it from the massive and destructive force of debris flows, requiring considerable expenditure for the construction as well as for maintenance. Long period required for the construction, and the cost/benefit with regard to rehabilitation should also be taken into account.

On the other hand, sediment discharge from the Mandu Khola is much more than the other tributaries of the Rapti River, causing serious problems even in the downstream area of the Rapti River. Further, although detailed surveys have not been made yet, it is assumed that an enormous amount of debris flow deposit remains upstream, which will continue to discharge and will affect the Rapti River unless effective measures are taken. Thus, a debris flow control plan for the Mandu Khola, if established, can be regarded as a plan for the whole Rapti River, not merely for the Mandu Khola.

In these circumstances, it is recommended ① to carry out debris flow measures in the catchment of the Mandu Khola and ② to reconstruct the intake, not in the original place but in a place where the impact of debris flows will be less. One of places to be proposed for the new site of the intake is that on the left bank just upstream of the bridge.

In order to minimize the effects on the Rapti River, it is important to construct a series of consolidation works to fix the river bed of the Mandu Khola so that the existing deposits may not be discharged downstream.

As mentioned in (2) 2), some measures to protect the consolidation works and steel dams/ check dams from the impact of big boulders will be necessary.

Revetment along the bent side of the river bank with a height sufficient enough to accommodate the rise in the water level due to bent flow will also be required.

(4) Confluence between the Rapti river and the Khani Khola (Bhainse)

1) General situation of debris flows (Fig. 6.2.5)

One of the serious problems here is that the tailrace of the Kulekhani No. 2 Power Station is in danger of being buried as the river bed of the Khani Khola has been continuing to rise. (Photo. 6.2.8)

In order to stop the riverbed rise, construction of check dams and other measures are being undertaken in the catchment of the Khani Khola under the Disaster Prevention Project for the Kulekhani Hydro-Power Project (Photo. 6.2.9). However, two check dams have already been filled up by sediment. (Photo. 6.2.10)

In the upstream, there are two tributaries, of which the one from the right hand side supplies more debris than the other. The debris flow deposit (limestone) of about 5,000 m^3 remains in the tributary. The representative grain-size is 50 cm with the maximum of about 10 m.

In the upstream of the upper most check dam (KA-2 in Fig. 6.2.5), there is a debris flow deposit of about 20,000 m^3. The representative grain-size is 20-30 cm. In this sedimentation area, there are five slope collapses, along the foot of which there are big boulders of the diameter of 2-5 m.

The upper part of the slope located above the right wing of the existing check dam was collapsed. As a result, the gabion works at the foot of the slope were broken and a part of the debris was discharged to the river. In the downstream of the lower most check dam (Consolidation Dam in Fig. 6.2.5), there is sediment of about 6,000 m^3 causing the problem of rise of the river bed.

2) Basic concept of measures

In order to fix the sediment existing in the upstream further beyond the effective range of the uppermost check dam, consolidation works are required. Consolidations are also required to prevent scouring of the foot of slope collapses existing along the sediment and their subsequent expansion.

The dam axis of the upper check dam is not at a right angle to the direction of the mainstream of the Khani Khola, therefore, debris flows flowing down over the check dam may hit and damage the left wing of the check dam in the downstream. Construction of revetment to regulate the direction of the flow from the left to the center of the river course is recommended immediately in the downstream of the upper dam.

In the upstream of the confluence there is a heavy deposit due to the sediment discharge from the Khani Khola combined with the backwater effect of the Rapti river. Therefore measures should be taken not only along the Khani Khola but also in the Rapti River downstream of the confluence. It is recommended to dredge deposits around the confluence, as the emergency measure, and then to construct a separation levee at the confluence, as the future measure, which will be effective to augment the tractive force of the river flow and to lower the river bed.

It might be advisable to use the dredged materials for public purposes, for example, for reclamation of the Bhainse village which is now relatively low compared with the river bed of the Rapti River and is in danger of inundation by even a smaller magnitude of flood.

(5) Upper stream of the Palung Khola

1) General situation of debris flows (Fig. 6.2.6)

The Palung Khala is a tributary of the Kulelhani River with a catchment area of 31.4 km^2 at the confluence with the Kitini Khola. A mountain slope collapsed in the catchment (crystalline schist zone) caused the debris flows of the Palung Khola, which flowed directly into the top of the alluvial fan resulting in an extensive damage to the Palung VDC especially to the Phedigaon village. About 60 persons died.

The debris flow deposit is estimated at about 50,000 m^3. The representative grain-size is 20-40 cm. 'The gradient of sedimentation is 10-15 degrees. The depth of the debris flow is assumed to have been 2 m.

The water discharged through the deposit, or a subsequent flow following the debris flow, flowed down in the form of a sediment flow with more water and less sediment, eroding the sediment of the fan and burying houses, schools, temples etc. by depth of 10-30 cm. The representative grain-size is rather small (about 10 cm) of the sediment flow.

2) Basic concept of countermeasures

The existing mountain slope collapses in the catchment will not expand progressively, because bedrock is already exposed at some places. However, hillside work will be required in the future to control the expansion of these collapses.

Measures should be taken, among other things, to restrict the re-movement of deposit on the alluvial fan downwards. For this purpose, a check dam is necessary at the top of the fan in order to retain the sediment from upstream and to control the flow direction in the downstream: A series of consolidation works are proposed on the fan to fix the deposit and to stimulate sedimentation in case of debris flows in the future.

There are many houses around the alluvial fan, therefore it may be advisable to use the fan area as a sand pocket to be surrounded by a revetment/embankment.

It is further proposed that a straight channel should be constructed from the fan downwards to the confluence with the mainstream of the Palung Khola so that the water discharged through the deposit may flow down smoothly without causing any damage to river banks downstream.

(6) Kitini Khola

1) General situation of debris flows (Fig. 6.2.7)

Kitini Khola is a tributary of the Palung Khola. A number of mountain slope collapses in the granite zone triggered a debris flow in Kitini Khola (Photo. 6.2.12). The collapsed area now occupies nearly 2 - 3% of the total area, though no such corresponding figure before the disaster is available.

Remnants of old debris flows were observed here and there scattered widely, indicating that debris flows repeatedly occurred in the past in this area.

The recent debris flow which contained a lot of boulders with diameter of 3 m to 4 m spread over the alluvial fan entirely from the fan top to the confluence with the Palung Khola, forming a debris flow moraine of about 27,000 m^3 (B = 150 m, L = 350 m). The depth of the debris flow is assumed to have been 2 m to 3 m. The gradient of the sedimentation is 5° to 10°.

2) Basic concept of measures

Hillside work will be necessary to reduce sediment production at a number of collapses in the catchment. Japan has a good experience of hillside work in granite zones (ex. Tanakami mountain) for more than a century. The technics developed there might well be applied to Nepal in view of the similar meteorological conditions between the two countries.

In order to prevent re-movement of the deposit and to store the sediment load from upstream, several check dams will be needed in the river section between the collapses and the fan top.

At the fan top, a check dam will be necessary in order to retain the sediment discharge and to control the meandering flow on the alluvial fan.

On the alluvial fan, there are many houses along the left bank of Kitini Khola and dispersion of debris flows on the fan may endanger their safety. It is therefore recommended to construct a direct channel from the fan top to the confluence with the Palung Khola. In this case, it is important to construct a series of consolidations on the fan in order to reduce the sediment transport to the Palung Khola and also to prevent erosion due to overflow from the channel.

The channel should be so designed as to join the Palung Khola downstream of the Palung bridge so that the discharge from the channel may not affect the bridge. Due to the topographical condition at the site, however, the joining angle can not be small. Therefore, if the sediment load from the channel is great, it may accumulate in the Palung Khola without being flashed and the flow of the Palung Khola will be compelled to run along the left bank. Revetment to protect the left bank of Palung Khola from scouring will be required.

6.2.3 Proposal on further studies

In order to plan/design/implement measures against debris flows effectively, it is proposed to carry out following studies:

It is considered most appropriate that these studies be conducted with the technical guidance of the Water Induced Disaster Prevention Technical Center, Ministry of Water Resources in the country of Nepal.

(1) Aerial photo analysis on the distribution of mountain slope collapses and their volumes:

(2) To make clear the state of river-bed deformation (aggradation, degradation) and volume of fluviatile deposits is river system by field measurement.

(3) To study the relation between rainfall and debris flow initiation.

(4) To study the detail suffering state of this event (such as the distribution of damaged houses and their damage state, debris flow deposit depth, etc.)

(5) To study the relation between the property of debris flows (grain-size distribution, specific gravity, internal friction angle etc.) and dynamic characteristics (velocity, fluid force, impact force etc.) How to estimate the external forces on sabo structure with high precise and improve dam design.

(6) To conduct the hydraulic model test in the laboratory in order to design sabo facilities properly.

(7) To establish an appropriate warning and evacuation system.

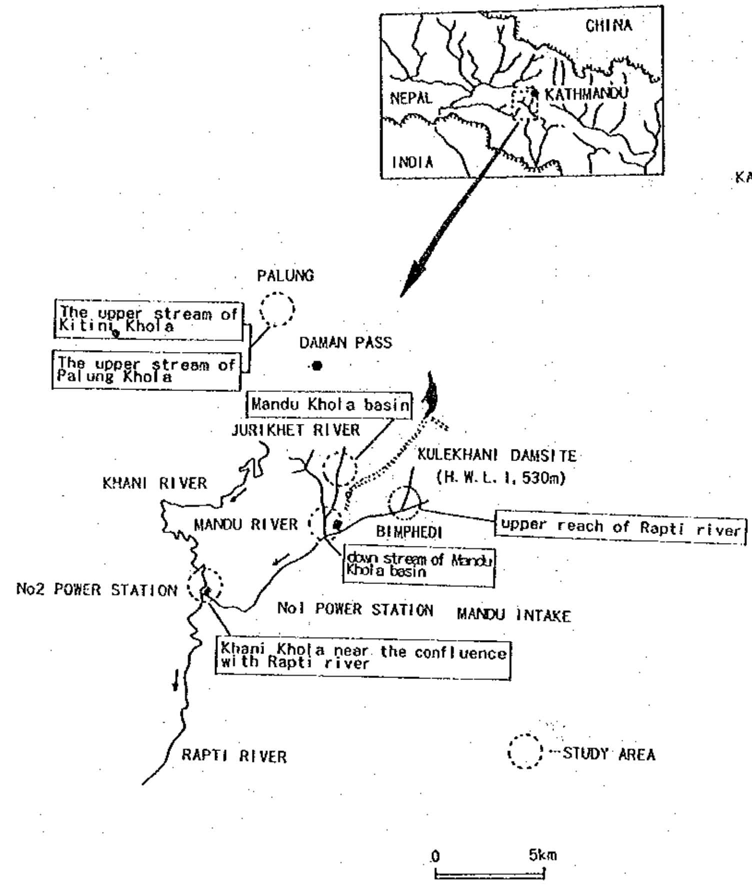


Fig. 6.2.1 Location of study area

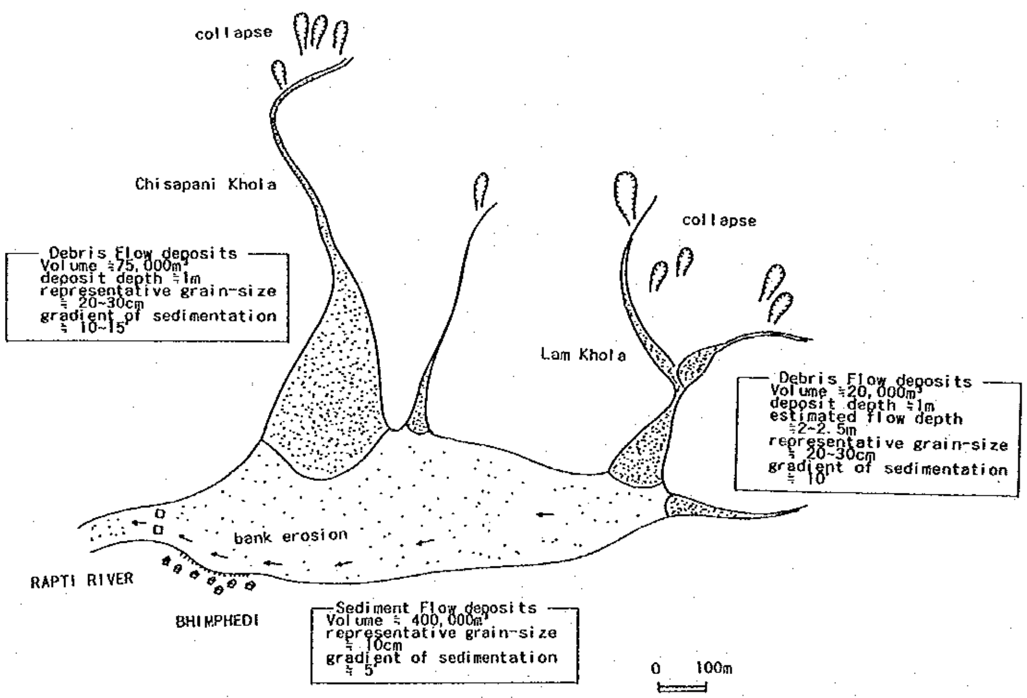


Fig. 6.2.2 Sediment discharge state in the upper reach of Rapti River (Bhimphedhedi VDC)

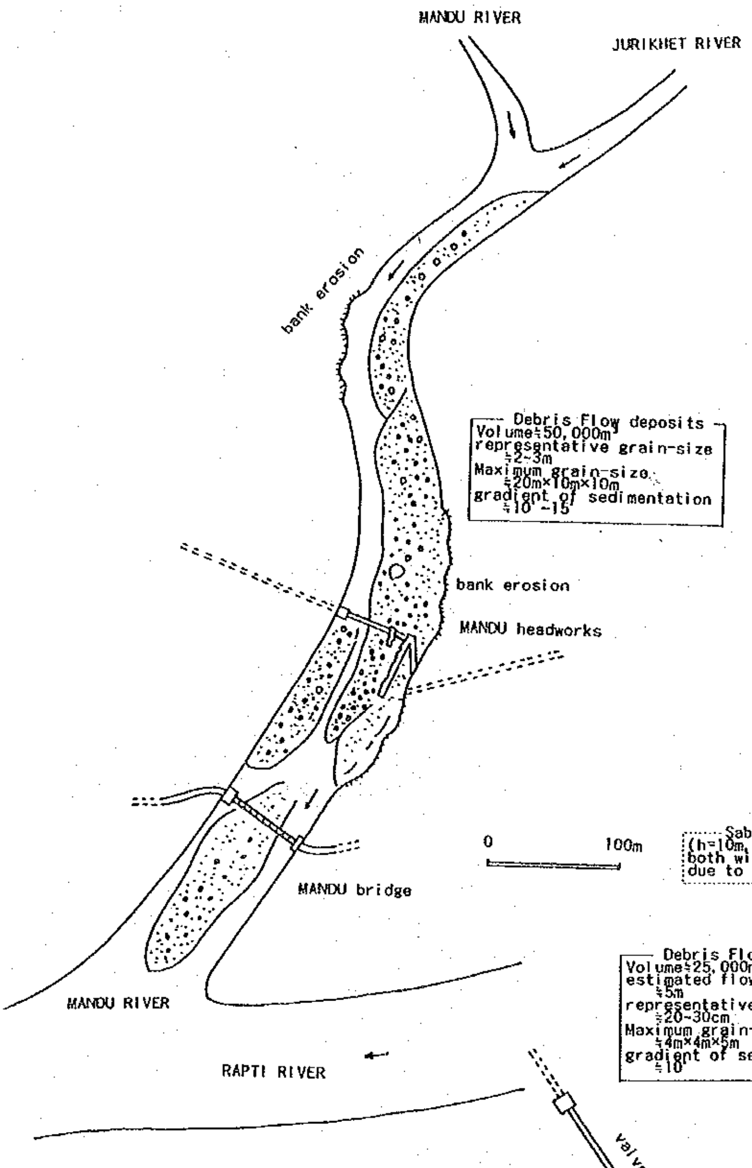


Fig. 6.2.3 Sediment discharge state in Mandu Khola basin

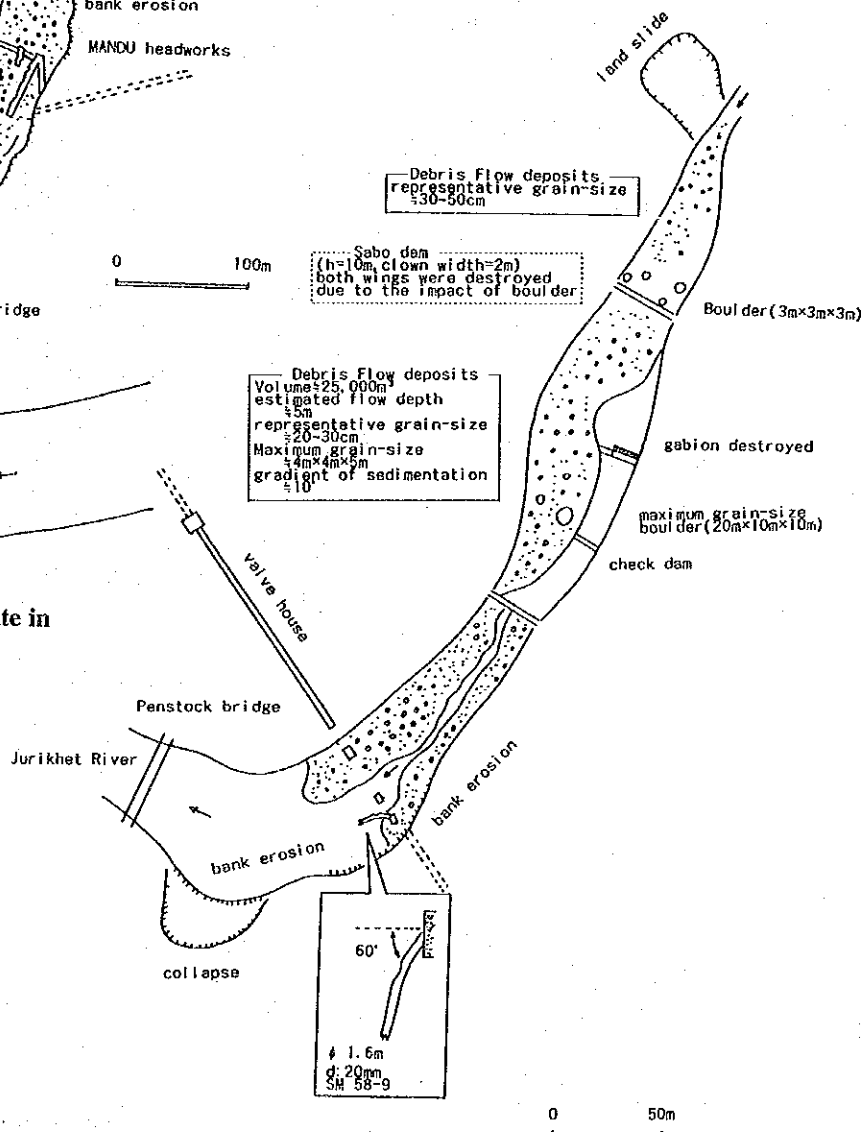


Fig. 6.2.4 Sediment discharge state in the down stream of Mandu Khola basin

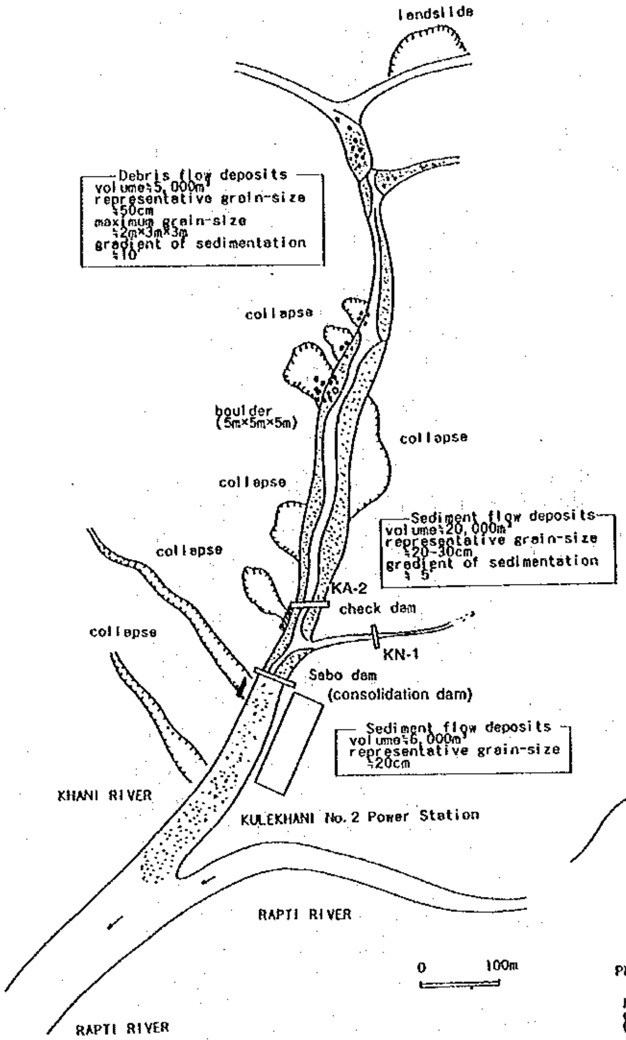


Fig. 6.2.5 Sediment discharge state in Khani Khola near the confluence with Rapti River

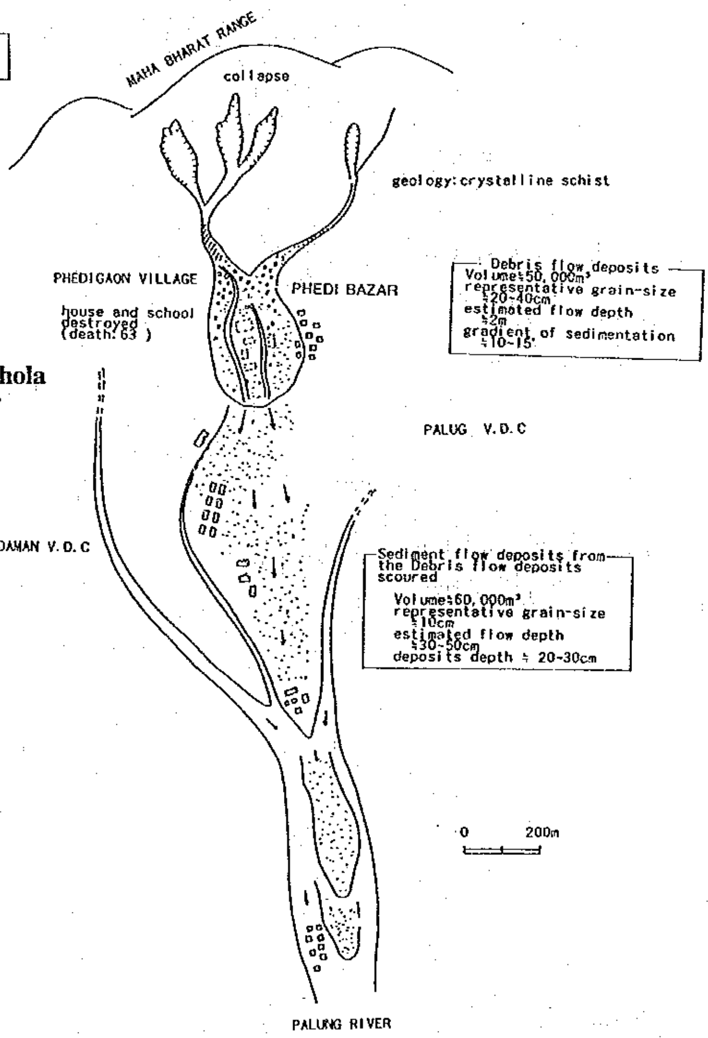


Fig. 6.2.6 Sediment discharge state in the upper stream of Palung Khola

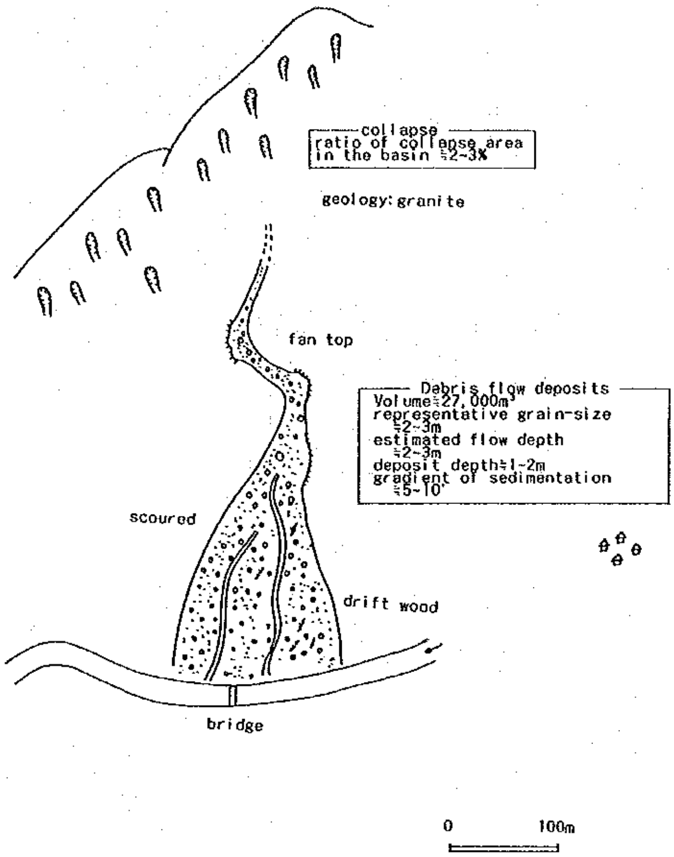


Fig. 6.2.7 Sediment discharge state in the upper stream Kitini Khola

Photo. 6.2.1 Sedimentation state in Bhimpedi Village, Makawanpur District

Photo. 6.2.2 Debris flows deposits in Chisapani Khola

Photo. 6.2.3 Bank erosion due to drift current of sediment flow at Bhimphedi village

Photo. 6.2.4 Check dam damaged by debris flow in Jurikhet Khola

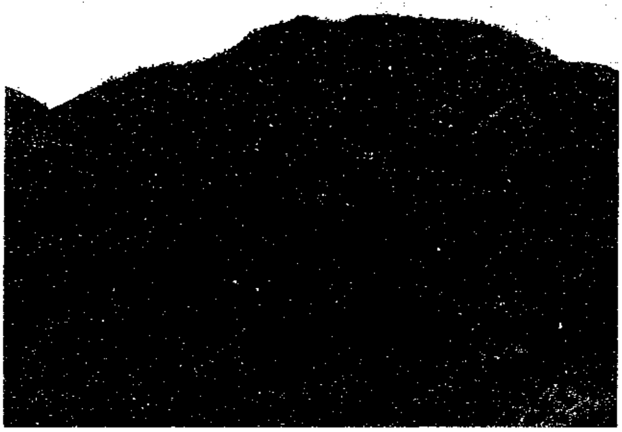


Photo. 6.2.5 Collapses in the upper stream of Jurikhet Khole

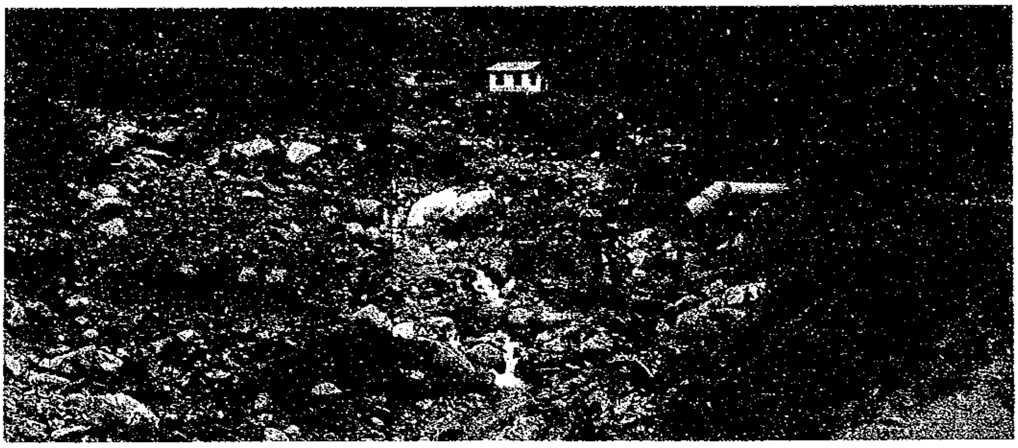
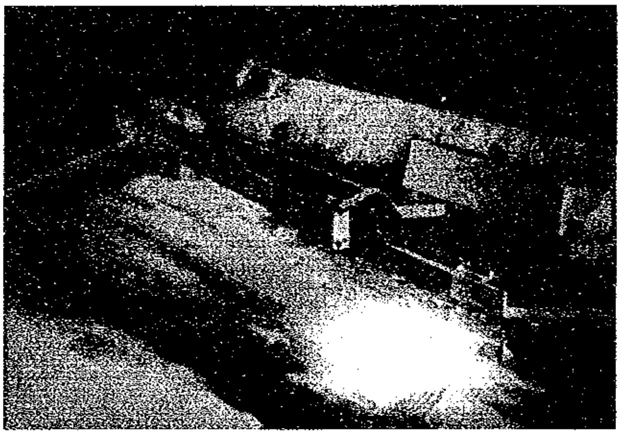


Photo. 6.2.6 Penstock pipe destroyed by debris flow in Jurikhet Khola



Before the Debris flow occurrence

Photo. 6.2.7 Mandu Intake (head work) destroyed and overlain by debris

Photo. 6.2.8 Aggradation of Khami Khola near the confluence with Rapti River

Photo. 6.2.9 A heavy sediment load in Khani Khola in front of the Kulekhani No. 2 Power House

Photo. 6.2.10 Sedimentation state in just upper stream of check dam shown in the photo. 6.2.9

Photo. 6.2.11 Debris flow deposits in Palung Khole

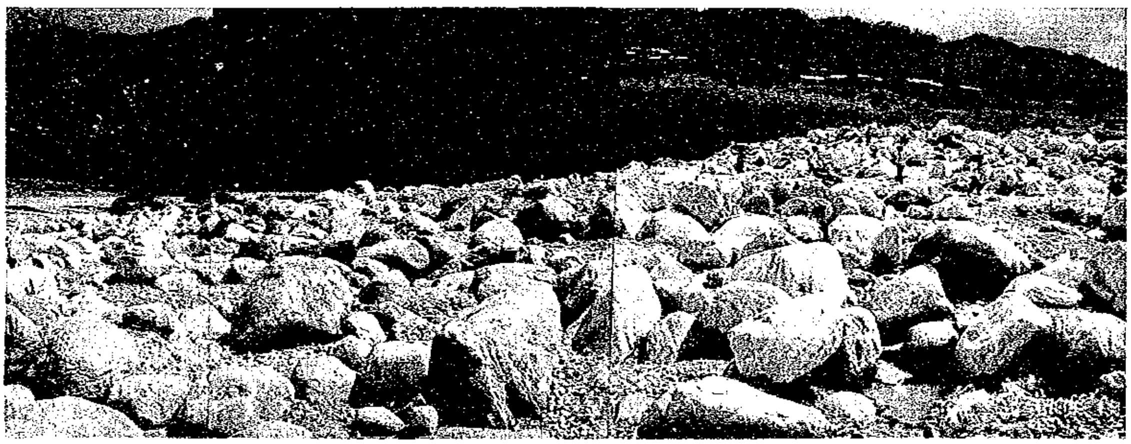


Photo. 6.2.12 A number of collapses in the granite area triggered debris flows in Kitini Khole

6.3 Landslides Occurred in Kulekhani Power Stations Area

Kulekhani power station area is an important basin for Nepal's electrical resources. This basin is consisting of mountain summits of the average elevation of 2,500 m and sharp gorges called as middle mountain. Fundamental geology is consisted of granite, limestone and schist strongly metamorphosed by tectonic movement. Landslides which damaged many important infrastructures such as power facilities and roads occurred on mountain side and gorge slopes.

Landslide movement forms show a quite different types depending on its geological condition and geomorphological situation. Suitable measures are, in principle, designed according to landslide mechanism discussed based on the data obtained from various kind of surveys such as bore hole investigation. This chapter deals with landslide features and its prevention methods obtained from field reconnaissance. Also only technical subjects are mentioned here in view of the nature of the mission of the Team and accordingly economic feasibility is not dealt with.

6.3.1 Valve house landslide

(1) Landslide situation and damages

This landslide closely locates on the left side of valve house standing on the slope facing southeast at the elevation of 1450 m. The signs of sliding movement of this landslide by the July 1993 rainfall have not been observed. This sliding mass keeps already stable condition by the completion of anchor work and other measures.

(2) Recommendation of stabilization procedures

As a result of completion of prevention works, there is no necessity to plan and to design additional protection works against this landslide.

6.3.2 Upper Jurikhet landslide (so called as small landslide)

This landslide occurred at the maintenance road, which is running toward Kulekhani dam reservoir, apart from the Upper Jurikhet in distance of 400 m.

(1) Landslide situation and damages

1) Rockslide having a planer slip surface in a scale of approximately 30 m in length, 15 m in width and 4-5 m in maximum depth occurred near mountain summit of 1,550 m facing to the east direction (Photo. 6.3.1). Head scarp area extends to the upper path of road shaping as hair-pin curve.

2) Sliding mass entirely flowed out from the source area toward the down slope except for little remaining earth material on the right side (Fig. 6.3.1, A) and fragment stones of less than 1 m diameter on some place (Fig. 6.3.1, B). On the landslide scarp surface only an earth cliff of 0.5-1.0 m in thickness mainly originated from weathering is observed (Fig. 6.3.1, C). Hard rock consisted of crystalline schist (N 10° W, 40° dip) is

continuously outcropped (Fig. 6.3.1, D). Especially geological formation in the landslide area is specialized as structure of dip gradient layer. Rockslide controlled by geological conditions defined as a dip gradient formation is a general form on this region. From the above mentioned reasons the expansion of landslide can not be anticipated in the future.

3) Sliding mass almost flowed down from the spot of beneath locating path as the moving forms of debris avalanche along the sharp gully channel is estimated at over about 6 m in width. Due to this sliding the beneath locating path for the maintenance purpose of Kulekhani dam reservoir is destroyed ranging over 6 m in length. Landslide in the future will be only small scale rock fall originated from the condition of jointed formation.

4) Although cause of this rockslide is directly heavy rain fall, primary causes are the particular geological formation, which is called as dip inclination and gully development due to the erosion of the Chisapani Khola extended to the landslide toe spot.

5) On the other hand, opening crack having 20 cm in maximum width, which is locating about 2 m above the slope side of road, continues parallel with the road running direction (Photo. 6.3.2). The continuous length of this crack extends over 100 m from the above mentioned rockslide toward Upper Jurikhet. The depth of this landslide (refers to lower landslide) is estimated to be a relatively shallow form judging from the dipped geological formation of its surrounding area and the only existence of opening crack without being accompanied by subsidence or uplift phenomena.

(2) Recommendation of stabilization procedures

1) Urgent measure

① Urgent investigation of the mechanism of movement of the lower landslide occurred on the slope exceeding over 40° slope should be made to decide and ascertain the scale and the sliding form through field geological reconnaissance. Warning system by using the extensometer is greatly effective for predicting collapsing time (Fig. 6.3.2)

2) Preventing measure

① Gabion works combined with H typed steel bar on the base, and if depth of weathering extends to deep range, anchor work with suitable free length should be planned against the lower landslide. Gabion work constructed on landslide head area will be easily destroyed if its base is not supported by steel bar or pile.

② Measures for new road to be constructed on Upper Jurikhet landslide are sufficient by construction of wet masonry wall based on the hard rock in order to prevent the further development of gully magnification and trimming work in order to remove the very small scale rock fall and the collapse of remaining earth material (Photo. 6.3.3). Slope protection works should be discussed on the outcropped slope after trimming, mortar spray work is effective to prevent the weathering process causing further rock fall.

③ As landslides form is controlled by the geological condition originated from the tectonic movement, the detailed investigation of geological structure should be planned. To assess the degree of danger of landslide prone area the investigation in regards with correlation between the landslide occurrence until the present day and gully development degree should also be planned.

6.3.3 Upper Jurikhet landslide (so called as large landslide)

This landslide occurred at the maintenance road which is approximately 400 m apart from Small Landslide. The landslide elevation is 1,600 m. Inherent geological condition of the occurred slope is same as Small Landslide.

(1) Landslide situation and damages

1) Landslide scale is estimated over 250 m in width, 300 m in length and 2 m in average depth. This landslide is characterized as a shallow depth moving contrary to wide sliding area. Many small gully forming of 2 m in depth and 2 m in width exist at the toe of landslide area (Photo. 6.3.4). On this area, gully scale becomes larger towards right side. Forming process of this landslide is surmised that sliding of fragment rock around the toe of landslide area is caused by stress release action due to gully's vertical erosion. Around the head area, movement of mass which is estimated to be relatively thick layer is mainly caused by the weathering of foot material depending on release action due to the magnification of gully.

2) Geology of the landslide area consists of quartz schist, mica schist and phyllite. The upper parts of sliding area is almost covered by fragment material originated from weathering. Then landslide toe area is locating on the boundary area between weathering prevailing area and head area of gully.

3) Primary causes of the landslide are the geological structure, alternation by weathering and gully development on very steep gradient condition.

4) Particular movement induced by the July 1993 rainfall is not existing. But unstable material in great volume still remains on this slope.

(2) Recommendation for stabilization procedures

1) Urgent measures

① As the rock fall is anticipated at any time, the location of rock fall occurrence should be identified through detailed field reconnaissance. If necessary, warning system by using wire sensor, which signs the red signal immediately when the wire is cut by falling stone, is available.

2) Preventive measures

① It is necessary to plan the prevention works in regards with the road rehabilitation so as to prevent the damages induced by rock fall and earth collapse. Wet masonry and concrete wall based on the hard rock is most effective for the road protection works because the scale of gully is not so large and mother rock is observed on the gully bed (Shown in the lower position on Photo. 6.3.4).

② In order to prevent creep activity on the head part of landslide mainly consisted of fragment material, gabion works combined with H shaped steel bar should be constructed. If necessary, anchor work of short free length should be planned.

③ If rock fall of remaining fragment stone is anticipated, trimming work should be carried out to remove it.

6.3.4 Jurikhet River landslide (locating on the opposite slope of penstock)

This landslide occurred at the road constructed along the Jurikhet Khola (a let tributary of the Mandu Khola) at approximately 400 m down stream from penstock bridge.

(1) Landslide situation and damages

1) Landslide of a scale exceeding 300 m in length, 200 m in width occurred at the middle area of mountain slope which shows mountain ridge of approximately convex topography facing toward south direction (altitude: 1,287 m the above sea level, Photo. 6.3.5). Sliding depth is estimated to be over 20 m. Head scarp estimated to be over 5 m in height locates at about 30 m below from the this summit (Fig. 6.3.3, A). This scarp occurs at the boundary place between almost straight topography of upper slope and approximately convex shaped of lower area. As this scarp continues clearly to the toe area (Fig. 6.3.3, B), the present sliding active is considered to be in the continued sliding situation by reason of existence of small scale collapse.

2) Geologically landslide mass consists of sandy schist of meta sediment. Its fundamental geological formation is a dip slope structure. This landslide type is assigned to weathered rockslide type composed of the fragment rock by reasons of topographical and sliding features such as occurrence on convex slope.

3) Two landslides areas of a scale of about 100 m in length, 80 m in width are confirmed clearly on the both flanks of presently occurred larger landslide (refers to larger landslide) on the aerial photograph taken in April 1989 (Fig. 6.3.3, C, D).

4) Two landslides areas and location can be easily pointed out because of continuous sinking topography in the form of horse shoe. Typical scarp topography of previous landslide being exceeding 3 m in height is clearly detected on the let side of two landslides (Fig. 6.3.3, E). Then the active area of presently occurred two landslides are approximately corresponding to the discriminated area on aerial photograph. Of the two landslides, the one at left side (Fig. 6.3.3, C) is estimated to be deeper as against the right side one judging from the existence of standing vegetation on sliding mass and clear scarp having subsidence exceeding 3 m of horse shoe shape which indicates one block sliding. Toe of these sliding extends to river bed of the Jurikhet Khola. Hence cause of these landslides, especially on left side landslide, is toe erosion by debris flow of this Khola.

5) Many cracks and another small scale landslide are observed behind two landslides (Fig. 6.3.3, F, G). This characteristic is clearer in the lower region. From the point of view of a sliding form the slip surface configuration is estimated to be a planer form type. On the condition of planer slip surface another landslide easily occurs behind upper slope. As this landslide clearly indicates the same characteristic features, moving type of this landslide is surmised to be a typical retrogressive form.

6) Main cause of larger landslide is a sliding of these previously occurred landslides which locate on the both flanks and gorge bank slope attacked by river flow. Erosion of sliding material of lower part of landslides reaching to Jurikhet Khola is a main cause of behind larger landslide. The erosional protection of lower two landslides is important to check the further development of behind larger landslide.

7) Road is entirely slipped down ranging over 80 m and 60 m respectively at the two spots (Fig. 6.3.3, H, I). This length is equivalent to width of landslide which is discriminated from aerial photograph observation.

8) Cutting action against two landslides locating at lower part of larger landslide for the rehabilitation of road is a cause of further sliding activity of larger landslide.

(3) Recommendation for stabilization procedures

1) Urgent measures

① Equipments of extensometer as warning system for the prediction of collapsing time should be urgently set up on main and sub-occurred crack so as to prevent the human damages until the completion of permanent measures.

② Erosion protection measures by using gabion work etc. should be taken so as to prevent scouring of toe of two landslides which may cause further development of larger landslide.

③ Drainage bore hole drilling is available as an effective measure for the first stage of permanent measure.

2) Preventive measures

① As this landslide is a retrogressive moving type and is composed of many blocks of each different scale form, the detailed investigations to confirm slip surface configuration and ground water situation should be conducted urgently to grasp the interaction of each landslide block.

② Banking work with high anti-scouring property for measure against the lower two landslides is effective because these landslide toe extends to river bed.

③ Permanent measures will include cutting of great amount volume to reduce driving force and anchoring work to restrain sliding force because landslide is large and slope gradient is steeper. It is necessary to discuss the occurrence of another landslide on cutting plane and supporting force of anchor plate, bonding resistance force and anchoring direction on anchoring work. Suitable measures should be considered such as tunnel road etc. after the discussion of landslide mechanism and of financial aspect as well.

6.3.5 Penstock landslide

This landslide occurred at a sharp gorge slope of Jurikhet Khola at the location close to the in penstock bridge.

(1) Landslide situation and damages

1) Landslide scale is estimated over 40 m in width, 30 m in length and 10 m in depth. Topography of sliding area is characterized by a clear triangular shape as against the

above mentioned sliding form of Jurikhet River landslide (Photo. 6.3.6). Clear scarp of subsidence phenomena exceeding 4 m in height continues from head cliff to toe area (Fig. 6.3.4, A). This subsidence phenomena is clearer toward right side (Fig. 6.3.4, B).

2) Geology of surrounding landslide consists of sandy schist of meta sediment. Fundamental geological structure observed on river bed is a dip slope formation (Fig. 6.3.4, C). However, joint system crossing this dip strike exists on the right side of landslide toe area (Fig. 6.3.4, D).

3) By reason of triangular moving shape, sliding depth will be thicker according to the approaching degree to toe area. And from the existence of clear subsidence of right side and of base rock in spite of fractured material in high elevation compared with left side (Fig. 6.3.4, D), left side is inferred to be deeper in sliding depth. The subsidence of road for maintenance of penstock is less than 1 m in contrast to the large subsidence of scarp area (Fig. 6.3.4, E). From this fact, slip surface gradient under road place will be a flat condition.

4) Slip surface seems to be located at the F line in the Figure because remarkable boundary line between deposit material and rock material is observed.

5) The toe area is located at situation of a frontal attack by flood and debris flow of Jurikhet Khola due to meandering of river course. Thus the cause of this landslide is a removal action of toe material by scouring.

6) By the discrimination of aerial Photograph taken by April 1989, this landslide of a triangular sliding form can be easily found out from the clear subsidence topography of a scarp and a frank crack. This landslide is located at lower left flank of behind landslide being over 3 times in area scale. Landslide occurred at behind slope, which does not show clear signs of sliding by July 1993 rainfall, possibly consists of fractured rock material (Fig. 6.3.4, G). Also strongly sheared zone is reported at boundary place between the fractured rock colored by dark brown and hard rock successively from river bed. This fragment rock is inferred to be a sliding material of behind landslide.

(2) Recommendation for rehabilitation procedures

1) Urgent measure

① Urgent investigation for sliding situation of behind landslide should be made. Equipments of extensometer on scrap tension and ground tiltmeter on behind slope should be set up to grasp the moving situation. Obtained data is the most useful as waning standard values during rehabilitation works of penstock because this landslide closely locates to penstock.

② Cutting work at the head area of the presently occurred two landslides should not be designed because such action possibly cause a large sliding of behind slope. Some actions for urgent rehabilitation of road are necessary to be carried out by observation and check of data obtained by the above mentioned equipments.

2) Preventive measures

① Rocks partially distributed at toe area are not so hard and are fractured into fragment materials in the central area. Anti-scouring works are recommended so as to avoid the landslide cause. This plan should be considered under the erosion control project including a series of sabo dam in order to recover the function of penstock.

② Drainage bore hole drilling is an effective measure as the first stage of permanent measure.

③ As the presently occurred two landslides and behind landslide show the topological feature of triangular sliding, cutting work of great amount volume may not be effective to attain the high safety factor of landslide slope. Permanent measures including anchoring works should be discussed under the situations of behind landslide. Then landslide surveys for the purpose of clarification of mechanism and interaction should be planned.

6.3.6 Bhimphedi road running along the foot of terrace plane

This road constructed for maintenance of Kulekhani dam is running along the right side foot of terrace plane on which Bhimphedi town is located.

(1) Road situation and damages

1) This road has been washed away entirely for the length over 800 m due to strong scouring action induced by debris flow of the Bhimphedi Khola. In this Khola, aggregated sediment of large diameter stone exceeding 2 m widely exists as traces of debris flow.

2) Damaged area due to scouring extends over the road to terrace plane cliff. Steep slope collapse indicating 10 m in width and 3 m in depth occurred at numerous places of the terrace plane cliff exceeding 10 m in height and 60° in slope angle (Photo. 6.3.7).

3) Terrace geology is consisting of the deposited material having the cobble of small diameter originated from the past debris flow. Sorting layer of deposited cobble can not be clearly observed on the collapsed slope face. Terrace deposit is mainly earth material. Then anti-erosion property of terrace cliff is very weak.

(2) Recommendation for rehabilitation procedures

1) Urgent measure

① At present, the damaged road is used after temporal repair works at the original place of terrace foot. However, this road can not be used as it is in danger of rock fall because the cobble stones in an unstable condition remain on the steep slope subject to easy erosion. Therefore field investigation for confirmation of unstable stone spots should be made so as to avoid the transportation damages.

2) Preventive measures
It is difficult to reconstruct the road along original route by the following reasons.

(a) As large diameter sediment stone is widely observed at the upper stream as well as at the river bed beside the road, large scale debris flow having strong scouring force will occur in near future. Destruction of road is anticipated again due to scouring by debris flow.

(b) River width beside the present road is less than 40 m in some places. Temporal repair road elevation is as same elevation as the sediment level of river bed generated by the present debris flow. Road surface should be planned at higher elevation so as to prevent the flooding onto the surface of the road.

(c) Strong anti-scouring high wall is necessary a long distance. Base of this high wall should be capable for fully supporting function to the future river bed fluctuation due to any different type flooding and debris flows.

(d) Slope protection works on steep gradient terrace slope mainly consisting of earth material which damaged transportation are also necessary for a long distance.

From the above mentioned reasons, following should be considered in planning rehabilitation of the road.

① New road should be constructed on the terrace plane not on the terrace foot.

② On this plan, channel drain works for surface water of road side and small scale slope protection works for cutting place exceeding 5 m in height which may cause slope collapse should be considered. Especially surface water cannel works to be constructed on the both sides of road are important to prevent the scouring of road surface and development of gully on terrace slope.

③ Vegetation cover works should be planned on the cutting face of terrace deposit so as to prevent the sheet erosion which may cause gully development.

④ It is necessary to consider, as an alternative, a new bridge at the road entrance onto terrace plane if the great amount cutting works is necessary.

⑤ As erosion and scouring of terrace foot caused by debris flow are anticipated, and material produced by these actions is one of major cause of damages to 2nd power station at the confluence place of Bhainse, a series of erosion control works such as groundsel and check dam against these scouring and erosion should be planned through the watershed management project.

6.3.7 The landslide landform locating near the 2nd power station

(1) Landslide situation and damages

1) The slope locating at opposite river side of the 2nd power station at Bhainse is inferred to be a landslide landform (Photo. 6.3.8). Major sliding activity of this landslide is considered to have finished in the past time, because the fairly decayed main scarp resulting from the long term erosion is clearly observed. But, main sliding block still remains on the right side of the Khani khola.

2) The scale of the previously occurred main sliding block is estimated over 200 m in width, 150 m in length and 30 m in depth. Landslide foot is partially eroded by flooding of Khani khola.

3) Small collapses in scale of the average of 15 m in width and 15 m in height induced by the July 1993 heavy rainfall occurred at the some foot slopes of the main sliding block mass (Photo. 6.3.9).

4) Two check dams were constructed for the protection gully erosion of main sliding block by debris flow. Those dams are effective for the prevention of reactivity of main sliding block by the weighty effect of sediment stone behind those dams.

5) The deposit of wasted earth material causing of debris flow is observed on the middle slope area of main landslide block.

6) Each check dam made by concrete and gabion were destroyed by large rolling stone with the diameter exceeding 5 m at the foot area of landslide landform.

(2) Recommendation for stabilization procedure

1) Urgent measures

① An abandonment of rock fragment and earth from limestone quarry on the top of main sliding block makes a cause of unstable condition. Abandonment of wasted material from the quarry should be prohibited to prevent the landslide movement.

2) Preventive measures

① To clarify the landslide situation, geological investigation and measurement are urgently should be made urgently.

② In the planning of erosion control works around the Kulekhani 2nd power station, this landslide situation should be considered.

③ As gully develops clearly at the landslide toe, groundsel works should be made to prevent the further gully slope collapse induced by vertical erosion.

6.3.8 Bhainse Bridge

(1) Bridge situations and damages

1) Debris flows of Rapti River caused many problems in Bhainse area. The Bhainse bridge was washed way, the river bank on both sides were heavily eroded (Photo. 6.3.10)

2) Some houses by the river were destroyed and many others were submerged. The rise of the river bed has caused not only the inundation of Bhainse village but also a serious problem to the tailrace of Kulekhani 2nd power station.

(2) Recommendation of stabilization procedures

1) These problems are interrelated each other. In order to solve these problems in an integrated way, a river training plan should be prepared as soon as possible, in that the protection of Bhainse village should be well taken into account (construction of embankment, reclamation of low area etc.).

2) Reconstruction of Bhainse bridge (location, length, clearance etc.) as well as the remedial measures for the problems of the power station should be well taken into account. If the river bed of Khani Khola in front of the tailrace rises by another 1 m the power station will have to cease its operation. The river bed rise of Khani Khola is mostly

due to the debris flow deposits in Rapti river in the downstream of the confluence with Khani Khola and the back water effect of Rapti River.

3) It is generally difficult to clarify the sedimentary or erosional mechanism in the confluence place. The most suitable method to find the best solution may be hydraulic experiment.

6.4 Landslides along the Prithvi Highway

6.4.1 Naubise landslide

This landslide occurred at the road side running parallel to the Mahesh Khola flowing through Naubise village.

(1) Landslide situation and damages

1) Landslide of a scale of about 80 m in width, 5 m in length, 10 m in height occurred with the moving direction toward river side (Photo. 6.4.1).

2) Retaining wall made by wet masonry supporting the road embankment was destroyed and tilted in ranging over 20 m. Degree of opening cracks scale and subsidence phenomena is greater and clear in proportion to central part of landslide (Fig. 6.4.1, A, B).

3) Geological structure consisted of sandy schist in the landslide area is observed as 45° tilted formation in contrast to the almost vertical bedding plane existing on river bet (Fig. 6.4.1, C). Outcropped rock layer observed on sliding ground surface forms a wave undulations (Fig. 6.4.1, D).

4) Landslide form is judged as a toppling by reasons of existence of obviously different bedding formation to river bed, wave structural formation and about 20 cm clear open cracks only at the road institution (Photo. 6.4.2).

5) Main cause of toppling is a release of counter weight of foot area by scouring of river flow (Fig. 6.4.1, E).

(2) Recommendation of stabilization procedures

1) Urgent measures

① Gabion work should be urgently carried out at the landslide foot to prevent the removal of earth material as a function of counter weight caused by further scouring of river flow.

② Sheet covering for prevention of surface water infiltrating into the sliding ground should be urgently made on the opening crack. And packing using clayey soil into opening crack occurred at road surface should also be made.

③ Warning system by using extensometer should be set up as early as possible to prevent damages to transportation.

2) Preventive measures

① Generally speaking anchoring work is often used as direct preventive measures to toppling movement. However, as this toppling mass is mainly consisting of earth material, the lack of sufficient supporting force for anchoring plates is anticipated. Therefore banking work supported by retaining wall constructed on hard rock of river bed is recommended. If hard rock for support of retaining high wall is not expected, the shifting of river course should be considered for much more banking.

② On the river side of road, surface water channel work to prevent the infiltrating water into ground and the development of gully occurred on landslide ground surface should be made.

③ As banking volume depends on the toppling mechanism, the investigation of geological structure should be made.

6.4.2 Jogimara rockslide

(1) Landslide situations and damages

This rockslide is located at the slope close to the old limestone quarry along the Prithvi Highway running parallel with Trisuli River.

1) Rockslide scale is inferred as exceeding 70 m length, 80 m width and 15 m depth. The landslide occurred on at the same place in August 1992, thus the traffic of Prithvi Highway is often disturbed by the Jojimara rockslide. (Photo. 6.4.3).

2) Extremely unstable rock block still remains on the left side slope of landslide ((Fig. 6.4.2, A). A volume of the remaining block is estimated at 3000 m^3 (a scale of about 30 m in length, 20 m in width and 5 m in depth (Fig. 6.4.2, A)).

3) As strongly fractured rocks zone is observed in raging over 15 m in thickness and 30 m width from the observation on the surface of scarp cliff, existence of another rockslide can be anticipated from the behind mountain slope (Fig. 6.4.2, B).

4) Geology of the landslide area consists of limestone, black schist and slate.

5) Although an original bedding plane is not parallel to slip surface, major joint system (N65° W, 74° N) is developed with concordance to slip surface (Fig. 6.4.2, C). The rock blocks are gradually detached from the bed rock along the joint system by sheeting action etc. and turn into unstable block. With an addition of heavy rainfall such blocks will collapse easily.

6) Major movement type of this landslide is inferred to be rockslide and rock avalanche. The slip surface considered to be a planer shape appears at 50 m above the road elevation.

(3) Recommendation for stabilization procedures.
After the field investigation at Jogimara the Team was briefed by the UK consultant at their office. Based on discussion with the consultant following measures are recommended.

1) In order to make the rehabilitation of the road running through this area with safety first, a tunnel work accompanied with route shifting is recommended.

2) Second recommended rehabilitation method is the cutting of a great deal of amount to reduce sliding force, combined with anchoring work of relatively long length. On this plan, it is necessary to construct a detour road against the falling rock which may damage to vehicles during cutting work. Features such as a scale and a slip surface configuration of rockslide occurred at surrounding area is controlled by geological structure of bedding plane. Slope gradient for cutting works should be designed in consideration of these geological character.

3) To make the constructive time shorter, rock shed work is recommended. On this plan, it is necessary to analyze the impact force induced by the future sliding of rock mass. This structure should be equipped with sufficient shock absorbing function. It is generally difficult to estimate the impact force for planning of shed structure, the most suitable calculation method provided until the present day may be Distinct Element Method by using high speed computer. On this calculation, as the obtained results vary depending on the inputting sliding mass amount, it is necessary to precisely assume the mass volume. Especially on this plan, when fragment debris depositing on road is removed, great attention should be paid to the still remaining sliding material at the right side of landslide area because the toe of its unstable mass continues to the head spot of corn deposited on the road.

4) Team strongly recommends the establishment of warning system of the following described equipments so that occurrence of rockslide and rock fall can be predicted. Wire type sensor is more effective for rock fall disaster, while extensometer set on the scarp spot of rockslide prone area is effective to predict the collapse time.
However, in view of the magnitude of this rockslide with massive rock still remaining in an unstable situation in landslide area and behind the cliff of slide, it is not possible for the Team to make an on-the-spot conclusion on the most feasible method for Jogimara case although either of the above mentioned methods is not impossible if considerable amount of fund be made available.

6.4.3 Measures to landslides occurred at road from Thankot to Naubise

(1) PC anchor method

PC anchor method has been applied to the landslide located to the west of Thankot under the Road Flood Rehabilitation Project. The method seems to have been effective during the heavy rains in July.

There was one comment from the engineering point of view. The distance between some anchors seems to be rather short. If the free length is not sufficient enough, the anchor can not have resistant force as designed. Spacing of PC anchors should be carefully designed to avoid the crossing of bonded spot. Especially designing method of anchor is depending on the construction spot of landslide as one is wait function and the other tighten function. When anchoring is planned, the standards collected by DPTC can be applied.

(2) Crib work

Proceeding further to the west, there is a crib work constructed as a retaining wall against landslide. This method is popularly used for landslide prevention works in Japan. It was learnt that this was the first in Nepal. It is recommended to use crib works more in Nepal in view of following advantages:

1) The crib work is flexible, therefore deformation of the foundation due to landslide movement does not cause any harm (like a crack) to the wall.

2) Excavation for foundation works is much less compared with the concrete retaining wall. It is important that in landslide area foundation excavation should be minimum so as not to induce the movement of the landslide.

3) The crib works usually uses boulder as the filling materials, therefore it is good for ground water drainage.

4) As the concrete skeleton of crib work is generally produced in factory or field plants, its quality is expected in high degree because of ready made.

   Comments of the crib work which was constructed along Thankot - Naubise road are as follows;

   ① The filling material should be boulders instead of soil.

   ② Coverage of the crown by concrete is not necessary.

6.5 Future Investigation Subject of Landslide

Investigation/analysis should be carried out on following subjects to progress and to develop the rehabilitation of damaged facility due to landslide.

(1) Aerial photograph on hazardous area is necessary to grasp exact situation of hazard and to make new prevention measures. It is also useful to compare before and after the disaster.

(2) Landslides occurred in the investigated area is categorized into the following types in regards with its occurrence place.

1) Landslide occurred at the weathered material zone which is locating at upper place of knick line. This landslide scale is generally not so large and depends upon the weathering depth.

2) Landslide occurred at the boundary place between knick line and river course. Toe of this landslide is characterized to be locating at the middle slope place and does not extend to river bed. Slip surface is controlled by geological condition such as bedding strike. This type of landslide is generally of large scale.

3) Landslide occurred at the river bank and then toe of landslide extends to river bed. This landslide scale is not so large, however, will become large if another landslide exists at the behind upper slope. In this case, landslide occurred at behind slope can be generally discriminated by aerial photograph.

Analysis of landslide situation by using aerial photograph is recommended to clarify the occurrence place.

(3) Generally slip surface of rockslide shows a planer configuration, and its moving form is controlled by geological condition. Then correlation analysis between geological condition and landslide moving forms is recommended to grasp the moving direction and sliding depth. On this discussion, landslide classification table which has been collected by DPTC is useful.

(4) Further, preparation of landslide risk mapping which is discussed under the information of landslide classification and moving types should also be considered on long term basis which will be useful in the selection and determination of highway route and power station etc.

In order to carry out the above mentioned investigation/analysis, DPTC should be consulted on technical matters whenever necessary.

6.6 General Recommendation for Measures of Debris Flows and Landslides

(1) Geological and geomorphological surveys of landslide site are necessary for future measure. Such researches should be enhanced for better understanding of the occurrence of the landslide hazards.

(2) Watershed management is important to safeguard the infrastructures in the downstream against floods, debris flows etc. Therefore watershed management projects should also be considered in planning reconstruction of infrastructures damaged by the disaster.

(3) In view of the fact that devastation in the Kulekhani catchment by concentrated rainfall caused floods and debris flows resulting in heavy damages to infrastructures as well as towns and villages in the catchment, it is recommended that the current Kulekhani watershed management project should be reviewed and a more intensified work plan should be drawn up.
The watershed management for Kulekhani River basin will be useful not only for mitigating damages to infrastructures and communities in the catchment but also for reducing the sedimentation in Kulekhani reservoir.

Photo. 6.3.1 View of Upper Jurikhet Landslide (so called as Small Landslide)

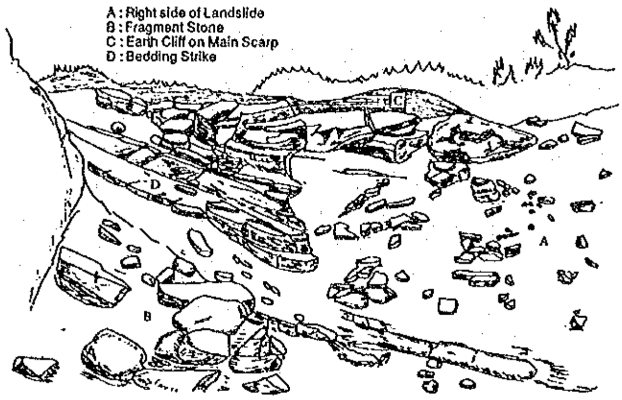


Fig. 6.3.1 Landscape Sketch of Upper Jurikhet Landslide (so called as Small Landslide)

Photo. 6.3.2 Tension Crack of Landslide locating along road

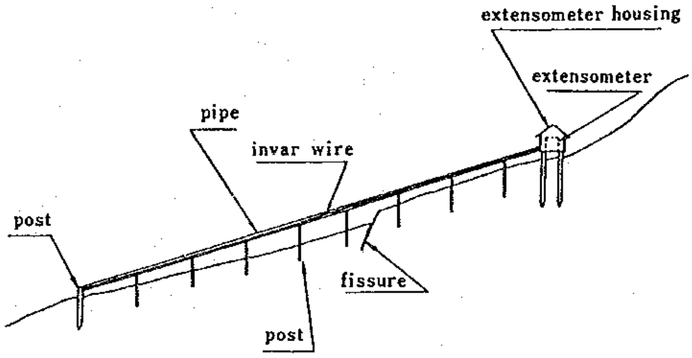


Fig. 6.3.2 Setting of an Extensometer

Photo. 6.3.3 View of Lower Part of Upper Jurikhet Landslide

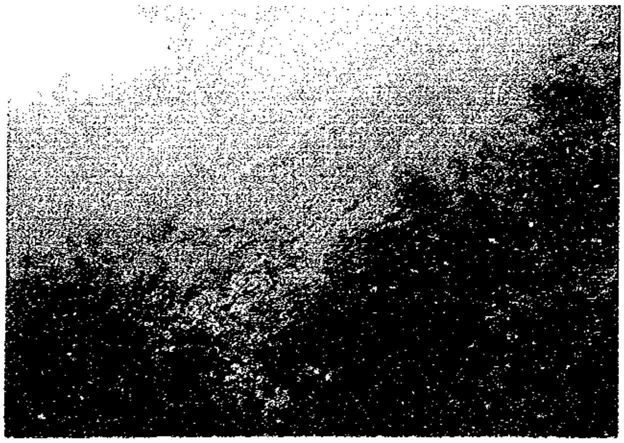


Photo. 6.3.4 View of Upper Jurikhet Landslide (so called as Large Landslide)

Photo. 6.3.5 View of Jurikhet River Landslide

Fig. 6.3.3 Landslide Sketch of Jurikhet River Landslide

Photo. 6.3.6 View of Penstock Landslide

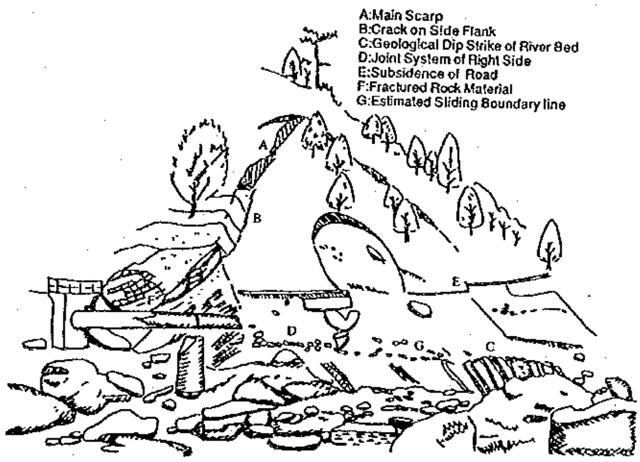


Fig. 6.3.4 Landslide Sketch of Penstock Landslide

Photo. 6.3.7 View of Bhimphedi Road

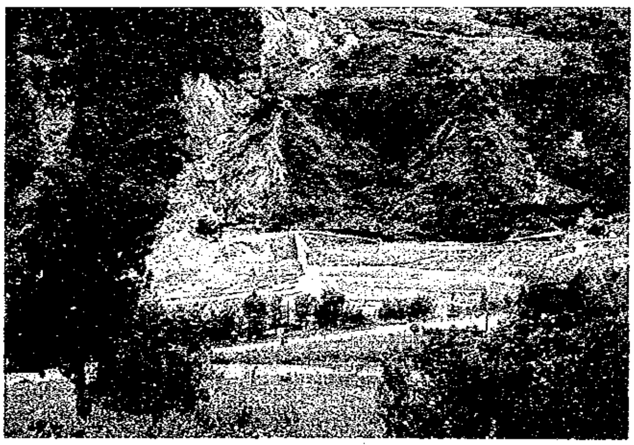


Photo. 6.3.8 View of opposite slope of 2nd Power Station

Photo. 6.3.9 View of collapse occurred at Landslide Landform Foot

Photo. 6.3.10 View of Erosive and Sedimentary Situation of Bhainse Bridge

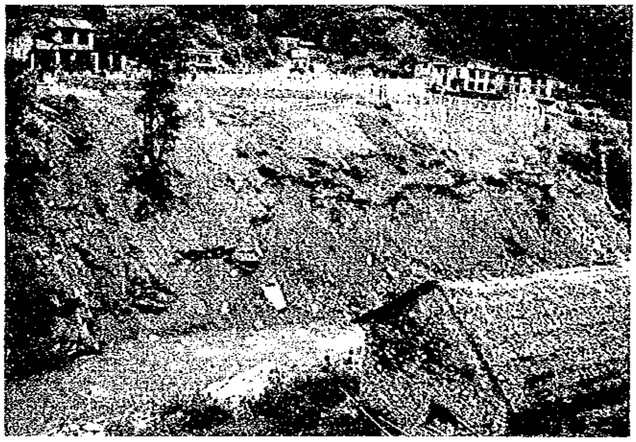


Photo. 6.4.1 View of Naubise Landslide

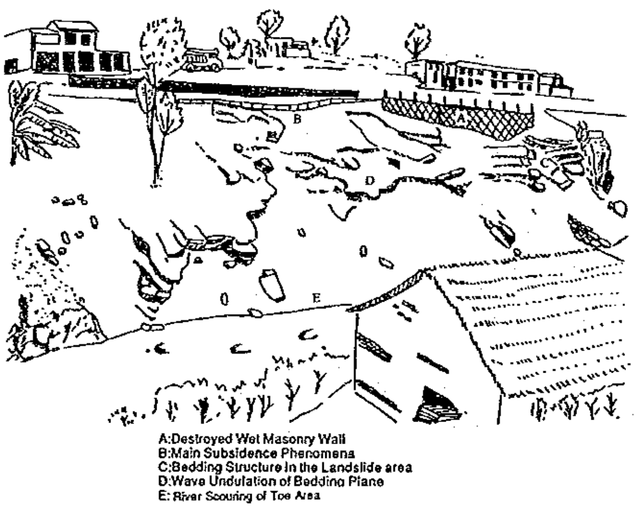


Fig. 6.4.1 Landscape Sketch of Noubise Landslide

Photo. 6.4.2 Open Crack occurred on Retaining Wall of Naubise Landslide

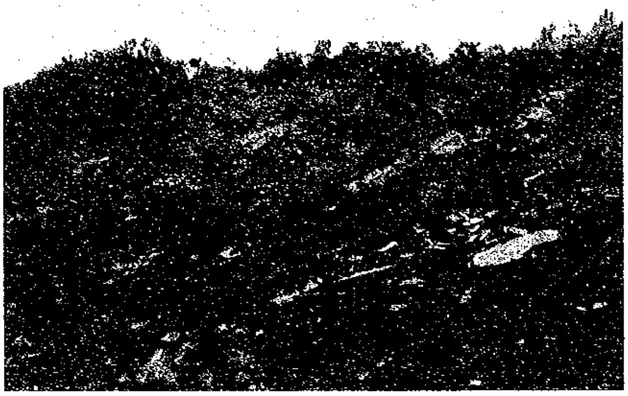


Photo. 6.4.3 View of Jogimara Landslide

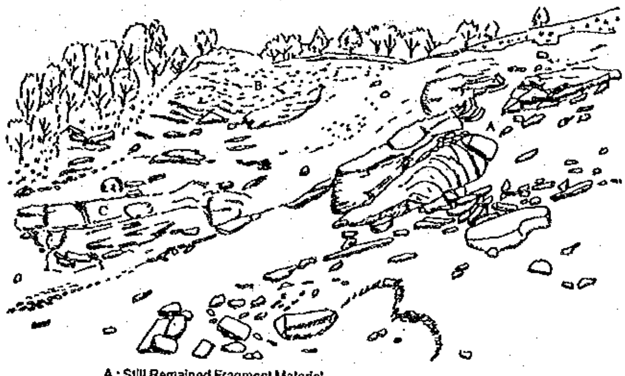


Fig. 6.4.2 Landscape Sketch of Jogimara Landslide

7. Acknowledgements

This work could not be completed successfully without the assistance and support provided by Ministry of Water Resources, Ministry of Home and Water Induced Disaster Prevention Technology Center (DPTC).

Voluntary effort by the Japanese who work in disaster prevention resulting from heavy rain and floods in Nepal is also acknowledged. The team would like to extend their heartful gratitude to those who worked hard with them in carrying out the teams duties

JICA