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Research Paper

Geomorphic approach of controlling mass movements on Tama Koshi road in Central Nepal

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ABSTRACT

The heavy monsoonal precipitation of 2012 in central Nepal triggered off or reactivated many mass movements on the Tama Koshi road. A site survey of unstable grounds was carried out to recommend short- and long-term control measures. The landslide control works were recommended mainly on the basis of detailed geomorphic mapping supplemented with some geotechnical investigation of soils, and most of these structures are working satisfactorily.

1. Introduction

Generally, the Journal of Lowland Technology International is dealing with the problems that have direct impact on low-lying areas affected by the sea or ocean. The present paper deals with the mountainous region and the effects are directed towards the valleys of major Himalayan antecedent rivers. The mass movements have a direct impact on the lower part of the valley, where the lowlands are contributed by the by-products of highlands (Miura et al., 1994; Manandhar et al., 2016).

According to Sharpe (1938), one of the early landslide classifications was given in Dana's Manual of Geology in 1863, where he distinguished debris flows, earth spreads, and rockslides. Heim (1882) was the first to distinguish between the type of material and type of movement in a landslide. He distinguished mainly three types of movement: slide, fall, and collapse. He also proposed a combination of these movements and classified the mass movements into simple, mixed, and compound types. In Italy, Amalgia (1910) divided the landslides into simple and mixed types. The simple landslides included surface movements, subsidence in clays, slides with distinct slip surface, slides with rolling, and falls.

Ladd (1935) classified landslides into flows, slope readjustments, collapses, structural slides, and clay ejections. On the other hand, Sharpe (1938) proposed a classification based primarily upon the type of material and the presence of water or ice. Hutchinson (1968) proposed a classification that gives a greater weight to the morphology of the movements, considering the mechanisms, the material involved, and the speed of the movement.

Varnes (1978) with the classification and visual diagrams distinguished five basic classes falls; topples; slides, in turn divided into rotational and translational; lateral spreads; flows to which the class of complex landslides is added. Each of the above classes is further subdivided on the basis of the material involved in the movement (rock or loose soil). Sassa (1984, 1988) drew up a classification which correlated the typology shear stress with the granular nature of the material with the movement type, such as sliding, liquefaction, and creep. Cruden and Varnes (1996) proposed a classification,

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which was derived from Varnes (1978). In the classification a new scheme of velocity scale is given.

In Nepal, Brunseden et al. (1975) introduced geomorphological mapping on the Dharan–Dhankuta Highway of East Nepal. Kojan (1978) studied the landslide problems on the Godavari-Bhatkanda Road of Far Western Nepal. Laban (1979) carried out a study on landslide occurrence in Nepal based on aerial photo interpretation and gave quantitative data on landslide density in order to assess the role of human activity in triggering mass movements.

Mass movements frequently damage or obstruct roads and highways in the mountainous terrain of Nepal. Most of them are active mainly during the rainy season. A number of new landslides were also triggered by the Gorkha Earthquake of 2015 (Kargel et al., 2016; Dhital et al., 2016). The Tama Koshi fair-weather road was gravelled in 2010 and upgrading was done within a few selected sections in 2012. During the 2012 monsoon period, many rockslides and soil slides obstructed the road traffic. Hence it was necessary to carry out further investigation and apply control measures to achieve uninterrupted traffic throughout the year.

For the purpose of assessing engineering geological conditions, field survey was carried out by a team of experts, comprising a geologist, a highway engineer, and a geotechnical engineer. Geomorphological mapping was based on walkover survey of each landslide, where GPS traverses were taken to delineate its extent and locate main features. Based on detailed field mapping of instabilities, measurement of discontinuities, and laboratory analysis of rock and soil samples, low-cost control or mitigation measures were recommended.

2. Geological setting

The investigated area (**Fig. 1a**) lies in the Lesser and Higher Himalaya of central Nepal. These two broad units are separated from each other by the Main Central Thrust. In the upper reach of the Tama Koshi River, the Lesser Himalayan metasediments represent the footwall of the thrust, whereas its hanging wall comprises medium- to high-grade metamorphic rocks and Miocene granites of the Higher Himalaya. At present, the Main Central Thrust is inactive.

The Lesser Himalayan sequence begins with the Kuncha Formation (Stöcklin 1980), extensively developed in the south portion of the area (**Fig. 1b**). Schelling (1987) included this formation under his Laduk Phyllites, comprising grey-green phyllites, chlorite schists, and graphite schists. The Suri Dobhan Augen Gneisses form a dome and contain muscovite, biotite, quartz, and alkali feldspar. The Chagu-Chilangka Augen Gneisses contain large (up to 10 cm across) feldspar augen, which are rotated and fractured. The overlying Khare Phyllites constitute about 2,500 m thick zone of graphite schist, talc schist, chlorite-biotite schist, as well as slate, quartzite, limestone, and magnesite. In the Khare Phyllites, the carbonate and quartzite bands are rather discontinuous, and alternating with black graphitic slates and some infrequent amphibolites.

The Higher Himalayan rocks override the Khare Phyllites rather abruptly, and they are constituted of the Alampu Schists, which are about 6,000 m thick and consist of well-foliated biotite-garnet schists, calcareous schists, quartzites, hornblende schists, feldspathic gneisses, and augen gneisses. The Alampu Schists are followed upwards by the Rolwaling Migmatites which attain a thickness of 6,000 m. They are predominantly sillimanite-bearing migmatites with muscovite, biotite, garnet, quartz, feldspar, and tourmaline. The migmatites are crosscut by a swarm of granitic and pegmatitic veins. Further upwards, the migmatites give way to about 6,000 m thick Rolwaling Paragneisses. The paragneisses are delimited from above by a sharp intrusive contact with the Rolwaling Granites and below by a gradational contact with the underlying Rolwaling Migmatites (Schelling 1987; Dhital 2015).

3. Mass movements

Since the mass movements ranged from debris flows to rockslides, the following five representative case studies are presented below to elucidate the severity of problems and recommended control measures.

3.1 Rockslide near tunnel portal

The wedge slide lies about 10 m south of the tunnel portal of the Upper Tama Koshi Hydroelectric Project, at an altitude of about 1960 m. It begins about 30 m above the road and continues for about 100 m below the road. The bedrock is represented by grey kyanite-garnet gneiss. It is moderately to highly weathered and the joint surfaces are wide open. The foliation and joints have formed a number of wedges. Debris slide and flow took place along a large wedge formed by the foliation (F: strike/dip = 109/56 N) and a joint set (J = 55/73 S). **Figure 2** gives the main features of the failure whereas **Fig. 3** depicts a general view of the slide. The wedge slide, cracks, and debris are shown in **Figs. 3 and 4.** At the crown of the portal, grey banded gneiss with pink garnets and kyanite is exposed. The orientation of foliation (F) = 123 (strike)/64 (angle of dip) N (dip

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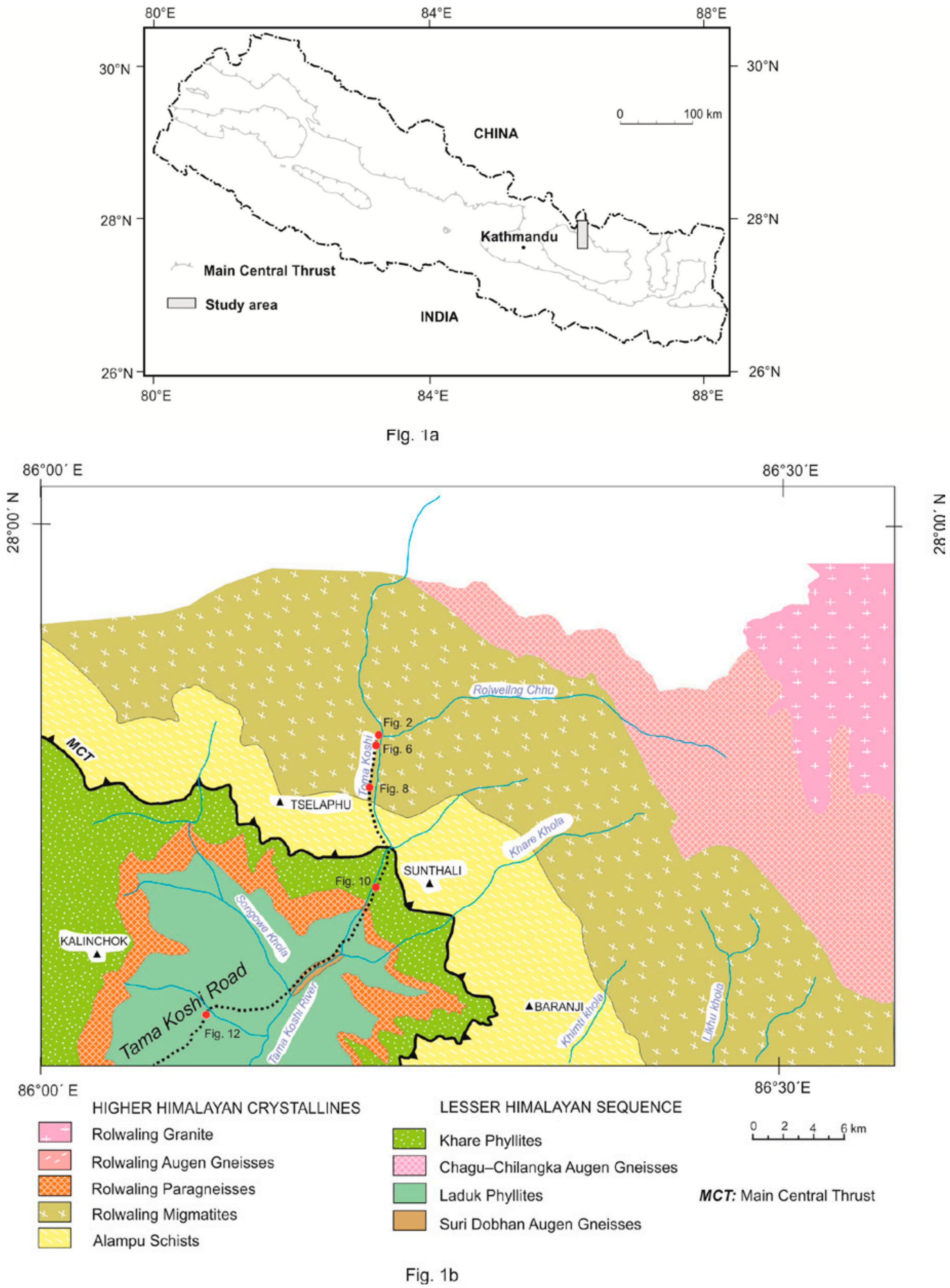

Fig. 1. The study area (**Fig. 1a**) and its geological setting **(Fig. 1b)**. Also shown are the locations (**Fig. 2, Fig. 6**, etc) of landslides described in the text. Source: Modified from Schelling (1987) and Dhital (2015).

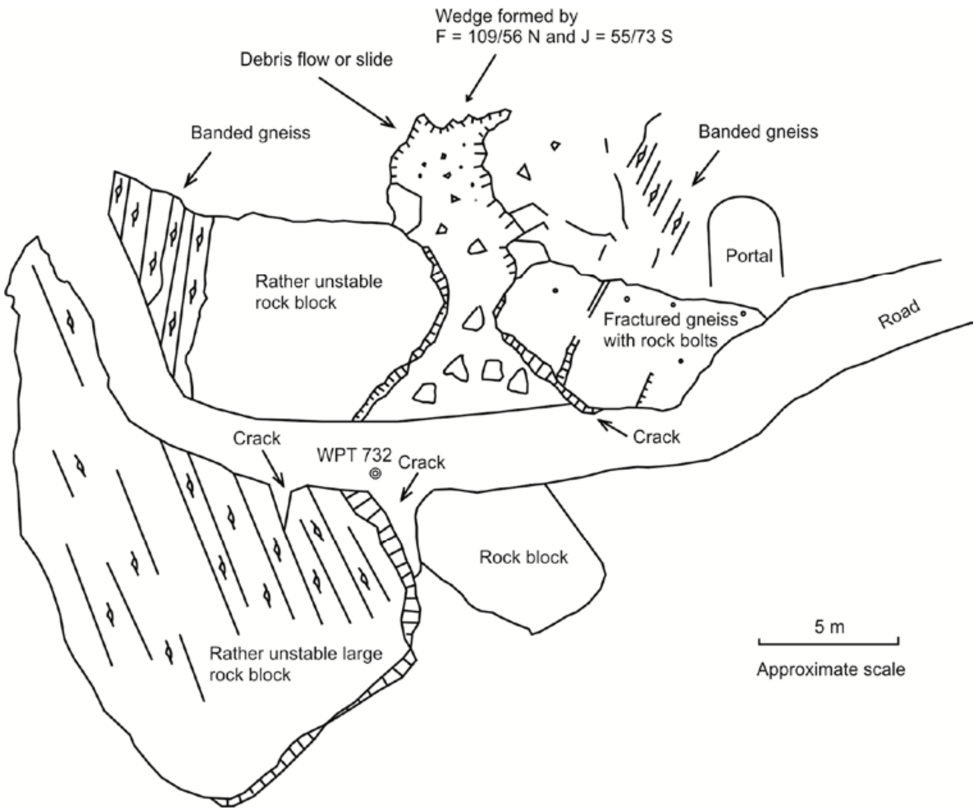

Fig. 2. Sketch of the wedge slide No. 1. Main cracks, large blocks, and wedges are shown.

Fig. 3. Wedge failure south of portal at Landslide No. 1. Note a precarious rock block through which the road is constructed by making a box cut. View to SW.

Fig. 4. Open joints forming wedges near tunnel portal.

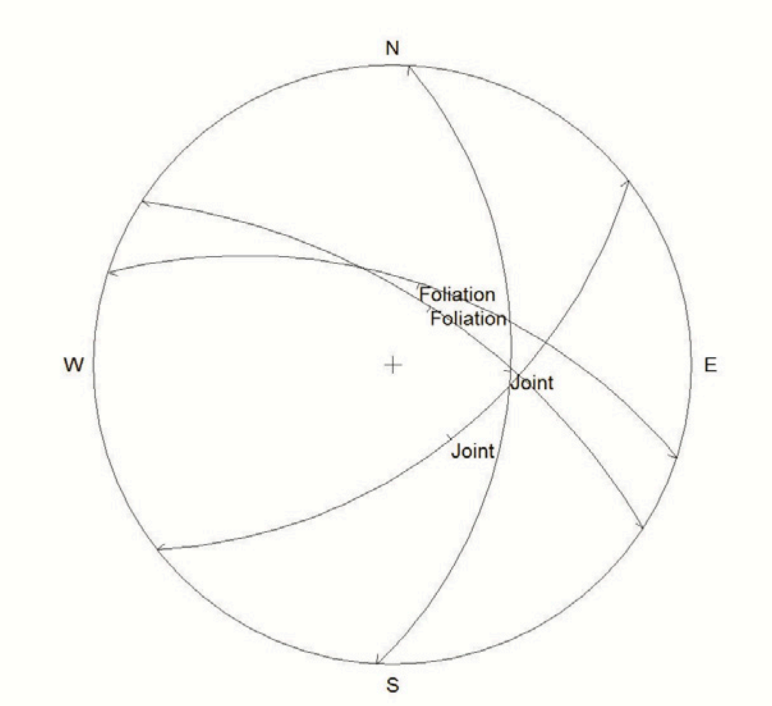

Fig. 5. Stereographic plot of discontinuities near tunnel portal. Lower hemispherical projection.

direction), 108/58 N; Joint (J1) = 52/55 SE, Joint (J2) = 3/47 SE. The stereographic projection of foliation and discontinuities also indicates a wedge failure (**Fig. 5**).

Since the tunnel portal is located close to the wedge slide, a complete control of the instability and protection of the area surrounding the portal was needed. Similarly, as there is a sharp turn of the road just after the box cut towards the portal and the road is narrow, some widening was needed. For this purpose the following measures were recommended: removal of loose and unstable blocks lying above the road, sealing of cracks with grout or shotcrete, construction of a toe wall and drainage, and widening the road towards the downhill side by making a RCC retaining wall near WPT 732. Also, a seismic survey was also proposed to assess the depth of fractured rock mass.

3.2 Landslide at Km 58+200 m

The road crosses a problematic concave bend at Km 58+200 m. This slide occurs at an altitude of about 1850 m, and it blocked frequently the access to Lamabagar during the rainy reason. The area is covered by colluvial debris that extends for about 100 m in height and about 75 m in width. The toe of the soil slide is one the road. There is a gully to the south, at the rock and soil interface. **Figures 6** and **7** show the main landslide and unstable boulders in a gully, respectively. Many large gneiss boulders are creeping and partly blocking the gully. The colluvial soil is from 10 m to 15 m deep and resting on rock. The colluvial mass is bulging and contains boulders at the base of the bulge (**Fig. 6**). The trees above the crown are intact. The rock is represented by grey banded gneiss and it is moderately dipping due N (F = 92/38 N). To the south end of the concave bend, anther minor plane rockslide is noticed.

The following mitigation measures were recommended.

- Trimming of the slope, removing loose boulders lying above the road on the uphill side.
- Construction of a side drain and careful management of water while diverting below the road.
- Construction of a causeway at the gully crossing.
- Construction of concrete walls below and above the road. The wall height should be about 3 m to 4 m above the road and 5 m to 7 m below the road. The walls should be carefully constructed and they should be founded on rock or a stable ground.
- Partly shifting of the road towards the downhill side on the fill behind the existing concrete wall where there is rock exposed in a few places.
- Removal of debris from the rockslide at the south end of the bend and trimming of the slope.

3.3 Landslide at Km 55

The rockslide in the vicinity of Km 55 is a very complex failure (**Fig. 8**). It obstructed the road from 3 July to 11 August 2012. There is a banded gneiss with kyanite and pink garnets. The rock is moderately to highly weathered and has many wide-open joints and foliation planes with the following attitude: F = 112/68 N.

At the plane rockslide area (**Fig. 9**), the hanging boulders of gneiss range in size from 30 cm to 10 m. The debris resting on slopes is loose. Below the road is spoil where the estimated depth of disposal is about 3 m to 5 m. Presumably there is rock below the road where it is covered by the debris.

It is a rather complex slide on weathered gneiss. Though most of it is a plane rockslide along the foliation, part of it is also toppled and some wedges are also developed.

The following control measures were recommended.

- Removal (if required, by blasting) of large hanging boulders resting above the road (at L1 in **Fig. 8**).
- Trimming the uneven slope above the road and removal of loose debris from there.
- Construction of a concrete retaining wall below the road (at L2 in **Fig. 8**).
- Construction of a side drain and a retaining wall above the road (L2).
- A retaining wall is also needed at the lower S-shaped bend (at L3).
- A few check dams or walls are needed at the end of the bend (at L4) to retain the debris above the road.

3.4 Landslide at Km 43+000 m (Totlabari Landslide)

At this location, in the last rainy season, the road stretch of about 20 m length was destroyed. The road section was then filled with tunnel muck. It is mainly a debris flow and debris slide the toe of which is essentially on the road (**Figs. 10 and 11).** The instability was triggered by a high-intensity rain leading to the formation of many debris flows and slides. Presently, most of the road is saturated with water. Since the high flood level of the Bhote Koshi River is below the landslide toe, the river has not contributed significantly in triggering the failure.

The debris flow disturbed the unsupported colluvium exposed by the road cut. The soil on the road is more than 10 m deep. It also contains many large (2 m to 5 m in diameter) boulders of laminated dark grey to black slate and siltstone. There are mainly three zones of failure (**Fig. 9**). Two of them are shallow slides and the central one is a debris flow. Presumably, the water from the central gully was obstructed and diverted in the central part, triggering the debris flow. The gully is more

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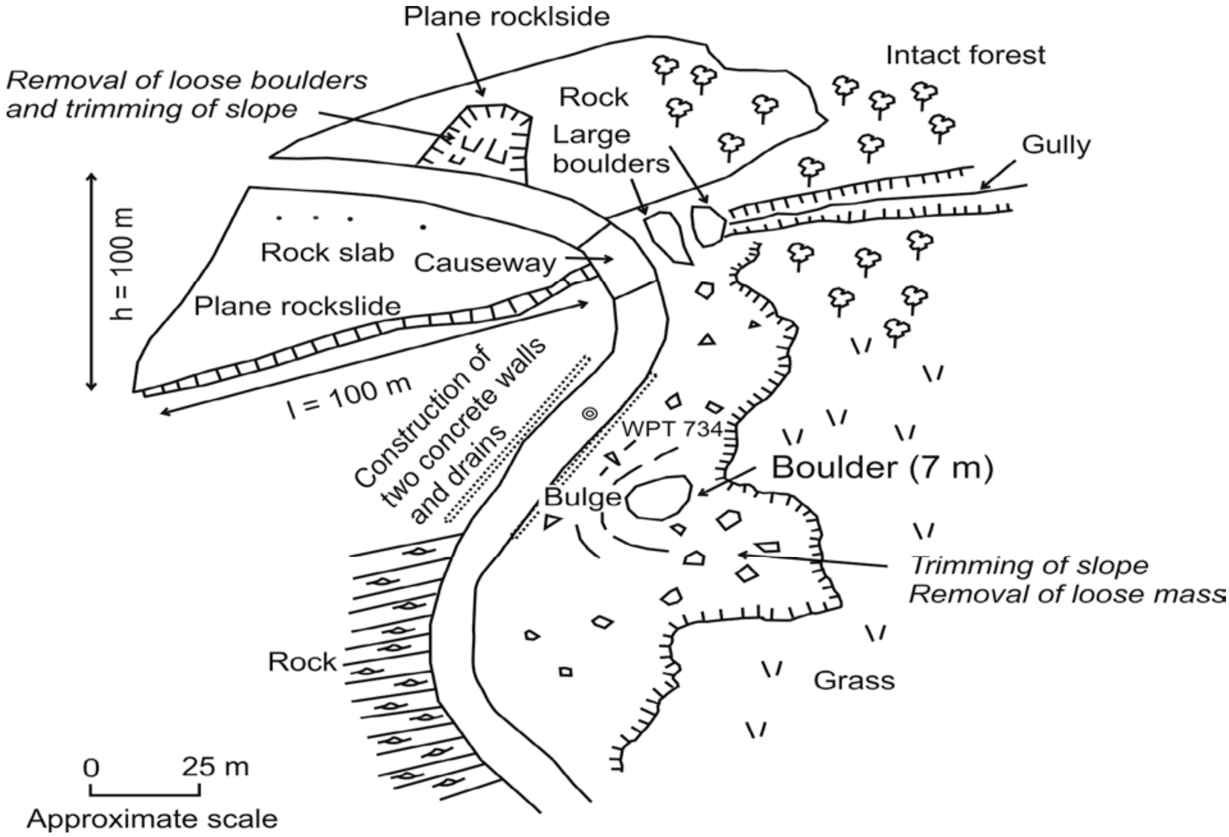

Fig. 6. The colluvial soil bulge and unstable round around Km 58+200 m.

Fig. 7. Large boulders creeping towards the road at Km 58+200 m.

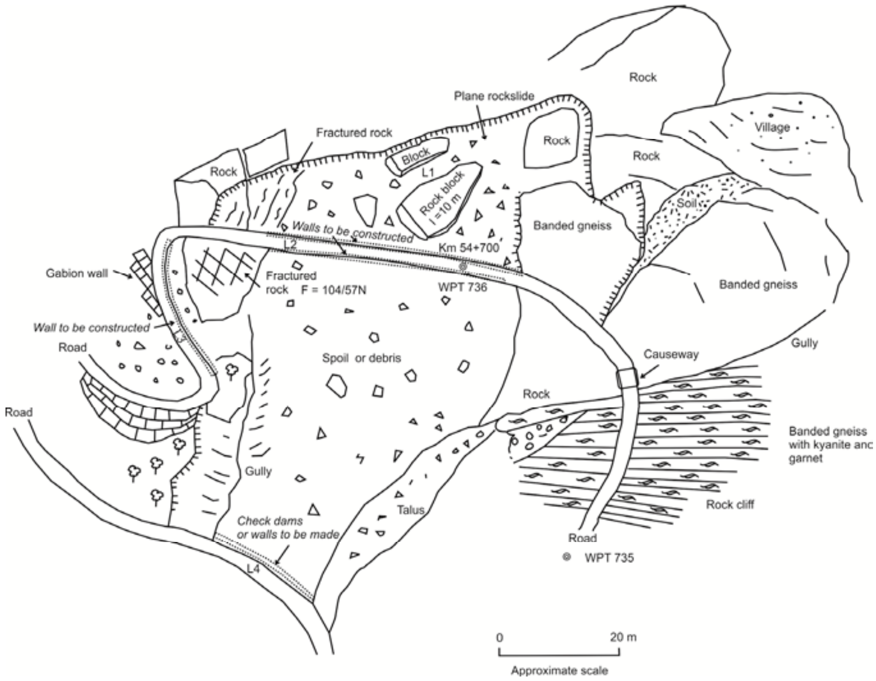

Fig. 8. Rockslide in the vicinity of Km 55.

Fig. 9. View of the plane rockslide from north. Note unstable large blocks above the road and spoil and debris below the road**.**

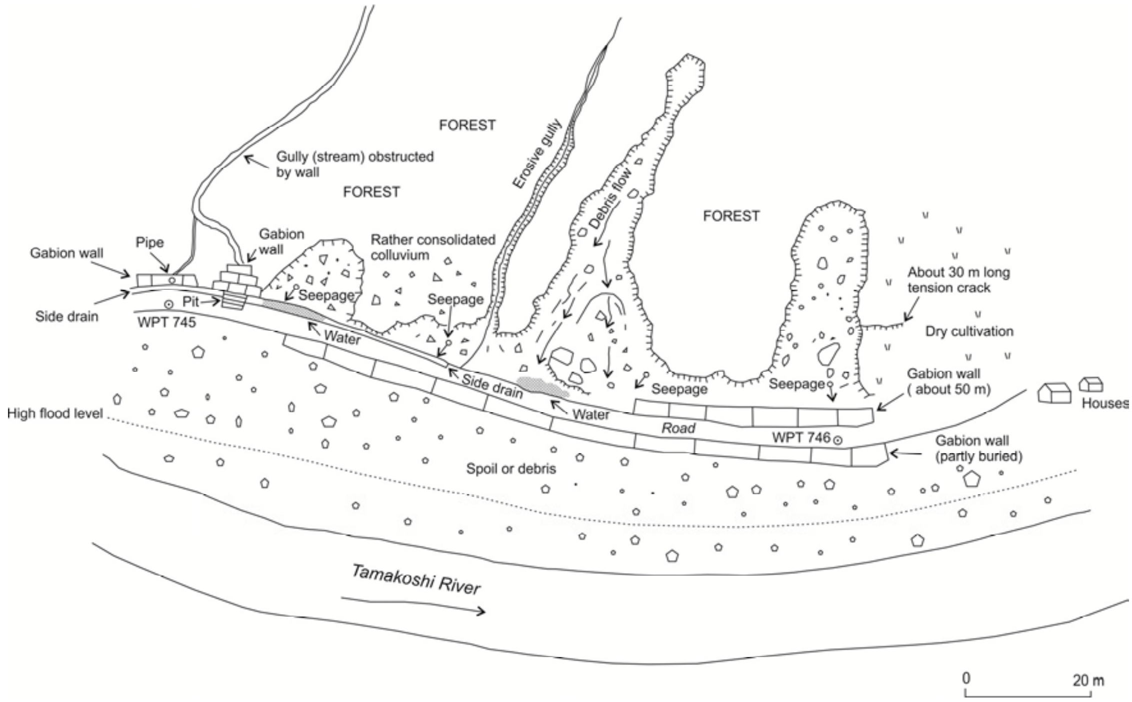

Fig. 10. The debris flow and debris slide at Km 43+000 m.

Fig. 11. View of the debris flow and debris slide at Km 43+000 m from north to south.

than 75 m long. Most of the soil on the middle and upper slopes is compact and partly cemented. The cut height or failure height exceeds 5 m on the road.

The following mitigation measures were recommended.

- Safely draining water from all the three gullies. Removal of loose debris from their banks and trimming of slopes.
- Construction of a concrete side drain.
- Removal of the loose debris from the landslides and debris flow zones, trimming of the slope above the road.
- Construction of a strong retaining wall at least 4 m high throughout the unstable ground. The wall should be founded on rock or firm ground.
- Application of bioengineering (grasses) above and below the road.

3.5 Landslide at Km 10+500 m

This is a reactivated large debris slide (**Figs. 12 and 13**). In this area, the road section of about 50 m length is sinking. It has settled for more than 5 m and shifted laterally for more than 12 m. The movement was severe in the rainy season and it is almost stable during the dry period. A weathered garnet schist is exposed on both ends of the soil slide.

The landslide can be divided into the following parts from top to bottom respectively (**Fig. 12**).

- New zone of cracks below old main scarp
- Newly activated scarp and sinking road
- Zone of transport
- Zone of pore pressure release
- Toe of the slide

3.5.1 New zone of cracks below old main scarp

The village above the landslide is on a stable ground. The right trail is essentially a partly reactivated past tension crack through which is runoff is presently channelized. The old zone of cracks is presently inactive or partly active.

The area above the road is mainly an old debris slide mass lying below the crown. Presently some hairline cracks as well as bumpy topography is noticeable (**Fig. 12**). Hence, this is the present zone of cracks bounded by the old main scarp and the new main scarp developed along the road cut. The dry cultivation is partly disturbed by the slide. But mostly the area is relatively intact.

3.5.2 Newly activated scarp and sinking road

The newly formed scarp (**Fig. 13)** runs through the upper part of the sinking road, where numerous springs and seeps are noticed in the rainy season. The pore water pressure has severely affected the road alignment and the saturated zone has become unstable. Consequently, the road shifted laterally as well as vertically towards the downhill side.

3.5.3 Zone of transport

The sinking road and the area below it belong to the zone of transport of the presently active debris slide. The lateral movement is more than 12 m and the estimated depth of slip surface is about 5 m. The debris slide has affected roots of the trees and they are haphazardly oriented. Since some of the trees are still upright, it seems that the landslide is not fully reactivated. But it can start moving as a large mass in the next monsoon season. A rock outcrop is seen at the lower right end of the landslide (**Fig. 12**). The zone of transport end almost near the irrigation canal crossing the road, below which is the paddy field.

3.5.4 Zone of pore pressure release

The area below the upper irrigation canal and above the stream belongs to the zone of pore pressure release. The groundwater as well as the water from the irrigation canal (which further aggravated the landslide by bringing more water into it) was partly released in this zone. Consequently, many lateral and transverse tension cracks are seen here. The entire zone is presently in the verge of collapse. If further irrigation or water from the landslide is brought here, the mass will invariable start moving during the next monsoon season.

3.5.5 Toe of slide

The toe of the slide rests on the streambed (**Fig. 13**). At the toe a number of secondary slides and bulges are developed. The stream is also partly pushed to the east, i.e., away from the slide. On the other hand, the stream is presently actively cutting the toe of the landslide.

The following activities were recommended to mitigate the debris slide.

- Detailed topographic mapping of the area. If required, geophysical investigation of the ground to locate the slip surface and the soil-saturated zone.
- Excavation of a temporary road towards the uphill side of the sinking ground.
- Investigation of the depth of groundwater under the sinking road.
- Removal of the subsurface water from the road and below it.
- Safe management of the irrigation canal and shifting from paddy cultivation to dry cultivation.
- Construction of retaining walls and other structures of the road.

Fig. 12. Engineering geological map of the soil slide at Km 10+500 m.

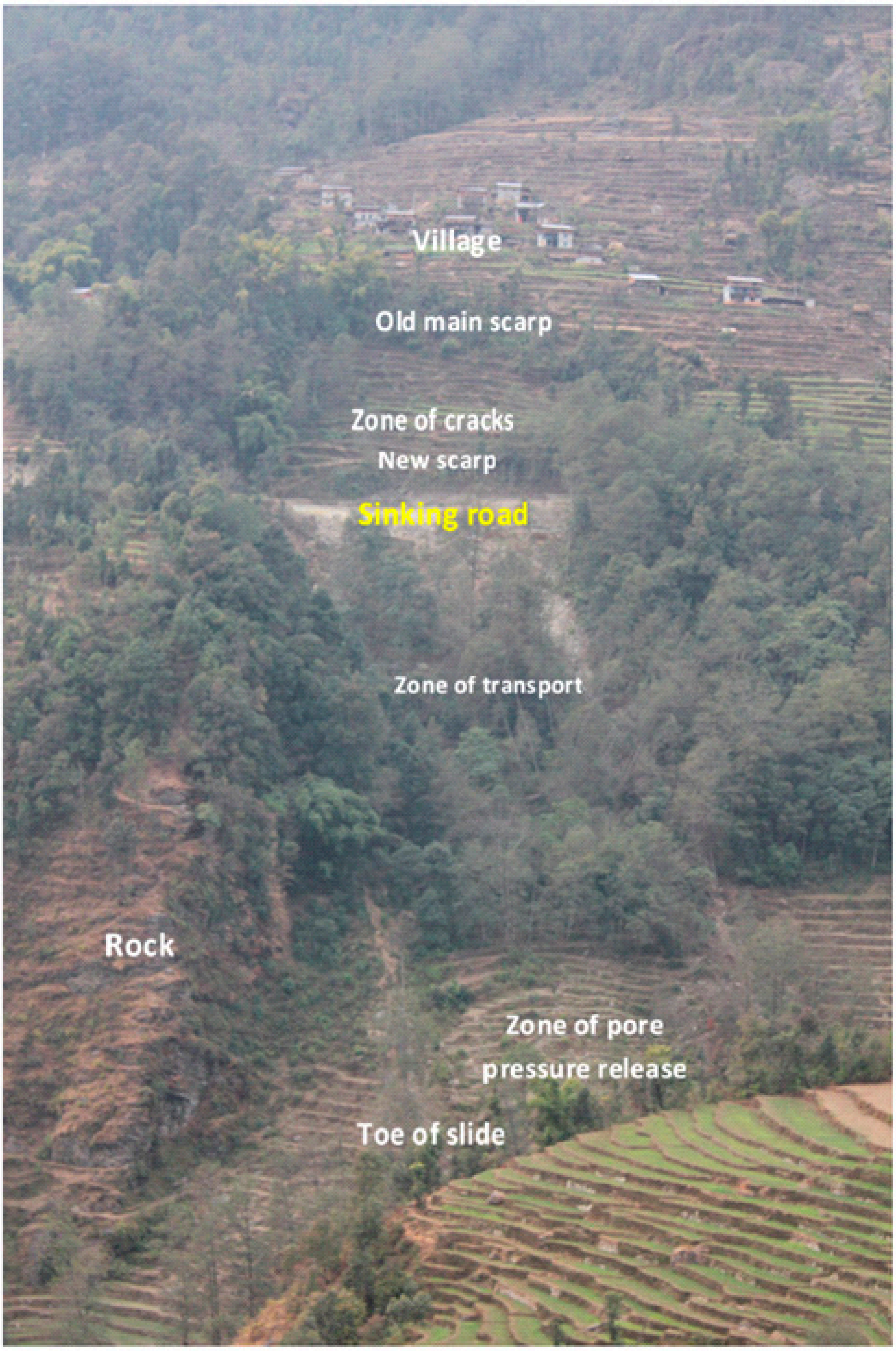

Fig. 13. General view of the debris slide at Km 10+500 m.

- Construction of a long drainage structure with check dams from the road level down to the toe of the slide.
- Construction of chevron-shaped open drains in the landslide zone.
- Making of side drains and cross drains at the road level and safely discharging the water into the constructed drainage.

3.6 Impact of Gorkha earthquake

The 25 April 2015 Gorkha Earthquake of Mw 7.8 triggered many landslides in the region (Kargel et al., 2015; Dhital et al., 2016a). Apart from that, a few short-lived landslide dams were also formed (Dhital et al., 2016b). But, the earthquake did not significantly reactivate the failures described above.

4. Conclusions

Detailed geomorphic mapping of landslides revealed a number of failure mechanisms, including rock falls, rockslides, rock toppling as well as translational and rotational sliding in soil. Most of rockslides were controlled by three, almost mutually perpendicular, joint sets, while the soil slides were reactivated by excessive pore water pressure and indiscriminate road construction in the old landslide zone without proper slope protection measures. The road did not have most essential structures, such as retaining walls, check dams, side drains, and cross drains. There was also no provision of removing groundwater from the unstable slope by making appropriate subsurface drains. This investigation was followed by detailed topographic survey, geotechnical assessment of soil, and protection of unstable grounds. The applied slope protection measures are presently working satisfactorily.

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