Journal of Nepal Geological Society, 2006, Vol. 34, pp. 81–94

Impact of July 2004 high-intensity rain on Hilepani–Jayaramghat–Diktel Environment-Friendly Road in East Nepal

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The high-intensity rain of 5–13 July 2004 activated numerous landslides, gullies, and debris flows in the watershed of the Dudh Koshi River in east Nepal. As a result, the Hilepani–Jayaramghat–Diktel Environment-Friendly Road was devastated. Apart from the rainfall, geological, geomorphic, land use, and road construction practices were other important factors leading to the disaster. Most of the damage was concentrated on concave slopes, whereas the ridges and convex slopes were relatively safe. The entire alignment was devoid of any breast or retaining walls necessary to protect the high, steep, and bare soil cut slopes, and it resulted in extensive cut slope failures. Similarly, side and cross drains were almost nonexistent. As a result, severe damage was seen at almost every gully crossing. There were very few gully protection structures (viz. check dams) and, like the retaining walls constructed below the road, they also suffered from poor construction quality and failed due to weak foundation and inadequate keying practices. Some of the most awkward structures were the loops founded on unstable slopes with high (up to 15 m) and robust gabion walls at the bends, and deep box cuts above them. In these circumstances, the concentrated runoff and subsequent debris flow from the box cut devastated the entire hairpin bend.

INTRODUCTION

The Himalayan environment is harsh and fragile, and road construction on these mountain slopes is a formidable task. Any kind of unsound engineering decision may lead to a disaster. Wherever the road passes through dip slopes, plane rockslides and debris slides may develop, whereas on counter dip slopes, rock falls, debris falls, and debris flows may prevail. In very thick (more than 10 m) colluvial zones, talus deposits, and residual soils, the rainwater easily infiltrates into and percolates through them. A thin and incompetent bed (or band) sandwiched between two resistant rock units and widespread faults (with crush zones) are other favoured areas of mass movement. Most of these types of mass movement are frequently triggered by a high-intensity rainfall and they may be quite difficult to control.

The 30 June 1987 rain in central Nepal severely damaged the Arniko Highway (ITECO 1987) and the Lamosanghu–Jiri Road at Charnawati. Large landslides developed near Dolalghat, Balephi, Kothe, north of Barabise, at Chaku, and near Kodari. The high-intensity rain of 19–20 July 1993 in south-central Nepal destroyed three bridges on the Prithvi Highway and also devastated the Tribhuvan Highway by sweeping away several bridges and triggering many landslides in the vicinity of Tistung, Daman, and Mahabir (Dhital et al. 1993). The debris flows and landslips triggered by the heavy downpour of 30–31 July 2003 partially blocked the Mugling–Narayanghat Road for two years.

The incessant rain of 5–13 July 2004 activated numerous landslips, erosive gullies, and debris flows in east Nepal, which were concentrated mainly in the Main Central Thrust (MCT) zone (Fig. 1), especially in the Dudh Koshi watershed (Fig. 2). As a result the Hilepani–Jayaramghat–Diktel Environment-Friendly Road (HJDEFR) was severely affected. The HJDEFR was being constructed under the grant-assistance of the Department for International Development (DFID) of the United Kingdom through the Rural Access Programme (RAP). Previously, the 9 km long Hilepani–Jayaramghat road stretch had been constructed by the District Development Committee (DDC) of Khotang, while the construction of the 81 km long Jayaramghat–Diktel Environment-Friendly Road (JDEFR) had been taken up by the Upper Sagarmatha Agricultural Development Project under the loan assistance of the Asian Development Bank (ADB). GOECE et al. (2002) prepared the final design report of the Jayaramghat–Halesi–Diktel Environment-Friendly Road for the Upper Sagarmatha Agricultural Development Project. The construction of Hilepani–Jayaramghat section was incomplete owing to the constraints of funds. Similarly, the JDEFR section was also incomplete because of the termination of the loan assistance by the ADB in July 2002.

Khotang is one of the districts where RAP was in operation, and a component of it was the district road construction. The HJDEFR is the only link road of the district to the outside world. Consequently, the DFID provided additional funds for the completion of this road. WSP International through RAP Project Management Unit entrusted ITECO Nepal (P.) Ltd., who was previously (i.e. between 2001 and 2002) involved in construction supervision of the Okhaldhunga–Phaplu Road and the JDEFR, in providing consulting services leading to the completion of

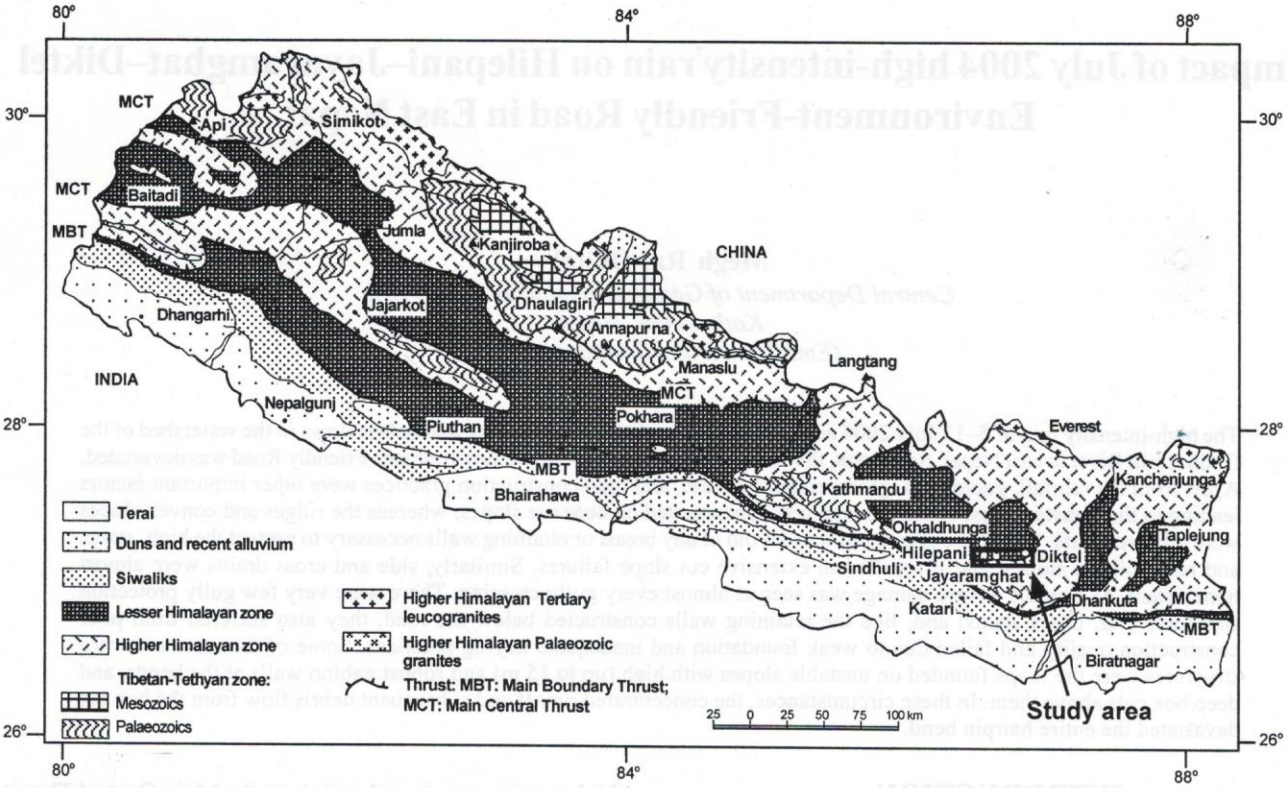

Fig. 1: Generalised geological map of Nepal (modified from Amatya and Jnawali 1994) showing the study area

the entire road alignment. The contract agreement for consulting services was signed between WSP International and ITECO Nepal (P.) Ltd. on 31 January 2003. Most of the construction works were completed before the monsoon of 2004 and it was planned to conclude the construction by the end of August 2004. Unfortunately, the situation changed drastically after the high-intensity rain.

FACTORS LEADING TO DISASTER

Though the high-intensity rainfall of July 2004 was the main trigger of the disaster on the HJDEFR, other factors such as geology, geomorphology, land use, and unsound road construction also played a significant role. A short description of these factors is given below.

High-intensity rainfall

As stated earlier, one of the main factors triggering numerous failures and flows was the high-intensity rain of 5–13 July 2004. According to DHM (2005), the records of rainfall between 5 and 14 July in Okhaldhunga were as follows (Table 1).

Though the rainfall records of Okhaldhunga show no precipitation on 5 and 6 July 2004, local inhabitants reported a quite significant amount of rain during that period in the study area. On the other hand, the rainfall records of Station No. 1207 in Okhaldhunga show a maximum of 260.8 mm on 10 July and a total of 627.3 mm between 7 and 13 July. The present area suffering from severe destruction might have experienced more than that amount, since the rainfall did not cause much damage to the slopes in the vicinity of that station.

Table 1: Rainfall records of 5–14 July 2004 in Okhaldhunga (Source: DHM 2005)

Station No. 1207	Elevation: 1576 m
Location: 27°29′N, 85°25′E	District: Okhaldhunga
Date	**Rainfall, mm**
5 July	0
6 July	0
7 July	70.3
8 July	87.5
9 July	75.7
10 July	260.8
11 July	42.2
12 July	55.7
13 July	35.1
14 July	0
Total	**627.3**

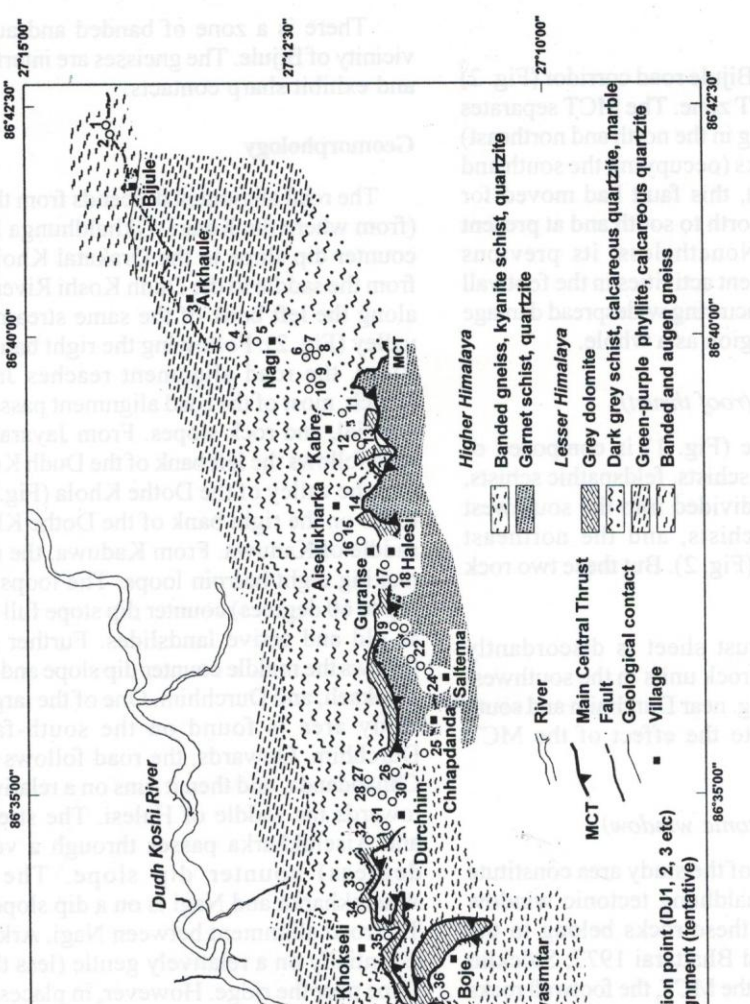

Fig. 2: Generalised geological map of Hilepani-Jayaramghat-Bijule road corridor

Geology

The Hilepani–Jayaramghat–Bijule road corridor (Fig. 2) passes basically through the MCT zone. The MCT separates the Lesser Himalayan rocks (lying in the north and northeast) from the Higher Himalayan rocks (occupying the south and southwest portions). In the past, this fault had moved for about 100 km essentially from north to south and at present it is practically motionless. Nonetheless, its previous movement as well as the subsequent activities in the footwall have played a significant role in incurring widespread damage to the road alignment and the region as a whole.

Higher Himalayan thrust sheet (roof thrust)

The Higher Himalayan zone (Fig. 1) is composed of banded gneisses, kyanite-garnet schists, feldspathic schists, and quartzites. It is tentatively divided into the southwest succession of gneisses and schists, and the northeast portion of schists and quartzites (Fig. 2). But these two rock units pass into each other.

The Higher Himalayan thrust sheet is discordantly overlying the Lesser Himalayan rock units in the southwest (Fig. 2). Many large landslides (e.g. near Durchhim and south of Kaduwa) can be attributed to the effect of the MCT movement.

Lesser Himalayan footwall (tectonic window)

The Lesser Himalayan rocks of the study area constitute the southern margin of the Okhaldhung tectonic window (Hagen 1969; Fig. 1). Most of these rocks belong to the Nawakot Complex (Stöcklin and Bhattarai 1977; Stöcklin 1980). Owing to the movement of the MCT, the footwall rocks of the Lesser Himalaya underwent widespread deformation, folding, and faulting (Fig. 2). The grey dolomite band passing through Halesi, Durchhim, Boje, Maitung, and Kaduwa is lying just below the MCT and it is strongly deformed. By judging at its position, irregular thickness, and some outliers southeast of Aiselukharka (Fig. 2), it is apparent that the band is disrupted and was carried away with the moving MCT.

The rocks underlying the grey dolomite are made up of grey graphitic schist, grey garnetiferous schist, and pale yellow to light grey quartzite. There are also a few alternating bands of amphibolite, marble, and calcareous quartzite.

The lowermost succession is represented by green, dark green, purple, and grey phyllite and schist alternating with very fine- to medium-grained, cream, light yellow to white, and pink quartzite, calcareous quartzite, and crystalline limestone or dolomite. This calcareous succession is well exposed between Kaduwa and Jayaramghat, especially in the Dothe Khola. The rocks between Arkhaule and Bijule are also inferred to be of the same unit (Fig. 2).

There is a zone of banded and augen gneisses in the vicinity of Bijule. The gneisses are interfingering with schists and exhibit sharp contacts.

Geomorphology

The road alignment descends from the saddle of Hilepani (from where the Katari–Okhaldhunga Road passes) via the counter dip slope to the Grakatal Khola (a stream flowing from the saddle to the Dudh Koshi River) and then continues along the left bank of the same stream to the Dudh Koshi valley (Fig. 2). Following the right bank of the Dudh Koshi River, the road alignment reaches Jayaramghat. In this stretch, most of the road alignment passes through colluvial, alluvial, and rock slopes. From Jayaramghat onwards, the road follows the left bank of the Dudh Koshi River and enters into the valley of the Dothe Khola (Fig. 2). It makes several loops on the right bank of the Dothe Khola and reaches the saddle of Kaduwa. From Kaduwa, the road reaches Byakta making eight hairpin loops. The loops are on a very steep (up to 60 degrees) counter dip slope full of colluvium as well as old and active landslides. Further east, the alignment follows the middle counter dip slope and reaches Chyasmitar, Khokseli, and Durchhim. One of the largest landslides in the study area is found on the south-facing dip slope of Durchhim. Onwards, the road follows the ridge line up to Chhapdanda, and then it runs on a relatively gentle dip slope towards the saddle of Halesi. The stretch between Halesi and Aiselukharka passes through a very steep (up to 60 degrees) counter dip slope. The stretch between Aiselukharka and Nagi is on a dip slope near the ridge top. The road alignment between Nagi, Arkhaule, and Bijule is essentially on a relatively gentle (less than 40 degrees) dip slope near the ridge. However, in places the slope is steeper.

Most of the damage is concentrated on concave slopes whereas the ridges and convex slopes are relatively safe. On the other hand, while descending from the ridge towards the valley, the extent of damage increases rapidly. Similarly, severe damage is seen at almost every gully crossing. These facts clearly indicate that the problem is related to poor water management along the entire road alignment.

Slope aspect and land use

Most of the road alignment runs through the north-facing slope covered by sparse to dense forest. But, it also encounters dry cultivated land and paddy field while passing through the villages and settlements. Since the north-facing slopes are relatively moister than the south-facing ones, springs, seeps, and wet areas are prevalent. Also, the north-facing slopes are saturated with groundwater and generally there occur relatively deep (more than 5 m) mass movements.

Road construction practices

The entire road alignment was devoid of any breast or retaining walls protecting the high, steep and bare soil cut slopes, and consequently extensive cut slope failures resulted. Similarly, side or cross drains (i.e., causeways and culverts) were almost nonexistent. Very high (up to 15 m) gabion walls without required foundation widths and lacking water management structures above and below the road aggravated the situation to a great extent. There were very few gully protection works (i.e. check dams), but like the retaining walls constructed below the road, the check dams too suffered from poor construction quality, weak foundation, and inadequate keying practices.

Mass movements

As there are very thick (more than 10 m) colluvial zones, talus slopes, and residual soils, the rainwater easily infiltrated into and percolated through them. It resulted in the development of a high porewater pressure, which triggered many slides and flows on the natural as well as cut slopes. On the other hand, owing to the presence of at least three joint sets, many plane rockslides, wedge failures, and toppling failures were generated. Wherever the road was passing through dip slopes (e.g. southwest of Nagi), plane rockslides were common while on counter dip slopes the road was affected by a number of large wedge slides, debris slides, and debris flows. The lithological contacts between resistant and weak rocks as well as faults (with crush zones) were other favoured locations of mass movement. A number of such mass movements existed prior to the high-intensity rainfall of 2004.

DESCRIPTION OF ROCK, SOIL, AND DAMAGE

The unprecedented rain brought about devastation to the Hilepani–Jayaramghat–Maure section of the road alignment. A short description of rock and soil types observed on the road alignment as well as major damaged sites is given below based on visual inspection of the slopes and road structures. The reference numbers (DJ1, 2, etc) are indicated in Fig. 2.

Road alignment between Bijule and Kabre

This road stretch passes essentially through the ridge where the bedrock is made up of the Lesser Himalayan metasediments with banded and augen gneisses. Generally there is a thick residual soil or colluvial cover on which many mass movements are developed.

At DJ1 (altitude, H = 1900 m, Chainage from Jayaramghat towards Diktel = Km 47+610 m), there is a box cut and hairpin loop in gneisses and colluvium. Boulders (diameter = 0.5 to 1 m) of weathered gneiss are scattered on the road. There is a cut slope failure whose failed slope angle is about 40 to 50 degrees. The friction angle of boulder-mixed sandy soil is about 35 degrees. At this location, water is flowing through the gabion walls that protect the downhill slope.

There are many long and high gabion walls below the road at DJ2 (H = 1840 m, Km 46+545 m). Some of the gabion boxes have failed due to debris flow and gully erosion. Poor water management resulted in deep gully incision. According to local villagers, the problem was caused by the water diverted into the drain from a gully lying to the south of this area.

In the vicinity of the village of Arkhaule (DJ3, H = 1620 m) grey-green garnetiferous schist and micaschist are alternating with thin (1–5 cm), light green quartzite bands. The schist bands are undulating and crenulated. Attitude of foliation (F) = N66W (strike direction in degrees) /55 (angle of dip in degrees) due SW (dip direction)

DJ4 (H = 1680 m) is positioned at the saddle and ridge near a peak SW of Arkhaule. The road alignment runs through the ridge north of Nagi where grey-green garnetiferous schist with undulating foliation (F = N82E/32NW) is exposed in the cut slope.

DJ5 (H = 1620 m) is located on a forested round peak about 1 km north of Nagi where the bedrock is made up of 5 to 10 m thick, light green to yellow (when weathered), cream coloured, massive, laminated marble (F = N60W/33SW) alternating with light grey-green micaschist bands and partings. The alternating marble and schist zone is about 30 m thick.

The slope south of Nagi (DJ6) is composed of jointed, massive, light green, white to yellow (weathered) or cream coloured, laminated marble bands (5 to 10 m thick) alternating with light grey-green micaschist bands or partings. There are also bands of dark green to blue-green amphibolite, green schist (weathered), and grey schist (F = N61E/23SE).

There is an unstable ground with an undulating gabion wall founded on loose soil (Fig. 3) where the bedrock is made up of 20 cm to 1.5 m thick, white to cream coloured marble bands alternating with dark green to blue-green amphibolite, green schist, and grey schist. At places karsts and caverns are developed in the marble zone. The failure is partly attributable to the open (10 to 20 cm wide) joints in the karstified marble. The road also suffers from water management problems.

DJ7 (H = 1700 m, Km 38+150 m) lies to the south of Nagi, below the peak of 1805 m, in the forestland covered by colluvium. From here, platy to flaggy, light yellow to light green, shattered quartzite (F = N86W/57SW) with thin schist partings begins. There is no water management at Km 38+150 m and the toe of about 2 to 3 m deep and 30 m long plane soil slide is resting on the road.

At the saddle (Deurali) south of Nagi where the road turns to west (DJ8, H = 1700 m), medium to very thick bands of grey calcareous quartzite, grey marble, and grey-green schist (Bedding, B = F = N63W/62SW) are exposed. The high-intensity rain has triggered many shallow soil slides, especially in the gully west of Nawalpur.

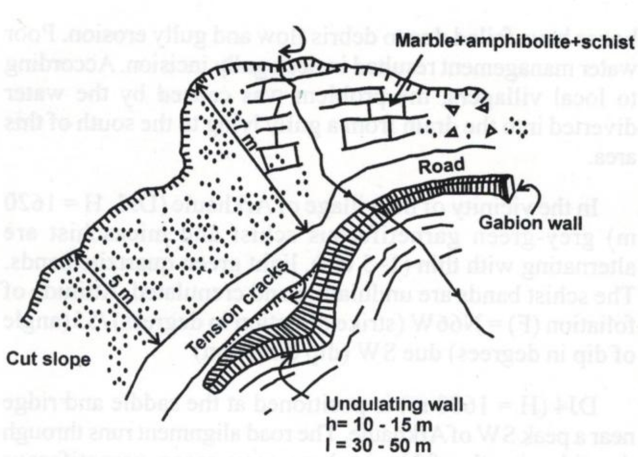

Fig. 3: Sketch of landslide and undulating retaining wall south of Nagi

A zone of plane rockslide begins at DJ9 (H = 1700 m) where thick- to very thick-banded, grey, blue-grey marble (B = F= N90E/48S) has grey schist partings (thickness = 10 to 20 cm). The failure zone (Fig. 4) is about 250 m long and extends beyond DJ10 (H = 1700 m) up to the second bend. Large blocks (1–1.5 m long) of marble (derived from the rockslide) are resting on the road. There are three sets of clean joints in the marble. Plane rock failure and debris flow problems (Figs. 4 and 5) continue to further northwest up to the bend.

Grey-green schist with rare calcareous schist or marble bands (F = N68E/53SE) crop out at the spur and trail to Aiselukharka (DJ11, H = 1680 m). Some shallow failures are present above the road and, after a turning, a wall founded on colluvium has also failed.

The south slope of Kabre (DJ12, H = 1600 m) is made up of colluvium with bumpy topography. It is also affected by gullies and failures. Sporadic outcrops of quartzite and graphitic schist are seen. Seepage is prominent and the area is wet. Most of the cut slope is lost by failures. In the future, there may develop a major deep soil slide.

Road alignment between Kabre and Byakta

In this stretch, the road alignment runs very close to the MCT and crosses a detached dolomite band for several times (Fig. 2). Very large rockslides are also encountered here.

The spur after a concave turn at DJ13 is made up of very thick-bedded, massive, grey dolomite whereas at the saddle and ridge of Aiselukharka (DJ14, H = 1500 m) grey-green garnetiferous (diameter of garnet grains = 1 to 2 mm) schist is alternating with thin quartzite bands (F = N 75E/41S). The dolomite ends about 100 m ahead of DJ14.

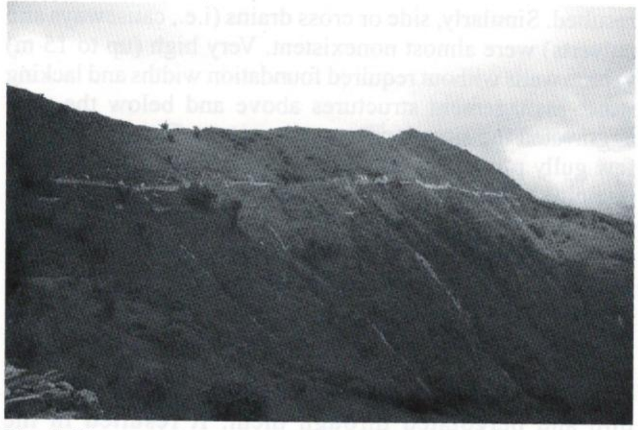

Fig. 4: Panoramic view of plane rockslides west of Nagi. View to SE. Photo by Cris Grant.

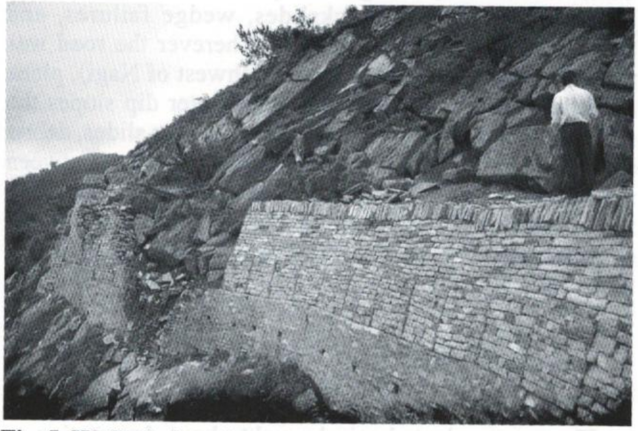

Fig. 5: Walls (below the road) damaged by debris flow in a gully west of Nagi. View to N. Photo by Cris Grant.

The north slope at DJ15 (Km 32+360 m, H = 1500 m) contains schist and quartzite at the base and is covered by red colluvial or residual soil. The damage is severe mainly in the gullies. Among them, two wide and deep gullies were affected by debris flows. Cut slope failure is also widespread at this location.

The approach to Halesi from Aiselukharka through the north and southwest slopes consists of red colluvial and residual soils. The area around DJ16 (H = 1500 m) is characterised by steep (more than 50 degrees) slopes where retaining walls are founded on loose soil. The road alignment passes through the crown and upper part of an unstable ground where sliding and erosion depths are about 4 to 5 m. The road stretch also suffers from intense gully erosion, debris flow, and slumping.

According to the local inhabitants, quite heavy and continuous rains began on 5 July 2004 and they became a very intense downpour on 6 July leading to the devastation on 10 July.

Fig. 6: Damaged road and failed gabion walls in the Narsinge Khola northeast of Halesi. View to NE. Photo by Cris Grant.

There is a hairpin bend on high (about 15 m) gabion walls and a box cut (unfinished) in grey dolomite just above Halesi. Manual excavation of the hard dolomite band in the box cut is very strenuous and a time-consuming task. The high walls and deep cut could have been avoided by aligning the road properly.

The road alignment passes through the valley of Halesi. The northeast slope around DJ17 (Km 30+800 m, H = 1400 m) comprises thick colluvial and residual soil of orange, red, ochre, and tan colours.

At the Narsinge Khola, extensive gully erosion and bank cutting is observed (Fig. 6). About 100 m long, 20 to 30 m wide, and 10 to 15 m deep erosive gully has developed on highly weathered grey to grey-green schist and quartzite covered by red soil. The problem is related to a high discharge in the gully due to flooding and debris flow. The water partly followed the road (as no cross drains were provided) and damaged the gabion walls (Fig. 6). There is also a zone of thin-banded light yellow quartzite (F = N88W/74SW) and garnetiferous (1–3 mm) schist.

The west end of Halesi around DJ18 (H = 1380 m) contains medium- to thick-banded, grey to brown quartzite and schist. There is a hazardous stone quarry just below the road, which may trigger a rockslide.

The Chiuri Khola (DJ19, H = 1400 m) is a large erosive gully situated to the northwest of Malakhu. It follows the contact between very thick-bedded (0.25 to 1.5 m) grey

Fig. 7: A large slide obstructing the gully at DJ22. View to N. Photo by Cris Grant.

dolomite (to the east) and highly weathered grey-green to brown schist and quartzite (to the west). The dolomite dip slope (B = F = N74W/60S) is excellently exposed.

The gully is deeply entrenched and the debris brought by it is resting on the road. The debris flow has also damaged about 10 m high check dam in the Chiuri Khola. Onwards, numerous landslide scars (shallow failures) are seen on schist and quartzite.

The road alignment at DJ20 (Km 28+662 m, H = 1390 m) passes through the box cut and spur after crossing an erosive gully southwest of the Chiuri Khola. The rocks are represented by grey, cream to light grey, thinly alternating quartzite (F = N70W/50SW) and phyllite.

The area around the loops at DJ21 (Km 27+050 m, H = 1410 m) has undergone extensive gully erosion and failure of box cut slopes. The road is almost completely destroyed.

There is a large and actively eroding gully to the west of the loops. One possibility could have been to realign the road beyond that gully, but the slope beyond too seems to be unstable. In GEOCE et al. (2002), there is a sketch of two failures on the left bank of the gully from where a spring is also emerging. Hence, it was already a problematic spot before the disaster of July 2004.

There is a critical gully passing through the loops in the vicinity of DJ22 (Km 27+000 m, H = 1440 m) and it is obstructed by a large (about 75 m long, 30 m wide, and 7 m deep) circular failure (Fig. 7).

The road about 1 km east of Saltema (DJ23, H = 1460 m) suffers from many gully erosion and soil slide problems.

In the spur north of Saltema (DJ24, H = 1480 m), grey garnetiferous schist and feldspathic schist are alternating with white to pale yellow quartzite (F = N80E/47SE).

About 300 m west of Chhapdanda (DJ25, H = 1480 m), the road alignment runs through the north-facing slope.

There appears about 20 to 30 m thick zone of grey gneiss in which banding is well developed. Onwards, thick to very thick, grey schist and light yellow quartzite (F = N62W/38SE) predominate. The quartzite-dominant zone is about 20 m thick, and then grey garnetiferous schist continues up to the saddle and further northwest.

The Tare Bhir (a rock cliff) begins at Km 26+200 m (DJ26, H = 1450 m). There are two houses and a small patch of dry cultivated land below the ciff (between DJ25 and DJ26). In this stretch many shallow cut slope failures and a few (3 or 4) deep (1 to 3 m) erosive gullies with debris flows are encountered.

At DJ27 (H = 1450 m), there is a sharp contact between the grey to dark grey dolomite (to the south) and yellow to pale quartzite (medium- to thin-banded) including dark grey to green-grey schist partings or bands (to the north). The road alignment runs on a spur where there is a box cut in the quartzite.

There are several loops with very high walls and steep as well as deep box cuts around DJ28 (H = 1380 m). It was probably not a careful decision to make such awkward cuts without proper protection measures. Most of the box cuts and walls could have been avoided by a careful ground survey and design. No drainage structures were provided for the water flowing into the box cut.

The loops to the north of Durchhim (DJ29, H = 1320 m) could have been reduced in number had the road ascended straight from the village instead of first descending and then ascending. The grey dolomite (B = N78E/64S) reappears here and continues to the southwest.

The two gullies northeast of Durchhim (DJ30, H = 1320 m) experienced debris flows, bank erosion, and colluvial slides. The erosion zone is about 30 to 50 m long and 2 to 3 m deep. The cut slope is damaged and most of the debris is resting on the road, but the walls are intact. The bedrock is represented by grey schist and quartzite.

In the gully from Sorchum and also at the road level (DJ31, H = 1270 m), platy to flaggy white quartzite (B = F = N81E/34S) contains grey-green schist partings. About 50 m above the road, the grey dolomite band reappears.

In the next gully (about 100 m north of DJ31), there is a damaged wall with undulating gabions (Fig. 8). The wall is 5 to 7 m high, about 10 m long, and was constructed on an unstable soil foundation. Big boulders (diameter = 0.5 to 1.5 m) are resting on the road.

The area north of Sorchum (DJ32, H = 1240 m) is represented by a grey dolomite cliff (the Gauri Bhir). About 15 m high composite wall (gabion, dry stone, and stone masonry) is bulging at its base (Fig. 9).

The road from Patalikharka to Khokseli (DJ33, H = 1200 m) passes through a cliff of grey dolomite (which extends to about 100 m above the road), grey-green garnetiferous schist (F = N86E/45SE, undulating to crenulated), and quartzite (below and on the road). Severe erosive gullies and debris flows are encountered here at the rock–colluvium interface. The debris has destroyed both the cut and fill slopes.

Fig. 8: Partly damaged gabion wall and overhanging stone masonry wall at DJ31. View to W. Photo by Cris Grant.

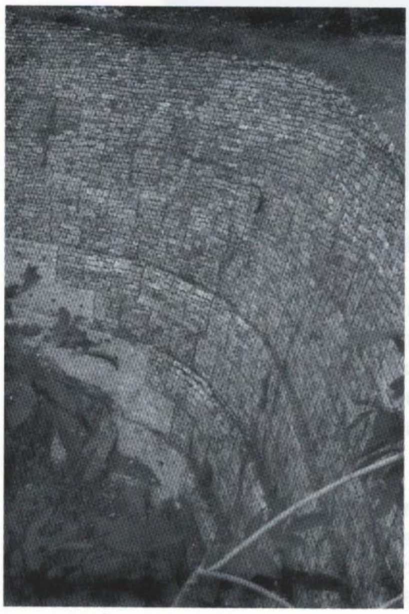

Fig. 9: The gabion wall is bulging near its base at DJ32. View to SW. Photo by Cris Grant.

On the road (DJ34, H = 1210 m) from lower Khokseli (E) to upper Khokseli (W), there are dark grey garnetiferous schist bands with a prominent dolomite band (about 30 to 40 m above the road). The rock is gently south-dipping (F = N 82E/23SE), but beyond the Dudh Koshi River it is apparently north-dipping, indicating an anticlinal closure through the river.

The gully south of Khokseli (DJ35, H = 12 10 m) underwent extensive erosion. At this place the road has

Fig. 10: A thick dolomite band exposed west of Boje, between Khokseli and Chyasmitar. View to N. Photo by Cris Grant.

Fig. 11: Active gullies in the vicinity of Maitung. View to SW. Photo by Cris Grant.

experienced many cut slope failures and mud slides on grey-green schist (F = N16W/53SE).

At DJ36 (H = 1240 m), the stream from Boje forms a high (about 40 m) waterfall on dark grey dolomite (Fig. 10). The contact between the dolomite and underlying thin, light yellow to white quartzite (about 50 m thick) is near a gully. To the east, many dip slopes made up of grey dolomite are seen. On the left bank, at the road level, the dolomite is intensely folded.

The rock on top of the dolomite towards Chyasmitar is made up of kyanite-garnet schist and feldspathic schist. The MCT passes through the top of the grey dolomite band and continues to the east up to Halesi and Aiselukharka.

There is a debris flow–slide in a gully (DJ37, H = 1250 m) below the ridge and peak of Chyasmitar. The slide is about 50 m long (above the road), 15 m wide, and 2 m deep. The debris contains many boulders of up to 1.5 m in diameter.

The gully west of Dalpu at Km 11+350 m (DJ38, H = 1160 m) has suffered from rockslide, debris slide, and erosion. The damaged zone is about 150 m long, 40 m wide, and 5 m deep. There are many big blocks scattered on the slope. The rock is represented by grey banded gneiss (10 to 20%), kyanite-garnet schist (60 to 80%), and quartzite (20 to 30%). It is one of the critical sites where the failure is basically a wedge slide. There are also some wide and open cracks. About 50 m west of the failure, a dry wall is bulging and it also has wide cracks. It is essentially a foundation failure problem caused by a high porewater pressure.

At Km 10+800 m (DJ39, H = 1130 m), the road above Maitung is severely damaged by gully erosion and debris flows. All the three gullies above Maitung have made wide (5 to 7 m) and deep (2 to 3 m) valley bottoms. They also suffered from side failures on the colluvium (Fig. 11). Extensive erosion and debris flow also took place in a large gully at DJ40 (H = 1120).

At the turning to Byakta (DJ41, H = 1120 m), grey kyanite-garnet-feldspar schist is prominent. The feldspar makes lenses of 5 to 7 cm in length and 3 to 5 cm in width. There is also banded gneiss (F = N71E/35S) with ptigmatic folds and lenticular quartz veins.

The second large gully southwest of Byakta crosses the road at Km 10+500 m (DJ42, H = 1090). It experienced debris flows, which have cleared their channel. At present, the channel is from 5 to 7 m deep. The road is washed away for about 30 m. Below the road, another colluvial flow–slide begins to the east. The gully has eroded its banks up to about 100 m above and below the road.

Loops above Kaduwa

The hairpin loops near Kaduwa are one of the most severely damaged structures on the HJDEFR. Most of them are positioned on the north-facing slope within the MCT zone.

The eighth loop above Kaduwa (DJ43, H = 1000 m) is represented by about 12 m high gabion wall. There is every possibility that the wall collapses (Figs. 12, 13, 14) in the near future as it is bulging and the joins of gabion boxes are wide open. The wall height could have been reduced significantly by extending the alignment to further southwest.

About 7 m high Loop No. 7 is intact, but the entire road alignment just below Loop No. 8 is destroyed. A debris flow from a gully and a colluvial slide have damaged the road.

The road between Loop Nos. 6 and 7 is covered by cut slope failures and debris flows. About 11 m high Loop No. 6 is mostly intact (as it is on a rocky spur), but its southeast end is partly damaged. About 50 m east and ahead (while descending) of Loop No. 6, there is a gabion wall which is partly damaged due to liquefaction and foundation failure (Figs. 15 and 16).

Fig. 12: Scene of Loop No. 8 from above. A sag pond is seen behind the wall. View to W. Photo by Cris Grant.

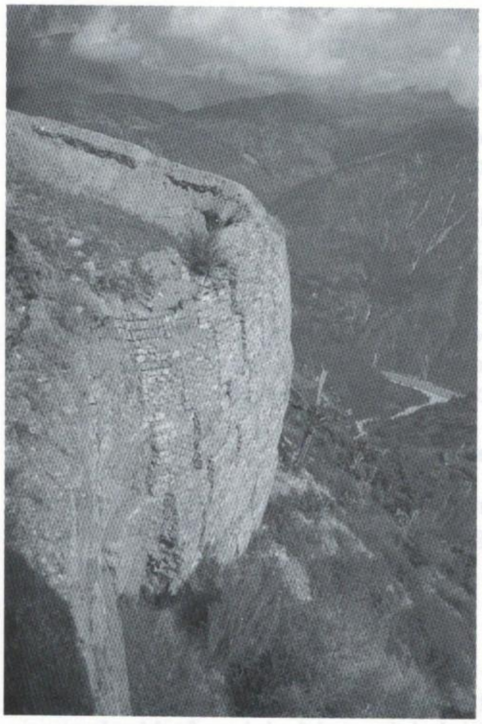

Fig. 13: Very high and bulging wall of Loop No. 8 as seen from the side. View to W. Photo by Cris Grant.

About 13 m high Loop No. 5 (H = 960 m) is completely damaged and a lot of debris is resting on it. The rock is represented by garnetiferous schist (F = N28E/50SE).

The intact Loop No. 4 at DJ44 (H = 920 m) has a wall height of about 7 m. The grey dolomite band reappears about 10 m below the loop. A large rockslide is developed on the dolomite about 5 m west of it. The slide is about 200 m long, 75 m wide, and at places 10 m deep. But in many areas bare rock is also visible. According to the local inhabitants, a smaller failure took place on 11 July 2004 near the toe of the

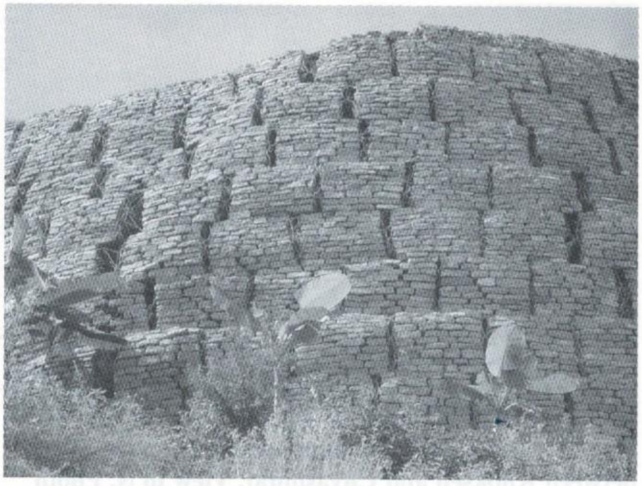

Fig. 14: Open joins between the gabion boxes of Loop No. 8. View to SW. Photo by M R Dhital.

present slide and the second (bigger failure) happened on 28 July. After that, a number of smaller failures have occurred.

The partly damaged Loop No. 3 (H = 900 m) consists of a high (13 m) gabion wall where grey garnetiferous schists are alternating with banded gneisses. The loop passes through the MCT zone and the alignment beyond it descends on the Lesser Himalayan grey dolomite where the road is almost completely destroyed.

The intact Loop No. 2 (DJ45, H = 890 m) with a wall height of about 9 m is constructed on grey dolomite (B = N68E/32SE). But there is no trace of road between Loop Nos. 3 and 2.

Around Loop No. 1 (DJ46, H = 850 m), there is grey dolomite (to the south) while grey-green garnetiferous schist (F = N88W/42SW) is exposed from about 25 m above the loop and continues to the north. The loop is intact but the road between DJ45 and DJ46 is completely washed away.

The box cut at Loop No. 1 is severely damaged and its high gabion walls are bulging. Similarly, the road is also damaged between Loop No. 1 and Kaduwa by a large rockslide on dolomite (which starts west of Loop No. 4). There is another large colluvial slide further west.

Vivid green phyllites with very fine calcareous quartzite bands are observed from about 25 m east of the saddle of Kaduwa at Km 6+000 m (DJ47, H = 720 m) and they continue westwards. At the saddle the rocks are intensely folded and a fault is inferred between this rock unit and the grey dolomite.

Alignment between Kaduwa and Jayaramghat

The road alignment between Kaduwa and Jayaramghat runs through the Lesser Himalayan low-grade metamorphics covered by residual and colluvial soils. Most of the damage is confined to the Dothe Khola valley.

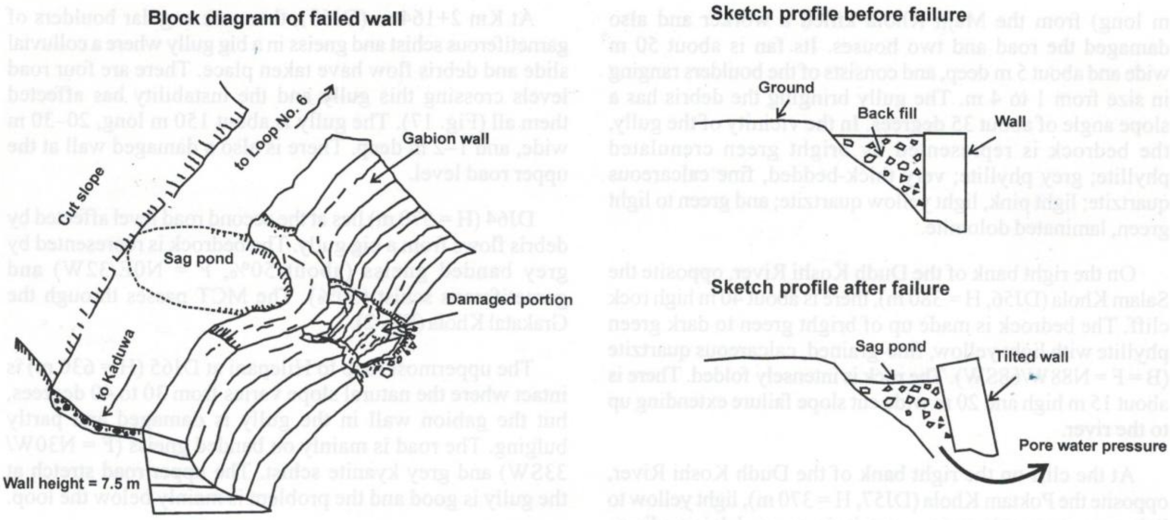

Fig. 15: Block diagram and sketch sections of the bulging wall between Loop No. 6 and Loop No. 5.

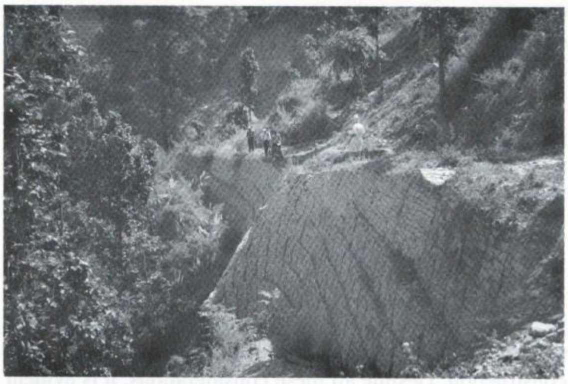

Fig. 16: Partly damaged and bulging wall east of Loop No. 6. View to NE. Photo by Cris Grant.

About 500 m west of the saddle of Kaduwa (DJ48, H = 700 m), cemented big boulders of light grey to green-grey dolomite and bright green phyllite are seen. There are also a few bands of light green and light grey quartzite in the cut slope.

The first loop west of Kaduwa at DJ49 (H = 660 m) is intact. The rocks between Kaduwa and the loop are represented by bright-green to green-grey phyllite and very fine-grained white calcareous quartzite (F = N0E/35W).

Loop No. 3 (from the Dothe Khola) is located at Km 3+370 m (DJ50, H = 570 m). Though this loop is intact, a wall about 50 m below is damaged. A gabion wall at Km 3+335 m is bulging.

The first loop (DJ51, H 500 m) to Kaduwa from the Dothe Khola is on its right bank. The bedrock is represented by alternating dark green, grey-green and grey phyllite, and light yellow to pink, fine- to medium-grained, thick-banded quartzite (F = B = N74E/76S). The rock is tightly folded at many places.

On the left bank of the Dothe Khola, a long gabion wall is founded on debris (colluvium) and it is partially damaged at DJ52 (H = 490 m).

At Km 1+500 m (DJ53, H = 480 m), in the road cut, thick- to very thick-bedded, light yellow to light grey, very fine- to fine-grained, laminated quartzite (B = N70E/30SE) as well as calcareous quartzite with bands of dark green to grey-green phyllite are exposed.

At Km 1+115 m (DJ54, H = 450 m), about 1 km east of Jayaramghat, on the left bank of the Dudh Koshi River, medium- to fine-grained, medium- to thin-bedded, pink to purple, light yellow to light grey quartzite contains dark green to grey-green, crenulated phyllite partings and bands. Some ill-preserved ripple marks are seen on the quartzite band (B = N74W/43SW).

Jayaramghat–Hilepani sector

In this sector, the road follows the right bank of the Dudh Koshi River and runs through the terraces dissected by gullies and streams up to the Grakatal Khola (Fig. 2). Then it ascends to the saddle of Hilepani making several hairpin loops.

On the right bank of the Dudh Koshi River, at Jayaramghat (DJ55, H = 360 m), the debris flow (about 20 m wide and 200 m long) from the Majh Khola killed a worker and also damaged the road and two houses. Its fan is about 50 m wide and about 5 m deep, and consists of the boulders ranging in size from 1 to 4 m. The gully bringing the debris has a slope angle of about 35 degrees. In the vicinity of the gully, the bedrock is represented by bright green crenulated phyllite; grey phyllite; very thick-bedded, fine calcareous quartzite; light pink, light yellow quartzite; and green to light green, laminated dolomite.

On the right bank of the Dudh Koshi River, opposite the Salam Khola (DJ56, H = 380 m), there is about 40 m high rock cliff. The bedrock is made up of bright green to dark green phyllite with light yellow, fine-grained, calcareous quartzite (B = F = N88W/68SW). The rock is intensely folded. There is about 15 m high and 20 m wide cut slope failure extending up to the river.

At the cliff on the right bank of the Dudh Koshi River, opposite the Poktam Khola (DJ57, H = 370 m), light yellow to light grey-green calcareous quartzite is exposed. It is medium- to fine-grained, thick- to very thick-bedded, and is alternating with dark grey-green phyllite bands (1–2 m thick). The rock is folded at a number of places (B = F = N80E/74NW).

On the left bank of the Blenke Khola (DJ58, H = 360 m), thinly bedded, grey-green, light yellow to white, very fine-grained calcareous quartzite and dolomite (B = N71W/46NE) is alternating with bright green, grey-green phyllite partings and bands.

About 300 m south, the beds dip 15–25 degrees due south or west, indicating their folded nature.

At Km 5+400 m (Chainage from Hilepani saddle to Jayaramghat), in the Kopche Pani Khola, at the first loop near Sokmatar (DJ59, H = 370 m), grey to bright green and sporadically purple phyllites are alternating with light yellow, pink, and light green to white quartzites. A few very thick (up to 1.5 m) beds of crystalline white dolomite (F = N70W/42NE) are also present.

The MCT passes through Km 5+100 m (DJ60, H = 380 m), just below the school of Sokmatar, where grey to brown banded gneiss and garnetiferous schist (F = N85W/37NE) are exposed in the road cut.

The second loop near Sokmatar (DJ61) passes through the right bank of the Hile Khola. A slope failure in the box cut extends up to the lower road level where dolomite and phyllite boulders (diameter = 1–3 m) are accumulated.

At the lower part of Sokmatar, in the gully situated at Km 2+940 m (DJ62, H = 500 m), light green to grey-green and bright green, crenulated phyllites (F = N40W/67NE) are alternating with light green, fine calcareous quartzite, and dolomite with rhodocrosite. At Km 2+900 m, there is a soil slide (length = 20 m, width = 10 m).

At Km 2+164 m (DJ63), there are angular boulders of garnetiferous schist and gneiss in a big gully where a colluvial slide and debris flow have taken place. There are four road levels crossing this gully and the instability has affected them all (Fig. 17). The gully is about 150 m long, 20–30 m wide, and 1–2 m deep. There is also a damaged wall at the upper road level.

DJ64 (H = 570 m) lies at the second road level affected by debris flows from a big gully. The bedrock is represented by grey banded gneiss (about 50%, F = N0E/32W) and garnetiferous schist (50%). The MCT passes through the Grakatal Khola (Fig. 2).

The uppermost loop to Hilepani at DJ65 (H = 630 m) is intact where the natural slope varies from 30 to 40 degrees, but the gabion wall in the gully is damaged and partly bulging. The road is mainly on banded gneiss (F = N30W/33SW) and grey kyanite schist. The upper road stretch at the gully is good and the problem is mainly below the loop.

There is about 25 m long and 7–10 m high damaged gabion wall in a gully at DJ66 (H = 720 m), about 75 m east of the saddle of Hilepani, where the HJDEFR joins with the Katari–Okhaldhunga Road (Fig. 2). The damage was caused by a colluvial debris flow–slide initiated at the cut slope (about 20 m high) failure.

The MCT footwall rocks at Hilepani (Fig. 2) are represented by grey-green phyllite alternating with black slate (or phyllite), dolomitic quartzite, and thin-banded white calcareous quartzite (B = F = N86W/55NE).

DISCUSSIONS AND CONCLUSIONS

The high-intensity rain of July 2004 has converted the HJDERP into an environmental disaster. GEOCE et al. (2002) mentioned various manuals and concepts for district road construction. Despite all these considerations, it is evident that a number of fundamental engineering norms were violated during the road design and construction. Some of them are discussed below.

Field observations showed that most of the cut slopes in soil were almost vertical without proper protection measures. In GEOCE et al. (2002), there are typical cross-sections for the design of cut slopes and box cuts (Figs. 18 and 19). In these cross-sections, the proposed cut slope angle in soil is 3:1 (i.e. about 72 degrees), which is significantly steeper than the friction angle of soils in that area (which is generally less than 35 degrees). Such steep cut slopes were designed and constructed without due considerations to appropriate protection measures (such as retaining or breast walls).

Though GEOCE et al. (2002) mention some bio-engineering measures to stabilise cut slopes, they were either not implemented or ineffective. It is worth mentioning that the vegetative measures alone can protect the slope up to a

Fig. 17: A large erosive gully affecting four road levels. View to SW. Photo by Cris Grant.

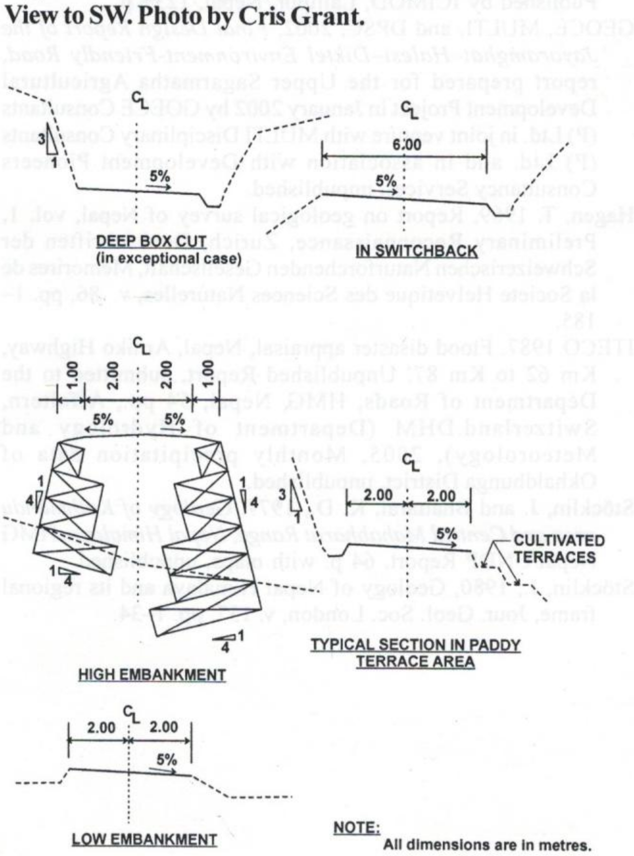

Fig. 18: Typical cross-sections for JDEFR (GEOCE et al. 2002). Note missing walls on soil slopes of box cut.

depth of a few centimetres, and they are not suitable for stabilising possible deeper failures, if used alone. For this propose a combination of inert structures (e.g. walls, check dams) and live structures is required. However, the bio-engineering measures (i.e. in Table 8.1 on p. 8-2 of GEOCE et al. 2002) were some simple vegetative systems alone.

GEOCE et al. (2002) provide some guidelines for gabion wall construction. Such retaining walls are proposed at

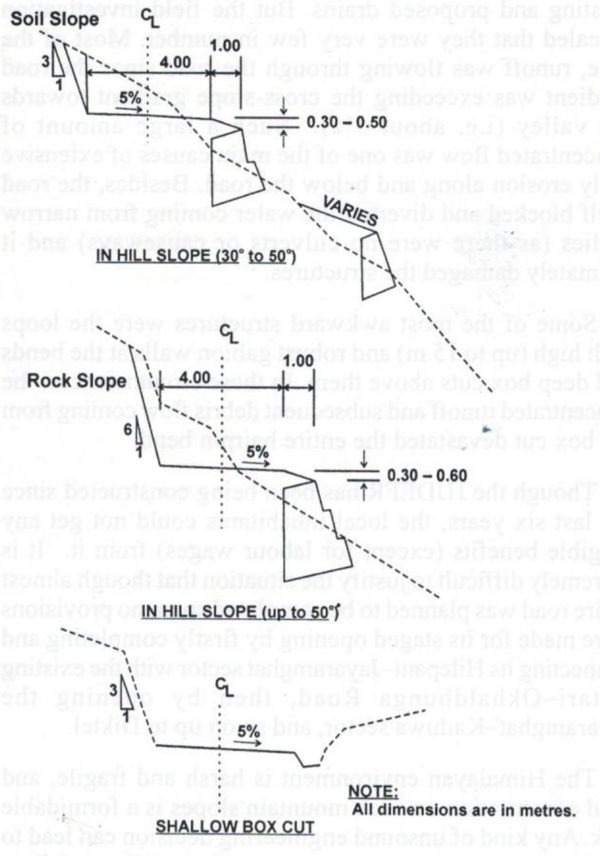

Fig. 19: Typical cross-sections for JDEFR (GEOCE et al. 2002). Note missing walls on soil cut slopes.

places with a slope angle exceeding 45 degrees and height more than 3 m. The following standards were considered: top width = 1 m; base width = 0.6 times the height; maximum height = 7 m. Evidently, the maximum wall height was constrained by the base width (which cannot be more than the road formation width of 4 m). Unfortunately, this last consideration of maximum wall height = 7 m was violated recklessly and hence many long and high walls failed. On the other hand, it is noteworthy that more than 75% (especially those shorter than 7 m) of the retaining walls survived the disaster.

GEOCE et al. (2002) also mention composite retaining walls (a combination of cement masonry, gabion, and dry stone). Many of such walls are functioning well. However, it is not always possible to construct a retaining wall of a very wide base width on such a steep mountainous terrain. Therefore, other wall types (viz. stone masonry and concrete) should have also been considered.

In GEOCE et al. (2002), there is a detailed description (with drawings of typical designs) of road surface drainage, subsurface drainage, slope drainage, and drainage from hairpin stacks. Similarly, there is a discussion on outlet protection and gully control measures together with a list of existing and proposed drains. But the field investigation revealed that they were very few in number. Most of the time, runoff was flowing through the road since the road gradient was exceeding the cross-slope gradient towards the valley (i.e. about 5%). Such a large amount of concentrated flow was one of the main causes of extensive gully erosion along and below the road. Besides, the road itself blocked and diverted the water coming from narrow gullies (as there were no culverts or causeways) and it ultimately damaged the structures.

Some of the most awkward structures were the loops with high (up to 15 m) and robust gabion walls at the bends and deep box cuts above them. In these circumstances, the concentrated runoff and subsequent debris flow coming from the box cut devastated the entire hairpin bend.

Though the HJDEFR has been being constructed since the last six years, the local inhabitants could not get any tangible benefits (except for labour wages) from it. It is extremely difficult to justify the situation that though almost entire road was planned to be completed soon, no provisions were made for its staged opening by firstly completing and connecting its Hilepani–Jayaramghat sector with the existing Katari–Okhaldhunga Road, then by opening the Jayaramghat–Kaduwa sector, and so on up to Diktel.

The Himalayan environment is harsh and fragile, and road construction on such mountain slopes is a formidable task. Any kind of unsound engineering decision can lead to a disaster. In these circumstances, it is unwise to follow some 'rules of thumb', 'heuristics', or 'standard designs' for the entire road stretch and ignore proper engineering knowledge and practices. Instead, site-specific and knowledge-based approaches should be applied.

ACKNOWLEDGEMENTS

RAP is thanked for giving me the opportunity to study this road alignment and for the permission to publish this paper. I am grateful to Padma Khadka, Ram Thapaliya, Chiranjivi Sharma, and Cris Grant for their valuable suggestions and lively discussions in the field.

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