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ENGINEERING GEOLOGICAL METHODS APPLIED IN MOUNTAIN ROAD SURVEY - AN EXAMPLE FROM BAITADI-DARCHULA ROAD PROJECT (NEPAL)

M. R. Dhital[1], B. N. Upreti[1], V. Dangol[1],
A. N. Bhandari[2] and T. N. Bhattari[1]

1 Department of Geology, Tribhuvan University, Kathmandu
2 Ga-1-451. Dillibazar, Kathmandu

ABSTRACT

Engineering geological studies were carried out for the Baitadi -Darchula Road in prefeasibility, feasibility, and detailed design stages. Methodology, application, and results from each stage are presented together with the geology and geomorphology of the region.

INTRODUCTION

Road construction in a mountainous terrain like the Himalaya, where the geologic processes are very active, usually poses serious environmental problems. Being a linear structure, the road may cross adverse geologic conditions and landforms, and encounter several kinds of instabilities. Improper road alignment selection not only intensifies existing geological phenomena, but also activates new processes of mass movement leading to environmental degradation. Therefore, it is necessary to develop a realistic approach for road survey, design, construction, and maintenance in hilly regions of Nepal for a sound infrastructural development.

An integrated method of road investigation including engineering geological, geomorphological, environmental, and engineering studies is not common in engineering practices of Nepal. Though such an approach was initiated in Rapti Roads Department of Roads, 1986), and slope stability methodology was developed by Wagner (1982) for the Nepalese hill terrain, no further attempt was made to continue it. It is for the first time that an integrated multidisciplinary approach of the road

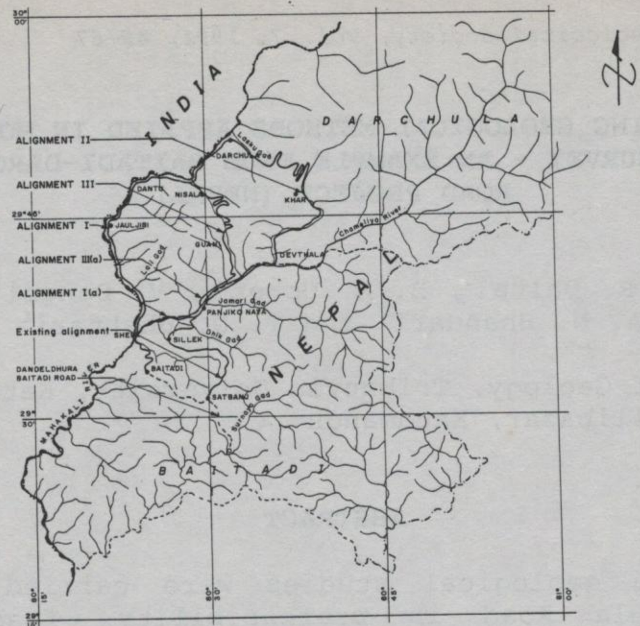

Fig. 1 Location Map of the Study Area

survey and design was followed from the prefeasibility to detailed design stages in the Baitadi-Darchula Road Project (BDRP) (Fig. 1). The Manual on Mountain Risk Engineering prepared by International Centre for Integrated Mountain Development was useful in this regard and extensively referred. We hope that the present methodology of geotechnical studies could be useful for similar projects and the study may serve as a good example for further discussion and comparison.

METHODOLOGY

The study was divided in prefeasibility, feasibility and detailed design stages. In the prefeasibility stage were analyzed all relevant maps, reports, aerial photographs, and meteorological data. At the same time, a reconnaissance survey was also carried out to verify the selected alternatives. In the feasibility stage, the selected alternatives were studied in the field, and necessary engineering geological, morphostructural, hazard and slope maps were produced. The best alignment was chosen from the above studies as well as environmental, socio-economic, engineering and other considerations. Further detailed geotechnical and engineering geological studies were performed for twenty kilometres in the detailed design stage. Geology and geomorphology of the area as well as the various stages of survey are discussed below.

GEOLOGY

The area studied belongs to the far western region of the Nepal Lesser Himalaya. The earliest note on the geological investigation in this part of Nepal was given by Heim and Gansser (1939) whose main work was confined to eastern Kumaon. They did some geological study in the NW part of Darchula district and their map shows that the lithotectonic units of Kumaon extended further east to Nepal. On his geological map of the Himalaya, Gansser (1964) has shown that the major lithotectonic units of Kumaon continue to far westerm Nepal. Hagen (1969) gave a somewhat different tectonic interpretation from that of Gansser (1964). Recently, a more detailed work has come from Bashyal (1981, 1986) and Upreti (1990).

The geological map (Fig. 2) is after Upreti (1990) with considerable modifications from the present field observations. In the study area, the rocks have been subdivided into two units: the high-grade metamorphics represented by schist, quartzite and metabasics, and the low-grade metamorphics comprised of slate, phyllite, dolomite, and quartzite. The former are thrust over the latter along the Parchauni Thrust, and occupy a narrow zone between Lali - Jouljibi and Bangabagar-Gokuleswor. Probably the thrust sheet occupied a greater area in the past and was subsequently eroded away preserving only in the central synformal core.

The quartzite and carbonate rocks with phyllite and slate partings and alternations are covering the region around Baitadi, Shera, Dhik Gad, and Satbanj. The beds dip 20-40 due NNW. The southern flank of the synformal thrust sheet is dipping 30-45 due N to NNW and its northern flank dips 40-50 due S to SSW. An antiformal axial trace is seen between the Lasku Gad, Dallek and the Naugarh Gad. A synformal axial trace is observed to the north of Jouljibi, the village Agar, and near Devthalla. Between Shera, Panjuko Naya and the Jamari Gad (along Chameliya river) lies another easterly plunging antiform. A synformal axial trace is also observed between the Padmoli Gad and village Khamtola.

The present geological study shows that major structural features have direct influence on the stability of the terrain. For example, the alignment II passing through the hinge zone of the Lasku Gad - Dallek -Naugarh Gad antiform, is one of the most

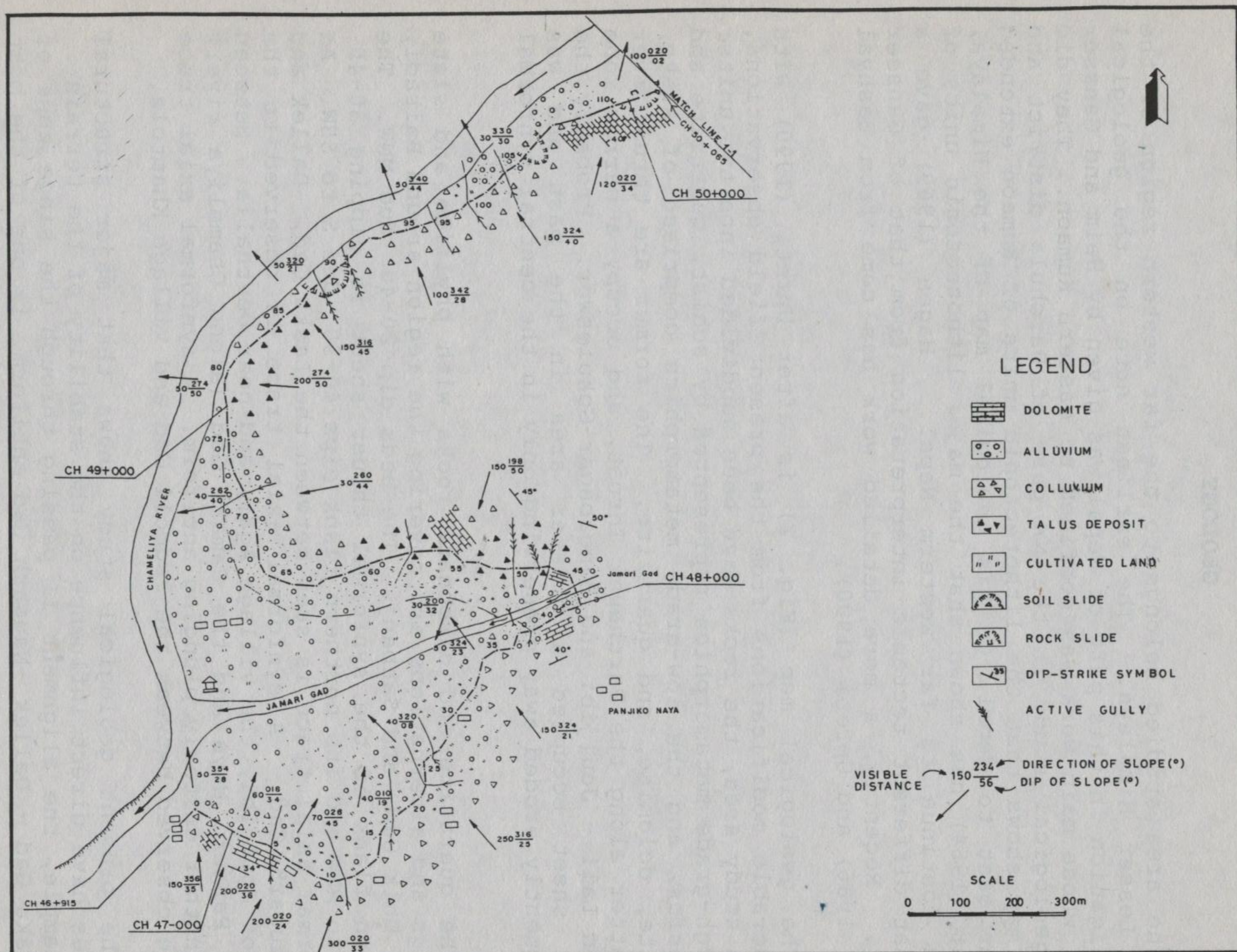

Fig. 2 Geological Map of the Baitadi - Darchula Region

hazardous zones. The deep gorge of the Chameliya River between Shera and Dhik Gad is associated with the periclinal closure zone. A large number of big landslides occurring in the vicinity of Devthalla, Gokuleswor, and the Jamari Gad are related to the tectonic activity of the Parchauni Thrust.

GEOMORPHOLOGY

Two snow-fed rivers: Mahakali and Chameliya, with a large number of tributaries drain the region. Geomorphologically, the terrain can be classified into the following landforms: 1. Steep rocky slopes and cliffs made up of dolomite or quartzite are observed mainly in the gorges of the Mahakali and Chameliya. 2. Moderately sloping hills are represented by the dip slope between Baitadi and Shera, old river terraces of Dhap and Nagtar and upper hill slopes in general. 3. Alluvial terraces are developed in Shera, Lali, Banku, Uku, Dhap and Darchula areas along the Mahakali river and also along the lower course of the Chameliya river. 4. Colluvial slopes widely developed along the lower section of the hills are typically characterized by the presence of thick colluvial cover. 5. Talus cones are found mainly along the Naugarh Gad and Dhap-Darchula sections. 6. Active alluvial fans are seen between Gokuleswor and Bangabagar, and to the south of Darchula.

Steep rocky slopes and cliffs pose a high hazard of rock fall, talus slide and wedge failure. In the moderately sloping hills, slumps, debris slides and gully erosion are common. Bank scouring and deep gully erosion hazards are encountered in the alluvial terraces. Steep colluvial slopes pose debris slide, boulder glide and soil creep hazards. Talus cones and alluvial fans create serious threat not only to the road alignment, but also to the cultivated land.

PREFEASIBILITY STUDY

Prefeasibility study was mainly aimed at outlining various probable alignments with the help of aerial photographs, maps and reports. Study of aerial photographs (1:50,000 scale) revealed general geologic and geomorphic features, existing mass movement processes, land use pattern, hydrologic and slope conditions. The available geological maps and reports of the area (Bashyal, 1981, 1986; Upreti, 1990) helped understand the general geologic conditions along the alignments. Study of topographic maps of

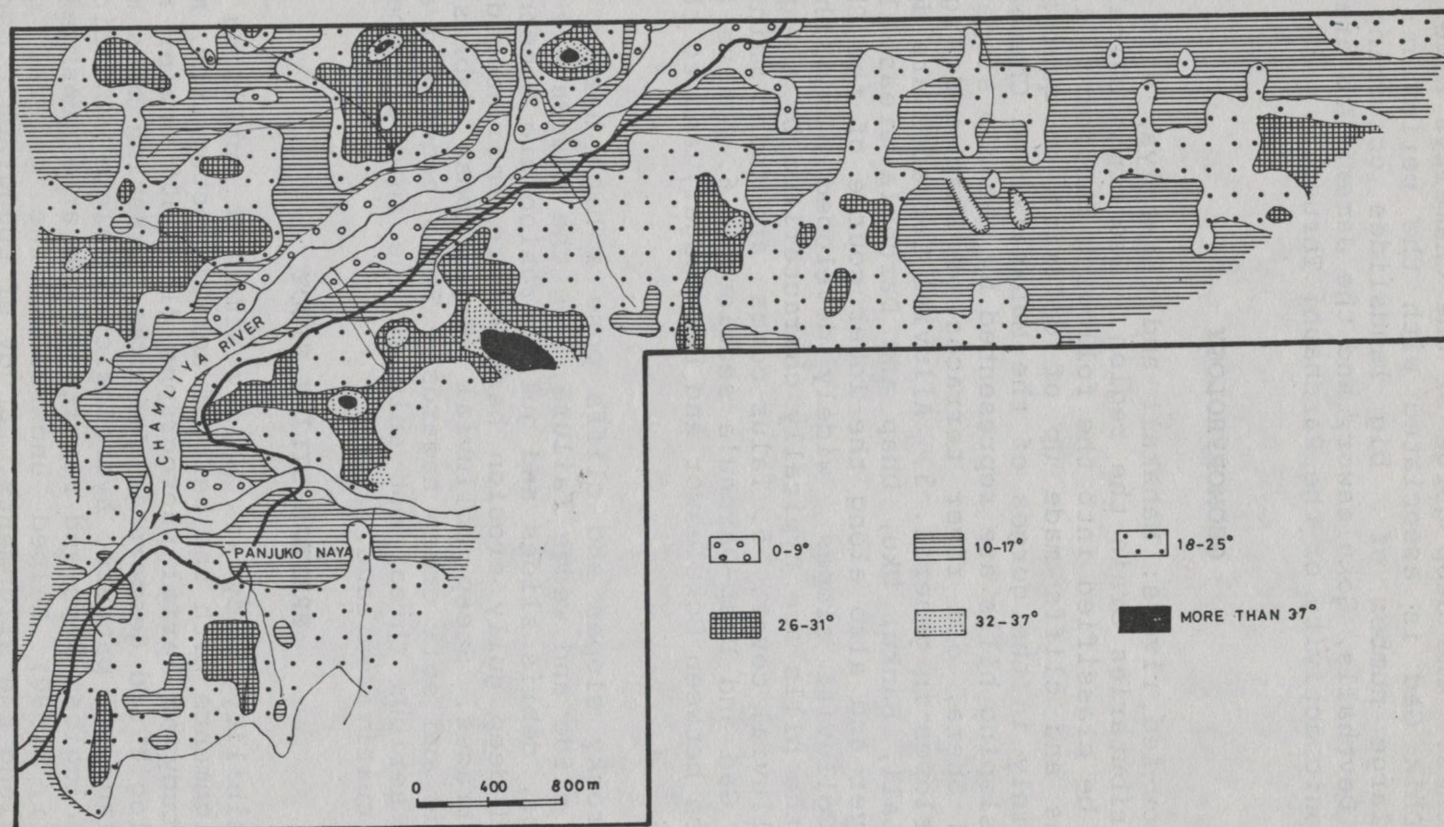

Fig. 3 Slope Map of a Part of the Road Alignment III along the Chameliya River

1:50,000 scale covering a wider area revealed the general topographic conditions, whereas the maps of 1:20,000 scale (blown up from 1:50,000 scale) were used for the preparation of slope maps along all the three alignments. Furthermore, climatological data, landuse maps (1:50,000 scale), earlier reports submitted to the Department of Roads by Scott Wilson Kirkpatrick & Partners (1989), and the technical proposal on BDRP by ITECO Nepal Pvt. Ltd. (1990) were also reviewed for the overall geotechnical assessment of the alignments.

After these studies and a short reconnaissance field visit, the three probable alignments were confirmed for further investigation in the feasibility stage and were plotted on the aerial photographs and topographic maps of 1:20,000 scale (blown up from 1:50,000 scale).

FEASIBILITY STUDY

Geological and geotechnical investigations were made in the field along the following proposed alignments (Fig.1): Baitadi -

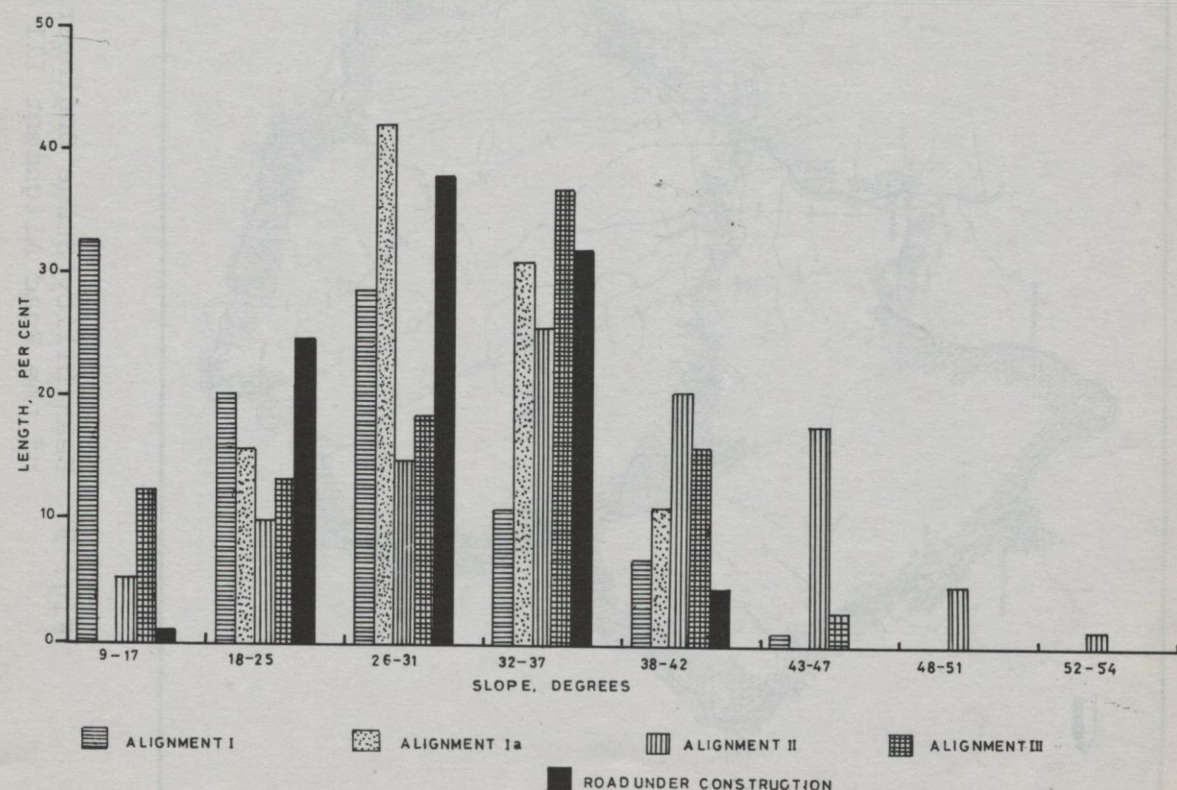

Fig. 4 Bar Diagram of Slope Conditions along Various Alignments

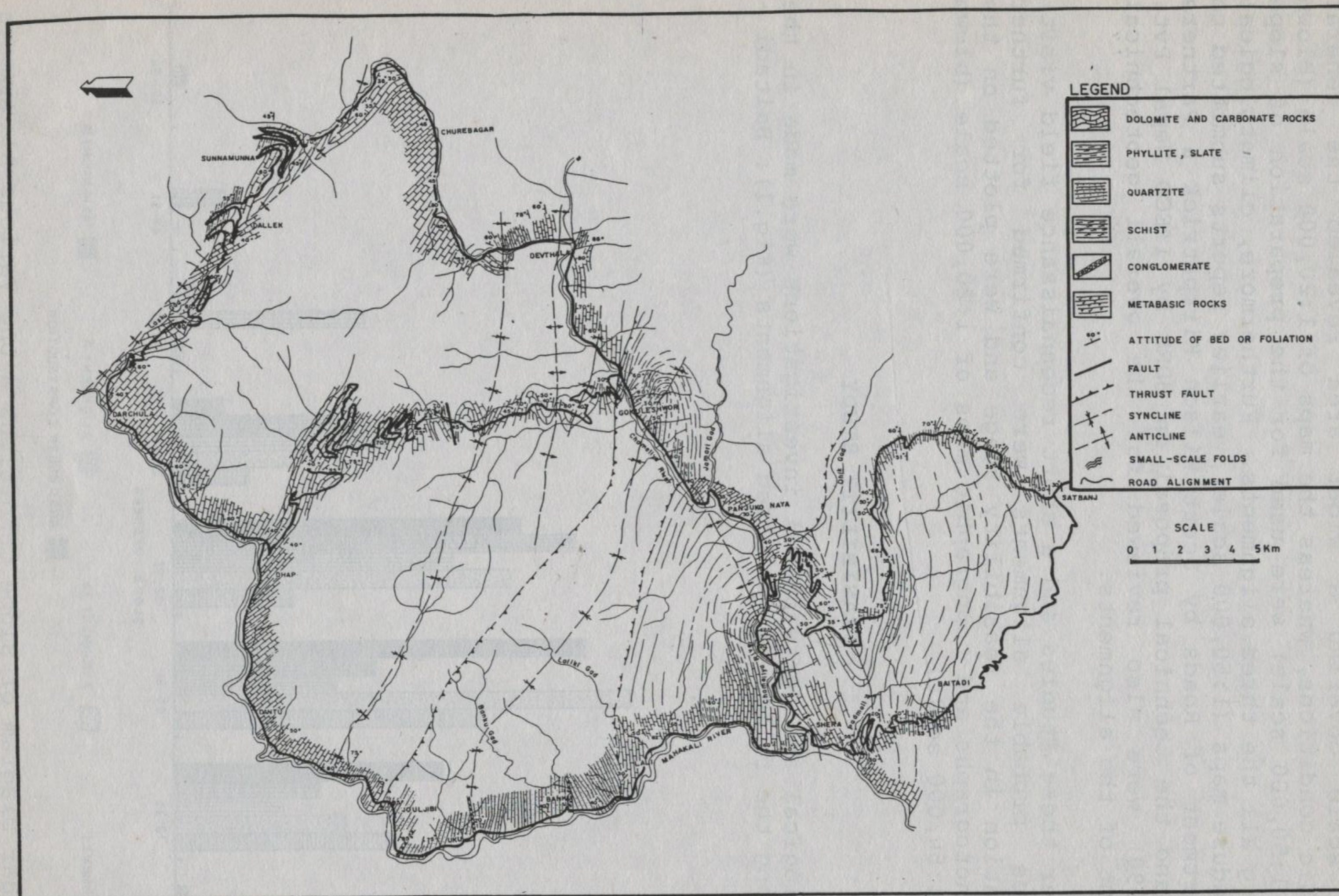

Fig. 5 Feasibility Stage Engineering Geological Map of a Part of the Road Alignment III along the Chameliya River

Shera- Dhap - Darchula (Alternative I),including a detour loop Salsena - Ratoda - Dhap - Darchula (Ia), Panjuko Naya - Gokuleswor- Devthalla - Dallek - Darchula (Alternative II), Panjuko Naya - Gokuleswor- Burmane - Dhap - Darchula (Alternative III) and Satbanj - Dhik Gad - Panjuko Naya (road under construction). The last alignment was surveyed to study the possibility of its stability and future extension.

The road alignment survey was made with the help of compass, tape and Abney Level. At the same time the appropriate changes and realignments were also made depending on the actual field conditions. This survey provided the basis for the detailed instrumental survey of the selected alignment. The prefeasibility study also took into account the grades and other necessary engineering standards followed by the Department of Roads.

Slope Maps

Slope maps (1:20,000) of all alignments were prepared before the field visit (Fig. 3), and an attempt was made to correct them in the field. As the visibility along the slope was often limited to 50 m up and down and on the alignment, the slope map correction was impractical. On the other hand, owing to the small scale of the map, the measured slope angles could not be transferred satisfactorily onto the slope maps.

Slope conditions along the alignments (Fig. 4) show that the alignment I passes through a terrain with gentler slopes (9-31) whereas, alignment Ia runs through steeper slopes (26-37). Though both alignments pass through the valley sections, their contrasting slope conditions are related to the fact that the former lies on the river terraces and the latter follows the steep gorge of the Chameliya. A uniform slope distribution of the alignment II (between 9-51 with a median at 32-37) is related to the fact that it follows valley, climbs to ridge and passes through section between Panjuko Naya and Darchula. But it is the only alignment, where 25% of the length falls through slopes exceeding 45 . The slope along the alignment III ranges between 9 and 42 with a median at 32-37 .

Engineering Geological Maps

The engineering geological maps (Fig. 5) of each alignment were prepared in 1:5,000 scale basically from the field observations. In the field, data were collected from rock (type of rock, study of joints and infilling material, foliation, bedding, interbedding/alternation of competent and incompetent beds/bands, weathering grade, etc.), and soil (genetic classification, Unified Soil Classification, depth of soil, etc.). Slope stability and mass movement (old and existing landslides), hydrogeological conditions (depth of water table, location of springs and seepages, river scouring, gullying), landuse pattern, vegetation, broad environmental considerations; availability of construction materials were also studied.

The natural slope parameters plotted on the maps show visible length along slope (in m.), direction of slope and slope angles (in degrees) up and down the alignment. On the map, the arrows indicate the direction of slope and the exact location lies at the intersection point of the arrow with the alignment.

Figure 6 shows that the rock exposure is highest (about 68%) along the road under construction. On the other hand, colluvium predominates (58-64%) in other three alignments and is distributed rather uniformly. Similarly, alluvium predominates

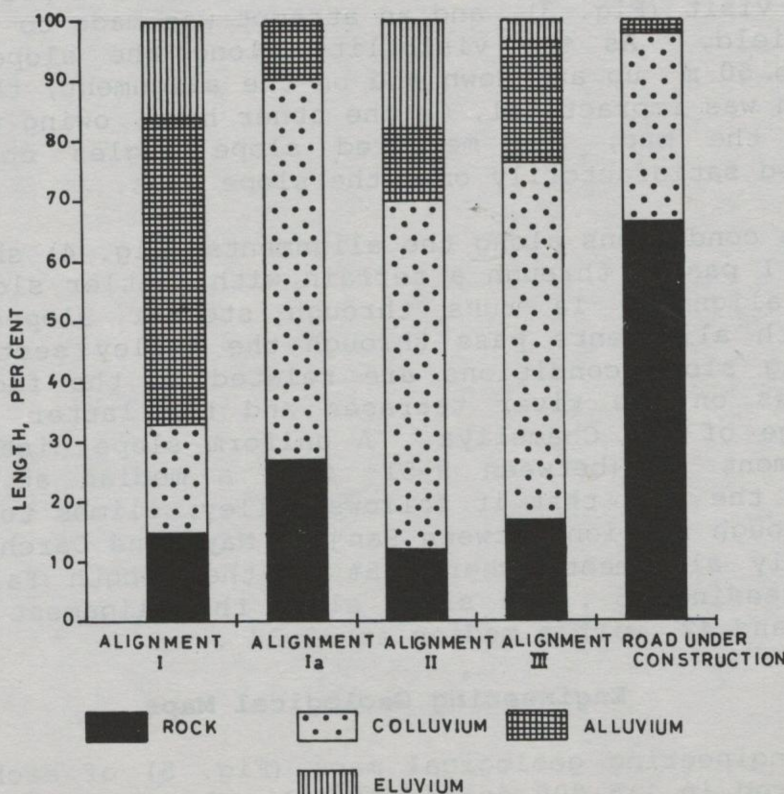

Fig. 6 Bar Diagram showing Distribution of Rock and Soil along Various Alignments

(52%) in alignment I. The negligible amount of alluvium and absence of eluvium in the road under construction are explained by the fact that the excavation was deep enough to remove the soil cover, and the road runs through ridges and climb sections without any river terraces. This observation points out that though soil cover is common in the ridge and climb sections, the underlying rock plays a vital role in slope stability.

Morphostructural Maps

The pertinent structural data such as attitude of beds, foliation, and joints were collected from the rock outcrops; they were plotted together with the natural slopes on the upper hemisphere of the stereographic net. Interpretation of stereograms indicates the probable rock slope stability. Morpho-structural maps in 1:20,000 scale were prepared (Fig. 7) using the stereograms as well as the structural (structural slopes, faults, fold axes), and geomorphic (spur, ridge, drainage pattern, river terraces, alluvial fans, talus cones, and landslides) features.

The detailed morphostructural analysis reveals that counter dip slopes are steep and, plane rock failure is common along dip slopes, wedge failure occurs in resistant rocks with two or more prominent joint sets, and debris slide is frequent in thick colluvium and other soils of the valley. Generally, wedge failure is more pronounced where competent and incompetent rocks alternate.

Hazard Maps

Rock and soil hazard maps of the road alignments were prepared in 1:20,000 scale (Fig. 8). Subjective judgement from the field were also taken into consideration in hazard calculations. Natural hazard assessment shows that generally dip slopes (Fig. 9, alignment II), steep slopes in thick colluvium, eluvium, and unconsolidated river terraces are most hazardous, whereas ridge sections (Fig. 9, Road Under Construction) and gently sloping terraces are least hazardous (Fig. 9, alignment I, III).

Preliminary Risk Assessment

Risk is the combined effect of the probability of occurrence of an undesirable event and the magnitude of the

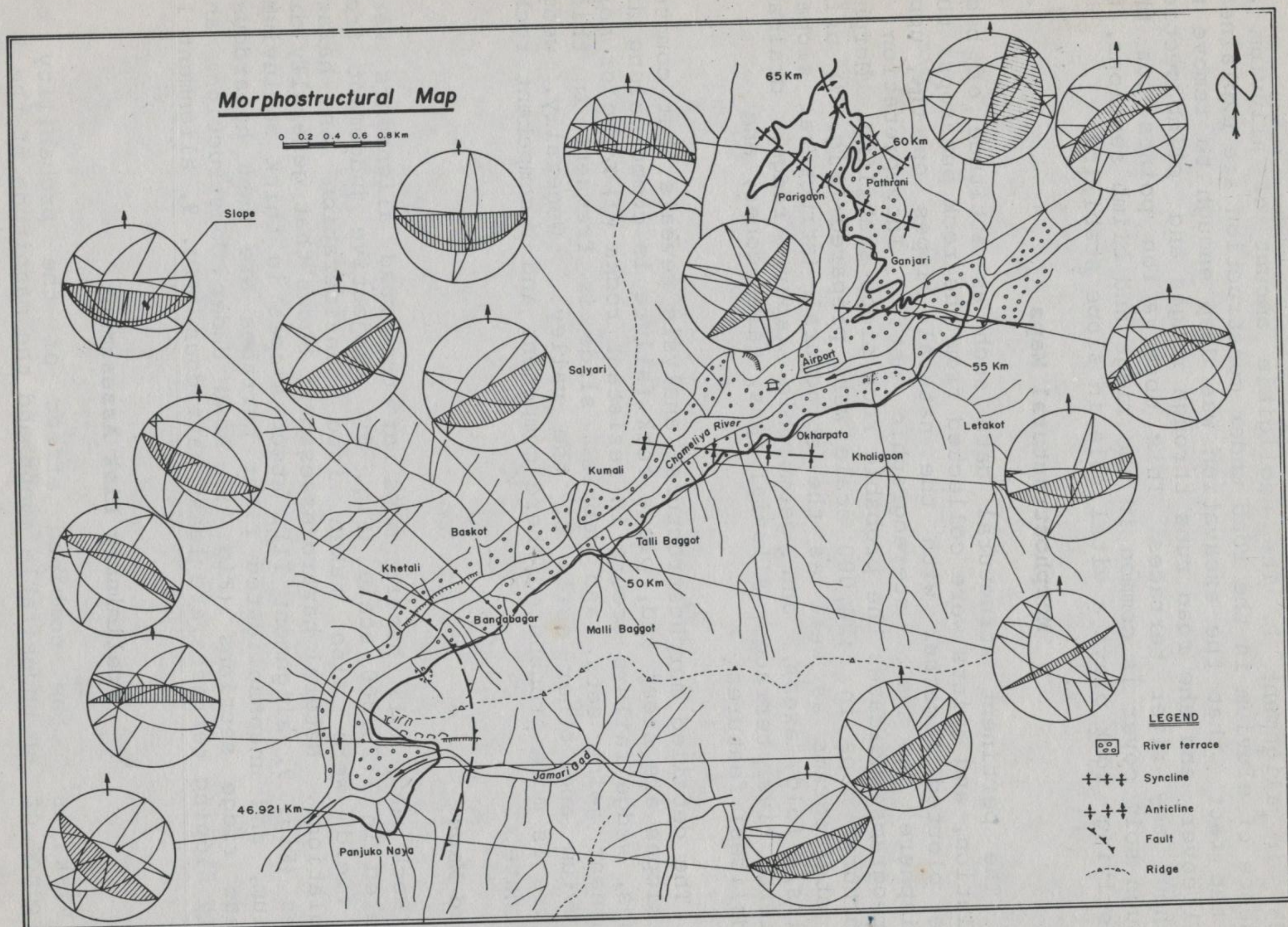

Fig. 7 Feasibility Stage Morphostructural Map of a Part of the Road Alignment III Along the Chameliya River

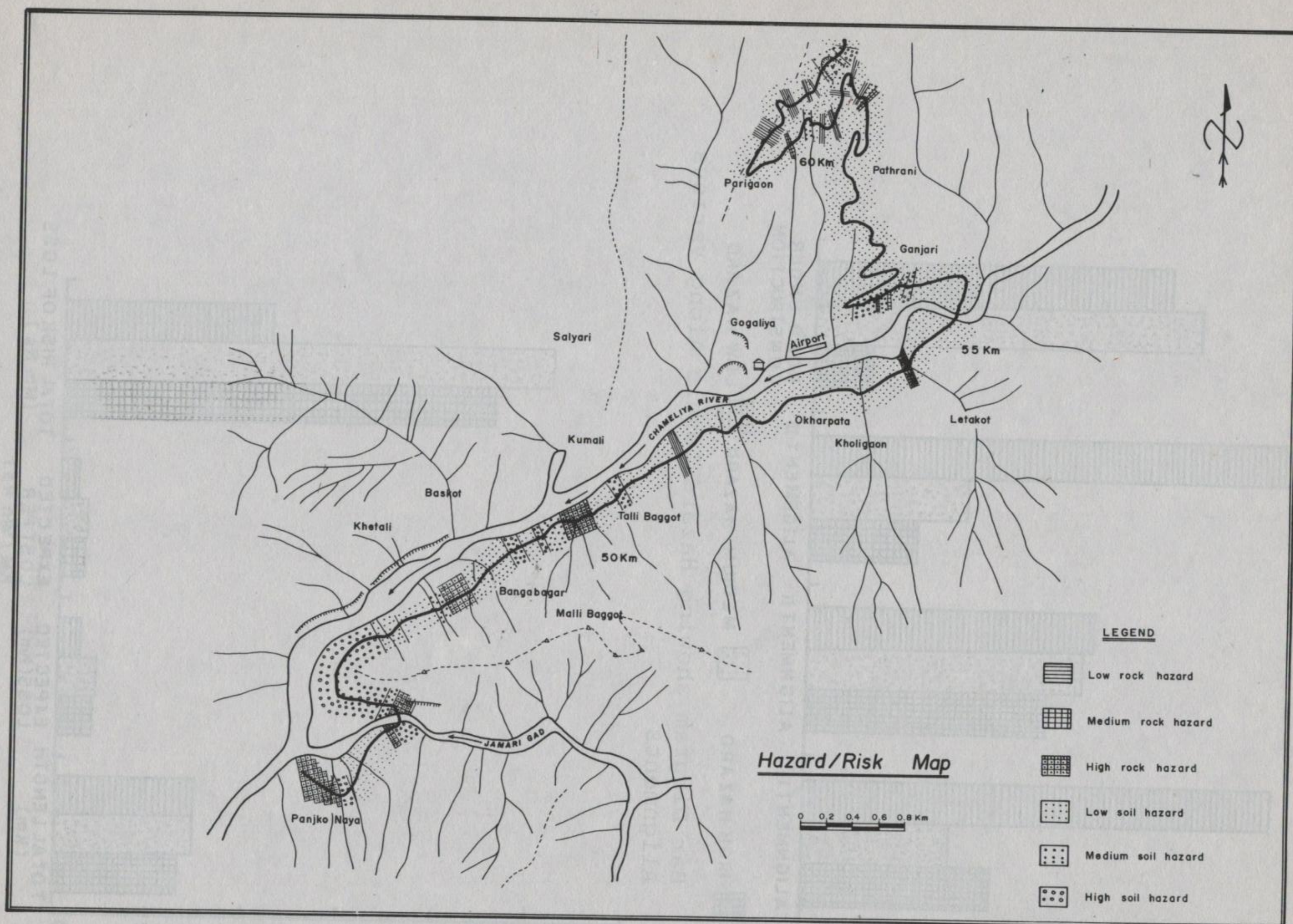

Fig. 8 Feasibility Stage Hazard Map of a Part of the Road Alignment III along the Chameliya River

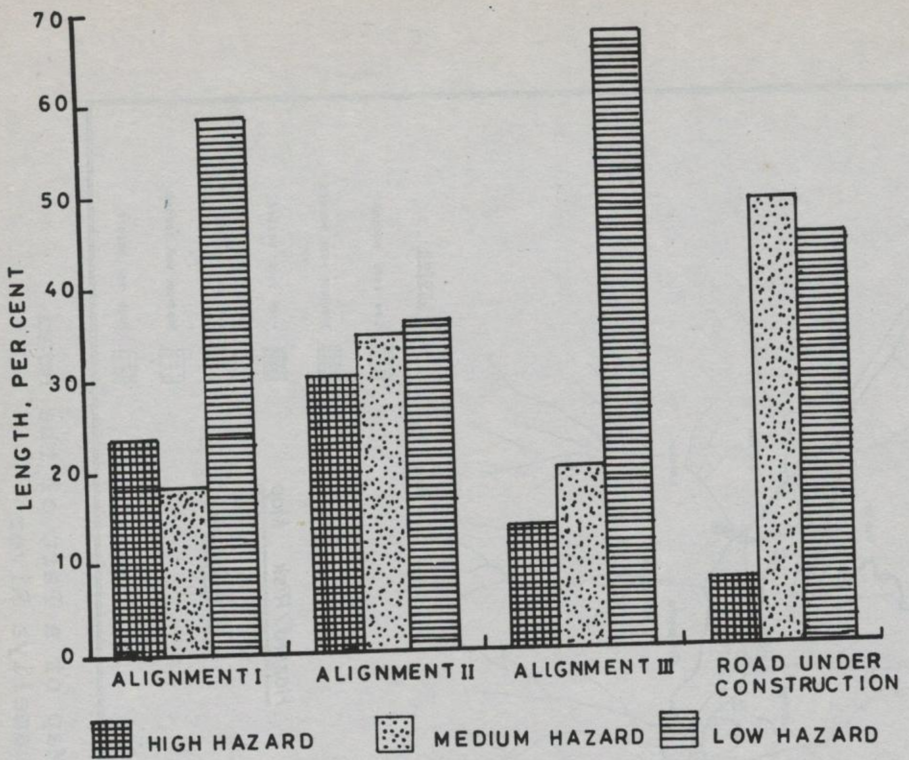

Fig. 9 Bar Diagram showing Hazard Levels Along Various Alignments

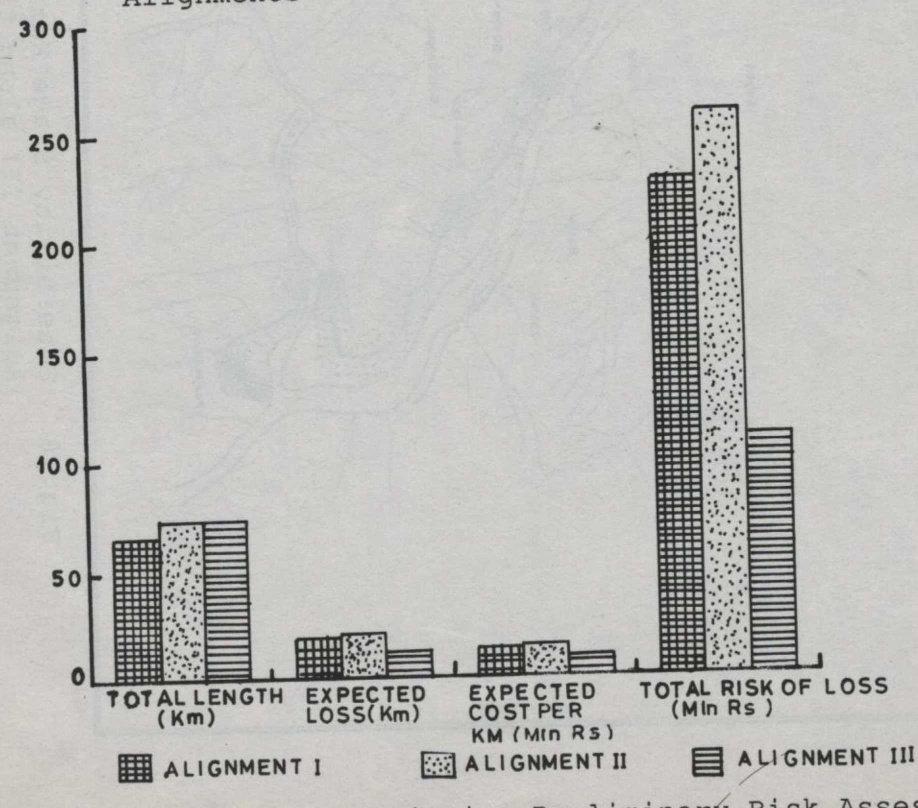

Fig. 10 Bar Diagram depicting Preliminary Risk Assessment Along Various Alignments

event (MRE manual); the risk assessment presented here is the natural risk without road as calculated in the feasibility stage.

To obtain the expected loss (E) of length of the alignment during 20 years of road life, the following formula (MRE Manual) was proposed:

$$E = L.D$$

Where, L is the potential damage length, and D is the probability of occurrence of danger.

The potential damage length L is calculated from the following formula:

$$L = T.H/100$$

Where, T is the potential danger length in percent, and H is the hazard length in metres.

The potential danger length T was guessed from the field observation and study of the hazard maps for every spot in percentiles of 5, 25, 50, 75 and 100. The probability of danger D was derived from the hazard map with the following conversion: for high hazard - 0.90; for medium hazard - 0.75; and for low hazard - 0.50.

To obtain the expected loss in Rupees, the corresponding road cost per kilometre is multiplied by the expected loss of road length (E) for each alternative alignment (Fig. 10).

The engineering geological study of the three alternatives revealed that alignment II is the most hazardous. While alignments I and III are comparatively equally hazardous, the latter was chosen for the detailed study owing to the fact that the risk level is lower, and it links the road under construction at Panjuko Naya. At the same time, such factors as number of bridges, road construction cost per km, economic internal rate of return (EIRR) and environmental aspects were also taken into account.

DETAILED STUDY

Detailed engineering geological studies were carried out

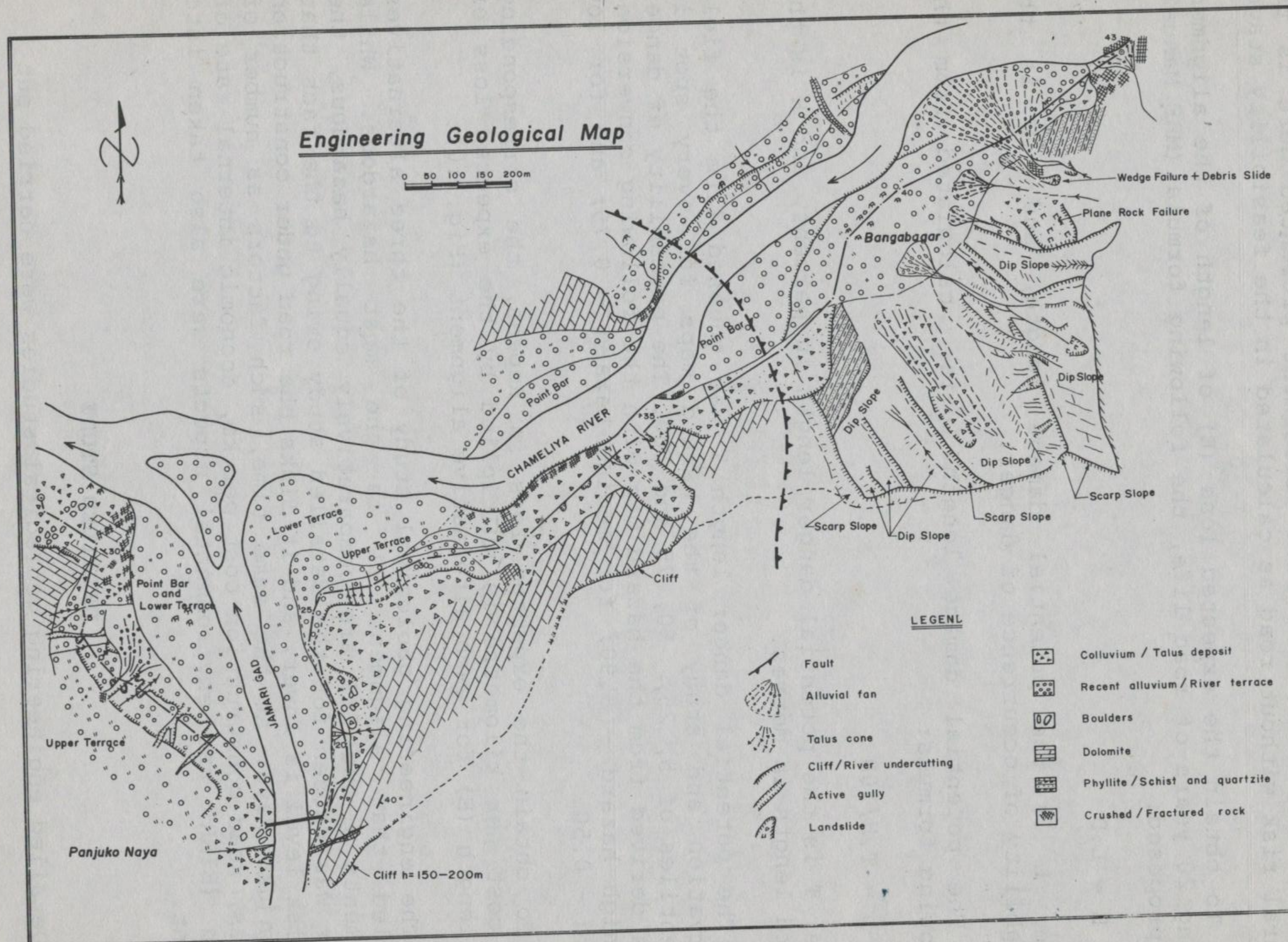

Fig. 11 Detail Stage Engineering Geological Map of a Part of the Road Alignment III along the Chameliya River

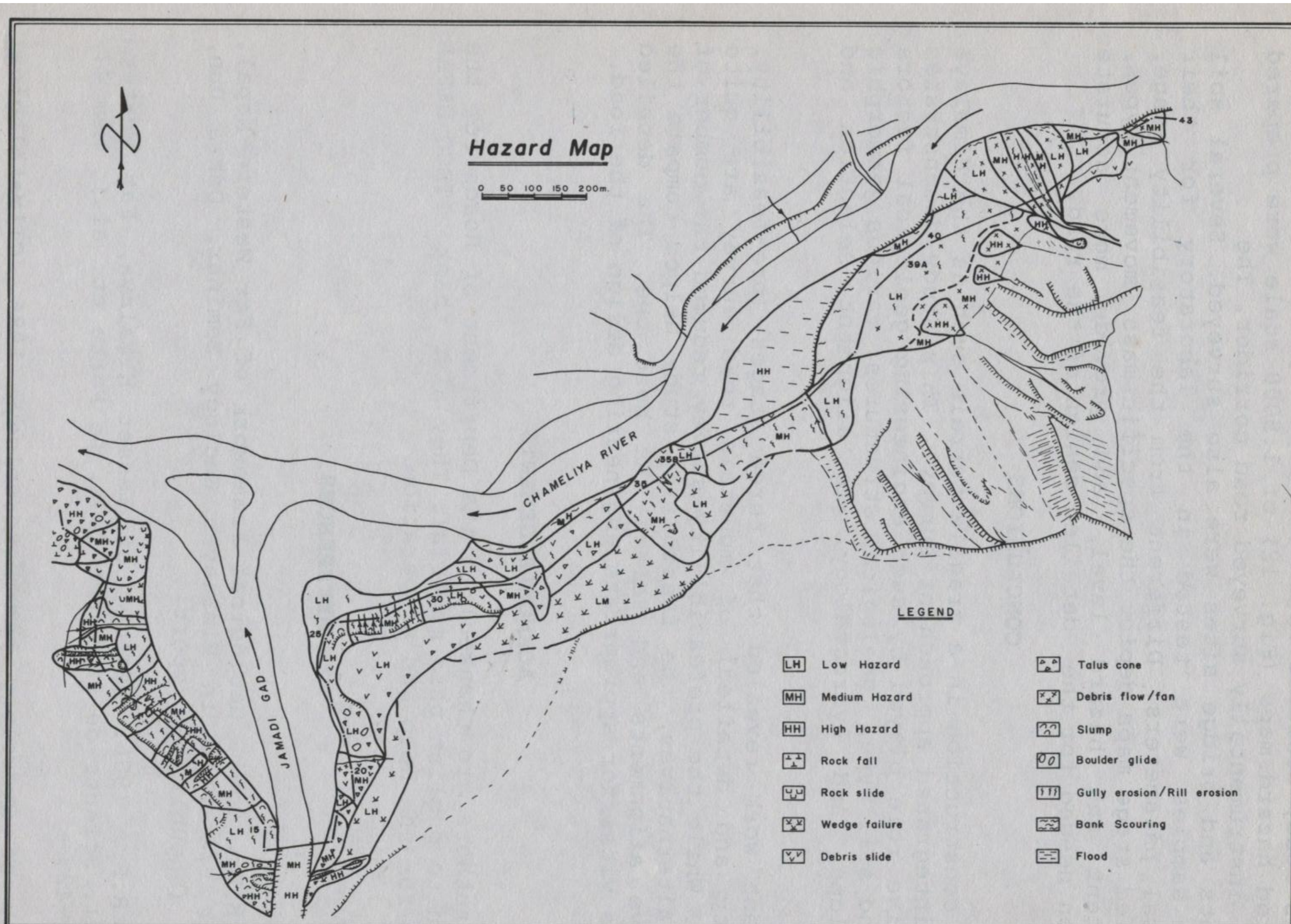

Fig. 12 Detail Stage Hazard Map of a Part of the Road Alignment III along the Chamelia River

from Panjuko Naya to Lekgaon for 20 km of the alignment III. During this study detailed engineering geological maps (Fig. 11) and detailed hazard maps (Fig. 12) of 1:5000 scale were prepared along the instrumentally surveyed road corridor. The realignments and bridge sites were also surveyed. Several soil and rock samples were tested in the laboratory for their geotechnical parameters. Different from the feasibility stage, the detailed stage maps depict the specific mass movement types, their extent and hazard level, and provide more accurate information needed for the detailed design of the road.

CONCLUSIONS

Road construction in a fragile terrain such as the Himalaya needs an integrated approach of survey. This study demonstrates the decisive role played by such engineering geological factors as rock and soil type, geological structures, various geomorphic units, slope, and hydrogeology, in alignment selection and design.

Present work revealed that three stages (pre-feasibility, feasibility and detailed) of mountain road survey are quite justified. While the prefeasibility survey reduced the number of probable alternatives, the feasibility study helped compare the alternative alignments and select the best one. The detailed survey was vital for appropriate engineering design of the road.

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