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Engineering geological investigation of trail bridges in western Nepal

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ABSTRACT

The study covers the engineering geological investigation of eight bridges; Kailashmandu (Bajura district), Khaniya Ghat (Baglung district), Listra Bagar (Bajhang district), Kunalo Gad (Bajura district), Samar (Mustang district), Lode Ghat (Achham district), Puima Gad (Humla district) and Ghatte Gad (Darchula district) of western Nepal. The study was carried out in conceal with the manual and checklist developed by HELVETAS as far as practicable. The present study intended to overwhelm the incompatibility, constraint and limitations of manuals and checklist of SBD by applying the suitable recent methods of engineering geology. During the field observation, the risk of possible bridge failure due to geological and geotechnical conditions was significantly reduced by using the actual rock and soil index parameters obtained from the laboratory test instead of the empirical range values given in the SBD MANUAL. Similarly the bridge construction cost was also abridged in some extent.

INTRODUCTION

Nepal is country of steep hills and high mountains. The snow-fed and rain-fed rivers have played a significant role in changing whole landscape of the mountainous area into deep valleys and gorges. Although these jagged areas are densely populated, the means of transportation is only foot trails. The expansion of modern transportation facilities in these areas are comforted with frequent natural impediments. The people live in these remote areas entirely use a dense system of foot trails for communication and transport of daily consumable goods. There are numerous confronted river crossings across these trails. Surprisingly, in some area, there exist either wooden bridges or wire bridges to cross the rivers. Peoples are using a well established local bridge building skill to construct these bridges. Such bridge constructed over the river crossing of the foot trail is often termed as Trail Bridge. Due to lack of scientific techniques in local level, it is hard to build sound and reliable bridge of longer span (Carroll 1997). An organization of His Majesty's Government of Nepal, Suspension Bridge Division (SBD) is dedicating in developing standard of study and design of Trail Bridge.

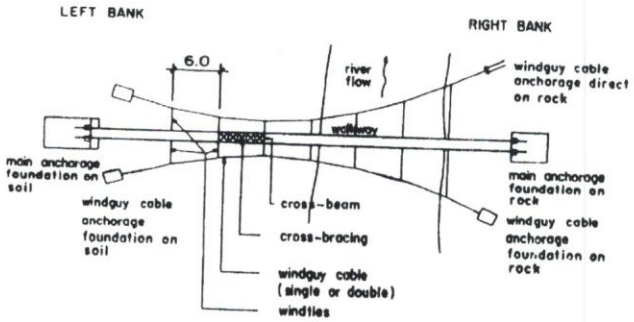
In Nepal, mainly two types of cable supported bridges are used as Trail Bridge: Suspension Bridge and Suspended Bridge (Fig. 1 and 2). The engineering geological investigation and design procedure of trail bridge is generally carried out according to the manual and checklists (SBD MANUAL) developed by Swiss Association for Technical Assistance (HELVETAS) for Suspension Bridge Division, His Majesty's Government of Nepal (Krahenbunl and Wagner, 1983 and Supension Bridge Projects, Nepal, 1982 and 1992).

The study covers the engineering geological investigation of eight bridges; Kailashmandu (Bajura district), Khaniya Ghat (Baglung district), Listra Bagar (Bajhang district), Kunalo Gad (Bajura district), Samar (Mustang district), Lode Ghat (Achham district), Puima Gad (Humla district) and Ghatte Gad (Darchula district) of western Nepal (Fig. 3). The study was carried out in conceal with the manual and checklist developed by HELVETAS as far as practicable. The information gathered from field as per the manual instructions could not able to cover the whole geological information concealed in the field, because in some cases the checklist does not match the site condition and the geologist must put own expertise. Checklist also do not able to deal with special geological conditions such as regional geological structures, relation of rocks and soils of foundation site with the adjoin area, and statistical analysis of discontinuities of rock outcrops.

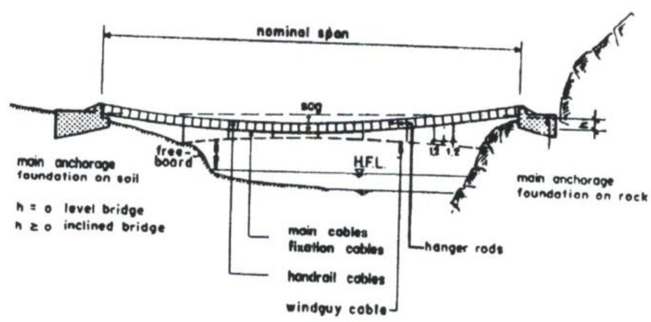
The field procedure of the soil classification for the foundation design is also inadequate during the estimation of range value of design parameter given in the manual. The manual do not deal with laboratory analysis of soil such as grain size analysis, maximum and minimum density estimation, specific gravity test etc.

For the rocky foundation sites, the manual and checklist suggest only for proper rock identification, estimation of weathering grade and single data measurement of different sets of discontinuities. In the design phase, the manual suggests some range value of bearing capacity for the rocky foundation as per the rock type only. It does not suggest for any index test of intact rock in laboratory.

The manual also gives full priority for the socio-economic conditions of the bridge site area and in some condition social demand of the bridge trounce the geological conditions of the bridge sites. As a result, many bridges, constructed by SBD, are facing extensive problems of bank erosion.

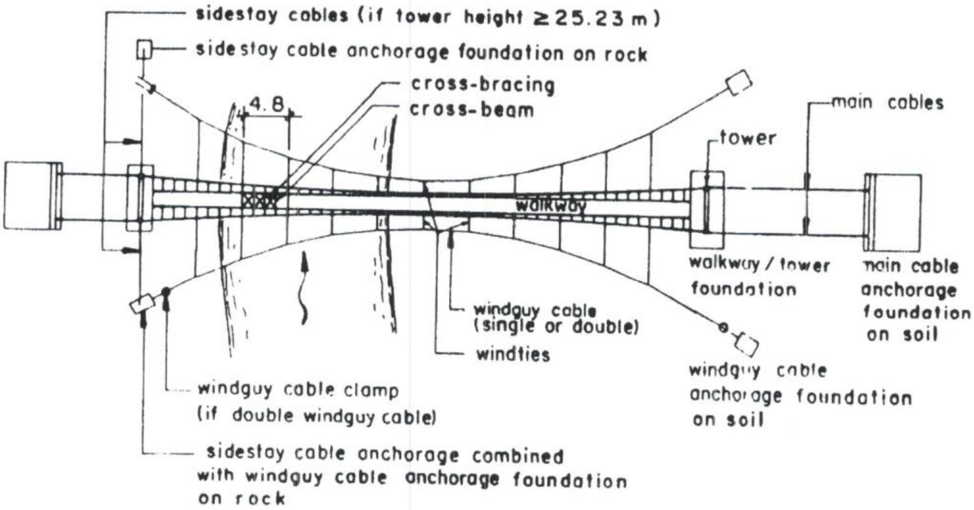


A) Plan



B) Side Elevation

Fig. 1: General layout of suspended bridge (source SBD Manual Vol. A, 1983).



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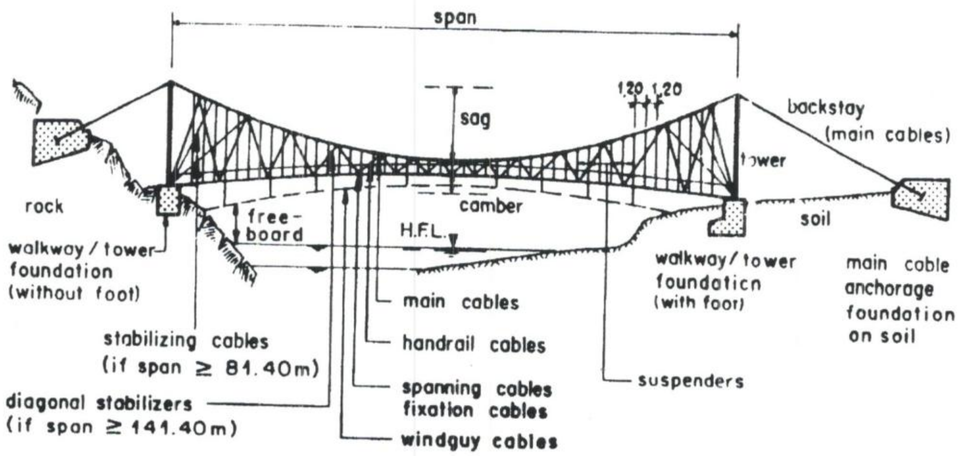

B) Side Elevation

Fig. 2: General layout of suspension bridge (source SBD Manual Vol. A, 1983).

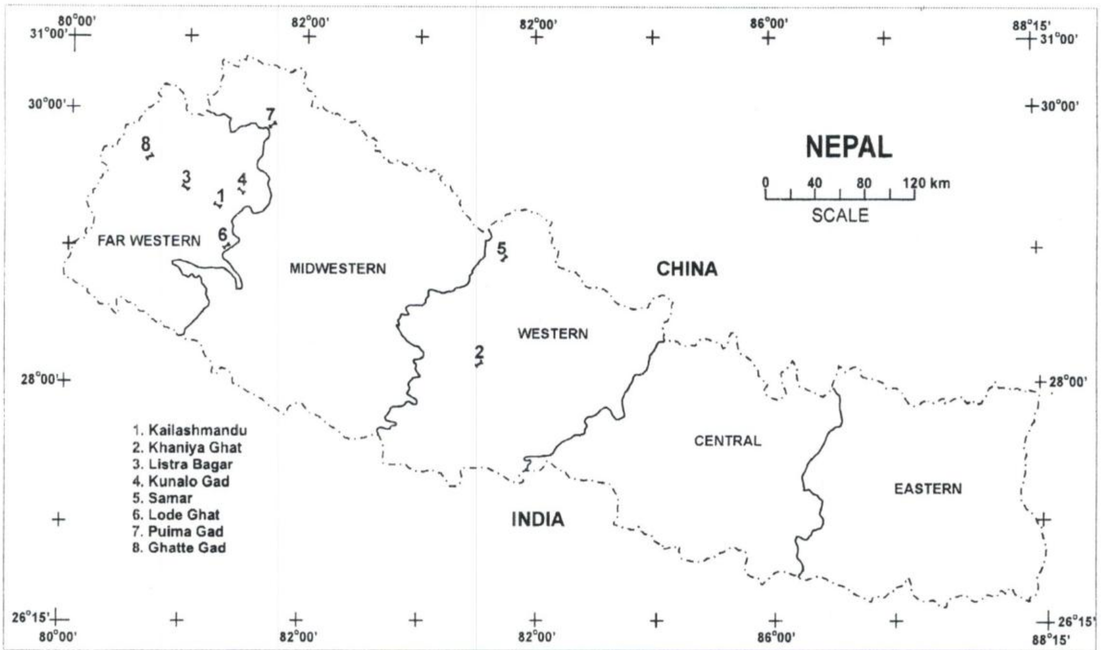

Fig. 3: Location of the eight bridges.

The present study intended to overwhelm these incompatibility, constraint and limitations of manuals and checklist by applying the suitable recent methods of engineering geology.

METHODOLOGY OF THE SITE INVESTIGATION

General procedure

In this study, checklists of the Field Survey Manual of SBD (Vol. B) were filled to gather the following information.

- Three alternative sites as per geology and socio-economic condition
- Fixation of bridge axis in the best site as per topography, geology, and slope hazard
- Soil and rock investigation for slope failure prediction
- Topographical mapping of selected site in the scale of 1:100 or 1:200
- Suggestion of design parameter according to the soil and rock type
- Information on protection requirement, high and low water level
- Information on general geology
- Location of bridge site with respect to traditional crossing point and
- River flow conditions

After gathering the field data, detail design of bridges were done according to the Design Manual (Vol. A) and Standard Drawings (Vol. C).

Site selection and engineering geological investigation in present study

Field Survey Manual (Vol. B) mainly deals with the site selection according to geological and topographical survey in very general way. The work done concurrently in this study with the Survey Manual Vol. B of SBD are summarised in the Table 1.

Similarly, photographs of main site and alternative sites, upslope, river bank, test pit, and bridge anchorage area were taken during the field survey.

In the engineering geological study mainly geomorphology of the slope, bank and river morphology, and groundwater conditions were taken into consideration. Similarly, in geotechnical investigation of bridge site mainly rock type, weathering, soil type, soil thickness, plastic behaviour of soil, and rock fracture were taken into importance. For soil classification, the Unified Soil Classification System (USCS) was used (USBR 1963). At least 50 joint data were collected for used in stereographic projection to identify the fracture and slope relationship.

EXAMPLES OF SITE INVESTIGATION ON EIGHT BRIDGE SITES

Summary of geological investigation is given in the Table 2. Details are given below.

Kailashmandu

The bridge over the Budhi Ganga River (a major tributary of the West Seti River) is named as Kailashmandu Bridge and it is situated in the Kailashmandu village of the Bajura

Table 1: Summary of work done in present study concurrently with SBD manuals.

SN	Bridge Name	Work done as per SBD guidelines	Work done in present study
1	Kailashmandu (Bajura district)	Fixation of three probable bridge sites near to the existing main trail and evaluation of all three sites in terms of geology, social benefit, and span. (Checklist 1)	Site selection priority was given for rocky slope, Left Bank (L/B) was selected in rocky slope.
		Detail geological survey at appropriate site around 50 m downstream and upstream area.(Check List 2).	Geological traverse was taken around 1000 m downstream and 300 m upstream due to extensive alluvial deposit seen at R/B
		Detail geomorphological study with rock and soil investigation was carried out as per Check List 3, 4, and 5.	Bank cutting history was noted from local people on R/B, detail joint measurement was done in rock exposure of the Left Bank (L/B)
		-	Grain size analysis of soil in laboratory, detail joint analysis was done by the help of stereonet and DIPS software.
		Design parameters of rock and soils were fixed according to the range value of the Manuals. (Check List 9)	Design parameter was calculated as per field data and laboratory data
2	Khaniya Ghat (Baglung district)	Fixation of three probable bridge sites near to the existing main trail and evaluation of all three sites in terms of geology, social benefit, and span. (Checklist 1)	Both tower and main anchorage site were selected at far behind the edge of banks
		Detail geological survey at appropriate site around 50 m downstream and upstream area.(Check List 2)	Site selected in straight channel, detail information of river flow pattern through out the year was taken from villagers, flat old river terrace was selected for bridge site
		Detail geomorphological study with rock and soil investigation was carried out as per Check List 3, 4, and 5.	Soil samples from each pit was taken for laboratory analysis, hill slope behind the anchorage sites evaluated for slope failure, regional geological structures and dissolution pattern were studies.
		-	Grain size analysis of soil in laboratory
		Design parameters of rock and soils were fixed according to the range value of the Manuals. (Check List 9)	Design parameter was calculated as per field data and laboratory data
3	Listra Bagar (Bajhang district)	Fixation of three probable bridge sites near to the existing main trail and evaluation of all three sites in terms of geology, social benefit, and span. (Checklist 1)	Suitable site was selected as per geological conditions. About 1000 m both upstream and downstream was investigated for bank erosion and availability of rocky foundation. The site marked by SBD was on alluvial deposits and was abandoned due to extreme bank cutting.
		Detail geological survey at appropriate site around 50 m downstream and upstream area. (Check List 2)	Detail geological survey was done in 1000 m downstream and 1000 m upstream from the selected site.
		Detail geomorphological study with rock and soil investigation was carried out as per Check List 3, 4, and 5.	The rocky upslope of the left bank was investigated for slope failure. Detail joint measurement was done. Relation of slope with bed rock dip was seriously evaluated in the field. Dissolution pattern on joint surface of calcareous rock is also noted. The semi-consolidated old debris of right bank was also carefully analysed in terms of erosion and compaction.
		-	Grain size analysis of soil in laboratory, detail joint analysis was done by the help of stereonet and DIPS software.
		Design parameters of rock and soils were fixed according to the range value of the Manuals. (Check List 9)	Design parameter was calculated as per field data and laboratory data
4	Kunalo Gad (Bajura district),	Fixation of three probable bridge sites near to the existing main trail and evaluation of all three sites in terms of geology, social benefit, and span. (Checklist 1)	During site selection full priority was given in the site near to the pre-existing trail because the river is fordable almost whole season and there may be no chance of operation of bridge if it is placed far from existing trail.
		Detail geological survey at appropriate site around 50 m downstream and upstream area. (Check List 2)	Detail slope condition, soil type, rock type, weathering and bank erosion problems were noted about 500 m upstream and 400 m downstream. Detail slope evaluation was also performed on upslope of left bank.
		Detail geomorphological study with rock and soil investigation was carried out as per Check List 3, 4, and 5.	Attention was given to sheet and gully erosion, soil thickness was noted on upslope. Problems of failures were also noted on slope. Rock and soil sample was taken for laboratory analysis. Detail discontinuities were measured for analysis of rocky slope failure.
		-	Grain size analysis of soil in laboratory, detail joint analysis was done by the help of stereonet and DIPS software.
		Design parameters of rock and soils were fixed according to the range value of the Manuals. (Check List 9)	Design parameter was calculated as per field data and laboratory data.

Contd......

Table 1 (continued)

SN	Bridge Name	Work done as per SBD guidelines	Work done in present study
5	Samar (Mustang district),	Fixation of three probable bridge sites near to the existing main trail and evaluation of all three sites in terms of geology, social benefit, and span. (Checklist 1)	The site was selected on the semi consolidated fluvio-glacial deposits. Free board very high in all three selected probable site. So, in selected site, free board was reduced.
		Detail geological survey at appropriate site around 50 m downstream and upstream area. (Check List 2)	The regional and local scale geological structures were analysed and the normal fault was noticed on right bank of the selected site. The main anchorage site was then selected on foot wall of the fault.
		Detail geomorphological study with rock and soil investigation was carried out as per Check List 3, 4, and 5.	Due to steep bank height and slope, the risky boulders of the fluvio-glacial deposits were noticed to remove during the bridge construction. Soil sample was taken from pits for laboratory analysis. Degree of soil compaction was investigated on the selected site. The amount of snow fall and period of ice covering was also noticed.
			Grain size analysis and plasticity test of soil in laboratory
		Design parameters of rock and soils were fixed according to the range value of the Manuals. (Check List 9)	Design parameter was calculated as per field data and laboratory data. Possible effect of the fault was also considered.
6	Lode Ghat (Achham district),	Fixation of three probable bridge sites near to the existing main trail and evaluation of all three sites in terms of geology, social benefit, and span. (Checklist 1)	Priority was given for the site situated on main trail.
		Detail geological survey at appropriate site around 50 m downstream and upstream area. (Check List 2)	The rocky left bank and right bank were investigated for slope failure. Detail joint measurement was done on both banks. Relation of slope with bed rock dip was seriously evaluated. Joint infilling materials were also analysed during the field visit.
			The thin veneer of colluvium on slope was also studied in terms of erosion and gully formation.
		Detail geomorphological study with rock and soil investigation was carried out as per Check List 3, 4, and 5.	Attention was given to sheet and gully erosion, soil thickness was noted on upslope. Problems of rock failures were also noted on slope. Rock and soil sample was taken for laboratory analysis. Detail discontinuities were measured on both banks for analysis of rocky slope failure.
		-	Laboratory test of soil (grain size analysis with maximum and minimum density test), detail joint analysis was done by the help of stereonet and DIPS software.
		Design parameters of rock and soils were fixed according to the range value of the Manuals. (Check List 9)	Design parameter was calculated as per field data and laboratory data.
7	Puima Gad (Humla district)	Fixation of three probable bridge sites near to the existing main trail and evaluation of all three sites in terms of geology, social benefit, and span. (Checklist 1)	Priority was given for the site situated on geologically stable. The rocky bank was selected for L/B abutments as the river is striking on.
		Detail geological survey at appropriate site around 50 m downstream and upstream area. (Check List 2)	Detail slope condition, soil type, rock type, weathering and bank erosion problems were noted about 400 m upstream and 400 m downstream. Detail slope evaluation was also performed on upslope of left bank.
		Detail geomorphological study with rock and soil investigation was carried out as per Check List 3, 4, and 5.	The catchments area of the river was investigated for the probable debris flow on the bridge area because there were huge boulders on river bed.
			The upslope, containing loose debris material, of the L/B was evaluated for probable slope failure and debris flow.
		-	Grain size analysis of soil in laboratory, detail joint analysis was done for R/B abutments by the help of stereonet and DIPS software
		Design parameters of rock and soils were fixed according to the range value of the Manuals. (Check List 9)	Design parameter was calculated as per field data and laboratory data.
8	Ghatte Gad (Darchula district)	Fixation of three probable bridge sites near to the existing main trail and evaluation of all three sites in terms of geology, social benefit, and span. (Checklist 1)	Priority was given for the site situated on geologically stable but off the trail. to avoid lose alluvium of both bank, L/B abutment was selected on stable cemented alluvium.
		Detail geological survey at appropriate site around 50 m downstream and upstream area. (Check List 2)	Detail bank condition, soil type, weathering and bank erosion problems were noted about 300 m upstream and 300 m downstream. Degree of compaction of alluvium on L/B was also evaluated and calcareous content was also examined
		Detail geomorphological study with rock and soil investigation was carried out as per Check List 3, 4, and 5.	The catchments area of the river was investigated for the probable debris flow on the bridge area because there were huge boulders on river bed.
			The R/B, containing loose alluvium and cultivated, was evaluated for probable seepage from cultivation and canal nearby.
		-	Grain size analysis of soil in laboratory
		Design parameters of rock and soils were fixed according to the range value of the Manuals. (Check List 9)	Design parameter was calculated as per field data and laboratory data.

Table 2: Summaary of geological investigation

SN	Bridge Name	District	Type of trail bridge	Span (m)	Left bank	Right bank	Rock type at MA	Rock type at DWG	Rock type at UWG	Rock type at TA	Unified Soil Classification of soil MA	Unified Soil Classification of soil DWG	Unified Soil Classification of soil UWG	Unified Soil Classification of soil TA	Remarks
1	Kailashmandu	Bajura	Suspended	101	Rock	Alluvial Soil	L/B Gneiss	L/B Gneiss	L/B Gneiss	L/B Gneiss	L/B ML	L/B ML	L/B ML	L/B ML	Thin soil cover on L/B
							R/B None	R/B None	R/B None	R/B None	R/B GM	R/B GM	R/B GM	R/B GM	
2	Khaniya Ghat	Baglung	Suspension	113	Alluvial Soil	Alluvial Soil	-	-	-	-	L/B GM	L/B GM-GC	L/B SC-SM	L/B GM	Flat River Terrace on both bank
											R/B SM	R/B SM	R/B SP	R/B SM	
3	Listra Bagar	Bajhang	Suspension	115	Rock and Alluvial Soil	Old debris fan	L/B Dolomite	L/B None	L/B None	L/B None	L/B None	L/B GM-GC	L/B GM	L/B GM-GC	Thin soil cover on L/B rocky slope
							R/B None	R/B None	R/B None	R/B None	R/B GM	R/B GM	R/B GM	R/B GM	
4	Kunalo Gad	Bajura	Suspended	55	Rock, Colluvim and Alluvium	Rock and thin colluvium	L/B Gneiss	L/B None	L/B None	L/B None	L/B GM	L/B GM	L/B GM	-	Thin soil cover on both bank
							R/B Gneiss	R/B None	R/B None	R/B None	R/B GM	R/B GM	R/B GM	-	
5	Samar	Mustang	Suspended	60	Compacted Moraine, huge boulders, pebbles	Colluvium in lower, Rock in middle and moraine in upper	-	-	-	-	L/B GM-GC	L/B GM-GC	L/B GM-GC	-	Deep goerge of Morane deposits, normal fault in R/B
							R/B None	R/B Shale	R/B None	R/B None	R/B CL	R/B CL	R/B None	R/B GM	
6	Lode Ghat	Achham	Suspended	142	Medium grained quartzite	Medium grained quartzite and Alluvium	L/B Quartzite	L/B Quartzite	L/B Quartzite	L/B None	L/B None	L/B None	L/B None	-	Thin cover of silty clay on the surface
							R/B Quartzite	R/B Quartzite	R/B None	R/B None	R/B None	R/B None	R/B GM	-	
7	Puima Gad	Humla	Suspended	60	Dolomite, fluvio-glacial deposit	Alluvium, River terrace	L/B Dolomite	L/B Dolomite	L/B Dolomite	L/B None	L/B None	L/B None	L/B None	L/B ML	Thick fluvio-glacial deposit in top of L/B and Alluvium in R/B
							R/B None	R/B None	R/B None	R/B None	R/B GP-GM	R/B GM-GC	R/B GM-GC	-	
8	Ghatte Gad	Darchula	Suspended	54	Compacted Allivium	Loose Alluvium	L/B Conglomerate	L/B Conglomerate	L/B Conglomerate	L/B None	L/B ML	L/B ML	L/B ML	L/B ML	Conglomerate is moderately weathered
							R/B None	R/B None	R/B None	R/B None	R/B GM	R/B GM	R/B GM	R/B GM	

MA: Main Anchorage DWG: Downstream Windguy UWG: Upstream windguy TA: Tower Anchorage L/B: Left Bank R/B: Right Bank district (Fig. 3). A suspended bridge of span about 100 m was feasible in this site. The left bank of the bridge site consists of rocky slope with thin colluvial soil layer of not more than 1 m (Fig. 4). Loose alluvial deposit of mainly sand, pebble, cobble and boulder outlined by flat cultivated river terrace is noticed in the right bank of the site.

The light gully and sheet erosion is present on the slope. Bed rock found in shallow depth has chance of plane and wedge failure (Fig. 5). But the fracture planes in gneiss are very irregular and discontinuous. All joint sets are discontinuous and inward extension of them is not noticed but care should be taken during excavation of foundation. The rock fall of back slope at right bank is far (100 m) from the site (Fig. 5) which can not create any problems to place the foundation. The general lay out of the bridge is shown in the Fig. 6.

Khaniya Ghat

The proposed Khaniya Ghat bridge site is located at Naglibang VDC at left and Baglung Municipality at right of the Kaligandaki River of the Baglung district. The river at the proposed site was almost straight with sharp bending at about 500 m downstream (Fig. 7). A suspended bridge of span about 120 m was feasible at this site.

The left bank of the selected bridge site has alluvial soil. The bank is followed by flat cultivated alluvial terrace. The alluvial materials on the bank are pebble, cobble with considerable amount of clay and silt. Transverse section of slope is smooth.

Right bank of this site is medium compacted alluvial deposit followed by flat cultivated alluvial terrace. The alluvial materials on the bank are pebble, cobble and boulder of diameter up to 1.5 m diameter with considerable amount of sand and silt. The up-slope, far from foundation site is densely vegetated and slope is moderately steep. Bank height is low and compacted and cemented alluvial deposits are observed parallel to the bank. The soil profile is very clear in the cut out section of the bank at the location of upstream windguy. The alluvial soil of the right bank is pervious and moderately compacted.

The right bank of the selected site has low chance of bank erosion due to the cemented alluvium parallel to the bank although the bank may experience river current strike during monsoon. The foundation site is almost flat and wide enough for suspension bridge. The grain size distribution curves of different bridge sites including the Khaniya Ghat bridge are shown in Fig. 8. The detail layout and cross section map of bridge site is shown in Fig. 9.

Listra Bagar

The Listra Bagar bridge site over the West Seti River interlinks the Malumela and Mori Bagar villages of the Bajhang District. The river course is straight along the stretch of the proposed site. Suspension bridge of span 115 m was feasible in this site.

Fig. 4: Rocky area on the left bank of the Kailashamndu Bridge Site with thin colluvial soil layer

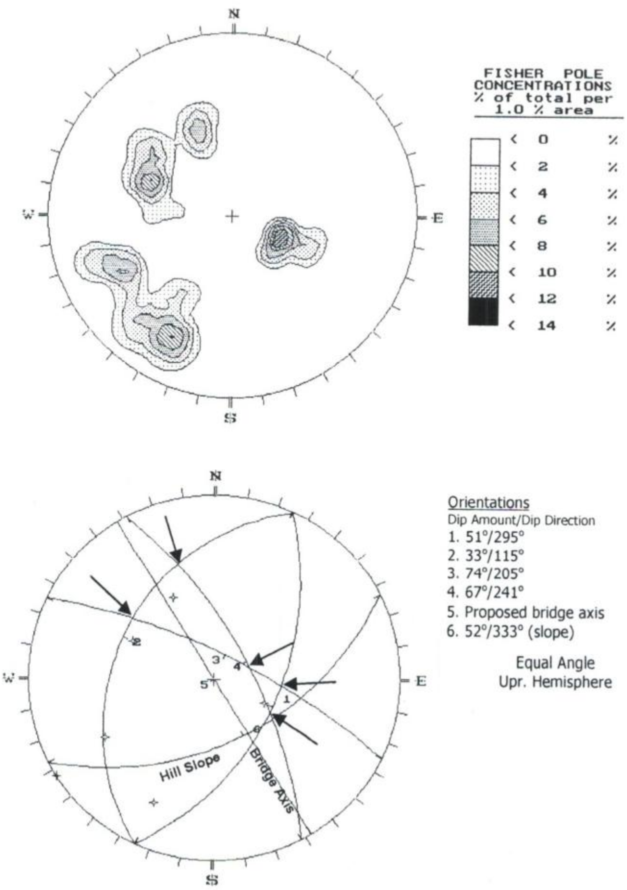

Fig. 5: Bedrock found in shallow depth at left bank of Kailashmandu has possibilities of plane and wedge failure

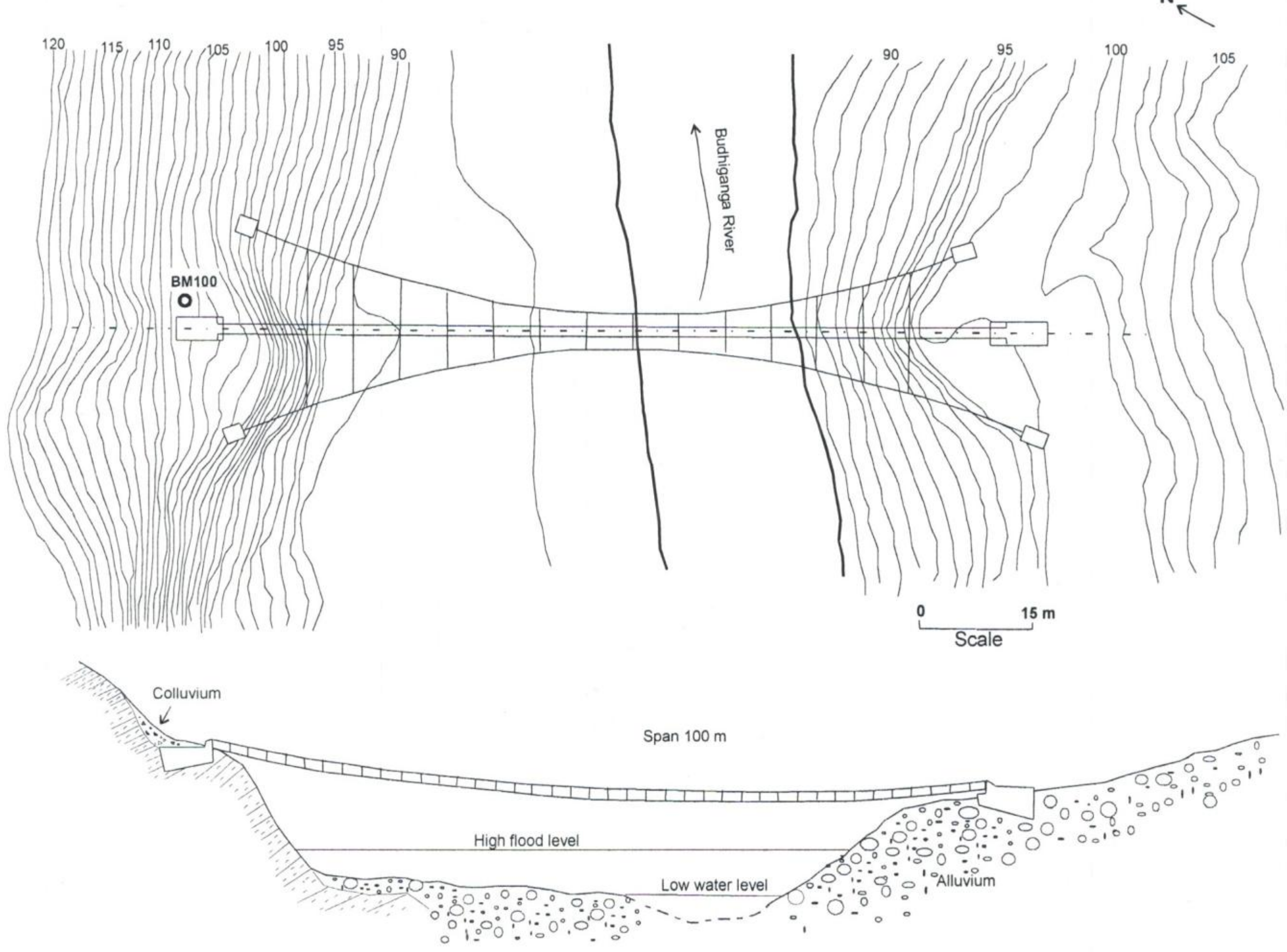

Fig. 6: The general layout map and cross section view of the Kailashmandu Bridge (Modified after HEET 1998).

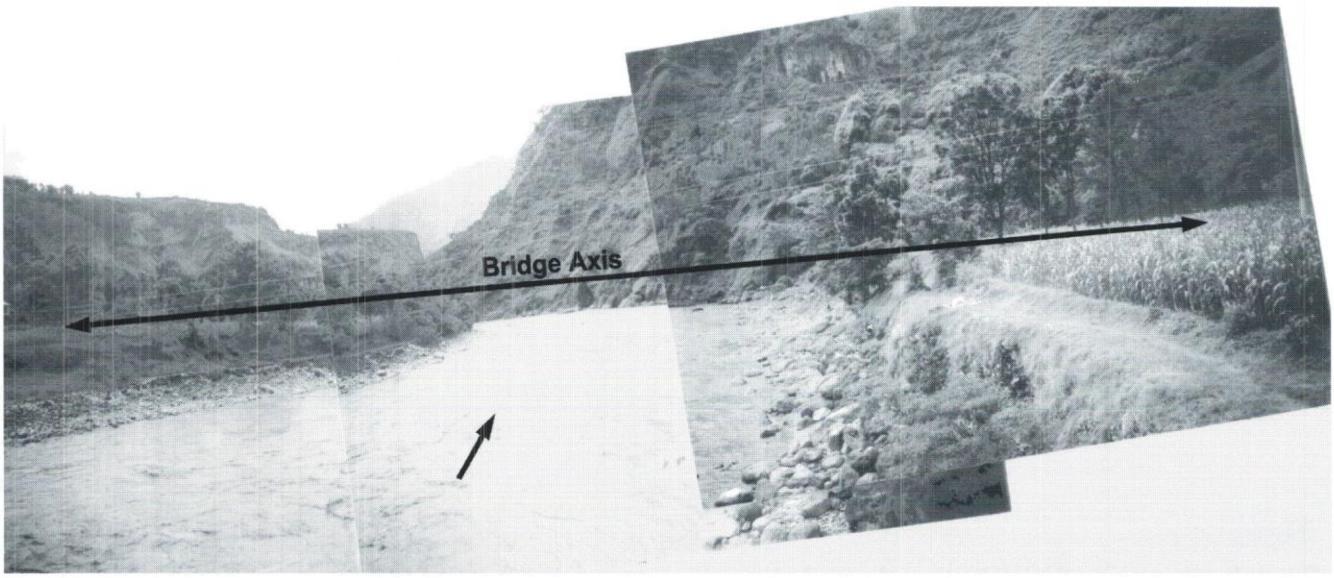

Fig. 7: Down stream view of the Kaligandaki River at the Khaniya Ghat Bridge Site.

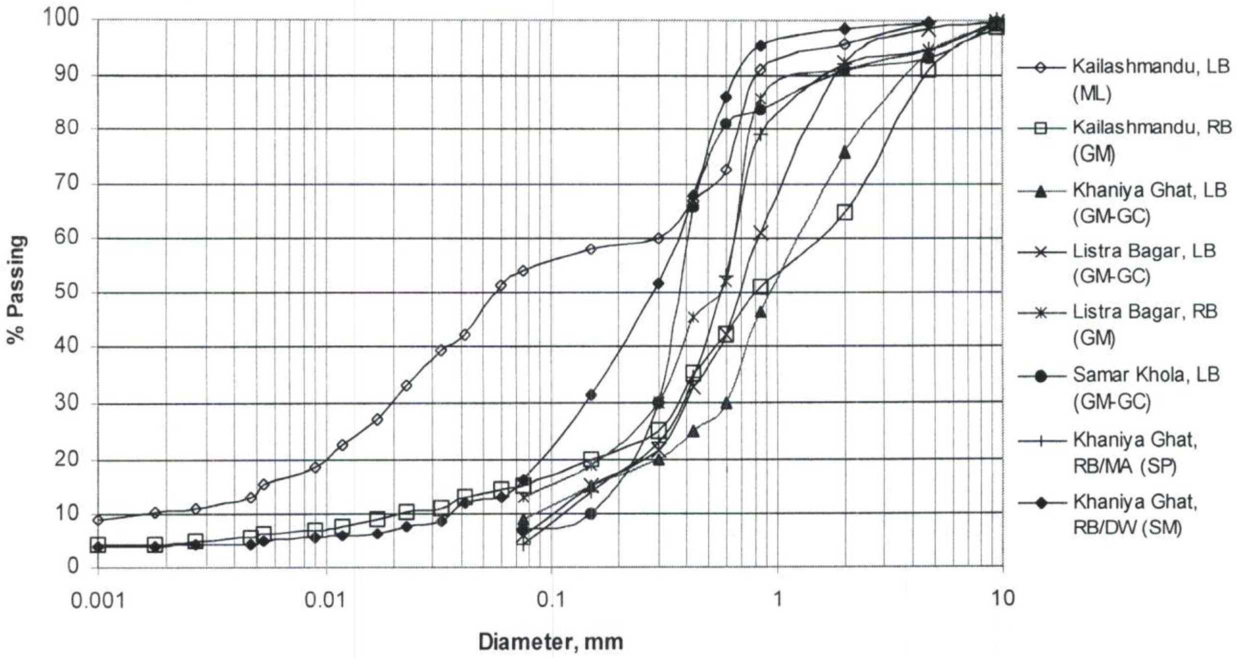

Fig. 8: Grain size distribution curve of soils from different bridge site

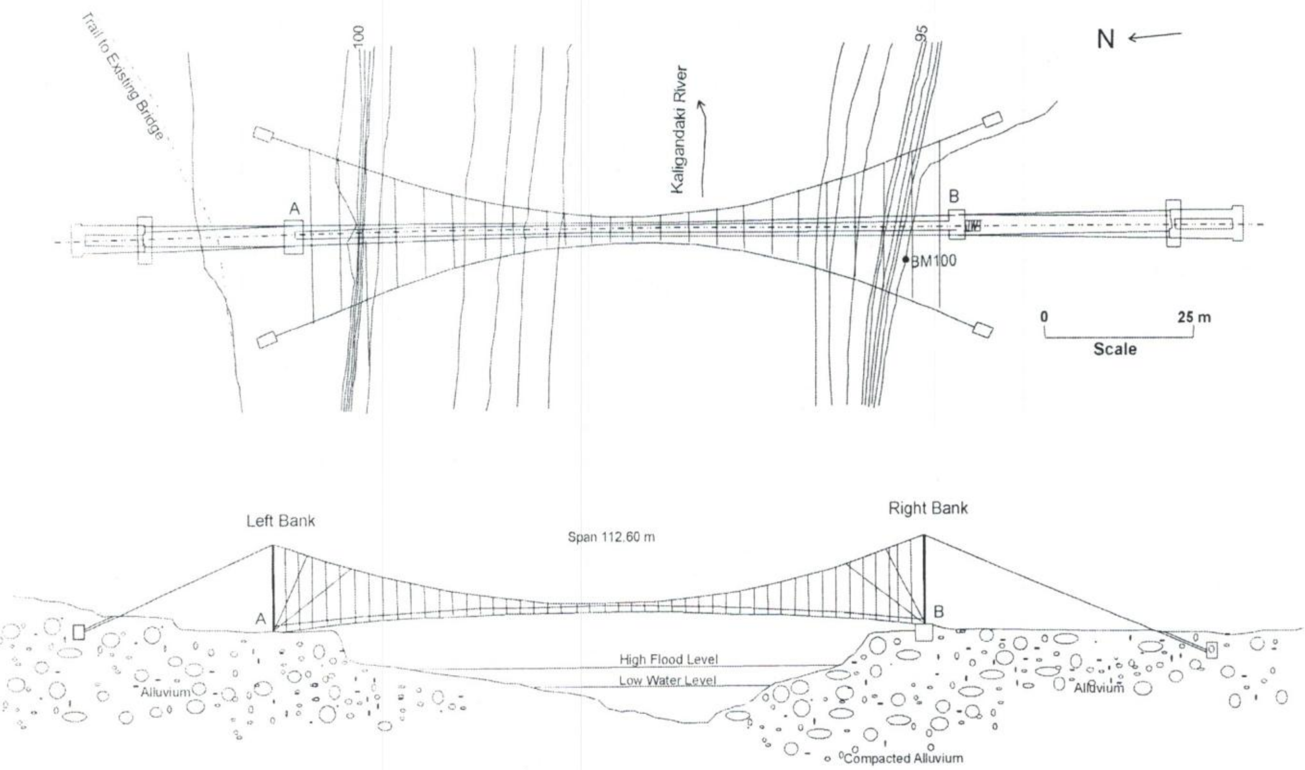

Fig. 9: General map of the Khaniya Ghat Bridge (modified after HEET 1998).

Left bank of the site consists of loose alluvial deposit followed by rocky slope. Bank height of the site is only 3 m and followed by small flat cultivated terrace, behind which rocky slope is present. The rock behind alluvial deposit on the slope is thick to thinly bedded dolomite. Although the rock exposure is forming rugged topography due to surface fracture, the slope is stable due to dip of beds and wedges are opposite to slope (Fig. 10). In this bank, the main cable anchorage must be placed at stable rocky upslope (Fig. 11).

Right bank of this site is an old debris fan. This has medium compacted colluvial soil. Slope is gentle and

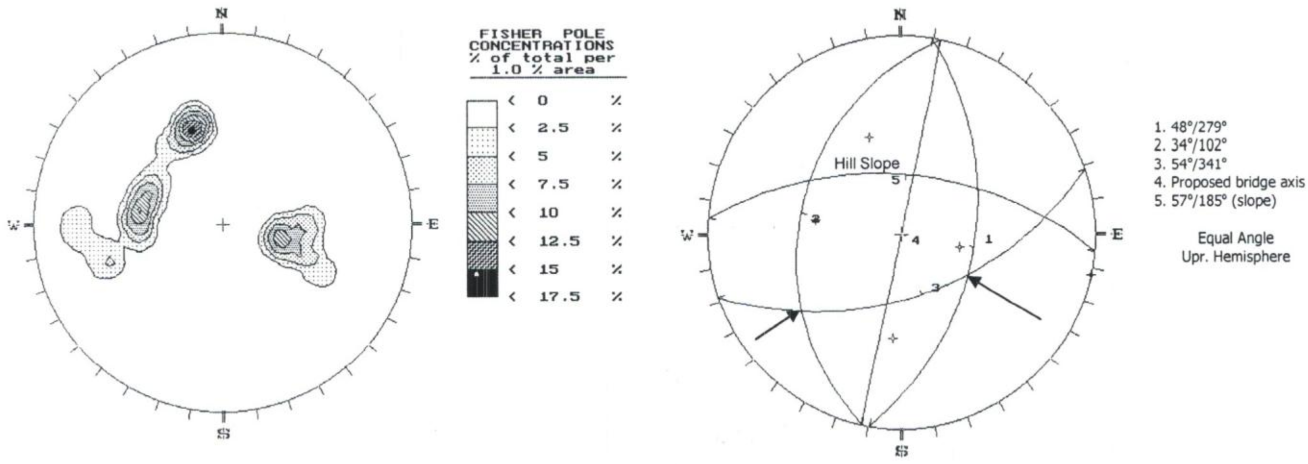

Fig. 10: Joint analysis of rocky upslope of left bank of the Listra Bagar Bridge Site.

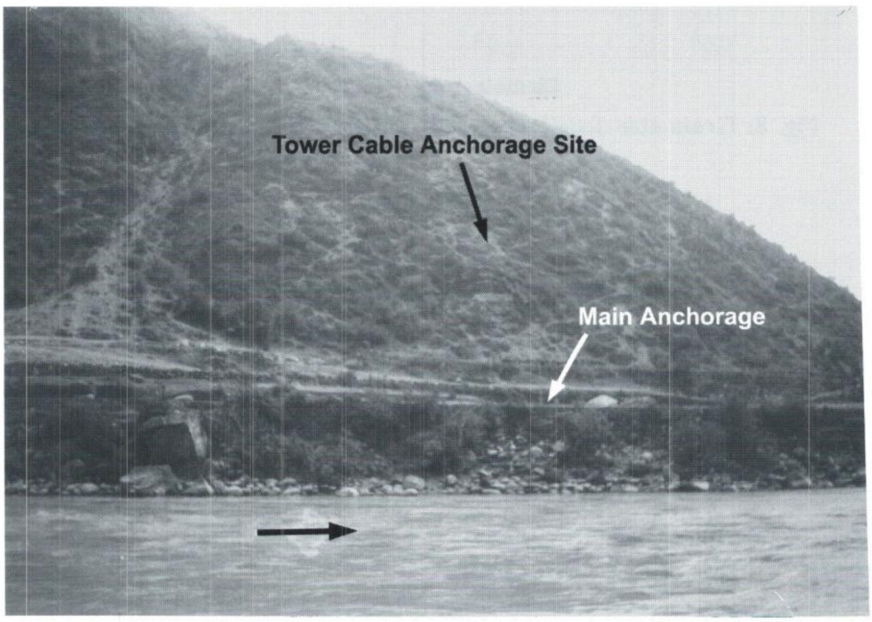

Fig. 11: Tower cable anchorage site of left bank at stable rocky upslope

cultivated bank height is 3 m. The angular pebble with silty clay is the main soil type of the right bank. Four pits had been dug out at the probable locations of main anchorage, tower anchorage, upstream windguy and downstream windguy.

The left bank is very also suitable for bridge site because rocky bank and huge boulders on the upstream are helping to prevent the left bank from the bank erosion. Futhermore, the tower foundation lies on alluvial materials and bank edge has chance of bank erosion during monsoon by surge not by river current. The general layout map and cross section view of the bridge is given in Fig. 12.

Kunalo Gad

The Kunalo Gad Bridge lies over the Kunalo Gad in the west of the Dhamkane Village of Bajura district. Kunalo Gad (river) is a perennial river, a tributary of the Budhi Ganga River, has high gradient and steep river terrace with old glacial deposit along the bank. This river is fordable in all season expect some days of rainy season. In the area, lower level terrace consists of river deposit only whereas upper level terrace consists of river deposit with glacial and fluvio-glacial deposit. The upper terrace of right bank is cultivated and has mainly clay silt with gravel. Coarse-grained banded gneiss and gneissic schist is noticed around the bridge site. Suspended Bridge having span 55 m was feasible in the site.

The left bank consists of concave rocky slope with thin cover of grey silty clay. Upslope is covered by forest. In this bank, main anchorage site can be placed on the bed rock whereas upstream and down stream windguys can be sited on alluvial terrace deposited over the bed rock gneiss. Joints and fractures on gneiss are irregular with opening up to 3 mm. Huge boulders are observed below the thin soil cover.

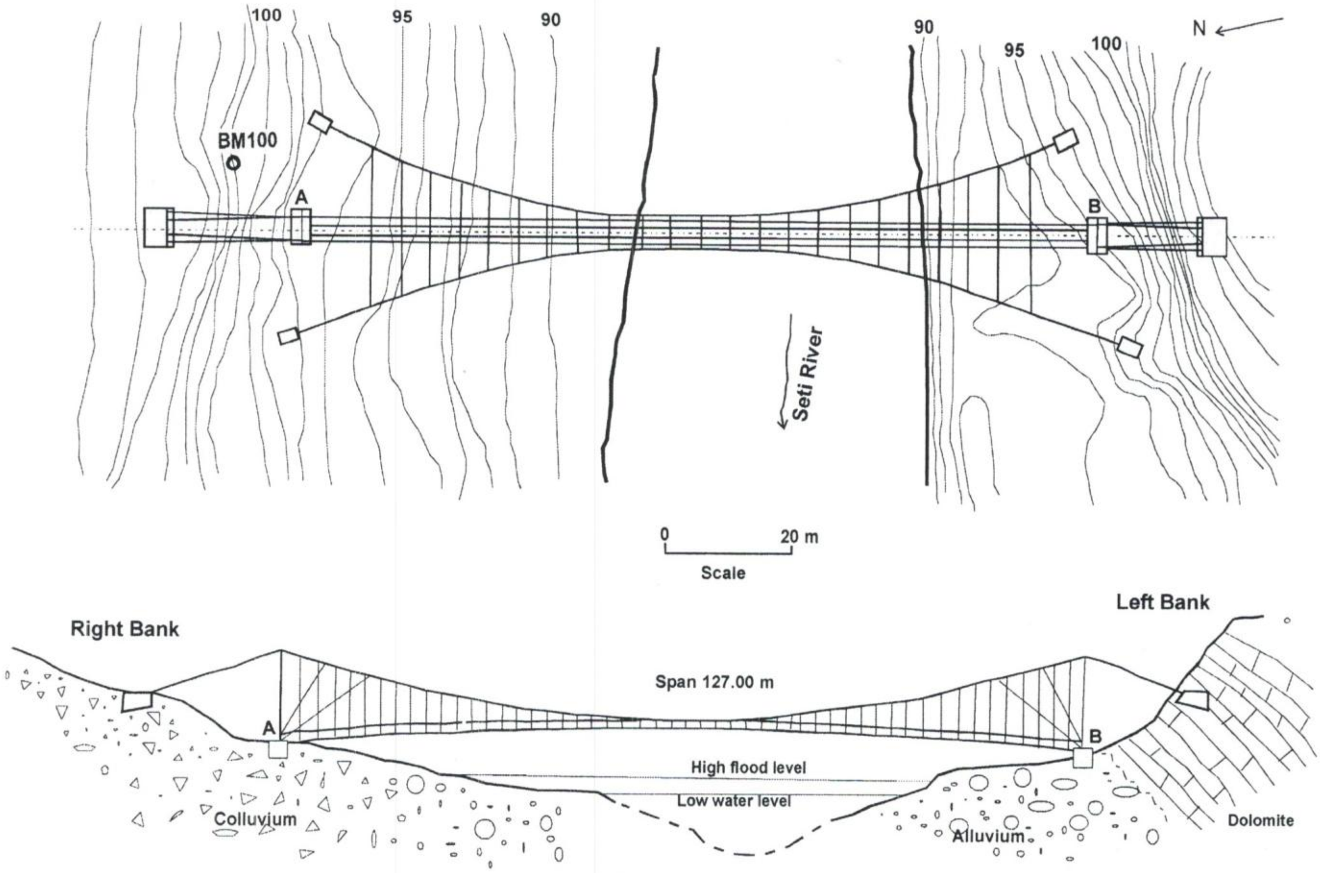

Fig. 12: General layout of the Listra Bagar Bridge with cross section view (modified after HEET 1998)

The right bank is also selected on rocky slope and is also high enough for suspended type of bridge. Bedrock of right bank is also gneiss as in left bank. Joints on rock are generally in three set; parallel to foliation, across to foliation and diagonally to foliation. General layout of the bridge is shown in Fig. 13.

Samar

The proposed Samar bridge site is located at Samar village of Mustang district. The Samar Khola is a tributary of the Kali Gandaki River. The river course is almost straight but river has deep gorge (Fig. 14) with almost vertical bank height (about 80 m). This river is fordable in all season expect some days of rainy season. The suspended bridge of span about 60 m is feasible in this site.

The left bank of the bridge site consists of compacted moraine deposit (Fig. 15). The moraine has pebble and cobble with huge boulders as main composition. This compacted moraine has low chance of dissolution because there is no any water runoff on the slope and bank. The slope is steep, dry and barren. Rill and sheet erosion are possible around main anchorage and uphill of the slope. Cut-out soil profile of this site has morainic soil. Right bank of this site is loose colluvium deposit followed by steep rocky slope. Few vegetation covers is present on the bank. On the upslope, moraine deposit lies unconformably over the bed rock (shale). The moraine is compacted and has huge boulders. So the bank experiences the problem of rock fall.

In the right bank at about 15 m downstream from the main anchorage site, a normal fault is noticed (Fig. 14 and Fig. 16). The hanging wall has brown coloured shale whereas footwall has black carbonaceous shale. The morainic terrace of upslope over the shale is not affected by this fault (Fig. 16) and fault is not active. The main anchorage block can be placed on footwall of this normal fault.

Lode Ghat

The proposed Lode Ghat suspended bridge site is located at Raniban village of the Aachham District. It lies on very important trail to Achham, Kalikot, Jumla, Bajura, Mugu and Humla. Porters of these districts carry daily use goods from Surkhet and Chisapani through this route. The terrain of Lode Gad area is rugged and exhibits diverse geomorphic features such as colluvial deposit, residual soils, river terraces, recent river beds, river fan with small gully erosion and bare rock cliff. River terrace and recent river beds are noticed along the both bank of the river around the selected bridge site. Quartzite is the main rock type of the bridge site. The rock is moderately weathered.

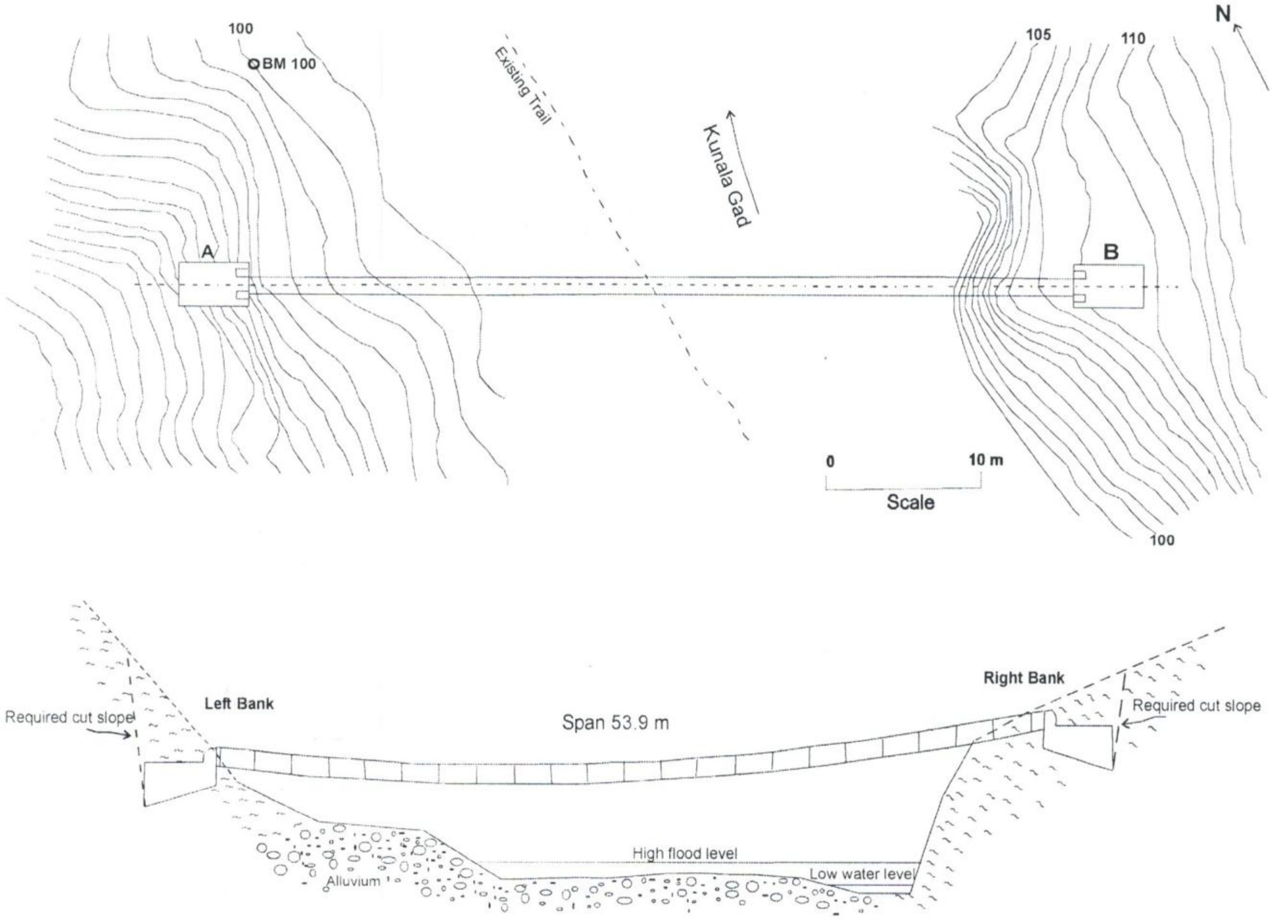

Fig. 13: General layout of the Kunalo Gad Bridge with cross section view (modified after NEC 1997).

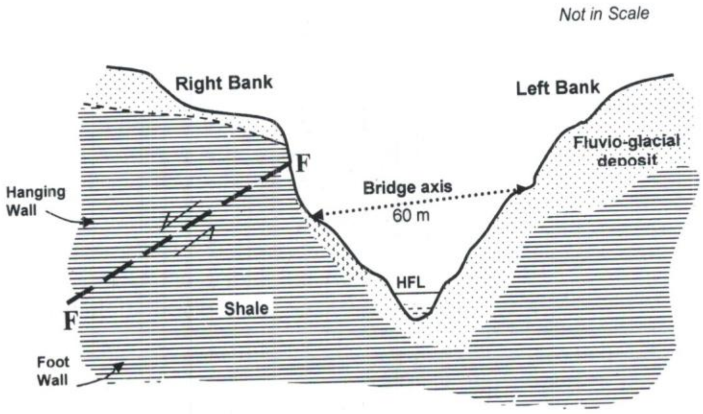

Fig. 14: Schematic cross section of the Samar Bridge Site.

The Lode Gad is a tributary of the Karnali River. This river is fordable in all season expect some days of rainy season. It flows NW to SE forming a wide valley in the confluence.

The left bank of selected bridge site has 8 m high rocky bank consists of light coloured medium grained quartzite with very thin layers of grey phyllite. Upslope from the bank cliff is very gentle ridge (Fig. 17) rising to NW direction where placement of main anchorage is very suitable. The closely spaced joints and fracture are in irregular pattern and has opening up to 4 mm. Very thin cover of silty clay is also noticed on the surface. In situ angular boulders of bedrock are also seen on the surface of rising ridge. Stereographic projection of joints shows that central wedges dip rather low than friction angle. One central wedge 103°/ 28° could be very risky from stability point (Fig. 18 and 19).

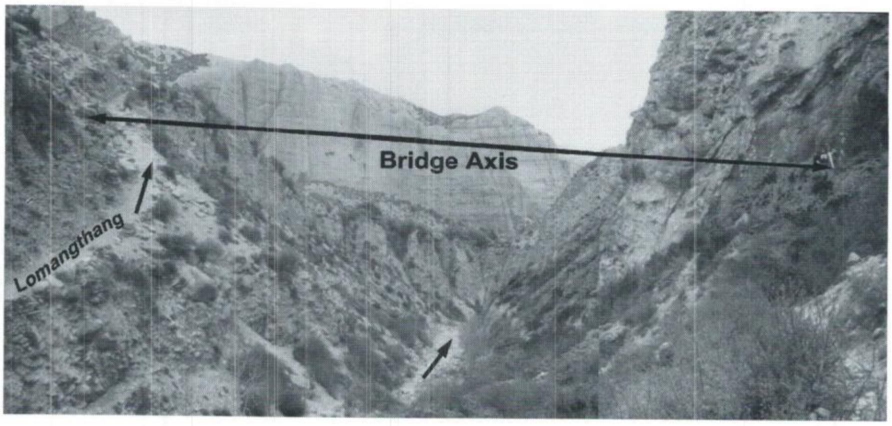

Fig. 15: Down stream view of the Samar Khola

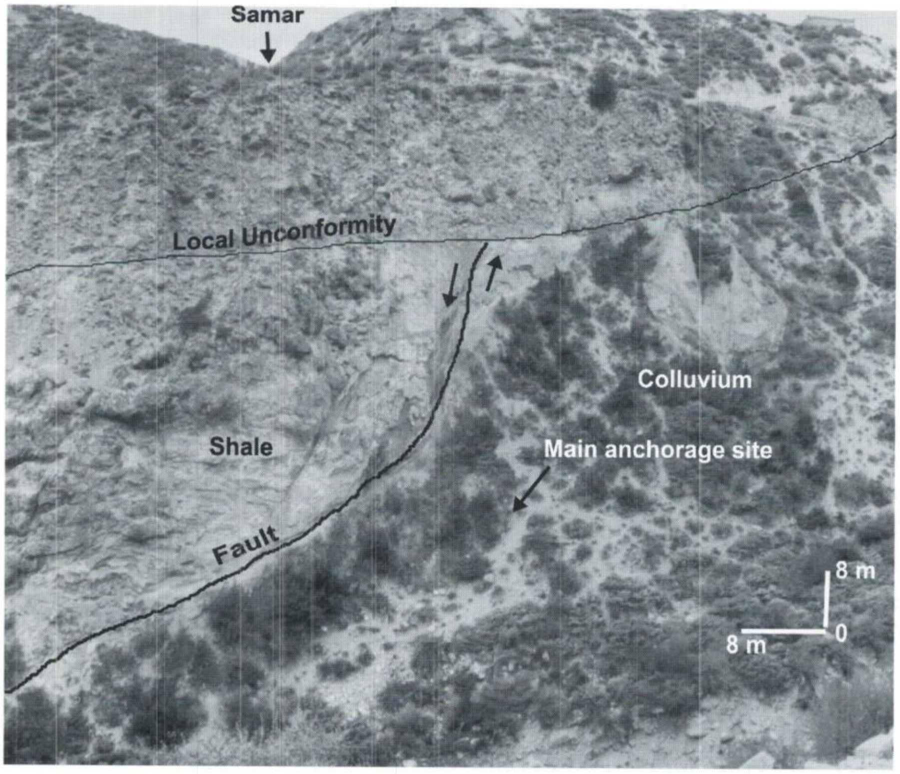

Fig. 16: Normal fault at right bank of the Samar Bridge

The right bank is characterised by a dome shaped peak and also has same quartzite as in the left bank. The rocky dome shaped peak is 14 m high from river surface and in situ angular boulders are noticed on the surfaces. In this bank, the downstream windguy and main anchorage can be placed on the rock where as upstream windguy should be placed on alluvial terrace of the Lode Gad.

Puima Gad

The Puima Gad Bridge lies over the Puima Gad which interlinks the main trail from Kalikot and Bajura to Simikot of the Humla district. The site is accessible by foot trails from the Bajura district which runs along the right bank of the Karnali River. The Puima Gad has high gradient, originates from north western part and terminates to the Karnali River at the Puima Ghat. This river is fordable in all season expect some days of rainy season.

The left bank consists of rocky slope of laminated dolomite. It consists of light vegetation on the slope and upslope has fluvio-glacial deposits. Closely spaced joints are present on bedding surface. The rock outcrops are well exposed on the proposed trail bridge site. There is a problem of plane failure is seen in the site but aspect of slope does not align with trend of joint plane.

The Right Bank of bridge site consists of alluvial terrace of the Puima Gad (Fig. 20). The terrace is cultivated and has huge boulders having diameter up to 4.5 m.

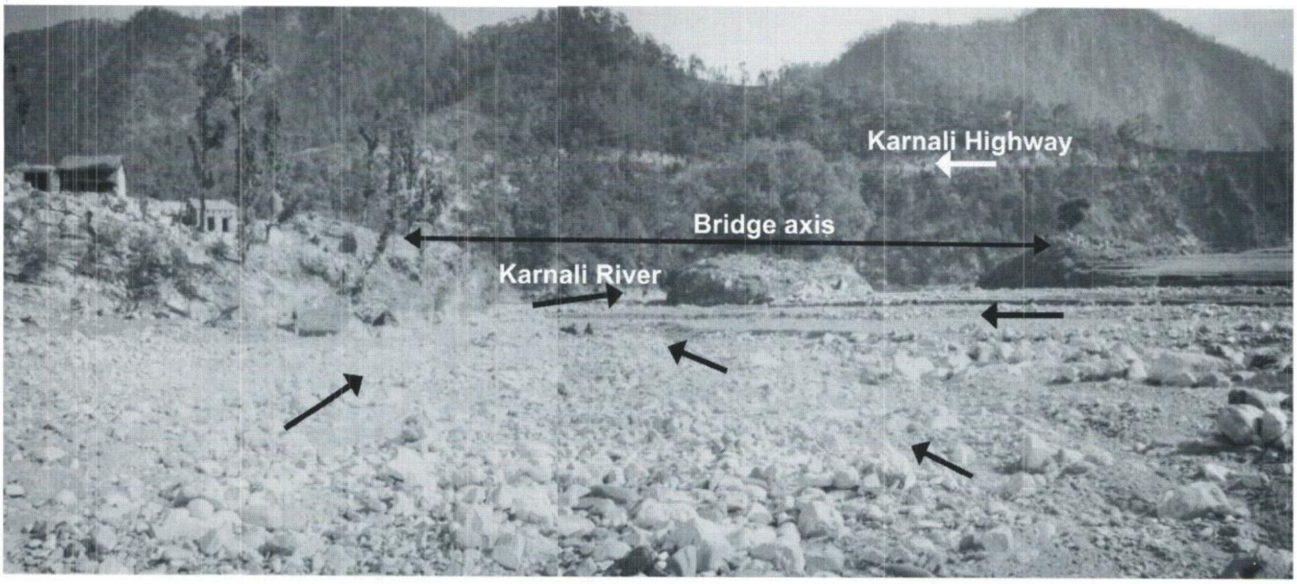

Fig. 17: Downstream view of the Lode Gad

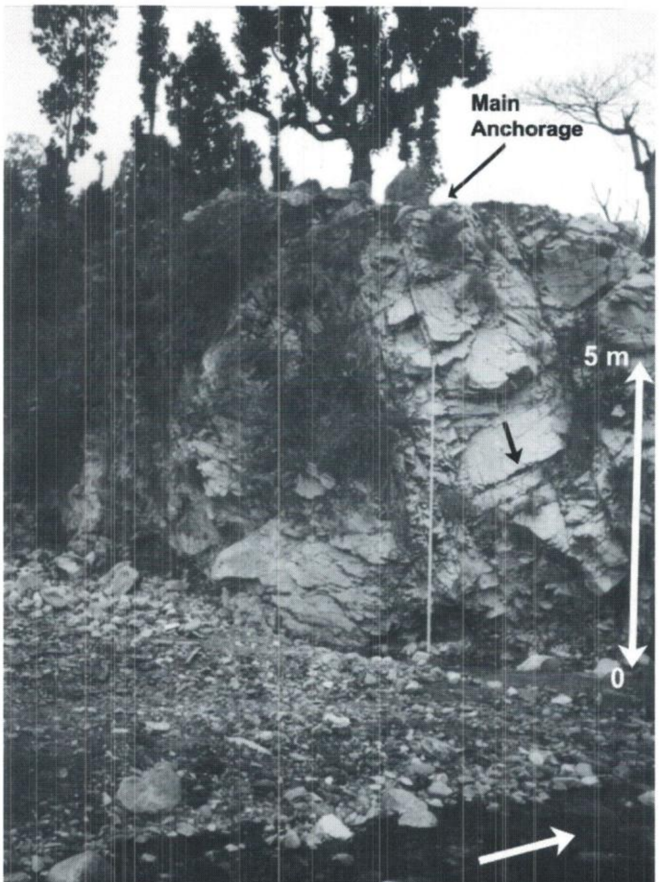

Fig. 18: Left bank of the Lode Gad Bridge site

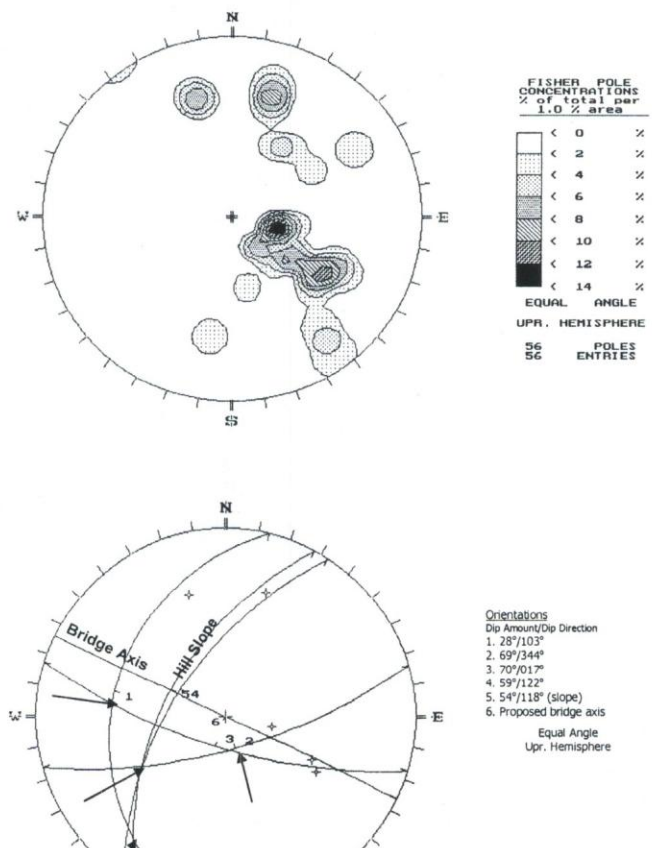

Fig. 19: Stereographic projection of rock fractures at left bank of the Lode Gad

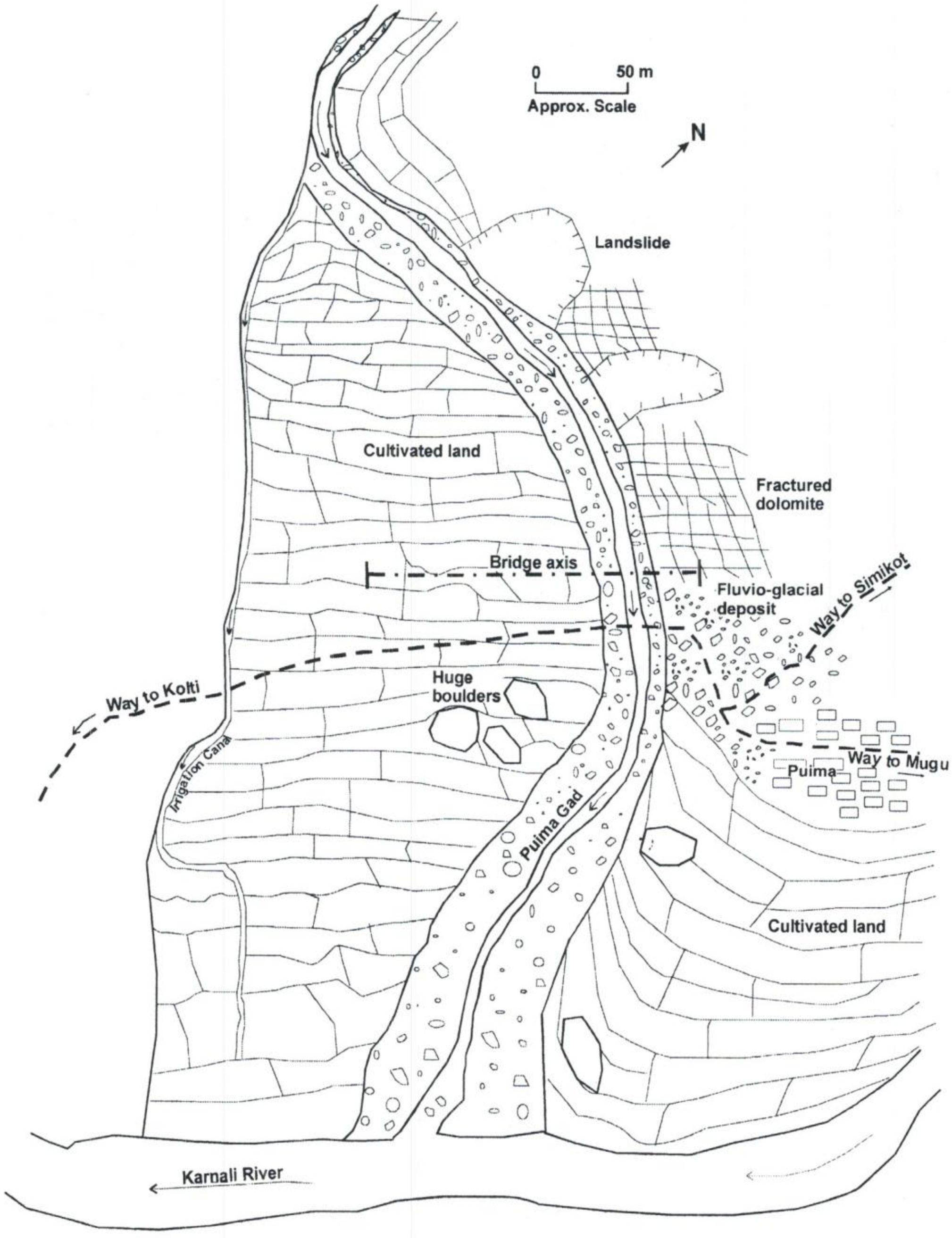

Fig. 20: Sketch map of the Puima Gad Bridge Site

Ghatte Gad

The proposed Ghatte Gad bridge site is located at Latinath village of Darchula district. It lies on the main trail from Gokuleswar to Ghusu via Tapoban. The Ghatte Gad is a tributary of the Chamaliya River. This rivulet is turbulent as it flows in a steeper gradient. The river course is more or less straight. This river is fordable in all season expect some days of rainy season.

The left bank of the bridge site consists of cemented alluvial deposit (Fig. 21). This compacted conglomerate has low chance of dissolution because there is no any water runoff on the slope and bank. The bank is almost vertical and bank height is about 7 m. The upper soil layer of the site consists of weathered conglomerate. Right bank of this site is loose alluvial deposit followed by flat cultivated alluvial terrace (Fig. 22).

DISCUSSION AND CONCLUSIONS

This study was concurrently done with the procedure suggested by SBD manual. In this study, the experience

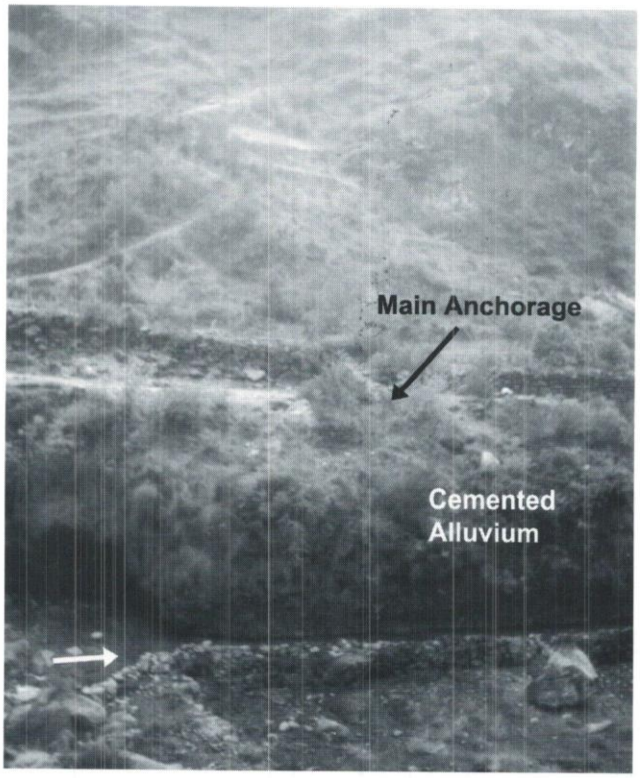

Fig. 21: Left bank of the Ghatte Gad Bridge Site

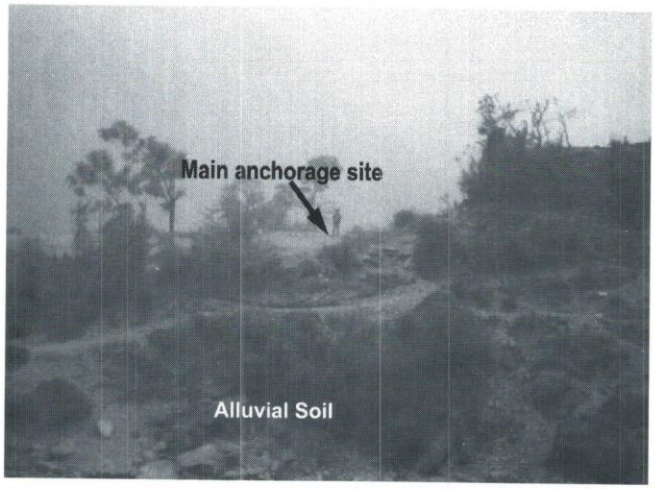

Fig. 22: Right bank of the Ghatte Gad

and difficulties faced during the survey as per SBD manual were carefully analysed by present methods of engineering geology. As a result, very ample consequences were felt after the studies, which are discussed below.

Limited soil investigation during field investigation as per SBD manuals could not give the exact soil classification. So some laboratory test was performed in the laboratory to classify the soil. As a result, exact values of design parameters were used during design by the help of SBD MANUAL. The proper soil classification is very necessary in Trail Bridge because all the design parameters of soil are fixed according to range value of soil given in the SBD MANUAL and SBD Course (SBD 1993). Proper soil classification also helps to reduce the cost of bridge construction because the SBD MANUAL suggest following basic bearing capacity formula of Terzaghi and Peck (1967) for ground shear failure.

$$Q = B\left[c.N_c + (\gamma t + q)N_q + \frac{1}{2}B\gamma N_\gamma\right]$$

In the given equation, B, c and γ are width of foundation, cohesion, and unit weight of the material and value of N_c, N_q, and $N\gamma$, depend on friction angle of soil (Terzaghi and Peck 1967). For 25° friction angle, value of N_q is 10.6 and for 35° friction angle it is 33.3. So sincere soil classification is very important for bearing capacity calculation. Similarly somebody prefers to use of range value suggested by SBD MANUAL for the friction angle and bearing capacity of soil, it is better to calculate main parameter such as grain size of the soil by the help of laboratory test to get good result.

During this study, in right bank of the Kailashmandu Bridge, the main anchorage area was selected in lower terrace of the Budhiganga River. The site was selected as per the villagers need. The SBD MANUAL also permits that for Trail Bridge, the site can be selected in loose alluvial deposit. In fact the tolerance flood may erode the loose alluvial deposit which could not be notified in field as per checklist. As a result, the heavy flood immediate after the field study washed the whole anchorage area of right bank and new anchorage site was fixed behind the previous anchorage during construction time.

Similarly, representing discontinuities were missed in the Lode Gad due to the numbers of fractures which could not consider in checklist, because the rock discontinuities analysis method is simple in the SBD MANUAL and only single data measurement and analysis is enough for discontinuities study. But, for this investigation work, the joint interpretation was performed as per statistical data analysis and the missed discontinuities were included in the study.

From this present study work following conclusions are aligned.

- Although the Trail Bridge construction intends to give priority to the simple and basic rules of field investigation, it is better to give full attention in rock slope stability analysis and proper soil test in laboratory. The parameters selected in design stage with limited field observation as per SBD manual and checklist with out any laboratory testing are sometimes become unfit with some rock and soil due to weathering grade, lateral variation, discontinuities surface characteristics and numbers of small scale faulting and folding structures. These problems have very significance role in our Himalaya.

- Soil test in laboratory, can help to set the real value of design parameters such as friction angle (ϕ) and unit weight (γ) rather than rage value suggested buy SBD manuals, which finally affect the cost of the bridge construction as happened in bridge Kunala Gad, Ghatte Gad and Khaniya Ghat.
- From the joint analysis of the Lode Gad, it was noticed that the measurement of single data of different joint sets and directly analyzed for slope failure was vague. So, it is better to analyze the distribution of joints on the slope by the help of analysis of joint distribution.
- From the experiences of Kailashmandu, in large river of Nepal, it is better to select bridge site in rocky terrain as far as possible, which prevent the bridge from bank erosion.
- It is better to study the detail slope morphology of the anchorage site rather than the area around 50 m.
- The geological problem could not verify during field observation due to out of scope of the SBD MANUAL such as local scale fault noticed as in the Samar Bridge site, sometime can create astonishing problems on the Trail Bridge after construction.
- The site such as in Puima where it is possibility of strike of river on the bank, it is necessary to place the block far behind the riverbank.
- From experience of Kailashmandu and Puima Gad, it is necessary to consider firstly geology and river morphology rather than social benefit of the area.
- The methods mentioned in SBD Manuals for geological investigation sometimes found to be unfit for the bridge site lies in Midlands or Lesser Himalayas. Same thing was happened for the Higher Himalayas and Trans Himalayas as in Ghatte Gad, Samar, and Kunalo Gad. Thus it is seriously felt that during the preparation of manuals for geological and geomorphological survey to work in various part of the Himalaya, care should be given to the physiographic division of Himalaya including different geomorphic provinces.

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