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Seismic Refraction Survey for Rolep Hydroelectric Power Project, Sikkim

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ABSTRACT

Rolep hydropower project is proposed to be constructed in the hilly terrain of east Sikkim at the downstream of confluence of the rivers Rangpo and Nathung Chu near Rolep village. The terrain represents mainly granitiferous quartz-biotite gneiss belonging to Darjeeling Group of Precambrian age. The area falls under the zone IV of seismic zoning map and experiences frequent shallow focus micro-earthquakes. The area had undergone tectonic disturbance resulting in differential weathering give rise to varied type of geotechnical conditions. Seismic refraction survey was carried out to find out the bedrock profile and to infer its quality, the status of the overburden as well as the structural features such as, micro faults/shear zones and other tectonically disturbed zones, which may affect the stability of the hydraulic structures. Twenty-five continuous seismic refraction traverses of varying lengths were run to cover the area where the important civil structures are to be located.

The results of the refraction survey revealed a three layer geo-seismic section consisting of loose overburden wave velocity between 200 and 500 m/sec followed by normal to compact and compact overburden (500 - 1700 m/sec). This overburden overlies the weathered to good quality bedrock (2000 - 4400 m/sec).

The depth to the bedrock was evaluated to be the deepest i.e. 40 m below ground level in the surge shaft area and the same occurred at shallow depths at dam axis i.e., from 6-17 m below ground level. Along the Head Race Tunnel (HRT) alignment, which is passing through surge shaft area the bedrock velocity was in the range of 2600 – 3400 m/sec suggesting the weathered grade rock. In the powerhouse area foundation grade gneissic rock was found with the velocity range of 2000 – 4400 m/sec. No major shear zones/weak zones were found in the area covered by seismic refraction method. Seismic results are in accordance with the borehole data.

INTRODUCTION

Rolep Hydroelectric Project envisages construction of a dam across river Rangpo in the hilly terrain, east of Sikkim. The site is located north of Rolep village (Lat. 27^0 16′ 00″ and Long. 88^0 43′00″) downstream of the confluence of rivers Rangpo Chu and Nathung Chu. From the proposed intake the water will be diverted through a 4 km long HRT to a 450 m long Penstock with a surge shaft in between and ultimately to a surface Power-house to be located at the left bank of Rangpo river, west of Lamaten village (Fig.1). The project will generate 30 MW of power by utilizing 350m head. On the abutment an underground desilting site is proposed.

Sikkim is a part of active Himalyan Seismic Belt and had been rocked by earth tremors several times in the past. The area falls in Zone IV of Seismic Zoning map of India (Mishra & BasuRoy 2001). According to them, the area also records a large number of shallow focus micro-earthquakes. These are mainly generated by the E-W trending Main Boundary Fault located south of the project area. Tectonic lineaments present in the area under investigation are shown in Fig.2. The map shows number of lineaments present in the area, which may have direct affect on the hydraulic structures of the project. Therefore, there is requirement for the geophysical mapping of the area for its minor tectonic disturbances and delineation of bedrock configuration.

For the design of foundation of the proposed hydraulic structures, information regarding the subsurface formations is essential. The information obtained by geotechnical tests or by drilling borehole is quite limited and is mainly confined to the particular location of investigation. As such, the data cannot be extended to the larger sections to estimate the rock topography. The continuous subsurface strata information could however, be obtained by interpolating on the basis of results of larger area sampling subsurface investigations i.e., by geophysical methods.

GEOMORPHOLOGIC SET-UP

High mountains and narrow valleys belonging to Middle Himalayas characterize the project site. The mountain ranges in the area are generally trending NE-SW. The Rangpo River, originating in the glacial/ permafrost region of extreme east, near China-Sikkim

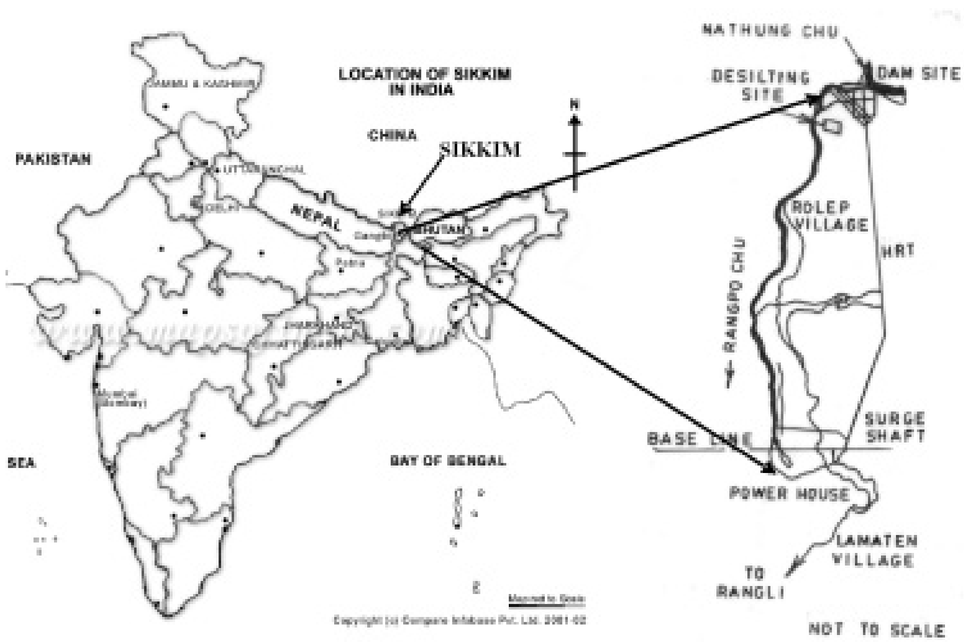

Figure 1(a): Key map.

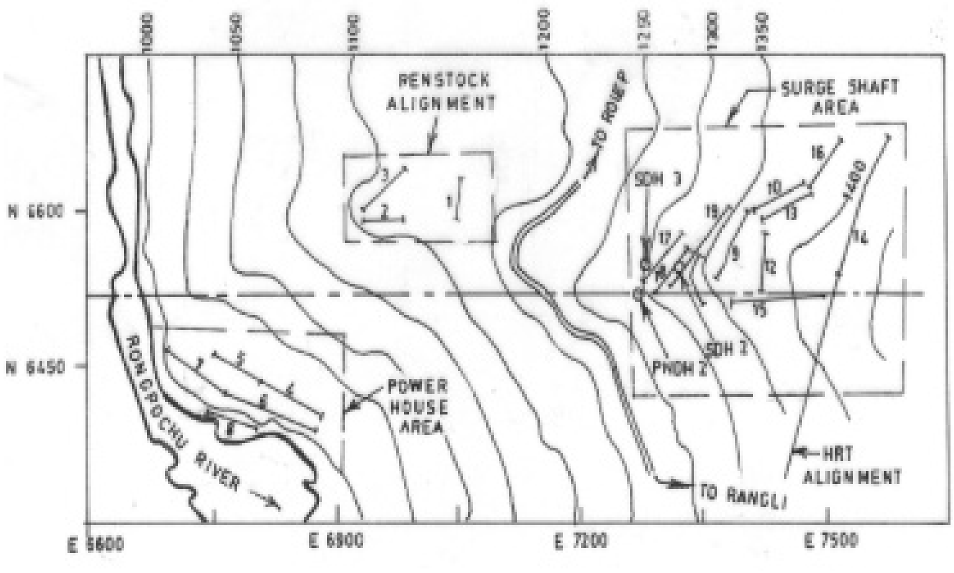

Figure 1(b). Powerhouse and surge shaft area.

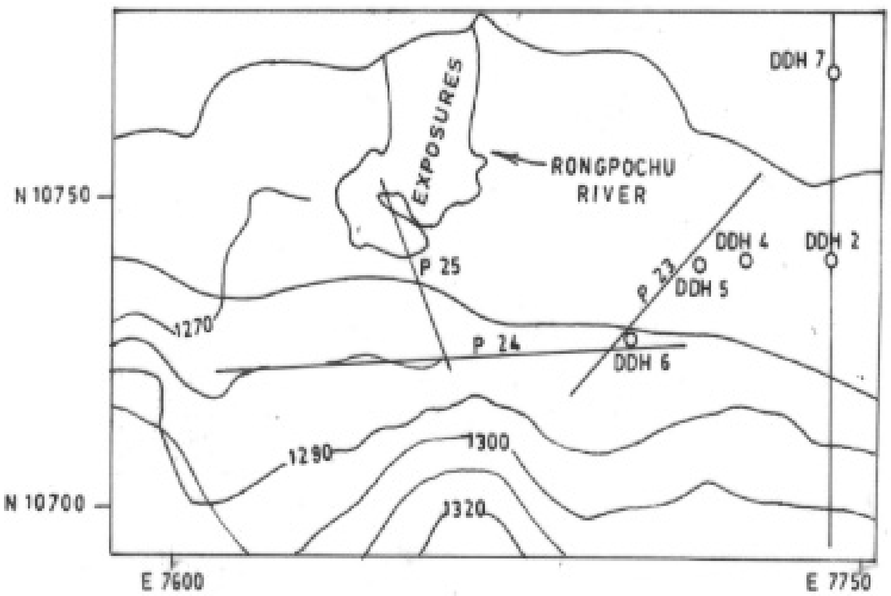

Figure 1(c). Dam site area.

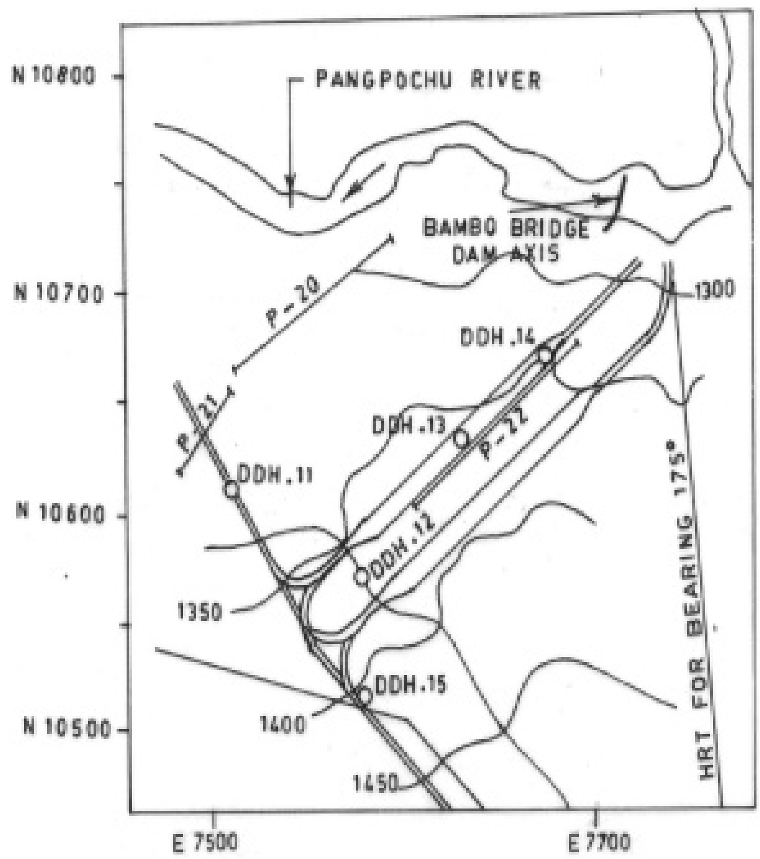

Figure 1(d). Desilting area.

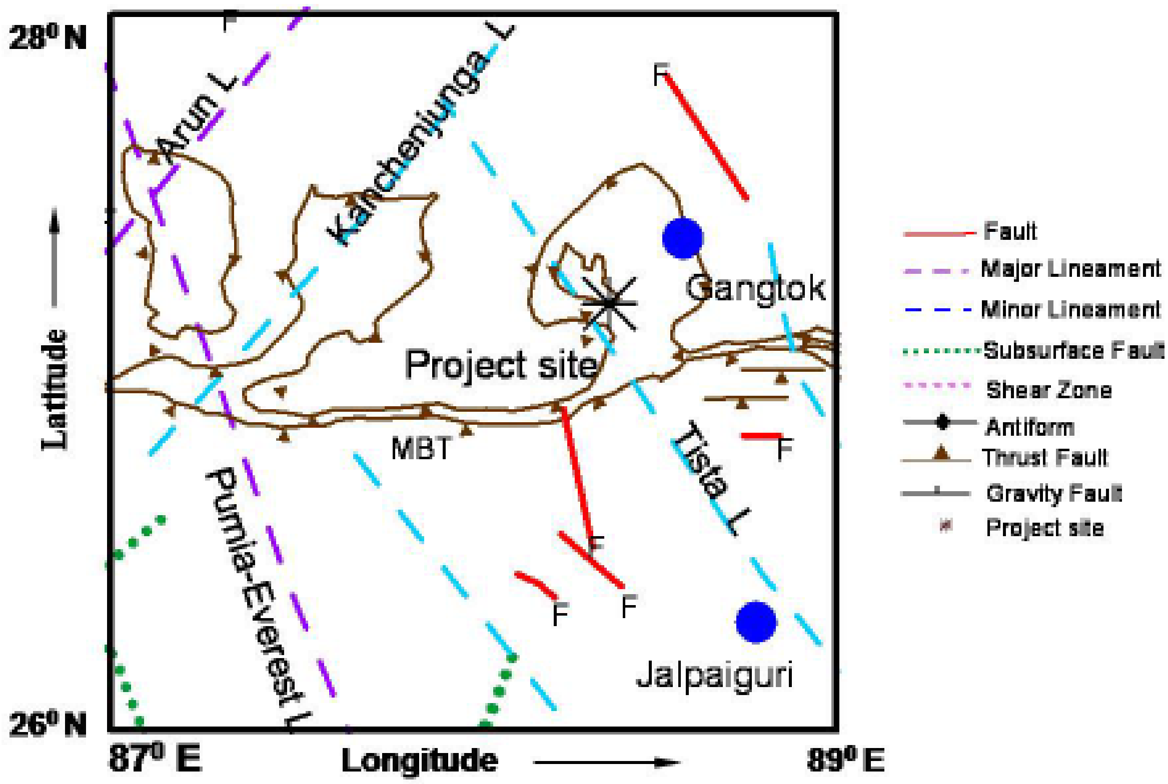

Figure 2. Tectonic map of the surroundings of project area.

border along with its tributaries forms the main drainage in the area. Nathang-Chu, a major tributary meets the Rangpo River at right angles, just upstream of the proposed dam site, thereby giving an indication that the rivers are structurally controlled. The river flow up to the intake is characterized by rugged topography, with development of gorges, steep escarpment and asymmetrical valleys. Asymmetrical terraces characterize the downstream. Slope instability is characterized by rock fall and rock-cum-debris slides due to erosion. The location of the proposed desilting chamber and the storage tank is in close proximity to one such terrace.

GEOLOGICAL OBSERVATIONS

This area had undergone tectonic disturbances resulting in differential weathering. The terrain represents mainly graniticferous quartz-biotite gneiss belonging to Darjeeling group of Precambrian age. The general strike of the foliation varies from N 40^0 E – S 40^0 W to N 70^0 E – S 70^0 W and is dipping 25^0 to 50^0 in South Easterly direction. Slope instability is characterized by rock fall and rock-cum-debris slides. Slope wash materials mainly cover the surface. Old and recent slides are common in the area and have been caused either by toe erosion high discharge or owing to steep slopes and presence of faults/shears. Following geological observations were made at the sites where the proposed structures are to be located.

At the dam site, the maximum width of the riverbed is about 30m. Competent and massive graniticferous quartz–biotite gneiss is exposed in the riverbed at about 135 m upstream as well as 50 m downstream of the proposed dam axis. Rock is also exposed on both the abutments along the dam axis. Since, gneissic rock is present on both the banks as well as in the riverbed, both upstream and downstream of the axis, it was anticipated that the rock would be available along the axis. Investigations were needed to confirm the bedrock profile.

The HRT which is 4 Km long will be below the high hills at RL 1280m and RL 1310m. Maximum elevation above HRT will be 500m. On geomorphic consideration, the HRT will cross 4 major tributaries of river Rangpo. Therefore, the surface above the HRT is required to be explored along the tunnel alignment.

On the desilting basin area, old slide debris is present. The depth of bedrock below these slides will have the key role in the placement of the desilting basin.

The surge shaft site is covered by old-debris and gneissic rock is expected at reasonable depth. However, investigation has to be done to decipher the rock-mass condition along the proposed surge shaft. The penstock alignment is proposed in the area where gneissic rock is either exposed or available under thin slope wash material. Investigations are required to confirm the same.

The powerhouse site is situated on the left bank of Rangpo River. Three steep terraces are present here, out of which the lower terrace is represented by a 3m to 4m high rocky escarpment. Hence, foundation grade gneissic rock was expected at shallow depth. At the uppermost and middle terrace level the depth of the bedrock has to be ascertained. In view of the above, geophysical investigation, consisting of seismic refraction method was carried out at proposed sites for various structures to reduce the drilling operation as well as to get additional data so that a realistic and bankable Detailed Project Report (DPR) can be prepared and minimum geological surprises are encountered during the execution of the project.

SEISMIC REFRACTION SURVEY

The shallow refraction survey is considered to be one of the most effective geophysical methods, which can be applied for investigating the sites for dams and other hydraulic structures and for mapping the landslides in the river valley projects. The main targets of the method are determination of status of the overburden, depth to the bedrock and its quality, the lateral and vertical changes in lithology, and investigate the structural features such as, micro faults/shear zones and other tectonically disturbed zones, which affect the stability of the structure. Many researchers have used this technique to characterize the foundation sites, assess the necessary parameters for sitting of structures (Sjogren & Sandberg 1979; Dutta 1984; Mohamed, 1993; El Behiry et al., 1994; Marzouk, 1995). Savich et al., (1983) presented the use of seismic refraction method in the study of properties and state of natural rock mass at dam site. Sudhindra et al., (1989) and Verghese et al., (1991) used seismic refraction method in characterizing overburden and bedrock and mapping tectonically disturbed zones for the Tehri dam in India. Moulina & Lavrova (1986) described characterization of rock mass of the foundation of hydraulic structures by using seismic refraction method. Louis et al., (1995) found p–wave velocities of rockmass and its elastic properties by seismic refraction and tomography surveys at the Platanovrissi dam site in the northern Greece. Ramteke et al., (2006) used mainly seismic refraction method to assess the quality of strata and delineate bedrock profile at barrage site for Lata-Tapovan project, India. In the present investigations seismic refraction survey was used to delineate the depth to the bedrock, map the overlying layers and other structural disturbances, if any.

DATA COLLECTION AND INTERPRETATION

The refraction survey was carried out at the locations where the hydraulic structures have to be sited to delineate bedrock topography and other subsurface weak zones, if any. In order to cover all the sites, twenty-five seismic traverses were run (Fig.1). Area wise seismic traverses are: Penstock - 1 to 3, Powerhouse - 4 to 8, Surge shaft - 9 to 19, Desilting 20 to 22 and Dam site 23 to 25. The traverses were taken based on requirement of subsurface information and availability of the space to run the profiles.

The seismic refraction investigation was performed using EG&G 12-channel Signal Enhancement Seismograph. The response of the site materials was recorded by vertical geophones arranged in traverses. The seismic traverses were conducted mainly along footpath with 12 geophones planted on the ground surface at convenient intervals in straight lines (Fig.1). The length of each traverse varied from 50m to 110m. Frequent curving of footpaths and insufficient distances for shot points was a limitation for the length of the traverse. Detonation of explosives buried in shallow holes of 1m to 1.5m depths provided the necessary seismic energy. Explosives were detonated at the end and in the middle of the each traverse. The offset shots were fired at both the ends of the traverse. The offset shots at both ends were taken at distances approximately equal to the length of the traverse or four to five times the expected depth of bedrock which ever was more. This resulted in a forward and reverse propagation of seismic energy. Travel time curves obtained from this recording were processed by the reciprocal method (Hawkins 1961) thus enabling the determination of the seismic velocities and the depths to the refracting interfaces. Using these results geo-seismic sections along all the traverses were generated.

Table 1. Results of seismic refraction survey.

Site → (RL, m) / Geotechnical conditions ↓		Surgeshaft (1300-1450)		Desilting (1300-1400)		Dam axis (1270-1290)		Penstock (1100-1200)		Powerhouse (975-1025)		Average	
		Layer Velocities (p - wave) and Thickness											
		V (km/s)	T (m)	V (km/s)	T (m)	V (km/s)	T (m)	V (km/s)	T (m)	V (km/s)	T (m)	V (km/s)	T (m)
Type - I	Loose overburden	0.3-0.52	3.4-9.0									0.3-0.52	3.4-9.0
	Normal overburden	0.52-1.0	6.7-21.5									0.52-1.0	6.7-21.5
	Compact overburden	1.5-1.7										1.5-1.7	d = 11.1-13.5
Type - II	Loose overburden	.22-.42	2-15	.20-.40	1-10.5			.35-.42	3-10			.20-.42	1-15
	Normal to compact overburden	.52-1.8	6-25	.50-1.4	3-17			.48-1.25	10-20			.5-1.8	2-25
	Weathered rock	2.0-2.5		2.16-3.1				2.0-2.5				2.0-3.1	d= 3-40
Type - III	Loose overburden					.2-.42	1.5-6.6			.25-.66	3-10	.2-0.5	1.5-10
	Compact overburden					1.1-1.7	2.5-11			1.0 - 2.0	4-18	1-1.7	.5-20
	W.Rock/ sound Rock					3.5-3.9				2.0-4.4		2-4.4	d= 2-30
Type - IV	Loose overburden	.42-.45	9.5-13									.42-.45	9.5-13
	Compact overburden	1.25 – 1.8	13-27									1.25	13-27
	Sound Rock	3.5 – 4.0										4.0	d= 22.5 - 40

Where d = depth to corresponding strata

RESULTS AND DISCUSSION

Three seismic layers were generally obtained from the seismic interpretation. The range of velocities obtained from different geotechnical conditions is shown in the Table 1. Average velocities and depths for each geological type at all proposed hydraulic structures were also computed and tabulated (Table 1). Typical geo-seismic sections are shown in Fig.3. From the table, in general four types of geotechnical conditions can be drawn. First and second types of geology overlap. Out of the five sites for the hydraulic structures, the surge shaft area shows varied geological conditions. Dam axis and Powerhouse area have similar type of geological conditions. This may be because of power- house being at the lower elevation and the dam axis being on the riverbed.

In Penstock alignment three traverses (1,2,3) were taken. Based on the results the area can be demarcated into loose overburden (350 - 420 m/sec), followed by normal to compact overburden (480 - 1250 m/sec). The loose and compact overburden is overlain by weathered rock with velocities varying between 2000-2500 m/sec. The depth of weathered rock varied between 13 and 30 m bgl (below ground level).

In Powerhouse area total 5 traverses namely 4 to 8 were carried out. This area revealed loose overburden, followed by compact overburden (1000 – 2000 m/sec) and weathered/good quality rock (2000- 4400 m/sec). In general, the depth to the rock in this area varies between 7 and 28 m bgl, being deeper towards profiles 4 and 5 and shallower towards profile 8. A typical section in traverses 6 & 7 are shown in Fig.3a. The bedrock inferred in drill hole PDH–1 is in agreement with the seismic results (Fig.3a). The core recovery in the borehole is more than 50%, indicating good quality rock.

A total of 11 traverses i.e. 9 to 19 were taken in surge shaft area. At this area, the thickness of loose overburden varies between 4 m and 15 m. The second layer shows normal to compact overburden with thickness range of 6 m -27 m. The third layer in this area has velocity ranges from 2000 to 4000 m/sec with the depth ranges of 8 to 40 m bgl. A typical section of traverse 17 is depicted in Fig. 3b. The drill hole results of SDH – 3 indicated the fragmented weathered rock upto the depth of 25 m bgl (Fig.3b). The recovery of core in the borehole was at this location was 0%. This is in accordance with the seismic results yielding 2500 m/sec velocity at this location.

Three traverses were taken in desilting site (i.e. traverses 20 to 22). In this area, the depth to rock varies between 4m and 27.5m with velocities in the range of 2160 to 3100 m/sec. This range of velocity can be attributed to jointed/weathered rock. This is overlain by normal to compact overburden.

Traverses 23 to 25 were run in the dam site area. At this site, the depth to bedrock varies from 4 m to 17.6 m having velocity range from 3500 to 3900 m/sec. This is overlain by compact overburden with velocity range of 1100 to 1700 m/sec. A geo-seismic section along traverse 23 is shown in Fig.3c. The depth to bedrock correlates well with the borehole data of DDH – 5 and DDH-6 (Fig.3c). The core recovery in these boreholes is 90% and above indicating good quality of rock. The area under investigation had undergone tectonic disturbances resulting in differential weathering. Slope instability is caused by rockfall, rock-cum-debris slides. Moreover, altitudes of the area varied from 975m to

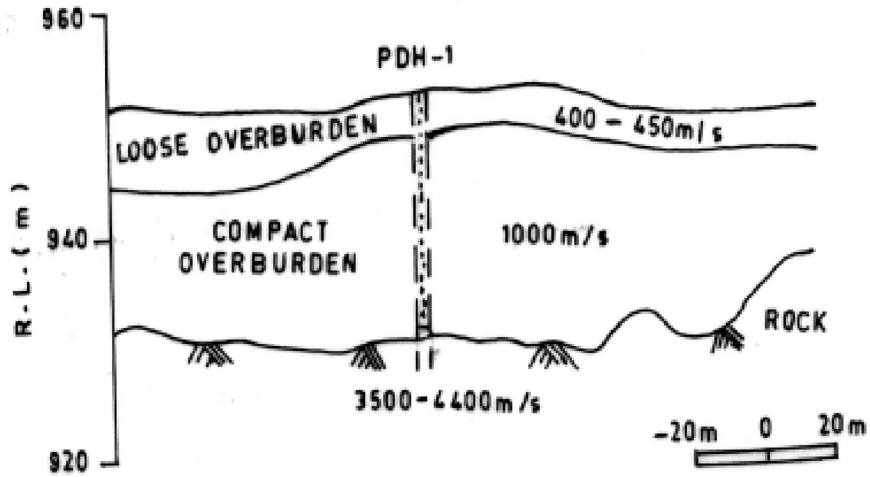

Figure 3(a). A typical cross section in traverses 6 & 7 at powerhouse area.

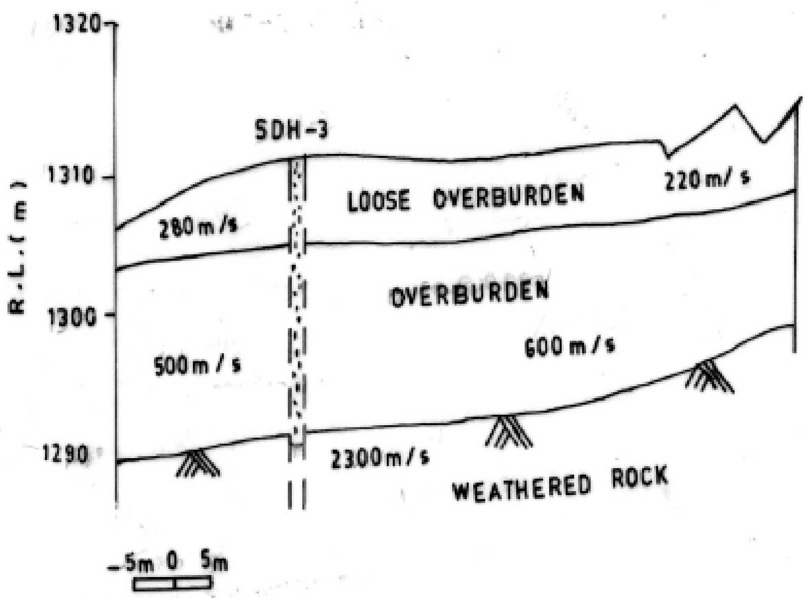

Figure 3(b). A typical cross section of traverse 17 at surge shaft area.

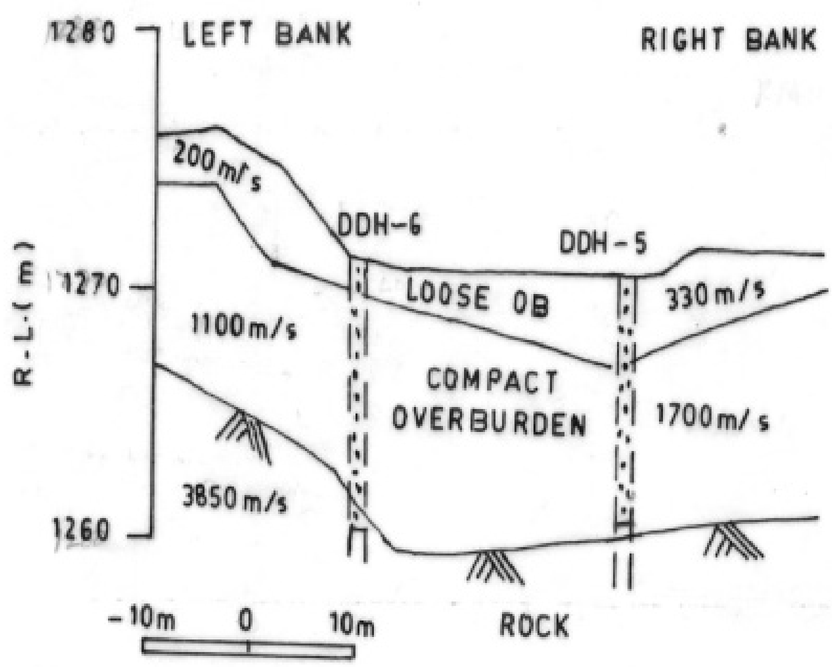

Figure 3(c). A typical cross section of traverse 23 at dam axis area.

1450m.All these factors have given rise to varied types of geotechnical conditions. Hence, the velocities observed in this area have wide range and can be grouped into four based on the geotechnical conditions. Type I comprises of loose overburden, normal overburden and compact overburden. Type II consists of loose overburden, normal to compact overburden and weathered rock. Type III has loose overburden, compact overburden and weathered to sound rock. Type IV has loose overburden, compact overburden and sound rock. The average velocities obtained for each type are shown in the Table 1. The elevation of the area is also showing effect on velocities. The surge shaft area, which is at highest elevation, has loose and thick overburden, whereas the dam axis and powerhouse areas, which are closer to the riverbed, have shallow rock.

CONCLUSIONS

The area under investigation had undergone tectonic disturbances resulting in differential weathering giving rise to varied types of geotechnical conditions. The seismic refraction technique was used to map minor tectonic disturbances like joints, faults or shear joints, if any. The survey was also aimed at assessing the quality of bedrock and its profile required for siting of structures for hydropower project. The refraction survey data analysis and the interpretation revealed, in general, a three layer geo-seismic section. The subsurface strata consists of loose overburden, normal to compact overburden and weathered to good quality bedrock The velocity ranges of the strata were 200 – 500 m/sec, 500 – 1700 m/sec and 2000 – 4400 m/sec respectively. The depth to the bedrock was the deepest i.e.,40 m bgl in the surge shaft area and the same occurred at shallow depths at dam axis i. e. 4 m-17.6 m bgl. This is because, the surge shaft is on higher altitude while the dam axis is on the river-bed where the exposures of the rock can be seen. At the surge shaft and penstock areas, comparatively the velocities evaluated for rock are low (2000 – 2500 m/sec) indicating weathered rock. Along the HRT alignment, the bedrock velocity is in the range of 2600 – 3400 m/sec suggesting weathered grade rock. In the powerhouse area, as expected, foundation grade gneissic rock was found with the velocity range of 2000 – 4400 m/sec. No major shear zones/weak zones were deciphered in the area covered by seismic refraction survey.

Variation of velocity of overburden and its depth is more in the higher altitudes compared to that in the riverbed. Lower overburden velocities are followed by lower velocity of bedrock. This may be due to higher weathering. Seismic results were in accordance with the borehole results because geoseismic sections are matching with borehole depths and percentage of core recovery. Hence, the geotechnical conditions obtained at limited drilling points can be effectively interpolated using seismic results.

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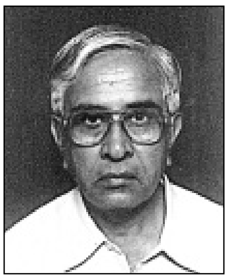

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