CHAPTER 3 . FIELD INVESTIGATION

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LIST OF TABLES

LIST OF FIGURES

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3.1 General

The first step for undertaking precise feasibility study is to clarify the topographical and geological conditions in the project area especially around the main structures. Prudent studies on selecting the sites and areas were made in order to perform the field investigation works effectively. Since the different dam and powerhouse sites were proposed in the "Master Plan Study" and the "Prefeasibility Study", it was required to set up the work plan upon assessment of the advantages and disadvantages of those sites. Before concentrating the field investigation to particular site, the alternative sites for dam and powerhouse were assessed in terms of surface geology, previously performed sub-surface geological investigation and topography. The results of assessment are given in the following paragraphs.

(1) Dam Site

The upstream dam site is preferable in view of better topographical and geological features around the same. One of the major reasons for selection of the upstream dam site was the presence of wide degradation at the middle reach of the Num Khola which joins with the Arun river immediately upstream of the downstream dam site. The very steep gradient of the Num Khola was observed to be bringing large scale landslide. This would have subjected dam, desanding basin and other structures of the downstream dam site to serious damages.

(2) Powerhouse Site

The upstream 240 MW scheme (Solakhani site) and the downstream 400 MW scheme (Kaguwa site) were proposed in the "Master Plan Study" and the "Prefeasibility Study" respectively. In addition to the previous reviews of these schemes in the "Prefeasibility Study", the above two schemes were again reviewed on the basis of topographic maps, load demand forecast and other factors and the downstream 400 MW scheme was judged to be superior to the upstream one.

For the downstream scheme, there are two alternatives; the Pikhuwa site proposed by the JICA team and the Kaguwa site already proposed in the "Prefeasibility Study". Based on the topographic features and anticipated geological conditions at these two sites observed during the first reconnaissance, the Pikhuwa site was judged to require less construction cost and have less risks in construction operaiton, and proposed accordingly. However, due to additional head gain of 15 m between these two sites at proximately 1 km distance from each other, the Kaguwa site was supposed to have larger benefit. Hence, it was decided that the proper decision on selection of the better site should be made upon comparative studies based on the designs of various structures and cost estimate induced from the detailed topographic and geological field investigation works.

(3) Scope of Investigation Works

Upon careful studies stated above, it was decided that the field investigation works including topographic survey, levelling and geological survey by means of core drilling, seismic prospecting should be performed in the area covering the upstream dam site and both the Pikhuwa and Kaguwa powerhouse sites.

3.2 Topographic Survey and Mapping

3.2.1 Aerophotographic Survey

Topographic maps of areas covering dam, powerhouse and other structures as well as access road were developed on the basis of existing aerophotographs of the area in the scale of 1/20,000.

(1) Dam - Powerhouse Area

Mapping for area covering dam site (including reservoir area) to powerhouse site (both Pikhuwa and Kaguwa sites).

Mapping area : 36 Km^2
Scale : 1/5,000
Contour : 5 m

(2) Access Road Area

Mapping for area covering access road connecting Hile and the Arun 3 project site (Alternative plan A & B).

Mapping area : 180.5 km^2
Scale : 1/10,000
Contour : 10 m

3.2.2 Ground Survey

(1) Dam Area

Mapping for area covering dam, diversion tunnel, power intake, desanding basin, borrow area, etc.

Mapping area : 210,000 m^2
Scale : 1/500
Contour : 1 m

(2) Powerhouse Area

Mapping for area covering downstream part of headrace tunnel, surge tank, penstock, powerhouse, tailrace, switchyard, borrow area, etc.

Mapping area : 287,000 m^2 (Pikhuwa)
: 96,000 m^2 (Kaguwa)
Scale : 1/500
Contour : 1 m

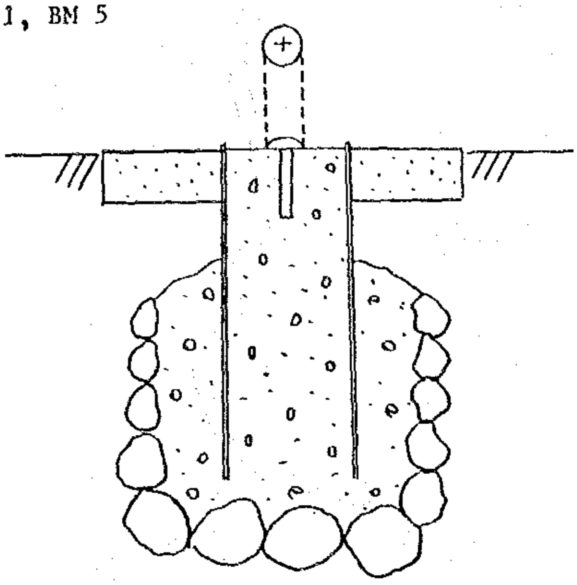
It is to be noted that field survey operation at the Kaguwa site was performed by the NEA's surveyers and mapping by JICA team in Japan.

3.2.3 Levelling

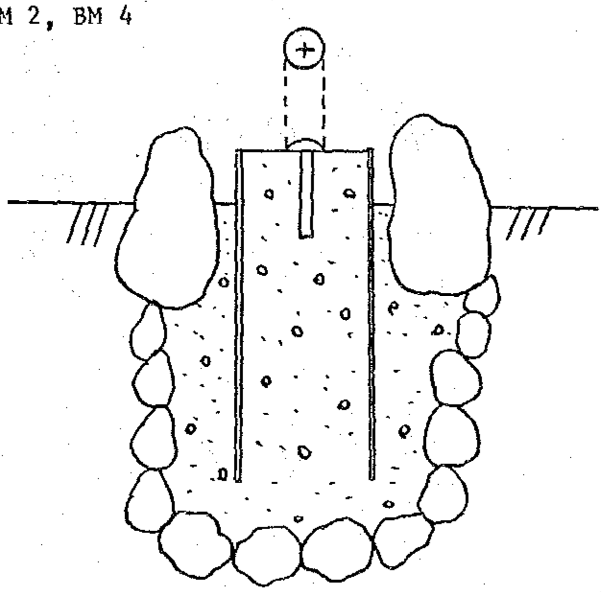
The levelling survey work of 15.7 km between dam site and powerhouse sites (Pikhuwa and Kaguwa) was carried out and five bench marks as illustrated in Fig. 3-1 were constructed at the locations shown in Fig. 3-2 and the detailed point descriptions are also given in Tables 3-1(1) to 3-1 (5).

Fig. 3–1 Sketch of New Monumentation of Bench Marks

BM 1, BM 5



BM 2, BM 4



BM 3

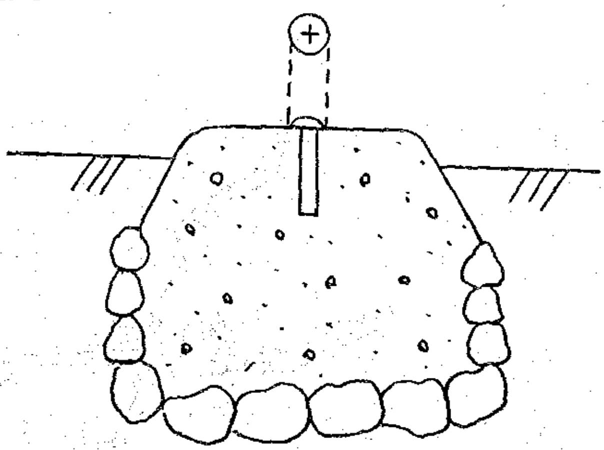


Fig. 3-2 Location Map of Bench Marks

1:50,000

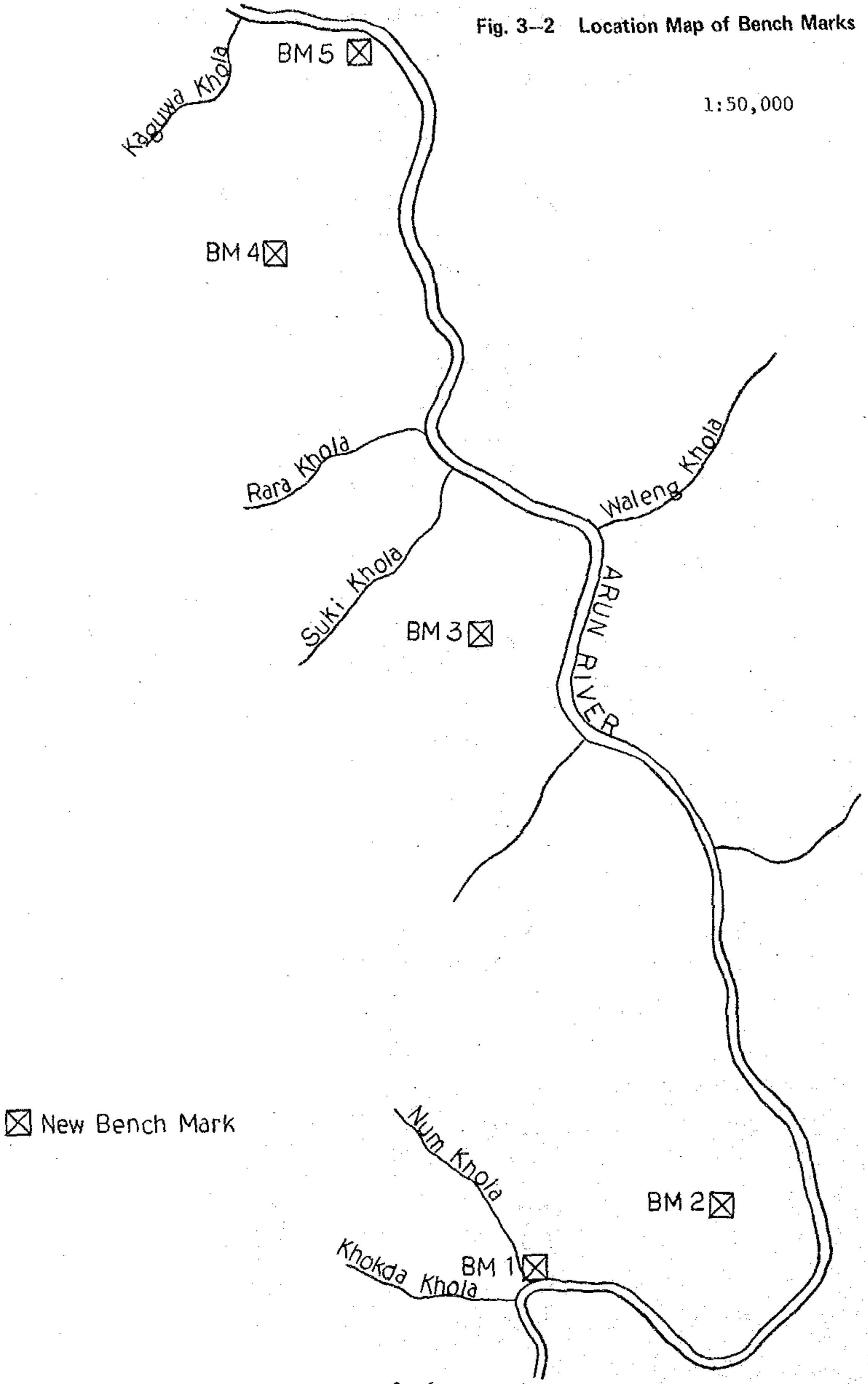
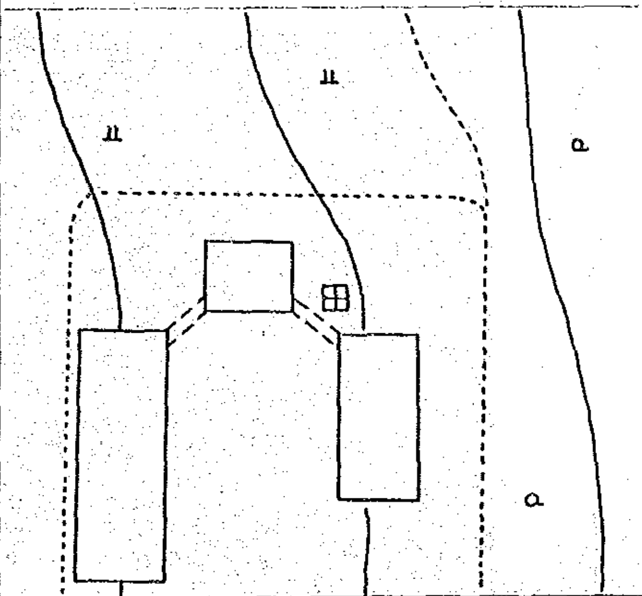


Table 3–1 (1) Point Description

Station No.		Operated by	MR. SHRESTHA
BM 1	survey no. D/ST-1	Checked by	MR. TOYODA
		Date	MAY 25 '86

Zone No.	Coordinates of Station		
45	N	E	H
Main Point	3048 534.07	529 790.49	808.36
Eccentric Point	.	.	.
Supplementary Point	.	.	.

Sketch-map of Station and Neighborhood	Photograph of Station
	

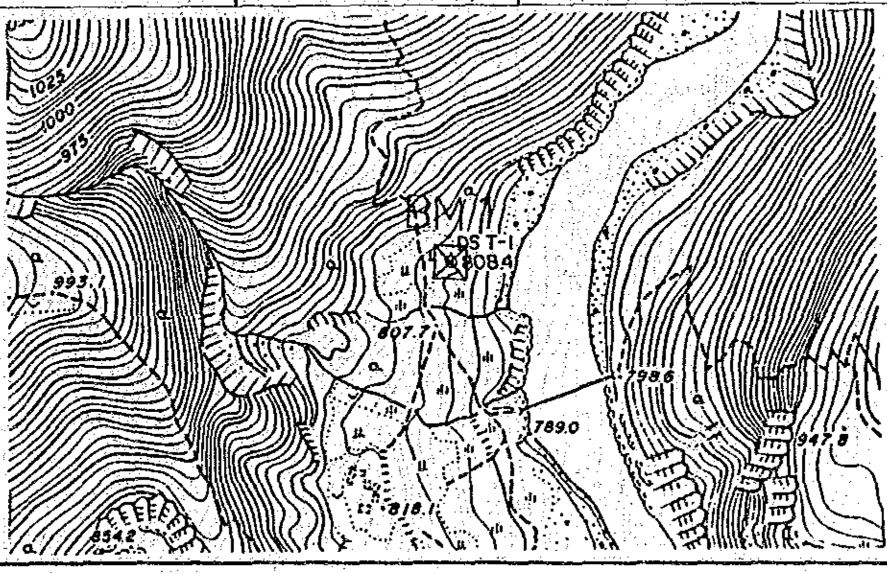
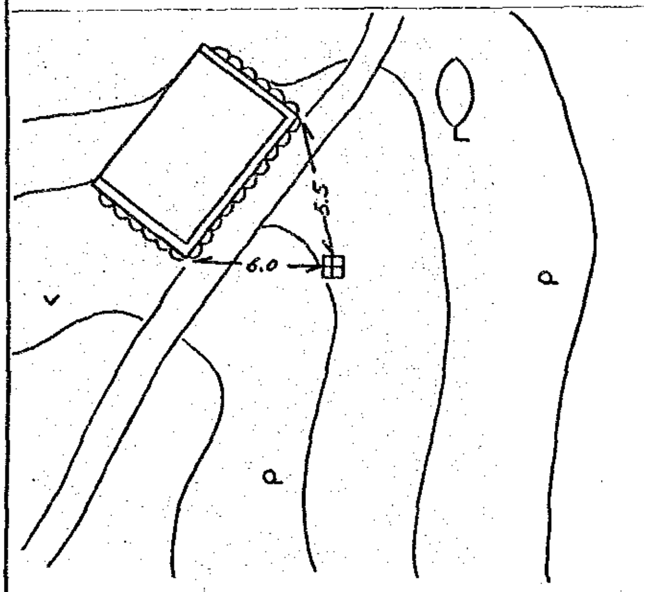


Table 3–1 (2) Point Description

Station No.		Operated by	MR. PRASAIN
BM 2	survey no. P14	Checked by	MR. TOYODA
		Date	MAY 25 '86

Zone No.	Coordinates of Station		
45	N	E	H
Main Point	3049 971.99	528 622.32	1 330.58
Eccentric Point	.	.	.
Supplementary Point	.	.	.

Sketch-map of Station and Neighborhood	Photograph of Station
	

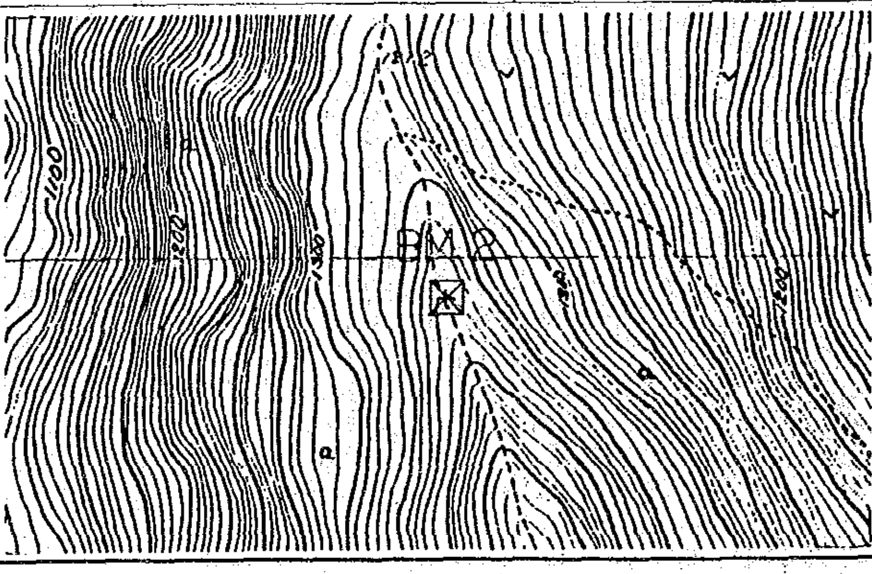
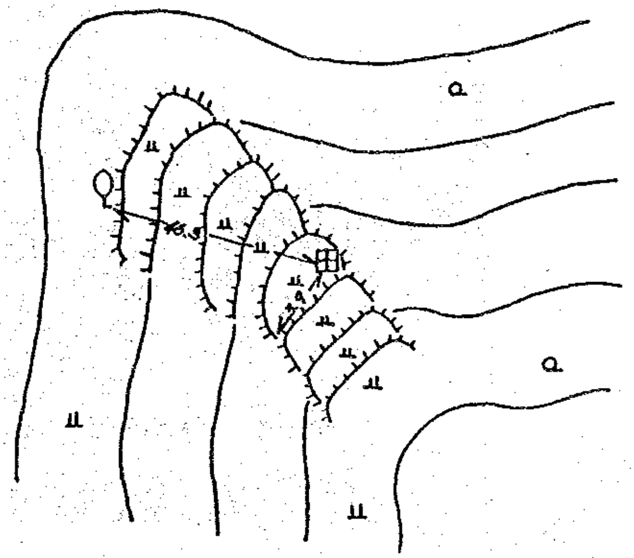


Table 3–1 (3) Point Description

Station No.		Operated by	MR. PRASAIN
BM 3	survey no. P12	Checked by	MR. TOYODA
		Date	MAY 26 '86

Zone No.	Coordinates of Station		
45	N	E	H
Main Point	3046 188.24	524 242.23	1 318.38
Eccentric Point	.	.	.
Supplementary Point	.	.	.

Sketch-map of Station and Neighborhood	Photograph of Station
	

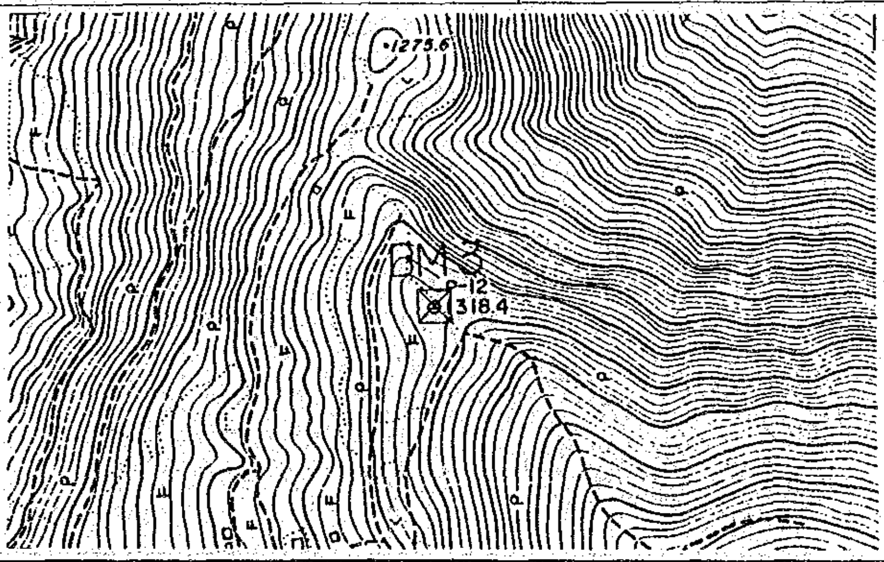
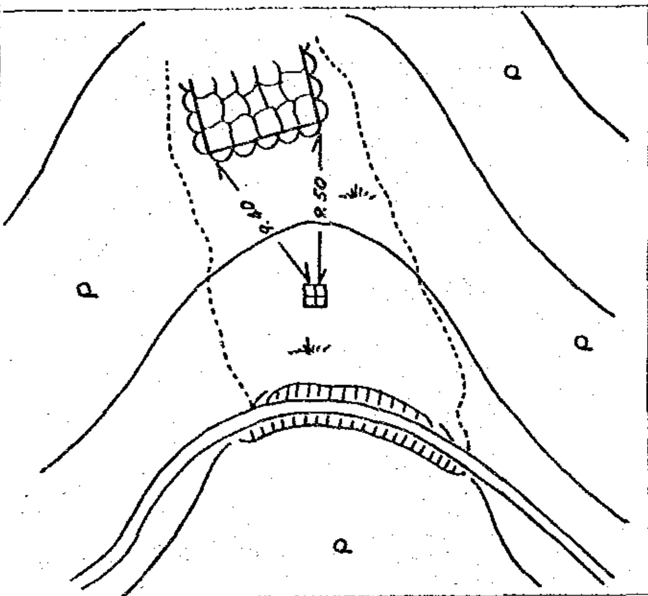
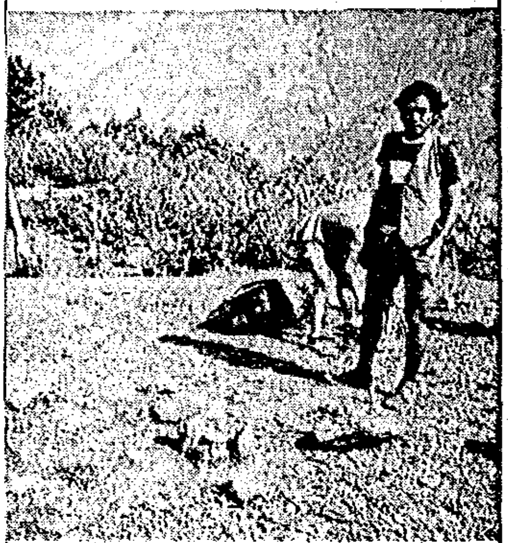


Table 3–1 (4) Point Description

Station No.		Operated by	MR. PRASAIN
BM 4	survey no. P9	Checked by	MR. TOYODA
		Date	MAY 21 '86

Zone No.	Coordinates of Station		
45	N	E	H
Main Point	3043 332.24	521 408.51	1 566.83
Eccentric Point	.	.	.
Supplementary Point	.	.	.

Sketch-map of Station and Neighborhood	Photograph of Station
	

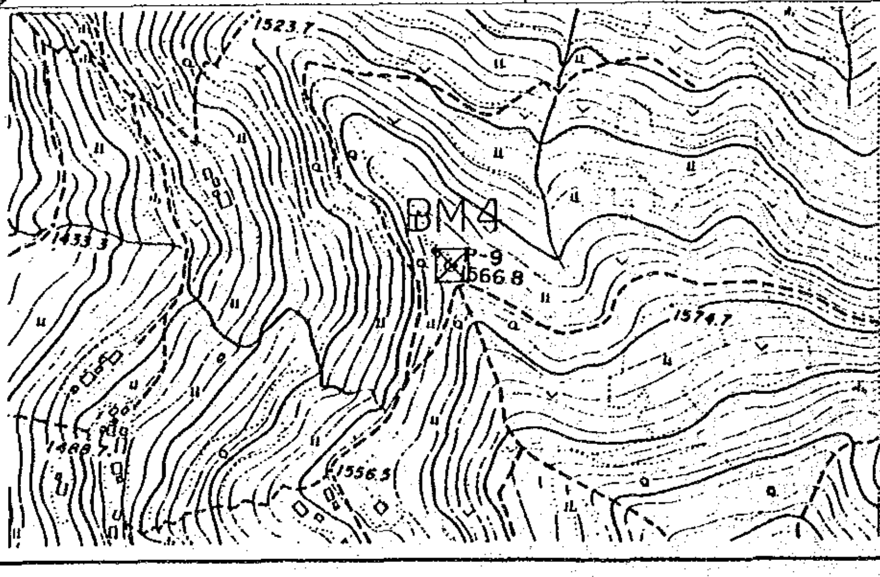
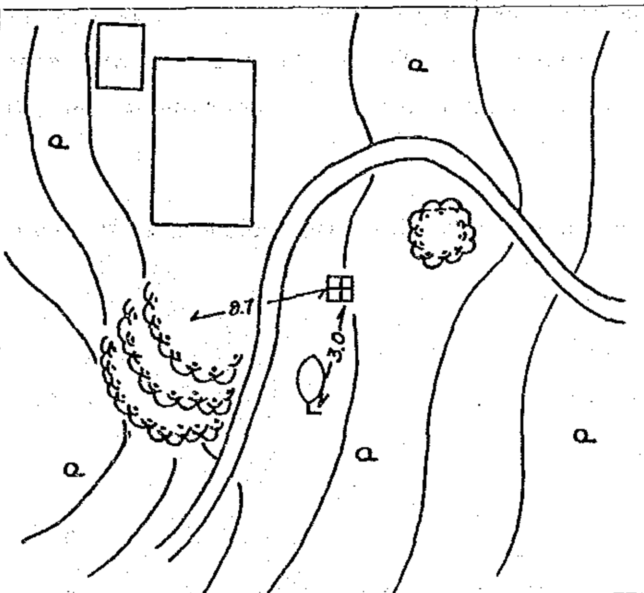
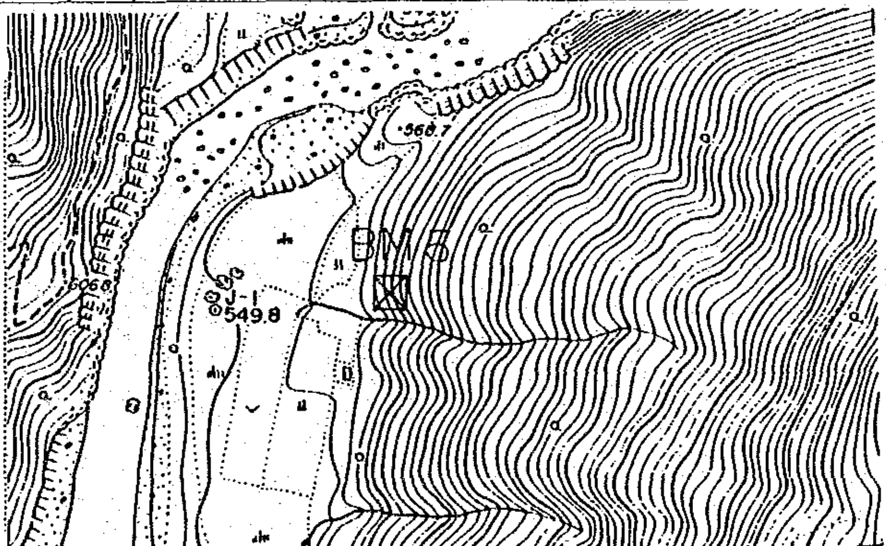


Table 3–1 (5) Point Description

Station No.		Operated by	MR. SHRESTHA
BM 5	survey no. S1	Checked by	MR. TOYODA
		Date	MAY 29 '86

Zone No.	Coordinates of Station		
45	N	E	H
Main Point	3043 748.03	519 434.63	574.66
Eccentric Point	.	.	.
Supplementary Point	.	.	.

Sketch-map of Station and Neighborhood	Photograph of Station
	



3.3 Subsurface Investigation

In order to clarify the thickness of overburden and a certain fault zone through the dam foundation as well as the geological conditions of rock foundation on which the main civil structures are to be constructed, core drilling was executed. Locations, lengths, etc of drill holes are shown in Figs. 3-3 - 3-5 and Table 3-2. In addition, descriptions of test holes drilled during the Prefeasibility Study are shown in Table 3-3 for reference. Geological logs of drill holes are illustrated in Appendix A-1.

The results of Lugeon test performed at drill hole UDH-7 located in the dam area are shown in Appendix A-2. In these figures, the records of injection pressures, unit infiltration volumes and Lugeon value induced therefrom at each section are indicated. Lugoen values at drill hole UDH-1 performed during the Prefeasibility Study are also attached for reference, making adjustment in consideration of underground water level.

The main equipment used for the above core drilling works are as shown below.

Tone boring machine (UD5) : 3 units
Acres : 1 unit

Fig. 3–3 Location Map of Drilling and Seismic Survey at Dam Site

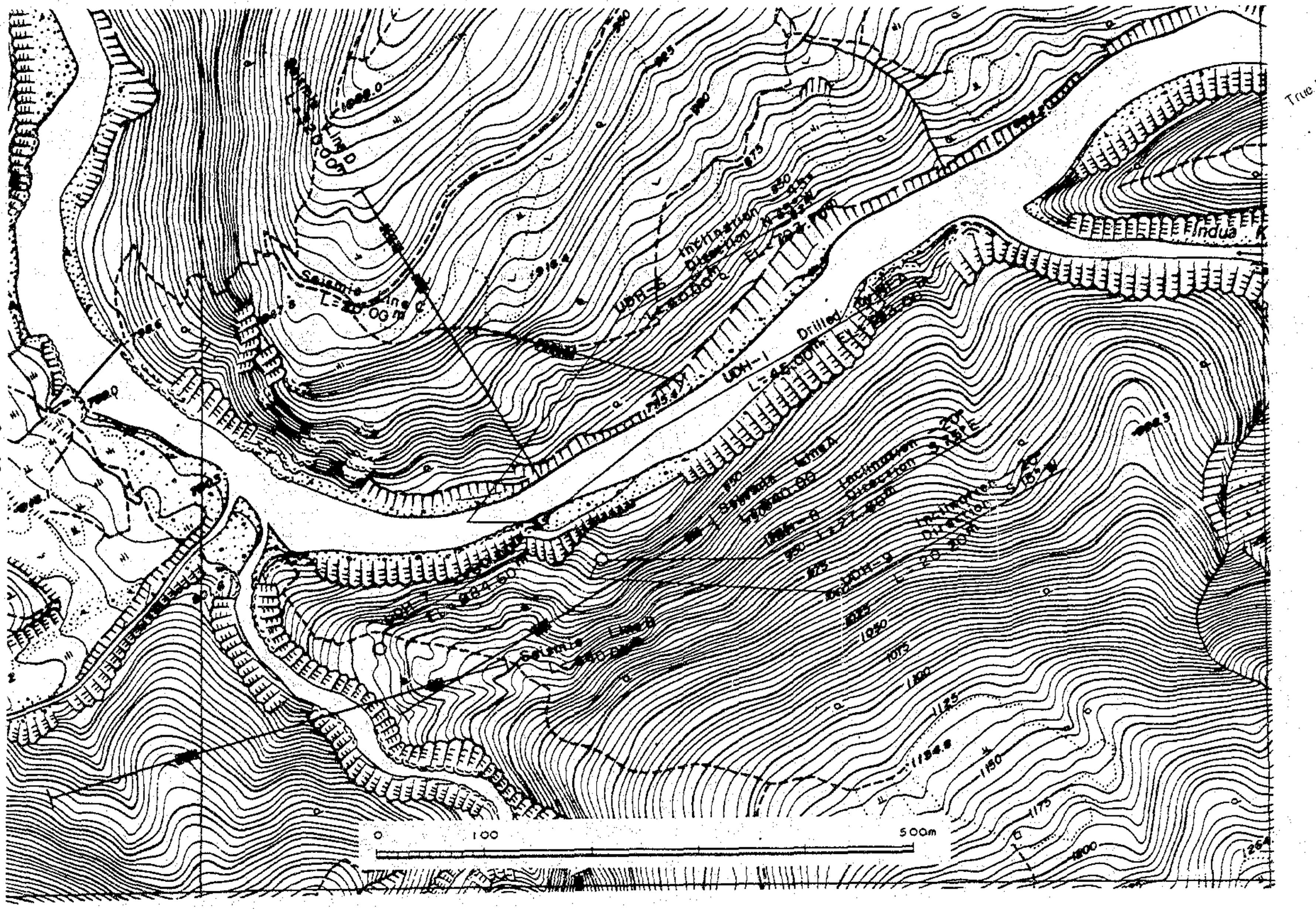


Fig. 3–4 Location Map of Drilling and Seismic Survey at Powerhouse Site (Pikhuwa)

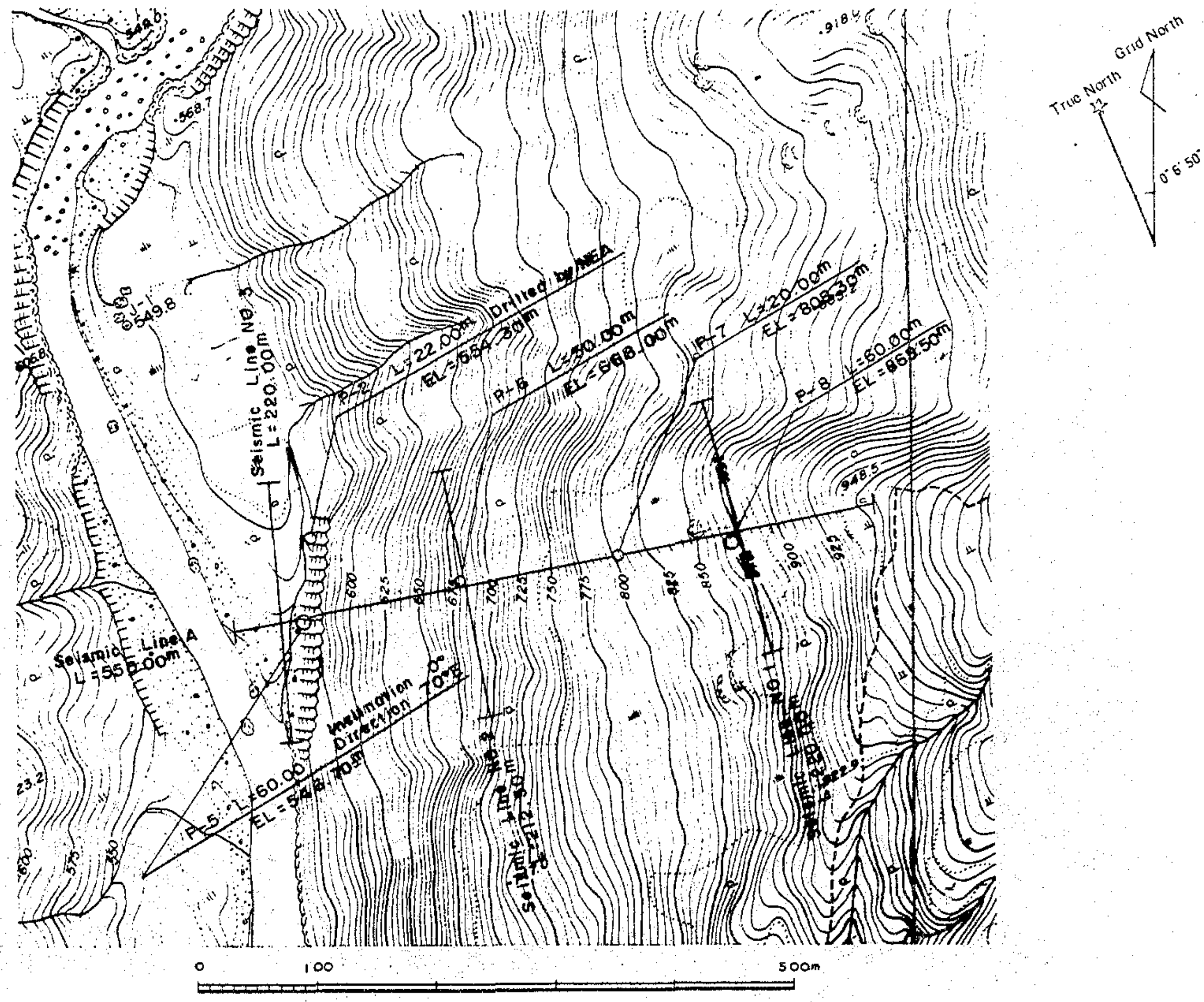


Fig. 3–5 Location Map of Drilling and Seismic Survey at Powerhouse Site (Kaguwa)

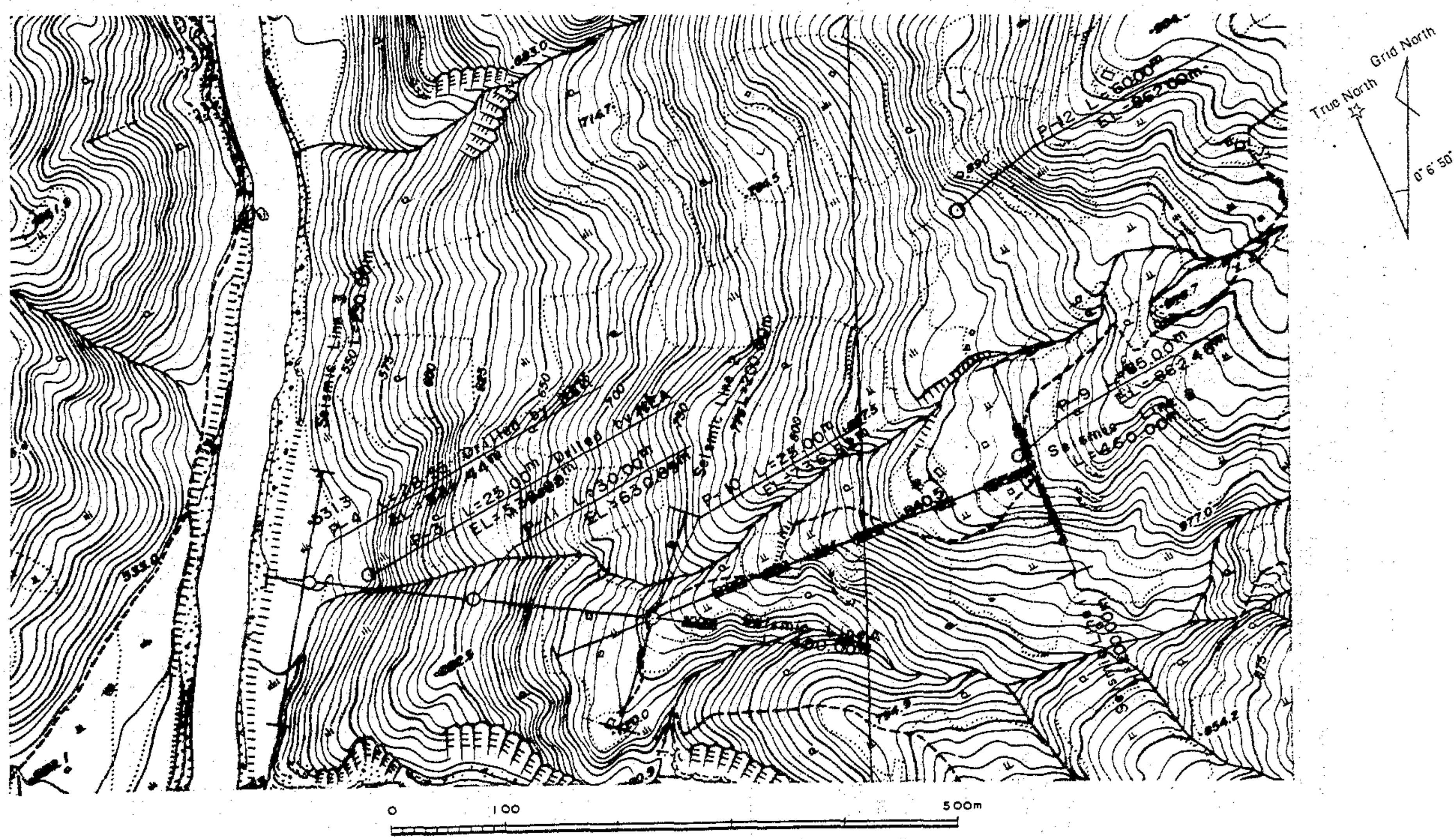


Table 3–2 Record of Core Drilling Works (F/S)

Location	No.	L (m)	EL (m)	Direction Inclination	Remarks
Dam site	UDH-6	40.0	793.74	N30°W/-45°	Riverbed
	7	80.0	884.57	Vertical	Desanding basin
	8	27.8	830.81	N75°E/-20°	Folding zone at intake
	9	20.2	831.21	S15°E/-40°	Folding zone at intake
	Sub-Total	168.0			
Power-house (Pikhuwa)	P-5	60.0	546.70	S70°E/Hori	Bedrock at powerhouse
	6	50.0	667.95	Vertical	Bedrock at penstock
	7	20.0	808.30	Vertical	Bedrock at pensotck
	8	60.0	869.34	Vertical	Bedrock at surge tank
	Sub-Total	190.0			
Power-house (Kaguwa)	P-9	85.0	862.46	Vertical	Bedrock at surge tank
	10	25.0	736.82	Vertical	Bedrock at penstock
	11	30.0	630.89	Vertical	Bedrock at penstock
	12	60.0	830	Vertical	Bedrock at surge tank
	Sub-Total	200.0			
	Total	558.0			

Table 3-3 Record of Core Drilling Works (M/P & Pre. F/S)

Location	No.	L (m)	Direction Inclination	Remarks
Dam site	UDH-1	45.0	Vertical	Riverbed
	2	40.0	Vertical	Riverbed
	3	100.2	1-60°	Right bank
	4	50.0		Right bank
	5	25.0		Right bank
	DDH-1	50.0	Vertical	Riverbed (D/S scheme)
	DP -1	40.35	Vertical	Intake (D/S scheme)
	Sub-Total	350.55		
Powerhouse (Pikhuwa)	P-1	45.0	Vertical	At terrace
	2	22.9	Vertical	At terrace
	Sub-Total	67.9		
Powerhouse (Kaguwa)	P-3	25.0	Vertical	At terrace
	P-4	28.5	Vertical	At terrace
	Sub-Total	53.5		
Powerhouse (Solakhani)	B-1	20.0	Vertical	Bedrock at penstock
	B-2	30.0	Vertical	Riverbed
	Sub-Total	50.0		
	Total	521.95		

3.4 Seismic Prospecting

In parallel with the direct geological investigation by core drilling survey, seismic prospecting was also carried out in order to clarify the continuous geological conditions of foundation rock on which the main structures are to be constructed. The arrangement of survey lines are shown in Figs. 3-3, 3-4 & 3-5, and the time-travel curves and cross section by seismic survey are shown in Appendix A-3. Outlines of seismic prospecting works performed for the Feasibility Study and the previous "Prefeasibility Study" are shown in Table 3-4 and Table 3-5, respectively.

Seismic prospecting was carried out at an interval of 5 m between detectors and 50 m between blasting points, with 6 to 7 (5 at minimum) blasting points per one spread. The main equipment adopted for seismic prospecting are as follows.

Fieldgraph : 24 channel, recording paper speed 30 cm/sec

Amplifier : 24 channel, Gain 90 db

Geophone : Vertical moving coil type, 14 Hz

Table 3-4 Record of Seismic Survey Works (F/S)

Location	Line No.	L (m)	Remarks
Dam site	A	340	Intake - desanding basin
	B	440	Desanding basin
	C	200	Inlet of diversion tunnel
	D	320	Right bank above dam axis
	Sub-Total	1,300	
Powerhouse (Pikhuwa)	A	550	Main line along penstock
	1	220	Sub-line at surge tank
	2	200	Sub-line at penstock
	3	220	Sub-line at powerhouse
	Sub-Total	1,190	
Powerhouse (Kaguwa)	A	460	Main line along penstock
	B	400	Main line along penstock
	1	210	Sub-line at surge tank
	2	200	Sub-line at junction of A & B
	3	230	Sub-line at powerhouse
	Sub-Total	1,500	
	Total	3,990	

Table 3–5 Record of Seismic Survey Works (Pre. F/S)

Location	Line No.	L (m)	Remarks
Dam site	SLDU-1	65	Dam foundation
	2	65	Dam foundation
	3	80	Dam foundation
	4	165	Left bank terrace downstream
	5	385	of dam
	6	45	"
	7	380	"
	SLI 1	215	Tunnel inlet (downstream scheme)
	2	143.5	Tunnel inlet (downstream scheme)
	3	75	Tunnel inlet (downstream scheme)
	SLD 1	115	Downstream dam foundation
	2	141	Downstream dam foundation
	3	158	Downstream dam foundation
	4	155	Downstream dam foundation
	5	155	Downstream dam foundation
	Sub-Total	2,342.5	
Powerhouse	SLP -1	492.5	Pikhuwa powerhouse site
	2	375.5	Pikhuwa powerhouse site
	3	385	Pikhuwa powerhouse site
	4	327.5	Pikhuwa powerhouse site
	5	225	Pikhuwa powerhouse site
	6	257.5	Pikhuwa powerhouse site
	SLPU 1	115	Solakhani powerhouse site
	2	122.5	Solakhani powerhouse site
	Sub-Total	2,282.5	
	Total	4,625	

3.5 Laboratory Test

3.5.1 Rock Mechanical Test

Rock mechanical test was carried out taking specimens from rock cores collected by the core drilling works. The test results of these specimens are listed in Tables 3-6 (1) and 3-6 (2), and the average values for the dam area and powerhouse area are shown in Table 3-7.

Table 3–6 (1) Results of Rock Laboratory Test

Drilling No.	Sampling Depth	Apparent Specific Gravity			% Ab-sorption	% Net pore-sity	% Water con-tent	g/cm^3 Unit Weight by volume	Velocity of Super Sonic Wave				Compre-ssive strength	*3 Esc	*4 Sc	Remarks
		Natural	Dry	Satu-rated					Km/s V(p)	Km/s V(s)	Edc *1 $Kg/cm^2 \times 10^5$	*2 Dc	kg/cm^2	$Kg/cm^2 \times 10^5$		
UDH-6	22.36 - 22.55	2.693	2.684	2.699	0.6	1.5	0.4	2.714	1.81	1.59	-	-	165	0.66	0.13	Augen Gn Mica ceans
	28.46 - 28.62	2.698	2.690	2.703	0.5	1.4	0.3	2.715	1.87	1.41	-	-	291	1.07	0.20	"
	38.78 - 39.00	2.690	2.681	2.692	0.4	1.1	0.3	2.732	1.89	1.58	-	-	413	1.52	0.17	Augen Gn
UDH-7	51.28 - 51.50	2.726	2.721	2.729	0.3	0.9	0.2	2.741	3.21	2.13	2.81	0.10	101	0.82	0.22	Augen Gn (Mica rich)
	60.15 - 60.31	2.707	2.698	2.712	0.5	1.4	0.3	2.724	3.45	2.30	3.24	0.10	91.6	1.07	0.25	"
	66.12 - 66.30	2.715	2.705	2.721	0.6	1.6	0.4	2.711	2.20	1.94	-	-	55.4	0.19	0.45	"
UDH-9	15.00 - 15.15	2.745	2.734	2.745	0.4	1.1	0.4	2.733	4.04	2.20	3.49	0.29	104	1.41	0.31	"
	17.80 - 17.95	2.704	2.691	2.703	0.5	1.2	0.5	2.724	3.63	1.90	2.62	0.31	188	1.05	0.36	"
	19.25 - 19.45	2.715	2.707	2.718	0.4	1.1	0.3	2.763	3.76	2.22	3.42	0.23	129	1.00	0.40	"
P-6	0.73 - 1.00	2.677	2.667	2.677	0.4	1.0	0.4	2.683	3.08	1.64	1.92	0.30	395	1.60	0.27	Augen Gn
	30.70 - 31.00	2.688	2.680	2.692	0.4	1.2	0.3	2.693	2.82	1.65	1.86	0.24	550	2.40	0.36	"
	39.05 - 39.25	2.654	2.647	2.658	0.4	1.1	0.3	2.693	2.87	1.67	1.91	0.25	599	2.36	0.44	"
P-2	1.50 - 1.70	2.645	2.637	2.653	0.6	1.6	0.3	2.662	3.14	1.78	2.18	0.26	467	1.90	0.37	"
	10.74 - 10.94	2.668	2.658	2.675	0.6	1.5	0.4	2.661	3.38	1.83	2.35	0.29	464	1.67	0.48	"
	20.77 - 20.95	2.661	2.654	2.665	0.4	1.1	0.2	2.674	3.81	1.90	2.62	0.33	475	2.20	0.26	"
P-3	10.30 - 10.56	2.662	2.654	2.666	0.4	1.2	0.3	2.691	2.78	1.55	1.69	0.27	326	1.25	0.38	"
	11.70 - 11.87	2.677	2.666	2.677	0.4	1.1	0.4	2.689	3.29	1.79	2.09	0.32	249	1.14	0.32	"
	15.25 - 15.40	2.691	2.684	2.693	0.3	0.9	0.2	2.679	3.11	2.12	-	-	314	1.62	0.39	"
UDH-1	14.42 - 14.60	2.708	2.700	2.712	0.5	1.2	0.3	2.707	2.96	1.54	1.73	0.31	147	0.75	0.24	Augen Gn (Mica rich)
	23.50 - 23.73	2.726	2.716	2.731	0.5	1.4	0.3	2.716	3.16	2.05	2.65	0.14	119	0.64	0.41	"

*1 Edc : Dynamic Modulus of Elasticity. *2 Dc : Dynamic Poisson's Ratio.
*3 Esc : Static Modulus of Elasticity. *4 Sc : Static Poisson's Ratio.

Table 3–6 (2) Results of Rock Laboratory Test

Drilling No.	Sampling Depth	Apparent Specific Gravity			% Absorption	% Net porosity	% Water content	g/cm³ Unit Weight by volume	Velocity of Super Sonic Wave				Compressive strength	*3 Esc	*4 Sc	Remarks
		Natural	Dry	Saturated					Km/s V(p)	Km/s V(s)	Edc *1 Kg/cm² x 10⁵	*2 Dc	kg/cm²	Kg/cm² x 10⁵		
UDH-1	31.00 - 31.30	2.716	2.708	2.719	0.4	1.1	0.3	2.690	2.94	1.90	2.26	0.14	154	0.79	0.20	Augen Gn (Mica rich)
P-5	4.10 - 4.30	2.648	2.637	2.655	0.7	1.8	0.4	2.687	3.96	2.96	-	-	361	1.87	0.46	Augen Gn
	27.50 - 27.80	2.662	2.653	2.665	0.4	1.2	0.3	2.643	4.16	2.46	4.03	0.23	507	2.64	0.48	"
	58.00 - 58.30	2.661	2.653	2.664	0.4	1.0	0.3	2.674	4.10	2.51	4.13	0.20	516	2.37	0.47	"
P-7	15.80 - 16.00	2.662	2.650	2.663	0.5	1.3	0.4	2.660	2.46	1.30	1.21	0.31	522	1.27	0.49	Fine"grained Gr.
	-	After saturated							3.13	1.43	1.52	0.37				
P-10	22.00 - 22.20	2.649	2.636	2.653	0.6	1.7	0.5	2.656	3.55	2.03	2.80	0.26	435	1.38	0.41	Augen Gn.
	-	After saturated							3.79	1.81	2.40	0.35				
P-11	8.74 - 9.00	2.656	2.643	2.657	0.5	1.4	0.5	2.637	3.28	1.53	1.71	0.36	675	1.67	0.46	Fine grained Gr.
	-	After saturated							3.33	1.67	2.00	0.33				
P-11	29.15 - 29.35	2.676	2.669	2.680	0.4	1.1	0.2	2.675	4.22	2.21	3.50	0.31	532	2.59	0.41	Augen Gn.
	-	After saturated							4.41	1.91	2.76	0.38				"
UDH-6	35.30 - 35.46	2.712	2.697	2.713	0.6	1.6	0.5	2.731	2.22	1.46	1.36	0.15	221	0.79	0.25	Augen Gn
	-	After saturated							2.52	1.54	1.59	0.20				(Mica rich)
UDH-7	75.65 - 75.85	2.709	2.697	2.710	0.5	1.3	0.5	2.740	3.61	1.65	2.08	0.37	6.	0.21	0.36	"
	-	After saturated							3.26	1.92	2.54	0.24				
	-															
	-															
	-															
	-															

*1 Edc : Dynamic Modulus of Elasticity. *2 Dc : Dynamic Poisson's Ratio.
*3 Esc : Static Modulus of Elasticity. *4 Sc : Static Poisson's Ratio.

Table 3-7 Physical Characteristic of Foundation Rock

Physical Properties \ Zone		Damsite	Powerhouse Site	
Rock		Augen gn	Augen gn	Gr
Bulk Specific Gravity	Natural	2.71	2.67	2.66
	Dry	2.70	2.66	2.65
	Saturated	2.70	2.67	2.66
Absorption (%)		0.7	2.72	0.5
Net porosity (%)		1.3	2.72	1.4
Water content (%)		0.3	2.72	0.5
Unit weight (g/cm^3)		2.72	2.72	2.65
Velocity of Supersonic Wave Km/s	Vp (km/s)	2.91	3.45	2.87
	Vs (km/s)	1.85	1.99	1.42
	Edc ($10^5 kg/cm^2$)	5.41	2.59	1.46
	DC	0.21	0.27	0.34
Unconfined compressive strength (kg/cm^2)		156	422	599

Note: Edc : Dynamic modulus of elasticity
Dc : Dynamic Poisson's ratio

Drilling was not conducted in main formations of mica schist. In cases where mica schist was intercalated in gneiss, only short core - fragmentary samples were obtained which were not suitable for testing.

3.5.2 Sieve Analysis

In order to examine the availability of alluvial deposit existing in the project area for concrete aggregates, sieve analysis was carried out. Total 7 samples (3, 2 and 2 at dam site, Pikhuwa site and

Kaguwa site, respectively) were taken from alluvial deposits existing along the Arun river on left bank. Tests were performed at the Nepal Engineering Institute, Pulchok and the results are as shown in Appendix A-4.

3.5.3 Water Quality Analysis

Water quality analysis of samples taken from the Arun river near the dam site was made at test laboratory in Japan. 10 samples placed for water quality analysis were taken during the period from March to July 1986 covering both the dry and wet seasons.

The results of water quality analysis are as shown in Table 3-8. The item indicated as discharge in this table is the river flow measured at the Tumlingtar gauging station and water samples were taken corresponding to the river discharge adequately dispersed in the range of 119 m^3/s to 943 m^3/s. Analysis was made in accordance with the provision of the Japanese Industrial Standard (JIS).

No particular problems were observed, except for rather high value of Cl^-. The value of PH ranges in neutral reaction zone, then it is experientially judged that the water quality will not cause any problem for tunnel lining concrete and steel liner in the future.

3.5.4 Component Analysis of River Deposit

Component analysis of the river deposit collected near the dam site were carried out by X-ray and electron microscope examinations. The results of analysis are as shown in Table 3-9.

Samples are gneiss rock system containing minerals like quartz, feldspar and mica. The Mohs' hardnesses of these minerals are 7, 6 and 2.5, respectively and the weighted average hardnesses of samples tested are in the range of 4.1 to 5.5. Furthermore, no sulphide was detected from rock samples by chemical analysis.

Table 3–8 Results of Component Analysis of Arun River Water

Item	1986.Mar. 2	1986.Mar. 5	1986.Mar.18	1986.May 22	1986.Jun.10	1986.Jun.15	1986.Jun.30	1986.Jul. 4	1986.Jul.22	1986.Jul.28
Water Temperature (℃)	14.5	14.5	15.0	14.0	16.0	13.0	12.0	12.0	10.0	11.0
PH	6.9	6.8	6.8	6.5	6.7	7.0	7.0	6.9	7.8	7.7
Suspension Material (mg/l)	<3.0	8.3	7.3	87	53	21	460	640	810	420
Evaporation Residue (mg/l)	150	130	140	200	340	590	1000	520	1500	620
COD (mg/l)	2.6	3.4	2.9	4.1	3.3	2.4	3.5	4.5	8.4	7.9
Cl^- (mg/l)	91	97	100	120	88	140	99	120	140	110
SO_4^{2-} (mg/l)	15	14	13	7.6	5.8	12	6.3	7.9	13	17
Mg^{2+} (mg/l)	3.6	3.1	2.6	1.7	1.7	1.4	2.0	2.0	9.7	5.9
Total Nitrogen (mg/l)	2.8	3.3	2.7	1.6	1.0	<0.04	<0.04	<0.04	0.7	0.6
Total Phosphorus (mg/l)	0.19	0.16	0.15	0.07	0.22	0.03	0.07	0.07	0.01	0.02
Sulphide (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Discharge (m^3/s)	119	126	119	176	292	376	874	548	905	943

Note : "<" indicates "less than detection limit."
Discharge was obserbed at Tumlingtar G.S.

Table 3-9 Results of Component Analysis of River Deposit

Mineral	Hardness (Mohs)	Sample Number					
		No. 1		No. 2		No. 3	
		Component (%)	Hardness x Component	Component (%)	Hardness x Component	Component (%)	Hardness x Component
Quartz	7	5.6	39.2	57.9	405.3	55.6	389.2
K feldspar	6	4.4	26.4	1.2	7.2	-	-
Plagioclase	6	35.5	213.0	10.0	60.0	-	-
Biotite	2.5	11.3	28.3	21.3	53.3	-	-
Muscovite	2.5	43.2	108.0	9.6	24.0	44.4	111.0
Total	-	100.0	414.9	100.0	549.8	100.0	500.2
Average of Hardness		4.1		5.5		5.0	

3.5.5 Microscopic Examination

In order to check the rock quality, microscopic examination was carried out. Total 7 samples (Augen gneiss 1, Gneissosed granite 1, Micaschist 3, Amphiobolite 2) were examined.

The results of the examination are shwon in Appendix A-5.

3.6 Geological Mapping

Schematic geological map indicated below was prepared based on the result of the field geological survey.

Scale : 1/500
Geologic map around the dam site
Geologic map of Powerhouse site (Pikhuwa)
Geologic map of Powerhouse site (Kaguwa)

Scale : 1/5,000
Geologic map of the headrace tunnel route between the dam site and the powerhouse

CHAPTER 4. GEOLOGY

CHAPTER 4. GEOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF DRAWINGS

CHAPTER 4. GEOLOGY

4.1 Description of Topography and Geology of Eastern Nepal

4.1.1 Topography

The Arun 3 hydropower scheme site is situated in eastern Nepal between east longitudes 87°12' - 88°20' and north latitudes 27°30' - 27°35'. Within this region are found the Kosi and Arun rivers which flow south ward from headwaters across the border in China, as well as the Tamur river situated in the easternmost extremety of Nepal. These rivers join near the vicinity of Tribeni to form a single flow referred to as the Sapt Kosi. The Sapt Kosi subsequently courses south into India to empty into the Ganges river. The total catchment of the Kosi, Arun and Tamur rivers at Tribeni is 61,000 km^2, of which 26,450 km^2 or 43% lies on the Chinese side of the border in Tibet.

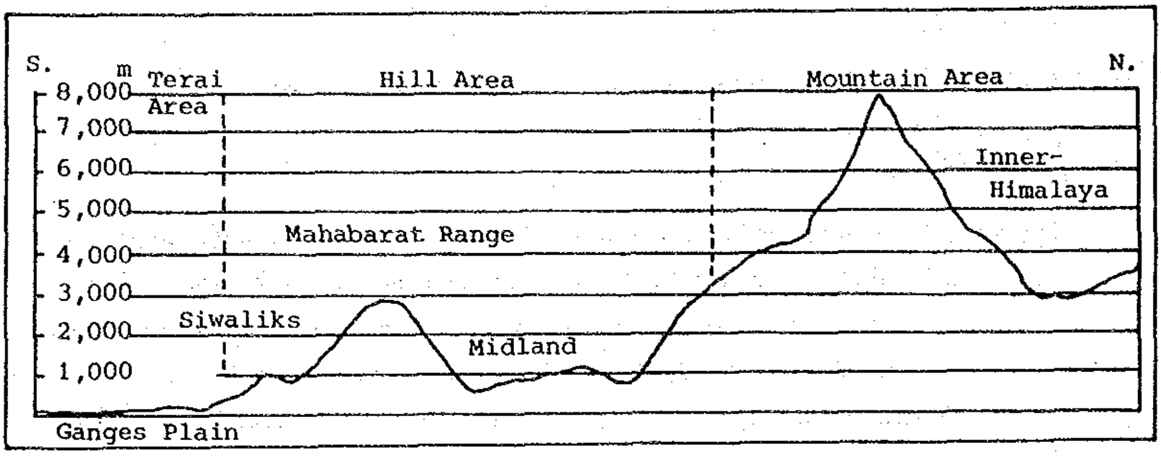
In sequence from the west, the Kosi river is fed by the tributaries Indrawati, Sunkosi, Tamakosi, Liku Khola, Dudhu Kosi, etc. The headwaters of these tributaries are 7,000 m peaks at the Himalaya range and their catchments lie within Nepal.

Eastern Nepal may be broadly grouped into three topographical classifications:

Mountain area
Hill area
Terai area

A simple topographical cross-section of eastern Nepal is presented in Fig. 4-1.

Fig. 4-1 Schematic Topographical Profile of Eastern Nepal



Mountain Area

Mountain area encompasses terrain over 3,000 m in elevation and ranges in a 30 - 40 km swath in width from the Himalaya peaks along the Chinese border southward. Steep topography consists of high mountains and deep valleys. Cultivable land is extremely scarce, and population density is accordingly very low. Peaks in excess of 5,000 m are perpetually snowcapped.

Hill Area

Hill area includes the southern slopes of the Mahabarat and Himalaya ranges as well as broad and relatively gently undulating midlands. Elevations range 300 - 3,000 m.

Climate is subtropical and population density is comparatively high. Rapid deforestation for fuelwood and expansion of cultivable land as a result of ever increasing population poses serious ecological threats of soil erosion and landslide.

Terai Area

Most of the rivers of the eastern Nepal region flow southward from the Mahabarat and Siwalik ranges. These rivers bear sediments which have formed the alluvial Terai plain. Elevations of the plain range 300 - 60 m with a north - south tilt of 1/300 - 1/500. The plain is situated at the northernmost extremety of the Ganges plain.

Until about 15 years ago, the area was largely forested. However, with commencement of a campaign to stamp out malaria in 1958, as well as increasing development of farmland, this area has been greatly deforested. At present, the Terai area is being transformed into a major grain producing region with a corresponding continuing decrease in forested area.

4.1.2 Geology

(1) Stratigraphy

A simple geological map of eastern Nepal is presented in Fig. 4-2. Stratigraphy is indicated in Table 4-1.

Stratigraphy may be broadly classified into 6 groups. Geological ages of these groups are given in Table 4-2.

Table 4-1 Geological Groups of Eastern Nepal

Possible period	Group	Lithology
1. Cenozoic	Recent Siwalik	Unconsolidated sediments gravels and sand, (alluvium) shale, sandstone, conglomerate
		— Main Boundary Fault —
2. Mesozoic - Paleozoic	Tethys	Shale and limestone
3. Paleozoic - Precambrian	Kathmandu Midland	Mainly clastic and carbonate rock Mainly clastic and carbonate rock
		— Main Central Thrust —
4. Precambrian	Himal	Gneiss and schist (highly metamorphic rock)
	Igneous Rock	Granite and paragranite

Fig. 4–2 Geological Map of Eastern Nepal

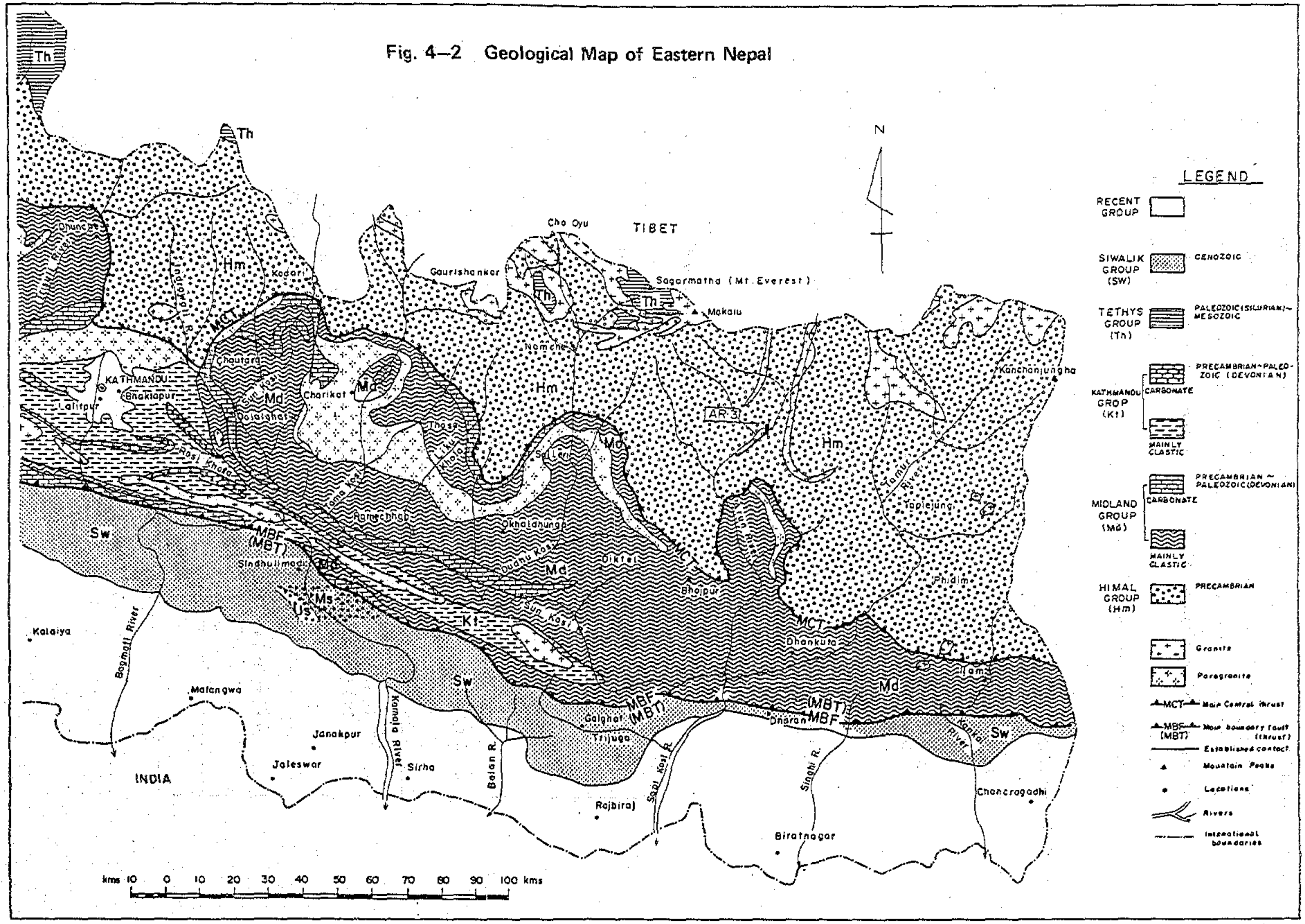


Table 4–2 Probable Age of Geological Formation

Group \ Age	Precambrian	Paleozoic						Mesozoic			Cainozoic		
		C	O	S	D	C	P	T	J	K	P	N	Q
Recent													—
Siwalik											—	—	
Tethys				—	—	—	—	—	—	—			
Midland	- —	—	—	—	—								
Kathmandu	- —	—	—	—	—								
Himal	- - —												
Granite							—				—	—	
Paragranite	- —	—											
Basic Rocks		—	—	—	—								

Geology of eastern Nepal is composed of various types of rock, namely slightly - highly metamorphic rock, marine and non-marine sediments, siliceous - maficigneous rock, etc.

(2) Distribution

Himal Group

Himal group is the oldest formation, believed to have been formed in pre-Cambrian period. The group is composed of highly metamorphic rock consisting of principally augen gneiss and various types of schist, and establishes the sharp terrain of the great Himalayan range.

This group is distributed along the Arun river, north of the Tumlingtar tectonic window.

Midland Group

This group is widely distributed in the hill area and consists mainly of phyllite, limestone, quartzite, and metasediments. These types of rock weather easily, and topography where the Midland group is distributed is relatively gentle.

Where dip of bedding and dip of slope coincide, landsliding readily occurs.

Kathmandu Group

This group is distributed from the vicinity of the Kathmandu valley to the Mahabarat range south of the Sunkosi and consists mainly of calcareous rock and clastics of the pre-Cambrian - Paleozoic periods. Geologic age is approximate to that of the Midland group.

In the Mahabarat range, the group is frequently intruded by granite.

Siwalik Group

The Siwalik group is distributed in the Siwalik range which extends east - west to the south of the Mahabarat range at a maximum elevation of 1,000 m. This group was formed during the Neogene period in the final stage of major Himalayan orogenic movement and consists of fluvial sediments carried from the Himalaya range. Lateral and vertical variation is consequently marked. The group comprises a complex geostructure with numerous east - west folding and faulting. Major components are shale, mudstone, sandstone and conglomerate. These layers are generally low consolidation and weak, than old formation.

Tethys Group

The Tethys group is found mainly in the vicinity of Mt. Everest at elevation over 7,000 m. Distribution of the group in eastern Nepal is limited. Main components are marine pelitic - calcareous sediments.

Recent Group

The Recent group consists of alluvial sediments forming the Terai and Ganges plains. These sediments are comprised of unconsolidated gravel, sand and clay.

(3) Thrust Fault

Distribution of the above described geological units is governed by two major thrust faults which impose an east - west pattern of extension. These thrust faults are:

MCT : Main Central Thrust

MBF : Main Boundary Fault

MCT

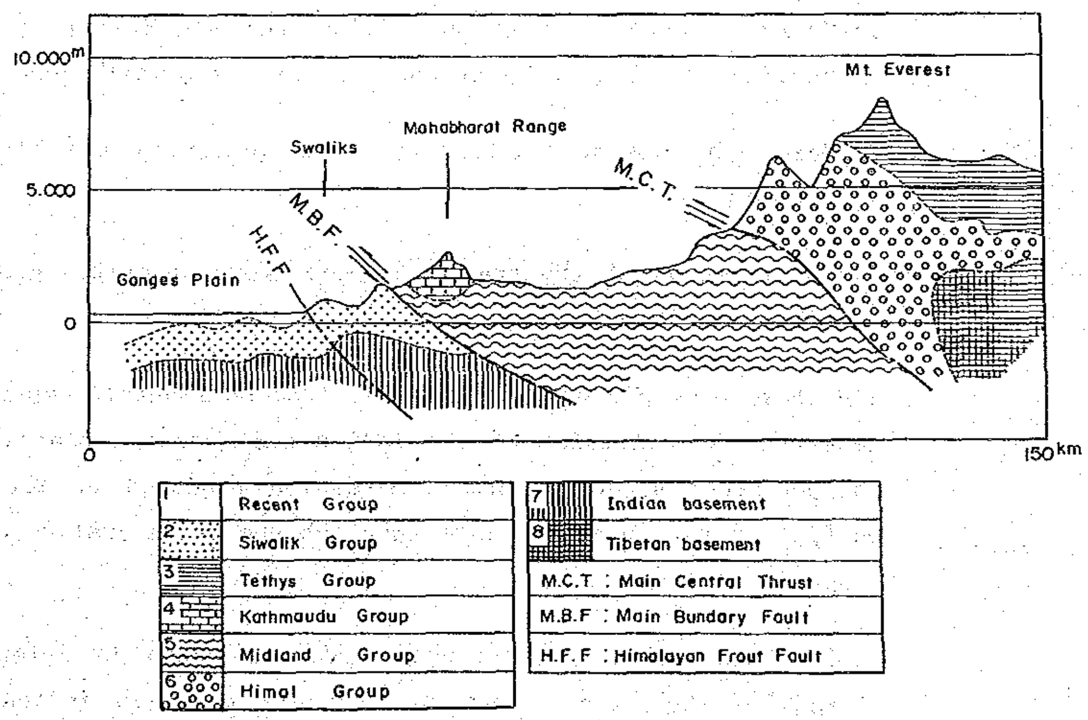
The MCT comprises the boundary between the Himal group to the north and the central Midland group, and bisects the hill area east - west.

MBF

This thrust fault extends east - west forming the boundary between the Siwalik and Midland groups.

The relationship between geologic groups and thrust faults is illustrated in the schematic geological profile in Fig. 4-3 below.

Fig. 4-3 Schematic Geological Profile



(4) Orogenic Movement and Plate Tectonics

Paleontological evidence is necessary to establish correlation between geologic formations. However, in the case of old formations such as the Midland and Himalayan groups, paleontological evidence is lacking due to the susceptibility of these groups to complex tectonic movements.

The two main thrust faults MCT and MBF from the structural lines delineating the geo-structure of the area. These two thrust faults trans-sect Nepal east - west and comprise the boundaries between the various geologic groups.

At present, the neotectonics of the Himalaya region remain unclear. Although there are numerous views regarding the geostructure of the area, it is currently widely accepted according to plate tectonic theory that Himalayan orogenic movement began subsequent to the advent of the Tertiary period.

The series of Himalayan orogenic movements may be briefly described as follows:

a) Upheaval of old sedimentary rocks and central axis during the Oligocene period

b) Maximum orogenic movement during the mid-Miocene period, particularly beginning of upheaval of the Siwalik zone

c) Main upheaval of the Siwalik zone following the Pliocene period

d) Continuation to the present of the above described geological movements

The above orogenic movements result from horizontal compression generated by collision of the Indian and Eurasian plates. It is generally accepted that compression produced at the deep portion of the Eurasian plate supplies the structural force for orogenic movement.

Radiometric dating of intrusive granite which is integrally linked to the final stage of orogenic movement indicates a relatively young age of 15 million years. This bears out the fact that the Himalayan range is comparatively young with upheaval still in progress at present. The region depicted in the geological profile in Fig. 4-3 coincides with the zone of direct inter-plate collision.

The mountain area is in a current process of orgenesis. Soil generated in this area is borne by rivers to their lower catchment areas. Sediment load of these rivers is large for the following reasons: i) maximum rainfall during the rainy season (June - October) exceeds 2,000 mm; ii) heavy weathering of rock occurs due to meteological conditions of high temperature, high humidity and heavy rainfall; iii) vegetal cover of slopes is poor due to steep topography; iv) surface layer is unconsolidated sediments - weathered soil highly susceptable to erosion; and v) river training works and prevention measures for soil erosion are not in effect.

The combination of the above factors results in susceptibility of slopes to landslide and collapse in much of the Study area.

Sedimentation load (suspended load) for the Kosi Basin studied by Dr. C.K. Sharma is presented in the Table 4-3.

Table 4-3 Suspended Load of the Kosi Basin by Dr. C. K. Sharma

River	Catchment Area (km^2) at Tribeni	Annual Sediment (m^3)	Sediment Load (suspension) (m^3/km^2)
Sun Kosi	19,230	54,200,000	2,818
Arun	36,533	34,600,000	947
Tamur	5,900	29,600,000	5,016
Total (Sapt Kosi)	61,663	118,400,000	1,920

4.2 Topography and Geology at the Project Site

4.2.1 Topography

The dam site for the Arun 3 hydropower scheme is situated 190 km directly east of Kathmandu. Access to the site is possible by helicopter, or by aircraft to Tumlingtar and the remaining 30 km from Tumlingtar by foot. Foot trails criss-cross the area, and the trekking path to the dam site is a major route in eastern Nepal, ultimately leading north into Tibet.

The broad highlands and 8,000 m peaks of Tibet, referred to as the "ceiling of the World", constitute the headwater of the Arun river, one of the major river of eastern Nepal. The river flows south through the east - west Himalayan range with ample enough discharge to continue cutting through the massive upheaval of the region.

The Arun river generally flows through steep, V-shaped gorges with consequently only narrow river terrace formations except at points of confluence with tributaries. Twenty five meter high river terrace (one portion being alluvial fan) is located on the left bank downstream of the dam site. This terrace area is relatively wide and level. At 100 m height from the riverbed, a sand and gravel layer of old terrace is present; however, erosion has proceeded to a point where it no longer constitutes a viable topographical unit.

To the west of the dam site, the river shifts direction to the north and then back to the south west before reaching the powerhouse sites (confluence of the Kaguwa Khola and Arun river). River length between the dam and powerhouse sites is 19.4 km, and elevation differential is 281 m. Average riverbed gradient is 15/1,000.

4.2.2 Geology

(1) General Description

Distribution of geological formations within the Project area is indicated in DWG.G-1 and DWG.G-2. The subject area is comprised primarily of gneiss and mica schist belonging to the Himalayan group.

Himalayan group is intruded by Granitic rock and amphibolite whose dip and strike is parallel to the stratification of the gneissosity of the Himalayan gneiss. Although Himalayan gneiss is generally massive and compact, it exhibits various facies depending on the degree of mica content. Gneiss distributed at the dam site is of higher mica content than gneiss at the power station site.

Mica-rich gneiss is distributed in the form of both thin layers of several centimetre to one metre, and thick layers at middle portion of the headrace tunnel alignment. This strata is extensively foliated and of high anisotropy. Foliation is parallel to the general trending of stratification.

° Geostructure

The subject area is situated on the eastern wing of the Arun anticline. Fig. 4-4 presents a schematic geological map of the Arun River. The anticlinal axis extends roughly north-south. As a result, the Himalayan gneiss of the subject area dips to the east.

Gneissosed structure of gneiss at the powerhouse site downstream displays strike of N20 - 30°E and dip of 20 - 30°. Gneissose structure at the dam site strikes N20 - 40°E and dips 45 - 70°. Dip angle increases away from the dam axis.

Apparent superposition of formations (ignoring layer deformation or disorderment caused by faulting, etc.) is indicated in Table 4-4 (successional column based on geological survey).

The Thin Sections[1/] are prepared for the petrological analysis and observed by petrographic microscope. Those results are attached on the Appendix.

A schematic geological map of the Arun 3 site vicinities is presented in Fig. 4-4, adapted from the geological map of a portion of Sankuwa Sabha and Bhojipur districts in eastern Nepal by P.N. Yadav.

The structure which determines the geology of the area is the WNW - ESE trend Ekulade fault running through Kumalgaon. The northern side of the fault is a gneiss distributed area belonging to the Himal group, while the Arun river right bank side is quartz - biotite schist. In addition, the Arun fault extending northwards from Kumalgaon in a N - S trend has also been reported by P.N. Yadav.

1/: A fragment of rock or mineral ground to paper thickness (usually 0.03 m/m), polished, and mounted between glasses as a microscopical slide.

Fig. 4–4 Schematic Geological Map along the Arun River

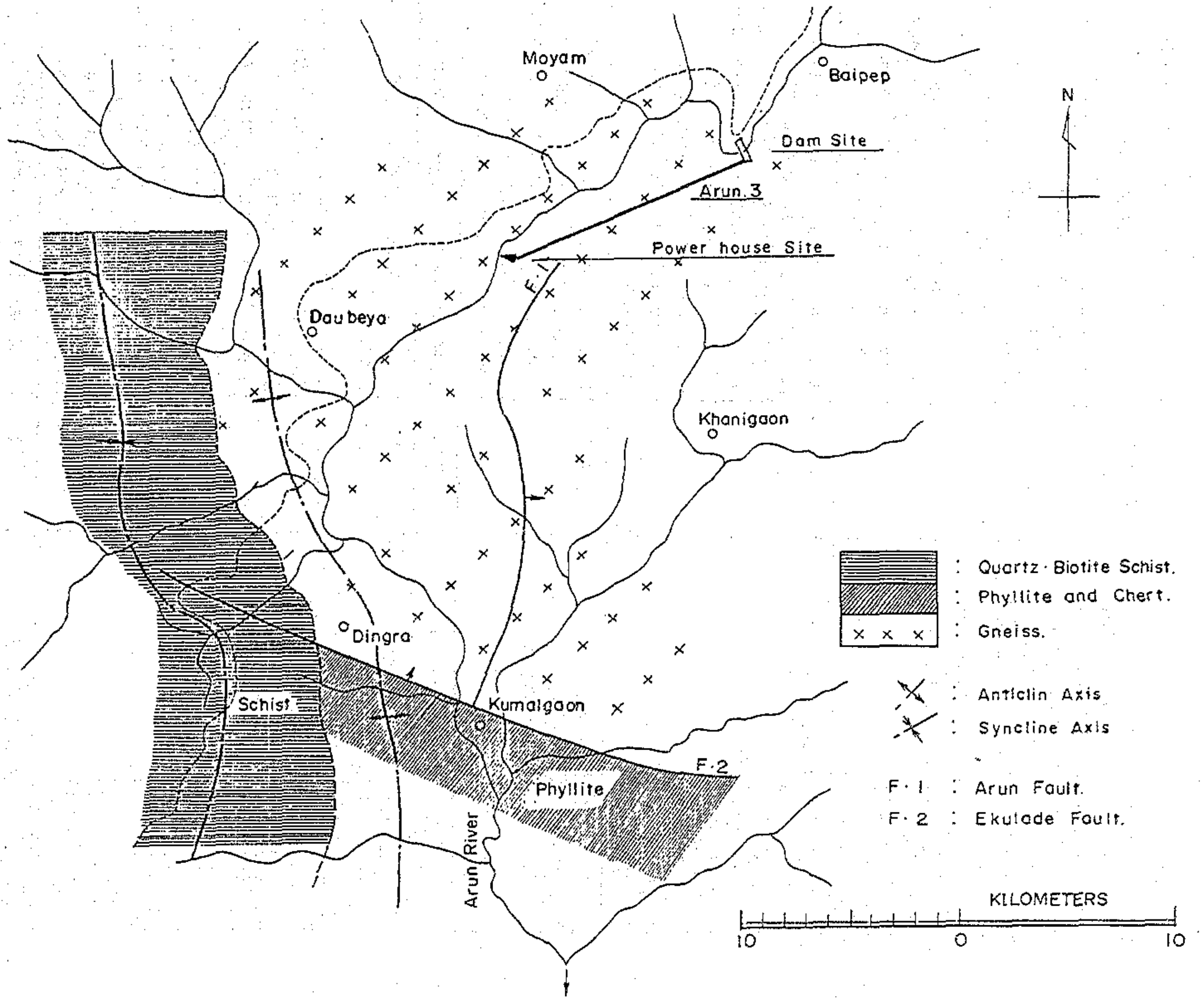


Table 4–4 Geological Successional Column on the Survey Area

Geological symbol	Geological succession	Thickness (m)	Remarks
	Talus deposit Aluvium deposit Terrace deposit		Gravels and sand Clay with breccia Gravels and sand
	Garnetiferous mica schist	370+	Rock facies are soft, having lamella structure. Mica biotite and muscovite, garnet 1m/m in average size, some parts 30 to 50m/m
	Augen gneiss	610	Rock facies are massive and hard. Augen is composed of porphyroblast (feldspar) and very hard. Matrix is composed of fine mica, quartz and feldspar, having strongly gneissosed and anisotropic structure.
	Gneissosed granite (Intrusion)	330	This formation is a composite igneous mass, having weakly gneissosed structure. Contact points are damaged, and constitute sheared zones.
	Augen gneiss	340	Same as upper augen gneiss.
	Gneissosed granite (Intrusion)	370	Same as upper gneissosed granite.
	Garnetiferous mica schist	1,700	Rock facies are soft, having lamella structure. Main minerals are two types of mica (biotite and muscovite), feldspar and quartz. Lenses of segregated quartz are included at some locations and said part is slightly hard. The distribution area of the formation has landslides.
	Gneissosed granite (Intrusion)	420	Same as above gneissosed granite.
	Augen gneiss	100	Same as above gneissosed augen.
	Gneissosed granite	40	Same as above gneissosed granite.
	Augen gneiss	415+	Same as augen gneiss.

(2) Landslide

General

Landslides in the Project area are indicated in DWG G-1. Off-slide material generated by these landslides included large boulders sometimes reaching 10 m in diameter. Landslides producing material of such size are consequently not concluded to be the result of weathered or soft ground.

Generally speaking, collapse of rock slope has been conventionly classified into two types:

i) Rockfalls (wherin material separates from a shear face), and

ii) Sliding (which is governed by slope contour an features of internal geostructure.)

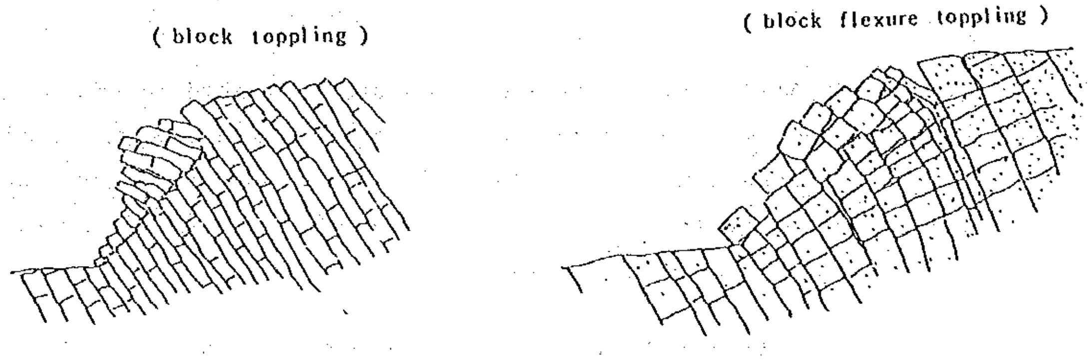
Particularly in the case of sliding, large scale slope collapse is possible. However, there occur slope failures which cannot be explained according to the above classifications and Ashby J.1/ has accordingly identified a third type referred to as toppling.

Mass movement in the Project area may be described as a complex combination of all of the above three types of landslide.

Two types of toppling referred to as flexural toppling (wherein the cross joint is the separation surface), and block toppling are illustrated in Fig. 4-5.

1/ Ashby J. : "Sliding and Toppling Modes of Failure in Models and Jointed Rock Slopes", M. Sc. Thesis, London University, Imperial College, 1971.

Fig. 4—5 Pattern of the Collaps Forms



Landslides in the Project Area

Landslides are indicated on the geological map in DWG. G-1 with area of slope failure numbered.

No.1

Location : Indua Khola left bank
Crest of slide : EL 1,040 m
Scale : 100 m width x 500 m slope length
Slope angle : average 43°
Geology : Mica schist

Landslide lies near the pondage area. Off-slide debris reaches to the Khola. The landslide zone is still active with a good likelyhood of sliding spreading to the upper slope. Slope gradient is steep at around 40°. Ground consist of low strength mica schist.

Relevance to dam plan: Design intake elevation is roughly 840 m. Although backwater following dam-up is not planned to reach this landslide zone, the presence of a source of potential debris entering the Indua Khola upstream of the dam site in addition to the sediment load of the Arun, could pose problems in dam operation and maintenance. For this reason, relevant countermeasures are recommended subject to further surveys.

No.2

Location : Dam axis right bank

Crest of slide : EL 925 - 850 m

Scale : 30 m width x 120 m slope length

Slope angle : average 30°

Geology : Augen gneiss overlain with talus deposits

Landslide is located on the right bank directly on the dam axis. Off-slide materials is loose talus deposit (bed thickness 5 - 10 m). Failure damage does not extend to baserock. Crest constitutes a steep face of several meters and appears stable at present.

No.3

Location : Left bank 1 km downstream of the Arun suspension bridge

Crest of slide : EL 1,020 m

Scale : 30 m width x 100 m slope length

Slope angle : average 32°

Geology : Augen gneiss overlain with talus deposits

Although this landslide block is small compared with others, it is currently active with danger of spreading laterally as well as vertically. However, the landslide has no direct bearing on the subject hydropower scheme.

No.4 (Bhimal Pahiro)

Location : Southeast slope at Num village

Crest of slide : EL 1,375 m (old crest : EL : 1,400 m)

Scale : 150 - 200 m width x 300 m slope length

Slope angle : average 56°

Geology : Fine grained granite, partly gneissosed

This landslide has a clear arc shaped crest. Type of movement is mainly toppling whereby rock has stripped away along gneissosed plains and dense joint plains running parallel to the slope.

Off-slide debris is relatively scarce at the site despite the relative large scale of the landslide block. This suggests that a major portion of said debris is washed off by the abundant rainfall of the region into the Num Khola where it is subsequently carried down to the Arun river. One portion of this material is assumed to have formed the alluvial fan at the confluence of the Num Khola and the Arun river. Sliding is believed to have begun around 1974. The block is still active and can been expected to expand both laterally and vertically.

Relevance to dam scheme: As discussed above, the slide is currently active and as a result there exists the danger of expansion of slide area. The fact that debris generated by sliding is rapidly carried downstream, as well as the fact that the landslide block is approximately 700 m from the Arun river, the dam axis was selected above the confluence of the Arun with the Num Khola to limit the problem of sedimentation.

No.5

Location : Southeast slope at Khokda village
Crest of slide : EL 1,320 m
Scale : 80 m width x 130 m slope length
Slope angle : average 56°
Geology : Mica schist bedrock overlain by talus deposit

This landslide block exhibits a clear slide crest. Slide damage extends to weathered portion of bedrock (mica schist) as well as surface overburden (4 - 5 m bed thickness). Landslide activity is in its initial stage, and extent of landslide block area may be expected to expand in the future.

Relevance to dam scheme : This landslide block is determined to have no direct effect on the dam scheme.

No.6

Location : Kharsu village slope
Crest of slide : EL 1,625 m
Scale : 400 - 600 m width x over 1,000 m slope length
Slope angle : average 25°
Geology : Mica schist bedrock overlain by talus deposit
(See No.7 for descriptions.)

No.7

Location : East side of Kharsu village slope
Crest of slide : EL 1,625 m
Scale : 600 m width x 1,000 m slope length
Slope angle : average 25°
Geology : Mica schist bedrock overlain by talus deposit

Landslide blocks 6 and 7 both exhibiting large-scale are shaped scarfs at EL 1,625 m. A major portion of off-slide material is washed away exposing bedrock at the valley bottom. These landslides are considered to have no direct effect on the dam scheme.

No.8

Location : Southwest slope of ridge running northwest from peak (1,775.8 m) between Kharsu and Diding villages

Crest of slide : EL 1,550 m
Scale : 1,000 m width x over 2,500 m slope length
Slope angle : average 25° - 30°

A large arc shape knick point is evident at around EL 1,100 m on the slope between Darbote and Kaguwa Kholas. Below this is a 250 m high cliff. The southern side of this zone is largely covered with talus deposits. Talus material is generated from a location around EL 1,700 m.

Although collapse at this site encompasses a large area, bedrock outcropping is evident at some points on the slope and in the valley and it is subsequently concluded that a major portion of off-slide material has been washed away. As new debris has not been generated to cover the above mentioned exposed bedrock, at present the slope is considered to be stable.

Relevance to powerhouse plan: The slope from the surge tank (planned at Pikhuwa) to the Arun river is covered with Talus deposits above EL 775 m. On this talus slope are scattered boulders of diameter in excess of 10 m and estimated weight of several thousand tons. If power generating facilities are designed above ground, either removal or anchoring, etc. of these boulders will be necessary during penstock construction. Furthermore, reinforcement of the talus slope would be required upon completion of construction to protect the powerhouse facilities below.

As a result of the topographical and geological conditions described above, the power generating facilities in this zone are planned to be underground for reasons of safety.

4.3 Geology and Topography in the Vicinity of Dam Site Area

4.3.1 Topography

The Arun River is one of the major rivers of Eastern Nepal. Its headwaters are in the Himalaya mountains and Tibet highlands. The river is a classic antecedent stream flowing southward through the uplifted Himalayan massif (extending east - west). The ample discharge of the river has enabled it to continue with the help of erosion cutting through the still rising Himalayan massif.

The Arun River valley generally comprises a steep "V" shaped gorge, with riverbed terracing occurring essentially only at confluence points with tributaries.

On the left bank, downstream of the dam site, the river terrace which is 25 m deep (one portion is in combination with alluvial terracing) forms a relatively wide flat area.

An old terrace gravel bed is observed at about 100 m high from the present riverbed in the left bank of dam site area. However, due to limited distribution and extensive erosion, this formation is not sufficiently widespread to comprise a topographical unit.

In this area, slope failure zones governed by geological composition are widely present. These include landsliding where slippage occurs along bedding planes, toppling where slippage occurs along joint planes, and talus slope failure of secondary sediments resulting from the first two types of slippage.

Landslide failure is present on the right bank at the dam axis. This failure comprises a typical example of bedding plane slippage where the present topographical surface and bedding plane surface are essentially the same.

4.3.2 Geology of Dam Site

A geologic map and geologic cross-section map of the dam axis vicinity are indicated in DWG.G-3, G-4, G-5 and G-6. Geological and topographical features at the dam axis are as follows:

- o The main component of foundation rock is Augen gneiss.
- o Augen gneiss consists of feldspar porphyroblast (1 cm x 2 - 3 cm), and smaller granuled quartz. Thin mica of 1 millimetre to several millimetre surrounds the feldspar porphyroblast. Fluctuating anisotropy exists in relation to a specific amount of mica.
- o Augen gneiss is intercalated with mica schist - micaceous gneiss along with amphibolite and granite of less than 1 m. At the dam axis, 2 layers of mica schist are present.
- o Mica schist is extensively foliated, exhibiting extremely strong anisotropy. Rock is weak in comparison with gneiss.
- o Elevation of the present riverbed is 780 m. Gravel bed thickness is around 12 m.
- o Gneissosity at the dam axis is generally N30°E strike and 60°E dip. However, undulation results in some variation in strike (N20° - 40°E) and dip (50° - 60°E).

- Consequently, the basement apparently dips 50° from the right bank to the left bank.

Right Bank

- Right bank basement at the dam axis consists of Augen gneiss.

- From the riverbed to EL 805 m, slope gradient is 70°, to elevation 850 m, gradient is 40° and the upper slope portion exhibits a gradient of 25°.

- The right bank geological formation has an apparent dip angle of 50°. At the slope between EL. 810 m and EL. 825 m is covered by talus deposit of maximum thickness 4 m and also bedrock grows loose.

- UDH-6 drilling indicates that mica schist distributed at a depth of 34.00 - 34.75 m follows the right bank slope 10 m below the surface. This bed is a source of landsliding.

- Excluding one portion, talus deposits located immediately upstream of the dam axis on the right bank comprise a landslide zone.

Riverbed

- Riverbed elevation is 794 m, with river width at 50 m. During the dry season, a 15 m wide stretch of the left bank side becomes dry land, with the main current of the Arun River flowing along the right bank side. (During the rainy season, this dry land section is completely submerged.)

- Flood mark in the vicinity of the dam axis is 5 m above water level during the dry season.

- The riverbed consists of sandy gravel comprising primarily gneiss of large to small sized cobbles.

- Basement Augen gneiss is both massive and hard. However, at UDH-1 and UDH-6, 2 beds of mica schist were identified. The results of core observation and Lugeon testing show a Lugeon value (5 Lu) trending slightly higher than that of the surrounding rock. Nevertheless, as a dam foundation, this basement presents no problem.

Left Bank

- o The left bank basement consists primarily of Augen gneiss.
- o From the riverbed to EL.830 m, slope gradient is a steep 75°. To EL.850, slope gradient drops to 35°. Above 850 m, a talus slope covering the depressed topography of the upper left bank slope is present.
- o On the lower steep slope, massive and hard Augen gneiss outcrops occur. This basement presents seepage problems as a dam foundation.
- o At EL. 810 m, a thin bed (20 - 30 cm) of amphibolite is present in 3 layers. In outcrops, amphibolite structure is consonant with that of Augen gneiss, with tight boundaries. In comparison with gneiss, amphibolite is somewhat soft; however, as distribution is small, no problem is present.

4.3.3 Geology of Intake

The location of intake has been selected on the left bank. Upstream of the dam axis, a micro-folding zone extends from the right bank through the Arun River to the left bank side. On the left bank, this zone forms a small depression covered with talus deposits which prevent direct visual inspection of the rock mass condition.

At UDH-9, the basement is Ch-Cm[1/] class Augen gneiss similar to that at the dam axis. Rock is stable. A site downstream of UDH-9 would be considered appropriate for the tunnel inlet.

4.3.4 Geology of Desanding Basin

The desanding basin for the Arun-3 hydropower scheme is planned underground on the left bank at the confluence of the Arun River and the Khotak Khola. Hilly terrain at this point extends from the southeast to the northwest. Valley slopes are a steep 60° or more, with ample space for excavation of an underground desand basin.

1/: The quality classifications of the foundation rock is shown on the geological sections and profiles mentioned below. Some quality classifications have still to be codified but those classification now used only in Japan.

Examples of Quality Classifications of Rock in Dam Foundation

Classification	Characteristics
A	Rock-forming minerals(1) are fresh and not weathered or altered. Joints and cracks are very closely adhered with no weathering along their planes. A clear sound is emitted when hammered.
B	Rock-forming minerals are weathered slightly or partially altered, the rock being hard. Joints and cracks are closely adhered. A clear sound is emitted when hammered.
C_H	Rock-forming minerals are weathered but the rock is fairly hard. The bond between rock blocks is slightly reduced and each block is apt to be exfoliated along joints and cracks by strong hammering. Joints and cracks sometimes contain clay and other material which may be coloured by limonite. A slightly dull sound is emitted when hammered.
C_M	Rock-forming minerals are weathered and the rock is slightly soft. Exfoliation of the rock occurs along joints and cracks by normal hammering. Joints and cracks sometimes contain clay and other material. A somewhat dull sound is emitted when hammered.
C_L	Rock-forming minerals are weathered and the rock is soft. Exfoliation of the rock occurs along joints and cracks by light hammering. Joints and cracks contain clay. A dull sound is emitted when hammered.
D	Rock-forming minerals are weathered, and rock is very soft. There is virtually no bond between rock blocks, and collapse occurs at the slightest hammering. Joints and crakcs contain clay. A very dull sound is emitted when hammered.

(1): Except quartz

In this zone, test boring at UDH-7 and seismic prospecting at A, B were undertaken. Results of this testing are presented in the geological cross-section map in DWG.G-6.

A folding zone is passing in the east portion slope with strike N 20 - 30°E and dip 50 - 60°E. This zone is a tectonic zone several tens of meters in thickness with extensive open jointing. Mica is concentrated in one portion forming a weak shear zone.

The excavation site for the desanding basin consists primarily of Augen gneiss distributed below EL 850 m. Geological features of the site are as follows:

- o Excavation area on the cross-sectional line of DWG.G-6 is a 200 m section below EL.850 m (width: 25 m; length along axis: 100 m).

- o Seismic prospecting indicates that the Vp of the basement in this zone is 4.4 - 4.5 km/sec. Almost the entire basin can be set in Ch[1/] class rock.

- o At the central portion, a low velocity zone (crack zone or micaceous zone) of 10 m width is distributed parallel to the geologic structure. The Vp velocity of this low velocity zone is believed to be an intermediate 2.3 - 2.4 km/sec. In comparison with the basement, this rock is of CM[2/] class with extensive jointing. However, rock strength presents no problem. Nevertheless, seepage problem remains with regards to permeability.

- o Permeability Evaluation

  Lugeon value trending for UDH-7 is given in DWG.G-6. A maximum value is 11.8 Lugeon, minimum is 0.4 Lugeon and average Lugeon value is 6.5. Lugeon value expresses the amount of water transmission per 1 m per 10 kg/cm^2 of injection pressure. As maximum static water pressure of the desand basin is 4 - 5 kg/cm^2, permeability of rock at the site presents almost no problem.

  Cement grouting will be performed where necessary to prevent water seepage. However, as water transmission occurs in this rock along joints only, grouting can be performed relatively easily.

1/, 2/: See foot note on page 4-24.

4.4 Headrace Tunnel

4.4.1 Topography

The entire route of the headrace tunnel is through steep hilly terrain. The upstream section above Solakhani village at roughly the halfway point along the route passes diagonally through the NE - SW ridge axes (ridge line runs at 1,500 - 2,000 m elevation).

On the other hand, the section downstream of Solakhani village passes through terrain of lower elevation (1,100 - 1,300 m) comprising the left bank of the Arun river. Ravines of the Suki Khola, Rarau Khola, etc. are found on this slope. Where the tunnel route passes under Suki and Rarau Kholas, elevation is around 900 m.

Tunnel overburden is in excess of 400 m for over 52% of the entire tunnel route, with maximum overburden being 1,050 m. Tunnel overburden is under 100 m for 240 m of the upstream section in the vicinity of Khotak Khola and 200 m in the vicinity Suki Khola, or 4% of the entire tunnel route.

4.4.2 Geology of Designed Headrace Tunnel

Geological map covering the project site is in the attached DWG.G-1 and G-2.

The geology of the project area consists of metamorphic rocks and intruded granite.

Metamorphic rocks are divided into two members, namely gneiss member and mica schist member.

The gneiss member is charactering by the included Augen porphyroblast. Rock facies of the Augen gneiss are massive and compact. The "Augen" (eye in German) is composed of porphyroblast of feldspar and rather hard. The matrix of the Augen gneiss is consisted by fine grained mica, quartz and feldspar etc. having clear gneissose structure causing strong anisotropy.

The mica schist is less compact and easy to be foliated, showing lamella structure and strong anisotropy. Mica schist consists of two mica (biotite and muscovite), feldspar and quartz etc. and invariable garnet of one millimetre in average size, in some places giant garnet crystals, one to five centimetres in diameter, were observed. Segregation-quartz lenses are included at some locations and said part is little bit harder than the schist without the quartz lenses. At surface many landslides were observed in the area of the Mica schist formation.

Granitic rock member is fine grained and leucocratic with weak gneissose structure. The crystals of tourmaline occurs in the granitic rock in some places and observed in Augen gneiss and also along the contact with Mica schist. As the granitic rock mass near powerhouse site contains the low velocity zone or sheared zone detected by seismic prospecting and also proved by diamond drilling, the rock mass results less stable foundation rock. The rock mass expected to occur between 0.6 km to 4.57 km of the headrace tunnel is accompanied by argillized zone of 1 m to 10 m thick and the zone is commonly observed on the ground.

General geological structure of the area is N20 - 30°E in strike and dipping 20° - 60° to the East. In appearance, lower formation is observed at the down stream area (powerhouse site) and upper formation is at the upstream area (Dam site). In other words those strata superpose from lower formational horizon at the down stream to the upper horizon at the upstream.

Headrace longitudinal axis and bed strike intersect at an acute angle of approximately 38°.

Abovementioned strata represent typical metamorphic rock zone (Himalayan gneiss zone) developed along the frontal zone of the High Himalayan belt, developed widely and distributed continuously.

The geological profile along the headrace tunnel titled "Headrace tunnel profile and geological section" is shown DWG.G-2.

The following geological formations are found along the headrace route in order of sequence from the intake side: augen gneiss, gneissosed granite, augen gneiss, gneissosed granite, mica schist, gneissosed granite, augen gneiss. Those relationship is given by

Fig. 4-6 of Schematic Geological Profile along Headrace Tunnel Alignment.

The total length of the headrace tunnel is 11.4 km. Geologically, 22.3% of the total length of the tunnel formation is occupied by Augen gneiss, 31.4% by Genissose granite and 46.3% by Mica schist.

At contact points, gneissosed granite exhibits fracture zones with clay. This is particularly evident in rock northeast of Solakhani village. Such fracture zone is not considered to affect the design formation of the envisaged tunnel. Length of the fracture zone is 130 m, or 3.7% of the total 3,550 m length of gneissosed granite formation.

The above mentioned fracture zones with clay are situated north of the Arun fault reported by P.N.Yadav, and there is a strong possibility that they are an extension of the same fault.

4.4.3 Geotechnical Considerations

(1) Physical Characteristics

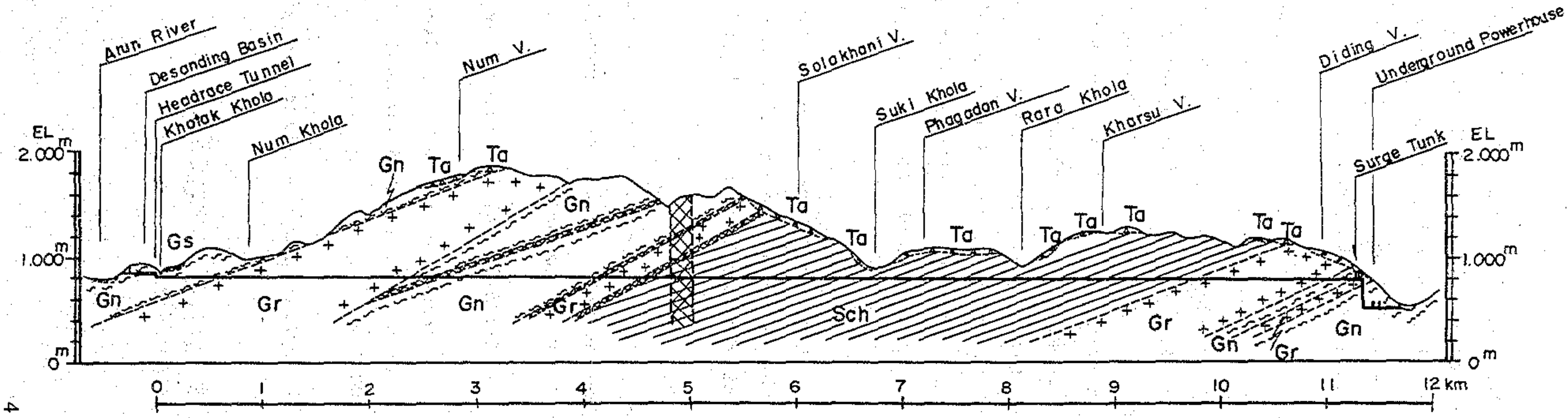
Laboratory testing was conducted on sample cores obtained through test boring. Data were grouped into reservoir side and power station side and average values were calculated. Results are indicated in Table 4-5.

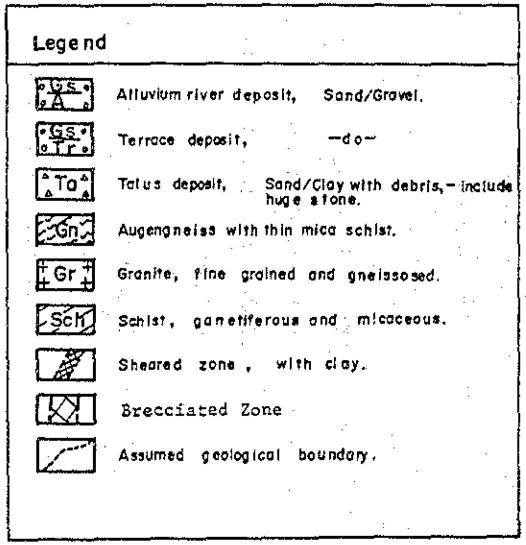
Table 4-5 Physical Characteristics of Foundation Rock

Physical Properties \ Zone		Dam site	Powerhouse site	
Rock		Augen gn	Augen gn	Gr
Bulk specific gravity	Natural	2.71	2.67	2.66
	Dry	2.70	2.66	2.65
	Saturated	2.70	2.67	2.66
Absorption (%)		0.7	2.72	0.5
Net porosity (%)		1.3	2.72	1.4
Water content (%)		0.3	2.72	0.5
Unit weight (g/cm^3)		2.72	2.72	2.65
Velocity of supersonic wave km/s	Vp (km/s)	2.91	3.45	2.87
	Vs (km/s)	1.85	1.99	1.62
	Edc (10^5kg/cm^2)	5.41	2.59	1.46
	Dc	0.21	0.27	0.34
Unconfined compressive strengh (kg/cm^2)		156	442	599

Note: Edc: Dynamic modulus of eleasticity
Dc : Dynamic poisson's ratio

Fig. 4—6 Schematic Geological Profile along Headrace Tunnel Alignment





During the subject survey, test drilling was not conducted in the main formation of mica schist widely distributed around Suki Khola. Furthermore, only short core - fragmentary samples unsuitable for laboratory testing were obtained in the case of drilling the mica schist intercalated with gneiss.

Gneissosed granite exhibits superior unconfined compressive strength with an average value of 600 kg/cm^2. Gneiss in the vicinity of the powerhouse site shows an average strength of 440 kg/cm^2, which is three times the value of 150 kg/cm^2 for gneiss near the reservoir site. This contrast in strength is due to variation in geologic structure of the gneiss and not because of differences in degree of metamorphism or mineral assemblage. In other words, the difference in strike of beds of the two zones (in contrast to the low angle of around 20° on the powerhouse side, the reservoir side exhibits a relatively high angle of 40 - 60°) results in a variation in unconfined compressive strength.

This highlights the important fact that rock strength may be anticipated to vary greatly depending on geological structure. This is particularly true of metamorphic rock of high anisotropy.

Strength of mica shist is considered inferior to the two types of formation discussed previously. Estimated unconfined compressive strength is a maximum 100 kg/cm^2.

(2) Geology of Tunnel Formation and Geotechnical Considerations

Classification of bed rock for tunnel excavation[1/] is given in Table 4-6. Geological distributions anticipated along the tunnel route are indicated in DWG.G-2.

Characteristics of each lithological classification are given in Table 4-7.

1/ Design Criteria, Chapter 3, Section 9 ("Tunnel"); Japan Road Public Corporation; 1985.

Table 4–6 Classification of Bedrock for Tunnel Excavation

Classification of Bedrock	Type of Rock	Seismic velocity (Vp, km/s) 1.0 2.0 3.0 4.0 5.0 6.0	Drilling: Core condition	Drilling: RQD %	Geological condition (Result of field geological survey)	Observation: Reaction when hammered	Observation: Interval of Joint (cm)	Assumed condition after excavation: Assumed geological conditon after excavation	Assumed condition after excavation: Space displacement (mm)
A	a, b, c, d1		• Core recovery is usually more than 90%. Core condition is completly columnar, usually more than 20cm in length.	90	• Very hard, fresh, massive less jointed and stable.	Hammer rebounds. Only slightly breaks when strongly hammered. Breaks along fresh planes	Above 50~100	• Plastic ground pressure is not active • Height of looseness : less than 1.6m	very small
B	a, b, c, d1		• Core recovery is usually more than 70%. Drilling core condition : includes incomplete columnar portion and fragments. For the most part core length is more than 5cm.	70~90	• Fresh, hard and comparatively less jointed. • Markedly hard but slightly altered by weathering. • Hard but layered; bedded and schistossed planes are developed; easily broken along said planes.	Breaks when strongly hammered. Breaks in large pieces mainly along cracks and joints.	30~70	• Generally plastic pressure is not active, but may activate in presence of shear zone and water seepage. • Height of looseness : 1.5~3.0m	very small
C I	a, b, c, d1, d2		• Core recovery is mainly 40~70%. • Drilling core condition is cracky and fragmental, and easily breaks mainly into splinter fragments of less than 5cm in length.	10~70	• Altered by weathering. • Comparatively hard with fine joints; thin clayey materials in opening spaces of joints. • Markedly layered and schistossed rock easily broken as lamoliae. • Narrow faults.	Breaks easily only along cracks, when hammered. Breakage is in comparatively small pieces.	below 50	• Plastic ground pressure often is active. • Height of loose or plastic zone : 2.0~4.0m	below 50
C II	a, b, c, d1, d2								
D I	a, b, c, d1, d2, e		• Core recovery is low, mainly less than 40%. • Core condition is mainly splinter fragments; sometime sandy with breccia and/or argillaceous.	below	• Heavily weathered; partly altered to soil having some hard remaining portions; soft, brittle and cracky. • Sheared zone wherein argillization is not highly developed; clay and fragmental rock are mixed and include some hard portions • Soil and talus zone.	Easily broken when hammered. Rock is brittle and can be easily broken with finger tips.	-	• Plastic ground pressure, and occasionally large unbalanced pressure is active. • Height of loose or plastic zone : 3.0~6.0m	below 60
D II	a, b, c, d1, d2, e					Breaks when only slightly hammered. Pick hammer sticks into rock.	-		below 200
E	a, b, c, d1, d2, e			-	• Fairly thick faulting with clay • Shear zone and thick talus zone which are subject to marked unbalanced pressure.			• Plastic ground pressure, and often marked unbalanced pressure is active. • Plastic zone : more than 7.0m	below 400

Note : Type of Rock
- a: Metamorphic rock (phillite, graphite schist, quartz schist, green schist, gneiss, etc.) Plutonic rock (gabbro, ultrabasic rock, etc.)
- b: Paleozoic and Mesozoic (slate, sandstone, conglomerate, wacke, limestone, chart, schalstein, etc.)
- C: Volcanics. (rhyolite, andesite, basalt, etc.) Intrusion (granite porphyry, quartz porphyry, porphyrite, diabase, etc.) Plutonics (granite, diolite, etc.)
- d: Tertiary and lower Diluvium (mudstone, sandstone, shale, tuff, tuffbreccia, agglomerate etc.) However, d_1: $qu \geq 200kg/cm^2$; d_2: $qu < 200kg/cm^2$
- e: Upper Diluvium (loam, clay, volcanic clastics, etc.) Aluvium (talus, top soil, etc.)

(from "Japan Public Road Corporation")

The section of mica schist occurrence (segment of thin overburden, and fracture zone) requires careful selection of tunneling method. Consequently, it will be necessary to excavate a test adit at the center portion of the tunnel route to accurately identify strength and deformation characteristics of the ground.

(3) Applicability of Tunnel Boring Machine (TBM)

As stated in 10.4.5, it is planned to use TBM for excavation of tunnel section of 7.5 km long of headrace tunnel (11.4 km in entire length) upstream of intermediate work adit.

It is presumed from the geological point of view that augen gneiss and gneissosed granite, mica schist and sheared zone are distributed in this section at percentages of 55%, 36% and 9%, respectively. Augen gneiss and gneissosed granite have their compressive strengths ranging from 440 kg/cm^2 to 600 kg/cm^2 according to the test results of rock specimens taken from cores drilled and are considered to be a sort of rock best suitable for the rapid excavation by TBM. The compressive strength of the mica schist is assumed to be approximately 100 kg/cm^2, therefore it can be easily excavated by TBM but low work progress is expected in the mica schist zone since some fine grained rock material may be adhered to the cutter head. Consequently, it is judged that TBM application will increase the total average excavation progress in comparison to the conventional blasting method.

However tunnelling method with TBM is less flexible to the change of geological conditions compared with coventional blasting method. When the undesirable conditions such as faults, abrupt decrease in rock strength at fractured zone, massive water seepage often observed in DI-d2 and E-DI-c zone, etc. which are sometimes unforeseen in advance it is a common practice to utilize relevant auxiliary countermeasure most suitable to each case to keep the TBM tunnelling progress.

Selection of the TBM cutter head and other mechanical options should be finalized by the detail studies of the geotechnical information from exploratory adit.

Detail construction plan of the tunnel including tunnel lining is described in 10.4.5 (1).

Many records of tunnel driving by TBM through the similar rock formation have been released.[1/]

1/ Robbins: Tunnel Machine Projects, Jan. 1981, USA
Wirth : Actual Results by TBM, West Germany

Table 4–7 Characteristics of Lithological Classifications

Lithological classification	Length of distribution	Distribution ratio (%)	Characteristics
B-a	2,550m	22.6%	qu 1/ exhibits 150~600kg /cm2 variation in augen gneiss. Tunnel face is stable. Although excavated surface without timbering shows some surface collapse at points, it is generally stable. However, timbering will be necessary at points of loose ground.
B-c	3,440m	30.4%	Fine grained gneissossed granite has qu of around 600kgf/cm2.
Cl-a~Cl-d_2	4,290m	38.0%	Mica schist zone with estimated qu = 100kgf/cm2. Tunnel face is stable. Excavated surface shows some surface collapse in vicinity of ceiling requiring timbering.
Dl-d_2	880m	7.8%	Consists of cracky zone in mica shist and zone of thin overburden directly below Suki and Rara kholas. Deterioration of rock from water seepage accompanying excavation is a source of plastic ground pressure and unbalanced pressure.
E~Dl-c	130m	1.2%	Cracky zone occuring along with clay in fine grained granite. Peripheral pressure causes extrusion to occur at face.
Total 2/	11,280m	100%	--

1/ qu: unconfined compressive strength
2/ Total tunnel length includes segment from end of sedimentation basin to surge tank.

4.5 Geology of Powerhouse Site

4.5.1 Topography

The powerhouse site is situated 11 km southwest of the dam site.

Two powerhouse sites were examined in this study. These are the Pikhuwa site, and the Kaguwa site 1.1 km further downstream. Both sites are on the left bank of the Arun. In the vicinity of the sites, the Arun River runs roughly north-south with a thin band of terrace plain distributed along the river course. Relative height from the water surface to the terrace top during the dry season is 10 - 15 metres.

On the left bank, landslide zones are present on the upstream slope of the Pikhuwa site and on the upper portion of the slope at the Kaguwa site. The location of those landslide zones is the principal governing factor in determination of headrace tunnel outlet and surge tank position.

Left bank slope at both power station sites features numerous small rivulets which exhibit no surface flow during the dry season.

4.5.2 Geology

As with the upstream dam site, the geology of the area is classified as belonging to the Himalayan gneiss zone, and consists of augen gneiss intercalated with geneissosed granite.

Preliminary visual inspection indicates that such formation in the vicinity of the powerhouse site is apparently located lower in terms of columnar succession of bedding than that at the dam site. Augen gneiss is intercalated with mica schist of units ranging in size from several cm to several m.

In appearance, foundation rock at the sites is lower than that at the dam site, and exhibits the following characteristics:

o In general Augen porphyroblast of feldspar contained in the gneiss is of fine granularity. Augen porphyroblast contains little mica.

- o Consequently, anisotropy of micaceous gneiss and mica schist is small in comparison with gneiss at the dam site.

- o Gneissose granite rock mass distributed concordantly with the general geological structure of the region, can be called composite mass or gneissose granitic complex because of the various rock facies. Seismic prospecting have directed many zones of low velocity in the bedrock and most of the zones are geologically correlated to the sheared zones with clay in places.

4.5.3 Pikhuwa Powerhouse Site

(1) Topography

A river terrace with a width of 180 m and a length of 500 m is distributed along the Arun River at this site. Said distribution is at the lower portion of the slope with an average 50° gradient. River terrace consists of low depositional terrace formed by the present river, and high terrace 15 - 16 m above the river surface during the dry season. Terrace is composed of gravel bedding, with one portion utilized for paddy cultivation and the remainder as pasturage. The high terrace is 110 m wide and 400 m long.

<u>In case of surface type power scheme</u>

The power station site is located on the downstream portion of the terrace. Penstock line is to be routed on the slope, and will run roughly E - W. The slope approximately 100 m upstream of the penstock route is covered with talus deposits.

The penstock route is over an entirely rock slope of 40° mean gradient from the riverbed, EL.540 to EL. 770 m. Above this to elevation EL.140 m, average gradient is 30°, and covered with talus deposits.

(2) Geology

Geology of the vicinity of the Pikhuwa power site is shown by DWG.G-7. Maximum elevation of terrace distributed at the riverbed is 552 m. Terrace is composed of gravel containing large cobbles.

- o According to P-1 drilling during the pre-F/S stage, the boundary between the terrace gravel bed and gneiss is at EL. 520 m.

- o Seismic prospecting indicates a Vp velocity for the terrace gravel bed of 2.2 - 2.5 km/sec. This is a higher seismic wave velocity than usual for unconsolidated sediment. The reason for this is that particularly the lower portion of the gravel bed is densely packed and/or is saturated with groundwater.

- o As shown in the geologic profile in DWG.G-9, talus deposits are widely distributed above the point (EL. 760) where slope variation occurs. Talus consists of fine soil, gneiss breccia and fragments which are unconsolidated and loose.

- o The upper part of the slope for the penstock, 800 m to 850 m above sea level and higher, is covered by thick talus deposits.

- o The maximum thickness of the talus is more or less 30 m observed at P-8 drilling point and the upper slope where the surge tank is being planned.

- o The underground water level during the rainy season (September) in 1986 at the P-8 drilling point was ground level minus 43 m (GL-43 m) suggesting preferable condition in excavation for construction.

- o Numerous boulders, some as large as 10 m in diameter, are scattered over the talus slope.

- o Foundation rock along slope is composed of gneiss at the lower part, and intruded with granite or gneissosed granite at the upper penstock line.

- o Intrusives are concordant with structure, strike (N 20 - 30°E) and dip (20 - 40°E) of gneiss.

- o Gneissosed granite is fine grained rock exhibiting leucocratic, compact rock facies, having gneissosed structure.

- o According to seismic prospecting, fresh rock distribution is at 40 m on the lower slope, and 60 - 70 m on the upper slope.

- o Results of P-6, P-8 drilling indicate that weathering and/or shearing the rock on the upper slope has extended to relatively greater depth than that of the lower slope.

- o Vp velocity of weathered rock at P-8 averages 2.4 - 2.5 km/sec.

- o Generally, rock of Vp velocity 2.4 - 2.5 km/sec is of Cm[1/] class, and with proper care may be utilized as structural foundation.

4.5.4 Kaguwa Powerhouse Site

(1) Topography

Slope at this powerhouse site is gentler than that at the upstream Pikhuwa site. A river terrace extends about 250 m along the Arun River with a maximum width of about 80 m. Difference in relative height of the water surface averages about 8 m with a maximum difference of 16 m. The river terrace is covered with gravel.

The powerhouse site is located on the river terrace. The gradient of the penstock route is relatively steep at the powerhouse site at elevations between about 536 m - 680 m. Average gradient is 40° with a slope of as much as 70° in one portion. The bedrock is distributed directly at the surface in the steepest section. The incline above this section is gentler with a slope of 15-30° and becomes steadily more gentle. Talus deposits cover the slope above El. 690 m.

1/ : See footnote on page 4-24.

(2) Geology

Geology of the vicinity of the Kaguwa power site is shown by DWG.G-13. Riverbed terrace deposits are distributed at about El. 439 m. Results of seismic prospecting in the Pikhuwa riverbed, particularly the results of sub seismic survey line No.3 and the P-1 drilling site, indicate a high possibility of terrace deposits in strata with seismic velocities greater than 4.4 - 4.5 km/sec. At P-4 drilling site, bedrock was not reached until about EL.503 m.

As shown in DWG.G-14, the thickness of talus deposits between EL.710 m- 885 m from the central area to the mountain side is approximately 30 m, while in the valley these deposits are very thinly distributed with a thickness of between 3 - 5 m. Moreover seismic prospecting identified six low velocity layers in the bedrock which has a seismic velocity of 4.5 km/sec.

The overall results of drilling at P-9 site indicate that the low velocity layer is composed of a weathered of the vicinity of surge tank location zone selectively weathered by groundwater seepage along a joint which runs parallel to the geological gneiss structure. Slope of the gneiss portion is 17° in cross section. The low velocity layer in the bedrock has a higher velocity than the 2 km/sec. of the layer above it but a slightly lower velocity than the 4.5 km/sec. of the bedrock. Judging on the basis of seismic velocity alone, the bedrock is generally classified as Ch[1/] grade rock, although there is some restraint found in the surrounding rock as well as some weakening due to weathering.

The underground water level observed at P-9 drilling point was ground level minus 44 m (GL-44 m). The volume of water seepage from the excavation can be safely pressumed to be small quantity and may not cause any trouble.

1/ : See footnote on page 4-24.

The velocity of the upper strata of the bedrock ranges from 2.2 - 2.4 km/sec. Although the rock is weathered, the seismic velocity suggests Cm grade bedrock including some CL[1/] class bedrock.

The fractured zone is extremely shallow and 2 layers or more of mica schist or micaceous gneiss were identified by drilling at P-11 as shown in DWG.G-15. This layer is composed of granite with a thickness of about 15 m and an estimated slope of 18°.

The thickness of overburden, especially on the mountain slope is assumed by the results of seismic prospecting, but not confirmed by any drilling holes.

4.5.5 Comparison of Powerhouse Sites

A comparison of the two powerhouse sites in terms of topography and geology is presented in Table 4-8.

On the basis of comparison, the Pikhuwa site is determined as superior for construction of either an above ground or a below ground penstock - powerhouse scheme.

4.5.6 Geology for Underground Powerhouse at Pikhuwa Site

A geological profile along the center line for the Pikhuwa powerhouse construction plan is given in DWG.G-8.

Seismic prospecting was conducted in this zone along a main line (550 m) and sub-line (220, 210 and 220 m) for a total of 1,200 m. Test drilling was carried out over 190 m (1 horizontal bore and 3 vertical bores).

Boring data is entered in the geological profile in DWG.G-8. Said data was projected on the profile taking into consideration geo-structure (strike of N20°E and dip of 30°E). Elastic wave velocity layers were estimated in reference to velocity layers occuring at each prospecting line - geological profile line intersection point.

1/: See footnote on page 4-24.

Table 4–8 Topography and Geology at Powerhouse Sites

	Kaguwa Site	Pikhuwa Site
(1) Foundation rock and tectonics	° Foundation rock is composed of Augen-gneiss intercalated with mica schist having thickness of same ten centimeters to several meters.	° Same to the left
	° Foundation rock forms an eastern wing of the Arun anticline structure with its strike and dip of N30°E and 20 - 40°E, respectively.	° Same to the left
(2) Topography and geology along penstock line	° Below EL. 600 m, there exists a cliff composed of fresh Augen-gneiss. A gentle slope above EL. 600 m is covered with thick talus deposit including big boulders.	° Below EL. 650 m, there exists a cliff composed of fresh Augen-gneiss. The slope above EL. 600 m becomes slightly gentler than the lower portion and is covered with thin overburden.
(3) Topography and geology upstream and downstream of penstock line	° Along the Arun river, there exists alluvial deposit of 30 m - 60 m in width, 250 m in length and 5 m in height above river surface.	° Along the Arun river, there exists alluvial deposit of 100 m in width, 400 m in length and 10 m in height above river surface.
	° At the upper part of penstock, there is an old slip surface resulted from landslide of horseshoe shape of approx. 700 m in diameter. At the bottom portion, there observed small round valley showing intricated topography with small creeks.	° Approx. 150 m upstream of the penstock line, there exists an indented belt of approx. 300 m wide, covered with thick overburden including big boulders resulted from landslide. ° The portion of approx. 500 m downstream of the above is forming a stable slope.
(4) Engineering judgement	° Surge tank and upper portion of penstock will be located in the area affected by the old, Large scale landslide and accordingly, the large amount of open excavation to the foundation rock will be required due to thick overburden. The outcrop of gneiss at the lower penstock portion and powerhouse is of small scale.	° Surge tank and penstock line is situated in the area outside the disturbed zone due to landslide and the thickness of overburden is thin. At the lower penstock portion, outcrop of fresh gneiss is extending over the wide area.
	° Due to the above-mentioned landslide, the ground surface in this area is fairly undulating resulting in difficulty in selecting adequate penstock line route.	° The area of approx. 500 m in width along the Arun river wherein the penstock line is to be located is formed with uniform and stable slope.
	° In view of the above, it is judged that the Kaguwa site has many disadvantages topographically and geologically compared with the Pikhuwa site.	° It is judged that the Pikhuwa site is preferable for construction of penstock and powerhouse of both outdoor and underground types.

(1) Surge Tank

Foundation ground for the surge tank is generally fresh gneissosed granite. Seismic wave prospecting indicates 4.4 - 4.5 km/sec values for bedrock. Although gneissosed granite shows some cracking, it is overall hard and relatively massive. Laboratory testing yields unconfined compressive strength values of 500 - 600 kg/cm^2 which indicate sufficient bearing capacity.

Excavated foundation surface for surge tank is in generally fresh rock.

Design diameter of tank excavation is 18 m at the top and 16 m at the bottom.

Groundwater was observed during the P-8 drill at GL-43 m in the rainy season. Consequently, groundwater is not anticipated as a problem for shaft excavation in the thick talus bed.

An open cut is necessary at the ground surface for the tank aperture. Taking into consideration the thick talus bed, minimization of cut dimensions would be desirable from the standpoint of cost effectiveness. Elastic wave velocity of the talus bed within which such a cut would be made is 0.7 - 1.3 km/sec and said bed consists of unconsolidated cohesive soil containing rock fragments. Slope gradient of the design cut is 30-35°. A cut face in such a slope is susceptible to collapse, and as such deterrent construction works to prevent sliding are necessary.

However, at the detailed design stage, it will be essential to calculate soil invariables, (cohesion, angle of internal friction and wet unit weight, etc.) and conduct slope stability study.

(2) Underground Powerhouse

The scale of cavern excavation for the turbine chamber is foundation elevation: 524 m; arch elevation: 504 m; maximum height:

41.5 m; maximum width: 25 m (main turbine chamber width: 18 m); length: 122 m.

The transformer chamber is situated about 45 m on the valley side from the turbine chamber and is to be designed parallel to the turbine chamber. The scale of cavern excavation for the transformer chamber is foundation elevation: 538 m; arch elevation: 554 m; height: 15 m; maximum width: 9.2 m; length: 122.2 m.

Structually, the most crucial element of these chambers is the arch portion. On the basis of P-6 drilling, formation occuring at the turbine chamber arch is concluded to be augen gneiss. Said augen gneiss is moderately weathered to a depth of 5 m, but below that consists of fresh rock of classification CH[1/]. Average RQD is 88.5%, and rock is determined as stable.

Geological profile of underground generating facilities (from vertical shaft connecting surge tank and turbine chamber to tailrace tunnel) was identified as a result of P-5, P-6 and P-7 drillings. Seismic prospecting was conducted (Pikuwa-A, Pikuwa-2 and Pikuwa-3 lines) to determine elastic wave velocity of the ground. From these investigations, the following conclusions are drawn:

a. The subject area is comprised primarily of augen gneiss.

b. Large fracture zones or faults are not present.

c. The major portion of underground excavation may be designed to occur in ground velocity layers of 4.4 - 4.5 km/sec elastic wave velocity.

d. One portion of the horizontal shaft connecting the surge tank with the vertical shaft is sited in gneissosed granite. The upper portion of the shaft would be located in slightly weathered ground which exhibits elastic wave velocity of 2.4 - 2.5 km/sec.

e. Overburden is of ample thickness at around 200 m.

1/ : See footnote on page 4-24.

f. Principal joint systems within the envisioned range of excavation are located at N70° - 75°E, N80° - 85°W and N45°E (all exhibit high angle dip). In addition, there is gneissed structure at N30°E (dip of 30°E). Consequently, various weak separation plains are anticipated within the excavation area.

(3) Geotechnical Considerations

No serious difficulties are envisioned in headrace tunnel and vertical shaft excavation.

Ground stability during cavity excavation is a crucial concern at the design stage. In this light, it is essential to identify initial stress, rock deformation characteristics and strength for the subject bed rock.

In general, where the overburden of an underground cavity is relatively shallow at less than 500 m, the ratio (modulus of lateral pressure) of horizontal and vertical components of initial stress are often over 1.0 due to effects of topographical and geological structure as well as tectonic and orogenic movement.

Where ground in-situ initial stress is dominant in the horizontal direction, the long axis of the cavity plan is made to conform to the primary principal stress orientation, and pressure bearing on the cross-sectional axis is subsequently minimized in order to maximize stability of the cavity.

On the basis of already known geological data on the pressure, the primary principal stress orientation is estimated to be perpendicular to the Arun anticline axis (and to the strike of the gneissosed structure). However, in order to precisely clarify this situation, it will be necessary in the future to excavate a test adit in the vicinity of the ceiling arch to accurately determine ground profile, bed rock deformation and strength characteristics) and initial ground stress.

Methods for determining initial ground pressure include the overcorring method (also known as the stress free method), the

AE method (Acoustic Emission method applying the Kisser effect), etc.

4.6 Concrete Aggregate

4.6.1 General Description

Concerete aggregates (fine aggregate and coarse aggregate) are necessary for powerhouse construction. Procurement of these materials in the vicinity of the construction site is the most economical approach.

Concrete aggregate should exhibit the following characteristics:

a. Rock is hard and durable.

b. For coarse aggregate, grain size is generally 20 - 50 mm.

c. Coarsely crystallized rock such as plutonics, metamorphics, etc. are not suitable as aggregate material as they may contain cracks between coarse crystals resulting in flat shaped fragments when crushed.

4.6.2 Rock Character & Quarry Sites

On the basis of geological conditions prevailing at the Project site, terrace sand and gravel, consisting of granite and gneiss are considered most appropriate as aggregate material.

(1) Natural Sand and Gravel

River terraces occurs on the left bank of the Arun river in the vicinity of the dam, and Pikhuwa and Kaguwa powerhouse sites. Relative heights from the Arun river during the rainy season are 25 m, 20m and 15 m, respectively. Scales of these terrace formations are 300 m x 150 m, 500 m x 140 m, and 350 m x 70 m, respectively.

These terraces are formed of sand and gravel borne from upstream. On the basis of visual inspection, grain size within the sand gravel beds ranges from large cobbles to fine silt. However, weight ratio of grains in excess of 50 mm dia. is estimated at over 50%. Both vertical and horizontal fluctuation in granularity is great.

Weight ratio for silt, sand, and gravel components of each terrace formation on the basis of grain size analysis of sediments are given in Table 4-9.

Table 4–9 Grain Size Analysis

		Silt % under 62 m	Sand % 62 m - 2 mm	Gravel % 2 mm - 50 mm
D/S	1 2 3	6 13 10	28 41 29	72 46 61
Pikuwa P/S	1 2	12 22	40 48	48 29
Kaguwa P/S	3 4	15 30	42 34	43 36
Arithmatic average		15	37	48

D/S : Dam site
P/S : Powerhouse site

Stones in excess of 50 mm dia. were removed prior to seive analysis of test samples.

Grain distribution tendencies are as follows:

Silt component : 6% - 30%; average 15%
Sand component : 28% - 48%; average 37%
Gravel component: 29% - 72%; average 48%

Grain size fluctuation both horizontally and ertically in terrace beds is great.

On the basis of visual inspection, relative weight of grains in excess of 50 mm dia. is over 50% for each terrace.

However, adequate amounts of aggregate material of appropriate grain size are not available from river terraces.

Furthermore, the terrace surface at each site comprises a valuable flat area which will serve as location for construction yard and also for power generating structures. Therefore, this valuable flat area should be spared instead of using for an aggregate borrow area.

(2) Crushed Aggregate

Canditate quarry locations for crushed aggregate should be located proximate to construction sites. Aggregate production process includes excavation and crushing.

Potential locations for crushed aggregate quarries are shown in Table 4-10.

Investigation results indicate that generally fine grained granitic rock is best suited for crushed aggregate due to homogeneity, hardness and strength of lithofacies.

(3) Conclusions

On the basis of topographical and geological conditions prevailing at the site, it is concluded that granitics are the most appropriate source of aggregate.

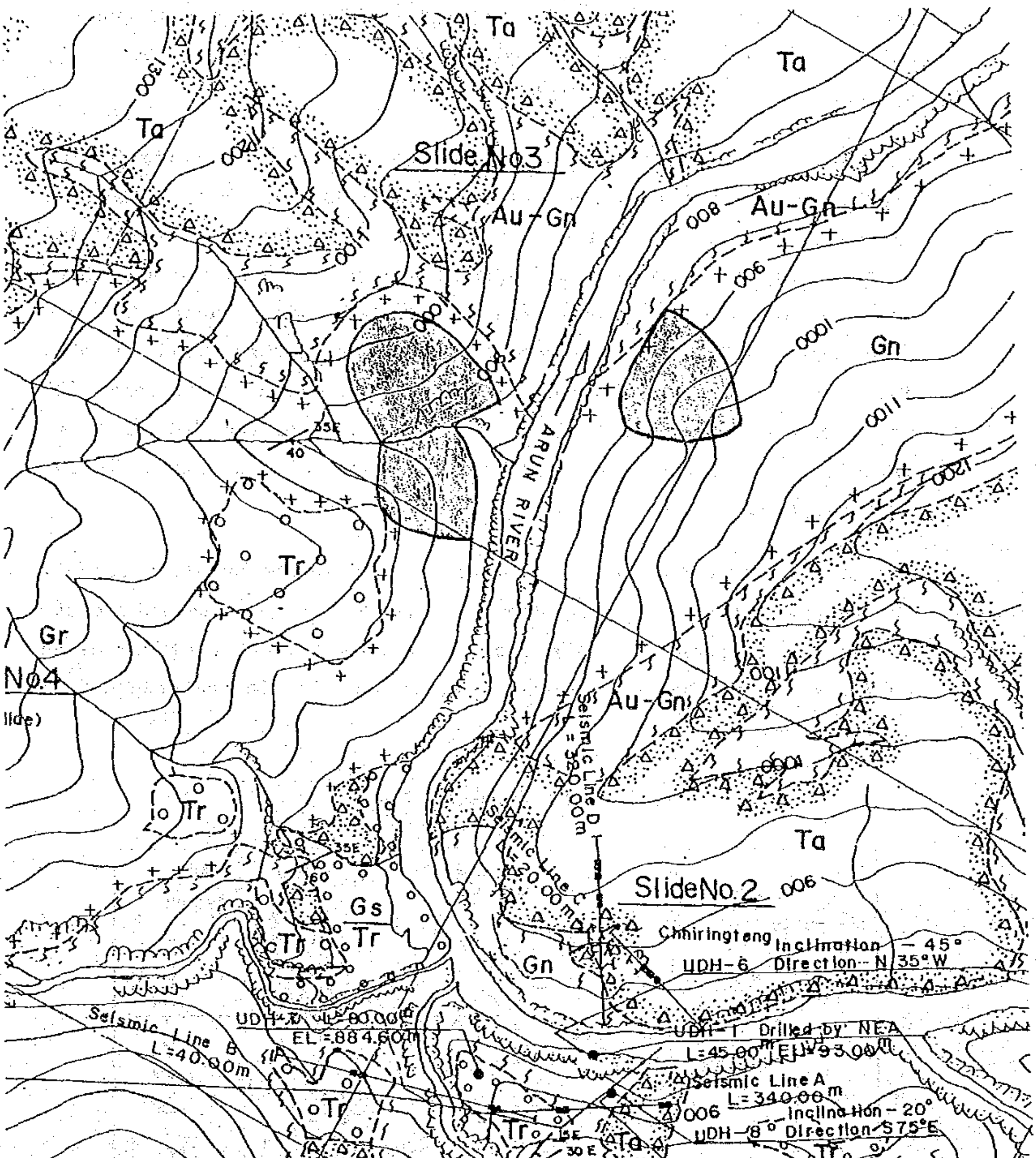
Potential aggregate quarry sites in the vicinity of the dam site are indicated in Fig. 4-7. In the vicinity of the powerhouse sites there is a granitic deposit on the west slope at Diding village; however, a detailed investigation is necessary to determine existing amounts and quality. Aggregate test method should be in accordance with criteria in "Guide and Recommendation for Concrete Large Dams" as recommended by the 1964 International Symposium on Large Dams.

Table 4–10 Comparison of Lithofacies

	Augen gneiss	Mica schist	Fine grained granitics	Amphibolite
Mineral assemblage	Quartz~feld-spar~mica	Biotite~muscobite~quartz~garnet	Quartz~feldspar~mica	Amphibole~feldspar
Texture	Composed of porphyloblast of augen feldspar and matrix in which mica~quartz banding is highly developed.	Mica group minerals highly rearranged. Partially contains lenticular segregated quartz.	Rock forming minerals are fine grained and relatively massive.	Fined grained, compact
Foliation	Matrix flakes easily from thinly foliated mica.	Flakes easily.	Exhibits some weak gneissosity, but not to the degree of gneiss.	Gneissosity developed along contact with other formations. Tends to separate easily along contact surfaces
Relative strength	Moderate	Weak	Strong	Strong
Relative density	Moderate (±2.5)	Low(2~2.4)	Moderate (2.5)	High(3.2)
Unconfined compressive strength	200~400	±100	500	500
Mode of occurence	Large formation; stratiform	Large formation, stratiform	Large formation, stratiform (intrusive)	Small formation, stratiform (intrusive)
Overall evaluation as aggregate	O	X	●	X

X: not acceptable
O: intermediate
●: good

Fig. 4-7 Planned Rock Quarry Location on the Dam Site



4.7 Earthquakes in Project Area

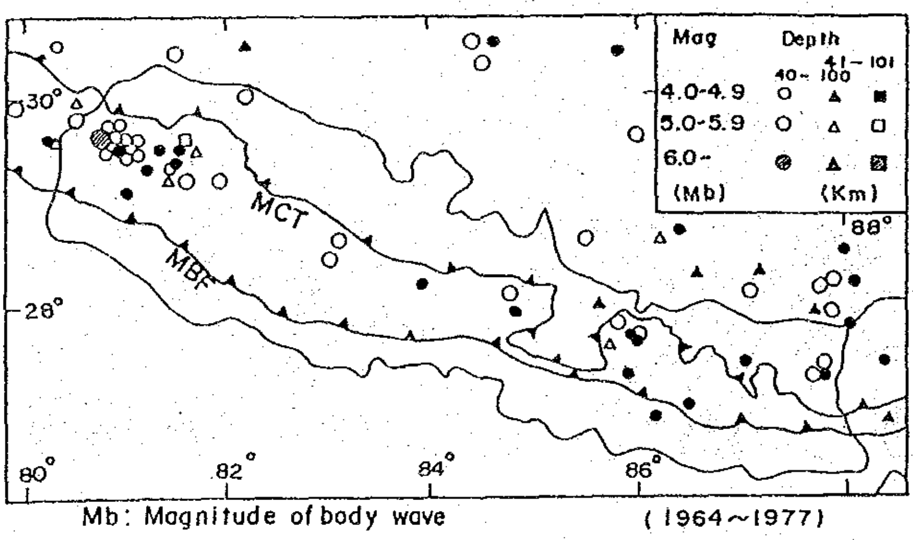
4.7.1 General

The crustal movements and earthquakes in the Himalayan area including Nepal are described in detail in "Master Plan Study on the Kosi River Water Resources Development, Final Report, Vol. II, Appendix III, March 1985, JICA".

According to the said report, the magnitude and distribution of earthquakes recorded in Nepal are as shown in Fig. 4-8, indicating frequent occurrence in the Western region. In the central and eastern regions, frequent earthquakes are observed in the area between the Main Central Thrust (MCT) and Main Boundary Fault (MBF) and also north of MCT, while, extremely few earthquakes south of MBF. The records of seismic waves in Nepal are limited to the past 100 years and only the records of damages are reported before them. Table 4-11 shows the records of major earthquakes took places in the 20th century.

For the study of the Arun 3 project, the magnitude and frequency of earthquake expected at the dam site as well as the seismic coefficient to be applied to the preliminary designs are analysed based on the above earthquake records in Nepal and also in the wide neighboring area.

Fig. 4-8 Earthquakes in Nepal



Mb: Magnitude of body wave (1964~1977)

Table 4-11 Major Earthquakes in the 20th Century

Date	Epicenter	Magnitude1/	Location and Damages
1916	30.00 N	7.5	Far Western Nepal
8.28	81.00 E		Extent of damage unclear
1934	26.5 N	8.4	Nepal - India Border
	86.5 E	(Ms)	Deaths: 8,519 (Nepal), 7,253 (India)
1.15	27.55 N	8.3	Houses Destroyed: 80,893 (Nepal)
	87.09 E	(Ms)	
1936	28.5 N	7.0	Western Nepal (Dhaulagiri)
5.27	83.5 E		Damages unclear
1966	29.6 N	6.0	Far Western Nepal
6.27	80.8 E	(Mb)	Deaths: 42, Houses Destroyed: 3,969
1980	29.6 N	6.1	Far Western Nepal
7.29	81.1 E	(Ms)	Deaths: 178, Houses Destroyed: 13,258

1/: Richter's local magnitude
Ms: Magnitude of surface wave
Mb: Magnitude of body wave

4.7.2 Study on Seismic Coefficient at Arun 3 Project

Based on the records of earthquakes took places in the project area and also the neighboring area, the magnitude and frequency of earthquake expected at the site are analysed to obtain the seismic coefficient necessary for the preliminary designs. The analysis is made referring to "the Earthquake Data File" compiled by the National Oceanic and Atmospheric Administration, Environmental Data Service, USA.

The number of data is 964 earthquakes took places during the period from 1963 to 1985 in the circle described with the radius of 1,000 km centering the project site.

The earthquake distribution by magnitude and epicentral distance is shown in Table 4-12 and Fig. 4-10.

Table 4–12 Distribution of Magnitude and Epicentral Distance of the Seismicity Data

Δ : Epicentral Distance [km]
M : Magnitude

	0≤ Δ<50	<100	<200	<300	<400	<500	<600	<700	<800	<900	<1000	Total
3.5≤ M <4.0	0	0	0	0	1	1	0	2	3	2	3	12
<4.5	1	0	4	4	5	10	10	17	21	30	33	135
<5.0	0	5	11	10	22	26	49	49	90	122	112	496
<5.5	2	8	4	6	7	16	22	33	30	64	58	250
<6.0	0	0	1	1	3	4	6	10	9	12	7	53
<6.5	0	1	1	1	0	0	0	4	2	3	3	15
<7.0	0	0	0	0	0	0	0	0	0	3	0	3
Total	3	14	21	22	38	57	87	115	155	236	216	964

The maximum acceleration of earthquake is to be estimated on the basis of those formulae proposed by C. Oliveria, R. K. McGuire, L. Esteva and E. Rosenblueth, T. Katayama and S. Okamoto. While the probability analysis is made on assumption that the third type of theory of extreme value is applicable for functional equation as follows:

$$P(X) = \exp\,[-[W - X)/(W - U)]^k]$$

where,

- W : Upper limit value of variable
- U : Characteristic value
- k : Shape parameter
- X : Log Amax
- Amax : Maximum recorded acceleration

Table 4-13 and Fig. 4-9 show the results of analysis and according thereto, it is observed that the maximum acceleration for 100 years return period will be in the range from 34 gal[1/] (C. Oliveria) to 231 gal (S. Okamoto) and for 1,000 years return period from 65 gal (C. Oliveria) to 436 gal (S. Okamoto). The values estimated by S. Okamoto's formula is conspicuously larger than the others and the arithmetical means of above five formulae are 88 gal and 165 gal for 100 and 1,000 years return periods, respectively.

Table 4–13 Maximum Accelerations for Five Return Periods

unit: gal

Model (Eq.No.)	Proposer(s)	Return Period . Tr (year)				
		50	100	200	500	1000
(1)	C. Oliveira	26	34	42	55	65
(2)	R. K. McGuire	71	84	97	113	125
(3)	L. Esteva & E. Rosenblueth	28	41	57	85	113
(4)	T. Katayama	38	48	59	75	87
(5)	S. Okamoto	164	231	298	381	436

Further, the maximum value that would have experienced at the project site is also examined on the basis of the records of the historically big earthquakes in this vicinity. The data composed of 8 earthquakes ($M \geq 7.5$) are dotted in the areas covering the northern part of Burma, Assam State of India, Nepal and the northern part of Pakistan as shown in Table 4-14.

1/ : 34 gal = 34 cm/sec^2 = 0.035 g

Table 4–14 Earthquakes of Magnitude Greater than 7.5 in the Vicinity of the Himalaya Frontal Arc since 1897 (After Singh and Gupta, 1980)

Date	Latitude (°N)	Longitude (°E)	Location	Death	Magni-tude
12 June 1897	25.9	91.8	Assam	1,600	8.7
4 April 1905	33.0	76.0	Kangra Valley	19,000	8.6
12 December 1908	26.5	97.0	Burma	-	7.5
8 July 1918	24.5	91.0	Assam	-	7.6
12 January 1934*	26.5	86.5	Bihar-Nepal	11,000	8.4*
30 May 1935	29.5	66.7	Quetta	30,000	7.6
29 July 1947	28.5	94.0	NE Assam	-	7.9
15 August 1950	28.5	96.7	Assam	1,526	8.7

Source: Bulletin of the Seismological Society of America, Vol. 76, No. 1, PP205-295, Feb. 1986

Large Artificial Water Reservoirs in the Vicinity of the Himalayan Foothills and Reservoir-induced Seismicity by H. K. Gupta and K. Rajendran.

According to the data shown therein, the maximum acceleration at the site would be caused by Bihar-Nepal earthquake on Jan. 12, 1934 of which the magnitude and distance from epicenter are 8.4 and 142 km, respectively. The maximum acceleration is estimated at 128 gal (R. K. McGuire), 122 gal (T. Katayama), 32 gal to 35 gal (L. Esteva et al, C. Oliveria).

In consideration of the results of analysis of the probable earthquake and the recorded maximum earthquakes, the seismic coefficient of 0.12 is selected for application to various designs. Finalization of the seismic coefficient will be made in the detailed design stage considering the MCT.

Fig. 4–9 Return Period for Maximum Accelerations

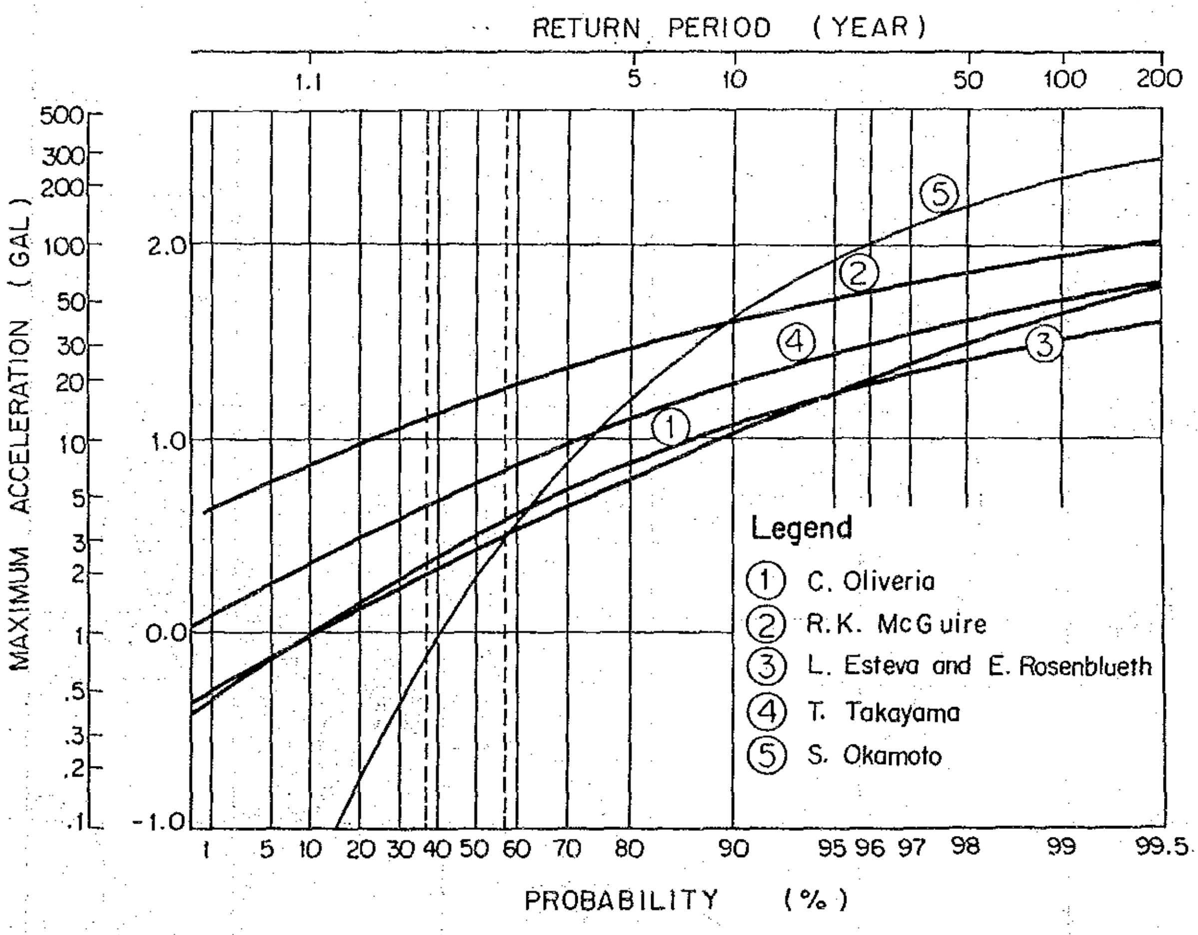
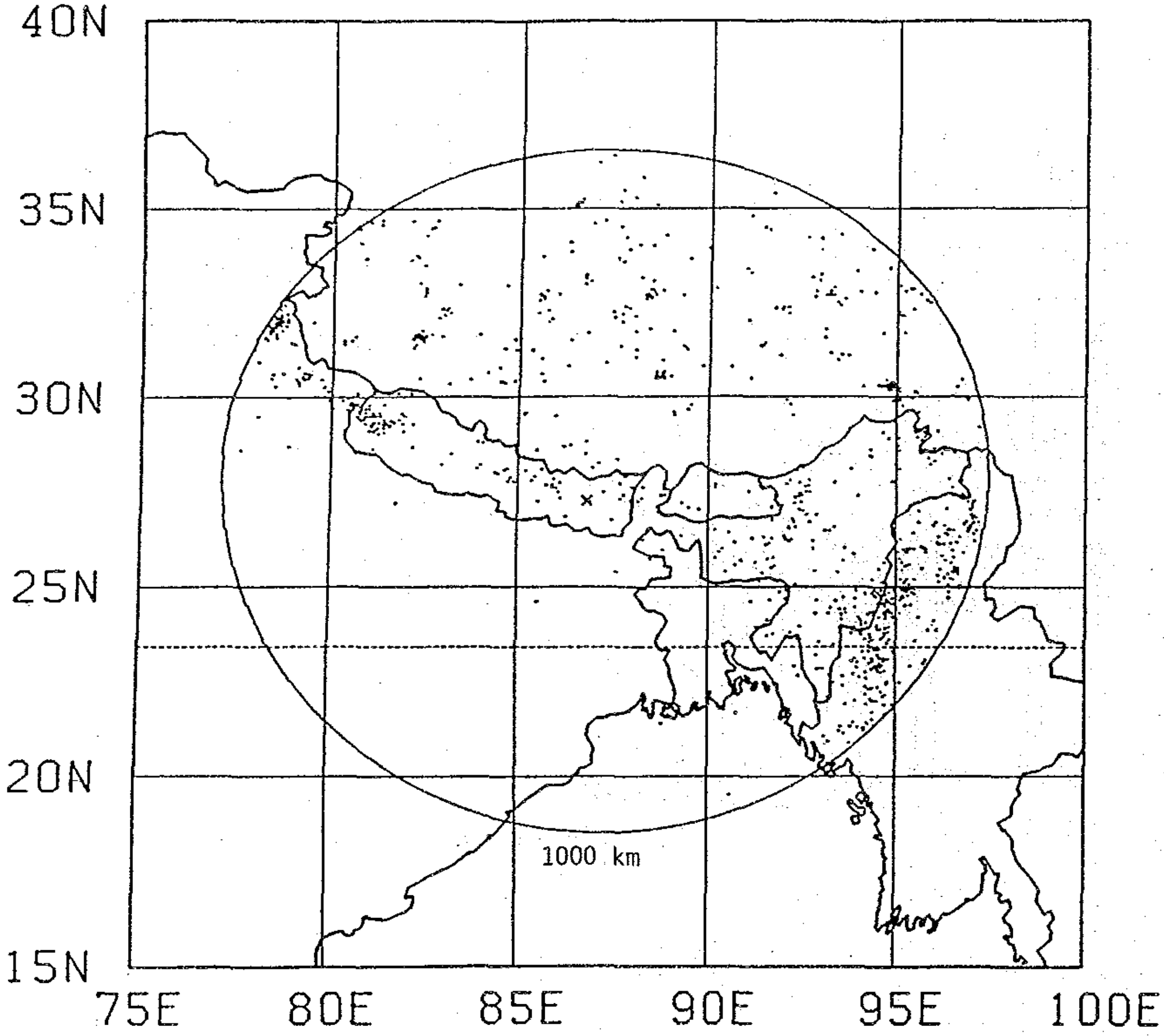


Fig. 4-10 Seismicity of All Data in 1963 - 1985



Total Number of Plots in the area of Δ ≦ 1000.0 (km) is 964.