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Geotechnical investigation of Chitral Slates, Hindu Kush Ranges, Northern Pakistan: case study

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Abstract

The present study was undertaken to find out different geotechnical properties of Chitral slates for heavy construction such as dam components like a weir, diversion and intake, sand trap, headrace tunnel, access tunnel and tailrace. The work has helped to analyze the behavior of these rocks during construction and under the imposed loading of any proposed structure. The highly deformed Jurassic Chitral slates are exposed along a large anticline in the Hindu Kush ranges situated in district Chitral, Northern Pakistan. A total of six bore holes were drilled, approximately at a distance of 1 km for each sample, for a detailed study of core samples and internal condition of boreholes. These include water pressure test, water table, Standard Penetration Test (SPT)/Cone Penetration Test (CPT), joints and fractures, and lithology. The studied core samples are highly jointed; average five joints per meter are present, which are in filled by clay and iron oxide. As a result of these joints, the water loss is very high. Water pressure tests were carried out at a specific depth in boreholes in uncased section. The picker test results were 26.75, 22.95 and 15.90 in Geo-11A and Geo-15 respectively. Many of the tests were not successful because of the jointed strata where the water pressure did not exceed the required pressure. The SPT failed in overburden due to the presence of heavy particles like boulder etc. The boreholes collapsed at various depths where they were grouted with cement to prevent them from collapsing. The borehole logs were prepared for each borehole along with detailed information.

Keywords: Geotechnical investigation; Hydrological study; Chitral Slates; Hindu Kush

1. Introduction

Geotechnical investigation is a standout amongst the most critical undertakings for the life and safety of Dam development. The geotechnical investigation give a first broad impression of the designing and topographical parts of the proposed site, and figure out whether further investigation of the site is warranted. The information got from site investigation would be utilized to arrange the sort, area, size of the outlined structure. This information can likewise be utilized for laboratory testing required as a part of future for more definite investigation. The Chitral slates are exposed along the Mastuj River at Birnus and its adjoining areas (Fig. 1). It was an extraordinary chance to divert the Mastuj River and build Dam for hydropower reason. The subsurface geotechnical investigation has been done for Chitral slates in order to discover the subsurface state of the strata/Chitral slates for heavy construction in the light of the boring and subsurface tests. The water flow in the Mastuj River is high because of high gradient and hard stream bedrock. The glaciers on the peaks of Hindu Kush ranges are great wellspring of water for Mastuj River due which the flow of water in Mastuj River is great as the year progressed. The study area is situated in district Chitral which is located at latitudes and longitudes 72°, 02', 05.48" E to 72°, 04', 10.01" E and 36°, 03', 34.43" N to 36°, 06', 00.44" N respectively. The studied sections situated about 50 Km north of the Chitral town at Birnus village.

1.2. Geography of the area

Chitral district is situated at the northern extremity of Khyber Pakhtunkhwa, Pakistan. Afghanistan is situated in the Northwest, Gilgit district in East and, Dir and Swat districts in the South (Fig.2). The total area of the Chitral is 14,850 square kilometers. It is surrounded by the Hindu Kush range in the North and West, the Mushamber range in the East and the Hindu Raj range in the South. There are about one hundred mountain peaks elevated above 6,000 meters, which remain covered by snow throughout the year. The Mastuj River is the main channel of water flow in the Chitral district, which is a combination of many tributaries (Chitral Profile, Govt of KP).

2. Regional tectonics

Northern Pakistan is an excellent example of the continental collision. In this region, the worlds' three highest mountain belts are situated the Himalayas, the Karakoram and the Hindu Kush. The mountain building process that formed these ranges commenced in Cretaceous time when the Indian Plate started moving and was carried northward (Scotese et al., 1988). In the late Cretaceous time, the Paleo-Tethyan completely consumed and Kohistan Island Arc collided with the Eurasian Plate. A suture zone was formed due to this continental collision which is known as Shyoke Suture Zone or Main Karakoram Thrust (MKT; Tahirkheli, 1982). After that, in the Eocene the Neo-Tethyan was consumed and the Indian Plate collided with Kohistan Island Arc which formed the Indus Suture Zone or Main Mantel Thrust (MMT; Tahirkheli, 1979; Bard, 1983).

3. General stratigraphy

Chitral possesses both sedimentary and meta-sedimentary rocks which are highly deformed and thrusting southward over the Kohistan Ladakh Island Arc along the MKT. From Chitral to Mastuj, late Paleozoic to Tertiary rocks are exposed. Chitral slates are exposed along a large anticline southwest of the Chitral town, the northwest limb of which is overlain by Cretaceous Krinj Limestone while its southwestern limb is overlain by Gahirat Limestone (Desio, 1955). In the Tethyan belt, 3-4km thick sequence is named as Chitral slates due to the vicinity of Chitral town. According to the Pudsey et al. (1975) the slates is largely without bedding but show complex structure. Graded bedding and slump structures are present and the base of the Chitral slates are not exposed.

4. Scope of the Present Study

The present study involves the subsurface investigation of the study area. The main purpose of this geotechnical investigation is to assess the surface and subsurface strata for heavy construction e.g. Dam components like weir, diversion and intake, sand trap, headrace tunnel, access tunnel, and the tailrace to analyze the behavior during construction and under the imposed loading of the proposed structure.

5. Objectives

The objectives of the present study are to;

- Find out core recovery and rock quality dissemination percentage in each drilling run.
- Perform water pressure test as per engineer requirement for each borehole.
- Record the ground water table, if encountered.
- Perform the cone penetration test (CPT/SPT) in soil or overburden as per Engineer requirement.
- Prepare the sub-surface lithological log of each borehole.

5. Methodology

5.1. Sub-surface Investigations

The subsurface investigation program is prepared to probe the sub-surface conditions, including drilling, Packer test and permeability tests.

5.2. Core Drilling

The purpose of core drilling was to collect information on

- Overburden thickness/depth of weathering
- Soil and rock mass permeability and ground water levels
- Rock mass quality
- Geotechnical properties of overburden and rock

5.3. Boreholes Details

Six boreholes were drilled for subsurface investigation. Total 266 meters drilling was performed in 266 runs.

5.4. Drilling Run

One meter of drilling borehole was counted as a single run. After each single run completion, the drilling equipment was removed from the borehole and core sample was preserved. The achieved drilling progress is given in Table 1.

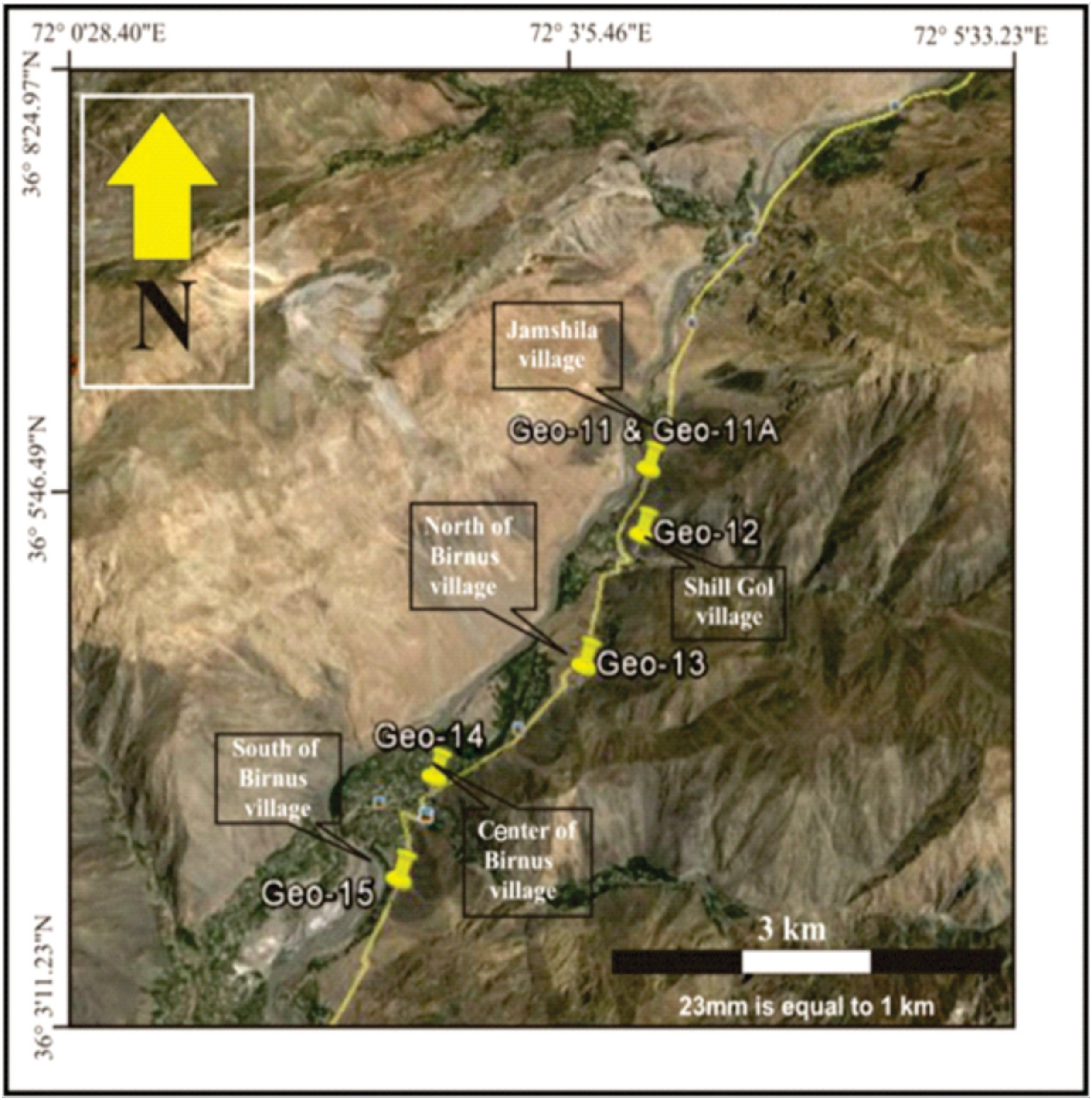


Fig. 1. Map shows the study area along with boreholes location (Google Earth).

Table1. A detail of borehole no, location and depth

Borehole No.	Location	Depth (M)	No. of run
Geo- 11	Jamshila village	35	35
Geo- 11A	Jamshila village	70	70
Geo- 12	Shill Gol village	24	24
Geo- 13	North of Birnus village	37	37
Geo- 14	Center of Birnus village	30	30
Geo- 15	South of Birnus village	70	70
Total		**266 meters**	**266**

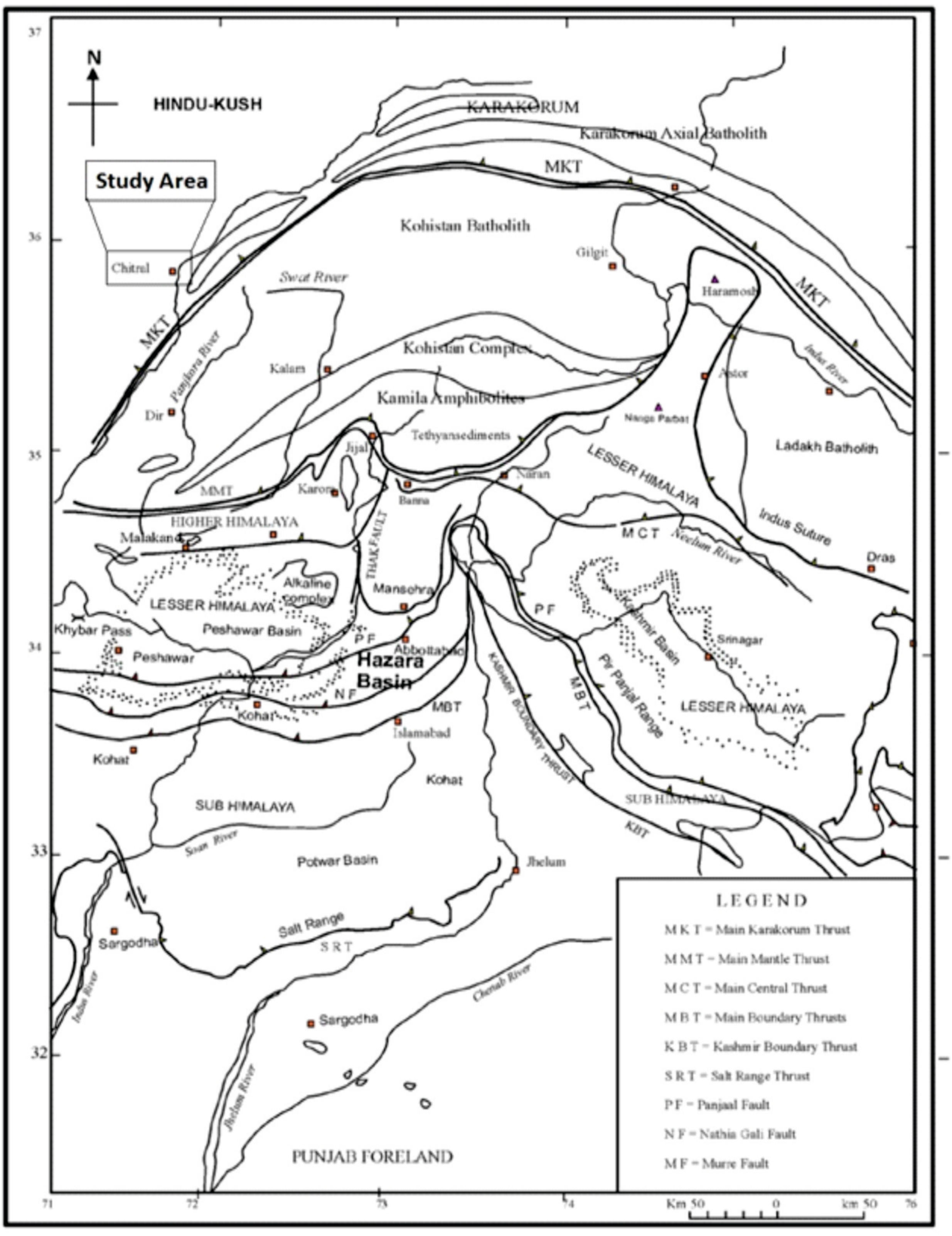


Fig. 2. Tectonic Map of North Pakistan (Ahsan et al., 2008).

5.5. Procedures

Core drilling in rock was carried out with straight rotary rigs. Casing was used in overburden to prevent the borehole caving and water was used as a drilling fluid. Core barrels of double tube, steel/diamond bits were used to produce "NQ" (NQ bit model have 76.7mm size hole) size. Core drilling started with a 1.0 meter run as the weathered rock was encountered. After the completion of each run, the core barrel was removed from the borehole and the core/rock was extruded from the core barrel. The rock samples were marked with the project name, borehole number, sample depth and date of sampling. These samples were preserved in standard size core boxes. The water permeability tests were carried out in the alluvial deposits encountered in the drilled bore holes and the water pressure tests (LUGEON) were conducted in the bedrock as given in Table 2. These tests were performed as per engineer requirement (specified method of test for the construction).

5.6. Packer tests / lugeon/water pressure tests

The packer or Lugeon test gives a measure of the acceptance of water by rock in-situ under pressure. The test was originally introduced by Lugeon, (1933) to provide an acceptable standard for the permeability of dam foundation. In essence, it comprises the measurement of the volume of water that can escape from an uncased section of borehole at a given time under a given pressure. The single packer method is suitable for soft rocks where the problem of caving is common. For sound rocks, the double packer method is more suitable. The major disadvantage of the double packer method is that the leakage through lower packer may go unnoticed which usually over estimates the permeability. The test is used to access the amount of grout that rock will accept, to check the effectiveness of grouting, to obtain a measure of the amount of fracturing of rock or to give an approximate value of the permeability of the rock mass. The results of the tests are usually expressed in terms of the Lugeon units.

6. Results and discussion

After the detailed study and observations, the borehole logs were prepared for each borehole which has the detailed information about the water table, strata lithology, joints, weathering, permeability, fractures, angle of joints, infilling, water loss, core recovery, rock quality dissemination and other information. For the better understanding, the lithological borehole model has been constructed to easily find out the depth of overburden materials (Fig. 3).

6.1. Ground Water Table

Ground water affects many elements of foundation design and construction, therefore, it's location needs to be established as accurately as possible, especially if it is within the probable construction zone. It is generally determined by measuring the water table in boreholes after a suitable time elapse (after each drilling run).

Table.2. A detailed information of field activities.

S. No	BH No	Location Name of borehole	Final Depth	No of Permeability Test	SPT/CPT	Piezometer Installed	No of water Pressure Test	Description of lithology
1.	Geo 11	Jamshila village	35m	Nil	Nil	Nil	1	Overburden /Slates
2.	Geo11A	Jamshila village	70m	Nil	Nil	Nil	3	Overburden /Slate
3.	Geo 12	Shill Gol Village	24m	Nil	Nil	Nil	Nil	Overburden/Slates
4.	Geo 13	North of Birnus village	37m	Nil	Nil	Nil	Nil	Overburden
5.	Geo 14	Canter of Birnus village	30m	Nil	Nil	Nil	Nil	Overburden
6.	Geo 15	South of Birnus village	70m	Nil	Nil	Nil	3	overburden /slate

6.2. Geo-11 Borehole

This borehole was bored up to 35m; however the proposed genuine depth of this borehole was 70m. The drilling was stopped at 35m because in the test section, i.e. 30 to 35m (picker Test) the edges of slates cut the picker tube since it was unable to get any result. In the drilling results, it was observed that two meters thick overburden material was present at this location. The overburden material was varied in size, i.e. clay, silt, cobble, pebbles to gravel size particles. The overburden material has metamorphic origin because it is the weathered produced of Chitral slates, which consist of talus, scree deposit very fine grained, very dense, angular to sub angular and dark gray in color. In the overburden, the water loss was 20% to 70%, but in the bedrock Chitral slates, the water loss was 100% through the borehole because of high joints.

After the two meter overburden material the strata was Chitral slates. Throughout the entire borehole section of slates, the strata were jointed, 5 to 7 major joints were present per meter. Except these joints the other minor joints were also present which was unable to detach from each other. The joint angle varies from 30° to 70°. The coring sample was Chitral slates, which was blackish in color, very fine grained, having a hard nature of drilling and highly weathered. The CR and RQD were below 70% (Fig. 4).

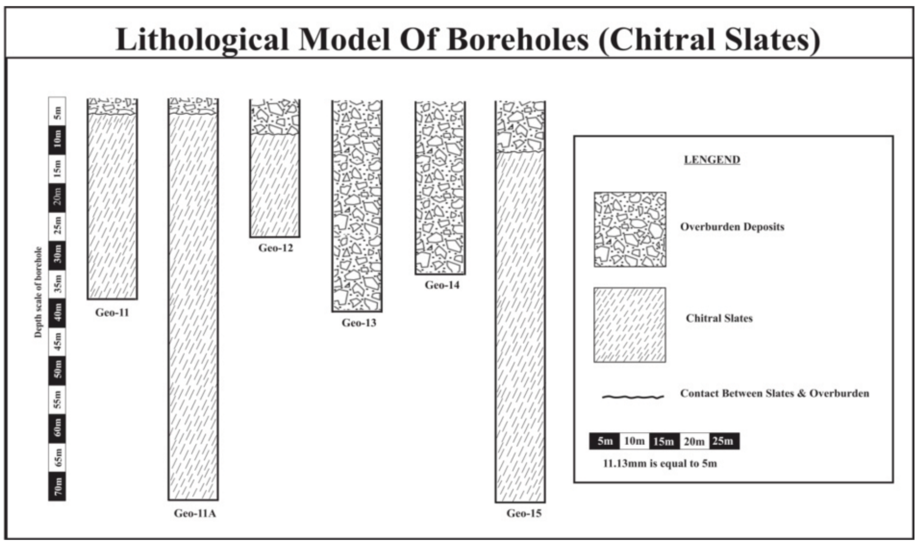


Fig. 3. Shows the borehole model, with lithology and depth.

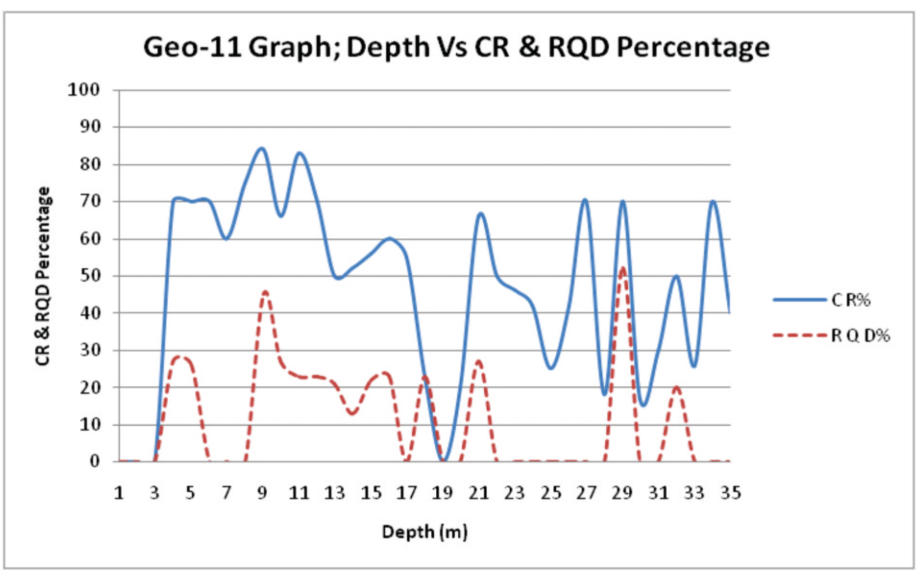


Fig. 4. Shows the CR, RQD percentage with depth.

6.2.1. Geo-11 test section (30-35m)

Due to the high joints, the edges of the joints cut the picker two times therefore the test was failed two times.

6.3. Geo- 11A Borehole

This borehole was drilled 14ft to the north of the Geo-11 because the water pressure test failed in the Geo-11, thus for the confirmation, Geo-11A was drilled. This borehole was drilled up to 70 meters. Similarly, at this location, two meters thick overburden material was present, which was same as Geo-11in size, color and origin. Water loss in overburden was 30%, but in the bedrock (Chitral slates) the water loss was 100%. The borehole collapsed several times, hence it was grouted with cement to stop the collapsing. At 19m and 70m depth the strata was highly jointed up to the extent that core recovery was zero. Two successful water pressure tests/ picker test were performed out of which one failed. The joint angle varied from 50° to 60°. Four major joints were present in one meter, other than the major joints, the minor joints were also present which was too much close and unable to detached from each other. Aperture value was <5mm with rough surface. Jointed surface was coated with iron oxide and infill by clay material. It was observed that the core samples were infilled by quartz and calcite veins. At 70 meters depth, the water table was checked but ground water was not present. The CR and RQD details are given in figure 5 and water pressure tests/ picker test details in figure 6.

6.3.1 Geo-11A failed test section 60m to 65m

The borehole collapsed at 63meters depth and grouted with cement to stop further collapsing as per engineering requirement and thus the water pressure test/ picker test is not allowed in grouted section.

6.4. Geo-12 Borehole

The borehole was drilled in the Shill Gol Village. The location of borehole lies in the contribute canal of river Mastuj. The borehole was drilled up to 24 meters and about six meters thick overburden material was present. Steel casing was used in overburden to protect the borehole from collapsing because the overburden material was too loose. The strata was Chitral slates, blackish in color, hard and very fine grained. CR value was not enough good as compared to Geo-11 and Geo-11A but the numbers of joints were less than those boreholes. 2 to 4 major joints were present per meter infilled by clay, rough surface, aperture = <5mm and 1mm. The joint angle varied from 20° to 70°. The CR and RQD graph is given in figure 7.

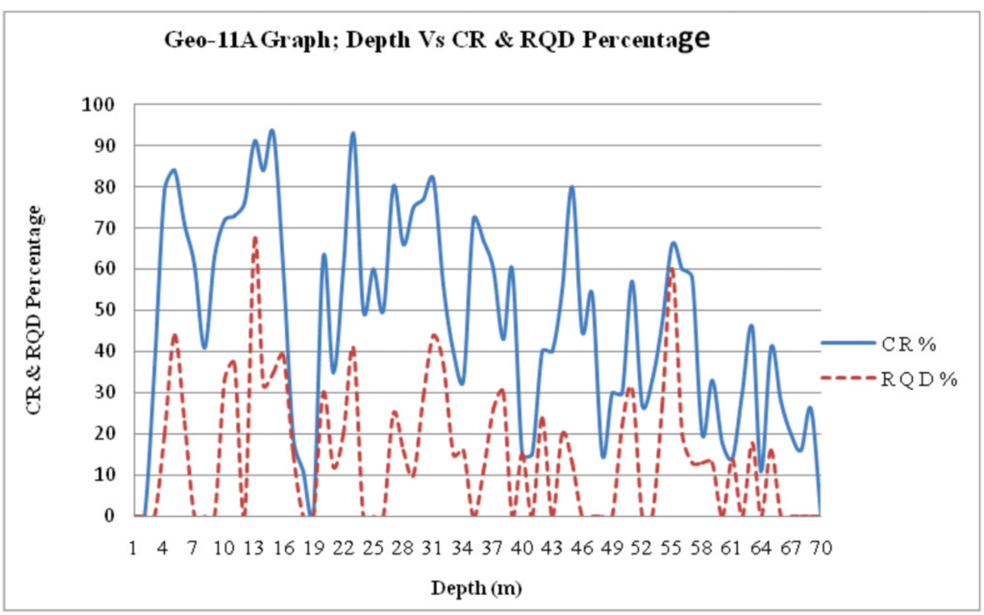


Fig.5. Shows the CR, RQD percentage with depth.

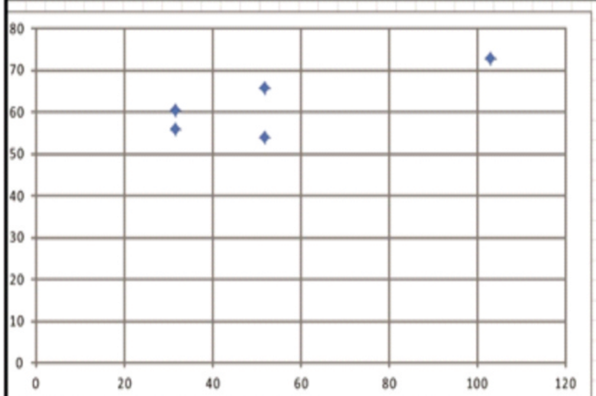
WATER PRESSURE TEST

TEST No.	1	BOREHOLE/ TESTPIT NO.	Geo-11A
PROJECT	Geotechnical investigation of Chitral slates	DATE:	25/08/13
TYPE OF ROCK	Chitral Slate	Type of packer	Mechanical

Top of Test Section	: 35 m	Ground elev. (m asl)	:
Bottom of Test Section	: 40 m	Intial groundwater level :	Not Encountered
Length of Test Section	: 5 m	Packer Pressure (Bar) :	3, 5, 10, 5, 3
Centre of Test Section	: 37.5 m	Gauge No.	:
Bottom of hole at time of test :	40 m	Diameter of hole in Test Area (mm) :	76
Bottom of Casing	2.5 m	Height of Pressure Guage (m)	: 1

Stage	Guage pressure (PSI)							Average flow (q) lit/min
1st Stage		Time (min)	0	5	10	15	20	
		Flowmeter Reading (cu.m)	70.8238	71.3645	71.6599	72.0793	72.2606	
	5	Water take (lit)		540.70	295.40	419.40	181.30	71.84
2nd Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	72.2606	72.7990	73.0673	73.4457	73.8149	
	10	Water take (lit)		539.30	267.40	378.40	369.30	77.72
3rd Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	73.8149	74.3893	74.8807	75.1130	75.5484	
	15	Water take (lit)		574.40	501.40	222.30	435.40	76.68
4th Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	75.5484	75.8475	76.1070	76.5416	76.9969	
	10	Water take (lit)		299.50	259.30	434.40	455.30	72.42
5th Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	76.9969	77.2393	77.4647	77.7379	78.0493	
	5	Water take (lit)		242.40	225.40	273.20	311.40	52.62

Period		Flow, q Liter/min (3)	Guage pressure		Friction head loss,m		Total head, h 1+2+5-6-7	Lugeon, LU
			Guage pressure, (4)	Head of water, (5)	In basic pipework, (6)	In extra rods and pipes, (7)		
1st		60.48	3.00	30.60			31.60	38.270
2nd		65.60	5.00	51.00			52.00	25.230
3rd		72.77	10.00	102.00			103.00	14.130
4th		53.96	5.00	51.00			52.00	20.753
5th		55.96	3.00	306.00			31.60	35.386



Slope of graph, q/h =	1.142	LU = (100/L)(q/h) in lugeon units =	26.75

WATER PRESSURE TEST

TEST No.	2	BOREHOLE/ TESTPIT NO.	Geo-11A
PROJECT	Geotchnical investigation of chitral slates	DATE:	6/9/2013
TYPE OF ROCK	Chitral Slate	Type of packer	Mechanical

Top of Test Section	: 48 m	Ground elev. (m asl)	:
Bottom of Test Section	: 53 m	Intial groundwater level :	Not Encountered
Length of Test Section	: 5 m	Packer Pressure (Bar) :	3, 5, 10, 5, 3
Centre of Test Section	: 50.5 m	Gauge No.	:
Bottom of hole at time of test :	53 m	Diameter of hole in Test Area (mm) :	76
Bottom of Casing	2.5 m	Height of Pressure Guage (m)	: 1

Stage	Guage pressure (PSI)							Average flow (q) lit/min
1st Stage		Time (min)	0	5	10	15	20	
		Flowmeter Reading (cu.m)	121.4713	121.7612	121.8858	122.0814	122.3435	
	5	Water take (lit)		289.90	124.40	195.80	262.10	43.61
2nd Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	122.3435	122.6432	122.9513	123.2942	123.7775	
	10	Water take (lit)		299.70	308.10	342.90	483.30	71.7
3rd Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	123.7775	123.9441	124.5672	124.9853	125.2916	
	15	Water take (lit)		166.60	623.10	418.10	306.30	75.705
4th Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	125.2916	125.5170	125.9285	126.2375	126.4372	
	10	Water take (lit)		225.50	411.40	309.00	199.70	57.28
5th Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	126.4372	126.5125	126.6545	126.93.04	127.1601	
	5	Water take (lit)		75.30	142.00	275.90	229.70	36.1

Period		Flow, q Liter/min (3)	Guage pressure		Friction head loss,m		Total head, h 1+2+5-6-7	Lugeon, LU
			Guage pressure, (4)	Head of water, (5)	In basic pipework, (6)	In extra rods and pipes, (7)		
1st		43.61	3.00	30.60			31.60	27.600
2nd		71.70	5.00	51.00			52.00	27.576
3rd		75.71	10.00	102.00			103.00	14.700
4th		57.28	5.00	51.00			52.00	22.030
5th		38.10	3.00	30.60			31.60	22.848

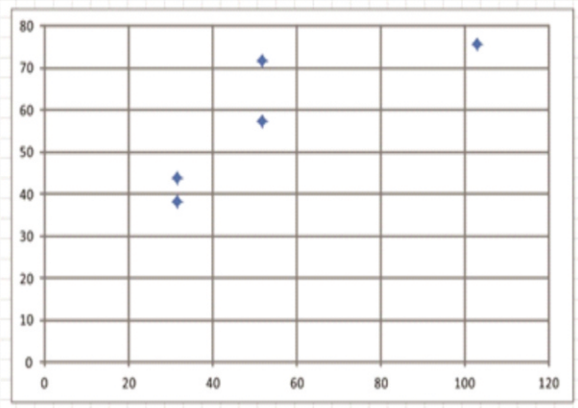


Fig.6. Shows the Picker test results of borehole Geo-11A.

6.5. Geo-13 Borehole

The borehole location lies in a hilly area. The borehole was drilled up to 37 meters but did not reach the bedrock (Chitral slates). Overall more than 37 meters overburden was present at this location. Steel casing was used to protect the borehole from collapsing. The overburden material is talus and colluvium deposits. The materials were silt, sandy clay, cobbles and gravels. Water loss was 100%. After every five meters depth, SPT was performed, but gave failed results because heavy particles were present in overburden material and no CR and RQD were recorded.

6.6. Geo-14 Borehole

Further 1 km southward to the Geo-13, the Geo-14 was drilled. The borehole was drilled up to 30 meters depth, but similarly to Geo-13, the bedrock was not touched. Overall the overburden material was present. The material is deposited by snow, water and gravity having different origins and size variations. A maximum particle size was 67mm. Water loss was 100%. Casing was used in order to protect collapsing of the borehole. The SPT failed due to the presence of heavy particles and no RQD and CR were recorded.

6.7. Geo-15 Borehole

This borehole location lies on the roadside (Chitral to Mastuj Road). The borehole was drilled up to 70 meters. Eight meters thick overburden materials was present at the location. Steel casing was used during the drilling in overburden. The overburden material was Blackish, very dense sands with some cobble and boulders. Gravel was fine to coarse, angular to sub angular and metamorphic in origin. The water loss was 100% in overburden materials. In core sample, Chitral slates were found, which was blackish grey in color, fine grain, hard, slightly weathered, cleavage surfaces, very closely jointed and have quartz veins. Due to highly jointed strata the borehole was collapsed several times and again grouted with cement to stop collapsing. At a depth of 38m & 39m, the 2meter thick local shear zone was observed. The core recovery was zero as just clay was extracted from this two meter drilling which indicated local shear zone. In bedrock, the water loss was 100%. The joint angle was mostly above 50̊. One to six numbers of major joints were present per meter. One out of three water pressure tests are successful. The CR and RQD data is presented in figure 8 and details of water pressure tests/ picker test is in figure 9.

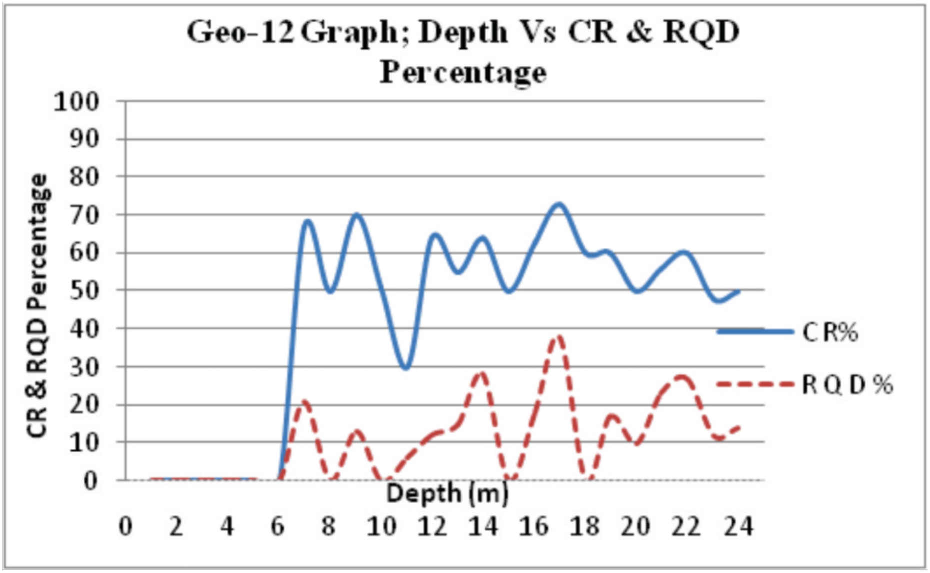


Fig. 7. Shows the CR, RQD percentage with depth.

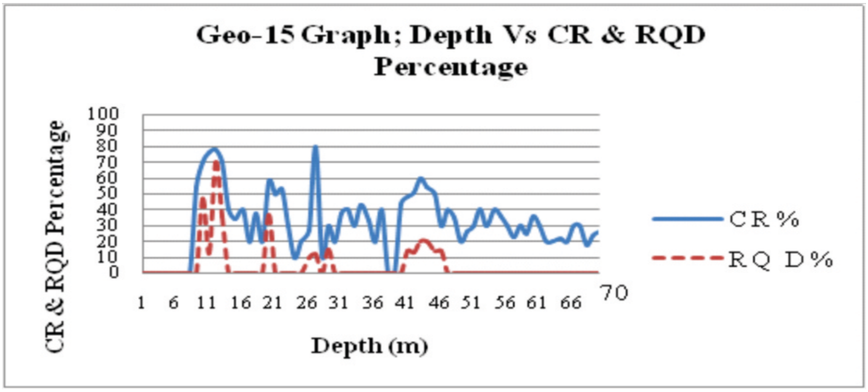


Fig. 8.Shows the CR, RQD percentage with depth.

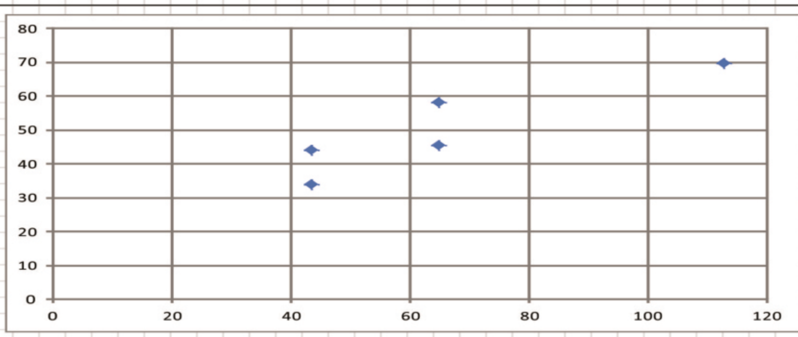
WATER PRESSURE TEST

TEST No.	1	BOREHOLE/ TESTPIT NO.	Geo-15
PROJECT	Geotechnical investigation of Chitral slates	DATE:	27/08/13
TYPE OF ROCK	Chitral Slate	Type of packer	Mechanical

Top of Test Section :	25	m	Ground elev. (m asl) :	
Bottom of Test Section :	30	m	Intial groundwater level :	11.1
Length of Test Section :	5	m	Packer Pressure (Bar) :	3, 5, 10, 5, 3
Centre of Test Section :	27.5	m	Gauge No. :	
Bottom of hole at time of test :	30	m	Diameter of hole in Test Area (mm) :	76
Bottom of Casing		m	Height of Pressure Guage (m) :	0.72

Stage	Guage pressure (PSI)							Average flow (q) lit/min
1st Stage		Time (min)	0	5	10	15	20	
		Flowmeter Reading (cu.m)	80638.90	80849.10	81002.50	81156.90	81314.50	
	5	Water take (lit)		211.00	152.60	154.40	157.60	33.78
2nd Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	81314.50	81518.60	81715.70	81934.70	82223.70	
	10	Water take (lit)		204.10	197.10	219.00	289.00	45.46
3rd Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	82223.70	82589.80	82864.50	83278.90	83619.50	
	15	Water take (lit)		366.10	274.70	414.40	340.60	69.79
4th Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	83619.50	83914.80	84285.60	84519.60	84781.70	
	10	Water take (lit)		295.30	370.80	234.00	262.10	58.1
5th Stage		Time (min)	0.00	5.00	10.00	15.00	20.00	
		Flowmeter Reading (cu.m)	84781.70	85207.80	85219.40	85447.80	85665.70	
	5	Water take (lit)		226.10	211.60	228.40	217.90	44.2

Period	Flow, q Liter/min (3)	Guage pressure		Friction head loss,m		Total head, h 1+2+5-6-7	Lugeon, LU
		Guage pressure, (4)	Head of water, (5)	In basic pipework, (6)	In extra rods and pipes, (7)		
1st	33.78	3.00	61.80			43.62	15.48
2nd	45.46	5.00	53.00			64.82	14.02
3rd	69.79	1.00	106.00			112.82	11.84
4th	58.11	5.00	53.00			64.82	17.92
5th	44.02	3.00	3.00			43.62	20.26



Slope of graph, q/h =		LU = (100/L)(q/h) in lugeon units =	15.90

Fig. 9. Shows the Picker test results of borehole Geo-15.

6.7.1. Geo-15 failed test section. (35-40m), (45-50m)

These tests were failed because of the highly jointed strata/ slates. The pressure could not reach to the required value which is mandatory for the test. The SPT/CPT was also not performed due to the presence of heavy particles like boulder etc. in the overburden.

10. Conclusion

Detailed subsurface study and different tests were carried out for Chitral slates which show that, in each borehole the strata was Chitral slates, and above the strata the overburden was present which is also the weathered product of Chitral slates. From the drilling process and core recovery, it is concluded that their results are not best but it is good enough for construction because the slates have fissility due which the large amount of core are losses during the drilling process. The core cover recovery in many places (e.g. run no. 37 and 38 in borehole Geo-15) are zero which show local shearing zone. So, in such places the treatment of the strata is necessary otherwise it may damage after or during the time of construction. The water loss is mostly 100% which indicate that the strata are highly permeable but it is a good sign that after the grouting the water loss are reduced or completely stopped. Owing to high permeability, it is concluded that the reservoir of the dam should be limited to hydropower generation and will not be used for other purpose due to which the water will store for long time. The overburden material should be removed because the overburden materials are present above the slates strata which may any time slide and cause the high damage.

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