TGB5100 ROCK ENGINEERING Atum 2012

Geological Investigation
Bogna Hydro Power Plant
Report

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1. Introduction

Bogna hydro power plant is situated close to the town of Steinkjer. The power station is relatively old. It was started in 1971. The aim of this investigation is to identify the rock type distribution, jointing and weakness zones along 1km long access tunnel.

The investigation is divided into four major parts:

- Desk study
- Surface mapping
- Tunnel mapping
- Laboratory testing

The desk study consists identifying possible weakness zones from aerial photos and studying the geological map to see the regional geology. The field mapping was made by walk over survey for one day along a chosen route and different rock outcroppings were identified and studied. In addition, weakness zone locations were also identified and measurements of dip & strike angle were made. Q-system was used to classify the rock types.

Along the 1000m long access tunnel a one day long investigation was also made so as to make sure what have been found in the surface mapping. Besides, water leakage, rock support and weakness zones are also identified.Stike and dip angle measurements were done, in addition Q – system was used to classify the rock mass.

The surface and tunnel mapping was done using topographical map with tunnel alignment, scale 1:5000,Geological map, scale 1:5000, Aerial photos, Stereoscope, compass and hand Hummer

Samples of different rock types were taken and tested in the laboratory to find drilling rate index, bit wear index & cutter life index.

2. Surface Mapping

Surface mapping is an important step in geological site investigation. After completing desk study a one day long surfacing mapping was carried out in Bogna. Distribution and character of rocks were studied. This was then followed up by mapping in the tunnel to compare the results of the surface mapping together with tunnel mapping.

2.1 Distribution and Character of the rock

Rock outcroppings along the field study path were evaluated and classified based on the exposures. The dip and strike angles were measured and the rock mass quality was also calculated at selected locations. Sixteen outcrops has been studied and presented below. A profile cross-section showing the rock types is plotted and can be shown in the appendix.

LOCATION – 1, 2 & 3

In these locations relatively massive sandstone with a very visible jointing and with no distinct bedding plane was found .Joint spacing is approximately 1m.

Fig.1.Sandstone

LOCATION-4, 5

A massive Green stone in between metasandstone was found (at location 4). It has no visible joint sets and no bedding plane.

Fig.2. metasandstone

LOCATION-6

In this location sandstone (left side) and phyllite which is intensely folded and fractured was found.

Fig.3.Phyllite

LOCATION-7

Slightly weathered metasandstone was found at this location.

Fig.4.Weathered Sandstone

LOCATION-8, 9 & 11

It cannot be proved exactly what type of rock it is at this exact location. It is a massive very strong which look like green stone was observed.

Fig.5.Greenstone

LOCATION-10

Slightly metamorphosed lime stone which is unclean .It was also found calcite containing sandstone.

Fig.6.Limestone

LOCATION-12 & 13

A metamorphic rock containing calcite, unclean marble or limestone with dense layers of sand. A very distinct bedding plane was observed also.

Fig.7.Unclean marble/limestone

LOCATION-14

The rock type that was found in this specific location is Gneiss or calcite.

Fig.8. Gneiss

2.2 Jointing

Jointing is the occurrence of joint sets forming the system or pattern of joints as well as the amount or intensity of joints. Joints are found in certain, preferred direction. One to three prominent sets and one or more minor sets often occur. In addition several random joints may be present. The joints delineate blocks. The block size is an extremely important parameter in rock mass behaviour. (Björn Nilsen & Arild Palmströn, 2000).

In the surface investigation we measured 30 strike bearings of joints on the exposed surface rock. The results from them can be seen in table 1, and on the joint rosette that was made. (Figure 9)

Strike	**Number**
N 0 - 15°	1
15 - 30°	2
30 - 45°	
45 - 60°	6
60 - 75°	7
75 - 90°	2
90 - 105°	1
105 - 120°	
120 - 135°	1
135 - 150°	6
150 - 165°	4
165 - 180°	
Sum	30

Table.1. Strike angle measurements

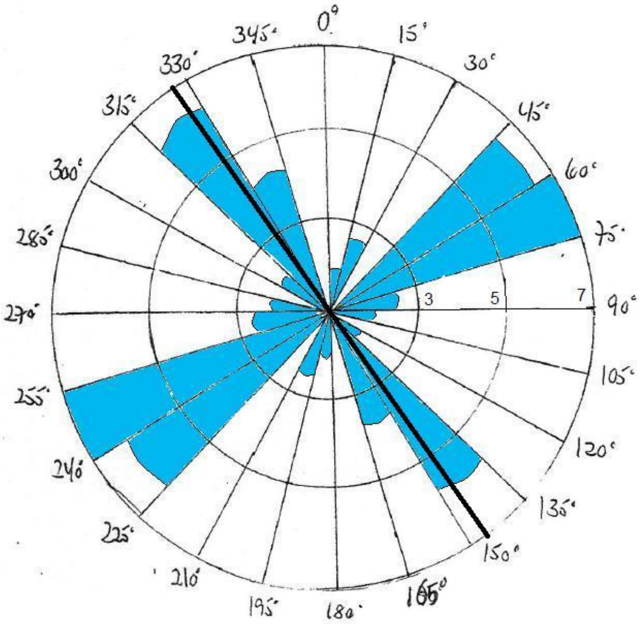


Fig.9.Joint Rosette. The black line is the tunnel alignment

As can be seen on figure 9 there are two main headings. On is from South West to North East and the other one is from North West to South East. There are also other measurements of one or two other headings but they are not major. The main directions are those two indicated in the figure above.

2.3 Weakness Zones

A weakness zone is a zone where the rock mass qualities are significantly poor. Aerial photographs have been studied and weakness zones have been identified in desk study. The weakness zones alignment is important to identify which will create extra costs & delays in tunneling because of its reduced mechanical properties. Two major weakness zones which are close to or crossing the tunnel alignment have been identified in the surface mapping even though there is dense vegetation in the area. Weakness zones generally can be identified as valleys or depressions on the terrain (Björn Nilsen & Arild Palmströn, 2000).

Fig.10.Weakness zone

2.4 Classification of Rock mass quality

There are various methods to classify rock mass .Q system has been used to classify the rock mass quality at certain points along the tunnel mapping path. Q system is based on the following parameters:

- Rock quality designation-RQD
- Joint set number-Jn
- Joint roughness-Jr
- Joint alteration-Ja
- Joint water reduction-Jw
- Stress reduction factor-SRF

These six parameters are grouped into three quotients' to give the overall rock mass quality:

$$Q = \frac{RQD}{J_n} * \frac{J_r}{J_a} * \frac{J_w}{SRF}$$

The first two parameters represent the overall structure of the rock mass, and their quotient is a relative measure of the block size. The second quotient is described as an indicator of inter block shear strength. Finally the third quotient is described as the active stresses (Björn Nilsen & Arild Palmströn, 2000).

The above parameters are highly subjective and need experience to come up with a reasonable values.The following values were obtained

Location	**RQD**	**Jn**	**Jr**	**Ja**	**Jw**	**SRF**	**Q-Value**	**Class**
1	80	9	1	1	0,66	2,5	2,35	Poor
6	75	9	1,5	1	0,66	2,5	3	Poor
12	75	9	1,5	4	0,66	1	2	Poor

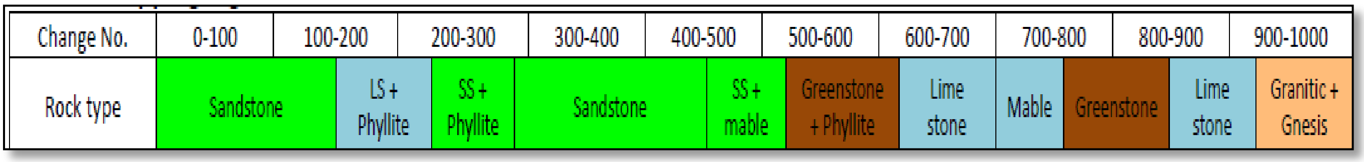
Table.2. Q-Values

3. Tunnel Mapping

The surface mapping results and the geological map were used as a background to confirm the rock type distribution, characteristics jointing and weakness zone along the tunnel.

3.1 Distribution and Character of the rock

The distribution and character of rock was done using the same method as of the surface mapping. The dominant rock types altering frequently along the tunnel are limestone and sandstone. The following table shows the distribution of rocks along the tunnel.



Change No.	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000

Rock type	Sandstone	LS + Phyllite	SS + Phyllite	Sandstone	SS + mable	Greenstone + Phyllite	Lime stone	Mable	Greenstone	Lime stone	Granitic + Gnesis

Table.2. Classification in tunnel

3.2 Jointing

In the tunnel study we measured 21 strike directions of joints on the tunnel wall. The results from them can be seen in table 3, and on the joint rosette that was made (figure 11)

Strike	Number
N 0 - 15°	1
15 - 30°	2
30 - 45°	2
45 - 60°	4
60 - 75°	
75 - 90°	2
90 - 105°	3
105 - 120°	
120 - 135°	3
135 - 150°	
150 - 165°	1
165 - 180°	3
Sum	21

Table.3. Strike angle measurement

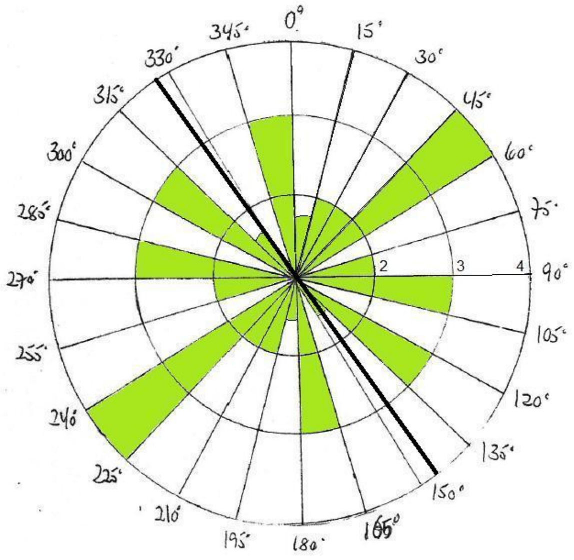


Fig.11.Joint Rosette. The black line is the tunnel alignment

As can be seen on figure 11, there is only one main heading. It is North East to South West. The other is almost equally distributed on other direction.

3.3 Weakness zones

In the tunnels we mapped couple of weakness zones. Mostly they were close to the bottom of the tunnels. We found weakness zones at 975 m, 740 m, 650 m and 550 m. They vary in width from about 8 m to 30 m. (For more details, see sheet from tunnel mapping in appendix)

3.3 Water leakage

Water leakage was estimated in the tunnel. There were no assessments made on the surface, to estimate how much water would be leaking in the tunnels.

The tunnel turned out to be almost dry. The walls on some places where wet but the leak from the walls was very small. In the ceiling there was water shielding placed a cloth so the water wouldn’t drip from the ceiling to the floor. There were only two places in the tunnels where the water leakage was significant. First at about 350 m from the entrance. There we estimated that the water was dripping at a rate of about 1 L/per.minute for a section of about 50 m. The other place that we estimated the water inflow was at about 150-200 m. There we estimated that the water was dripping at a rate of 3 L/per.min. (For more details, see sheet from tunnel mapping in appendix)

Water leakage was probably much more when the tunnels where being built because the weakness zones were closed up with concrete so no water got threw there. Weakness zones often carry the most water. That is because the rock there is often broken up and more open than in other places (Björn Nilsen & Arild Palmströn, 2000).

3.4 Rock Support

The rock support methods, such as scaling, rock bolting, shotcrete, concrete lining or grouting, are commonly used in hydropower tunnel. Tunnel in Bogna trip, rock was hard enough so that they used minimum rock support method. We could find the 6 concrete lining for supporting the sections with exceptionally poor rock like, weakness zone, and shotcrete and dozens of rock bolts. Also, we could find the steel mesh on the top of the tunnel. For those rock support methods, we had difficulty in studying tunnel mapping.

4. Comparison and discussion on mapping results

From the data we collected in the surface mapping and desk studies, we can compare what we thought we would find, to what was the reality from the tunnel mapping.

If we first look at the characteristics of the rock and distribution, we found that there was much more of limestone in the tunnel than we had mapped on the surface. That is probably because limestone is a weak rock that is easily weathered away and not many outcrops where left on the surface. The few that were not covered with soil and vegetation were not many and we only walked after a road that can have curved away from some openings. We also did some Q measurements on the surface and in the tunnels and the Q values from the surface are lower than those from the tunnel. At the surface, out Q value was around 2-3 but in the tunnels it was from 9-47,5. That might be because at the surface the rocks that are left behind are the strongest rocks. Erosion has had a long time to erode them away so they may look weaker because of that. More faults and other characteristics like that are probably more outstanding. It has also be taken into account that we were doing a field investigation like this for the first time and in the tunnel we had more experience from the day before.

In the tunnel investigation we also saw more of greenstone and alteration between limestone and sandstone dominate more in the tunnel.

We mapped faults in the rocks both at the surface and in the tunnels. We did 30 measurements at the surface of strike and dip of faults planes and 21 in the tunnel. In both cases we had the same main directions. The most obvious one is the one from 45°-60 to 225°-240°. That can be seen on both rosettes. On the surface, were we did more measurements, we can see that there is an obvious second main direction. That is the direction from 135°-150° to 315°-330°. That is aligned with the tunnel direction so that is not a favorable direction to build a tunnel in. Inside the tunnel we don’t see this as obvious. There are other measurements distributed in almost all direction and no second main direction. That could be explained by the fact that this faulting is in the same direction as the tunnel and because of that it could be harder to measure it in the tunnel. The walls were sometimes covered with concrete so it can be hard to see obvious faults. Maybe if we had done more than 21 measurements in the tunnel, we had seen some other results, but, the distribution of measurements could be a result of blasting in the tunnel and cracking from that.

Weakness zones had been mapped in the desk study before the trip and in the surface mapping, we walked passed some of the mapped zones. We didn't see anything that suggested that this could be anything else. The characteristics were all there. In the tunnel we marked a weakness zone when there had been cast a thick concrete in the wall and the ceiling. Because of the weakness in these zones, an extra good support is needed. We saw some evidence of swelling clay, and that has to be monitored extra well, because that can cause big trouble.

Rock support and water leakage was less in the tunnel that we had predicted from the surface mapping. We had suspected that there would be less support in the tunnel and since the tunnel had been built, the company who ones the tunnel, had put up extra rock bolts and other preventive measures. Water leakage was only in two places of any volume. Possibility for that is because the weakness zones had been closed off, and they often carry a lot of water. Also the Q value was much higher in the tunnel so water doesn't have much space to move though.

5. Laboratory work

Laboratory tests are used to determine the mechanical properties of rock. Different rock samples were taken and tested.

5.1 Drilling rate Index

There are two laboratory methods that assess the drilling rate index. That are the brittleness value (S_{20}) and the Sievers J-value SJ.

The brittleness test is performed as shown in figure X.

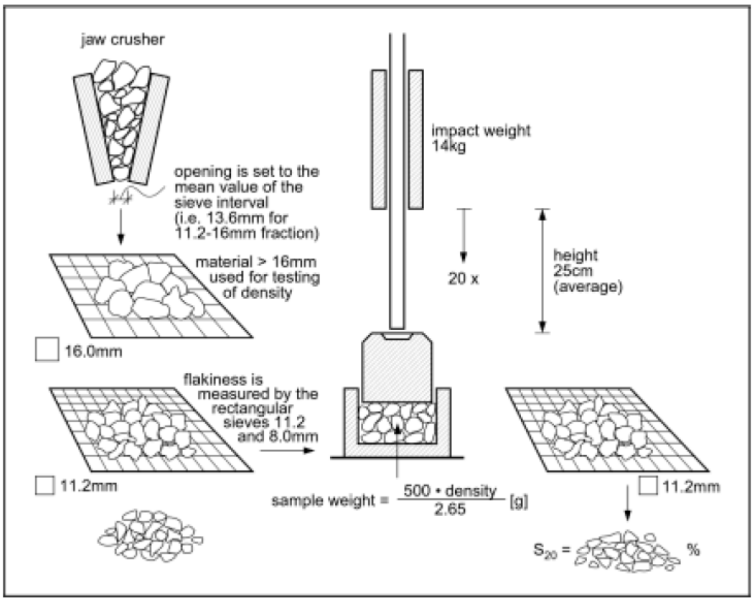


Fig.12.Brittleness test

The brittleness test gives a good measure for the ability of the rock to resist crushing by repeated impact.

The Sievers J-value is found out by a drilling test and it measures the surface hardness of the rock. After pre-cutting the rock, you find a good spot on it, where the rock doesn’t have any crakes or other features that are not representing the whole rock. The test is shown on figure 13.

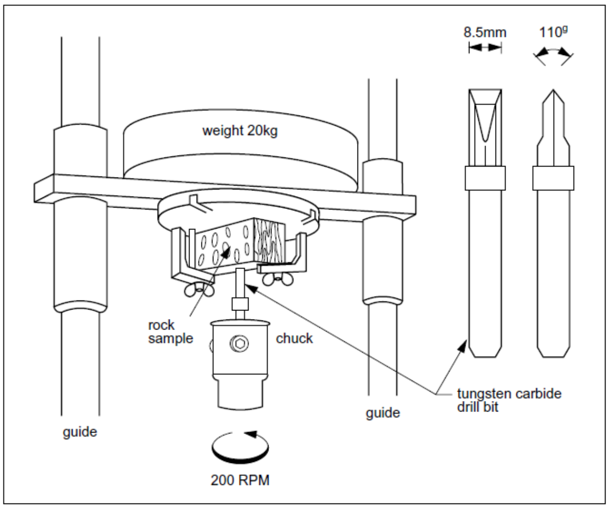


Fig.13. Sievers J-value

To find out the drilling rate index, a graph (figure 14) is used and the results from the two test. On the X axis is the brittleness value and on the right Y axis is the Sievers J-value. Where the two factures intersect, the Drilling rate index is read from the left Y axis.

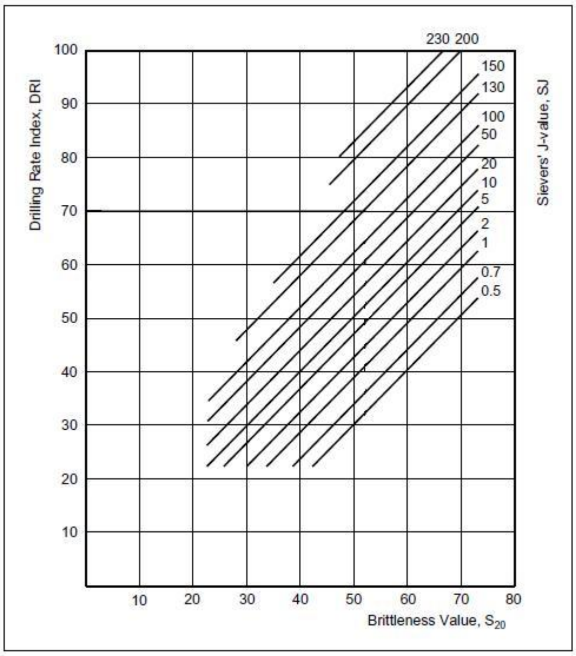


Fig.14.Drilling rate index chart

5.2 Bit wear Index

The figure below shows how abrasion test is performed and we had crushed our sample to be smaller than 1 mm. The test we made was to measure abrasion value (AV) and Abrasion Value Cutter Steel (AVS). The AV test measures the weight loss of a steel block after 100 revolutions of the disk. The AVS value is the measured weight loss of cutter steel after the disk has turned 20 revolutions. The weight loss in milligrams is the abrasion value (Amund Bruland, 1998).

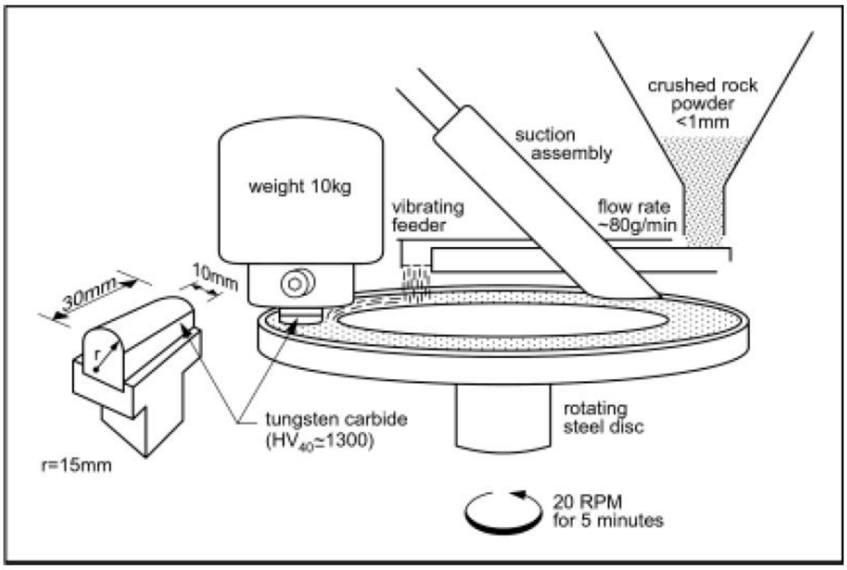


Fig.15. Abrasion test apparatus

To estimate the Bit wear index, we used our measured AV value and measured drilling rate index (DRI) and read of the chart (figure 16). We find where the DRI line intersects the AV value.

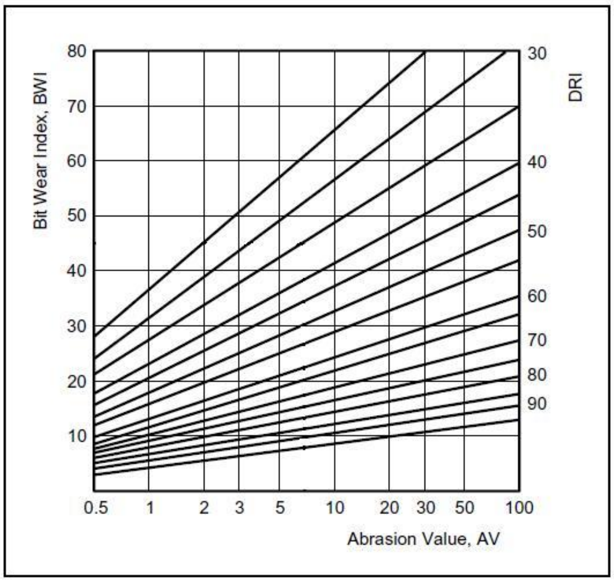


Fig.16.Bit wear Index chart

5.3 Cutter Life Index

The cutter life index uses the SJ value and the abrasion value steel (AVS). The CLI show how long the cutter rings will last in the tunnel boring machine. The CLI is based on normalising field data from actual cutter life versus tested rock parameters.

The formula is:

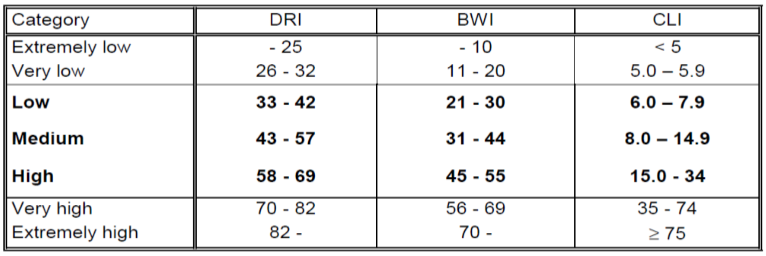
$$CLI = 13{,}84 * \left(\frac{SJ}{AVS}\right)^{0{,}3847}$$

6. Discussion on mechanical properties

The laboratory test results are tabulated as shown below.

	HA Phyllite	HB Limestone	HC Limestone	GA Amphibolite	GB Sandstone	GC Sandstone	EA Granitic gnesis	EB Gnesis
Brittleness (S20,11,2-16,0mm)	61,7	47,7	61,7	40,1	36,8	38,2	48,8	57,4
Flakiness	1,32	1,34	1,39	1,35	1,41	1,4	1,4	1,47
Compaction index	3	2	1	1	1	1	0	2
Density.g/cm3	2,77	2,77	2,75	2,8	2,72	2,78	2,66	3,02
Sievers' J-Value(SJ)	21,4	71,2	48,2	2	25	2,1	2,8	42,1
Abrasion value (AV)	1	1	1	5	2	3	18	4
Abrasion value cutter steel (AVS)	4	0,5	0,5	5	4	5	9	6
CALCULATED INDICES								
Drilling Rate Index (DRI)	66	58	70	32	41	30	42	65
Bit wear Index (BWI)	13	16	12	47	29	44	44	18
Cutter Life Index(CLI)	26,4	93,2	80,2	9,7	28	9,9	8,9	29,3

Table 4. Laboratory test results



Category	DRI	BWI	CLI
Extremely low	- 25	- 10	< 5
Very low	26 - 32	11 - 20	5.0 – 5.9
Low	**33 - 42**	**21 - 30**	**6.0 – 7.9**
Medium	**43 - 57**	**31 - 44**	**8.0 – 14.9**
High	**58 - 69**	**45 - 55**	**15.0 - 34**
Very high	70 - 82	56 - 69	35 - 74
Extremely high	82 -	70 -	≥ 75

Table.5. Classification of indices

After reviewing the results we have made a couple of points about them and what they can tell us.

- The DRI value for the phyllite sample lies on the high range .The bit wear index is very low and cutter life index lies in the very high range.

- The two limestone samples DRI values varies by about 12% this might be due to the samples mineral content, but the DRI is high to very high. BWI values are fairly close which lies in the very low range. And CLI is extremely high for limestone.
- The amphibolite sample's DRI value lies in the very low range. BWI value of the sample lies on the high range and CLI value lies in the medium range.
- The DRI value for the two sandstone sample lies in low and medium range, there 11% difference between this two samples this might be due to mineral content and the test methods (it is recommended to do more of the same kind test to get a reasonable average result).The BWI values also lie in low and medium range, CLI values lies in medium and high values.
- The granitic gneiss samples DRI values lies in low and high range. BWI values in very low and medium class, CLI values also lies in medium and high range.

From this we can see that in general the rock types are all good to drill inn except the granitic gneiss, which is a hard and solid rock. That is why the designer of the hydropower plant wanted to have the powerhouse in the granitic gneiss. The range of the measured values for each rock should be taken with provisionally, because we did very few samples and sometimes only one of each rock type. For a big project, it is recommended to do much more and take the average of the test results.

7. Conclusion and recommendation

We had such a great experience how to investigate the rock for constructing the excess tunnel for 5 days including desk studying, surface mapping, tunnel mapping, and laboratory testing. In reality, to construct tunnel for hydropower, it has to take a lot of time for desk study and surface mapping to make sure about the rock types, joints, and weakness zones. However, this field trip is aim to know all the process for investigation. We only take few days to investigate and only stop by few locations to look into on surface and in tunnel, so our surface mapping and tunnel mapping shows some different results. Another reason for the differences is that we are not that expert so we could make mistake for distinguishing rock types and measuring Q-system and dip and strike.

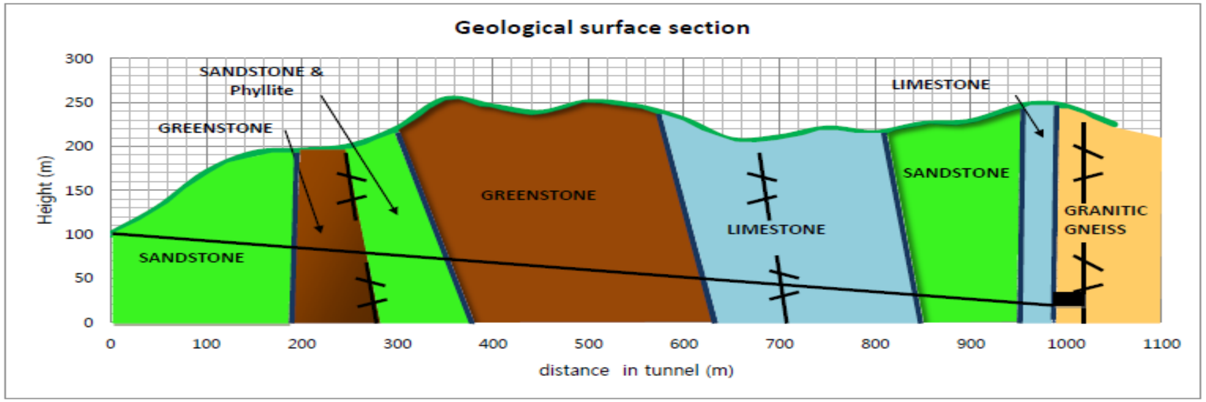
For this big project, we know that it is important to spend much time and effort for desk studying and investigations. If you have not done correct desk studying and investigation, you might be able to spend more time, effort and a lot of money in construction and management. It is very inefficient and uneconomical and it might collapse. Therefore, we recommend that somehow you have to spend much time and work with experts; you try to obtain information as much as you can about the underground for construction. Then you can have successful tunnel for hydropower.

8. Bibliography

Björn Nilsen & Arild Palmström (2000). *Engineering Geology and rock engineering, Handbook nr.2.* Oslo: Norwegian group for rock mechanics (NBG).

Amund Bruland (1998). *Hard rock tunnel boring – Drillability, Test methods.* Trondheim, Norwegian University of Science and Technology.

9. Appendix



Tunnel mapping logs

Change No.	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000
Rock type	Sandstone	LS + Phyllite	SS + Phyllite	Sandstone	SS + mable	Greenstone + Phyllite	Lime stone	Mable Greenstone	Lime stone	Granitic + Gnesis
Foliation		✶ ✶	✶ ✶	✶	✶	✶		✶	✶ ✶ ✶	✶ ✶
Jointing	Mainly Three joint set ③				③ +irregular joint set	③	Covered with shotcrete	② ③ (shotcrete)	③ ②	② ③
Weakness zones						Weakness Zone 8m and 8m	Weakness Zone 25~30m	Weakness Zone 10m		Weakness Zone 8m
Rock support	Rock bolts		Shotcrete	Rockbolts Steel mesh	10 Rock bolts	2 concrete lining+ shotcrete	Concrete lining +shotcrete	Shotcrete Two concrete lining		Concrete lining
Water		3l/min Water flow		1l/min Water flow		Little water flow			Dry	Dry
Remarks	Q=10.4		Q=16.2							Q=12.75 and 31.66

✶ : Foliation is found in this location.