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# Engineering Geology of Ghomroud Tunnel with Emphasis on Water Inflow-A Case Study

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## ABSTRACT

This paper mainly focuses on pre-investigations and on optimal extent of preliminary investigations. Different investigation methods are tested in varying geological conditions. In this paper results from site investigation carried out on Ghomroud Tunnel are discussed and compared with what have been encountered in geological conditions and water leakage during excavation. The rock types are, however, quite different.

KEYWORDS: Engineering geology, tunnel, water inflow, rock properties

## INTRODUCTION

Awareness of the influence of geological conditions on tunneling operations is a natural extension of a satisfactory site investigation. Changes in geological conditions which result in decreased competence of the rocks surrounding the excavation lead to increasing tunneling costs. This is in addition to efficiency as well as operational and safety aspects. Consequently, in-depth appreciation of the geological conditions plays an important role in designing, planning, construction, eventual commissioning and operation of the tunnel.

The Ghomrud Tunnel in central Iran is a 36 km long water supply tunnel from Dez river to Golpayagan dam (Farrokh *et al.*, 2008, Figure 1). The lithology of this area consists of a sequence of Jurassic-cretaceous formations (Figure 2). The cretaceous formation consists of massive limestone and dolomite while the Jurassic formation mainly consists of slate schist and metamorphic shale and sandstone units. The majority of the rock mass is considered to be of weak to fair quality. This long tunnel is divided into four parts, the following project is located in the second part. This research is focused on main tunnel and access tunnel No.1.

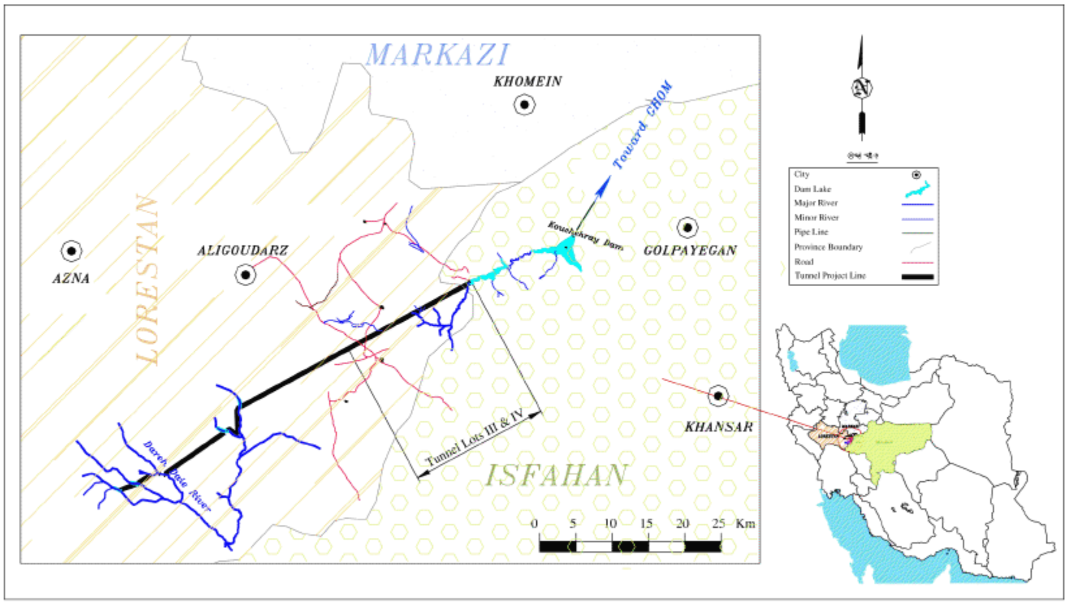


**Figure 1:** Location of the project area

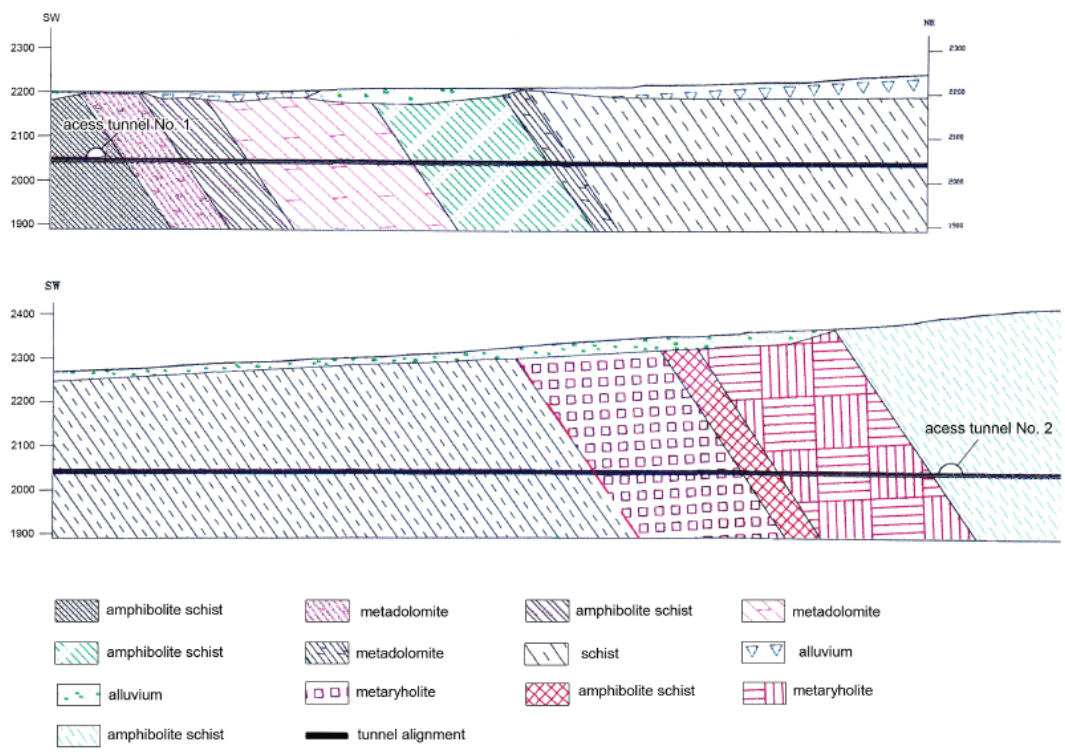


**Figure 2:** Geological map of the main tunnel (scale 1: 5000)

## PROJECT DESCRIPTION

The length of the main tunnel will be 9 km and the tunnel diameter will be 3.7 m. Access tunnels No.1 and No.2 were excavated 5 m in diameter and 1687m and 1800m in length, respectively.

### Engineering Geology of main tunnel

This area consists of rocks such as schist, amphibolite, slate, quartzite, meta-dolomite, meta-diorite, and marbles.

Because of different lithology there are variations in morphology, and the difference between highest and lowest part is 350 m. Different sections in terrain are as follows:

QLa, Qs,Qt: This group of rocks consists of conglomerate, sandstone and mudstone. Three boreholes were drilled to achieve these results. Often the strength of these rocks is very low(UCS, 30-40 MPa). During exploration drilling they were separated from each other easily.

Md3, Md4, Md6, Md7: These sections are meta-dolomite with interlayers of schist, thick dolomites, and dolomitic limestone with interlayers of quartzite.

Sh3, Sh5: This group consists of schist, amphibolite schist, mica schist .

As1, As2, As3, As4: This group consists of amphibolite schist.

Trh1, Trh2: The rocks here are meta-rhyolite.

Tsh: The rock type consists of amphibolite schist with interlayers of mica-schist.

Tma: This section consists of dark massive marble.

Sch1: This unit consists of dark to green schist with interlayers of dolomite limestone.

### Engineering geology of the access tunnel

The gradient of this access tunnel is 10 %. The portal excavated with 150 m open trench and 1687 tunnel with 5 m diameter. At the beginning of the tunnel, based on surface geological observations, there are 15 m alluvial and weathered rocks. The type of this alluvial is sandy silty clay and located in 3.5 m depth. After this depth, there are weathered schisthy and micaschisty rocks. The thickness of these rocks extends to 60 m, and is defined with Qs section. This section consists of old sediments from areas and extends to 1300 m of the tunnel.

### Exploration Boreholes:

Three boreholes were drilled to find geotechnical characteristics:

*Borehole No.1:*

This borehole is drilled at the beginning of the tunnel and is 40 m deep. The tunnel passes through the depth of borehole from 7 to 12 m which consists of schist and slates of SH5 unit with RQD (Deere, 1964) 20 that show the rocks are weak. When depth increases, RQD also improves and weathering decreases. Because of crushed rocks and extension of different joints, the measured value of permeability is 82.4 Lu. As the water tables is 3 m below the surface, during the excavation of SH5 unit water flow to the tunnel was observed due the gradient. The most joints have dips 0 to 10 degrees and 30 to 50 which shows care should be taken to use installation of reinforcements especially rock bolts.

*Borehole No.2*

This borehole is drilled from 350 m of the opening of the tunnel and is 33 m deep.

The tunnel passes through the borehole from 28 m to 33 m, the rocks consists of greenschists of SH5 unit which have RQD 74 to 90 showing good strong rocks. The permeability is 0.7 Lu which shows less weathering and crushing. The water table is 9.7 m below the surface. The extension of the joints is similar to borehole No.1 and care should be taken to have reinforcements.

*Borehole No.3*

The borehole is drilled from 870 m of the tunnel and is 92 m deep. Alluvial occurs in 43 m and then amphibolite schist, green schist to the end of the borehole. The rate of weathering is medium and the RQD equals 77.9, indicating good rock. The tunnel passes through from 73 to 78 m depth and the RQD ranges from 60 to 90. The permeability is 13.7 Lu and the extension of the joint sets is nearly vertical, there is good relationship between permeability and opening of the joints. Care should be taken during excavation and facilating grouting.

From here and before the end of the tunnel, alluvial terrace is defined to Qt. These sediments are often sand and gravel which have some rocks such as micaschist, amphibolite, metadolomite and limestone. The depth of these sediments is 40 to 50 m. Fortunately, Qt and Qs do not cross the tunnel section. Alluvial sediments occur in very wide area with some outcrop. The type of the rocks are divided to two groups:

Hard rocks such as MDL7, MDL6, MDL5

Weak rocks such as SH5, AS3, AS2, AS1

SH5: These are metamorphic rocks which consist of slate and schist (micaschist, amphibolite schist). There are often interlayers of dolomite and dolomite limestone with 10 to 15 cm thickness.

MDL7: This section consists of dolomite limestone with interlayers of quartzite in 4 cm to 1 m thickness.

AS3: This section consists of amphibolite schists with dark green color which sometimes change to micaschist.

MDL6: 220 m of the tunnel cross the massive metadolomite rocks with interlayers of chert and quartzite in 4 to 10 cm thickness.

AS2: They are amphibolite schist with light green color and less micaschist .

MDL5: This section consists of thick massive metadolomites with interlayers of schist in a few centimeters to 2.5 m thickness.

AS1: The last section which is located at the end of the tunnel and intersection of main tunnel is amphibolite schist.

## Structural geology of the tunnel

There is no fault in the terrain and joint survey is done with different groups as follows:

A-this group consists of hard rocks such as MDL5, MDL6, MDL7 and contains following joints:

J1: S30W 60NW

J2: N16E 70SE

J3: N82W 50SW

J4: N50W 50NE

B: this group consists of weak rocks such as AS1, AS2, AS3, SH5 which indicate weathering and crushing. The specific characteristic of these metamorphic rocks are good schistosity such as: Schistosity N65W 55NE. Intersection of joints 1 and 2 with 3 creates wedges which may cause instability and subsequently to be controlled with anticipated reinforcement.

## The geohydrology of the access tunnel

At the beginning of the tunnel there is no special problem about water intrusion, and with pumping it is possible to solve it. The permeability changes very rapidly and reaches 82.4 Lu, and faces water intrusion. Due to discontinuities and joints here water moves towards the face and pumps should evacuate the water to sump stations. When the tunnel cross the weak rocks (AS1, AS2, AS3, SH5 units) instability happens and the water worsen the situation, thus reinforcements should be considered.

## Geomechanical parameters of the access tunnel

For each type of rocks, rock mass classification (1946, 1964, 1974, 1989, 1997) is defined and based on laboratory tests physical properties of the rocks are specified.

(1) SH5

There are dark schists without weathering, fine gains with calcite and quartz veins. The joints have often planar surfaces, opening less than 1 mm with calcite coatings.

Rock mass classifications are as follows (Table 1).

**Table 1:** Rock mass classification for SH5

| NGI | RMR | Deere | Terzaghi | GSI |
|---|---|---|---|---|
| 0.19-1.815 | 33-45 | weak | Jointy to very jointy | 30-35 |

Physical and mechanical properties of rocks are as follows (Table 2):

**Table 2:** Physical and mechanical properties

| Tensile strength (MPa) | UCS (MPa) | Slake Durability | Porosity (%) | Density Dry | ($gr/cm^3$) Saturated |
|---|---|---|---|---|---|
| 6.7 | 40 | 99.6 | 1.15 | 2.80 | 2.81 |

The other characteristics of the rock mass are as follows (Table 3):

**Table 3:** Mechanical properties

| Ø (Degrees) | C (MPa) | Em (GPa) |
|---|---|---|
| 28-30 | 0.2-0.3 | 2-2.4 |

AS1, AS2, AS3

There are amphibolite schists, fine grains without weathering, very strong with calcite and quartz veins. The joints have planar or wavy surfaces with calcite or ferro oxide coatings. The openings of the joints are low, maximum reaching 2 mm.

Rock mass classification is as follows (Table 4):

**Table 4:** Rock mass classification for As1, As2, As3

| NGI | RMR | Deere | Terzaghi | GSI |
|---|---|---|---|---|
| 0.52-4.62 | 30-45 | Very good | Jointy to very jointy | 30-35 |

Physical and mechanical properties of rocks are as follows (Table 5):

**Table 5:** Physical and mechanical properties

| Tensile strength (MPa) | UCS (MPa) | Slake Durability | Porosity (%) | Density Dry | (gr/cm3) Saturated |
|---|---|---|---|---|---|
| 5 | 60 | 99.71 | 0.48 | 2.96 | 2.97 |

The other characteristics of the rock mass are as follows (Table 6):

**Table 6:** Mechanical properties

| Ø (Degrees) | C (MPa) | Em (GPa) |
|---|---|---|
| 35-40 | 0.25-0.35 | 2.5-3.0 |

QLa

These are often coarse grain conglomerates with clay cement, and sometimes calcite chert. Due to lack of good samples, the data is very limited . Rock mass classification is as follows (Table 7):

**Table 7:** Rock mass classification

| NGI | RMR | Deere | Terzaghi | GSI |
|---|---|---|---|---|
| 0.0125-0.05 | ----- | Very weak | ------- | ------ |

Mechanical properties are as follows (Table 8):

**Table 8**: Mechanical properties

| Ø (Degrees) | C (MPa) | Em (GPa) |
|---|---|---|
| 35-40 | 0.05-0.07 | 0.7-1 |

### MDL5, MDL6, MDL7

These are meta-dolomites with calcite veins and without weathering. Rock mass classification is as follows (Table 9):

**Table 9:** Rock mass classification

| NGI | RMR | Deere | Terzaghi | GSI |
|---|---|---|---|---|
| 0.9-6.7 | 35-55 | good | Jointy to very jointy | 30-40 |

Physical and mechanical properties of rocks are as follows (Table 10):

**Table 10:** Physical and mechanical properties

| Tensile strength (MPa) | UCS (MPa) | Slake Durability | Porosity (%) | Density Dry | ($gr/cm^3$) Saturated |
|---|---|---|---|---|---|
| 7 | 64 | 77.07 | 0.48 | 2.80 | 2.81 |

The other characteristics of the rocks are as follows (Table 11):

**Table 11:** Mechanical properties

| Ø (Degrees) | C (MPa) | Em (GPa) |
|---|---|---|
| 40-42 | 0.40-0.45 | 3.0-5.8 |

## Support system of the access tunnel

It is decided to utilize rock bolt with 1 m system bolting, 15 cm reinforced (fiber) shotcrete and grouted rock bolt 3 m long (Figure 3), at portal, fault and crushed zones and also intersection of the main tunnel with the access tunnel (Figure 4).

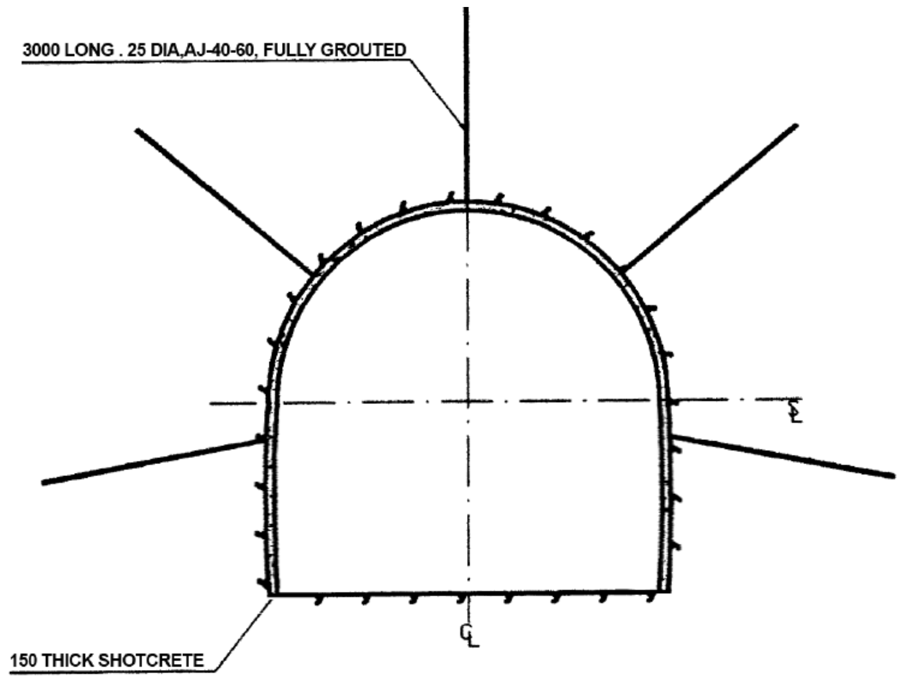


**Figure 3:** Support system of the access tunnel (Scale 1:50)

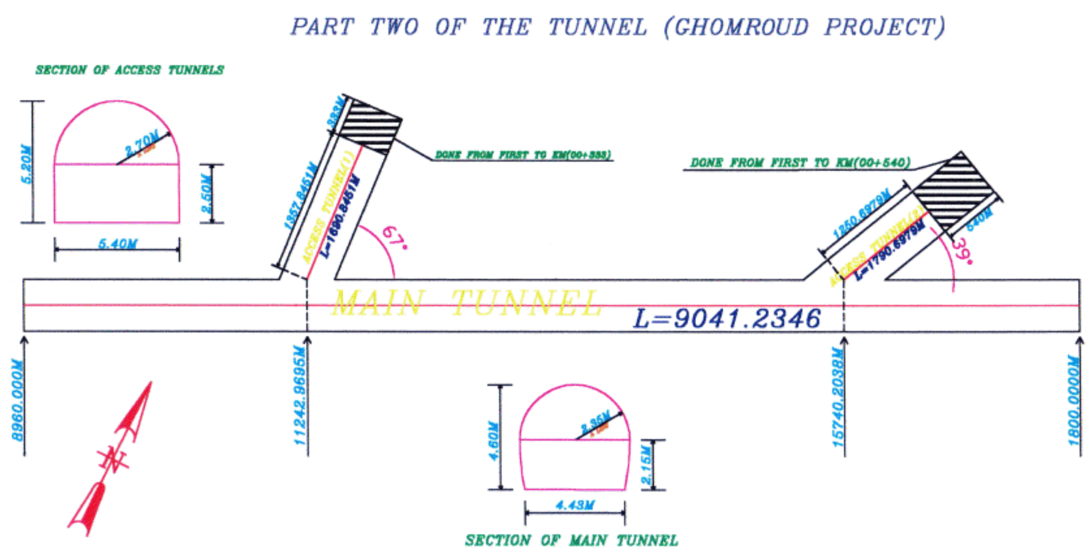


**Figure 4:** Plan view of the main tunnel

## Excavation method of the access tunnel

Strong rocks group has less weathering and high strength. Lithology of strong rocks generally consists of dolomites, meta-dolomites with interlayers of cherts and quartzite. According to lithology, high strength, chert and quartzite, high $SiO_2$ content, the conventional drill and blast is chosen. A one-boom hydraulic drill jumbo is used for drilling. Medium and weak rocks have medium to high strength, due to lithology. Rocks of these groups consist of metamorphic rocks, such as slates, schists, and amphibolite schists.

## Road-header selection

Essentially, there are two ways of excavating underground openings in rock, by conventional drill and blast methods or by mechanical excavation techniques. Road-headers have played a major role in the driving of roadways in coal mines and soft rocks in the world, but when applied in stronger strata, with a uniaxial compressive strength (UCS) greater than 70 MPa, the limitations of earlier designs became apparent. Cutting in stronger strata resulted in excessive pick consumption, high maintenance costs and frequent breakdowns which often showed the use of earlier machines are uneconomic. The development of heavier duty road headers has greatly extended the range of rock conditions which could be excavated by this type of tunneling machines. McFeat Smith (1982) has presented a comparison between different types of excavation. The main difference between tunneling machines and drill & blast techniques is the flexibility of the latter. As a result where costs are about the same, the greater flexibility of drill and blast in coping with difficult conditions is often the deciding factor in its favor. On the other hand, tunneling machines are selected because they offer faster progress and lower costs in appropriate tunneling conditions. The range of ground to be excavated and supported on any project must be clearly defined so that machine manufacturers can design accordingly. Based on the reasons mentioned above, for the 9 km long tunnel, the road-header is considered. One of the greatest benefits of a road-header in relation to the drill & blast operation lies in the smooth excavation of rock mass in critical zones, e.g. weak or soft, unstable rock formations and fault zones. In these zones the smooth and precise cutting of rock mass with a road-header might be able to avoid a lot of problems mainly caused by the blasting shock (normal damaged zone in >0.5), which considerably damages the rock mass around the tunnel and open up cracks so water leakage increases. An additional big advantage of the road-header excavation method is the avoidance of bigger over excavation: the excavation method by road-header gives the possibility to cut with a trained crew a rather exact cross-section according to the given theoretical profile. Rock strength and CAI (West, 1989) are the main parameters forming the base of geotechnical evaluation regarding the operation of a mechanical excavation machine. Therefore, the parameters are put into a scheme for assessment of cutting performance and pick consumption and for . The whole range of UCS clearly lies within the cutting range of a medium weight road-header, and the mean CAI value of all the different rock types is in a certain range (0.61 to 1.21) and all are studied in the lower range of the rock abrasivity scale (from little abrasive to moderately abrasive). The volume of cut rock per effective cutting time defines the net cutting rate (Schneider, 1988). The effective cutting time is defined by the time the cutter head is in contact with the rock and actually cutting. Thus, supplementary profiling on loading time does not count to the effective net cutting time. There are a lot of documents about cutting performance which is valid for intact to moderately fractured rock mass, which corresponds to approx. RMR=100 to 60. According to definition of rock mass, rating of Bieniawski (1989) needs very good or good conditions. If rock conditions, but with different Rock Mass Rating of 40, 30 or 20, the net cutting rates can be increased by up to 50 % or even more. The rock conditions of this project in regard to Rock Mass Rating were in general fair conditions; this can be related to RMR of 40 to 60.

## Water inflow to the access tunnel

The most important thing in tunnel is anticipation of water inflow and then to solve the case. In this tunnel there were both cases. We observed that the joint crossed the axis of the tunnel, the joint filled with clay (2-5 cm thickness sometimes 7 cm) and water flow 1600 lit/s. Role of engineering geology is a key element to face the situation. For example, there was a joint which passed small water and repeated again. This happened exactly in the tunnel. If you could succeed in anticipating the situation, then you can prepare all facilities needed to face the problem. Due to results obtained and rate of advance in one of the cases, it is anticipated that after 60 m water inflows happens. Before the tunnel reaches this change pilot holes drilled with 15 m length, and the results showed that it is possible to predict water flow and control it . The amount of water inflow is important. If it is small you can drain it with passageways. If it is medium, with different capacities of pumps you can solve the case, but if it is high the other solutions such as grouting can help the case and seal the position. For instance, we used wooden wedges and packers into the joint to control the water inflow, but due to high pressure of water it was not totally appropriate. For this reason several holes were drilled to reduce water pressure. Subsequently, 6 holes were drilled for grouting with 9 m length, 3m distance and 30 degrees in respect to axis of the tunnel which formed an umbrella. With these requirements, the water flow reduced to 70 lit/s and the capacity to pump water was 150 lit/s. The shotcrete and mesh put on the joint and the tunnel stabilized without any major difficulty.

## CONCLUSIONS

The main conclusion based on this study is that the importance of understanding geology can not be overestimated. Through the study of geology of available geological information, detailed geological mapping is the first and most important investigation and will be the base for proposal of excavating system to be applied for the project.

## ACKNOWLEDGEMENTS

The author would like to thank Stratus Company for providing data from the Ghomroud tunnel. The constructive comments of Dr. Morfeldt and Prof. Shaikh are gratefully acknowledged.

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