Indian J.Sci.Res. 9 (1): 137-145, 2014
DOI: 10.5958/2250-0138.2014.00022.4 ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

# TUNNELING MACHINE SELECTION MODEL BASED ON GEOLOGIC PARAMETERS USING AHP METHOD CASE STUDY: NOSOUD WATER TUNNEL

**SHAHAB FAHIMDANESH[a1] AND NASER HAFEZI MOGHADAS[b]**

[a]Ph.D Student of Geology Engineering, International Campus of Ferdowsi University of Mashahad, Mashhad, Iran
[b]Associate Professor of Department of Geology and Geology Engineering, Ferdowsi University of Mashhad (FUM), Mashhad, Iran

## ABSTRACT

**According to the features of tunnel drilling machine that are not easily removable after start to work, and geological parameters that makes these devices functions be different in different contexts. On the other hand, causes to detect the excavation team and their weigh influencing on TBM devices choice. For this purpose this article after identifying these factors using AHP method classified them and studied them for case study of Nosoud water tunnel. This study can be classified in terms of functional results and in terms of executive approaches it can be classified in analytical category. The results showed that among the two main factors: geological and geotechnical hazards, the greatest weight is related to distance between joints sub factor in geological factor. Also, among single-pass drilling, open and telescopic machines the recent car considering all factors considered as the best drilling machine.**

**KEYWORDS:** TBM, geology, AHP, tunnel, excavation, NOSOUD

Select a tunneling machine suitable for use in different ground situations is extremely sensitive and performs an important section of the plan to form a tunneling project. That decision is almost irreversible and once the car is on the site, there is almost no way of withdrawal. And any major modification and updating is very time consuming and costly (KhademiHamidi et al., 2009). Technological, mechanical and geometric characteristics of drilling tools with the physical, mechanical and tectonic will affect effectiveness and efficiency of drilling machines (Bellopedo et al 2011, Carda et al. 2009, Oreste and Castellana, 2012). Assessment of general and specific maps led to the initial cognition of the geological and hydrogeological conditions and provide information for further study techniques. Very varied geological conditions require concentrated preliminary harvest. The goal should be to provide geotechnical interpretation of geological and hydrogeological tunnel project needed to be clear and understandable as possible. Whatever initial survey will conduct better and understandable and it have valid basis, selecting methods and tunneling machine is better (DAUB, 2000). Uncertainty in geological and geotechnical investigation for tunneling projects will require existence of additional tools to help project decision makers and tunnel construction project.

In many cases the actual rates are lower than the expected and anticipated rate of progress. Therefore, it is reasonable to accept the idea that TBM performance of the project is dependent on many factors which can be classified into three categories; Machine Specifications, machine features, and operational parameters. In tunneling projects land characteristics is an important parameter to select the device and characteristics (Hassanpour et al. 2010). The main reason for dealing with the difficult circumstances of land is lack of knowledge about complex and variable ground conditions. Thus at all stages of the design and construction of tunnel geological uncertainties must be considered. Therefore, it is necessary to decide whether the chosen method be optimal and select a specific car for a tunnel based on knowledge of the geological and geotechnical conditions of the area (depending on whether optimistic or pessimistic forecasts) should be optimized. The basic problem is always formed because of heterogeneous physical and geotechnical rock mass that tunnel should be drilled in. For mechanized excavation of all sections of tunnels that is a relatively rigid system, drilling resistance heterogeneous materials (rock and soil) is much more important (Barla and Pelliza,2000).

According to the above mentioned options it can be found that awareness of soil mechanics and geological conditions of site is important forunderground work. In practice it has been shown that the cost of these studies will be offset by savings in time and cost. Obviously, this is not separated from the TBM device selection. So far, several methods and standards for selection of tunneling machines are offered in a variety of geological conditions. Khademi et al, using a fuzzy hierarchical analysis technique based on risk began to select tunneling machine (khademi et al, 2009). Shahriyar and others choose the tunneling machines in rock tunnel based on geotechnical risk

[1]Corresponding author

reduction (shahriar et al, 2008). They investigated how to choose all sections tunneling machine in difficult conditions of the geround (Barla and pelliza, 2000). According to what was said main research question would be what geologic factors influence tunneling grounds and how much is their impact? After identifying and weighting them, using the Analytic Hierarchy Process (AHP) Nosoud tunnel as a case study will be examined.

## THEORETICAL FOUNDATIONS OF THE RESEARCH

Several classification systems is required for various applications TBM based on size, ground conditions and the final lining. However, according to the type of land being drilled, especially time of being stable, TBM can be divided into two main groups: TBM for soft ground and TBM for rocky environment. All section tunneling machines for rock are divided into two groups: open for sustainable rocky environments and shield consist of single-shield machine and double-shield machine for jointed and smashing environments. Each machine has its own benefits and defects with respect to the operation and its suitability to meet anticipated and unanticipated ground conditions.For example, the original domain of single-shield machine uses is for soft ground (5 to 50 MPa compressive strength. But if according to evaluation of costs and project schedules,its choice be unavoidable it can be used in hard grounds (strength greater than 50 MPa). The double-shield machine that its scope of application is for soft and hard grounds, in terms of compressive strength of rock tunnel path does not have usage limitation. So far different geological- geotechnical are proposed in order to studyin determining excavation method orchoosing the tunneling machine. For example, Italian tunneling Forum knows the most important geotechnical-geomechanical parameters associated with the mechanized tunneling as stress state, physical properties, Hydrogeological conditions and other parameters like abrasive, hardness, pit ability, adhesion and friction behavior of the Earth (AITES,2000). According to the Association of German tunnel (DAUB) parameters such as compressive strength, tensile strength, layering pages, degree of weathering, fault zone, mineralogy, abrasion hardness, pressure of groundwater levels and specific aspects such as initial stress state, rock blasting, Inflammation, Earth Summit, the occurrence of karst and the rock temperature must be considered in selecting a mechanized tunneling method (DAUB, 2000). Some of these parameters are not important in selecting the all section tunneling machine in rock or their effect count in other parameters. Therefore, in entire summary, geotechnical and geological parameters affecting the choice of all sections tunneling machine in rock is:

- Compressive strength, tensile or shear strength of rock material
- Rock mass quality index (RQD)
- Discontinuity spacing in place
- Geotechnical precarious conditions (difficult ground), including gas leaks, the influx of ground water, tunnel wall instability, unstable bench tunnel fault zone, be crumpled.

**Factors influencing the geology**

Compressive strength of rock: each of tunneling machines are designed for specific range of uniaxial compressive strength of rock. It may be believed that the stone with low resistance is preferred to a stone with medium resistance. For example, poor sandstone with low degree of cementation or integrated clay shale are sturdy than the dense type. This point may be true for ease in cutting but in making the walls (the walls of the tunnel) by propellants jacks to provide reactive power jack and more strength to stop smashing rocks, cutting and falling is preferred. Experience has shown that when the lateral stress on the tunnel wall rock reach to compressive strength of the un-surrounded rock critical conditions for the onset of cleavage and creep phenomena occur. Higher the amount of stress to rock strength, the incidence of cleavage, falling and creep increases. This could lead to the closure of the tunnel (Deere, 1981). In resistance less than 40 MParock mass in the location of wall making, the machine may not have the bearing capacity of the wall making. This causes breakage and penetration of walls at the location. Sometimes in order to avoid penetration in walls into the tunnel wall the surface area of walls are increased (AFTES, 2000).

Rock quality index (RQD): Leonard (1984) stated that as a general rule, the smaller rate of 25 RQD is to soft ground. Using open machines is possible only in grounds with higher RQD of 45 and in grounds that have RQD between 25 and 45, using explosion and making pits are recommended. The length of time that should be spent on the maintenance of such land is high, and it decreases the performance of open machine and economically is not affordable (Leanard, 1984). Sinha believes open machinescan be used in digging grounds with RQD between 25 and 45 (sinha, 1984). In some sources the rock quality index is mentioned as a criterion for decision-making (DAUB, 2000).

Discontinuity spacing: One of the factors involved in choosing the tunneling method and the performance of tunneling machines is discontinuities and low levels in rock. Among the geo-mechanical properties (including shear stiffness and normal stiffness of discontinuity surface, the roughness degree of seams expansion) and geometrical features of discontinuities surface, orientation and opening discontinuities) discontinuity spacing has the greatest impact on the choice of tunneling method. So existence of discontinuities in the ground stuck inside the tunnel drilling at both the initial installation and maintenance are important. In cases where the situation of fractures and discontinuities in the rock mass be in such circumstances that create great instability on tunnels during excavation causing loss of stone blocks in the tunnel bench, there is possibility of the formation of large cavities above tunnel that crosses these conditions may be possible only using shield-machines (Barton, 2000). In ground that the discontinuity spacing is less than 0/6 m a tunneling machine without a shield may face troubles because of limitation in using walls. This will create less problems for telescopic tunneling machines. First, this type of machine has grater wall and secondly these machines have the capacity that without using walls act as a single-shield machine. And provide their propulsion force by relying rear jacks with lining Tunnel (DAUB, 2000).

**Geotechnical hazards (in difficult circumstances of the ground)**

Geotechnical hazards in tunneling operation with TBM refers to ground difficult conditions that the selected machine cannot dig as predicted functioning (Barla and pelliza,2000). These conditions include unstable walls drilling, bench drilling instability, fault zones, being crumpled rush of underground water and gas leaks.

Tunnel wall instability: the instability of excavation walls is considered a restricted characteristic for open TBM. Problems arise when the instability occurred immediately after installing the back plate of digger and installing and running of the main system and placing the walls will face troubles. In general, the problems of instability of the quality of the stone walls and RQD increases. Shield machines (single-shield or double-shield) is not more sensitive than open machine to the instability of excavation walls. Because a lining prefabricated concrete or steel can be installed inside or in enclosure of shield. Shield machines relying on lining and independent of instability can be progress. In the case of tunnels with medium to large diameter (6 to 12 meters), difference in behavior and progress rate among open and shield machines under unstable conditions of wall significantly increases. And naturally, the benefits are in using a shield machines (Ibid).

Influx of groundwater: flow of water into the tunnel is a factor that should always be considered. Water flow reduces stability of sensitive stones to water by softening, washing reduction surface roughness. Seams fillers in the presence of water reach to an inflammation pressure and this issue can lead to the elimination of the tunnel amplifiers. In summary we can say that the open machine can be applicable in areas where the groundwater flow is controlled. In the shield machines the digger screen is open machine and there is no hydrostatic pressure of water. But compared to the open machine can tolerate more water pressure. This amount for shield machines is 3/5 MPa (Palmstorm, 1995). Although modern TBM are capable to work even under conditions of relatively high flow of water. But water damaged electrical and mechanical systems. And this leads to a reduction in periods between failure and the potential for increased time to repair the TBM components (Laughton, 2005).

Unstable bench: falling in bench may goes beyond a problem because they cause interlock and stop handling equipment and Conveyors systems. Stop working for several times in a shift to remove large pieces of stone blocks may reduce the progression rate of the vehicle efficiency. Variations on the bench can also cause damage to the discs, stuck canal digging and loading material related problems is to replace the drive.

Fault Zone: crossing the fault zone in tunneling operations generally indicate a problematic event and usually accompanied by low feed rate. The types and extent of instability that may occur in such cases, may simultaneously include falling of tunneling bench. Pressurized stream of water into the tunnel, the influx of fine-grained watered material, resulting in the formation of vacuoles in tunnel corona or front of the machine (Barla and pelliza, 2000). If open machine without doing exploratory speculation is faced with this situation, the situation to deal with this problem may be extremely grave. But when a shield machine (single-shield or double-shield) to be treated with a similar faults, although there is no possibility to continue drilling. But the improvements in fault zones is allowed within the shield and simultaneously can protect machine completely buried (Ibid). Sinha believes that open tunneling machine can pass a fault zone with a width of less than 0/9 and in passing through the fault zone between 0/9 to 9 meters will face problem. And in the fault zone with a width of 9 meters, it is impossible to pass machine (sinha, 1989).

Be crumpled: one of the most difficult geological conditions are face to crumpled ground. This phenomenon is usually occurs in weak rocks (Including Micaschist, clay stone, clay shale and marl clay). Deformation caused by crush behavior of stone may be interrupted during tunnel construction, or may persist long after the tunnel construction.

Major problems during use of all sections tunneling machine in crush ground conditions are: (Barla, 2001).

- Instability bench
- Lack of machine flexibility in changing the sections of drilling
- The problem in reactions of sufficient force due to caused problems in the area of open-type tunneling machine hoofs.
- Problems to control the machine in the actual path of the tunnel due to weak or non-homogeneous ground.

If crumpled behavior to the ground is expected, use the time machine should be carefully reviewed. An open machine with adjustable common roof and lateral supports have great flexibility and less likely to tangle. In these circumstances, the walls of the tunnel may not be able to handle walls force, in In this case temporary method of wall stability are used including cover plates (for wall distribution) or propellant force of the auxiliary cylinders. If the geological conditions of large percentages of tunnel path for using open tunneling machine because of streaming or comminuted ground is not suitable therefore, it is necessary to use a shield machine (Dowden and Cass, 1991). Although a single-shield machine due to the short length of its shield has lower probability of entrapment, but this machine is inherently slower than a double shield machine. Furthermore, tension and torque reaction force shield is dependent on to the lining.Since in double shield tunneling machine lining installation is done independently of drilling operation, as a result the rate of all sections double shield tunneling machine progress is more than single-shield machine. Therefore in the stones with regular crush behavior and low rate of convergence, double shield tunneling machine performance is better (Friant and Ozdemir, 1993). Gas leak: When digging underground construction or mining areas in the many sedimentary rocks may treat toxic gases (methane, hydrogen sulfide). In the many cases, hydrogen sulfide and sulfur dioxide observed in seams of any kind of rock containing iron sulfides. These sulfide minerals, especially pyrite oxidized, when exposed to air, produce hydrogen sulfide gas. Hydrogen sulfide in large amount and high toxicity exists in oil fields and natural gas that is a constant threat for drillers. Limestone formations have high porosity and permeability that, when inside the impermeable layers such as shale or sandstone are cutand provide good trap to transport gas from mother rock toward high levels. This gas dissolves in water to create acid which can cause corrosion in TBM. So appropriate exploration and development actions should bedone to prevent such injuries to machine, in the tunnel that has hazard probability.

## SCOPE OF RESEARCH

Nosoud water transfer tunnel to divert Sirwan river water toward DashtZahab in Azgale region in the west part of Kermanshah Province and geographical coordinates of 45° 51\` 125\`\` ,N 34° 49\` 183\`\` E is currently under construction (Rezai et al, 2012). One of the longest water transfers tunnels in Iran is 48 km in length. Overburden height of 1,000 meters in some places. However, the average altitude of overburden is 400 meters. Nosoud Water Transfer Project involves two water transfer tunnel that is made for transmission of around 70 cubic meters of water per second in west of Iran. In this study tunnel number2 has 26 meters length which is under construction by using double shield machine with 6/37 meters diameter. Geographical location of the project is shown in Figure 1.

Based on geological survey results, main rock units that tunnel will pass through them include: shale, limestone and layers of Marley. The tunnel passes through Pabdeh, Gurpi and Ilam formations. The oldest geologic units along the tunnel route is gray-brown iron ore from Ilam Formation.

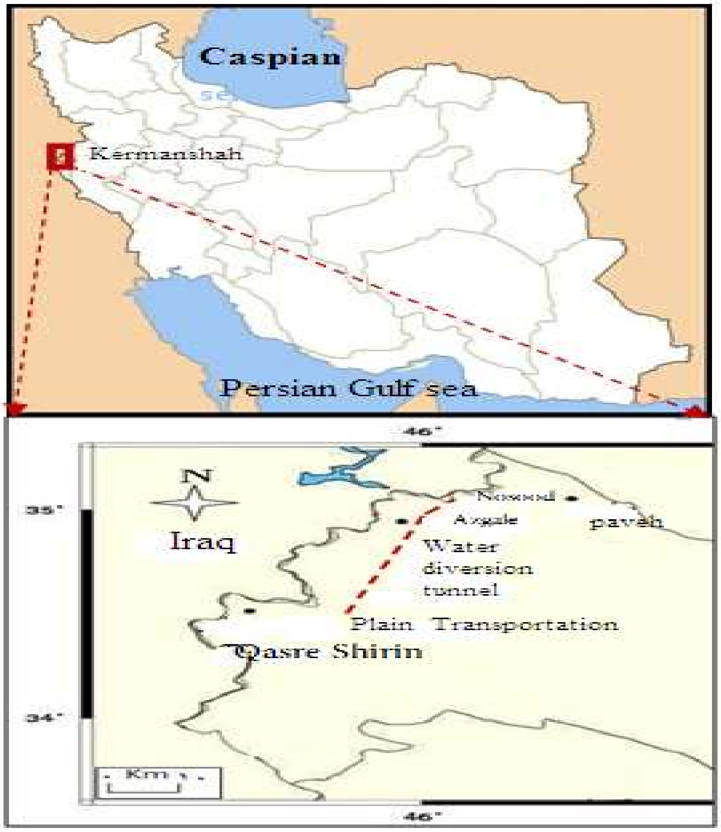


**Figure 1: Position and region of Nosoud water transfer tunnel (Previous)**

Due to frequent changes in rock unit and geological conditions, the project is one of the most challenging tunneling projects. During the first 9 km tunnel encountered with many difficult geological conditions (KhademiHamidi et al, 2009). In some parts of the Zagros long tunnel (Nosoud) addition of iron sulfide minerals, there are geological formations such as Pabdehand Gurpi that are main area contains oil (gas) in East of Iran. In these areas, lack of suitable geological structures and formations with low permeability to large oil reserves, has been observed that the formation of hydrocarbons from Formations containing oil are transported upward. Therefore, the only remaining effects of the hydrocarbons in mentioned formation is black bitumen-like liquid. Often during Zagros tunnel excavation has been observed that the liquid has leak through the holes and voids between the primary lining segments of the tunnel into inside the tunnel. Also in Nosoud tunnel, in extreme conditions, gathering more than 100 ppm $H_2S$ gas has been recorded causing stop of tunneling for 4 months (shahrialr et al, 2009). Therefore a lot of gas leaks in the tunnel leading to stop working and decrease speed of drilling operations. As a result, utilization rates of TBM greatly reduced.

## METHOD

Multi Criteria Decision Making (MCDM) is a powerful tool which can widely use for the evaluation and ranking of problems with multiple conflicting criteria (Bilsel, et al, 2006). Multi-criteria decision-making models generally fall into two categories: multi-objective models (MODM) and multi-criteria model (MADM). Many methods have been proposed for multi-criteria decision making. Hierarchical analysis was presented for the first time by Saaty (CHIAN, 2002) is a branch of multi-criteria decision making (MADM). This method is based on paired comparisons. First, the evaluation criteria and their weights are determined according to their importance (Bernardini and Macharis, 2011). The modeling procedure involves the following steps; (saaty, 1990).

1-Create a hierarchy of problem

2 - Determine the matrix of paired comparison judgments imposing

3 - Calculate the relative weights of criteria and options and the final weigh of options

4 - System Compatibility

If the goal of the AHP method chosen tunneling machine suitable for all sections of the tunnel, then you must choose the right machine at the highest level of considered standards. (Criteria for geological and geotechnical hazard) which have a high degree of efficiency will be in the next level. Then the sub criteria for each of the criteria place on the next level (lower) and finally proposed options for all sections tunneling machine in the rocky environment are in the lowest level. In AHP method elements at any level are compared with their corresponding elements in higher level. Thereby a wise pair comparison procedure obtained. The results of the comparison is shown as follows in matrix (1).

$$A = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \alpha_{2n} \\ \\ \alpha_{n1} & \alpha_{n2}\ldots & \alpha_{mn} \end{pmatrix} \text{A=[a] I,j=1,2,…,n}$$

In which aij is priority of i element compared to j element. After measuring solutions weights in comparison to criteria weight, the overall preference for each option is calculated.

## DISCUSSION AND ANALYZE

This section includes the following three steps:

Step 1: identify the purpose, criteria, and options for each hierarchy. At this point all the information (the path of tunnels) are collected and the main factors influencing the selection of geological and geotechnical tunneling machines were determined. Based on studies carried out in this phase 2 major criteria and 9 sub criteria and 3 goals were identified as components of the hierarchical structure. Development hierarchy is shown in Figure (2).

Step 2: At this stage, based on engineering judgment, to make matrix paired comparison parameters are used. To form paired matrix at first questionnaires that contain all the information and factors influencing the tunneling machine was prepared and have been asked from various experts to determine the importance of the criteria by numbers given in the tables. Using these data, the frequency diagram outlined and degree of importance of each criterion was determined. In this paper some developed matrix is given in tables 1 to 6.

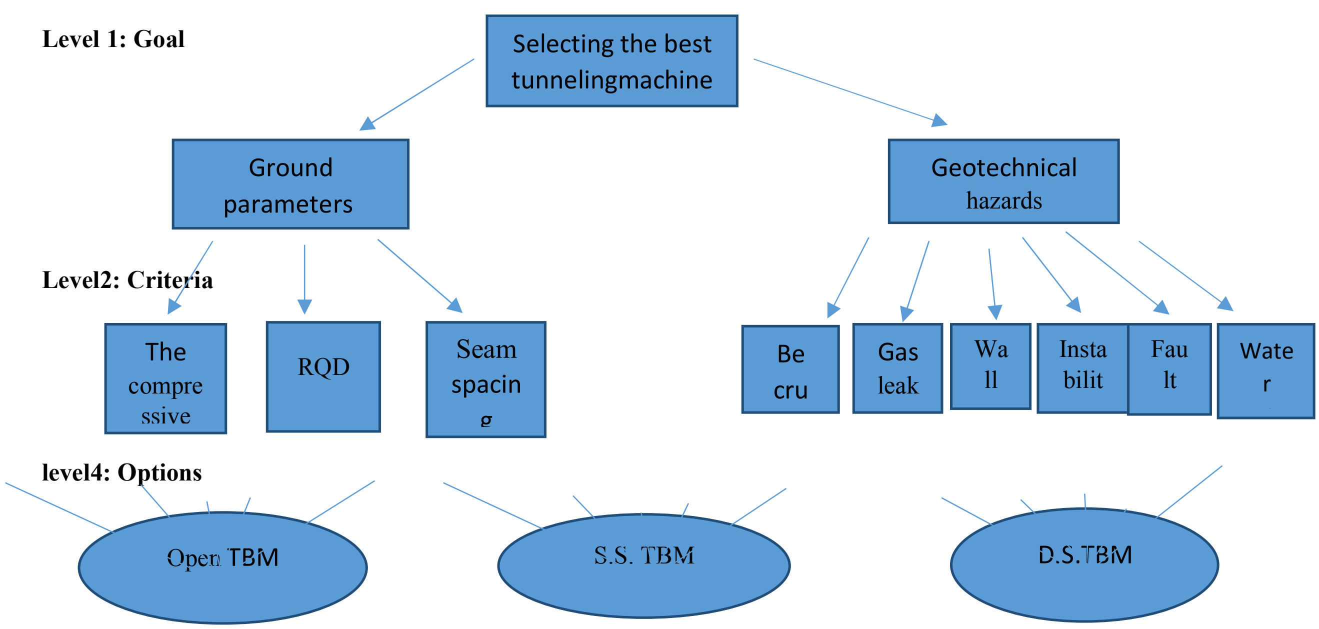


Figure 2: Hierarchical structure to select the most appropriate all sections tunneling machine in rocky environment according to the parameters and geotechnical hazards (writer)

Step 3: At this stage, the calculation of regional and global dominance of parameters and different types of machines was performed with (Expert choice) the final result is given in Table 7.

**Table 1: Paired comparison matrix under the criteria of geotechnical hazards (writer)**

| Geotechnical hazards | Be crumpled | Gas leak | Instability of walls | Unstable bench | Fault Zone | Presence of water |
|---|---|---|---|---|---|---|
| **Be crumpled** | 1 | | | | | |
| **Gas leak** | 1/3 | 1 | | | | |
| **Instability of walls** | 1 | 2 | 1 | | | |
| **Unstable bench** | 1/2 | 1 | 1/2 | 1 | | |
| **Fault zone** | 2 | 3 | 2 | 3 | 1 | |
| **Presence of water** | 1/2 | 1 | 1/2 | 2 | 1/3 | 1 |

**Table 2: Paired comparison matrix following geological criteria (writer)**

| Geological parameters | Strength of the rock mass | RQD | Seam spacing |
|---|---|---|---|
| **Strength of the rock mass** | 1 | | |
| **RQD** | 1/5 | 1 | |
| **Seam spacing** | 1/5 | 1 | 1 |

**Table 3: Paired comparison matrix for three types of all sections tunneling machine according to the compressive strength of rock material sub criteria (writer)**

| | Open machine | Single-shield machine | Double-shield machine |
|---|---|---|---|
| Open machine | 1 | | |
| Single-shield machine | 5 | 1 | |
| Double-shield machine | 7 | 3 | 1 |

**Table 4: Paired comparison matrix for three types of all sections tunneling machine according to the being crumpled sub criteria (writer)**

| | Open machine | Single-shield machine | Double-shield machine |
|---|---|---|---|
| Open machine | 1 | | |
| Single-shield machine | 1/5 | 1 | |
| Double-shield machine | 1/7 | 1/3 | 1 |

**Table 5: Paired comparison matrix for three types of all sections tunneling machine according to the Instability of walls sub criteria (writer)**

| | Open machine | Single-shield machine | Double-shield machine |
|---|---|---|---|
| Open machine | 1 | | |
| Single-shield machine | 9 | 1 | |
| Double-shield machine | 9 | 1 | 1 |

**Table 6: Paired comparison matrix for three types of all sections tunneling machine according to the Fault zone sub criteria (writer)**

| | Open machine | Single-shield machine | Double-shield machine |
|---|---|---|---|
| Open machine | 1 | | |
| Single-shield machine | 9 | 1 | |
| Double-shield machine | 9 | 1 | 1 |

## CONCLUSION

Knowledge of geological and geotechnical conditions is the most important principle for the planning and execution of a tunneling project. According to this point that selecting machine type for mechanized digging tunnel is essentially an irreversible decision for tunneling project, and any machine is used in specific geological conditions. Therefore parameters and geological hazards and geotechnical rock mass of the tunnel should be known and forecasting. In this research considering three types of machine for tunnel excavation in the rocky environment (tunneling machine, open type, single-shield and double-shield) after computing and engineering judgments criteria and sub criteria weighting was applied and paired judgment matrix was formed. Finally, double shield machine has earned the highest score among other three options and selected as the most suitable machine for Zagros tunnel excavation according to its changing geological conditions. However, it has determined that in experts' point of view the most important issue is distance between seam in the rock environment and RQD, and minimum importance is for compressive strength of the rock mass and gas leak.

**Table 7: Final calculations using Expert choice (Author)**

| Goal | Criteria | Sub criteria | relative weight | Options | Final weight |
|---|---|---|---|---|---|
| Choose the most suitable machine for Zagros large tunnel all sections tunneling | Geology | The compressive strength of the rock mass | %9 | Open machine | 0/113 |
| | | RQD | 0/45 | Single shield machine | 0/413 |
| | | seam spacing | 0/95 | | |
| | Geotechnical hazards | Be crumpled | 0/229 | Double shield machine | 0/456 |
| | | Gas leak | %92 | | |
| | | Instability of walls | 0/185 | | |
| | | Instability of bench | %88 | | |
| | | Fault zone | 0/322 | | |
| | | Water existence | 0/112 | | |

## REFERENCES


Rezai, S. Sahabi, F. memarian, H. (2012), to investigate the origin of H2S production in the Nosoud tunnel (West of Kermanshah), Mining Engineering, Year 7, No. 15, pp. 1-14.

AITES, 2000, "Guidelines for the selection of TBMs", ITA Working Group No. 14, www.ita-aites.org

AITES, 2000, "New recommendations on choosing mechanized tunneling techniques'. www.ita-aites.org

Barla, G., 2001, Tunneling under squeezing rock conditions, Eurosummer-School in Tunnel mechanics, Innsbruck.

Barla, G., Pelliza, S., 2000, TBM tunneling in difficult ground conditions. Geoeng, Melbourne, Australia.

Barton N., 2000, TBM tunneling in jointed and faulted rock. Balkema, Brookfield, p 173.

Bellopede, R., F. Brusco, P. Oreste and M. Pepino, 2011. Main aspects of tunnel muck recycling. Am. J. Environ. Sci., 7: 338-347.

Cardu, M., P. Oreste and T. Cicala, 2009. Analysis of the tunnel boring machine advancement on the bologna-florence railway link. Am. J. Eng. Applied Sci., 2: 416-420.

DAUB, 2000, Recommendations of selecting and evaluating tunnel boring machines", www.ita-aites.org

Deere, D.U. 1981, Advance Geology and TBM Tunneling Problems." Proc. Rapid Excavation and Tunneling Conference, California, May, pp. 576-585.

Dowden, B.P., Cass, T.D., 1991, shielded TBM's-Matching the machine to the job, Proc. Rapid Excavations and Tunneling Conference, Seatle, WA, pp. 787-805.

Friant, E. J., Ozdemir, L., 1993, Tunnel boring technology- present and future, Proc. Rapid Excavations and Tunnelling Conference, Boston, MA, pp 869-888.

Hassanpour, J., Rostami, J., Khamehchiyan, M., Bruland, A., &Tavakoli, H. R. (2010). TBM performance analysis in pyroclastic rocks: a case history of Karaj water conveyance tunnel. Rock Mechanics and Rock Engineering, 43(4), 427-445.

KhademiHamidi, J., K. shahriar, B. Rezai , J. Rostami, H. Bejari, 2009, Risk assessment based selection of rock TBM for adverse geological conditions using Fuzzy-AHP, Bulletin of Engineering Geology and the Environment, Springer Publication.

Laughton, C., 2005, Geotechnical problems encountered by tunnel boring machines mining in sedimentary rocks, AITES-ITA World Tunnel Congress, Istanbul, Turkey, pp. 857-862.

Leonard, J. W., 1984, Problems of TBMs encountering soft or fracture rock and attempts to quantify the limitations of rock-TBM relationship, Journal of Advances in tunneling Technology and Subsurface Use, Vol. 4, No. 4, pp. 285-287.

Oreste, P. and M. Castellano, 2012. An applied study on the debris recycling in tunneling. Am. J. Environ. Sci., 8: 179-184.

Palmstrom, A., 1995, RMi- a rock mass characterization system for rock engineering purposes: PhD thesis, Oslo University, Norway.

Saaty, T.L. 1990, Decision making for leaders, RWS Publications, USA.

Shahriar K, Rostami J, KhademiHamidi J (2009) TBM tunneling and analysis of high gas emission accident in Zagros long tunnel. Proceedings of the ITA-AITES World Tunnel Congress 2009 and 35th ITA general assembly, Budapest, Hungary.

Shahriar K, Sharifzadeh M, KhademiHamidi J, 2008, Geotechnical risk assessment based approach for rock TBM selection in difficult ground conditions. Tunnel Underground Space Technology 23:318–325

Sinha, R. S., 1989, Under-ground structure design and instrumentation, Elsivier Science direct Publisher, B. V.