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Underground Structures, Rock Structures and Rock Mechanics from Ancient Era to the Modern Age

İlk Çağlardan Günümüze Yer Altı Yapıları, Kaya Yapıları ve Kaya Mekaniği

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ABSTRACT

Usage of underground space is an old habit for human beings since ancient era. Our ancestors have used caves as a shelter for protection from the wild life and nature, and they excavated caves to extract valuable minerals. They also used them as sanctuaries, tombs or for storage of goods. In addition, they built tunnels to be used as assault systems or to underpass fortifications during ancient warfare. Later on, tunnels were driven to supply water to the towns or to protect the towns from floods. They also built them for communication purposes. Though not knowing the exact time when they were first used, natural underground structures which have several interconnections were also built for underground dwelling purposes through the human history. In the following centuries, due to the need of transportation facilities, transportation tunnels were constructed where new excavation techniques were also used. Navigation canal tunnels, railway tunnels and road tunnels were constructed during that period. All these structures were mostly excavated in rocks. The first excavations were performed manually. Later on, fire technique had been used to excavate more easily. This was followed by the methods in which gunpowder, explosives and tunneling machinery were used. By some means or other, ancient civilizations had used fundamental principles of rock mechanics and applied these principles in the construction of the underground structures. Principles of rock mechanics are the sine qua non for all of these structures and facilities. In this review paper, the history and evaluation of rock mechanics will be given briefly and some examples of historical and monumental underground and rock structures will be presented.

Keywords: Ancient Underground Rock Structures, History of Rock Mechanics, Rock Engineering, Rock Mechanics Applications.

ÖZ

Yer altındaki alanların kullanımı insanlar için antik dönemlere uzanan eski bir alışkanlıktır. Atalarımız, mağaraları vahşi hayattan korunmak için barınak olarak kullandılar, ayrıca değerli mineralleri çıkarmak için kazarak yer altı boşlukları oluşturdular. Bu boşlukları kutsal alan, mezar veya depo olarak kullandılar. Bu kullanım amaçlarına ek olarak, savaşlar sırasında saldırı veya surları geçmek amacıyla tüneller inşa ettiler. Daha sonraları, tüneller yerleşim yerlerine su getirmek veya söz konusu alanları selden korumak amacıyla yapıldı. İlk kez ne zaman kullanıldıkları bilinmemekle birlikte, birbirleriyle bağlantılı olarak inşa edilen yer altı yapıları insanlık tarihi boyunca barınma amacıyla da kullanıldı. Sonraki yüzyıllarda, ulaşım sistemlerine duyulan ihtiyaç nedeniyle yeni kazı tekniklerinin *kullanıldığı ulaşım ve iletim* tünelleri inşa edildi. Bu dönemde, çoğunluğu kaya ortamda yer alan *su geçişi tünelleri, demiryolu tünelleri ve karayolu* tünelleri yapıldı. İlk kazılar elle yapılmış olup, daha sonra kolay kazmak için ateşin kullanıldığı bilinmektedir. Bu tekniği, barut, patlayıcılar ve tünel açma *makinaları takip etmiştir. Şu veya bu şekilde, eski uygarlıklar kaya mekaniğinin temel prensiplerini kullanmış ve bu prensipleri yer altı yapılarının inşasında uygulamışlardır. Kaya mekaniğinin prensipleri, tüm bu yapıların olmazsa olmaz unsurudur. Bu derlemede, kaya mekaniğinin tarihçesi kısaca anlatılacak, tarihi ve anıtsal yer altı ve kaya yapılarından örnekler sunulacaktır.*

Anahtar Kelimeler: *Antik Yer Altı Kaya Yapıları, Kaya Mekaniği Tarih*çesi*, Kaya M*ühendisliği, *Kaya Mekaniği Uygulamaları.*

INTRODUCTION

Rock defined as aggregate consisting of mineral components is formed from natural processes and characterized by the type and amount of minerals (Bonapace et al., 2010). Our prehistoric ancestors used primitive tools that were made up of rock. They also lived in natural or manmade shelters carved in rock. Rock was excavated for mining to extract valuable materials. Astonishing sculptures and constructions such as Ephesus Temple (Figure 1), Stonehenge and Pyramids were built of rock. The underground structures were constructed and used for sanctuaries, tombs or for storage of goods. Besides, depending on the mankind needs, rock tunnels were driven to transfer water to the towns or to protect the towns from floods as well as to communicate with other societies. In this review paper, some breathtaking examples of rock structures of ancient and modern times will be given and a brief explanation about the development of rock mechanics will be presented.

Figure 1. A view from Ephesus (photo courtesy of Dr. H. C. Mertol).

Şekil 1. Efes Antik Kenti'nden görünüm (Fotoğraf Dr. H.C. Mertol'un arşivinden alınmıştır).

ANCIENT UNDERGROUND ROCK STRUCTURES AND ROCK MECHANICS APPLICATIONS

ANCIENT TUNNELLING

Underground structures have been served for a variety of purposes. One of the oldest underwater tunnels of the world, Terelek Tunnel, was constructed beneath the Kızılırmak River, in the northern part of Turkey, probably more than 2000 years ago (possibly 5000) because of defensive reasons (Akyol, 2012; Garry, 2012).

Another significant reason for underground structures can be stated as transportation by means of passenger and traffic. In the ancient Babylon around 2000 BC, a 1000 m long tunnel located between the temple of Jove and the royal palace was built under the Euphrates River (Szechy, 1973). During the construction of the oldest transportation tunnel built by the Babylonians, the River Euphrates was diverted. The tunnel was 3.6 m high and 4.5 m wide. The walls and the roof were built by brickworks and vaulted arch (Szechy, 1973).

About 2700 years ago, qanats, which were special water management systems in Iran were constructed. The aim of the construction of the qanats was to supply water to settlements and arid areas for irrigation purposes. This water supply system consists of shafts and a tunnel that connects these shafts. Water, collected from water table via shafts and transferred to the tunnel, is transmitted through the tunnel by gravity. Gonabad Ghasbeh Qanat is the oldest qanat with 45 km length (Alemohommad and Gharari, 2010; Garry, 2012). Tunnels were also constructed for water supply purposes. Greek engineer Eupalinos of Megara constructed the Eupalinos tunnel (Figure 2) that was excavated from both sides, in Samos Island in 520 BC (Garry, 2012).

Figure 2. A general view of Eupalinos tunnel constructed in Samos Island (Wikimedia Commons-a, 2017).

Şekil 2. Sisam adasında açılan Eupalinos tünelinden genel bir görünüm (Wikimedia Commons-a, 2017).

There was also need for underground structures in order to be protected from surface runoff water. During the first century of Roman times, in order to protect the harbor from floods and overflows, the Titus Tunnel was excavated. The length of the Titus Tunnel is about 1380 m and it is located in Samandağ, Antakya in the south eastern part of Turkey (Gençtürk et al., 2007; Türkiye Kültür Portalı, 2014). A photograph of the Titus Tunnel is presented in Figure 3.

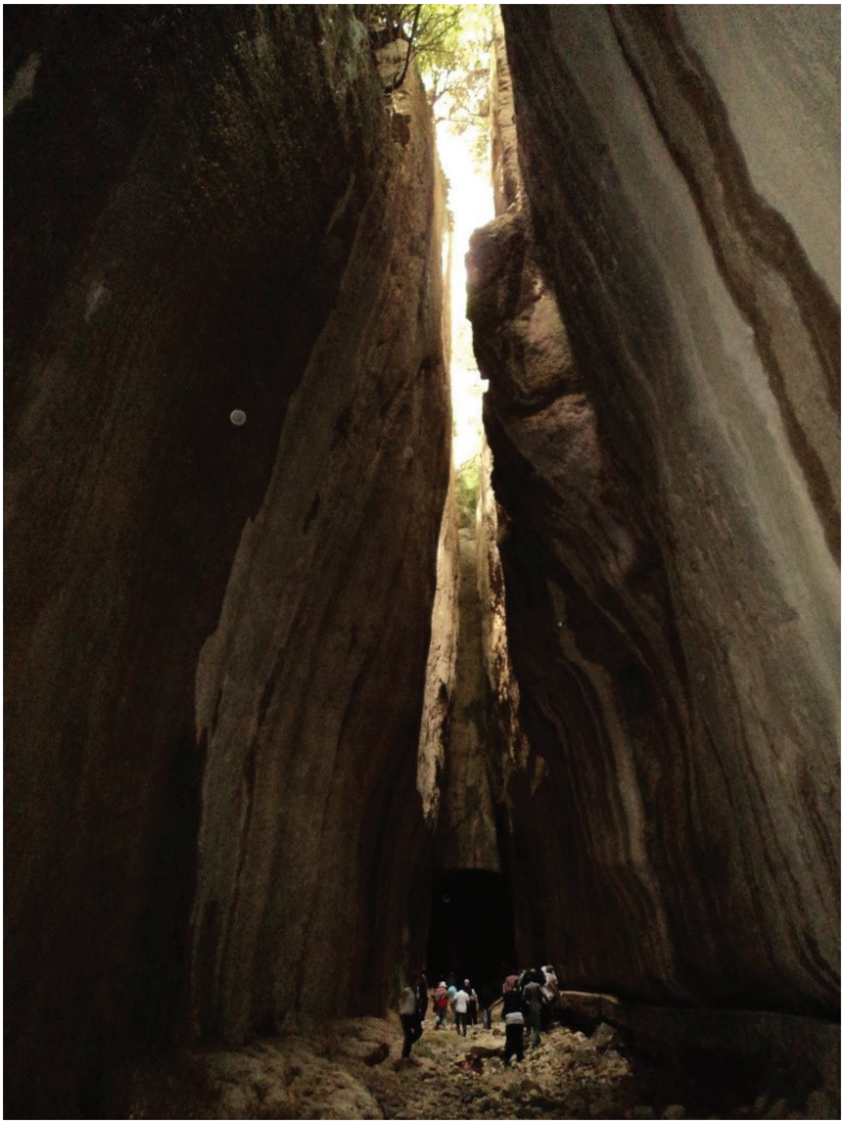

Figure 3. A photograph of the Titus Tunnel (photo courtesy of Dr. H. C. Mertol).

Şekil 3. Titüs Tüneli'nin fotoğrafı (Dr. H.C. Mertol'un arşivinden alınmıştır).

The Mina Tunnel in Spain was built to protect the citizens of Daroca from flooding in 1560. Quinto Pierres Bedel, the engineer of the tunnel, started the excavation from both sides of the mountain and it was finished within 5 years. The tunnel is 600 m in length, 6 m in width, and 7 to 8 m in height. The Mina Tunnel still serves for public works as a remarkable construction for Daroca city (Ubierna, 1998).

In 1843, another underwater tunnel was built beneath the River Thames in London. In 1825, Isambard Kingdom Brunel began to construct a tunnel in soft ground under the river. In order to overcome the difficulties encountered during the construction of the tunnel, a new technique was developed by Brunel and his son. They are assumed as the first engineers who applied first shield tunneling technique (Szechy, 1973; Garry, 2012). Thames Tunnel (Figure 4) which is 396 m long, served firstly for pedestrians and horse carriages, then after 1865, it is used as a railway tunnel (The Brunel Museum, 2017).

The use of rock structures as a part of public transportation can be mentioned as another significant progress. In 1863, the Baker Street Station, the oldest underground station, was built as a part of subway system. The Tunnel in Istanbul is known as the 2nd subway system and is followed by big cities such as Paris, Berlin, Chicago, Stockholm, Moscow, Budapest etc. (Szechy, 1973; Garry, 2012). A photograph of the Tunnel is presented in Figure 5.

Figure 4. The Thames Tunnel. Lithograph by Taulman after Bonisch is distributed under public domain (Wikimedia Commons-b, 2017)

Şekil 4. Thames Tüneli. Bonisch'den sonra Taulman'ın litografisi (Wikimedia Commons-b, 2017).

Figure 5. The Tunnel in İstanbul. (Photograph by Florian Lehmuth is distributed under a CC BY-SA 2.0 license (Wikimedia Commons-c, 2017).

Şekil 5. İstanbul'da Karaköy - Beyoğlu arasındaki Tünel. Fotoğraf Florian Lehmuth tarafından çekilmiş olup CC-BY-SA-2.0 ile lisanslanmıştır. (Wikimedia Commons-c, 2017).

UNDERGROUND CITIES, CARVED STRUCTURES AND ANCIENT MINING ACTIVITIES

Usage of underground space is an old habit for human beings from ancient era. Many stunning underground structures were built since Neanderthal man who had lived in 40,000 BC (Hood and Brown, 1999).

The ancient Egyptians who strongly believed after-life, constructed underground tombs in about 2778 BC (Salam, 2002). The ancient Egyptians used drilling and sawing techniques with copper tools to construct the underground structures (Hood and Brown, 1999; Salam, 2002). Most of the underground structures located in Kings Valley that is bounded by hills with relatively flat slopes. This region is underlain by two formations, namely Thebes Limestone formation and Esna Shale formation. Most of the tombs were constructed in limestone. During the construction, some unfavorable conditions such as slope deformations, failures due to rock discontinuities might be encountered (Salam, 2002).

Ancient city Petra of Jordan was carved in sandstones between 200 and 300 BC by Nabatean and Roman. It is one of the most attractive historical cities with manmade rock monuments and several hundred tombs (Paradise, 2013; Rihosek et al., 2015). The monumental monastery, El Deir, carved out of rock in Petra is shown in Figure 6.

Figure 6. El Deir monastery in the ancient Jordanian city of Petra. Photograph by Berthold Werner, is distributed under a CC BY-SA 3.0 license (Wikimedia Commons-d, 2017).

Şekil 6. Antik Ürdün şehri Petra'daki El Deir Manastırı. Fotoğraf Berthold Werner tarafından çekilmiş olup CC-BY-SA-3.0 ile lisanslanmıştır (Wikimedia Commons-d, 2017).

Another reason for the construction of underground structures is religion and remarkable examples exist in India and China. India's Ellora cave temples dating back to 6^{th}-11^{th} century are notable monumental structures (Figure 7) which were carved from basalt (Singh et al., 2015). Besides, Ihlara Valley in Turkey is another historical sanctuary and dwelling example of rock structures, which housed more than four thousand dwellings and a hundred cave churches decorated with frescoes.

Figure 7. A view of the monuments located in Ellora that is accepted as a world heritage. Pphotograph by Danial Chitnisis distributed under a CC BY-SA 2.0 license (Wikimedia Commons-e, 2017).

Şekil 7. Dünya mirası olarak kabul edilen Ellora kasabasında yer alan anıtsal kaya yapısından bir görüntü. Fotoğraf Danial Chitnis tarafından çekilmiş olup CC-BY-SA-2.0 ile lisanslanmıştır (Wikimedia Commons-e, 2017).

The demand for the construction of subsurface settlements arose due to several reasons including hiding against enemy attacks, protection from climatic changes and natural hazards. About 1500 years ago, underground settlements have been carved in the Cappadocia Region and there are a total of twenty two identified underground cities that are composed of kitchens, storage chambers, bedrooms, dining halls, wine cellars, dwellings, connected underground settlements and religious buildings such as churches, monasteries, hermits' cells. Also, they are connected to the houses in the region by hidden tunnels. Soft tuffs of the region that enables easy carving might prompt people to use the subterranean space around the Cappadocia (Topal and Doyuran, 1997; 1998; Aydan and Ulusay, 2003; Erdem, 2008; Aydan and Ulusay, 2013).

Underground works have also well remembered with mining activities. The mining works which took place in the first half of the first century, in Las Medulas in Spain can be classified as one of the greatest works. These mining works depended on the extraction of 960.000 kg pure gold over 200 years. Galleries and vaulted tunnels (about 325 km) were excavated by fire setting technique in the first centuries AD (Ubierna, 1998). The mining industry has also developed notably. In 1855, the mine in Bendigo (Australia) was known as the deepest mine in the world with a depth of 975 m (Hood and Brown, 1999).

SOME EXAMPLES OF HISTORICAL AND MONUMENTAL ROCK ENGINEERING APPLICATIONS IN ANATOLIA

As one of the ancient rock structures, caves have been used for different purposes. Yarımburgaz, Karain, Üçağızlı and Öküzini Caves are good examples from Anatolia from the sub-Paleolithic age (Cai et al., 2004; Kirman and Ulusoy, 2005). Due to the needs of living such as the storage of food and goods, caves were enlarged. Taşkale and Karaman caves can be given as impressive examples of storage caves in Anatolia. Ancestors needed to improve the caves that can be called as underground structures in order to protect themselves from enemies. Underground cities; Kaymaklı (Figure 8), Derinkuyu, Mazı, Özlüce, Özkonak, Tatlarin and Acıpınar were constructed such that, they were able to maintain their daily life (Evelpidou et al., 2010). Underground cities located in Cappadocia Region have been carved in white, grey and pink colored, soft volcanic tuffs that are several hundred meters thick (Aydan and Ulusay, 2013).

Figure 8. Kaymaklı underground city in Cappadocia. Photograph by Nevit Dilmen is distributed under a CC BY-SA 3.0 license (Wikimedia Commons-f, 2017).

Şekil 8. Kapadokya'daki Kaymaklı yer altı şehrinden bir görünüm. Fotoğraf Nevit Dilmen tarafından çekilmiş olup CC-BY-SA-3.0 ile lisanslanmıştır (Wikimedia Commons-f, 2017).

The conical tumulus and surrounding sculptures (Figure 9) are one of the attractive rock engineering applications in Nemrut Mountain, in Adıyaman, eastern Turkey. The tumulus was made up of crushed limestone pieces and encircled by three terraces on which god sculptures and guardian animals were built by Commagenian in 69-31 BC (Evelpidou et al., 2010; Akoğlu and Saltık, 2015; Topal et al., 2015).

The rock structures were also used for religious purposes. The religious monument, Sumela Monastery (Figure 10) or The Virgin Mary that was carved into Karadağ Mountain in Maçka, Trabzon (northeast Turkey) was built in the first century and restored several times throughout the centuries. Monastery is located on a steep slope that is 300 m above the bottom of the valley involving a rock church, chapels, student rooms, library, kitchen, sacred spring and a guest house (Gelişli et al., 2010; Ministry of Culture and Tourism, 2017). The Lycian tombs are astonishing examples that were carved into mountain in Dalyan (southwest Turkey) (Evelpidou et al., 2010).

Figure 9. Head statues at Nemrut Mountain. Photograph by Urszula Ka is distributed under a CC BY-SA 3.0 license (Wikimedia Commons-g, 2017).

Şekil 9. Nemrut Dağındaki heykeller. Fotoğraf Urszula Ka tarafından çekilmiş olup CC-BY-SA-3.0 ile lisanslanmıştır (Wikimedia Commons-g, 2017).

Figure 10. Sumela Monastery. Photo courtesy of Dr. H. C. Mertol.

Şekil 10. Sümela Manastırı. Fotoğraf Dr. H.C. Mertol'un arşivinden alınmıştır.

Derleme / *Review Paper*

DEVELOPMENT OF ROCK MECHANICS AND ROCK MASS CLASSIFICATION SYSTEMS

It is obvious that, rock mechanics principles have been used to construct various kinds of structures for centuries. By the late nineteenth century, squeezing and rock bursting problems were experienced in tunnels and galleries. Researchers, Rziha (tunnel expert) and Heim (Professor at Zurich University), studied on the horizontal forces acting in tunnels and galleries, and these studies may be considered as the first attempts in rock mechanics (Jaeger, 2009). After the mining industry had entered a boom particularly in Europe and North America, researches on theoretical and practical problems were conducted and also the techniques for measuring strains, rock deformations and rock elasticity were developed (Hood and Brown, 1999; Jaeger, 2009). So, in the early twentieth century, studies on the rock bursts, mechanical properties and material models of rock and the theories related to structural mechanics and strength of materials were carried out (Hood and Brown, 1999). Furthermore, Schmidt (1925) introduces stereonets and Stini (1922) has developed methods for studying of joint systems in rock masses in 1920s . By the twentieth century, journals on rock mechanics and rock engineering were begun to be published, and "Geologie und Bauwesen" that was edited by Josef Stini was the first one. In the forthcoming years the name of the journal was changed to Rock Mechanics first and then Rock Mechanics and Rock Engineering. The dissemination of experience and knowledge had become a requirement after the disastrous failures. In 1959, a total of 450 people died in France as a result of failure of Malpasset concrete arch dam; in 1960, a coal mine in South Africa collapsed in which 432 people were killed and in 1963, 2500 people passed away because of the landslide occurred due to the overtopping of Vaiont dam in Italy (Hoek, 2007). Many more catastrophic events which occurred in manmade structures have revealed the necessity of rock mechanics to prevent tragic future events. Meeting, seminars, congress were held on rock mechanics and in 1962, International Society for Rock Mechanics (ISRM) was established in Austria under the leadership of Leopold Müller (Hood and Brown, 1999). The definition of rock mechanics in the Statutes of ISRM was stated as: "*The field of Rock Mechanics is taken to include all studies relative to the physical and mechanical behavior of rocks and rock masses and the applications of this knowledge for the better understanding of geological processes and in the fields of Engineering*". In 1960s, soil mechanics principles and elastic stress analysis were applied to rock slope design. Although elastic theory was used in many mine and civil engineering projects, the effect of structural discontinuities could not be taken into account (Hood and Brown, 1999). In the first Congress of ISRM in 1966, Prof. Müller made the following important statement: "*Many experts agree with me that discontinuity and anisotropy are the most characteristic properties of the material rock and that the properties of jointed media depend much more upon the joints of the unit rock block system than upon the rock material. Therefore, any theoretical investigation of that material has to go its own ways, in the same way as the construction material of soil years ago suggested to soil mechanics its own methods, which differ greatly from the way of thinking technical (or continuum) mechanics*" (Brown, 2011). During 1960s and 1970s, as well as the strength and deformation behavior of rock joints, the sliding behavior of the joints was started to be investigated. Then, Patton (1966) and Barton (1976) introduced the effect of joint roughness on the shear strength of joints (Hood and Brown, 1999). Between 1968 and 1972, a research project on analyzing the stability of slopes depending on the measured rock properties that was founded by a number of mining companies at Royal School of Mines- Imperial College of Science and Technology were carried out by Prof. Evert Hoek and his colleagues. As a result of that project, a very well-known handbook namely "Rock Slope Engineering" was published by Hoek and Bray (1974) .

Many researchers have pointed out the importance of discontinuities in the rock behavior and this has brought out the importance of geological data collection and interpretation. Laboratory testing of rock specimens is an important issue, but should be evaluated very thoughtfully due to structural features. The tests performed on a limited size rock specimen may result in misestimation of the rock mass properties (Hoek, 2007). In other words, if the in-situ rock mass has heavily jointed, it is not very easy to get a representative sample in order to use it for laboratory tests. In order to overcome that problem, the Hoek Brown failure criterion is proposed with rock classification systems (Hoek and Brown, 1980, 1997; Hoek, 1983, 1994; Hoek et. al, 1992; Ulusay and Sonmez, 2000).

The first classification system for rocks has its origin in the sixteenth century. In the fifth chapter of the De Re Metallica, Agricola mentioned and explained the principles of underground mining (Hoover and Hoover, 1912). Different rock mass classification schemes relied on the different engineering geological characteristics of the rock masses that were obtained as an outcome of the experience from variety of civil engineering case histories. Rock mass classification systems of Terzaghi (1946) and Stini (1950) can be referred as the earliest but base of the modern rock mass classifications (Aydan et al., 2014). Terzaghi (1946) explained the rock mass descriptions depending on the engineering geology information for the design of tunnel support. He classified rock as intact, stratified, moderately jointed, blocky and seamy, crushed, squeezing and swelling rock. Then, Lauffer (1958) related rock mass quality with the stand-up time for unsupported span of the rock mass. After qualitative descriptions of the rock mass, researchers focused on quantitative descriptions (Hoek et al., 1995). Deere et al. (1967) worked on estimating the quality of the rock mass quantitatively and the Rock Quality Designation Index (RQD) which is the one of the basics of RMR and Q systems. RQD was followed by another quantitative method called Rock Structure Rating (RSR) suggested by Wicham et al. (1972). Bieniawski (1973) used the uniaxial compressive strength, RQD, spacing conditions and orientation of discontinuities, ground water conditions to classify rock quantitatively, and finally called the system as Rock Mass Rating System in 1976. Several revisions have been done depending on the case studies in years 1974, 1976, 1979 and 1989. Researchers studied on the adaptation of RMR system to the mining and modified rock mass rating system (MRMR) and modified basic rock mass rating system (MBR) were described (Hoek et al., 1995). The RMR systems were widely used and depending on the results of extensive geotechnical investigations of case studies in Turkey, Modified Rock Mass Rating System was developed by Ünal and Özkan (1990). By this method, the weak, stratified, anisotropic and clay bearing rock masses could be modelled and MRMR of rock masses can be calculated manually or by using a computer program. (Ünal and Özkan, 1990; Ünal et al., 1992; Ulusay et al., 1992; Ünal, 1996). MRMR system was also improved by Gökçeoğlu and Aksoy (2000).

Barton et al. (1974) proposed a Tunnelling Quality Index (Q) to classify the rock mass and to determine the tunnel supports by using the measures of block size, inter block shear strength and active stress of the rock mass (Hoek et al., 1995). This study has been extended and published in 2002 (Barton, 2002a; Barton, 2002b).

There were limitations in the application of two widely used classification systems RMR and Q to the poor rock masses such as having zero RQD values. In order to cope with these issues, a new classification system, Geological Strength Index (GSI) relied on assessment of the lithology, structure and condition of joint surfaces in the rock mass, was developed (Hoek, 1994; Hoek et al., 1995, 1998; Osgoui et al., 2010). GSI can be used to assess rock mass parameters such as Mohr Coulomb or Hoek Brown strength parameters or deformation modulus. Due to the difficulties encountered in poor and very poor rock masses, studies were carried on and the GSI charts were modified by several researchers (Hoek et al., 1998; Sönmez and Ulusay., 1999; Marinos and Hoek, 2000; Marinos and Hoek, 2001; Cai et al., 2004; Marinos et al., 2005; Marinos et al., 2007; Osgoui et al., 2010).

SOME EXAMPLES OF MODERN UNDERGROUND STRUCTURES AND ROCK ENGINEERING APPLICATIONS

Underground structures serve for extraordinary objectives. Mount Rushmore sculptures (Figure 11), one of the amazing structures of the rock engineering, were completed in 1941 after being carved for 14 years. 18 m high sculptures of George Washington, Thomas Jefferson, Theodore Roosevelt and Abraham Lincoln were carved from granite made in the Black Hills of South Dakota (Romana et al., 2007; America's Library, 2016.). This structure may be one of the best example in which art meets rock mechanics. Before carving the sculptures, a detailed investigation was performed at site and weathered rock was removed by blasting (Goodman, 1989).

Figure 11. Mount Rushmore sculptures. Photograph by Kelly Martin is distributed under a CC BY-SA 3.0 license (Wikimedia Commons-h, 2017).

Şekil 11. Rushmore dağı heykelleri. Fotoğraf Kelly Martin tarafından çekilmiş olup CC-BY-SA-3.0 ile lisanslanmıştır (Wikimedia Commons-h, 2017).

Moreover, in our century, underground structures such as Swedish Royal Library and Le Grand Louvre Museum exhibit aesthetic scenes, too. Additionally, underground provides isolation from all climates as temperature within the soil or rock offers a moderate and uniform thermal environment compared with the extremes of surface temperatures. Itakeskus underground swimming pool in Finland, underground storage facility in Kansas City and The Volcano Room, Cumberland Caverns McMinnville, Tennessee may be given as attractive examples. These structures also protect people from severe weather conditions and earthquakes.

Underground structures provide more open space in three dimensions. One of the most complex and challenging projects for urban transportation can be called as The Big Dig Project in Boston. Through this project, the extraordinary traffic congestion has been avoided and the mobility in Boston has been improved, several parks and public space have been created. Distinctive tunnels are widely used for communication purposes. Together with the amazing railway projects like Channel Tunnel (50 km) that connects England and France, Sheikan Tunnel (53.9 km)- a link between Hokkaido and Honshu islands of Japan; the developments in the automotive technology cause a rapid increase in the highway tunnels. Mont Blanc Tunnel (12.65 km) between France and Italy, Laerdal Tunnel (24.5 km) in Norway, Zhongnanshan Tunnel (18 km) in China can be named as some of the remarkable tunnels (Akyol, 2012).

CONCLUSIONS

Utilization of rocks and rock structures requires knowledge and experience of rock engineering principles. Throughout the history of mankind, rock is used for different purposes such as tools for carving, wheels or construction material. Even at that time, the principles of rock mechanics were applied unconsciously or in other words without naming it. Rock engineering has solved challenges of rock structures from ancient times. Principles of rock mechanics have been used to design various distinctive structures. Nature keeps its own prosperity and secrets but for a seeing eye it has quite knowledge to offer. Civilizations that understood the nature thoroughly have succeeded. Therefore, whatever the purpose of usage is, rock mechanics and engineering principles should be understood clearly. The structures presented in this paper, is a mixture of human intelligence, the necessities and implementation of rock mechanics. A number of amazing examples are given to show how the rock mechanic principles have been used for spectacular manmade structures. Additionally, the development of widely used methods in rock mechanics is briefly presented.

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