ROCK ENGINEERING AND ITS DEVELOPMENT

LECTURE 1

Content

1.1 INTRODUCTION

Rock engineering is a discipline which mostly deals with the design of structures built in/on rocks. These structures encompass building foundations, dams, slopes, shafts, tunnels, caverns, hydroelectric schemes, mines, radioactive waste repositories and geothermal energy projects. Rock mechanics subject systematically explains the basic principles behind rock engineering, which remains the same even though the projects are different. In the first ISRM conference (1966) in Lisbon, accepted definition of rock mechanics is "*Rock mechanics is the theoretical and applied science of the behavior of rock; it is that branch of mechanics which is concerned with the response of rock to the force field of its environment*". Rock mechanics is different from the domain of soil mechanics as later is the disintegrated part of the former (Soil is disintegrated part of rocks). In soil mechanics, we mostly talk about strengths, where as in rock mechanics, it is all about weaknesses. The transition from rock to soil mechanics can be visualised by progressively fractured rock mass, bearing in mind that rock is fractured insitu, where as individual soil grains have usually been transported. Intact rock madeup of indivisual grains and crystals but is interlocked or cemented. When progressively fractured, rock becomes increasingly granular. An arbitrary but convenient division between rock and soil compressive strength of 1MPa.

The strength of rock reduces with increase discontinuities/ fractures/ joints which plays a decisive role. Discontinuity can be of same scale as the excavation, but this may not be the case for soils, they may not be fully interconnected. It's the joint that makes rock mechanics domain outside the domain of soil mechanics. Moreover, the behavior of rock is seriously affected by confinement. Rock mass found in the field seldom intact and the strength and deformation characteristic of the rock mass (figure 1) mostly depends upon the joint characteristics. Many a times the rock is highly disturbed and disintegrated specially if found near shear zones. Figure 1 shown below are typical pictures of disturbed rock mass encountered in the field. Rock Strength reduces with increase in discontinuities/ fractures/ joints. Discontinuity can be of same scale as the excavation, but this may not be the case for soils. Moreover, discontinuities are not necessarily fully interconnected.

In the last few decades, rock engineering has developed into a mature subject built on solid foundation of geology and engineering mechanics. Many researchers from different disciplines have contributed a lot to this subject and have developed a wide range of practical tools and techniques. There is still a great deal of room for development, innovation and improvement in almost every aspect of the subject and it is a field which will continue to provide exciting challenges for many years to come (Hoek, 1997).

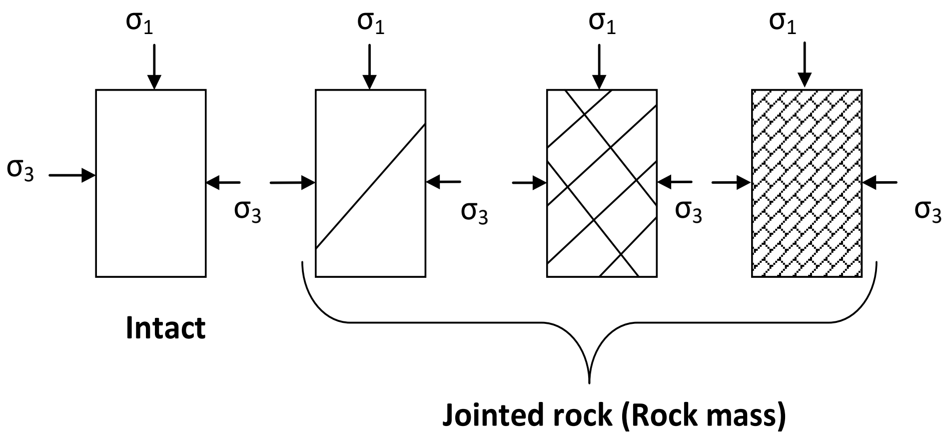

Figure 1.1: Description of intact rock and rock mass

Figure 1.2: A typical view of rockmass encountered in the field

1.2 HISTORICAL PERSPECTIVE

Though the modern rock mechanics may be 50-60 years of old, but in the history there are number of examples of structures made out of rocks. In India, one can see most of our old temples, monuments are actually built of stones/rocks. Famous Taj Mahal at Agra constructed during the year 1631-1643 is made with marvels where as many of the other Mughal monuments are made-up of mostly sandstone e.g., Delhi's Red fort is constructed with red sandstone.

(a)

(b)

Figure 3: Famous monuments from India a) Taj Mahal in Agra, madeup of marvel b) Redfort, Delhi, madeup of sandstone

The famous Brihadishwara temple (Big temple) or Peruvudaiyar Kovil located in the city of Thanjavur, Tamil Nadu constructed during the Chola dynasty is one of the largest temples in India. The entire BIG temple structure is made out of granite and was built by emperor Raja Raja Chola I and completed in 1010 AD.

Figure 4: Famous 10th century BIG temple in Tanjavur, India

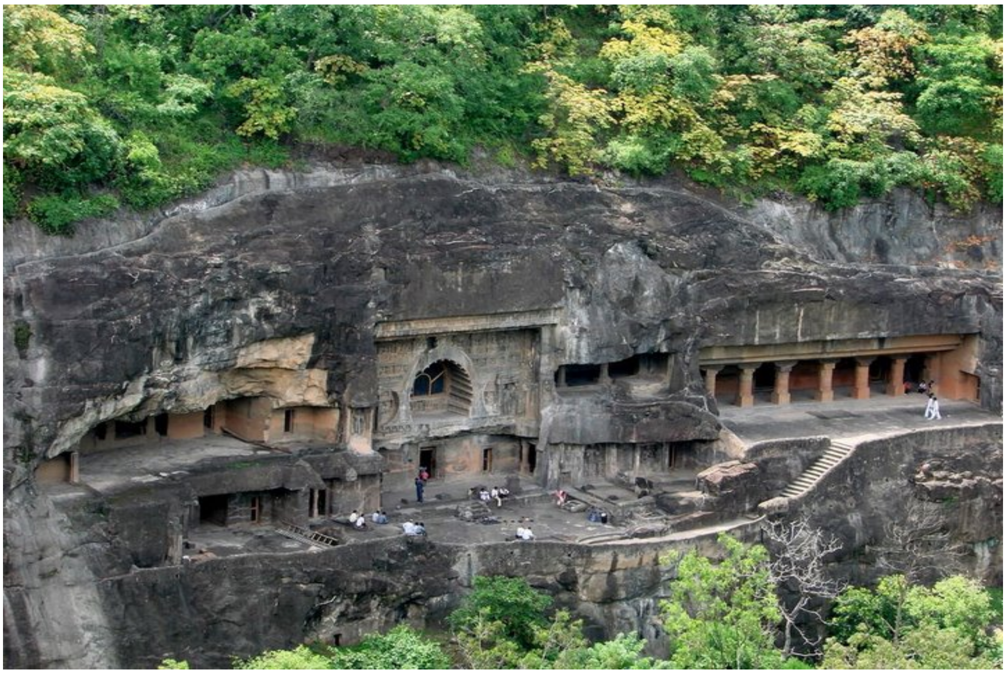

Figure 5: Ajanta cave, Aurangabad, India.

Much earlier and ancient use, we have information that in 40,000 yrs BC natural caves were used as shelter in Australia. Mining activities has to deal with lot of rock excavations and traces of oldest mine was found in Swaziland, SA. In 4000 BC copper melting used to be done in Sumerian (IRAQ) and in 3000 BC Gold mining started in Egypt. The very famous Pyramids in Egypt were built during 2900 BC which was made of enormous quantity of rock. Many good examples of water conveyance tunnels are found in 600 BC. In the year around 120 AD use of coal by Romans started and by the year 1225 AD the underground Mining of salt in Poland started. More recent example of marvels of rock engineering is the Gothard railway tunnel is a 15 km long railway tunnel Switzerland connects Göschenen with Airolo and was the first tunnel through the Gotthard massif. It is built as one double-track, standard gauge tunnel from 1871 to 1881. Construction was difficult due to financial, technical and geological issues, leading to the death of many tunnel workers due to different causes.

Figure 6: Northern end of the Gotthard railway tunnel, Goschenen, Switzerland

In 1959 Mont Blanc highway tunnel 12.7km was built and 1964-84 Seikan railway tunnel was built, Japan of a total length of 54 km, out of which 23 km under water. The very modern example of tunnels is the channel tunnel, 50 km, 1987-93, connecting France and UK. Another feather in the rock engineering marvels is the Gotthard Base Tunnel (GBT) is a railway tunnel in the heart of the Swiss Alps expected to open in 2016, with a route length of 57 km and a total of 151.84 km of tunnels, shafts and passages, it is the world's longest rail tunnel, surpassing the Seikan Tunnel in Japan. This challenging project consists of two single-track tunnels connecting Erstfeld (Uri) with Bodio (Ticino) and passing below Sedrun (Graubünden). It is part of the AlpTransit project, also known as the New Railway Link through the Alps (NRLA), which includes the Lötschberg Base Tunnel between the cantons of Bern and Valais and the under construction Ceneri Base Tunnel (scheduled to open late 2019) to the south. It bypasses the Gotthardbahn (Gothard tunnel), the winding mountain route opened in 1881 across the Saint-Gotthard Massif, which is now operating at capacity, and establishes a direct route usable by high-speed rail and heavy freight trains.

The turning point in rock mechanics came after Malpasset Dam (France) failure (figure 1), December, 1959 when 450 people killed and after october 1963, Longarone in Italy when 2500 people killed due to landslide generated wave which overtopped the Vajont dam. After these two failures, International society of rock mechanics (ISRM) was started 1963 and with the inaugural ISRM congress in 1963, Lisbon, Portugal. In the first ISRM conference) accepted the definition of rock mechanics. "Rock mechanics is the theoretical and applied science of the behavior of rock; it is that branch of mechanics which is concerned with the response of rock to the force field of its environment ".

Figure 7: Remains of the Malpasset Dam as seen today.

Figure 8: Vajont dam, Longarone , Italy

Engineers have been building structures on or in rock for centuries and the principles of engineering in rock have been understood for a long time. New rock mechanics is merely a formal expression of some of these principles and it is only during the past few decades that the theory and practice in this subject have come together in the discipline which we know today as rock mechanics.

1.3 ROCK ENGINEERING PROBLEMS AND APPLICATION AREAS

Rock Engineering is an interdisciplinary area, and its application includes in many different disciplines like Civil engineering, Mining engineering, Petroleum engineering, Geology and Geophysics. A particularly important event in the development of the subject was the merging of elastic theory, with the discontinuum approach. The gradual recognition that rock could act both as an elastic material and a discontinuous mass resulted in a much more mature approach to the subject than had previously been the case. At the same time, the subject borrowed techniques for dealing with soft rocks and clays from soil mechanics and recognised the importance of viscoelastic and rheological behaviour in materials such as salt and potash.

Some specific application to rock engineering areas include,

- Tunneling and underground space
- Geological hazards, landslides, slope instability, seismicity etc.
- Selection of construction materials
- Selection and layout of construction sites
- Analysis of stability of embankments, slopes, foundations.
- Site investigation, laboratory and insitu test, insitu stress determination
- Design of blasting operations
- Design of support systems
- Design of hydraulic fracturing programs in petroleum applications
- Bore hole stability, petroleum industry
- Design of instrumentation programs
- Evaluation of excavation characteristics and stability
- Studies of rock deformation at high temperatures and pressures (structural geology)
- Geothermal energy and nuclear waste /geological repositories.
- Hydro electric projects etc.

The main problems associated are,

- ➢ Information obtained from the testing of rock specimens or from field observations are not sufficient to provide a complete picture of the rock mass due to uncertainties while dealing with rock mass.
- ➢ Rock is a very complex material and comes with discontinuous (micro-discontinuities like pores, microcracks and macro-discontinuities joints, shears, faults).
- ➢ Highly anisotropic as its properties vary with directions and highly heterogeneous as its properties vary from point to point.
- ➢ Properties can be time-dependent and scale-dependent. The scale dependency implies that when modeling a rock mass, we need to take into account the relative scale of the structure of interest with respect to the scale of the major rock mass features (figure 9).

- Geological processes are coupled in a strong non-linear fashion. The processes can be mechanical, hydrological, thermal, chemical, and/or biological. An exact prediction of rock mass behavior is not possible.
- Because of the complex nature of rock as an engineering material, the design methods in rock engineering can vary depending on the geologic environment, the rock type, the type of engineering structure, the design loads that have to be considered, and the end uses for which the engineering structure is intended.

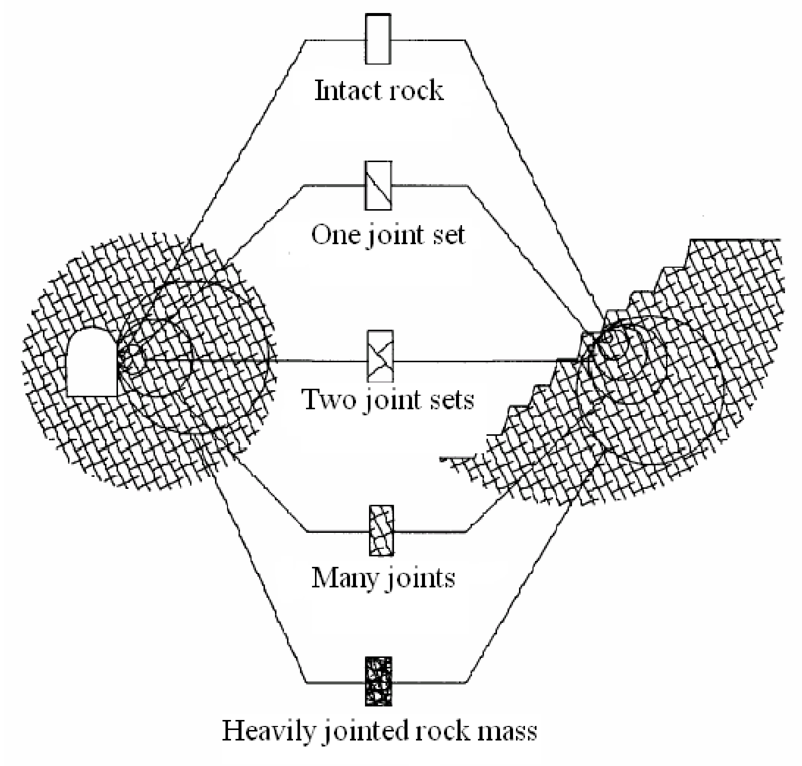

Figure 9: Idealized diagram showing the transition from intact to a heavily jointed rock mass with increasing sample size (Modified after Hoek, 1994).

1.4 ROCK ENGINEERING PRICIPLES

All these rock engineering projects, can be summarized in the three main aspects as shown in figure 10 (Hudson & Harrison, 1997). Here the outer ring represents the whole project complete with its specific objective-and different projects can have widely differing objectives. the middle ring represents the inter-relation between the various components of the total problem. For example, there will be relations between rock stresses and rock structure in the rock mechanics context; and there will be relations between rock support systems and cost implications in the rock engineering context. Finally, the central ring represents the individual aspects of each project, such as a specific numerical analysis or a specific costing procedure.

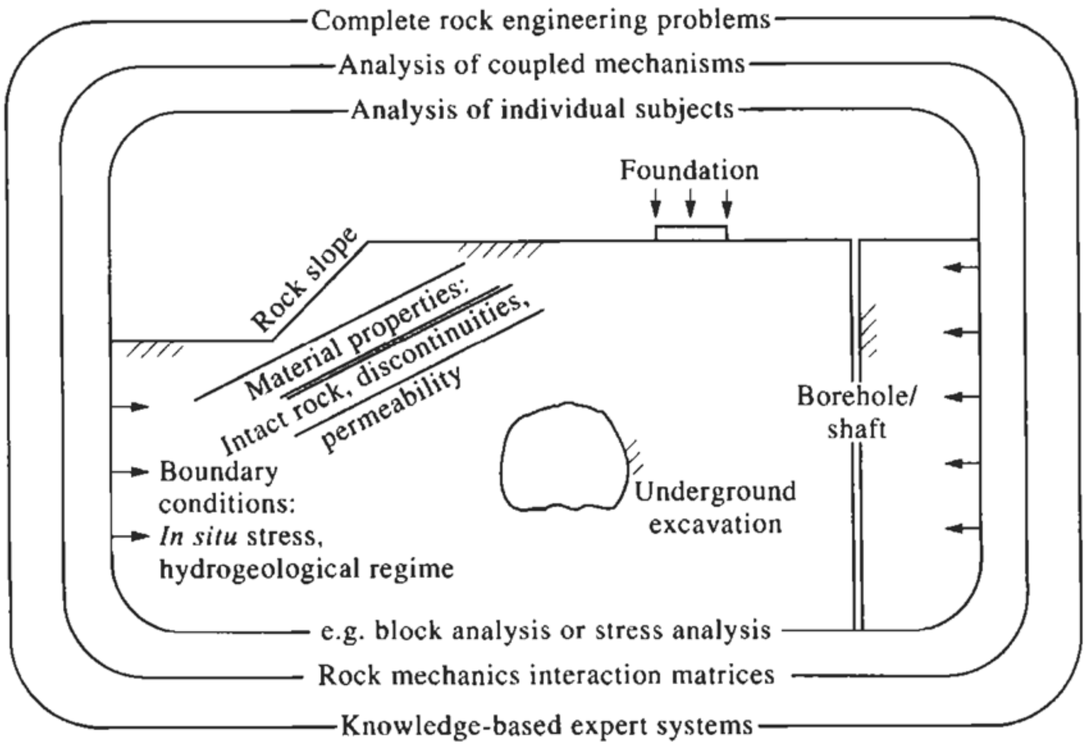

Figure 10: Three-tier approach to all rock engineering problems (Hudson & Harrison 1997).

Broadly the three types of rock mechanics or geotechnical problem we usually encounter, equilibrium/stability, stress and deformation behavior and drainage. To handle such problems, and as the subject is interdisciplinary in nature, a basic knowledge of mathematics, basic mechanics including fracture mechanics and plasticity with basic knowledge of hydraulics is helpful to understand the overall rock behavior. There are some basic principles of rock engineering as described by Hudson, 1989. They fall into nine main categories and direct with tenth dealing with the interactions between these nine principles. These nine principle are,

- Deformability, strength and failure of intact rock - Intact rock characteristics
- Deformability, strength and failure of rock masses - Rock mass characteristics
- Discontinuities and stereographic projection
- Natural and induced stress
- Permeability of rock
- Anisotropy
- In-homogeneity
- Representative elemental volume
- Continuum and discontinuum method of analysis

Additionally there are interaction of the construction processes with the ground and also various rock properties themselves during all engineering activities. It would be logical to consider these interaction among three primary rock characteristics namely, rock structure, insitu stress and water flow in the rock mass.

1.5 SUMMARY

Rock engineering is a challenging field and requires a multidisciplinary approach to deal with any projects. It has many components from site investigation to insitu stress determination, from design of tunnel to stress reduction, from slope protection to landslide study, from simple instrumentation to large TBMs, from petroleum to geothermal energy..and nuclear waste, each area is a challenge its own way. Though, last 40 years great development happened in the area, still many areas requires good attention for the overall growth of the field. Without proper attention and development of the rock engineering field, the geotechnical engineering is incomplete and possibly may not be able sustain for a long time.