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CONSTRUCTION OF TUNNELS, BY NEW AUSTRIAN TUNNELLING METHOD (NATM) AND BY TUNNEL BORING MACHINE (TBM)

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ABSTRACT

Tunnels have played a vital role in the evolution and Sustenance of man-kind through the ages. History has seen the evolution of tunneling starting with cave formation, for water management, under ground transportation, mineral extraction and for warfare purposes. Initially hand dug with crude tools like chisels, Hammers, spades and shovels, the civil engineering tunneling technology has seen progress in leaps and bounds. The ever increasing needs of the modern human race have driven the tunneling technology to its pinnacle. This is being realized through rapid advancements in terms of geological and hydro-geological engineering, tunnel design, capacity, construction methods and speed and maintenance during operations. Safety during construction and operations is getting integrated in all aspects through conscious and educated decisions. In most of the cases tunnel construction is expensive but it saves time and provides comfort. Large excavation of soil or rock etc. is necessary for a tunnel construction. With the availability of modern equipment, excavation and backfilling has become easier. In this paper we will explore some advanced methods of tunneling.

KEYWORDS: Construction Sequence, Methodology, New Austrian Tunnelling Method (NATM), Support Systems Tunnel Boring Machine (TBM)

INTRODUCTION

Tunnel Boring Machine

TBM is a recently developed technique and it has revolutionized the tunneling industry both in making the construction of tunnel safer and economical. TBM is nothing but an inbuilt underground factory which carries out all the activities (Shotcreteing, rock bolting and many more) required during the construction, for a stable tunnel. TBMs are large machines that tunnel through ground, progressively installing concrete linings, to support the excavated tunnel. Excavated material is transported through the machine to the surface, for removal by trucks. TBMs are typically used in the construction of underground tunnels. They are tailored for specific ground conditions and are more than 100 meters long and weigh up to 1,000 tones.

List of Main Constitutive Components and their Function in Brief

- Front face where the soil is excavated with special tools (shield or cutting wheel/cutter head)
- Steering mechanism part with drive engines for forward movement.
- Control mechanism for deviation and inclination

- Muck Removal installation, for transporting excavated material through the machine, to a separator or directly onto an independent transport system.
- Installations behind the working chamber permitting either further soil improvements i.e., with rock bolts, shotcrete or injections) or are used for preliminary investigations.
- Support installations within the protection of the tail shield.
- Eventually, grouting the void at the shielded tail created between the lining and the subsoil.

OPERATING PRINCIPLES OF TBM

The TBM is usually fabricated, to match the rock conditions. TBM is designed based on the geological conditions, for hard rock condition, soft rock conditions or mixed conditions requirement torque, thrust type cutter head and many parameters are different. So, to predetermine the type and specifications of the TBM study of geology is of utmost importance. If the TBM is not powerful enough for the rock the machine will be overstressed and be prone to breakdown. Similar to an electric drill the TBM operated by using the thrust and torque. Like the drill, the motor rotates the cutter head, whereas the thrust for the electric drill is provided by the person operating the drill, TBM receives its thrust by cylinders that push the cutter head against the rock face. TBM gets its forward thrust by pushing against the precast segmental linings.

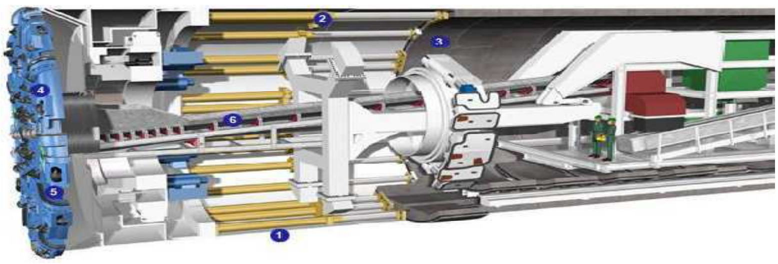

Figure: 1

Shield

This component provides the closure to the TBM, it helps in carrying our construction activities inside the TBM as the shield protects the excavated heading portion from collapsing inside the machine. This shield provides safety for the workers inside the machine.

Cylinders

These cylinders provide thrust force for the rotation of the cutter head. Design of these cylinders for the thrust force is very important. In hard rock conditions thrust force should be sufficient enough to meet the requirement for rotation of cutter heads otherwise overstressing and breakdown of the machine may occur. In soft rock conditions thrust force should not be more or less than its requirement. If thrust is more cutter heads may cut the face in an uneven and non uniform pattern causing change in the alignment of the machine which may get stuck eventually.

Erecting Device

This component helps in installation of segmental linings throughout the periphery of the tunnel section. While ring building of the precast or cast in situ segmental linings, there is always one key, which is very critical in its installation process. Key is nothing but a last segmental portion which completes the ring. As space required is minimum it is the most tricky and difficult part. After installation of segments annular grouting is done to fill the gap between installed segments and the exposed ground face.

Cutter Head and Cutting Tools

Cutting tools are attached to the TBM cutting head and are used to penetrate the rock. The type of tool is determined by type or hardness of the rock. In soils or very weak rock, drag type tools are used. For hard rock, disk cutters are used. Disc cutters are the standard TBM cutters used now days. The disc cutter generally consists of solid steel alloy disc with a tapered cutting edge with a replaceable cutting edge of hardened steel around the perimeter.

Following are types of cutter heads:

Figure 2: Single Disc Cutters

Figure 3: Twin Disk Cutters

Figure 4: Centre Disk Cutter

Scraper

These scrapers consists of buckets which collect the excavated muck which is produced during the excavation by cutting tools. This muck is collected in the buckets and transported via belt conveyors.

Conveying Devices

Conveying system in the form of belt conveyors collects the excavated muck collected by scrapers and transports it to the muck deposition yard.

DESIGN OF SEGMENTAL LININGS

The lining of tunnels built by underground construction must fulfill several requirements both during and after the construction

- Securing the rock, to prevent the rock fall.
- Handling the dead weight and overburden weight.
- Sealing the tunnel against the water ingress.
- Structural stability to the tunnel.

Ring Geometry

For curve drives tapered rings are used Tapering is nothing but a maximum to minimum difference between widths of the linings that can be kept in case of curvatures. Tapering (K) can be calculated from following formula

$$K = \frac{OD \times Bm}{R}$$

Where,

OD = Outer diameter of the segment ring

Bm = Mean ring width

R = Minimum curvature radius

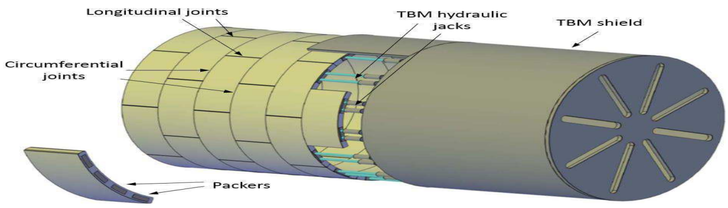

Figure 5

Above figure shows the installation of the segment linings.

Longitudinal joints of every adjacent ring should be staggered. TBM hydraulic jacks give the thrust force which moves TBM into forward direction. This thrust force is achieved from the thrust action from the previously installed segmental rings, so while designing the segments consideration of this thrust force is very important. Packers are the interlocking arrangement for every ring which is bolted through the packers.

ADVANTAGES AND DISADVANTAGES OF TBM

TBM can achieve greater production rate with less labor work force compared to that in NATM. TBM is safer as shield protects the working area and there is no blasting of explosives is involved as it is in NATM, so it is comparatively safer. Because in TBM blasting activity is not involved there is no concern with vibrations and over break. However use TBM is a costly affair as initial capital cost is high and mobilization time is longer. In NATM no initial capital investment is required and mobilization time is also less. In TBM operation highly skilled workers are required. The major disadvantage of TBM is its lack of versatility with regards to tunnel shape and its inadaptability in varying or mixed geological conditions. Power requirement is huge and many times TBM as a whole unit cannot be reused in different projects as requirements and demands can be completely different.

NEW AUSTRIAN TUNNELING METHOD

Introduction

NATM is not a construction method for tunneling it's a strategy for the smooth work of all the construction activities with safety and economy being the main principles. Flexibility in the operation and construction works is the main advantage of the NATM technique. It can be used for hard rock conditions, soft rock conditions and for mixed ground conditions as well.

Before starting of the construction activity it is of utmost importance to know the geology and geotechnical features of the ground. To have a good idea about the ground conditions bore holes at required locations are taken.

GENERAL SEQUENCE FOR THE CONSTRUCTION USING NATM

Marking of Drill Holes

In this process drills are marked on the face of the tunnel based on the blasting pattern. Whether, a wedge cut or a burn cut.

Drilling of Holes

In this process holes are drilled using manual excavators if face is of soft soil/rock or with the boomer machines if the face is of hard rock.

Charging with Explosives

In this process explosives are inserted into the drilled holes and are connected with detonators. Finally all the detonators are connected at one prime connection.

Charging and Blasting

In this process the prime connection where all the detonators are connected is exploded which consecutively allows the explosion of each explosive placed in each drilled hole at a designed interval (generally at 1 millisecond interval).

Scaling and Mucking

This process starts after complete removal of the dust and harmful gases which occurred during blasting. In this process loose cuts which remain intact on the face are removed.

Installation of Primary Support

This is one of the most important and tricky part as standup time of the ground plays vital role. Standup time is nothing but a duration for which the unsupported ground which remains stable on its own after blasting or manual excavation. In primary support measures shotcrete or rock bolts are used. The thickness and grade of shotcrete and length, type and diameter of rock bolt, depends upon its design

Construction of tunnel can be subdivided into parts, such as heading, benching and invert.

Provision to Avoid Ingress of Water

Water ingress inside the tunnel is the major concern as it may lead to the failure of the structure. To avoid this situation water proofing membrane in the form of Dimplex or Nyllex strip is provided, after the installation of primary support system.

Secondary Support or Extra Structural Support

If the strata demand more support and structural stability, supports in the form of Lattice girder, steel ribs, second layer of shotcrete etc. can be provided.

Final Lining

In this process, kicker beam of precast or cast in situ sections are installed, followed by kicker lining throughout the periphery of the tunnel section.

SUITABILITY OF NATM

For construction of any tunnel, choosing of appropriate construction technique is the most important aspect. Analysis for whether to go for NATM or TBM is vital.

Following are the some situations where NATM is suitable

- For projects with highly varying ground conditions, as methodology can be altered according to the changes in the geology.
- As this is a flexible technology it can be used for different geometry of the tunnels. By changing the blasting patterns required geometry of the tunneling sections can be achieved.
- When there is a high risk of water inflow precautionary measures can be taken like pipe roofing, fore polling etc. Installation of water proofing membranes can also be used wherever required.
- Sometimes TBM installation is difficult due to the congestion and inadequate space at the site. In such cases NATM is preferred as construction area required is less compared TBM.
- NATM is mainly beneficial for small length tunnels as quantity of explosives and detonators is less compare to that in longer tunnels. Environmental, Ecological Issues may occur due to abundant use of explosives.

GROUND STABILIZATION TECHNIQUES

Sometimes it is necessary to improve the ground conditions before actual construction of the tunnel. In some cases problems such as high ingress of water or cavity formation etc may occur during the construction activities and these are one of most risky and hazardous effects. To avoid these situations ground stabilization is done by following methods.

Ground Improvement

Geological faults or fissures can be stabilized by this method. Failure due to cavity formations can also be rectified. In this method jet grouting is done from the ground surface or from the tunnel, whichever is nearer to the fault, fissures and cavity. Jet grout is nothing but a slurry based concrete is applied under pressure to fill the faults, fissures and cavities.

Ground Reinforcement

In this method structural element such as bolts, anchors or piles etc is inserted.

Dewatering

In case of ingress of water due to water table or underground water flows structural stability of the tunnel can get hampered. To avoid these dewatering or lowering of water table is done.

NATM FOR SPECIAL CROSS SECTIONS

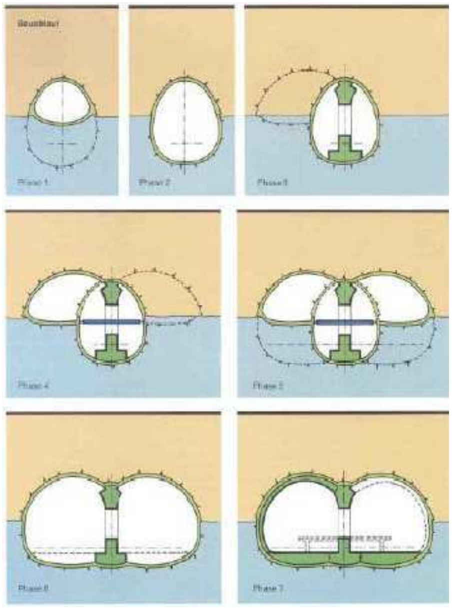

Figure 6

This is the classic example, which suggests how NATM is very beneficial for various types of shapes as methodology is flexible and can be changed according to the demand. In this figure construction of two parallel tunnel tubes is shown. In 1st phase of construction only heading part is constructed followed by its benching and invert in 2nd phase. Thereafter Column is constructed in between the excavated portion to take and distribute the load from the two adjacent heading portions as shown in 4th and 5th phase. After that benching and invert is constructed in 6th phase. In 1st and 2nd phase the structural members of the side walls are temporary to distribute the load of heading through column. After completion of the heading and benching part of the adjacent tubes as shown in phase 5th and 6th the temporary structural side wall supports are removed. NATM becomes very useful in such complicated construction methodologies where flexibility in construction sequence is essential according to the demands.

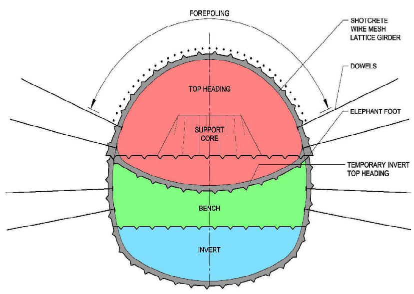

Figure 7

This is typical cross section of the tunnel which can be achieved by NATM. In this section heading part is excavated first and after certain progress in the heading excavation once the heading portion ahead gets stable excavation of benching and invert is started. After excavation of heading portion elephant foots are provided at the bottom to support and distribute the load from heading. During excavation of heading a temporary invert is also excavated to avoid stress concentration at the corners. By providing temporary invert shape of the heading section is adjusted to have considerably minimum stress concentration at corners. As NATM is a flexible technique we can optimize the cross section of the tunnel as per the requirement economically. The main considerable point here is if invert portion is strong in the first place with enough strength we don't require to excavate the invert portion and then again fill it. Whereas in TBM as the shape of TBM is circular we excavate full section even when invert portion is not required to be excavated. Considering this point NATM proves to be very economical due to this tweaks in the methodology, so NATM is a very optimum and economical method.

Design and Monitoring Concepts

This Is very important concept it mitigates the hazard and risk during the construction phase. An alarm plan is designed, in which 3 different levels of the alarm are set corresponding to anticipated or allowable settlement criteria.

Level 1 – Warning level (70% of allowable settlement) Level 2 – Standby level (90% of the allowable settlement) Level 3 – Alert level (100% of the allowable settlement)

GENERAL GEOLOGY BEHAVIOR

Knowledge of the geology is very important for NATM as well as TBM as structural support system depends on geology only. Some of the geological behaviors and measures to be taken are as follows

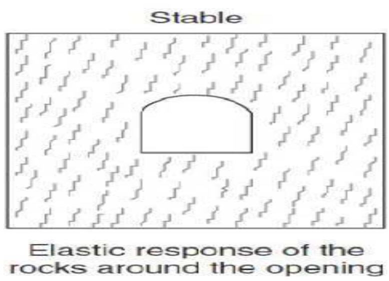

Figure 8

Elastic response around the tunnel section is considered stable.

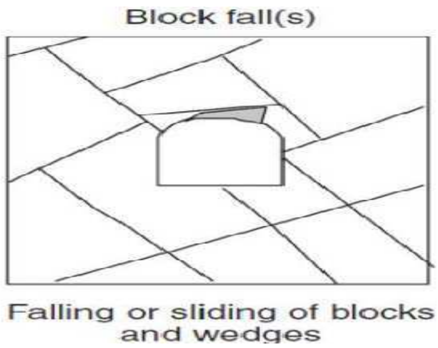

Figure 9

In this case rock bolts can be used to stitch the faults and stabilize the rock fall.

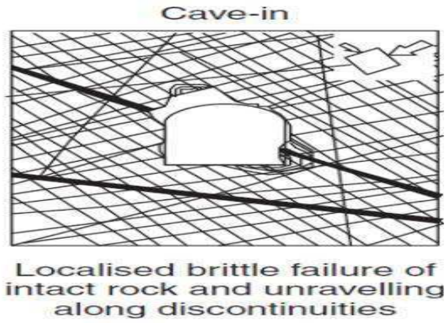

Figure 10

To avoid the failure due to cave in rock filling or grouting is done to fill the cavity completely.

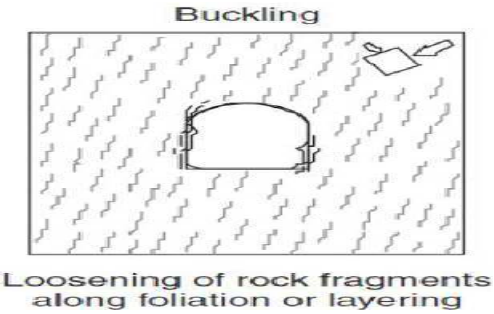

Figure 11

To avoid the buckling of the tunnel side walls it should be strengthened with the use of lattice girders, steel arches ribs, shotcrete or anchors etc.

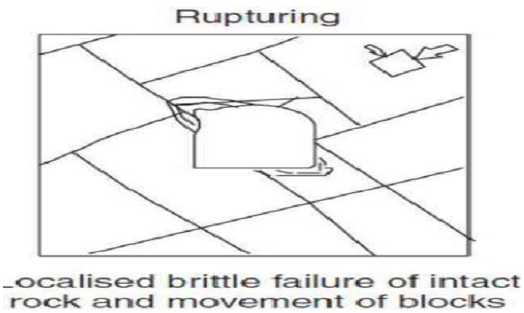

Figure 12

Permanent anchors are provided to avoid the rupturing.

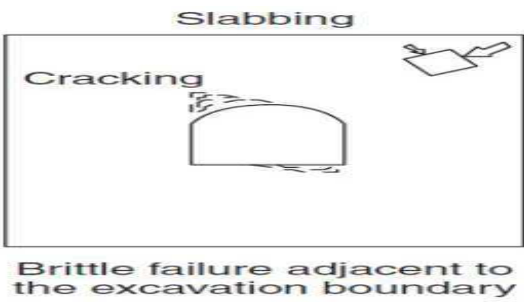

Figure 13

Fore polling and grouting should be done to stabilize and avoid the further cracks due to slabbing.

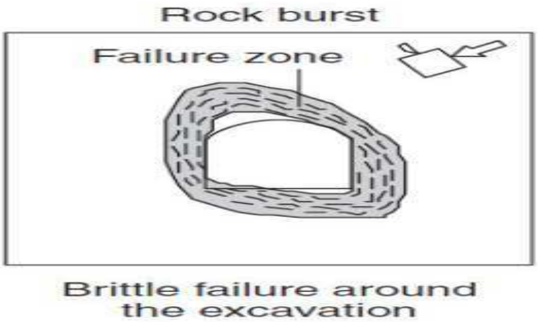

Figure 14

Rock burst is a relatively unpredictable situation. To avoid the rock burst in the burst prone geological conditions excavation technology should be modified with changes in blasting and drillings patterns.

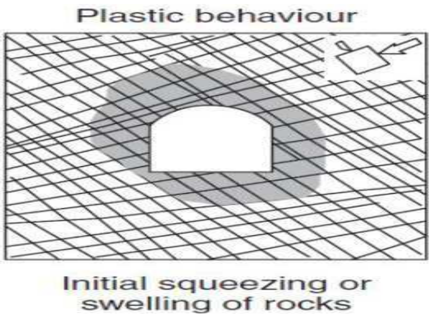

Figure 15

If plastic behavior with squeezing or swelling of rocks is observed geometry of the tunnel section should be modified. Circular geometry which distributes the stress around the tunnel Periphery smoothly can be the solution. Stiff lining is also required

CONCLUSIONS

Nowadays Tunnels are becoming important infrastructure which needs to be constructed in speedy manner and for which there is great scope especially for developing urban infrastructure, underground rail and road networks, transportation in mountainous regions and so on. Refinements in Mechanized tunneling and advanced machineries along with good designing capabilities tunneling are becoming safer from construction point of view. Mechanized

Tunneling is useful for getting good progress along with reducing risk and to tackle with various unforeseen scenes which cannot be predicted with Geotechnical investigations. A greater level of mechanization of tunnels will reduce construction time and help early revenue generation.

ACKNOWLEDGMENT

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