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New Austrian Tunneling Method (NATM) in Himalayan Geology: Emphasis on Execution Cycle Methodology

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Abstract **: Tunneling is a vast and continuously growing field in the construction industry. It is considered as the most complex construction methods considering the unexpected behavior of the rock mass during the construction phase. Generally wedge formations, shear zones, debris material, presence of nalas/small water channels, less overburden, heavy ingress of water and many more are the conditions which may be encountered during the execution phase. Therefore a precise and safe method is required which could save time and provides safer environment for the construction. New Austrian Tunneling Method (NATM) of tunneling is considered as the most effective method in the region of varying geology, as it works on the observational approach of tunneling. This paper gives a brief idea about the various sequences followed and material specifications for the construction of the tunnels by NATM method.**

Keywords: NATM; Himalayan Geology; Tunnelling Method

1. INTRODUCTION

This paper is based on the observations made during the construction of the tunnels in Udhampur-Srinagar-Baramulla Rail Link Project (USBRL Project). The project is of national importance which is directly monitored by the PMO(Prime Minister Office). Since the project is in Himalayan range with varying geological conditions the most effective method for tunnel construction seems to be the New Austrian Tunneling Method (NATM) which works on the principle of continuous observations after each execution cycle. Furthermore, the stages in an execution cycle have been explained.

1.1 NATM CONCEPT

The New Austrian Tunneling Method can be defined as a support method to stabilize the tunnel perimeter with the help of sprayed concrete ,anchors and other support and uses regular monitoring to control stability of the tunnel. It was Rabcewicz in 1948 who patented the very idea of this tunneling method (Schubert,2015).

1.2 NATM is based on the following principles of :

- Prevention from disintegrating of rock mass, hence keeping its strength
- Rock mass classification
- Shotcrete protection
- Monitoring the behaviour
- Construction measures

1.3 Action of Stress on Tunnel Opening

Rocks are initially stressed, and any opening created can cause changes in the initial stress. The study of stresses around underground openings gives an insight into the basic mechanisms like displacements and the stress fields and helps to provide suitable support for the underground opening. The major conditions around an opening can be classified as in-situ stresses– due to the overburden rock, induced stresses– due to the excavation for the opening and traffic loads– not significant in the case of deep tunnels.

2. GEOLOGY OF HIMALAYAN REGION

The Himalayas, which stretch over 2400 km are the result of an ongoing orogeny, the result of a collision between two continental tectonic plates. The Geology of the Himalaya is a record of the most dramatic and visible creations of modern plate tectonic forces. This immense mountain range was formed by huge tectonic forces and sculpted by unceasing denudation processes of weathering and erosion, which resulted in varying geology of this region.

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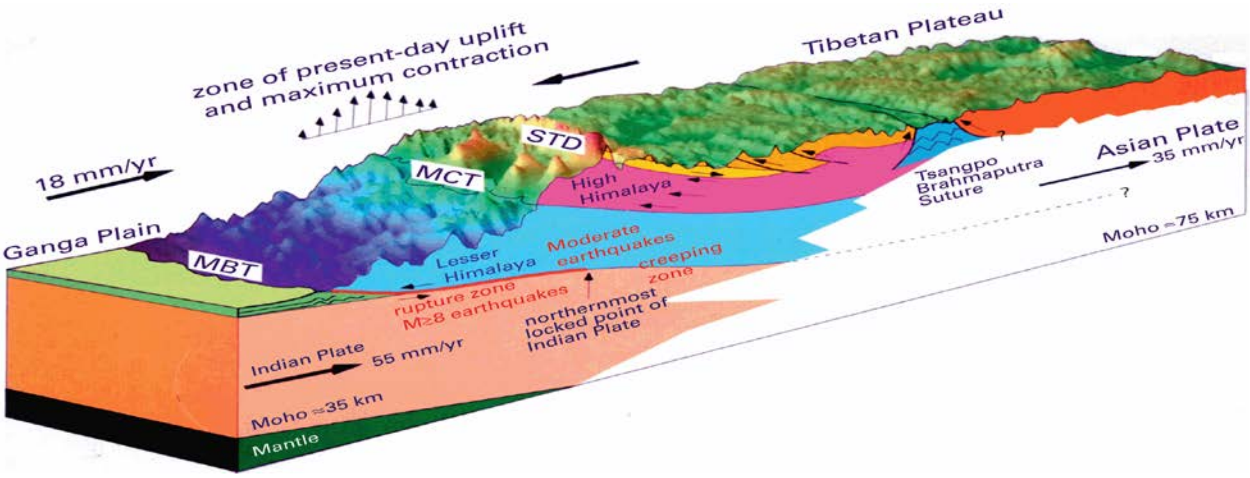

Fig. 1 Himalayan Geology

With the presence of soft rock formations such as limestone, siltstone, claystone with the occurrence of active earthquake zones and faults it is difficult for the civil industry to conduct construction activities in this mountainous region. During excavation stage of tunnels at every 100 m interval the geology differs which means the same designs cannot be applied to every rock formation. Henceforth, The NATM methodology is widely used for these kinds of geological situations as it is based on observational approach and design measures are taken accordingly.

3. SEQUENCE OF NATM:

The sequence followed here for the initial support system through NATM is as follows:

1. Profile marking
2. Face Drilling
3. Charging and Blasting
4. Defuming
5. Mucking
6. Scaling (if required)
7. Geological Face Mapping
8. Face Sealing Shotcrete
9. Lattice Girder Erection
10. Fore polling (if required)
11. 3D Monitoring Targets installation
12. Initial Lining with Shotcreting
13. Rock Bolting & Grouting

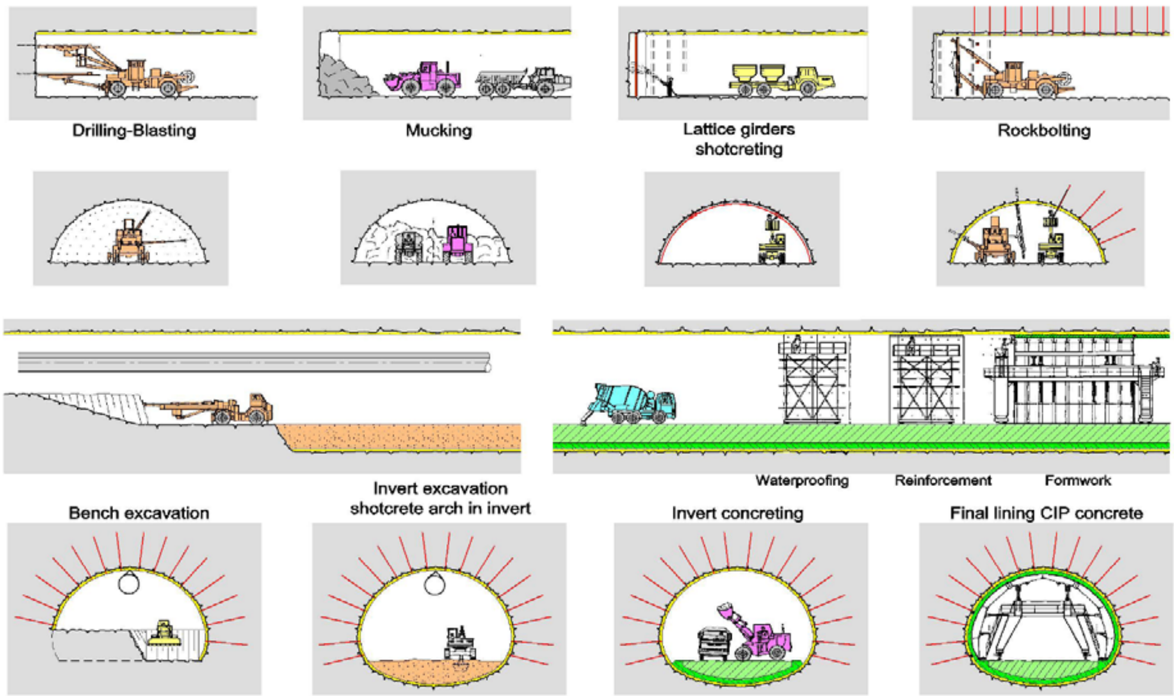

Fig.2 NATM Sequence

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3.1 PROFILE MARKING

To achieve the designed shape profile marking is required. It has its own significance in the sequential excavation method. Its main purpose is to define the minimum excavation line on the working face. Accuracy in profile marking helps to maintain the minimum excavation line and prevents over breaks. Points are defined and marked by the survey team. Equipment used here is Leica total station with TMS (Tunnel Measurement System) software.


Fig. 3 Profile Marking


Fig.4 Face Drilling

3.2 FACE DRILLING

Once the profile is marked working face is drilled with the help of 2 boom hydraulic boom Jumbo (figure 4). The drilling pattern followed is VEG CUT. 107 number of holes (variable) are drilled having a diameter of 41mm. The Number as well as length of holes (pull length) varies, depending on the rock type, if the rock encountered is in good condition then length of the hole can be increased. Generally, 1m, 1.5m, 2m pull lengths are used here, depending upon the Rock class.

3.3 CHARGING AND BLASTING

Inserting the Explosives and charging them for blast is termed as charging and blasting. Charging of holes is done manually by expert staff. Drill Jumbo’s basket is used so lift the man-power to charge the holes which are on the upper portion of the working face. The explosive is having 32mm diameter and 300mm length weighing 120gm. Non-electric detonators are used with cortex wires (figure 5 to 10).

Fig. 5 Emulsion explosive cartridge


Fig. 6 Detonating cord/cordex

Fig. 7 Exploder

Fig. 8 Ohm meter

Fig. 9 Charging

Fig. 10 Blasting

NED significances include simultaneous working practices and efficient working in damp to wet conditions. Trained engineers and foreman are deployed to execute the work in most efficient and safe way. Minimum clearance distance of 100m is taken to avoid any accident. Figures 4-11 shows the materials used in charging and blasting.

3.4 DEFUMING

Once the blast is taken various harmful gases are emitted in the tunnel. Expelling out these harmful gases is termed as defuming as shown in figure 11. Generally, due to their lighter weight they travel along the crown portion of the tunnel. A proper ventilation system with jet fans has been planned to maintain fresh air and to take out harmful gases from the tunnel. Ventilation duct is installed along the crown portion considering the height over less diameter of tunnels. All the workers are provided with air filter masks as a safety precaution. A minimum of 15-30 minutes is required for defuming.

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Fig. 11 defuming of gases after blasting from tunnel

3.5 MUCKING

Material obtained from blasting/Fragmented rock after blasting is termed as Muck, shown in figure 12, the whole procedure of gathering and removal of muck is known as mucking. Machinery used for mucking depends on the availability of working area inside the tunnels. Since
the diameter of Rescue/Escape tunnel is less therefore Hagg Loader (figure 13) is used for collection and filling of Muck in dumpers. Whereas, diameter of Main Tunnel is enough for the movement of side tilt loader. Dumpers with a Capacity of 25 tons are used to carry muck from tunnel face to the acquired dumping yards.

Fig. 12 Muck in the tunnel

Fig.13 Hagg Loader used in removal of muck

3.6 SCALING AND CHIPPING

Fig.14 Chipping

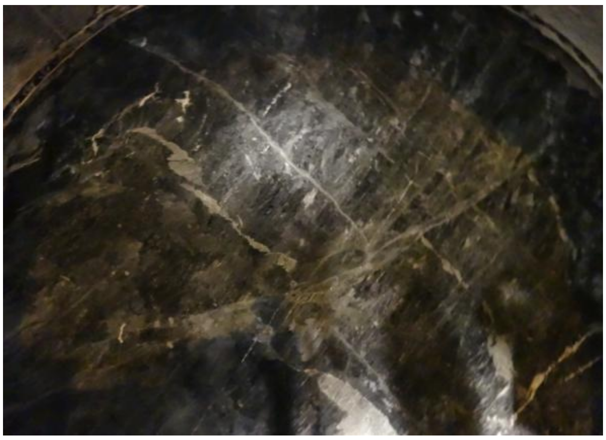

Fig.15 Geological Mapping of Tunnel face

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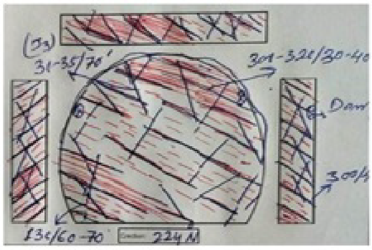
Once mucking is completed the whole blasted area is thoroughly checked for presence of undercuts or some loose material or cracks which are removed with the use of excavators or breakers. Scaling is necessary to provide accurate excavated profile for the installation of Lattice girders and safety of the workers executing the works.

3.7 GEOLOGICAL MAPPING

Examining the types and number of joints and type of rock conditions of the obtained face is termed as geological mapping (figure 15 and 16). After scaling and chipping geologist along with survey team and other supporting workers inspect the face. Geologist examines the face and prepares a face log after every pull and keeps a record of the same. Based on the actual site conditions and face log geologist decided whether designed support is enough or less or more for that section.

Escape Tunnel Face-1									
Tunnel Face Mapping Sheet (TFMS)		USB/T-15/F9-1				Prepared By			
North Portal	ET Face 01 North Portal					Date		22-04-2019	
General Characteristics									
Front Proceeding from				Elevation at the front [m]					
Distance from the portal [m]				Overburden [m]				78-80	
Tunnel excavation face at Ch [km]			85147.7	Excavation method				NATM	
Unsupported length [m]			12	Excavation approach				Drill & Blast	
Support Section type (actual)			E	Support Section type (design)				E	
Bolting distance from the front [m]				Final lying distance from the front [m]					
Lattice girder installed at 1.0 m spacing				L.G. Ch.-				85147.97	
Tunnel Excavation Face Geotechnical Description									
Legend									
claystone									
siltstone									
clayband									
seepage									
Geo-lithologic characteristics									
Lithology 1-									
Claystone, Siltstone									
Main structural thems		The strength of rock mass is very low < 5-15 Mph. Rock mass are highly weathered, smooth claystone with siltstone along with clay band along the joint plane							
Main discontinuties									
Type	Dir/Dip	Space (mm)	Pers. (m)	Rough.	Aperture. (mm)	Alterat.	Infill.	Joint Ori.	Note

21	300-320/30-40	<60	1-3	5 m	1-5	H.W.	>5	Fair	Clay Band
22	130/60-70	<60	1-3	5m	1-5	H.W.	>5	V. Unfair	
23	30-35/70	<60	1-3	5m	1-5				
Other parameters									
UCS [Mpa]	<5 to 15	RQD [%]	<25%		Damp to wet				
Instability phenomenons									
Rock Mass	Front	Roof	Support	Ribs	Shotcrete	Bolt	Others		
None			deformation	L.G.					
Wedges instability		√	Lowering	√	√	√			
Caving			Breaking						
Spalling/ rock burst			Others						
Squeezing									
Note:									
Contractor's Geologist:			DDC's Geologist:				Client's Geologist:		
Name:			Name:				Name:		
Sign:			Sign:				Sign:		
Date:			Date:				Date:		

Fig. 16 Face Log

Whereas Survey team examines if any over break is there or not and brings in the notice of the face in charge after which required measures are taken to control the over breaks.

3.8 FACE SEALING SHOTCRETE

A protecting layer is applied on the obtained face and the periphery to avoid falling of loose materials which is termed as face sealing shotcrete (figure 17). Minimum 30mm and maximum 50mm face sealing is applied depending on the site conditions. The main purpose of applying face sealing shotcrete is to prevent any casualty which may happen due to falling of loose material from the excavated face. It acts as a protecting layer or umbrella under which workers and machines can perform safely.

Fig. 17 Face Sealing Shotcrete

3.9 3D MONITORING TARGETS INSTALLATION

The NATM principle includes the 3D monitoring instrumentation, which plays a very important role in tunneling, Observation is required whether the support system is sufficient for the particular rock type or not. In instrumentation the 3D monitoring targets are installed to check the deformations inside the tunnels after the excavation. Monitoring targets as shown in figure 18, are attached to rocks in the periphery. Once they are installed initial readings are taken and recorded with the help of total station. After installation of targets readings are taken in the following pattern:

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1-5 days – Daily
6-15 days – Every Alternate day
16-27 days – Every 3rd day
28-41 days – Weekly
42-69 days – Every Next week
70-99 days – Monthly

Depending on the rock class longitudinal distance between two consecutive targets are:

Class A –25m
Class B – 20m
Class C1 –15m
Class C2–15m
Class D – 10m
Class E – 5m

Radial Deformations with whole cross section are:

Class A – 20mm
Class B – 40mm
Class C1 – 60mm
Class C2– 60mm
Class D – 80mm
Class E – 100mm

Fig. 18 Optical Target for 3-D Monitoring

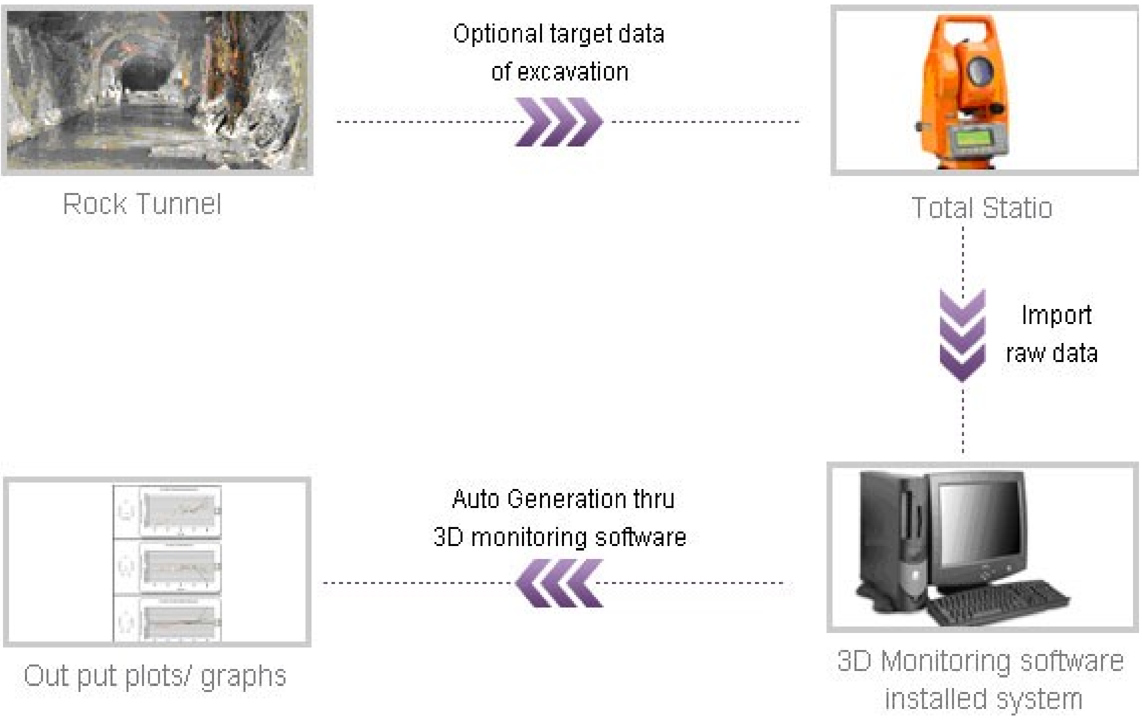

Fig. 19 3-D Monitoring Process

3-D monitoring process is shown in figure 19.Once the deformation reaches warning limit additional rock bolts are suggested for better support but if deformation reaches alarm limit then additional supports such as erection of ribs or closing of ring by providing deep invert is done.

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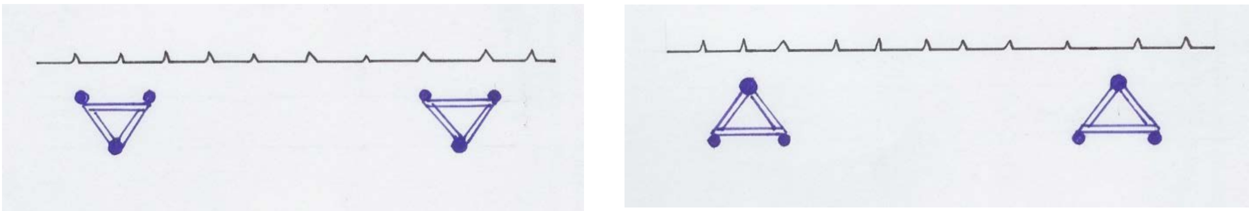
3.10 LATTICE GIRDER ERECTION

Once the protecting layer is applied then survey team along with the supporting staff reaches the face. Survey team with the help of total station marks the location of the Lattice girders and executes the placing of LGs. Lattice girders act as initial support and provides a defined shape to the tunnel (figure 20). Figure 21 shows layout system of lattice girder. Three types of LGs are used here:

(i) Type one – Three steel bars of 25mm dia.
(ii) Type Two – One steel bar of 25 mm and two steel bars of 32mm dia.
(iii) Type three – Three steel bars of 32mm dia.

Fig. 20 Lattice Girder Ach



(a) (b)

Fig. 21 Layout System; (a) Standard, (b) Vienna

3.11 FORE POLING

The process of installing fore poles is termed as fore poling (figure 22). In case of weak rock in the crown portion fore poles are provided for additional support.In this project the length used is 4m with 0.3m center to center spacing for a pull length of 1m at an angle of 50- 7°.

Fig. 22 Forepoling

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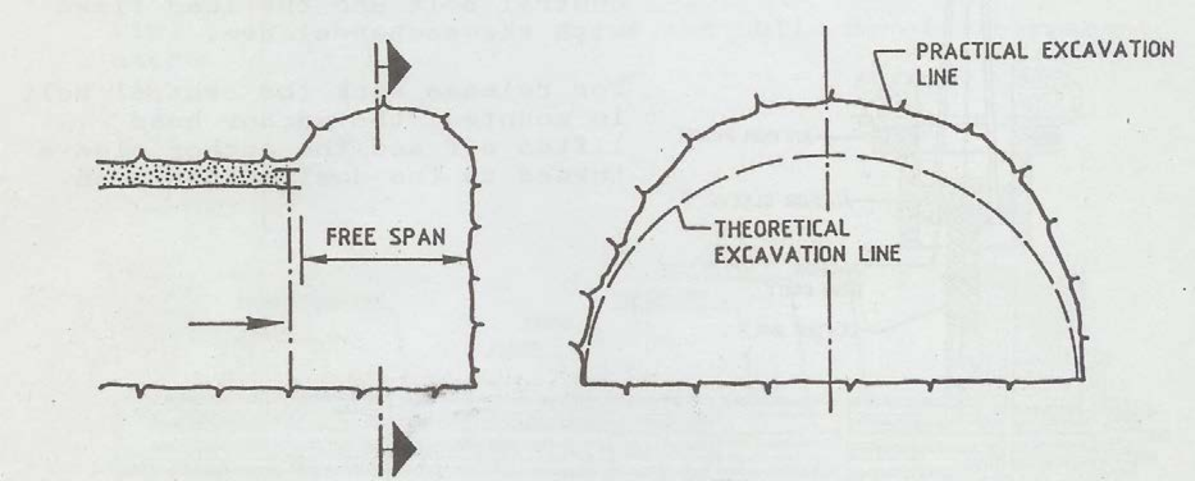

Fig. 23 Shape of Excavation without Forepoling

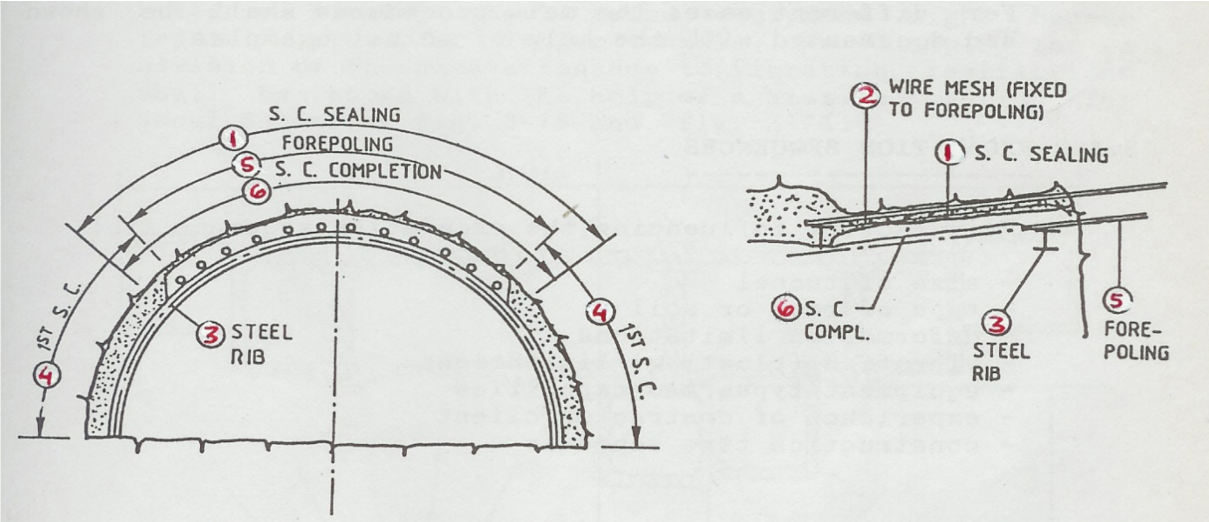

Fig. 24 Shape of Excavation with Forepoling

The material used is Self-Drilling Anchor having a diameter of 32mm. SDAs have a minimum yield strength (fy) of 200KN. These are installed with the help of 2 boom hydraulic jumbo. Moreover, they are passed through the lattice girder to counter the weight of the rock mass in the crown portion. Figure 23 and 24 shows shape of excavation with and without forepoling.

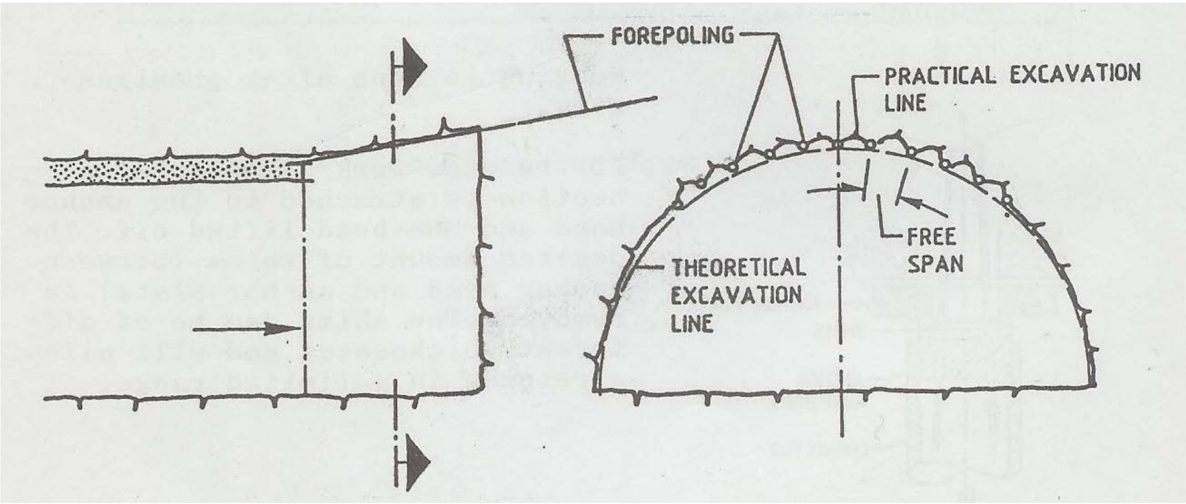

Fig.25 Construction Steps:

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1. Sealing shotcrete
2. Installation of wire mesh (fixed to previous forepoling)
3. Erection of steel rib
4. Shotcreting: Complete 1st layer where no forepoling to be installed
5. Installation of forepoling
6. Completion of 1st layer shotcrete

3.12 SHOTCRETING

Shotcreting is considered as one of the main component of initial support system. Shotcreting is of two types : sealing shotcrete and main shotcrete. Sealing shotcrete is used to avoid loose ground and prevent fall-downs, whereas main shotcrete is used to carry load uintroduced by ground in the lining. After the installation of LGs a thick layer of shotcrete is applied. Putzmister is used to spray the shotcrete. Highly skilled staff is required for this work. Mix inclusive of cement, sand, aggregate and admixture is poured in the putzmister where accelerator is also added and then sprayed for quick setting. Face is cleaned with high pressure air or water before application. A minimum of 1.5 m and maximum of 2.5 m distance between the nozzle and the face should be kept for best results. Thickness of shotcrete layer depends on the rock conditions. If poor rock is encountered, then 300 mm thickness is applied and in case of good rock class thickness is reduced to 250mm to 200mm to 100mm. Two types of reinforcements are used here during Shotcreting:

(i) Wire mesh – 150*150*60 dia.
(ii) Steel Fiber-2D

If the thickness of shotcrete layer is 250 mm then two layers of wire mesh is applied. One on protecting layer of thickness and other at 130mm. In case of steel fiber 30 kg per cubic meter is used applied directly on the face. Different type of shotcreting is shown in figure 26.

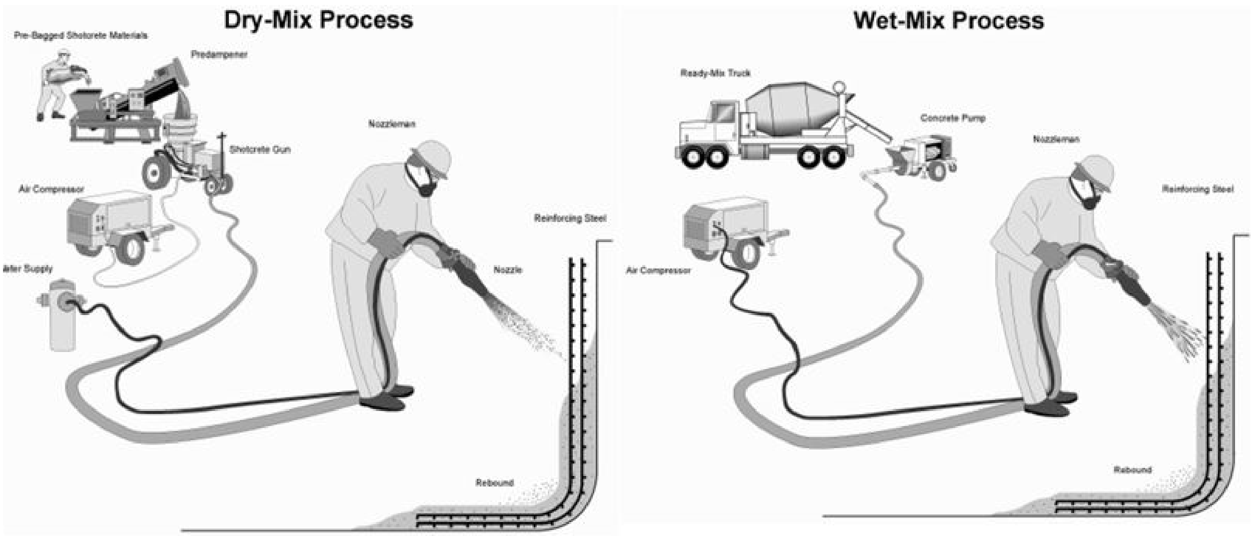

Fig. 26 Shotcrete methods : (a) Dry method; (b) Wet Method

3.13 ROCK BOLTING

After the application of shotcrete rock bolts are installed to stitch the whole shotcrete with the rock so compact that shotcrete and rock becomes one unit for supporting the whole burden. The rock bolts help to stitch the joints and make it a bulk body, bolts used here are Self-drilling Anchors with a diameter of 32mm and length 3m & 4m in general. Directions of installing rock bolts are shown in figure 27 and figure 28 shows the flow chart of different types of rock bolts.

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Fig. 29 Tunnel Profile with rock bolts and forepoles

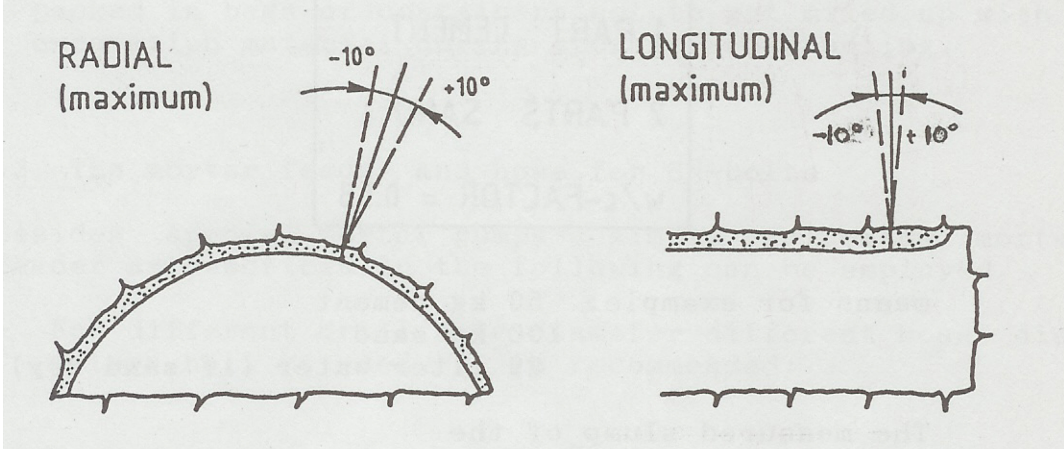

Fig. 27 General the Direction of Rock Bolts

TYPES OF ROCK BOLTS

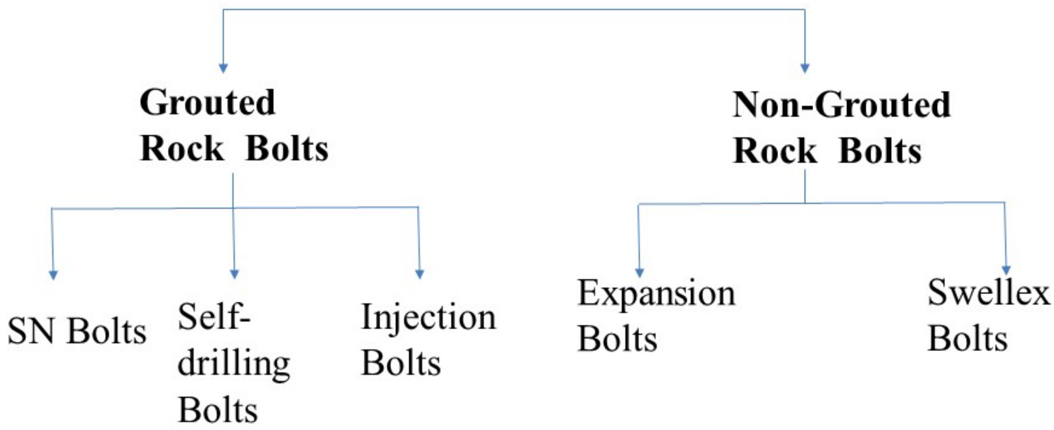

Fig. 28 Flow Chart of Types of Rock Bolts

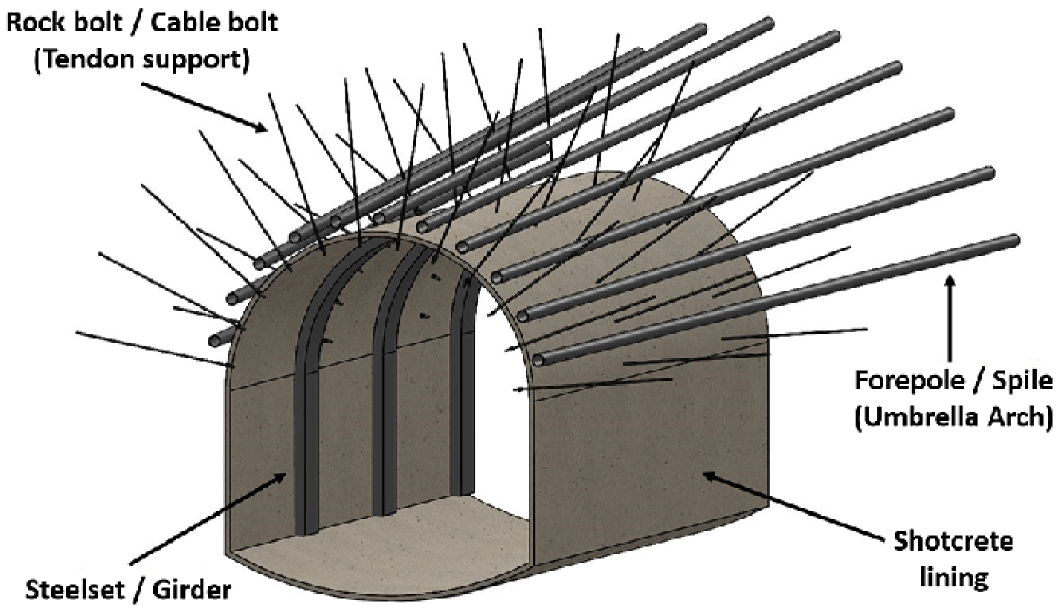

Fig. 29 Tunnel Profile with rock bolts and forepoles

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Fig.30 Rock Bolt Installation

2 boom hydraulic jumbo is again used to drill these bolts in the periphery. A staggered pattern is adopted in installing these bolts with a spacing of minimum 1 m longitudinal and 1.75 radial. Then grout is injected in rock bolts which fills all the cracks up to 3m or 4m. Grout is a mixture of cement and water. Desired quantity of water is added in grout mixture so that it can easily flow in the cracks. Bearing plates of 250*250*10 with nuts are installed after grouting. 10 hours after injecting grout torqueing is done to tighten the bearing plates and if any space is left between plate and the face then padding is done with cement sand mixture in the ratio of 1:4.

Various rock bolts of grouting and non-grouting categories are shown in figure 31,32 and 33, 34 repectively.

Fig. 31 SN Bolts

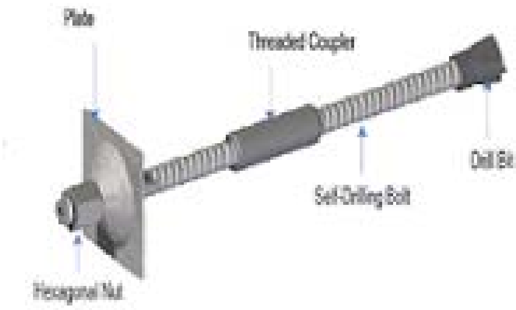

Fig. 32 Self-drilling Bolt

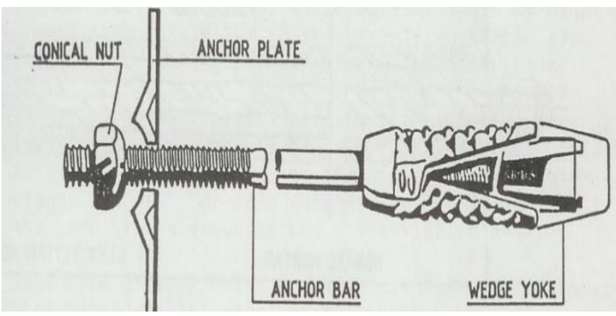

Fig. 33 Expansion Rock Bolts

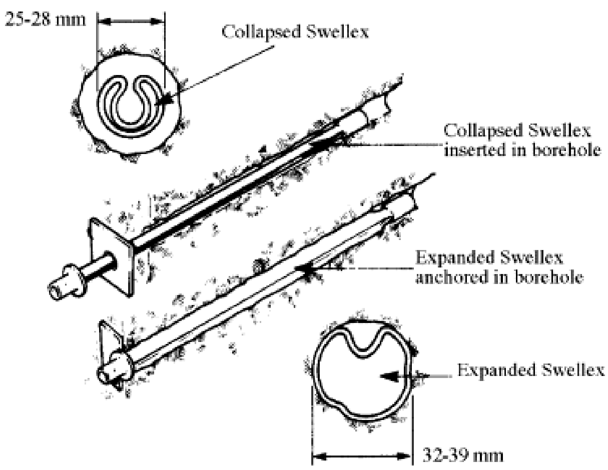

Fig. 34 Swllex Rock Bolt

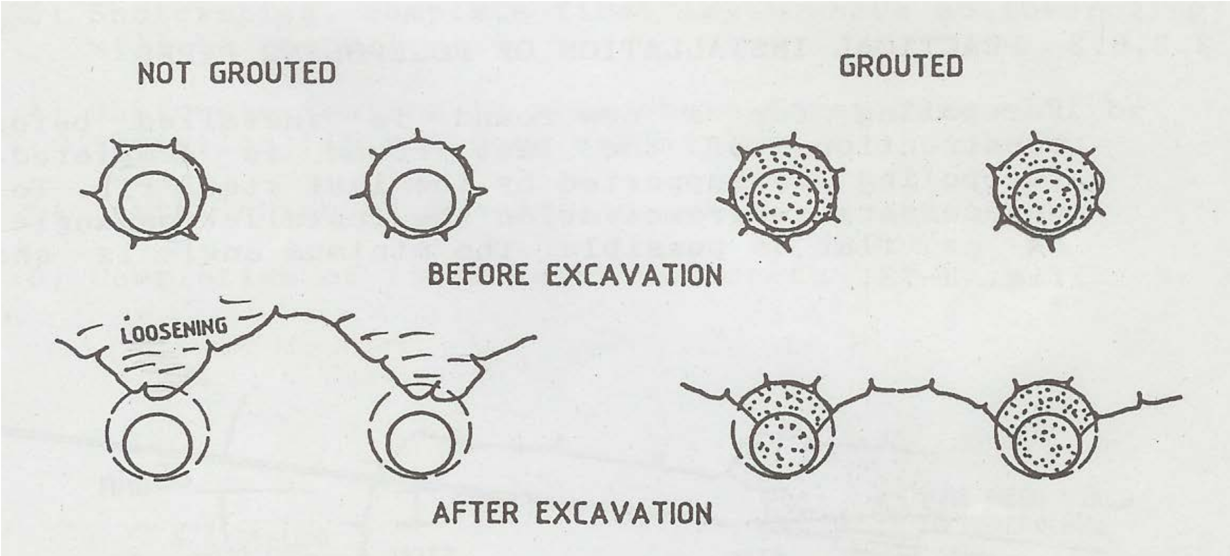

Fig. 35 Difference between not grouted and grouted forepoling installed in pre-drilled holes

CONCLUSION

NATM is based on the observational approach whole outcome depends on the Geological interpretation and 3D Monitoring data. This method provides flexibility to change the support systems at regular intervals depending on received data from face logs and 3D monitoring. A quick analysis is done and applied on the field saving time, money and material. With this approach and sequence followed better progress is achieved in a safer environment. Deformation data provided by 3D Monitoring ease outs in identifying the exact locations to be countered for additional supports thus reducing the number of mis happenings. Moreover, we can say that NATM provides better options to choose between anticipated conditions and actual conditions due to its flexible nature thus saves our time, money and material. and provides better progress in such unexpected conditions.

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