CONSTRUCTION OF TUNNEL BY CONVENTIONAL METHOD IN BHUTAN

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Abstract

All large hydropower projects in Bhutan constructed and those under construction have the components of underground excavation works. The construction of Underground Power House, Head Race Tunnels, Pressure Shaft and Tunnel Race Tunnels are constructed in complex geology of young Himalaya. The challenges in construction embroil various complexities in terms of difficult terrain, shear zones, in-situ stresses, ingression of water etc. These factors pose great risk to the lives of manpower and equipment during the course of construction processes. Such extreme geological conditions further aggravate when proper rock support measures and other equivalent technical requirements are not put in place which result in increased project cost and delay of completion time. Bhutan lies in a high level of seismicity that it is important to keep abreast with the advancement of tunnel construction technologies. The mostly common practices followed in the geological strata of Bhutan, the experiences especially gained from construction of MHEP 720MW are put in place to understand the basics of tunneling works.

1. Introduction

What is conventional tunneling? What are the other types of tunneling? Commonly there are two popular ways of excavating tunnels by Conventional Tunneling Method (CTM) and by Tunnel Boring Machine (TBM). Conventional method of tunneling is defined as the construction of underground tunnels of any shape (Circular, D-shape, Horse shoe, modified horse shoe shape etc) using cyclic processes of activities.

Tunnel boring machine is a mechanical method of excavation through very competent rock strata without having to use drill and blast method. The CTM is a drill and blast method which is the most typical method applied to a wide range of rock conditions.

Nowadays, with the intensive use of TBM around the world, it can be also termed as conventional method but the general understanding still prevails that the method of excavation by drill and blast method is termed as Conventional Tunneling Method.

2. Methodology

2.1 Excavation

Conventional tunnel can be carried out by different methods of full face, head & benching, multiple drifting etc. depending upon the suitability of section and strata of excavation.
Full face excavation is the tunnel excavation carried out in single round in entire face. (Face is the advance end of wall of a tunnel or shaft where the work is progressing).

Heading & benching is carried out in two steps – first at the crown portion and benching down to required grade and line. Blast holes are usually horizontal in heading and vertical in benching down. The multiple drifting which is usually employed in adverse geological situation, initial excavation is done with small cross-sectional area within the tunnel face. The full face is achieved widening around the pilot hole.

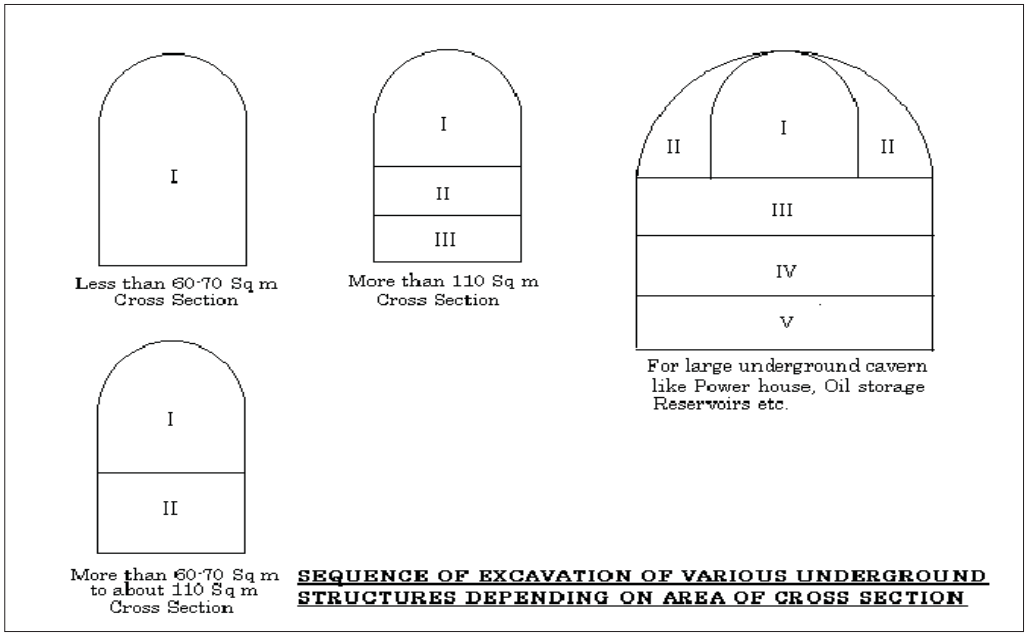

Fig-1: Full face and heading & benching

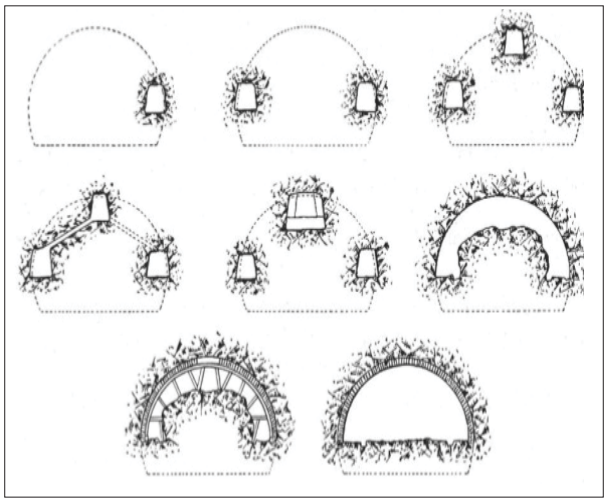

Fig-2 Multiple drifting

The sequence of activities in the excavation of tunnel follows the repeated cyclic process of following activities:

1. Profile survey
2. Drilling
3. Loading and blasting
4. Defuming
5. Hauling of excavated materials
6. Pull survey / measure
7. Rock support

The rig bores drill the holes in the face of the tunnel as per the design of drilling pattern. The drill holes are filled with explosives, detonators and attached to the explosive devices. After ensuring the safety of machineries, equipment and manpower, the blast is initiated from the safe distance. The blast causes the rocks to fly at the high speed producing lots of fumes and gases. These fumes have to be taken out forcing fresh air into the tunnel using ventilation fans and ducts. Any loose rocks after the blast have to be removed manually or using heavy equipment to achieve the profile of tunnel as per the construction drawings. The blasted materials are removed from the face of tunnel by load haul system, track or continuous loader.

The geologists and engineers examine the fresh face of rock to determine the classification of rock. The geologists map the structure of rock using geological

compass and log the properties of rock such as its dip, thickness, joints, types of rock, ingression of water etc. As per the classification of rock mass, various rock supports are installed which includes shotcreting, inserting rock bolts, installing steel ribs, lattice girders etc. concurrent with excavation. Specific and combined rock supports are installed after careful examination of geological conditions which mainly depend on the ratings of Rock Mass Classification.

2.2 Major equipment

A set of following equipment is used for the excavation and providing rock support measures.

i. Drill Jumbos
ii. Shotcrete Machine
iii. Grout Pump
iv. Scissors Lift Platform
v. Concrete Pump
vi. Loader and Dumpers

The CTM is widely used in the Himalayan region where it is tectonically active young mountains having complex and unpredictable geology. The New Austrian Tunneling Method (NATM) suits best to provide safe rock support system in the tunnel. NATM is a method where the tunnel engineers examine the characteristics of rock and provide appropriate support systems according to advancement in work progress.

Owing to the varying nature of geology, CTM with its standard set of equipment is best suited for its flexibility to construct underground tunnels. During the course of excavation, CTM allows to increase or decrease the rock support system (the number of rock bolts, the size and length), the thickness of shotcrete spray, adoption of excavation methodology, increase or decrease in length of tunnel, change in shape, variation of quantities of explosives and detonators and treating ground conditions by contact or consolidation grouting and understanding the prior geology conditions by drilling probe holes.

2.3 Literature review

Before delving into detail cyclic activities of tunnelling, it is important to understand what causes failure especially in the tunnels. The tall but young Himalaya poses many challenges to tunnel engineers from conceptualizing the project to implementation due to its complex geological conditions. Due to the continuous collision of tectonic

plates, the rock is subjected to stresses and high pressure leaving the Himalayan region vulnerable to earthquakes.

The history of Himalayas date back to about 50 million years ago when two large landmasses India and Eurasia collided creating the Himalayas. The movement still continues which build up tremendous pressure within the earth crust that occasionally relieves in the form of earthquakes.

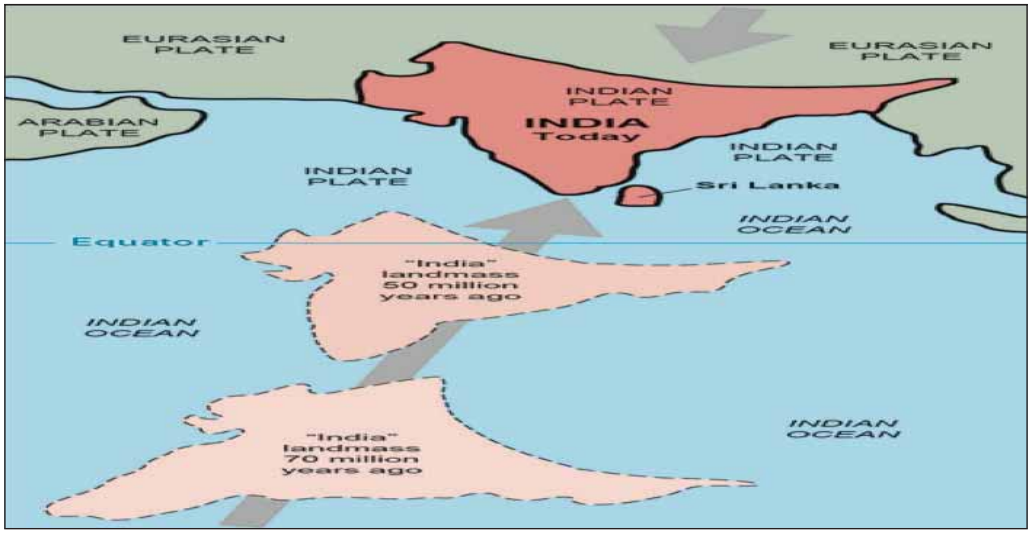

Fig. 3: Artists image (Courtesy: Sorkhabi 1999)

The four distinct litho-tectonic physiographic zones have been recognized which are separated from each other by major faults and thrusts:

(a) Siwalik Range or Outer Himalaya (Altitude ranges from 600-1500m)
(b) Lesser or Middle Himalaya (Altitude ranges from 1500-3500-4500)
(c) Greater Himalaya (Altitude 4500- 6100m)
(d) Tethys or Tibetan Himalaya (Altitude 6100-8000m and above)

Each zone has varying width with different and complex composition of rock and soil deposits.

Hydropower projects in Bhutan which are constructed mainly in underground are located in Lesser Himalaya which has multiple thrusted sedimentary and metamorphic rocks comprising plutonic and volcanic materials.

During the excavation of tunnel, the stresses of rock mass which are in the equilibrium state are disturbed and often give way to failure in the form of squeezing, swelling or flowing. The new state of equilibrium is achieved with appropriate and accurate installation of rock supports. The tunnel becomes unstable when the pressure generated under such conditions is higher than the stress of in-situ rock mass. The challenges increase when there is ingression of water.

2.4 Activities in Tunneling

Tunnel is one of the most difficult projects in construction. It is also very expensive that every activity of operation has to be carefully designed to achieve more pull or advance per round at minimum cost. The advance of tunnel per round depends on the drill and blast technique.
The sequential activities of tunnelling are explained below:

2.4.1 Drilling

Drilling pattern is designed to achieve greater efficiency in breaking rocks from the face of tunnel. The design of drilling pattern depends on the geometry & size of tunnel, types of rock, size and depth of drill holes and types of explosives used. The blast in tunnel is restricted due to availability of free face for breakage of rocks to occur unlike the blast in mines where it has more free faces. In tunnel blasting, an initial free face is created with the set of cut holes which are drilled at certain angle or the dummy holes with larger diameter drilled parallel to the cut after which the surrounding area is widened using proper series of delays.

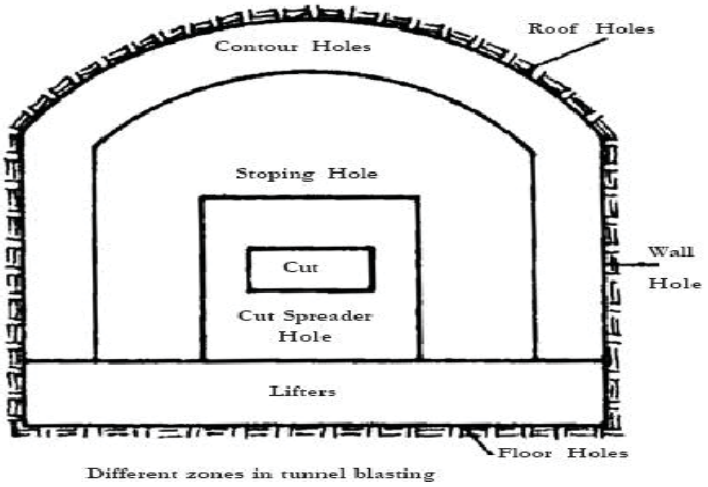

Fig-4 Cut design

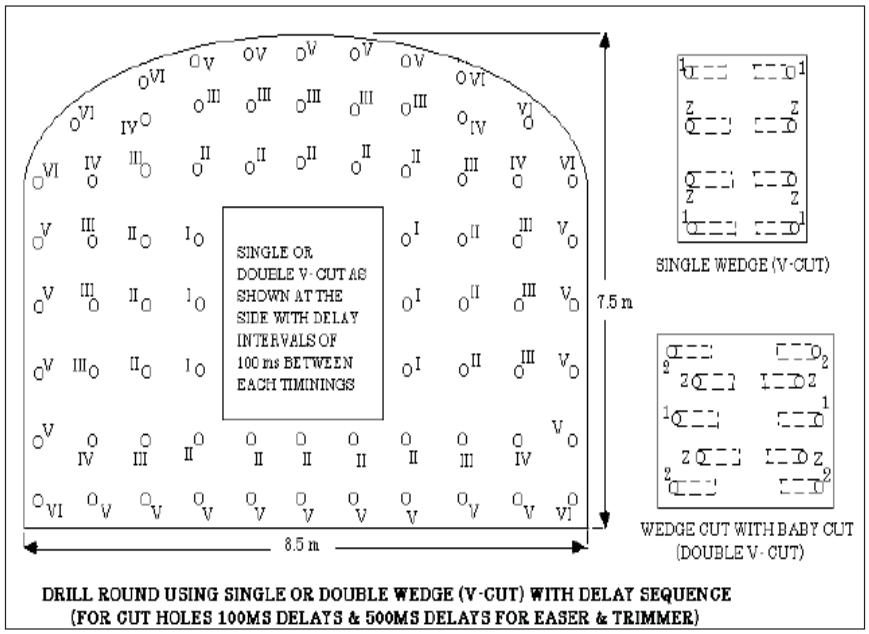

Fig-5 Blast design

Depending on the factors, various types of drilling pattern can be designed. The Burn Cut (parallel cut), Wedge Cut (V cut) are often used in the tunnel excavation.

While the short delays are used in the cut holes, appropriate long delays are used to break surrounding rock which mainly depends on the conditions of rock mass. Depending on the time to take for the rocks to crack and throw out, the combination of short and long delays is also in use. Non-electronic detonators are safe and commonly in use for the sequence delays in tunnel blasting.

2.4.2 Blasting

The quality of blast determines the pull in a round, stability of tunnel, time and cost to the overall project. A good blast ensures more advance of excavation, perfect shape and more standing time of tunnel. It saves time and cost from scaling and minimizes support system.

The tunnel engineers decide the blast design and the appropriate quantity of explosives is decided. The drill holes are charged accordingly and the fire is shot.

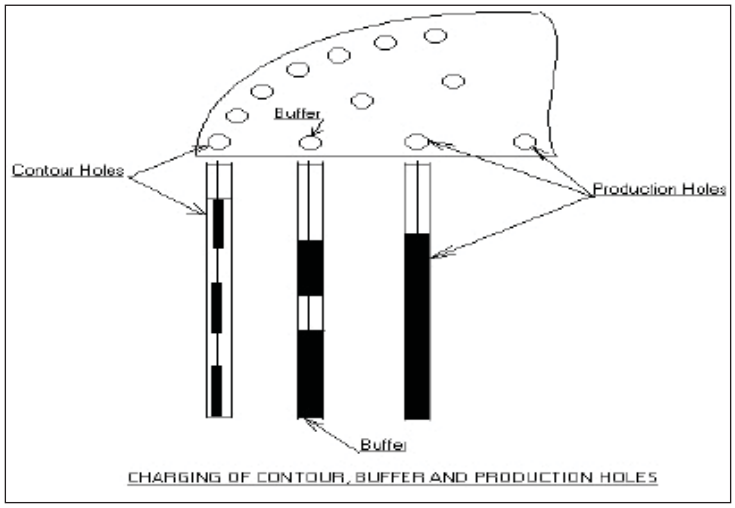

Fig. 6: Types of drill holes in tunnel

The common explosive materials used in tunnel blast in Bhutan are gelatine, NED, LED etc. The quantity of explosives used per unit of rock blasted is called as powder factor. The optimum powder factor for any surface depends upon various factors such as geology of rock, blast design and types of explosive used.

2.4.3 Ventilation (Defuming)

The tunnel construction carried out by drill and blast method produces huge quantities of obnoxious fumes, dusts and gases which affect the health of workers. After each round of blast, a huge fumes and dust covers the tunnel which is not fit for the workers to continue next course of activities. Therefore, it is essential to provide fresh air inside the tunnel using electric ventilation

system. For each worker to work safely in the tunnel, about 300-500 cft per worker of air has to be continuously supplied. There are various types of ventilation system which depend on the length of tunnel, size of tunnel, powder factor of explosives, humidity and temperature, gases produced from the ground, types and number of diesel operated machines.

Table 1: Density of Dust Emitted due to Tunneling Works

Tunneling Works	The Density of Dust Formed in mg/m3
Excavation	10 -1000
Loading of materials that are excavated	10 – 1000
Mucking	10 – 100
Drilling	1--50

Table 2: Allowable density of poisonous gases

Gas	Allowable density (ppm)
CO	100
NO	25

The ventilation system in the tunnel follows the principle of blowing fresh air from outside to tunnel face, taking out foul air from inside to outside using electric operated axial flow pressure fans. To blow fresh air inside, a flexible fabric pipe is used but it is necessary to use rigid duct that does not collapse if air is exhausted. In smaller size tunnels, the blowing in air is commonly in use. Depending upon the length and size of tunnel, quantity of explosives and fumes generated, the size of motor is installed to provide adequate fresh air.

2.4.4 Mucking

The process of taking out the loosened rocks from the face of tunnel after its blast is called mucking. The mucking is carried out using different mechanisms and equipment. Load and dump is commonly used in Bhutan. The conveyor and locomotive systems of mucking can also be carried out depending up the size and length of tunnel.

The ventilation is put on after 15 minutes of blast to take out the fumes only after which the mucking of blasted rock is initiated using loaders and dumpers. In some cases, the track is used for mucking. Nowadays, the use of continuous loader is gaining its popularity. The continuous loader scraps the blasted rocks and dumps onto the dumper through its conveyor belt. The various methods of mucking methods are depicted in the subsequent pictures.

Load and haul

Track system

Continuous loader

2.5 Tunnel Support System

The general approach to the tunnel designs are site investigations, in-situ monitoring and the analysis of stresses and deformations. The Finite Element Method is used to determine the loads, deformations and induced stresses developed around tunnel excavation. The design procedure for tunnel depends on the geology and ground situations of site, methods of excavation and support system used. Since each site conditions differ from each other, it is important to consider the numerical analysis of the response of tunnelling sequence along with the experiences of tunnel engineers. Design of support system is important in tunnelling. Under-design of support systems can be fatal while overdesign can be costly. The stresses which are in equilibrium state are disturbed in each blast and the tunnel undergoes deformation.

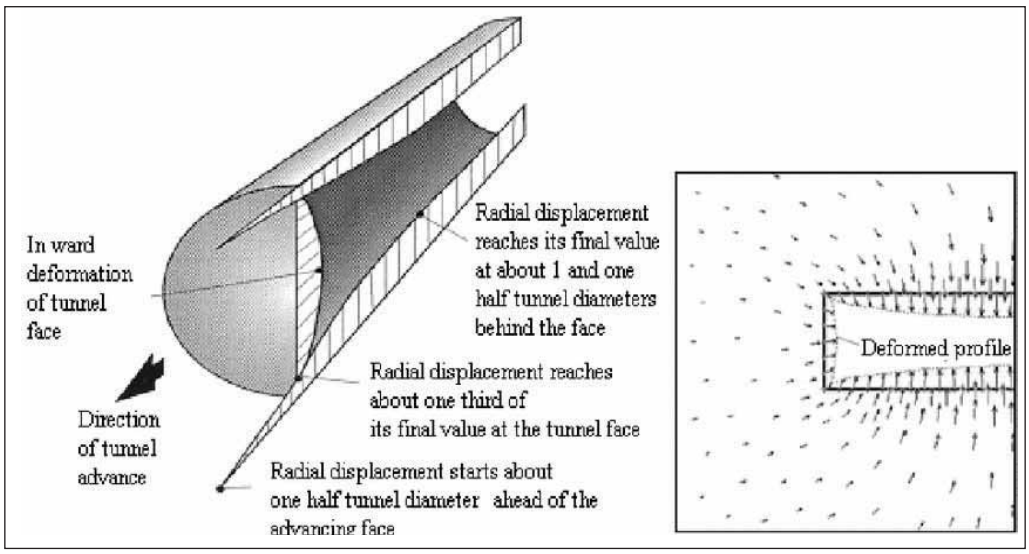

Fig. 7 : Pattern of deformation in the rockmass surrounding an advancing tunnel (source: Evert Hoek, Consulting Engineer, 3034 Edgemont Boulevard, North Vancover, British Columbia, Canada, V7R 4X1

The design of support for tunnels in weak rock is complex and challenging. In some cases the apparently logical approach of installing more and heavier support to resist the squeezing pressures is, in fact, the wrong approach. Flexible support systems, with the use of fore pole umbrellas or of yielding elements where required, will usually result in a support system that is both effective and economical. It has not been possible to explore all of the options available to the weak rock tunnel designer. Many of the concepts of design have not been fully developed and, in some cases, better alternatives can be developed. There are ample opportunities, for those interested in rock engineering research, to carry these ideas further and to develop a logical methodology for tunnel support design.

To stabilize the tunnel, the supports measures such as Rock Bolts, Anchors, Shotcrete, forepoling, Pipe Roofing etc are installed. The concepts of some of these rock support measures are explained below in the following paragraphs.

Shotcrete is a concrete which is sprayed with high velocity through a conduit on to the walls of freshly blasted surface of tunnel to achieve high strength and low permeability. In tunnel excavation, the spray of shotcrete arrests the stress built from opening and stabilized the surrounding rock mass.

The standing time of tunnel depends with the in-situ strength of rock. It is important to secure the roof (crown) of face. Depending on conditions of rock, appropriate rock support measures should be installed within the standing time.

The New Austrian Tunneling Method follows the installation of rock bolt, forepole, pipe roofing, grout and shotcrete. Under the flowing conditions, consolidated grouting, pipe roofing and forepoling are the measures put in place.

Rock bolt consists of reinforcement rod which is a mechanical/cement grouted/ resin end anchorage and a plate and nut on the threaded end. It is a stressed or post tensioned reinforcing element to be stressed immediately after installation by torquing or jacking by means of an approved calibrated stressing device. Rock bolts shall be fully grouted or un-grouted. Rock bolt is an active rock support.

The following types of rock bolts are frequently in use according to the ground conditions:

1. **Resin/cement grouted rock bolts**

   Rock bolts of yield strength not less than Fe500 grade are recommended for use. A resin package which is easily ruptured is inserted into the drill hole. A

bolt is inserted and a rotary tool is then coupled to the free end of the bolt which breaks the package whereby the resin is mixed. The bolt is anchored after the resin is fully cured. The remaining length of the bolt is grouted with Portland cement mixed with sand at the ratio of 1:1.

2. Water expandable friction anchor

Water expandable friction anchors are installed as the temporary support at the location where strata is poor and it is not possible to provide other types of rock support within a reasonable time.

These friction anchors come in a folded form to be inserted into the hole with the injection of high water pressure which inflates the folded tube into intimate contact with the borehole.

3. Self drilling hollow core anchor

Self drilling hollow core anchors are fully threaded steel bar which can be drilled and grouted without the use of a casing. The bars have a hollow bore for flushing or simultaneously drilling and grouting.

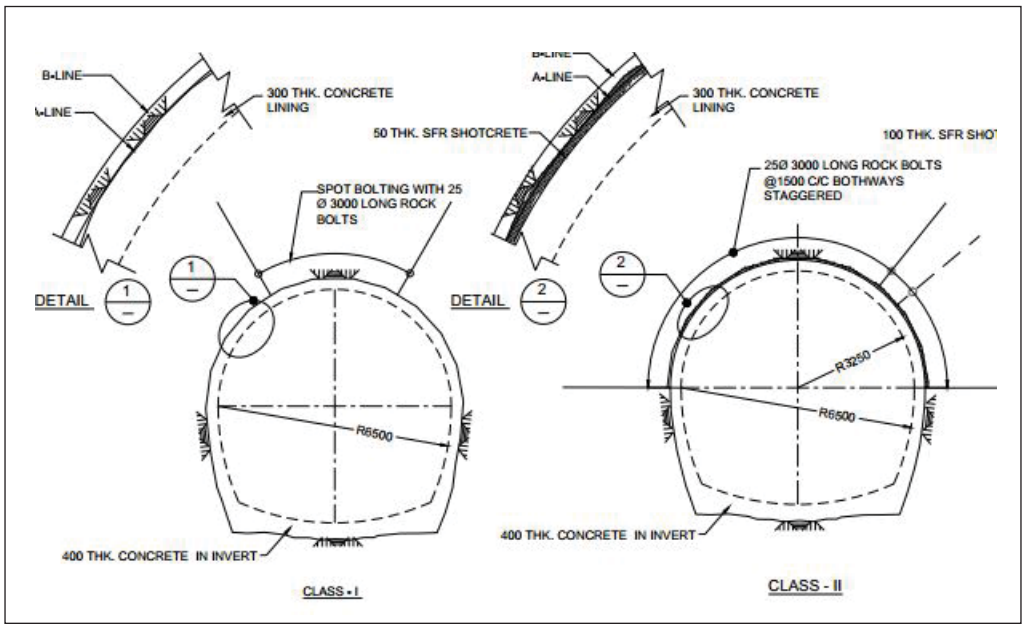

Fig. 7: Rockbolt, shotcrete in tunnel

Rock anchor is an un-tensioned reinforcing element consisting of a rod embedded in a cement mortar filled hole. The rock anchor shall have a plate and a nut. Extension pieces may need to be provided on rock anchors for anchorage of concrete structures. The rock anchor is synonymous with passive rock anchor.

The following types of rock anchors are in use depending on the ground conditions:

(i) Grouted Anchor Bar

Grouted anchor is a reinforcing element consisting of a reinforcing bar embedded in a cement mortar-filled hole. It shall extend into structural concrete to provide anchorage of concrete structures.

(ii) **Pipe Roofing**

Pipe roofing consists of high tensile seamless pipe casing driven into the medium using symmetric drilling system. The pipes are spaced at 300mm to 500mm center to center along the periphery of the tunnel at inclined 5 degrees outward from periphery.

5. Conclusion

Tunneling or any underground components in Himalaya and especially in Bhutan are extremely difficult that it is important to plan the project properly. Adequate investigations need to be carried out and the excavation done with right methodology. Much of the tunneling works can be made smoother using right equipment, fielding experienced manpower and installing appropriate rock support system.

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Author's Profile

Prior to his current post in Construction Development Corporation Limited, Mr. Ugyen Gyeltshen worked as the Executive Engineer, overseeing the construction of twin 1.6km stepped (vertical and horizontal limbs) Pressure Shaft in Underground Power House Complex, 720MW Mangdechhu Hydroelectric Project Authority. He has served in various organizations before he resigned from the Civil Service in 2013. Mr. Gyeltshen hails from Khaling. He has a Bachelor of Engineering (Civil) from Visveswariah Technological University.