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A Case Study of Cavity Formation and its Rectification Works in Small Sized Tunnels with Excessive Water Inflow

Asim Timasina[a*], Nischal Dhakal[b], Ujjan Paudel[c]

[a]*Geologist, Tri – Chandra Multiple Campus, Tribhuvan University, Ghantaghar, Kathmandu, 66400, Nepal*
[b]*Civil Engineer, Khowpa College of Engineering, Tribhuvan University, Libali ,Bhaktapur, 44800, Nepal*
[c]*Civil Engineer, Kantipur Engineering College,Tribhuvan University, Dhapakhel, 44703, Nepal*
[a]*Email: asimt098@gmail.com,* [b]*Email: nickdash09@gmail.com,* [c]*Email: paudelujjan2015@gmail.com*

Abstract

Tunneling in Himalayan geological conditions can always present difficulties in underground excavations due to presence of active tectonic divisions, fault, thrust, complex geomorphology and ground water inflow. These factors can be pre-determined through various methods of geological investigations such as detailed Geological Survey, bore hole logging, ERT survey, Seismic survey, etc. and can be constructive in tunnel alignments design. As such investigations are rarely done in case of hydropower projects in Nepal, encounter of weak geological conditions and subsequent cavity formation is common. The particular case of penstock tunnel of MMKJA (14.3 MW) includes similar weak geological conditions, presence of clay bands, open joints and cavity zone formation due to high water ingress. This paper establishes a particular model and methodology for advancement in small sized cavity related tunnels with high water ingress. The model consists of Rib erections, forepolling, Shotcrete / Shotcrete backfill and channelization of water inflow. The model purposed in this paper can be helpful for advancement in similar conditions encountered elsewhere.

Keywords: Cavity; Shotcrete; Sandstone; Phyllite; Fore poling.

1. Introduction

Small sized tunnel for the purpose of this paper refers to the tunnel size ranging from 2*2(D- shaped tunnel) up to size of 3*3(D shaped tunnel). These types of tunnels are mainly used in hydropower projects as Adit tunnels to main HRT tunnels, also purpose as penstock tunnels, smaller flushing tunnels for underground desander, diversion tunnels, outlet tunnels for underground desander, pathways to several underground structures, etc.

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* Corresponding author.

Tunneling is basically done for hydropower projects in Nepal. The concept of large tunnel and mechanization to obtain progress is seldom thought of the Clients/investors and similar kind of ideology is ingrained among consultants and designers. Observing several hydropower projects, the tunnel size varies from 2.5m (dia) to 3.5m (dia) inverted D-shaped tunnel. Multiple numbers of cliets are targeting the construction of small sized tunnel with the advancement of smaller sized machinery mainly imported from China and India in Nepal. While it is easier to advance in small tunnels for smaller length, with the increment in length, several problems with regards to ventilation, wear and tear to the mucking vehicles are common and the constructability get worsen, the clients are still moving for the smaller sized tunnels to save funds. Also progressing in small sized tunnel will always be a challenging in the weak geological condition, geomorphological condition along with ground as well as surface water conditions.

The physiographic conditions as well as geological conditions of Nepal Himalaya shows more prospect of tunnel engineering rather than existing classical methods of engineering infrastructural development of road, hydropower, irrigations, mining, motorways, railways etc. However, constructing underground tunnels in complex geological areas are more challenging as we can find many examples of serious collapsing of underground tunnels because of the rock properties and various factors of geological conditions. For example, the Fujiachong tunnel in Yi (chang) –Ba (dong) express way in China had collapsed due to the presence of surrounding soft rock of shale and conglomerate which possess open joints, weathered rock with presence of ground water inflow [6]. Summing the facts, we can find many other examples of the tunnel construction history throughout the world; the Zhegushan and Laodongshan tunnels in China, tunnel 35 of the Ankara- Istanbul high-speed railway project in Turkey, Head race tunnel at Kaligandaki A hydroelectric project, Adit 2 of Khimti Head Race Tunnel and Modi project in Nepal [3].

The presence of uncertainties in rock mass properties has always been a trailblazing task in supporting a tunnel design for squeezing and collapsing situations. Various methods of tunnel support designs have been established by numbers of researchers throughout the history and the research is still on. Basically, three methods are carried out for the achievements as they are empirical methods, analytical methods and numerical methods which are considered as the most scientific and effective way. There are many literatures regarding the support structures of tunnel. The tunnel of the studied area follows the Norwegian Q value methodology [7] for the support design of the tunnel.

In this paper geological settings and conditions of the study area along with the formation of cavity zone and its rectification works are present. Tunnels of the studied area reported maximum numbers of small- and large-scale multiple as well as single clay bands along with high discharge of water ingress. Regarding this the main purpose of the paper is to establish advancing methods applying strong support system for tunnel collapsing through the afore-mentioned complexities.

2. Location of the Study Area

The studied area is located in the North West part of Rasuwa district, Uttargaya Gaupalika, ward no. 1, Rahare village upstream to Mailung Dovan (figure: 1). The studied area is the part of the MMKJA 14.3 MW

Hydroelectric Projects tunnel.

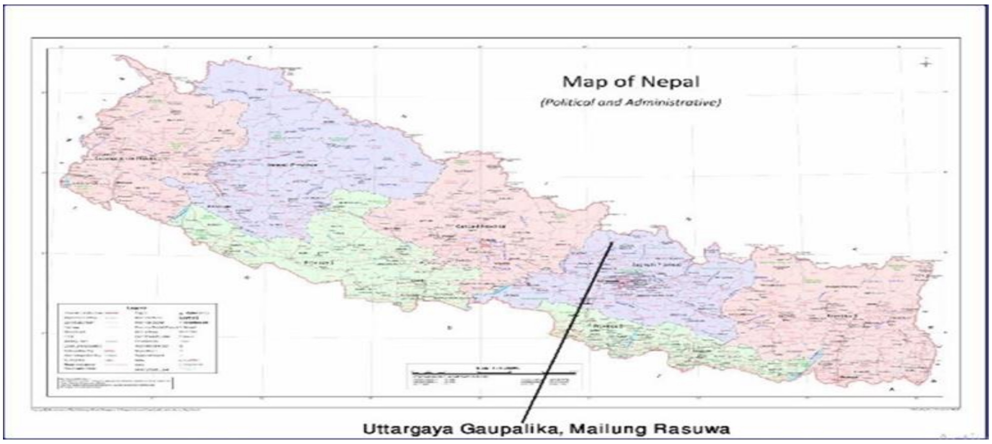

Figure 1: Location of the studied area.

3. Geological Settings

The study area lies in the Nawakot complex rocks of lesser Himalayan regions. The lesser Himalayan rocks of Bagmati – Gosaikunda region (figure: 2) comprises a wide portion of Midland Antiform in the inner zone between Nuwakot and Dhunche, they also form an open fold representing the Great Mahabharat synform [1]. The rocks of central Nepal are divided into the Nawakot Complex and overlying Kathmandu Complex belonging to the Himalayan Crystallines and Tibetan Tethys Himalayan sequence [5]. The Nawakot Complex rocks represents a sedimentary to low grade metamorphic rocks which comprise phyllites, metasandstones, quartzites, slates, shales, and carbonate rocks [5]. The Nawakot complex rocks are further divided into Lower Nawakot group and Upper Nawakot group. The lower Nawakot group rocks are the oldest rock sequence in the lesser Himalayan regions [4, 5]. The study of tunnel lies in the Kunchha formation of lower Nawakot group of Nawakot Complex rocks which comprises of phyllites, phyllitic quartzites, and phyllitic gritstones, grey wacke [5].

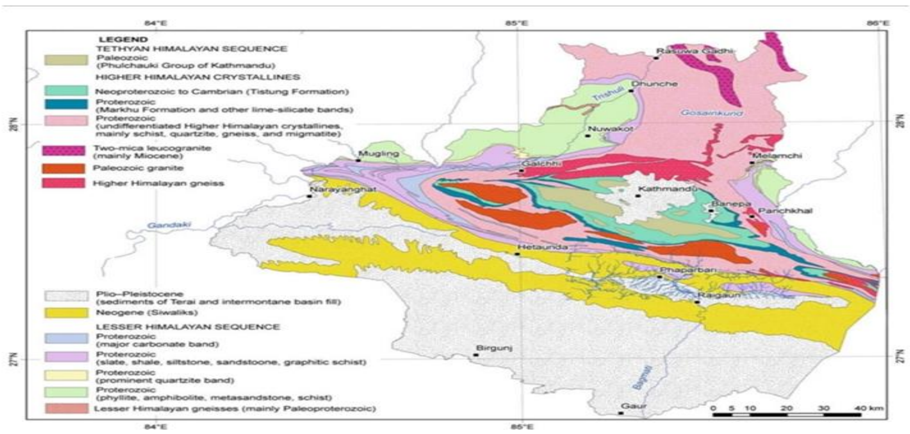

Figure 2: Geological map of Bagmati – Gosaikunda region Based on Stocklin and Bhattari (1977), Stocklin and his colleagues (1982), Shrestha and his colleagues (1986)

4. Description of the Study Area Based on Lithostratigraphy, Geomorphology and Drainage System

The study area lies in the older rocks sequence of lesser Himalayan zones known as Kunchha formation. The kunchha formation rocks in these areas are phyllites and Meta-sandstones intercalated with each other. The phyllite is soft rock which has high possibility of weathering; thus the geomorphology of the study area is very steep, large opening apertures of joints, voids and prone to numerous landslides during monsoon seasons. The main drainage systems of the study area are Mailung Khola which flows directly from the Himalayas (Ganesh Himal) following the Higher Himalaya with its minor other tributaries and three minor rivulets that flow from the steeper slope which crosses the path at ground surface of tunnel alignment. Ground water in this area is recharged mainly through precipitation and surface water infiltration.

5. Engineering Geological Properties and Tunnel Problems Faced in the Studied Area

5.1 An overview of the tunnel system in the studied area

The Head Race Tunnel (HRT) of 2.8*2.8 dimensions has the total length of 1735m and vertical clearance of 337m from the highest elevation followed by the 46.64m length (including transition) Forebay section. The forebay section is again followed by 2.5*2.5 dimension penstock tunnels: Horizontal Tunnel (HT-01) 151m, Vertical Tunnel (VS01) 225m, Horizontal Tunnel (HT 02) 298.89m, vertical tunnel (VS02) 190m and Horizontal Tunnel (HT-03) 228m (figure: 3 , 4).

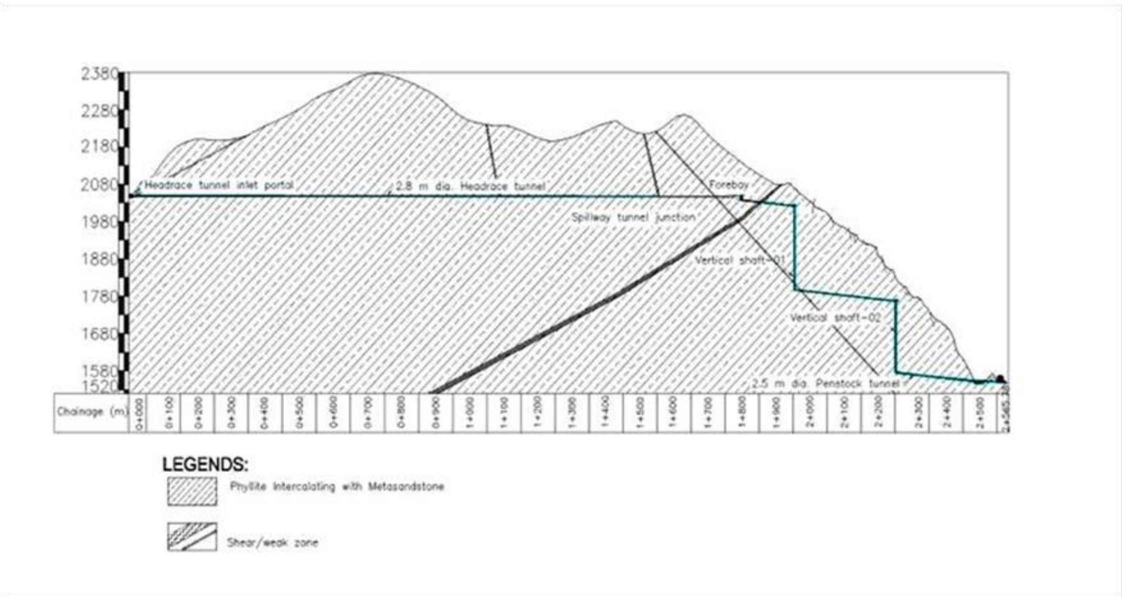

Figure 3: Overall Tunnels of MMKJA 14.3 MW

The overall tunnel consists of Forebay section vented through Spillway Tunnel and one Adit Tunnel at HT02. The overall tunnel passes through the steep geomorphological terrain with presence of big open joints, weathered and fractured rocks, thin to medium as well as thick clay bands and three minor gulleys that meet the mailung khola at bottom.

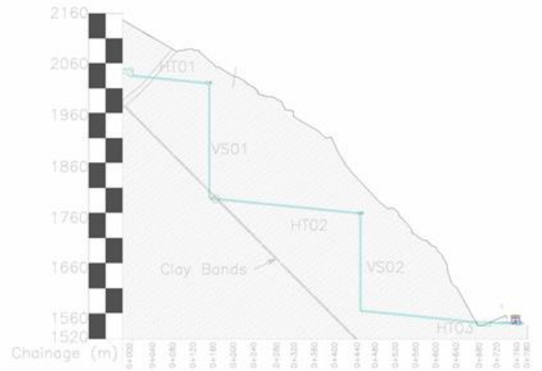

Figure 4: Formation of cavity at HT 02 tunnel.

The bed rock is Proterozoic phyllites, schist and Meta sandstones [1] having 30-60 dip angle facing Northwest direction. The tunnel passes through the jointed area J1, J2 and J3 and the spacing of joints are 20-30cm, 20 - 35cm and 20-30cm respectively (table: 1). The shear joints are prolonging far and wide which are filled with silty clay minerals. Surface waters serve this areas recharge with precipitations, small's gulley, springs and bed fissure on rocks.

Table 1: Engineering properties of Mailung Khola area.

	Dippings	Spacings	Infilling Materials
Foliation (J1)	30-60	20-30cm	silty clay
Joints (J2)	50-70	20cm -35cm	silty clay
Joints (J3)	50-80	20 to 30 cm	silty clay

5.2 An outbreak of cavity formation

As previously mentioned, the tunnel is mainly constructed in weak geological area which posse's clay bands, open joints and high-water Ingress causing various affects in tunneling. The multiple clay bands present in HT02 Penstock tunnel @0+ 173.78m (figure: 4, 5) has the dipping of 45 against the tunnel alignments facing 140 south east (table: 2). The clay band was intersected with the open joints of 80cm aperture with the attitude of 181/85 (figure: 6). The 2.5m dia penstock tunnel has grade of 1:10, and during the excavation the clay bands of 5 to 30cm thick consisting thick fine clay out washed along with the intersected joint infillings materials due to water discharge of total approx. 15ltr/sec (figure: 6) from the face which loosened the heavily disintegrated rocks from the right wall, crown and from the left wall as well resulting in the formation of open cavern at the crown (figure: 7). The opening of crown along the direction of clay bands upward is 5-8m. The loose material has been released since the clay bands started to move from SPL level towards crown from the chainage 0+1730.78 to 0+170.98 reaching its maximum hanging position above crown up to chainage: 0+167.78m releasing loose materials forming cavern at the two corner of the crown (figure :7)

Table 2: Engineering Properties of cavity area**.**

	Attitude	Aperture	Spacing's	Infilling Materials
Foliation (J1)	330/32	0.5mm	10cm-15cm	silty clay
Joints (J2)	204/61	1-2cm	5cm -10cm	silty clay
Joints (J3)	145/71	1-2cm	5cm to 30 cm	silty clay
Open joints	185/81	80cm	-	Clay/ crushed rock
Clay bands	140/45	30cm	-	Clay

Figure 5: Picture showing Multiple clay bands

Figure 6: Presence of water inflow from the face

5. Support System

The support system is key elements in the progressive tunnel excavation for the strength and the durability of the tunnels. The geological report is the main leading factors for the support system design while excavating the tunnels through very weak geological conditions as this would address the best method for a cost-efficient support design.

6.1 Support system based on Norwegian Q value methodology and NMT

The studied tunnel, in fact overall tunnels of the project follows the Norwegian Q value [7] method for the support type and determination of rock quality. The Q value defines the rock mass stability of underground excavation of jointed rock masses.

Figure 7: Formation of open cavern.

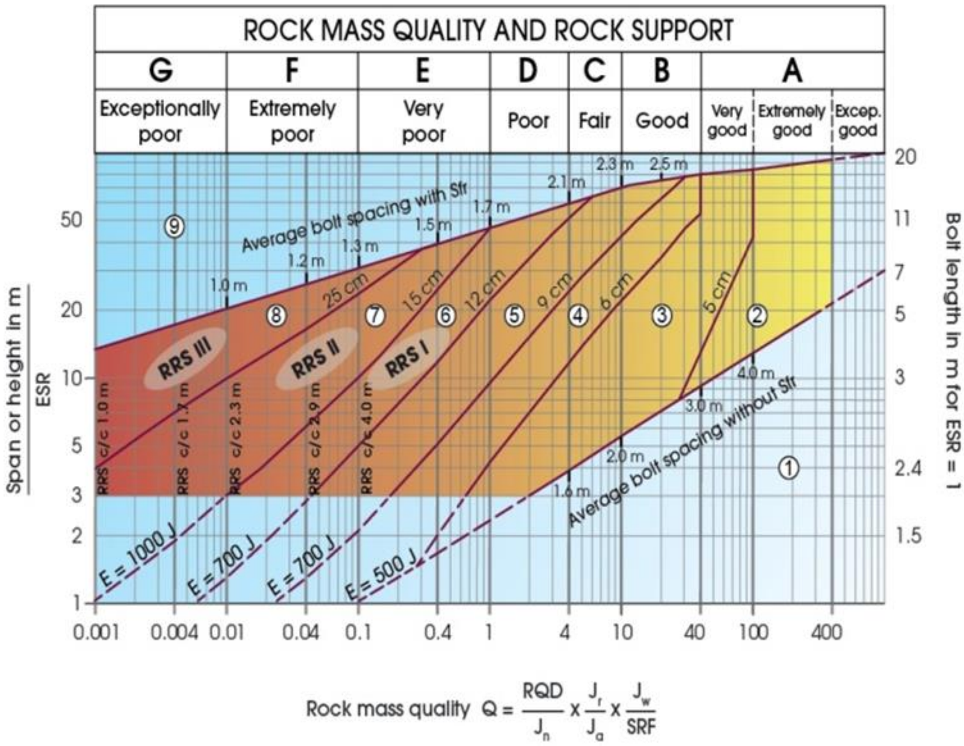

Figure 8: The Barton and his colleagues 1974 Q-based support chart [8].

The Q value is determined using six parameters as:

Q = RQD/Jn*Jr/Ja*Jw/SRF

RQD = Rock Quality Designation

Jn = Joint set numbers

Jr = Joint roughness

Ja = Joint alteration Numbers

Jw = Joint water reduction factors

SRF = Stress Reduction Factor

The support system for the cavity formation zone of the small sized penstock tunnel HT02 of studied area follows the Norwegian methods of tunneling (NMT).

6.2 Methods used for the support of cavity at the studied site

The engineering practice has already shown the rock mass in grade V support class (figure: 8, 9). Following the NMT, the support started after removing the cavity muck followed by the installation of Rib sets, anchor bolts, spilling, shotcrete and drain holes (figure: 10). Since grouting is rarely an option for the rectification works in high water ingress areas, chemical grouting and water freezing using liquid nitrogen is done which is very costly to the low Budgets projects in Nepal.

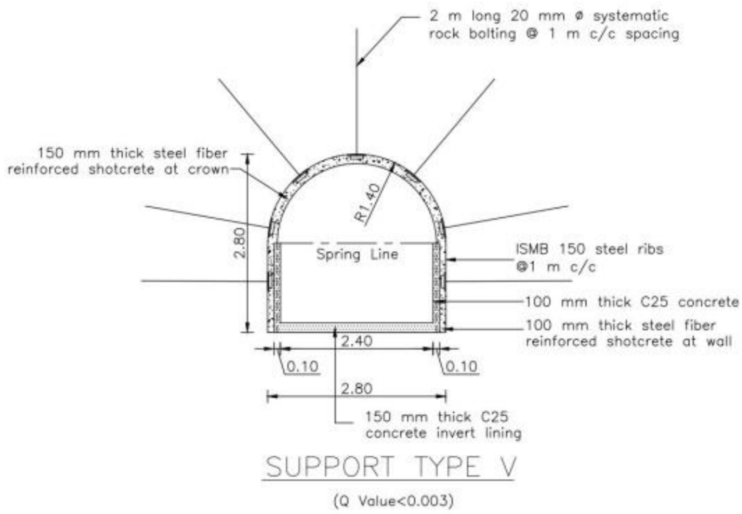

Figure 9: Rock support based on support class V.

The studied area cavity supports begin with the clearance of the dropped muck & loose materials. The ISMB 150*75*75 Rib set of 2.8*2.8 is used along with the tie rod of 25mm dia at the crown and 20mmdia below SPL line. Since the cavity is formed perpendicular to the crown and over-break of certain areas at the left side, the dry-stone packing of one layer of 0.25m at the crown is done to reduce the load. The crown is supported by further installation of umbrella fore poling (figure: 14) of 3m long 25mm dia rod. C30 plain shotcrete is used in the rib parameters and C12/15 back filling is done above crown followed by the installation of 110mm dia HDPE pipe as a drain hole and shotcrete backfilling hole (figure: 10).The mix design ratio for the shotcrete and backfill is given in table 3. Pre-grouting is almost impossible in cavity section following high water ingress whereas post grouting can be done to solidify the disintegrated rock mass above the Rib set.

The detailed approach of cavity protection methods (figure: 10) used is:

- Mucking is done to clear the debris in front of the face.
- The ISMB Rib set of bigger size 2.8*2.8 (figure: 11) dimension at 1 m spacing is used instead of 2.5*2.5 rib of penstock tunnel.
- Rib supports done using 25mm dia tie rod at the crown and 20mm dia below SPL line.
- Wire mesh is used in the whole perimeter section of rib (figure: 12)

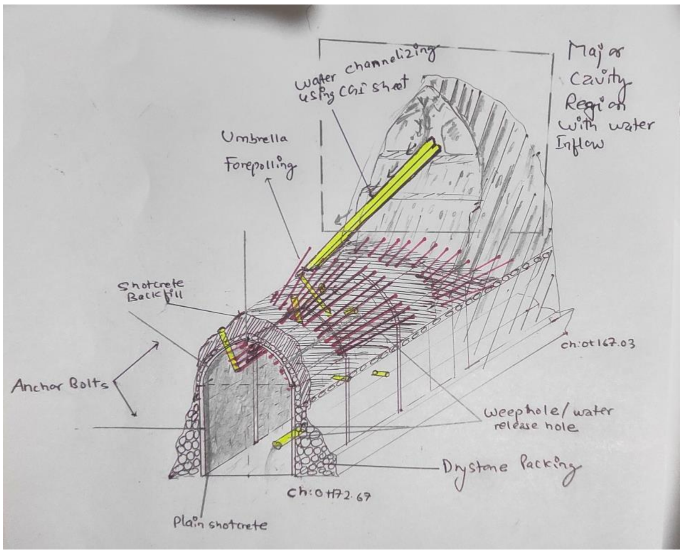

Figure 10: Sketch showing detailed approach of cavity protection method.

- Dry stone packing is done at the both sides of ribs up to SPL level and one layer up to 0.25m thickness dry stone packing is done over the crown to minimize the load.
- Plain C30 shotcrete is done at the ribs perimeter and C12/15 backfill is done between the voids and the rock surface above the crown (figure: 13, table: 3).

Figure 11: Full support of tunnel after rectification works. **Figure 12:** Photo showing wire mesh used above Rib set.

- While advancing through the main cavity area just after the installation of RIB's, CGI sheet of 4m long is used in inclined position i.e. one face attached to the water seepage area and other just above the shotcrete backfill area along with the 110mm dia HDPE pipe for water release holes (figure: 10,13).
- While advancing, umbrella forepoling of 3m long 25mm dia is used as per site conditions (figure: 14).
- Anchor bolts of 2m long 20mm dia. 7-pattern is used in every rib installed.

Table 3: Mix Design Used for Protection Works.

Grade of Shotcrete	Cement(kg)	Sand(kg)	Aggregate (kg)	Micro silica(kg)	Accelerator(kg)	Water(lit)
C12/15 Backfill	300	1279	552(20mm)	-	-	180
C30 Plain Shotcrete	450	1221	527(10mm)	225	5.40	206

Figure 13: Photo Showing C30 Plain Shotcrete and HDPE water release pipes

Figure 14: Photo showing Umbrella for poles

6. Discussion And Conclusion

Ascribing the above case study, forward progression in small tunnel with cavity is possible by following a specific model as presented in this paper. In small sized tunnel, there might be a greater problem due to its lack of space for mobility of tunnel personnel's and high-water flow; but with procedural protection, high water flow area can be navigated with safety of tunnel personnel. The safety for working can be insured with proper channelization of the inflow as well as post grouting (when the inflow is low) to solidify shotcrete backfilling above the rib. Similar condition encountered in tunnel can be progressed using the same procedure up to a tunnel size 3*3m. Aforementioned methods is limited within the parameters of geological conditions, water discharge level and tunnel size. For larger tunnel, several modifications to the procedure will be needed whereas for large scale cavity and void chemical grouting is done. Also for the water inflow treatments, water freezing methods may be used depending on the financial budget of the client / investors.

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