Geological investigation on the causes of collapse of irrigation tunnel. -a case study from Hulikere, Mandya district, Karnataka

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Abstract

Hulikere tunnel, which is in Pandavapura taluk of Mandya district, Karnataka, is the oldest 2.8 Km [3.9X3.66m (HXW)] irrigation tunnel conveying potable water to four taluks.The basement rock of this region is granitic gneisses. Dolerite and pegmatite dykes have been intruded at many places into this basement rock. Structurally 1-3 sets of joints are found all along the axis of the tunnel. They are cross cutting either N-S or NW-SE directions. Innumerable fractures are also seen in gneisses and schistose rocks. Collapse of some portion of this tunnel (at Ch 2060m) was occurred during March 2012, due to deteriorating effects of rock pressure and water seepage. The crown portion of the tunnel was collapsed along with over burden, and also the masonry lining constructed earlier with surki mortar was also damaged and collapsed, thereby the vent of the tunnel was completely blocked with the fallen muck and masonry.

The rock in collapsed zone consists of garnet-biotite schist, amphibolite, chlorite schist, pegmatite and basement gneiss, which are highly jointed and weathered. These rocks particularly are highly sheared because of overburden and intense weathering at crown portion. The collapse is due to interaction of water with schistose rocks leading to the formation of hydrous/anhydrous/clay minerals which are susceptible for slow settlement. This report gives the geological consequences for the collapse of this irrigation tunnel.

1. Introduction:

Tunnel is an underground route or passage rather shortest route drilled for some specific purposes. They are the underground structures and key elements of nation's infrastructures used for urban transportation, water, sewerage, oil and gas transportation as well as in hydroelectric power. Old and historical irrigation tunnels were generally constructed through dry and sound rock conditions with or without any lining except where the rock was incompetent to carry the loads. However, due to local ground movement or settlement over tunnel and surface or groundwater infiltration through joints and cracks there is a possibility of deterioration of rocks and various tunnel elements.

The influence of water penetration on rock, soil mass and tunnel elements are critical especially in the cases where tunnel is located above the water table. However, because of longer usage, due interaction of water with the rocks the crown portion of the tunnel becomes unstable causing the collapse. There are innumerable cases on collapse of tunnel due to ground settlement, weathering of rocks, change in geological formation and poor maintenance (1-8). In fact, continuous water seepage into tunnels leads to reduction of rock mass stability around the tunnel and increase pressure on temporary and permanent supporting systems. (6, 9, 10). ITA working group (11)on tunneling reported damage caused by water on rock, soil, building materials and structures and discussed suitable consideration in designing and construction for 48 case histories of tunnels, submitted by 12 countries.

Hulikere tunnel, which is in Pandavapura taluk of Mandya district, is the oldest irrigation tunnel in Karnataka, conveying potable water to four taluks of this district collapsed during March 2012. This paper gives the preliminary geological investigationson the collapse of this tunnel and recommendation for regular maintenance which is very much required at an early stage for the remaining weak portion of the tunnel to avoid any further unexpected cave-in situation.

2. Location and description of study area:

Mandya district lies between North latitude 12^{o}13’-13^{o}04’ and Eastlongitudes 76^{o}19’-77^{o}20’ falling in SOI degree sheet 57H and57D. The study area is located in Hulikere village of Pandavapura taluk, Mandya district, which is 20 Km NW from Mandya town.

The Tunnel is located in an elevated region of the entire route of Vishweshwaraiah Canal. The surface topography is in the form of undulating plain situated at an average elevation of 720 m above MSL. There are few sporadic out crops of rocks as small hills and few shallow valleys. The runoff is towards the low gradient topographic depressions forming ponded water at some spots near to the route / axis of the tunnel.The near surface soil is brown and red colored sandy soil, with disintegrated rock material consisting of embedded decomposed gravel and cobbles. In all most all the tunnel area, the soil is dry except in irrigated land. Fig.1 shows the location map of the study area.

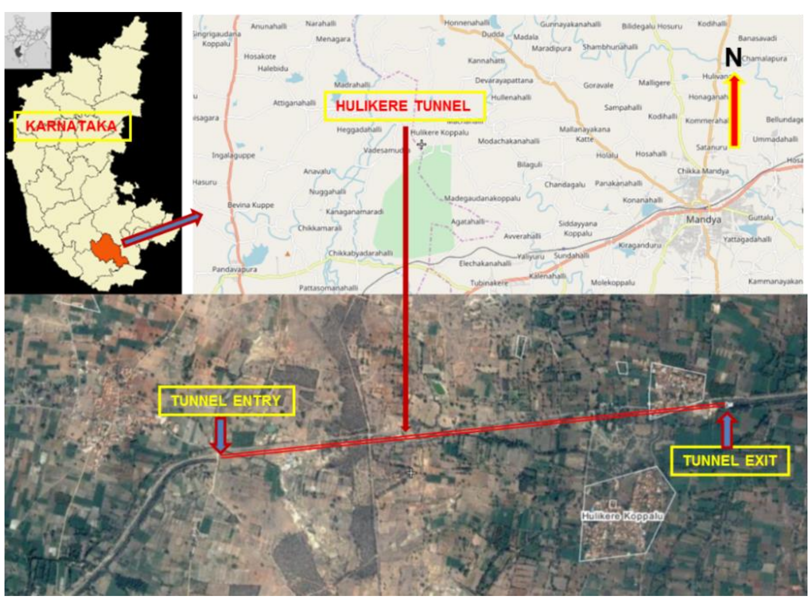

Figure 1 Location map of study area

3. Geology of the area:

The major rock types of this area is granite belong to Archaean era. They have been subjected to deformation and have undergone metamorphism forming gneiss. Hence, major portion of the study area is covered by granite and granitic gneisses. However, bands of chlorite and garnet-mica schist along with intrusives like pegmatite and dolerite occur as isolated patches. The gneiss has one set of joint parallel to bedding and 2-3 types perpendicular to the bedding plane which are irregularly spaced. The intrusives pegmatite and amphibolite are dipping 40-50ºE cutting the gneiss.

4. Brief history and technical details of the tunnel:

Vishweshwaraiah Canal is left bank canal of Krishna Raja Sagara Reservoir (popularly known as KRS Dam) and runs for a total length of 45.60Kms. In the beginning, it was planned to supply water from a heightof 60 feet from the bottom of the dam, through canals for agriculture. Thecanal had to pass through Hulikere hill, which was 40 Km away from thereservoir. For this purpose, it was planned to construct a tunnel of nearly 2.8 Km length through this hill and to extend the canal up to about 50 to 70kilometres distance. This canal in the beginning passes through 42 Km of plains and then through Hulikere tunnel and provides irrigation water to 1, 20,000 acres. The total length of branches, sub-canals of this canal is about 288 Km.

In Vishweshwaraiah canal, the Hulikere tunnel is located in between ch 40.700 Km and 43.500 Km (22/26th Mile to 9/28th Mile). This is the oldest historical irrigation tunnel in Karnataka, constructed from June 1928 to October 1931.Following table gives the technical details of the tunnel.

Table-1
The technical details of the Hulikere tunnel

Sl No	Technical details	Chainage
1	Length of tunnel	2.80 KM (9100 ft)
2	Flow area	16.05 Sqm (172.75 Sqft)
3	Vent area of Tunnel	16.59 Sqm (178.64 Sqm)
4	Perimeter of the vent	14.95 mts (49.06 ft)
5	Wetted perimeter	12.22 mts (40.11 ft)
6	Velocity of flow in tunnel	3.77 m/Sec (12.38ft/ sec)
7	Gradient	2.30m/Km (12ft /mile)
8	Designed discharge	1902 Cusecs
9	Lined length	750 mts (with surki mortar)(2460 ft)
10	Height	3.90 m (12.77 ft)
11	Bed width	3.66 mts (12 ft)
12	Maximum depth of tunnel bed from GL	43.30 Mts (142 ft)
13	Vertical shafts	4 Nos located at ch 345.50, 815.00m, 1455.60m and 1888.50 mts (1130, 2665, 4760, 6175 ft)
14	Inclined shafts	2 Nos 1467.90 mts and 2278.30 mts (4800 and 7450 ft)

The tunnel has been excavated in the form of D shape and the sides of the tunnel have been lined with UCSR masonry with surki mortar and over surki mortar plastering has been provided. From tunnel ch 0.00 Km to 1880.40m, only the sides of the tunnel have been lined and the top have left without any treatment. And from ch 1888.40m to 2800.00 m (i.e. exit of the tunnel) the sides and arch have been lined with stone masonry with surki mortar and plastered with surki mortar.

5. Cave-in of the tunnel:

The crown portion of the tunnel was collapsed at ch 2060 m, on 15-03-2012,at 6.30 A.M. along with the over burden, and also the masonry lining constructed earlier with surki mortar was also damaged and collapsed, thereby the vent of the tunnel was completely blocked with the fallen muck and masonry. The collapsed cavern is about 15 m length, 5 m width and about 14 m height above the crown. At the top of the cavern, disintegrated rock mass and reddish soil are exposed. Fig. 2 (A & B) shows cave-in portion and damaged portion very near to crown portion of the tunnel.

Figure 2 A) Overview of the collapsed zone (Just after the collapse) and B) Damaged portion near to the crown portion

6. Detailed geological investigation along the axis of tunnel:

A detailed geological fieldwork near to main route as well as inside the tunnel (throughout for 2.8 km) was carried out for rock types and structure.Apart from this extensive field work around tunneling area, some studies on lithology and structures inside the tunnel (throughout for 2.8 Km) was also carried out. The trend of the tunnel is N80^{o}E-S80^{o}W. All the shafts were studied to get some information on types of rocks and nature of bedding planes and soil profile. There are four shafts and in one inclined shaft several pumping system have been installed and water from the tunnel is being pumped for nearby land which is well within the tunnel-bound area.

From the field study, it is confirmed that the basement rock of this region is granitic gneisses. Dolerite and pegmatite dykes have been intruded at many places in to this base rock. All these rocks are medium to highly fractured and 2-3 sets of joints were noticed. The tunnel in most of the places are excavated through three sets of jointed granitic gneisses and seepage was observed. The N-S trending gneiss is highly fractured and weathered and the joints are well exhibited and joint plane thickness ranges from 0.5 cm to 20 cm [Fig.3 (A & B)].

Figure 3A) Field photograph showing the outcrop of weathered gneiss.
B) Highly jointed gneissic rock

Weathering of rocks varies from place to place along the tunnel. It was also noticed that all along the tunnel axis all weathering grades were seen. At the collapsed zone and shaft-4, apart from basement rocks, metamorphic rocks like amphibolite schist, garnet-biotite schist and quartzite have been identified. They are dipping >60ºE and in most of the cases they are highly weathered. It was also noticed that due to higher degree of weathering hydrous and anhydrous minerals have formed and owing to continuous flow of water from the surface, these minerals have been washed away creating cracks causing collapse of the crown portion of the tunnel.Different types of rocks, its structural criteria and its effect on seepage are listed in Table 2. It can be seen that only small portion of the tunnel is devoid of seepage and in cultivated area more seepage followed by leaching of minerals have been observed

Table 2

Lithology, structure and water effect at crown portion of entire route of tunnel (inside)

Chainage (Mts)	**Rock types**	**Structure**	**Seepage**	**Remarks**
0-150	Granitic gneiss intruded by pegmatite and dolerite dyke	3-types of joints, moderately dipping, fractured	Less	Tunnel entrance
150-190	Granitic gneiss intruded by pegmatite and dolerite dyke	No joints, moderately dipping	Nil	
190-200	Gneiss-Pegmatite	Joints and fractured	Less	
200-230	Granitic gneiss and mica schist	No joints	Nil	

230-275	Gneiss	Major joints up to 5 cm	Nil	Ridge above the tunnel
275-325	Gneiss-Pegmatite	Highly fractured	More	Water pouring, small drainage above the tunnel
325-350	Gneiss-Pegmatite	Fractured	Less	
350-450	Gneiss-Pegmatite	1-set of joint	Nil	Ridge above the tunnel
450-550	Gneiss-pegmatite	Joints	Less	
550-575	Gneiss-pegmatite-dolerite	Joints and highly weathered	More	Maximum seepage, critical zone
575-750	Gneiss	3-sets of joints	Nil	Ridge above the tunnel
750-1280	Gneiss-Schist	2 to 3 sets of joints	Less to medium	Clay minerals found
280-1400	Gneiss-dolerite dyke	No joints	Nil	
1400-2060	Gneiss-Schist-Pegmatite dyke	3- sets of joints	Less	Near to collapsed zone
2060-2190	Gneiss-Schist-Pegmatite-Dolerite dyke	3- sets of joints, steeply dipping beds, fractured and weathered		Collapsed zone
2190-2800	Granite gneiss and schist	Fractured and weathered	Nil-Less	Survey was done above the tunnel as inside is completely enveloped with mortar

7. Discussion on the geological field investigation:

This 2.8 Km rock tunnel has an extension of total Government area of nearly 3.0 sq.km. The surrounding rock of this area is granitic gneisses intruded by pegmatite and dolerite dyke along with schistose rocks. This area is highly fractured having 2-3 sets of joints all along the axis of the tunnel. The rocks are trending N-S and dipping 40-50ºE.

The major rock having one set of joint trending almost EW has spacing of 10-20 cm, which allowed water to infiltrate and due to slow seepage the underlying schistose and amphibolite rocks weathered resulting in hydrous/anhydrous minerals like chlorite, epidote, sericite and clay minerals formation.Joints controls the water leakage and as rocks at the surface are more jointed large leakage through open and permeable joints present in the gneisses causing instability due to weakening and disintegration of weak rock mass strata consisting of mica schist (12) The slow accumulation of these minerals and high stress produced squeezing effect which resulted in gradual weakening of the rock mass in the tunnel and finally crushed and weathered rocks mass came from the crown went through invert. The residual soil zone above the crown and nature of joints inside the tunnel are shown in Fig.4 (A & B).

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Figure 4 A) Residual soil zone (approximate 14 Mt) just above the collapsed area.
B) Multiple joints in gneisses at the crown portion of tunnel (inside)

Highly deformed and buckled nature of rocks were noticed near to the collapsed (in inclined shaft), which indicated the rocks have been sheared (Fig.5A) and in such cases reinforced structural elements are very much required as permanent support. But, just a stone masonry arch and lining support were constructed (UCSR masonry) at the time of tunneling which was not sufficient to take the load of entire overburden (Fig.5B).

Figure A) Deformed and swerved weathered gneissic rock with divisional planes of joints.
B) Stone masonry arch construction at the collapsed zone.

The joint patterns represent structural weakness in rockmasses and can be substantially influence the stand-up time of different rock types. They arelikely to influence the mode of rock failure and character of its collapse potential duringtunnel excavations (13) Rain water seepage is highly suspected during rainy season as the tunnel will pass through highly fractured/weathered rock masses and eventually reduce the shear strength of the rock masses (14). The decomposition of minerals caused by chemical weathering eventually may change rock fragments into clay minerals (15). There are five factors that are important in the process of weathering in the rock mass; discoloration and staining, change in texture and fabric, disintegration, decomposition and strength reduction

In the present study, cultivated land is seen above the tunnel and surrounding area. The soil thickness in these cultivated area is 3-8 mts, which has made the water to flow easily in to the weathered rock following by fractured rocks. Apart from this, some old houses exists nearer to exit region of the tunnel. Similarly, influence of water penetration on soil mass is critical especially in tunnel located above the groundwater table and soils are unsaturated and susceptible to water (16).

In the present study the tunnel has been excavated in gneiss and schistose rock. The schistose rocks are highly deformed at some places 2-3 sets of joints are seen. It is relevant in this context that in the Himalaya, tunnel stability problems are mainly related to the existence of weak, highly deformed, highly schistose rock mass and high degree of weathering and fracturing of the rock mass and needs suitable segmental linings (17).

8. Conclusion:

The geological studies around tunneling area confirm the bed rock consists of granitic gneisses. The gneisses are of good quality, however due to tectonic activity and geological processes caused fracturing and formation of weak zones. These gneisses, schistose rock and amphibolite converted to weak rocks with the development of fissures due to shear failure. The contact between the different rocks and 2-3 sets of joints perpendicular to the bedding plane are the weak zones. Further, they have undergone chemical weathering particularly at collapsed zone due to large amount of surface water inflow into these rocks. Different lithologies found in the study area show different degrees of alteration due to surficial weathering. As a result of this primary minerals present in the rock show alteration to secondary minerals like sericite, epidote, hydrous iron oxide etc., and clay minerals. The shear failure of the rocks and alteration of rocks due slow interaction of water at crown portion of the tunnel are the main causes for the collapse.

Recommendation to avoid any further collapse in this tunnel:

Based on preliminary geological and reconnaissance survey in and surrounding area of the tunnel following recommendations are made as some portions of the tunnel is having same characteristic features and is prone to this type of sliding in future.

- The area should be considered as prohibited area
- All along the length of the tunnel, farmers should not grow any crops and should be considered as non-irrigated zone
- There are four shafts and the inclined shafts have been used for pumping the water and hence all the shaft bound area should be considered as restricted area.

- The ultimate and permanent solution to give life for the tunnel is to go for segmental lining throughout the length of tunnel though it is costly. This is inevitable because if there is continuous seepage of water in this tunnel the whole district will become a dry land.

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