Failure of Pressure Tunnel Constructed in Soft Media - A Case Study Focused on Possible Cause

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Abstract

Failure of a low pressure tunnel constructed through highly weathered granite gneiss at Umium-Umtru Stage IV Hydroelectric Project in Meghalaya despite provided with adequate support has puzzled the engineers and geologists associated with the project. In the paper the author carried out the investigations of the tunnel failure and discusses the possible causes of failure and remedial measures.

Introduction

The Umiam-Umtru stage-IV Hydro Electric Project, located in the East Khasi Hills district of Meghalaya state and commissioned in the year 1992 consists of 43 m high concrete gravity dam, 6.13 km long Head Race Tunnel (HRT), a surge shaft, penstock and a surface powerhouse with an installed capacity of 60 MW.

Geological Setting

The Project is located in an Archaean terrain with granite gneiss as the principal rock type. With intrusion of numerous pegmatite and quartz veins. The foliation trend in gneiss varies from E-W to N40ºE-S40ºW with dip 30º-85º on either side. The Project area is characterized by deep weathering by which the country rock has been transformed into a very soft medium in the upper mantle of weathered zone.

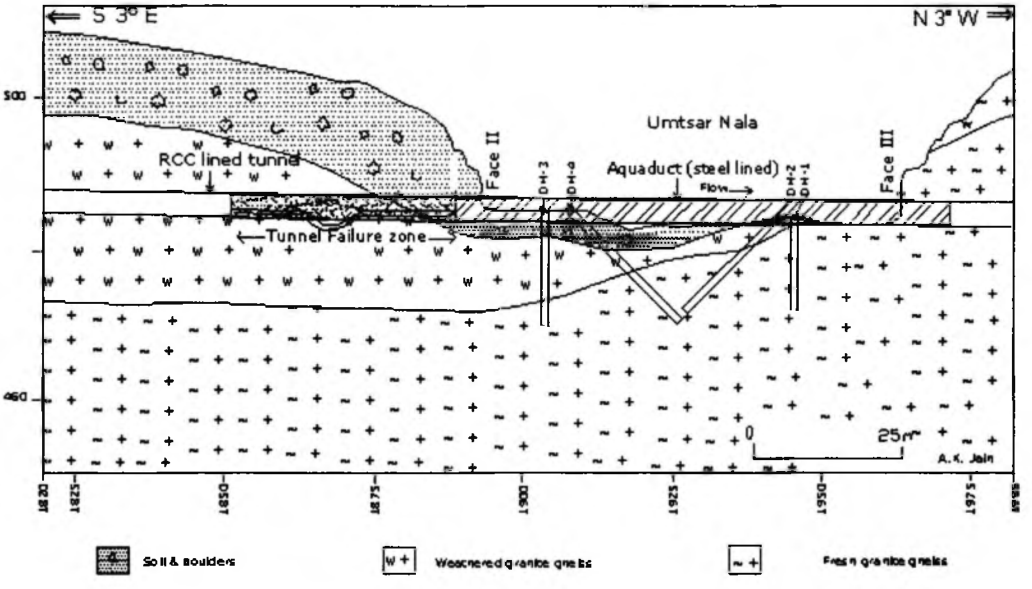

Fig. 1. Geological section along HRT aligment between RD 1820 and 1985 of scage 10 H.E. Project ar investigation scane

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Geology in critical reach of HRT

The 6.13 km long HRT provided with a slope of 1 in 250 has its invert at El. 490 m at the intake. The tunnel with excavated and finished diameters of 3.96 and 3.60 m respectively was constructed through 6 faces. Among the construction faces, Face II and III were located on either bank of the Umtsar nala. The geological forecast was that the tunnel will have a medium of highly weathered gneiss for 150 m length from Face II on left bank of nala, i.e. from R.D. 1745 m to 1895 m (Bhatia, 1987). At Face III, fresh rock was expected at a shorter distance.

At Umtsar nala the tunnel surfaces and crosses the nala through an aqueduct. The 80 m long aqueduct is supported by a steel liner which ends in fresh gneiss in right bank and in highly weathered rock in left (Fig, 1).

Construction of HRT

Heading and benching carried out tunneling in weathered zone and the heading was excavated with the support of fore poles. The excavated short reaches were provided with steel rib support at 0.5 m interval immediately after excavation as its stand-up time was small (Fig. 4).

Besides, the circular shaped tunnel was supported with RCC lining consisting of two layers of 20 mm bars at 200 mm centre to centre in 200 mm thick concrete lining extending for 150 m (identified as highly weathered rock zone). The adequacy of reinforcements were reviewed after the leakage from tunnel and confirmed by the designers. The RCC support ended in fresh rock where adequate rock cover was available to take care of the total internal water pressure. Beyond this reach, the support specification varied depending upon the nature of medium. After the commissioning of the Project in 1992, the tunnel was functioning satisfactorily for two years.

Leakage in HRT

Leakage from the tunnel was first noticed on 4th July 1994 at RD 1905 m on the upstream side of Umtsar nala crossing. Initially it was 0.017 cumec, which subsequently rose to 0.04 cumec. The quantum of leakage was found to be fluctuating in tune with the water level in reservoir. The engineers of Central Water Commission confirmed from a dye test that the leakage from the tunnel it. They felt that the long term remedial measures can be carried out only from inside the tunnel for which emptying of the tunnel is a pre-requisite. But it was not desired for the apprehension that the unreinforced parts of the tunnel lining may collapse due to external water pressure besides causing shut-down of the powerhouse for a long time.

The rate of seepage apparently was not alarming and hence, the authorities desisted from taking the extreme step of shut down. However, it was decided that the leakage shall be constantly monitored and the quality of water checked regularly to ensure that it did not carry any material washed away from the tunnel lining or rock. Under the circumstances, power generation from the powerhouse continued for a further period of seven years without any hindrance and the leakage was monitored.

Sequence of events leading to failure

The rate of leakage from the tunnel suddenly increased abnormally to 1.0 cumec in November, 2002 following occurrence of a landslide in overburden that covered the tunnel in the critical reach after a heavy precipitation (Fig. 2 & 3). The slide was apparently caused due to weakening of toe by leakage water from the tunnel and was triggered by the rains. Before any remedial measures could be taken, the tunnel developed major leak on 1st December 2002 leading to draining of the tunnel. Consequently the intake gate of the tunnel was closed and the reservoir was emptied.

Observations from the failed reach

After the slide and subsequent erosion due to heavy leakage, the concrete lags and the ribs were found exposed in the failed reach.

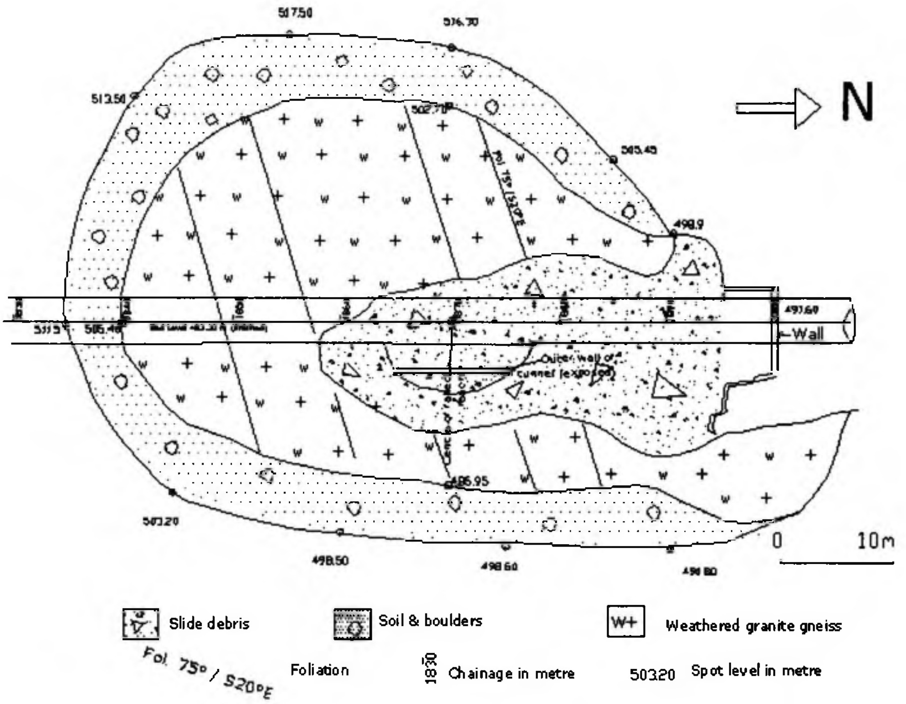

Fig. 2. Surface Geological Map of the HRT area of Umium Umtru Stage IV H.E., Project after tunnel failure

From inside, the lining in invert portion from RD 1866.5 m to 1873 m has been washed away leaving a 6.5 m long and 2.0 m wide crater at the bottom. In cross section, the opening extends from the invert-overt joint on right wall to the centre line and beyond centre line by about 1 m towards left wall (Fig. 4).

In addition to the above, longitudinal cracks have developed along the cold joint between the overt and invert lining from RD 1852 m to RD 1888 m on the right wall of the tunnel (Fig. 3). Between RD 1860 m and RD 1866.5 m the cracks were found pronounced with about 10 cm wide opening. There were several oblique cracks of smaller dimension. The damage was found to be confined to the invert section of the tunnel and the overt was intact.

Remedial Measures

After careful examination of the problem, the tunnel was repaired by providing reinforced concrete below the tunnel invert level and 2 m long 25 mm dia anchor bars at 1 m spacing near the invert portion. The steel liner of 16 mm thickness and 3.5 m dia was extended from the aqueduct end for a distance of 115.5 m including 2.5 m of transition zone at both sides. Repairing of eroded lining zones and filling up of voids created behind the concrete lining was also carried out followed by consolidation and contact grouting.

Discussions

The geotechnical studies have indicated that the medium of tunneling was highly weathered granite gneiss from RD 1754 m to 1895 m warranting heavy support. Besides rib support, the tunnel was provided with RCC lining consisting of two layers of reinforcements which is considered adequate. Considering a small water head of about 21 m acting from inside the tunnel, the failure of the tunnel is intriguing despite heavy supports. It is apparent that the supports were designed for total internal water pressure ignoring the weathered rock cover.

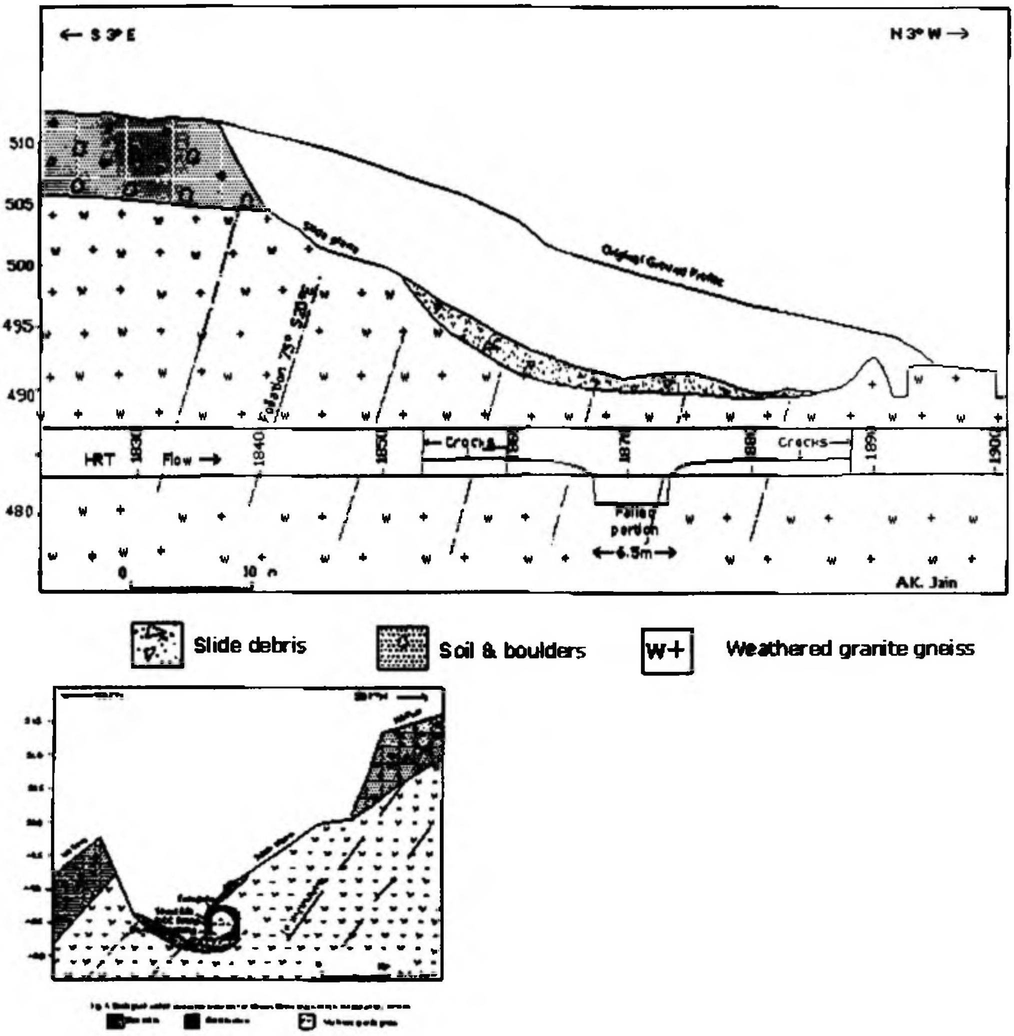

Fig. 3. Geological section along HRT of Umium Umtru Stage IV H.E. Project after tunnel failure

Authors' perception

During examination of the damaged portion of the tunnel from inside, the author observed that the rods used in reinforcement of lining were not making full circle. The outer layer of the reinforcement rods were found anchored to the floor of the tunnel on flanks and the inner layer ends abruptly on the sides of invert leaving the floor unreinforced for about 2m width. It is here, the crater had developed during leakage and the spot surmised to be the origin of leakage. Statically, the tunnel is considered as a thick walled tube, consisting of rock and support and /or lining. Since a tube is statically acting as tube only if is not slit, the closing of ring is of special importance (Muller-Salzburg, 1978).

Conclusions

The author is of the opinion that the tunnel failed at the invert notwithstanding low internal water pressure because of the discontinuity in reinforcement at the invert. Since, the failure of the tunnel occurred in unreinforced invert, leaving the reinforced overt intact, perhaps it has not acted as a tube due to absence of reinforcements at the invert. For the occurrence of failure at the particular spot, it is understood that the spot falls at the end of the critical reach where the internal pressure is suppose to be marginally higher compared to other reaches due to the gradient of the tunnel.

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