Geotechnical Problem Encountered in HRT of Pallivasal Extension Scheme, Idukki District, Kerala

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Abstract

Pallivasal Extension Scheme is under construction by Kerala State Electricity Board (KSEB), to replace the water conductor system of the existing Pallivasal Powerhouse (37.5 MW) and augment the installed capacity of the Project by putting up an additional power house of 60 MW capacity. It is proposed to construct a 3,396 m long, 3.5 m dia. power tunnel, with intake sill level at 1442 m above m.s.l., 7 m dia. 49 m deep circular surge shaft, 1,019 m long 2.5 m dia. pressure shaft, two penstocks, one 1161 m long 2.0 m dia. and another 800 m long with 1.6 m dia. to feed both the power houses. The tail waters of the new powerhouse would be collected in the tailrace weir and flow into the Sengulam Reservoir by gravity. Barring excavation for the initial stretch of power tunnel and surge shaft, other excavations are nearing completion. Hornblende biotite gneiss (migmatite), Pink Granite gneiss and pegmatite forms the foundation/tunnelling media with 5 sets of prominent joint planes were including the foliation joint.

While driving the HRT towards the intake direction, problem raised due to land subsidence in the Tata Tea Estate, subsequently geotechnical evaluation have been made at the subsidence area. The reason for the subsidence is directly linked with the reported loose fall in HRT Face – II, since the subsidence area falls in the alignment of the HRT at ch. 1170.50 m (10° 03' 57" E, 77° 03' 32" N), within the Tata Tea Estate. An area of about 10 m dia. has been subsided above the tunnel heading face. The subsidence has created a sink hole of about 6 m depth. Grouting with cement slurry from the surface has been recommended to avoid further sinking of the subsidence. But, the area between ch. 1148 and 1165 m in HRT Face-II show fairly a good rock mass with RQD 75; GSI 40 to 50; 'Q'= 7.5, classified as Fair rock mass quality and RMR = 69, Classified as Good rock mass rating. Since, the effort to drive by method of fore poling have failed, 'Pipe Roofing along with grouting' is suggested for further advancement continuing soft rock tunnelling method, with advance probe hole explorations and these recommendations have been incorporated by the KSEB and are presently being executed.

1. Introduction

Pallivasal Extension Scheme (PES) is under construction by Kerala State Electricity Board (KSEB) to replace the water conductor system of the existing Pallivasal Powerhouse (37.5 MW) and augment the installed capacity of the project by putting up an additional power house of 60 MW capacity. The first machine of the existing powerhouse was commissioned in 1940. Its penstock got slightly deflected due to soil

creep, since its inception. A new project was proposed to construct a 3,396 m long 3.5 m dia power tunnel, with intake sill level at 1442 m above m.s.l., 7 m dia, 49 m deep circular surge shaft, 1,019 m long 2.5 m dia pressure shaft, two penstocks, one 1161 m long 2.0 m dia and another 800 m long with 1.6 m dia to feed both power houses (plate 1). The tail waters of the new powerhouse would be collected in the tailrace weir and flow into the Sengulam Reservoir by gravity.

This paper pertains to the work done during the GSI's field season 2012 -13 in the PES. Geotechnical investigation and 3D geological mapping have been carried out in the HRT and investigated Face – II of HRT between ch.1148 and 1165m to ascertain the site conditions, after the reported loose falls culminated in cavity formation above the crown and consequently led to the development of a surface depression at ch.1170.50 m.

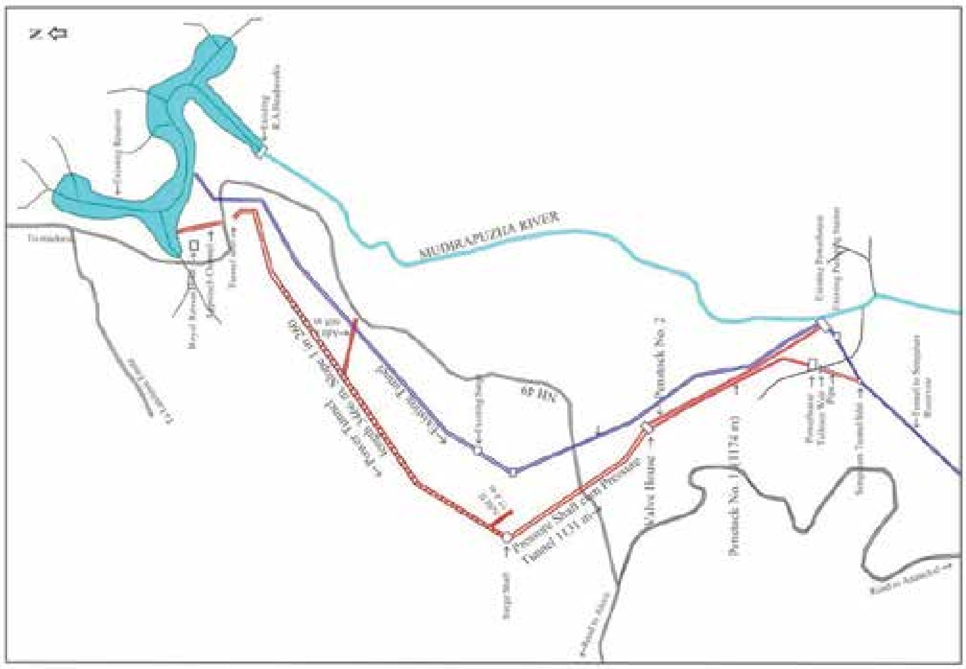


Plate 1 Layout of Pallivasal Extension Scheme, Idukki Dist.,Kerala

2. Geological Framework of the Project Site

The project area is located in an Archaean metamorphic terrain, along the western slopes of Western Ghats, with charnockite, migmatitic gneiss and pink granite as predominant rock types. The regional foliation trend is in WNW-ESE direction with steep dip towards NNE direction.

Within the project site, pink/grey gneiss is the host rock exposed in most of the excavations in the tunnel, except in power house area where charnockitic gneiss/migmatite is found. The host rock is profusely intruded by pink granite/ pegmatite. As these pink intrusions are highly susceptible to weathering, a number of weathered seams along the major joints altered to clay are seen in all the excavations. In the surge area, a major weathered pegmatite body was encountered, leading to cavity formation and later back filled. Thickness of overburden is very high in the intake area which gradually

getting reduced towards powerhouse site. The overburden material includes, boulders, completely weathered rock, lithomargic clay and slope wash materials, etc.

Four sets of joints are prominent, other than the foliation plane and their spacings are irregular. The joint spacing, in particular, is very close in the areas of pink granite emplacement. No major shear zone or dykes have been observed so far. At the powerhouse site have thin (20 to 30 cm) foliation parallel shears filled with mylonitic gouge, rich in biotite mica are recorded. No major adverse geological feature other than profuse weathering of rocks is observed in the project area. Presence of these small and large weathered geological units along the prominent discontinuities is the main stumbling block for the smooth excavation.

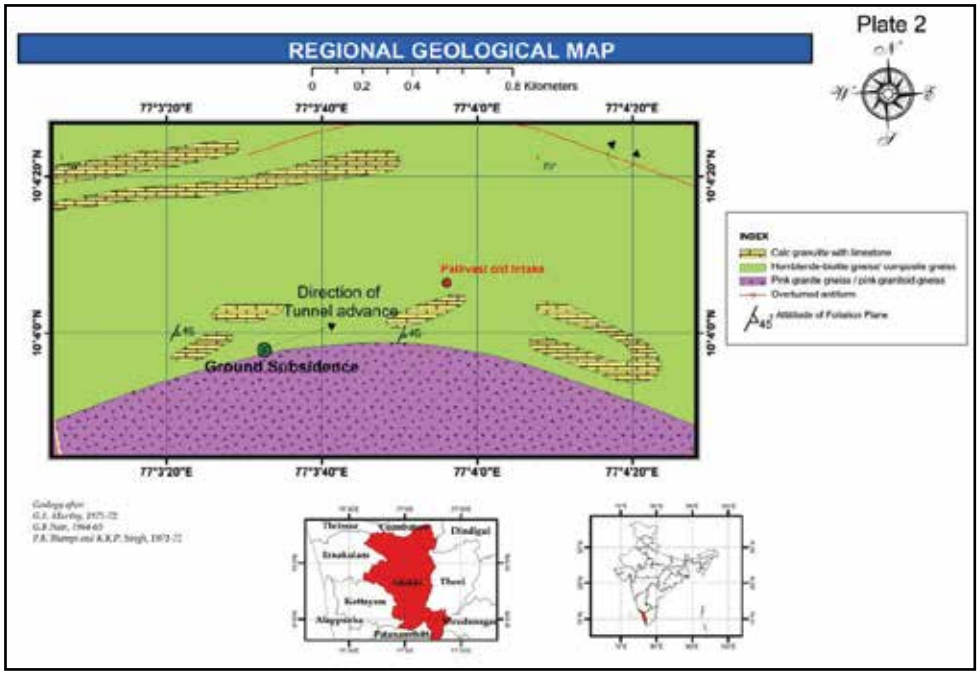


Plate 2 Geological Map of Pallivasal Extension Scheme, Idukki Dist.,Kerala

3. Geotechnical Evaluation

Geotechnical Evaluation was carried out at the collapsed reach of HRT – Face – II at ch. 1165 and from ch. 1148 to 1165 m to ascertain the condition, after the reported loose falls culminated in cavity formation above the crown and consequently led to the development of a surface depression.

The reach consists of pink and grey migmatitic gneiss with pegmatite veins. The tunnel is oriented in N75°E – S75°W direction (N75°E towards intake). The rock mass has foliation which is swinging frequently from NE-SW to NW-SE due to warping and dip direction also changes accordingly. The following are the prominent joint sets seen in the tunnelling media.

No.	Strike	Dip	Dip direction	Spacing
i	N 20° E – S 20° W	65°	N 70° W	0.50 m to 1.00 m
ii	N 40° E – S 40° W	70°	N 50° W	0.80 m to 2.00 m
iii	N 45° W – S 45° E	65°	S 45° W	0.10 m to 0.50 m
iv	N 60° W – S 60° E	70°	N 30° E	0.10 m to 0.50m

The Tunnel in these reach is transected by predominantly steeply dipping joints oriented across and along the tunnel direction. Joints are tight, closed, rough and planar. A few small pegmatite veins have been emplaced along the joints and they are completely weathered. Two shear zones trending N10° to 20°W –S10° to 20°E have been observed between ch. 1054.50 m and 1058 & 1062.50 m and 1066.00 m oriented near perpendicular to the tunnel. The thickness of shear zone is 3.00m. Along the shear zone the rock is highly weathered.

During the GSI's field season 2010 -12, HRT – Face –II was mapped by the first author and gave prognostic view about the site condition in these reach. The excerpt of concerned text is reproduced below.
"It is apprehended that tunnelling conditions would further deteriorate with each advancement, as the rock cover would deplete. The need, therefore, should be to provide support measure without a time gap, for which support assembly should be made ready prior to disturbing the face"

Further it was recommended to ***"immediately back fill the cavity after removing the accumulated rock debris. It is however, expected that the said removal would initiate further fall of the rock material initially, and subside/cease subsequently. Further advancement of the tunnel face should be attempted with utmost caution by employing fore poling with 6 m length rods with 2 m overlap directed at 15° from the horizontal and immediate steel rib support, in view of very short stand up time"***

But, unfortunately due to hindrance in implementation of recommendations the tunnel started caving at ch.1169 m, forming a cavern and surface depression atop the alignment. Consequent upon request from KSEB, the site was again inspected and evaluated. The detailed observation and evaluation are discussed herein

A. Cavity Formation in the HRT

At the tunnel grade, cavity formation beyond Ch. 1165 (figure1) was reported, which however, could not be seen as the face was plugged by gunny bags filled with muck. Geotechnical assessment of the section between ch.1148 and 1165m, which is unsupported, has revealed exposure of fresh to slightly weathered hornblende biotite gneiss and pink granite gneiss. Foliation trending N 80°E – S80°W, with 30°-50° dip due N10°W, strikes sub-parallel to the tunnel axis (heading due N70°E). The other prominent joints being:

- N35°W – S35°E, dipping 65°/NE
- N70°W – S70°E, dipping 85°/SW

Importantly, between ch.1148 and 1165, tunnelling medium is found to be quite satisfactory, as borne out by the estimated rock mass parameters

- The **RQD** is calculated as = **75** (Palmstorm[1852] = 115 – 3.3 Jv, *where Jv = 12)*
- Geological Strength Index (**GSI**) ranges from **40 to 50**
- Barton's **'Q'= 7.5 ,** Classified as **Fair** rock mass quality
- **RMR = 69,** Classified as **Good** rock mass rating

Since the reach beyond ch.1165m was already supported by steel ribs and therefore could not be assessed, it is quite likely that rock mass conditions are severely deteriorated. Structural wedges formed at the crown due to intersection of 3 joints in the water charged zone, possibly contributed in cavity formation.

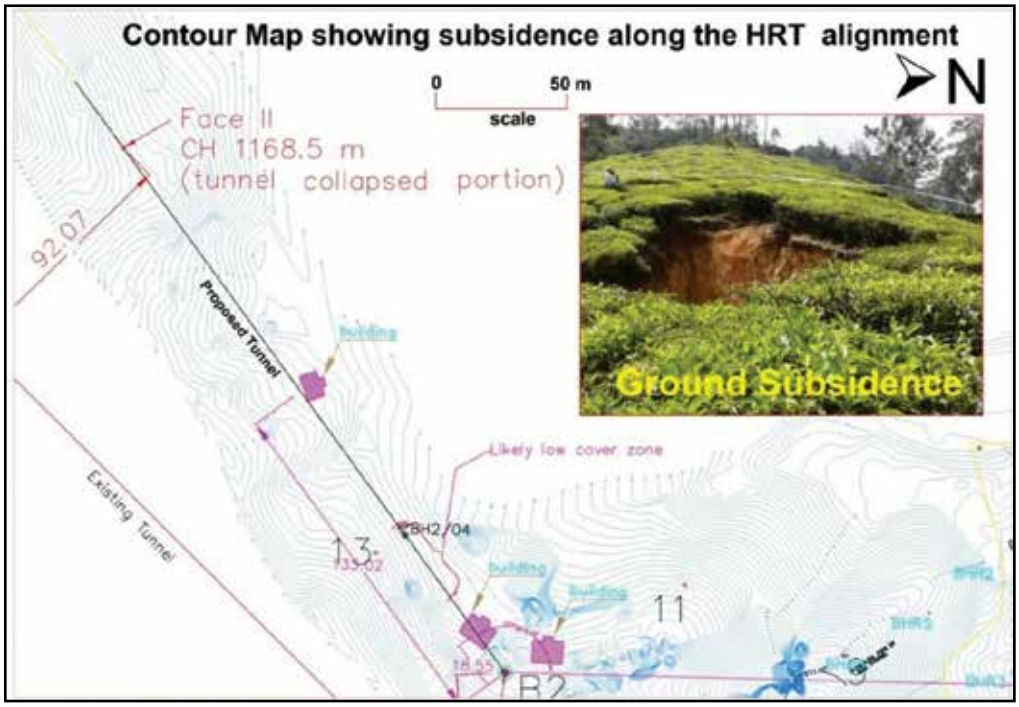
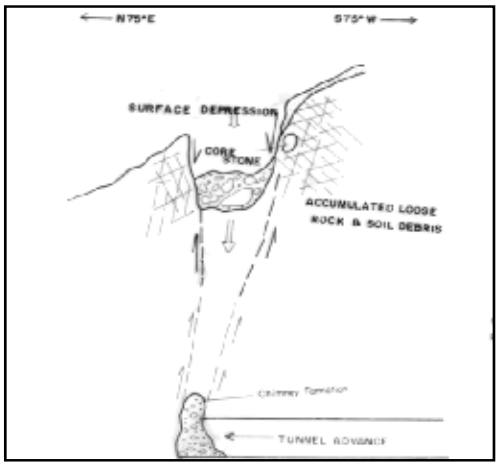


Plate 3 Contour Map showing Subsidence along HRT alignment

Picture 1 Photograph of HRT- Face 2 at ch.1170 m taken during site inspection

Figure 1 Cavity formation in HRT Face 2 at ch.1170 m



B. The Failure Mechanism

The section close to the formed cavity is marked by blocky jointed rocks. The instability has arisen due to gravity falls of the jointed rock blocks from the crown. The falling blocks are separated from the surrounding rock mass by at least 3 intersecting joints to form a free falling wedge (figure 2). The vertical line drawn through the apex of the wedge falls within the base of the wedge, thus satisfying the condition of wedge failure. The 3 great circles plotted in a stereo net (figure 3) representing 3 joint planes, form a closed figure surrounding the centre of the net (representing apex of the wedge).

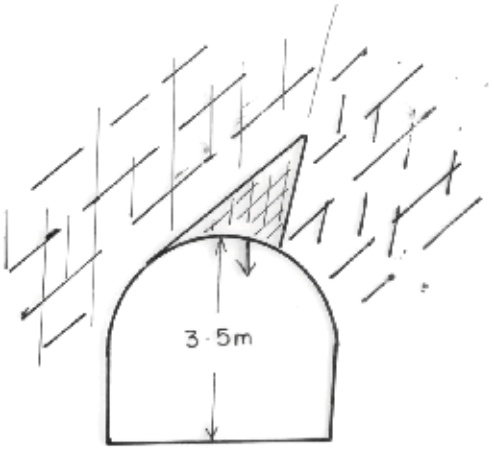


Figure 2 Wedge failure from the crown of HRT Face-2, at ch. 1170 m

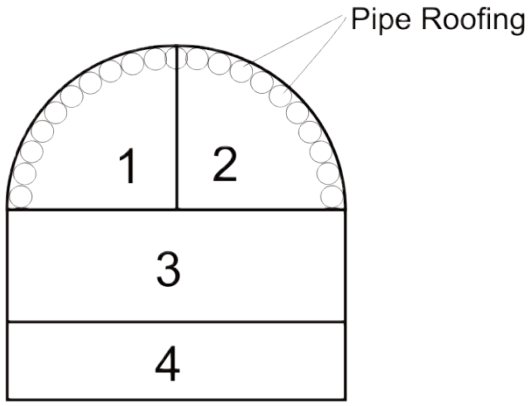


Figure 3 Proposed Excavation Sequence

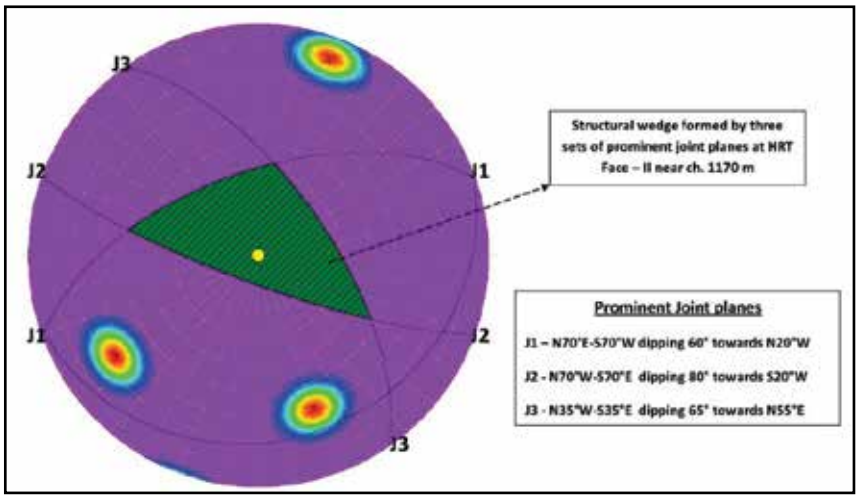


Figure 4 Stereo net showing formation of Wedge with its vertex at the centre

Ever since the initial failure from the crown (before October 2011), much deformation of the rock mass has already taken place and the initial support pressure provided by steel ribs failed to sustain the load imposed by the distressed jointed and weathered mass. Removal of the accumulated rock debris from below the cavity also facilitated further

deformation and deterioration as the natural support available to the failing rock mass got disturbed. The distressing phenomenon progressively reached higher level and subsequently formed a passage for water, especially during heavy rains. Consequently the saturated weathered and distressed rock mass along with overburden started sinking, to form a huge depression on the surface, in the sloping land of Tata Tea Estate.

C. The Seismic Refraction Data

Seismic refraction survey carried out by NIRM along the tunnel alignment, for a length of 230m, from close to the present face and B_2 Bend (plate 3), suggest very undulating profiles of velocity layers. Though the location of cavity, at the present face and surface depression, is not represented (Ch 1168.5m) in the velocity section, it is however, evident that close to this location, the low velocity layer with V_p = 350 - 1500 m/sec considerable falls down by >24m, thus suggesting a high grade of weathering and open jointing.
Further 40-70 m short of B_2 Bend, the geometry and the behaviour of velocity profile V_p 2500 – 3500, indicates abrupt decline of sound rock cover, at the tunnel grade, which calls for caution while advancing though this reach.

D. Support Measures in the HRT

i. G.I. pipes of 6-9m length were suggested to be pushed into the cavity for grouting. Then, cement-sand grouts (1:1) were suggested to be injected to consolidate the water saturated mass. This is necessary to consolidate the loose dead rock mass (and debris) above the crown in the cavity zone to enable advance by providing steel rib-support at 40cm c/c spacing, with proper lagging and drain holes. It was also recommended for grouting the face for strengthening
ii. To further strengthen the crown and facilitate a safe advance, pipe roofing or pipe umbrella system was recommended (figure 3). This is felt necessary as earlier attempts to provide pre-support by fore poling failed to succeed, perhaps due to lack of suitable machines for installation. Conventional drill jumbos or special machines were suggested for deployment to install the pipes. The steel pipes were suggested to be installed from the tunnel face in the crown to the front, directed at 5° to 10° upwards, in an umbrella or canopy like arrangement, preferably with the following specifications.
    a. Spacing – 0.30m or even less.
    b. Diameter of pipe – 60 – 150mm
    c. Wall thickness – 4 to 8 mm
    d. Length – 9 to 12m
    e. Overlap- 3-4m
iii. Subsequently, the face needs to be driven through the grouted mass sequentially, in compartments from the top, as depicted in figure 3
iv. Support assembly were said be made ready since it would require concurrently to be placed behind the advancing face, as stand up time in the distressed, weathered and saturated zone would be limited. Any delaying in giving support would only allow deformation to take place.

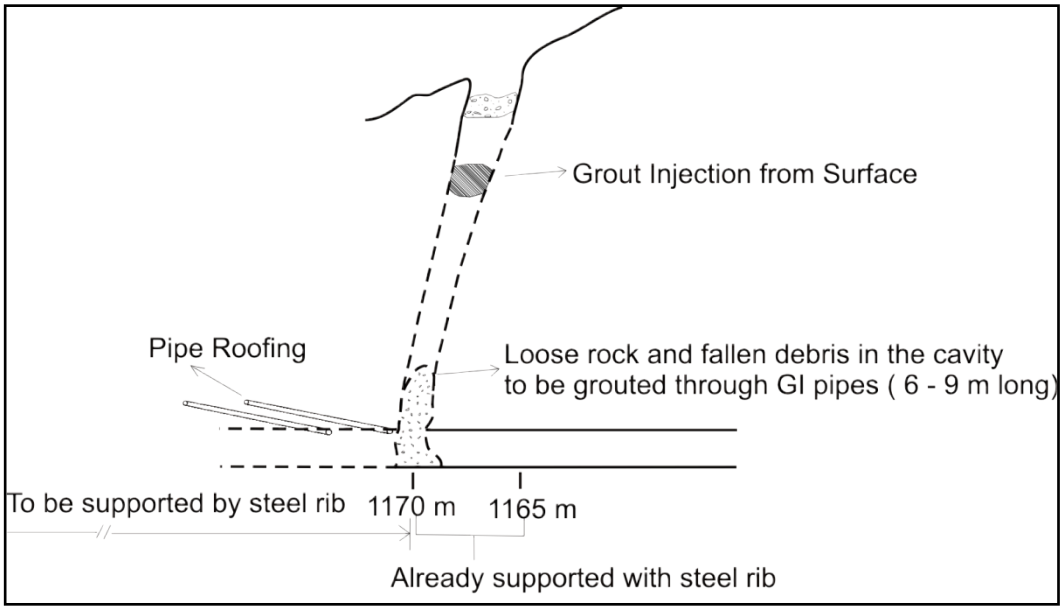


Figure 5 Proposed Support Measures

4. The Surface Depression

The surface depression was formed along the HRT Face II alignment at ch.1170.50 m (10° 03' 57"E, 77° 03' 32"N). The depression is observed with highly weathered rocks (W_3 – W_4 grade) affected by at least 3 sets of joints and overlain by 1-3 m of overburden are involved in land subsidence creating a depression (8x8x12m), on a N75°E facing slope of Tata Tea Estate (plate 2) At this location, total vertical cover is said to be 80m approx. above the tunnel. In the lower topographic levels, water saturated conditions are evident showing signs of subsidence.

Picture 2 Surface depression at ch.1170.50 along HRT – Face II alignment

The failure in the tunnel and subsequent development of ground subsidence on the surface above the tunnel cavity warrants a systematic approach in giving suitable treatment. Therefore, in order to arrest further sinking of the ground surface and its attendant impact on the tunnelling condition, beneath the surface, grouting from the surface is advised. As part of this process, grout is to be injected from the surface, at an intermediated level between the tunnel crown and the ground surface (figure 5). The grout is intended to mainly support overburden and to impart homogeneity to an otherwise block, weathered and highly jointed rock mass. Grout material may comprise of slurry of suspended particles (silica flour, cement, bentonite etc) which would behave as a viscous fluid during injection.

5. Conclusion:

In HRT – Face-II at ch.1170 m, considering the total available vertical cover of about 80m, for a tunnel of diameter 3.5m in hard gneissic terrain, it is felt that further advancement of tunnel along the proposed alignment should not be a difficult task what is required is pooling of some additional mechanized resources and execution of work in stages, with caution. Though the rock mass is observed to be good from ch.1148 and 1165m, which is unsupported, the reaches beyond 1165 is supported with steel ribs packed with sand bags

Structural wedges formed at the crown due to intersection of 3 joints in the water charged zone, possibly contributed in cavity formation at ch.1170 m in HRT Face-II. The deformation and deterioration of the cavity was also due to removal of accumulated rock debris from below and the distressing phenomenon progressively reached higher level and subsequently formed a passage for water, consequently the saturated weathered and distressed rock mass along with overburden started sinking, to form a huge depression on the surface

Therefore, the loose dead rock mass above the crown in the cavity zone were recommended for cement-sand grout (1:1) to consolidate the water saturated mass by pushing 6 – 9 m length G.I. pipes. In addition to the steel rib support, to further strength the crown and facilitate a safe advance, pipe roofing or pipe umbrella system was recommended. To impart homogeneity to the weathered rock mass in the subsided land on Tata Tea estate (picture - 2), it was recommended to grout from surface, with slurry of slica flour, cement and bentonite. Accordingly, the KSEB has incorporated the suggested recommendations and advancing driving the HRT without any hindrance.

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