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SYNOPSIS Varahi river in Karnataka State, India originates on the Western Ghats and is harnessed for power generation by constructing three dams. The water is conveyed through two inclined pressure shaft to the underground power house below the Ghats. The underground power house of the Varahi Hydro Electric Project executed by the Karnataka Power Corporation has 2 units of 135 MW each in the first stage with a provision to add two more identical units. Three underground cavities are excavated parallel to one another for housing the rotary valves, generators and the transformers respectively and are at a geo-static head of about 230 m. The paper deals with a case history of the excavation practice and the stabilisation measures adopted during the excavation of the cavities for housing the underground power house complex of the Varahi Hydro Electric Project in Karnataka, India.

INTRODUCTION

Varahi Hydro Electric Project is one of the major projects successfully commissioned in the year 1990 by Karnataka Power Corporation in the state of Karnataka situated in the Southern part of India. Varahi river one of the West flowing rivers, which has a total length of 72 kms originates on the Western ghats at an elevation of 730 m above MSL and traverses in a Westerly course in a deep rivine losing heights of about 455 m in its middle reach and finally joins the Arabian Sea. The project is situated between Longitude 75°.0 -75° 5' and Latitude 13° 40'-13° 45'.

The project comprises of three masonry dams for storing waters above the hills and a system of water conductor system comprising of two RCC tunnels, two inclined pressure shafts, inclined at an angle of 55° to horizontal penstocks.

The undergrouund power house has valve house, machine hall and transformer hall as main components (Fig-1).

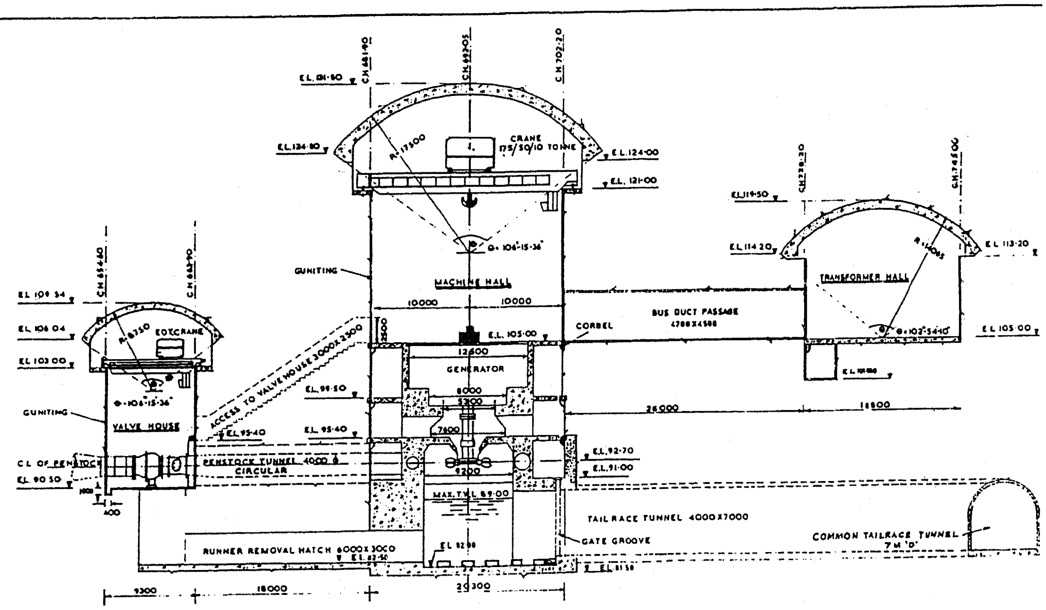

FIG-1 VARAHI UNDERGROUND POWER HOUSE
CROSS SECTION THROUGH C.L.OF UNIT.
SCALE

REGIONAL GEOLOGY

The area coming under the influence of project comprises of peninsular Granite gneiss rock intruded by dolorite dykes. Within the body of the Granite gneiss rock, intercalations of horn blends biotite schists have been noticed. The regional trend of the rock is NNW-SSE and the dip varies between 40 and 70 Easterly due to minor warping experienced by the granite gneiss suite of rocks. The hill slope in which inclined pressure shafts are driven is made up of meta-volcanic suite of rock below which peninsular gneiss rock occurs.

GEOLOGICAL INVESTIGATIONS

The three caverns of the underground power house are situated at a depth of nearly 250 m below surface. The geological investigations for the Underground Power House and tail race tunnel comprised of drilling NX boreholes. One inclined borehole was drilled to an inclined depth of about 215 m from the hill slope to assess the quality of rock immediately above the roof of the machine hall cavity. Few bore holes were drilled to shallow depths along the Tail race tunnel alignment to determine the hard rock cover abovve the roof of the tunnel and a few were drilled upto the tunnel grade to know in advance about the condition of rock at the tunnel grade (Fig-2).

In order to take advantage of the competency of the existing rock, the rock ledge of 1.8 m and 1.3 m were proposed to be retained for supporting rails required for movement of EOT cranes in machine hall and valve house respectively at the planning stage itself and it was possible to retain these ledges due to the sound rock met with during benching operations. This arrangement gave an advantage of saving time and elimination of RCC works for columns.

Plain concrete arch of 1 m thick for machine hall and 0.6 m thick for valve house cavern were provided in addition to systematic roof bolting for supporting the arch. 5 m long, 22 mm dia roof bolts were provided in a grid pattern of 1.5 m c/c. Dovels of dia 22 mm, depth 2 m at a grid spacing of 1 m were provided for high vertical walls of the power house caverns in order to stitch the disturbed rock in the vicinity of surface. 50 mm thick guniting was sprayed all along the high vertical wall in order to seal off the joints.

SEQUENCE OF EXCAVATION

Normal practice of excavating the arch first and providing treatment to the arch followed by the removal of the bench to the full size is followed in excavating the three caverns. A brief discription of the excavattion sequence adopted for the machine hall cavern is as follows:-

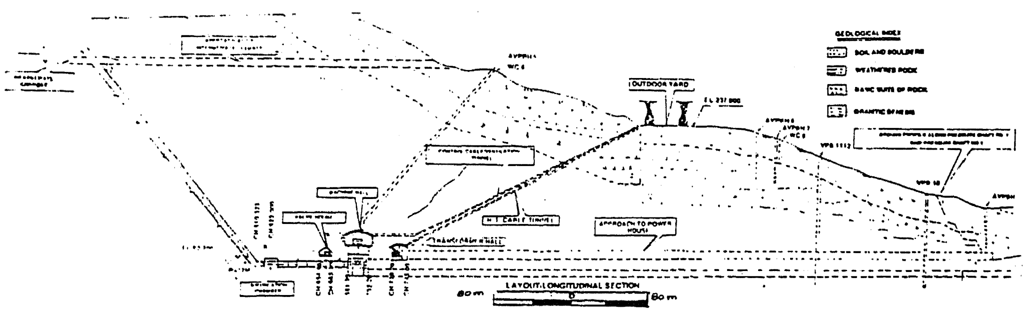

Fig-2 Layout -Longitudinal section

As part of the rock mechanical investigations, insitu stresses were measured at three locations and measured values are as under:

RESULTS OF INSITU STRESS MEASUREMENTS ALONG WATERCONDUCTOR SYSTEM VARAHI PROJECT

LOCATION	OVER BURDEN IN METER	MEASURED STRESS IN Kg/Cm Pv	Ph	PRIMARY STRESS IN Kg/Cm σV	σH	$\frac{\sigma H}{\sigma V}$
TOP ADIT	80	193	100	153	116	0.76
INTERMEDIATE ADIT	260	258	133	177	146	0.82
BOTTOM ADIT	230	309	108	181	103	0.57

A value of $K = \frac{\sigma H}{\sigma V}$ =0.52 is adopted for further design computations.

LAYOUT OF UNDERGROUND POWER HOUSE

A parallel cavern arrangement comprising of three caverns is adopted. With an emphasis on the observational method of design and from the post experience gained from tunneling in similar geological set up, the widths of the rock pillars retained between caverns is 18 m and 26 m between valve house, machine hall and transformer hall respectively.

The main access to the power house was through an approach tunnel reaching the repair bay at EL 105.00 m and valve house at EL 90.35 m. From the repair bay level of EL 105.00 m a ramp tunnel was excavated to reach EL 113.0 m in 1:13 grade. With a 180° turn, another ramp was excavated between EL 113 m and EL 124 m which is the haunch level of the machine hall cavern. The ramp tunnels were of size 7.00 m x 5 m and these two ramps were so adjusted that they are accommodated within the final section of the main cavity. (Fig-3).

A pilot tunnel was then excavated at EL 124.0 m for the entire length of the machine hall and afterwards further widened for the full width by multiple drifts methods (Fig-4). The widening was restricted to a width of 20 m against the final width of 28 m, leaving 4 m wide haunches on either side. Excavation of the haunches was done in a staggered manner and concreted by inserting sufficient anchors immediately so that at no time, the entire width of 28 m was exposed before the haunches were stabilised. The roof was supported by a plain concrete arch 1 m thick in addition to 5 m deep grouted rock bolts systematically driven in a grid pattern.

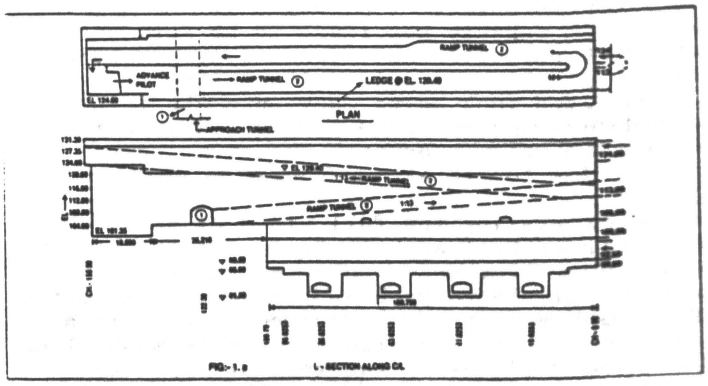

Fig-3 Arrangements of ramps for Machine hall excavation

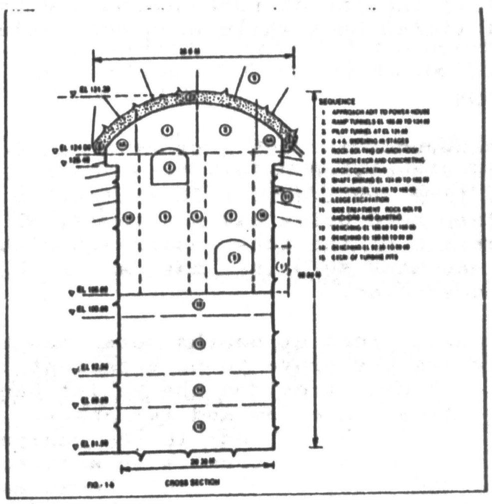

Fig-4 Sequence of Excavation of Machine hall

Benching below EL 124.0 m upto the turbine pit level of EL 81.5 m was carried out in stages. A gullet was opened between EL 124 m and EL 105 m, initially and then widened for the full width in the form of a rectangular nitch. Mucking between EL 104.5 m and EL 100 m was done by using CK 300 poclain with backhoe/front end loader attachment stationed at EL 104.5 m platform. Lowering of the bench from EL 100 m to EL 81.5 m was done by putting shafts and mucking through the tailrace tunnel which was ready at that time.

One of the special features of this power house is that no separate columns and beams were cast for running the crane gantry and instead of that, a rock ledge of 1.8 m wide in machine hall and 1.3 m wide in valve house were retained at the time of excavation for seating the crane rails. By adopting the pre-splitting technique, it was possible to achieve an undamaged rock ledge at EL 120 m.

VALVE CHAMBER

The approach adit was reaching the springing level of the valve house beyond the repair bay and another branch of it was reaching the valve house bottom at EL 90.35 m. Hence the approach adit was continued to form the valve chamber cavern chamber at the springing level. This excavation formed the pilot drift to the full length which was later widened to the required level. Here again, crane beam was made to rest on a 1.3 m wide rock ledge retained longitudinally throughout the length (Fig-5).

Fig-5 Rock Ledges in Valve Chamber for EOT Crane

TRANSFORMER HALL

From the approach adit at EL 104.5 m, a ramp was excavated upto the springing level of EL 113 m and subsequently widened out to the full section. Benching was later done in the conventional manner after protection of the roof by 60 cms thick plain concrete.

GEOTECHNICAL PROBLEMS AND TREATMENTS

The normal assumption that the rocks at great depths become more massive without many joints has been found to be not always true as in the case of peninsular granite gneiss rock met with during excavations. The gnesic bandings were very much pronounced and the schist intercalations contained foliation joints in plenty. The main joint pattern observed in the Power House complex are as below:

Foliation joints (N 25-30W S 25-30 E)	**Warped at places and dipping at 40-60 NE ie., slightly skew to the u/s wall**
Sub horizontal joints	**Widely spaced (1 m to 3m apart)**
E-W - joints	**Vertical (--"--)**

The main power house cavity is aligned 60-70 skew to the strike direction of the granite gneiss and as such orientation of the long axis of cavities is favourably disposed.

The peninsular gneiss rock exposed in the cavities of the power house complex are associated, at times, with hornblande-biotite schist. These appear in the form of thin bands and lenses and are disposed parallel to the

strike of the granite gneiss rock. Schist being a highly foliated rock, excavation for the arch portion or the side walls could not be cut true to line and hence resulted in overbreaks.

Insertion of rockbolts for stabilization of schist rocks in the roof and sides of the ramp tunnels was not desirable as these ramps were to be later knocked down for the formation of the full caverns and during rock bolts in the intermittent stage may pose problems resulting in undercuts while benching down.

The large patches and bands of pegmatite-quartzo felspathic rock were also encountered in association with the granite-gneiss rock. These quartzo-felopathic rock become brittle and unstable over a period of 2 or 3 days after the excavationb and chunks of this rock tend to fall down from the roof necessitating repeated sealing in such regions to avoid rock falls. rock become brittle and unstable over a period of 2 or 3 days after the excavation and chunks of this rock tend to fall down from the roof necessitating repeated sealing in such regions to avoid rock falls.

At the roof level in the valve house chamber and in the vertical wall of the machine hall chamber one sub-horizontal layer of basic rock has been identified. (Fig-6) 1.5 m thick basic rock layer is accompanied by several off-shoots disposed in different directions. The adjoining rock immediately above and below have developed parallel set of joints which were slightly open and hence caused rock instability in the arch portion of the valve chamber. This thin layer of basic rock was either sealed down or secured to the rock behind by insertion of rock bolts.

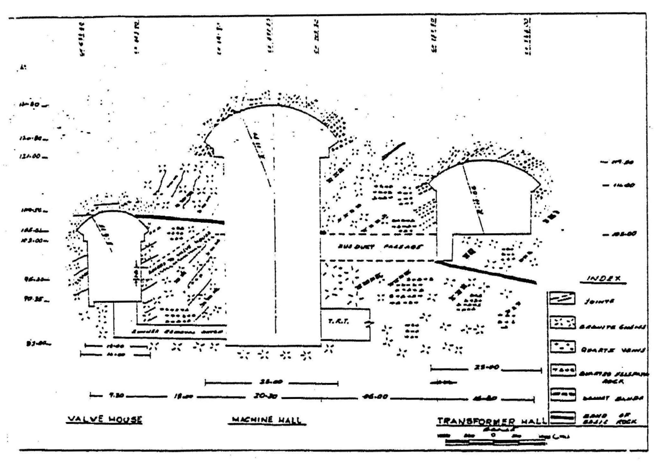

Fig-6 Geological Cross Section

During the course of excavation of the arch of the machine hall it was found necessary that systamatic rock bolting of dia 22 m to a depth of 5 m had to be adopted in a grid pattern of 1.5 m c/c to stabilise the arch. It was observed that providing rock bolts with Conbextra rock capsule enhanced the stability of arch to its final width of 28 m at the haunch level. Conbextra rock capsule is a ready made capsule containing special dry grout powder requiring soaking in water for less than 4 minutes and is capable of giving working anchorage within 2 to 4 hours. After soaking the capsules, they are stemmed into drill hole and bolt is driven to establish contact with the rock throughout the length of the hole. This rock capsule was found to be very handy for roof supports where injections of ordinary cement grouting is difficult or slow to set. The grouted rock bolts increased the frictional resistence against sliding along discontinuity planes and also prevented the dilation of joints due to vibration shocks.

While excavating the full width of the Transformer hall arch to 22.4 m at the haunch level huge blocks of rocks fell down creating a triangular shaped gash at the roof to an extent of 3 to 4 m above the required level. This happened due to the sliding of rock mass along the smooth planes of two sets of opposite dipping joints converging at the roof in the form of an inverted 'V'. By insertion of grouted rock bolts from the haunch level upwards the jointed roof rock was safely anchored to the intact rock behind and then the gash was filled back while arch concreting was done.

CONCLUSION

Many weaknessess in rock mass at great depths cannot be visualised before hand due to heavy cost and time involved for investigation. One or two deep bore holes may not reveal all the characterstic of the rock underneath with the result that many surprises may have to be faced during excavation.

Granite gneiss rock at depths more than 250 m below surface may prove to be excellent tunnelling medium provided the schist bands and pegmatite lenses are few and far apart. The association of schist bands in the peninsular gneiss rock, no doubt, creates an anistrophy favouring dampening of blasting shocks may pose problems of rock collapses from the sides and roof if they are unfavourably disposed with reference to the long axes of the underground caverns, especially when the span is more than 10 m.

It is advantageous in respect of cost and time to retain the undamaged rock ledges along the two sides of the underground caverns for resting the crane beams, provided the rock to be excavated is found to be competant. This can be achieved by scrupulosly following the pre-splitting technique during excavation.

Reaching the springing level for the full stretch of the underground caverns through ramps accommodated within the final dimensions of the caverns, stabilising the arch portion by rock bolts and plain concreting and then knocking off the bench in stages to the ultimate size and shape are the simple conventional methods adopted while excavating underground caverns of the Varahi Hydro Electric Project.

Grouted rock bolts are preferred over the ordinary type of wedge type rock bolts for achieving the desired results.

The three underground caverns are behaving satisfactorily without showing any signs of distress either at the roof or at the vertical walls since last 3 years of their commissioning.

ACKNOWLEDGEMENT

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