Case History of a Partially Underground Power House

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SYNOPSIS : In the normal rock conditions, conventional type surface power houses have been built, whereas in structurally sound rock with sufficient rock cover, underground power houses have been attempted in India. The geological uncertainities plays major role in deciding the type of power house at a particular site. While in the surface type conventional power house huge excavation and concreting are involved, the access to the power house involves major work in the case of underground power house. There are very little examples when semi underground type of power houses have been attempted in India. The Mahi power house-II of Rajasthan is the sole attempt of shaft type of power house after the succesful completion of small Giri power house in Himachal Pradesh. This paper presents the case study of this shaft type semi underground power house. Important features about its layout, design and construction have been discussed here.

INTRODUCTION

Mahi Bajaj Sagar Project is a multi purpose river project providing irrigation facilities besides generation of power at two power houses. The power house-I is located at about 8 Km upstream of Mahi dam. The water released from this power house is discharged through balancing reservoir No.1 and thereafter through the canal and hydel channel to balancing reservoir No.2 which is the forebay of power house-II. The power house-II is having installed capacity of 3x45 MW. This power house was initially planned as a conventional type of surface power house involving nearly 3.75 lacs cum of excavation in 58 M deep open pit and 44,000 cum concreting. The huge quantities of excavation and concrete and availability of reasonably good rock strata made to re-think about the whole planning of this power house. By that time nearly 90,000 cum of rock excavation had been completed as per original layout. After examining all aspects about the geology and the type of treatment required, the power house layout was modified and the idea of shaft type power house was conceived.

GEOLOGICAL FEATURES

The country rocks in the area are phyllities intercalated with amphibolites quartzite or quartzite bands of Aravali super group, later being in much lesser quantity. The foliation strikes from N 30^{o}W - S 30^{o}E to N 20^{o}E-S20^{o} W with 20^{o} - 40^{o} dips on either side. The values of 'c' and 'ø' obtained were 22.5 Kg/sq.cm. and 66^{o} respectively.

LAYOUT FEATURES

Since the excavation work as per the conventional type surface power house layout had already been taken up upto certain elevation, the revised layout was proposed on the following lines.

(a) The power house has been excavated as an open pit upto the erection bay level i.e. El-147.5m. (NSL being 176.0m). The auxilliary space requirements have also been accommodated in the open pit excavation.

(b) The generating units have been placed in individual circular/vertical shafts of 16.3 m dia and 30.5 m depth. Rock ledge between unit 1&2 is only 6.0 m whereas between unit 2&3 it is 10.25 m as the unit 3 was taken up at a later stage when shafts for unit 1&2 had been excavated & protected by rock bolts & shotcrete.

(c) For the access to the various parts of generating units, the inter connecting tunnels have been provided at 3 levels at generator floor at El-139.80 m, turbine floor at El-136.15 m and draft tube inspection gallery level at El-126.10 m.

(d) Separate tunnels for penstock and draft tube have been provided with each shaft for entry and discharge of the water. For control/regulation of the downstream water levels, the draft tube gate shafts have been excavated in oblong shape.

(e) The approach to the power house is available only upto El-166.0 m and therefore, unloading bay has been provided at this level. Provision of lift alongwith staircase has been kept for access to the auxilliary floors, erection floor and generator floor.

(f) Various pipes, cables etc. from the generator level have been taken to the auxilliary floors through the nitches excavated in the shafts to house their requirements.

(g) The excavation to the downsteam of unit bays had been restricted to the level it was

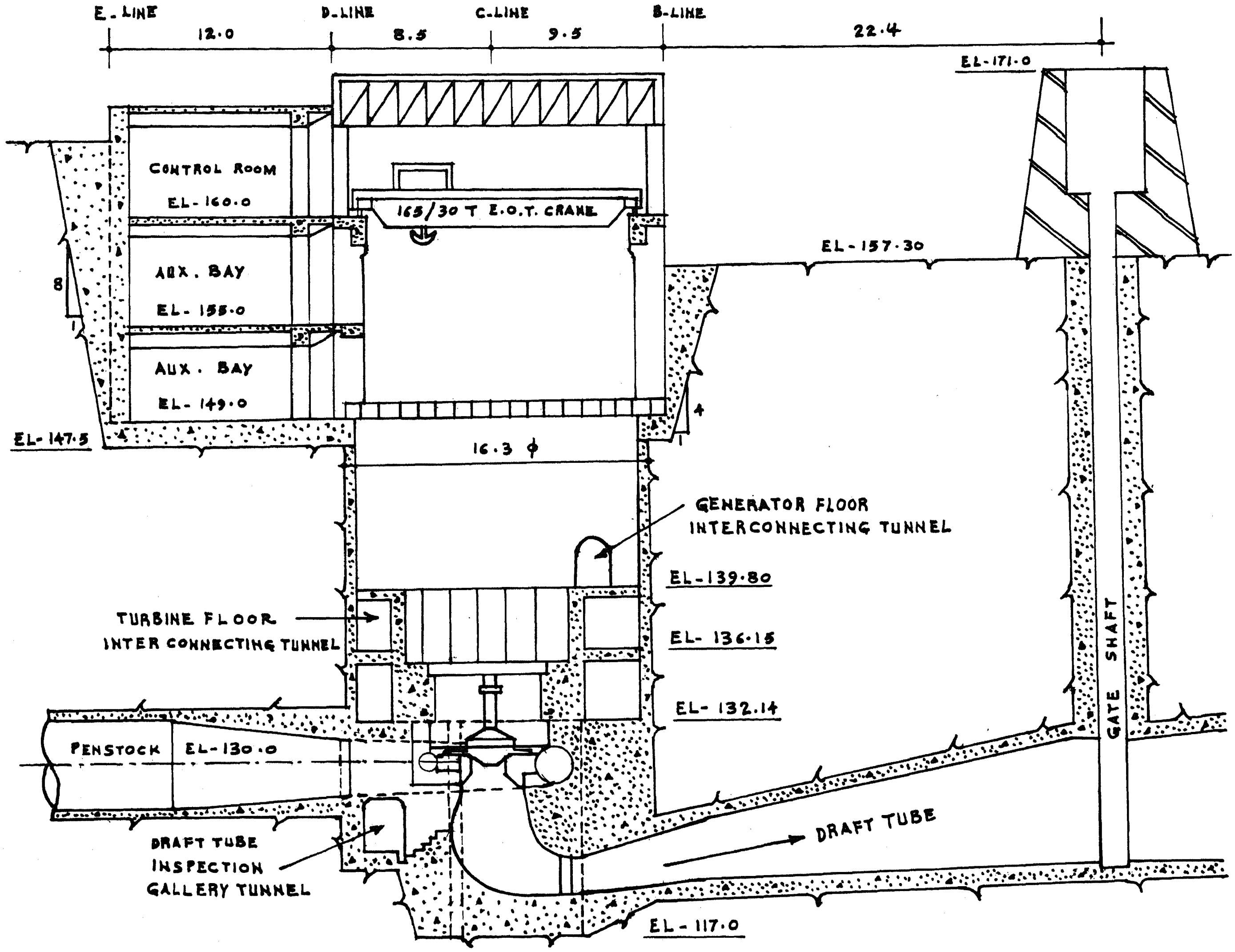

Fig.1 Cross section of power house

carried out till revision in the layout was made to save the height of protection wall.The protection wall of nearly 14 m height has been provided to protect the power house from the floods of river Anas flowing downstream of the power house.

DESIGN FEATURES

The shafts had been excavated after going for an open excavation upto the El-147.5 m on upstream side and upto El-157.0 m on downstream side. In open excavation stable slope of 1/4:1 had been adopted from top upto El-157.0 m and of 1/8:1 below El-157.0 m. The greatest risk involved in underground construction projects is the uncertainity in predicting ground conditions and assessing rock behaviour at the site. For stability of vertical rock surfaces in the shafts, surface treatment consisting of rock bolts and shotcreting have been adopted. Adequate drainage arrangements to drain rocks around the shafts have been made. Further, R.C.C. lining has also been provided to help in resisting the hydro-static pressure from the rock.

Rock Bolting

Tensioned rock bolts with the slot and wedge type anchorage have been used as rock reinforcement to prevent the deformation or dilation of the rock,to mobilise the rock's natural competency to support itself with its inherent strength and to provide resistance to inward movement of rock. Rock bolts of 4 m length made from 25 mm dia for steel bars were installed in a regular pattern at a spacing of 1.75 m c/c. For a rock bolt adequate anchorage is very important. The effectiveness of the rock bolts was ensured through pull out tests. Fig.2 gives results of some of the such pull out tests. The rock bolts were further grouted pneumatically under a pressure of 3.5 kg/sq.cm. with neat cement paste to get full length bonding with the rock surface and to avoid the loss of

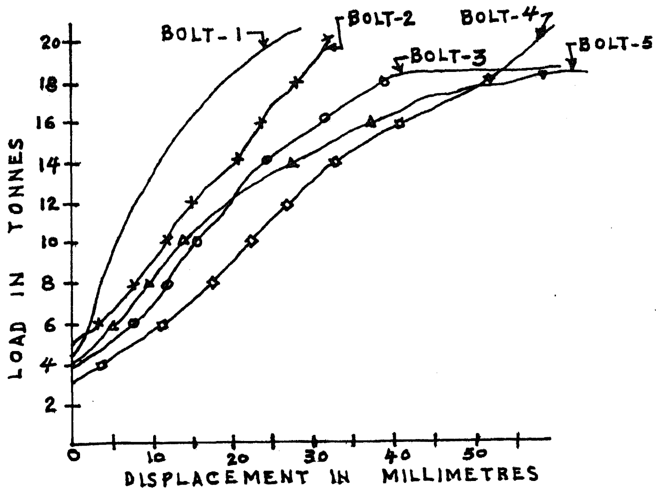

Fig.2 Rock bolt pull out test results

anchorage at a later stage. Ungrouted rock bolts were capable of taking 5 M.T. tensile load without any appreciable displacement.

Shotcreting

To make the supporting system more effective, 75 mm thick shotcrete in 3 layers of 25 mm each reinforced with 10 gauge G.I.wire 50x50 mesh chain link fabric was applied on rock faces after rock bolting in shafts. The chain link fabric was fixed on the rock surface with the help of anchor bolts. Shotcrete mix was designed satisfying requirements such as shootability, self supporting without segging or sloughing early strength, durability, minimum rebound, economical etc.

Shotcrete was applied with dry mix technique at a pressure of 3.5 kg/sq.cm. Natural river gravel in maximum size 12.5 mm were used as coarse aggregates. The mix of the shotcrete finally selected was as below.

Ingradients	Batch weight.	Percentage of total batch weight.
Cement	525 Kg.	23.16
Gravel	697 Kg.	30.74
Sand	1045 Kg.	46.10
Total	2267 Kg.	100.00

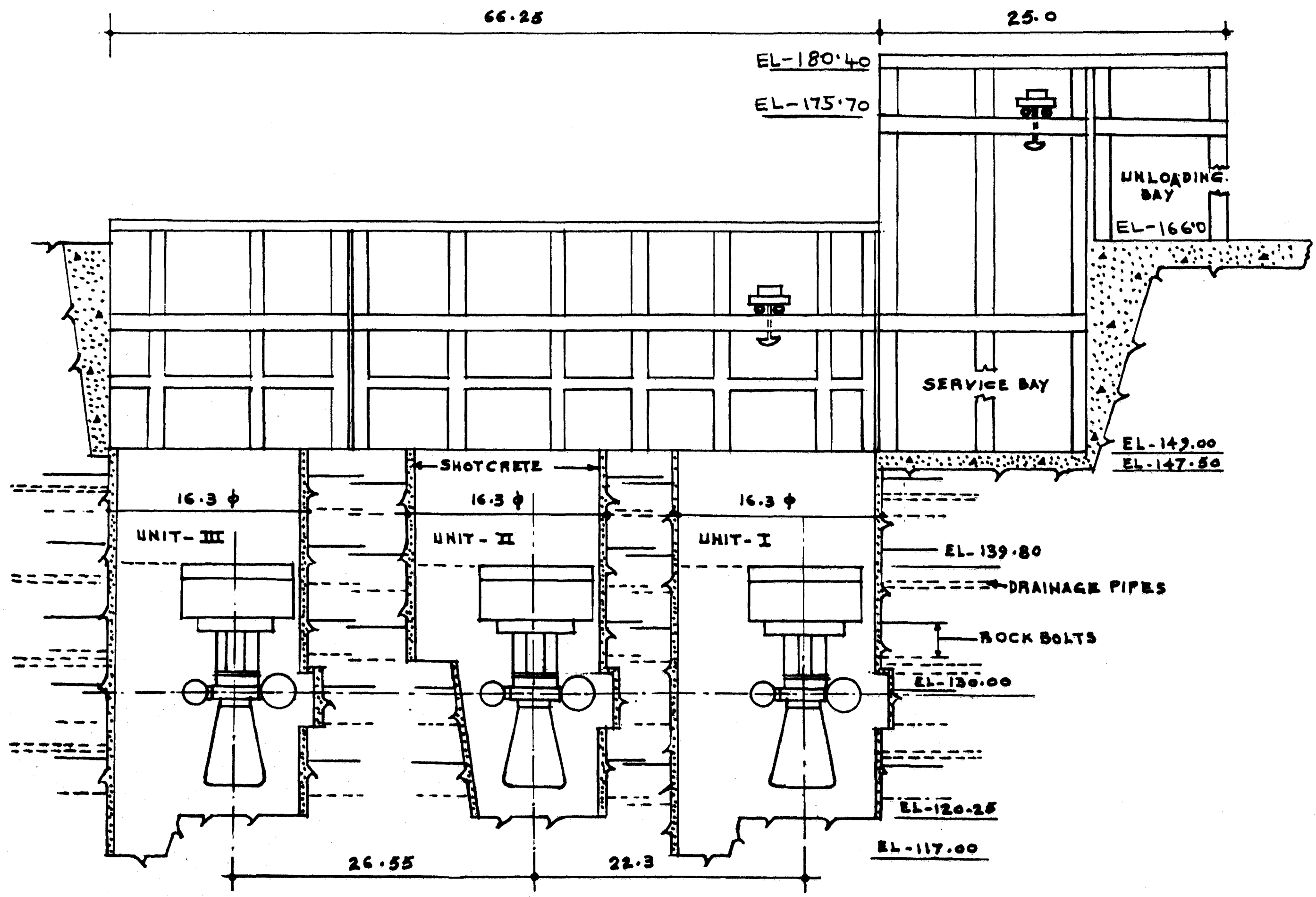

Fig. 3 Longitudinal section of power house.

The shotcrete with the above mix gave compressive strength of above 250 Kg/sq.cm. 2% sodium carbonate in dry powder form by weight of cement was used as set accelerator admixture for locations where rapid gain in early strength was required. With this mix, maximum rebound noticed was 30%.

Drainage Arrangement.

In order to release the pore pressure inside the rocks, drainage arrangements have been provided by inserting 4 m long, 75 mm dia. perforated pipes at a staggared spacing of 3 m c/c in the rocks. These perforated pipes allows seepage water from inside the rock to percolate into the drainage pit through a system of horizontal and vertical pipes. Apart from canalising the seepage water, arrangements have been made to divert surface water also. A drainage sump at the bottom most auxilliary floor at El-147.0 m has been provided to collect seepage water from the rock mass above shaft level through perforated pipes and porous drains.This seepage water collected into the sump is then pumped into the downstream river.

Structural Lining in the Shaft.

R.C.C. Lining 400 mm thick duly anchored to the rock surface has been provided in the shaft to resist the hydro-static pressure from the rock. Although arrangements for percolation of water have been made to reduce the hydro static pressure on the lining but due consideration has been given in the design of lining for this too. Residual in site pressure have also been accounted as function of overburden pressure. R.C.C. raft has been provided to transfer the load from crane columns to the rock masses. This arrangement has not only cut down the excavation further for the column foundations but also avoided any damage to the shafts due to concentration of stress as the columns are very close to the periphery of the shafts.

CONSTRUCTION FEATURES

The main features of construction are rock excavation, rock bolting, shotcreting, concreting and equipment erection work. Time leg in different operations such as excavation, rock bolting, shotcreting etc. is a very important parameter which largely depend upon quality of rock and site conditions. This time leg should be kept at minimum so that strains of inelastic nature are arrested early following excavation.

Excavation

Excavation for shaft has been carried out by controlled blasting and pre-splitting technique to safeguared against the damage to rock face and to keep the overbreak to the minimum. Rock ledge between shaft No. 1&2 is only 6m. and all precautions were taken to prevent any damage or overbreak in this rock ledge. Certain overbreaks were observed along the periphery at top in the initial stage for which special treatment had to be carried out as the column edges were falling on some overbreak portions.

Rock Bolting.

The strength of a rock bolt is determined by its anchorage and adequate anchorage is very critical to the proper performance of the rock bolt. In a slot and wedge type rock bolt anchorage is obtained by inserting the wedge into the slotted end of the bolt and expanding the slot by driving the wedge against the end of the drill hole. Hence strict control over the length of drill hole has to be exercised. Further hammering cap was used to prevent damage to the threads of the bolt on hammering. Full expansion of slot by maximum insertion of wedge into it is to be ensure required tension of 5.0 M.T. in the rock bolt.

Although rock bolts were installed in regular pattern, additional bolts in localised areas of instability and weakness were also provided as spot reinforcement. All rock bolts were grouted under pressure of 3.5 kg/sq.cm. with neat cement slurry through a small key hole slot left in the bearing plate. The drill hole was 40 mm and the rock bolt was of 25 mm dia deformed bars therefore not much space was there between the hole and the rock bolt and so great care was required to ensure complete packing of the cavity.

Shotcreting

Dry process shotcrete was adopted for the shafts and tunnels applied in 3 layers of 25mm each

Fig. 4 Photo showing shafts

with chain link fabric as reinforcement. Highly experienced operator and nozzleman are required for good quality shotcrete work. Nozzleman alone controls main factors effecting quality of shotcrete work such as water-cement ratio, distance between nozzle and the surface, angle of the nozzle, stream & motion of the shotcrete etc. Uniform air and water pressure was ensured to prevent uneven flow of dry mix and to minimise pulsations in the delivery hose. Constant vigil over the pressure gauges was kept for controlling the shotcrete thickness steel pins were anchored in the rock. Reinforcement was located in the final layers of shotcrete to keep it near the outer fibers of shotcrete to make it more effective and useful in playing its important role of resisting bending moment which may develop in the rock. Chain link fabric due to its flexibility could be easily placed on undulated rock profile in the defined 75mm thickness of shotcrete. It is the work which requires close control and supervision at all levels.

Concreting.

The concreting in such power house carries significance specially in the shafts. Quantitatively it is small but it requires adequate arrangements. Since direct approach to the shafts for transportation of materials is not available, the concreting in shaft is possible only through a crane or any heavy handling equipment. The other important and little difficult item is the circular lining in the shafts. The lining is required to be anchored to the rock surface properly. The special features of the construction is raising of this lining not from the bottom but from higher elevation i.e. from generator floor level in the shafts. Since the area in the shafts is quite limited and the erection of electrical parts may create problems due to the very little space available between the vertical face of the shaft and electrical parts, the lining in these portions has not been raised till the time the erection work is completed. This requirement of the erectors resulted in change in the pattern of construction and thus raising of lining from higher elevation. This arrangement involved additional anchoring and formation of a ring beam at this elevation. Great field problems have been experienced in raising the lining from higher elevation as it involved a massive scaffolding arrangement and the preparation of a plateform for handling of materials. The thickness of concrete lining is only 400 mm and placement of reinforcement and maintaining its continuity becomes more difficult in such small section particularly where vertical header pipes for carrying the seepage water to the drainage pits have been encountered.

Such difficulties in concreting have resulted into more time consumption in placement of reinforcement and erection of shuttering. Difficulties for proper access to the shafts mainly in the gate shaft have also been felt during the construction.

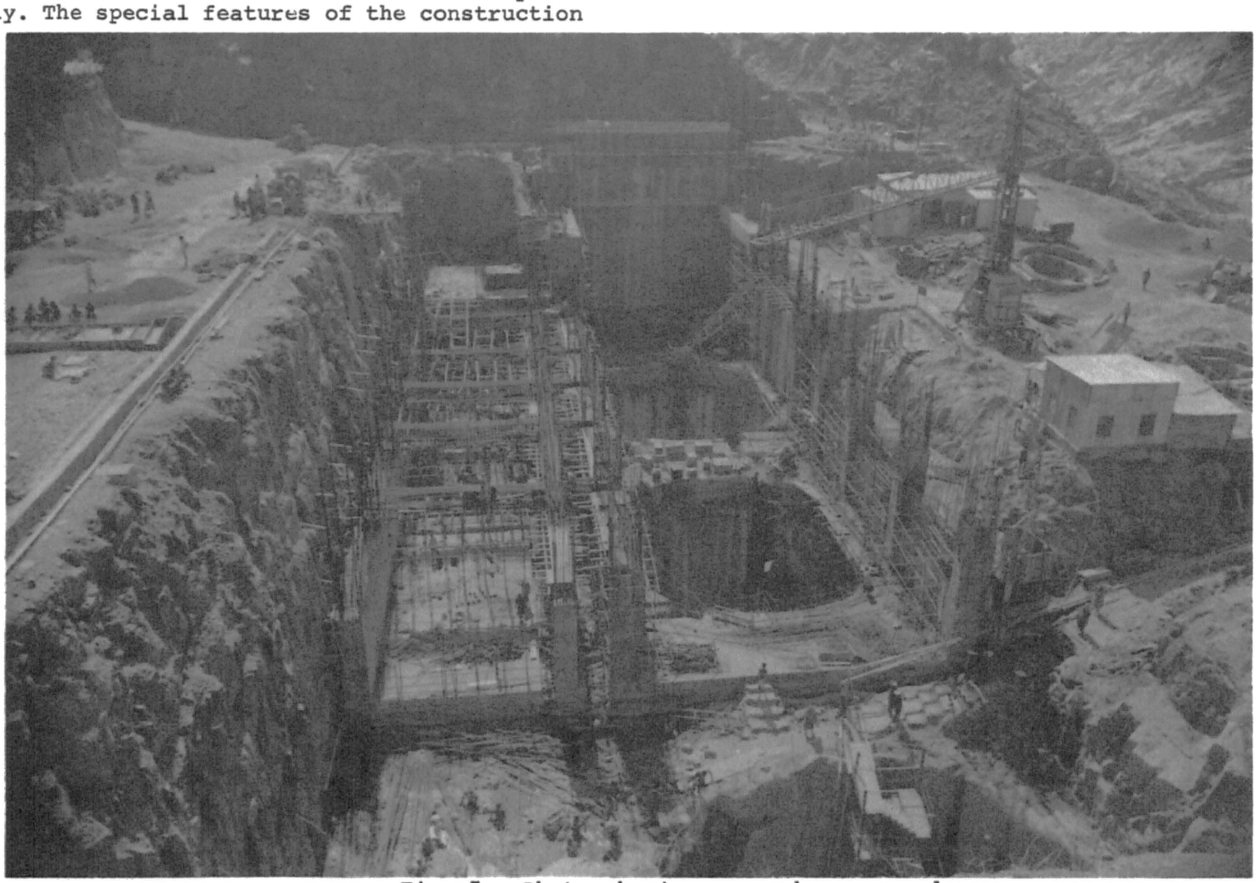

Fig. 5 Photo showing power house complex.

ERECTION FEATURES

Normally in the conventional type of power house, the erection is started when the E.O.T. crane is put to operation. A different approach has been adopted here. The erection of the draft tubes has been carried out with the help of a mobile crane. Similarly, speed ring has also been lowered with the help of mobile crane. The limited working space in the shaft poses many problems in the erection work.

CONCLUSIONS

The power house shafts after rock bolting and shotcreting were left for more than 2 years without any construction activity because of some unavoidable circumstances. The supporting system has proved to be very effective and useful as the vertical surfaces of shafts faced all adverse effects of weather including rains successfully for 2 years and no adverse effect or instability or deformation in any portion of shafts was observed.

The planning of a shaft type of power house is an important and interesting feature. It is definite that these power houses are quite economical both in respect of cost and time. However, judicious planning is required both for the layout and construction. Margins for the overbreaks and under cuts had to be made while deciding the location of columns, Nitches etc. Although the quantum of excavation and concreting gets reduced in shafts, but at the same time it requires more accuracy, it is costly and time consuming due to restricted space, areas and limitations of access. While deciding the layout of equipments, the erection space required for handling and erection of equipments requires due consideration.