Excavation of Turbine Pits for a Hydroelectric Project - A Case Study

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ABSTRACT

The paper deals a practical case study of excavation of turbine pits in the powerhouse cavern of the Sardar Sarovar Project, India. These pits are to be used for installation of six Francis type reversible turbine generators, each of 200 MW. The pits were excavated by drilling and blasting method under adverse geological conditions such as distress problem in the cavern, presence of shear zones, thin rock ledges, etc.

For overall stability of the cavern and pit walls, the vibration due to blasting was minimised by excavating the pits in three stages and by reducing the maximum charge per delay to the extent possible. The details of the drilling, charging and initiation patterns used for different stages of the pits are given. The overbreak was controlled by adopting modified line drilling/smooth blasting techniques. The deviation of the actual line of excavation from the designed vertical wall of the pits was measured and the percentage of overbreak in terms of the total volume of the pit was calculated. The treatment provided to the pit walls, pit bottoms and shear zones are also discussed in the paper.

Keywords: Controlled blasting, turbine pits, rock excavation, powerhouse cavern

1. INTRODUCTION

The drilling and blasting is the predominant method of excavation of powerhouse caverns, tunnels and other underground structures. Unlike mine openings that serve for a limited period, the underground structures for hydroelectric projects are intended to serve for several decades. Hence, excavation of these structures demands greater control over blasting so as to minimise the blasting damage to the surrounding rock mass. Controlled blasting techniques (ISEE, 1998; Olofsson, 1991) are widely applied world over to preserve the inherent strength of the rock mass adjoining the underground openings and to ensure their long-term stability. Several controlled blasting techniques such as line drilling, presplitting and smooth blasting are used to minimise fracturing and loosening of the rock mass beyond the predetermined excavation line/profile. Contrary to conventional blasting that aims at minimising the unit cost of rock excavation without much care to blasting damage, controlled blasting aims at minimising overbreak, ground vibration and support requirements at lowest possible cost of excavation.

There has been considerable interest abroad in the area of fracture control techniques such as notched boreholes, unconventional types and placement of explosives (Holloway et al., 1987). The practical application of these techniques is yet to be established. However, the underground construction can be benefited from the well-established principles of controlled blasting. It may be appreciated that hydroelectric projects in India are adopting controlled blasting techniques in place of conventional blasting.

The National Institute of Rock Mechanics (NIRM) has provided technical guidance related to controlled blasting to several hydroelectric projects in India. At Sardar Sarovar Hydroelectric Project in Gujarat, NIRM was involved in removal of the concrete plugs in the draft tube tunnels (Adhikari et al, 2001a), removal of the ramp (Adhikari et al., 2001b) and excavation of the turbine pits in the powerhouse complex. The turbine pits were excavated during March 2000 to June 2001 under the guidance of NIRM.

2. DETAILS OF THE TURBINE PITS

2.1 Layout of the Turbine Pits

The underground powerhouse at the Sardar Sarovar project is 23 m wide, 56.6 m high and 220 m long. The powerhouse cavern will house six Francis type turbine units rated at 200 MW each. For this six turbine pits were excavated from (-) 1.9 m level to (-) 11.6 m level, that is to a depth of 9.7 m. The layout of the excavation of turbine pits is given in Figure 1. The width of each turbine pit was 18 m on the downstream wall and 7.0 m on the upstream wall. The length of the pits was 17.7 m. The rock ledge between the pits was as small as 7.0 m. Approximately 15000 m^3 of rock had to be removed for excavation of the turbine pits. The shape and dimension of the pits were decided by the dimension of the turbine units and were similar to those of the powerhouse cavern of the Srisailam Hydro-electric project in Andhra Pradesh State of India which also has six turbine units, each of 150 MW (Mande et al., 1999).

2.2 Geology of the Turbine Pits

The turbine pit area mainly consists of dolerite sill and partly of porphyritic basalt and agglomerate. The rock is fresh and strong. The physico-mechanical properties of the rocks present in the pits are summarised in Table 1.

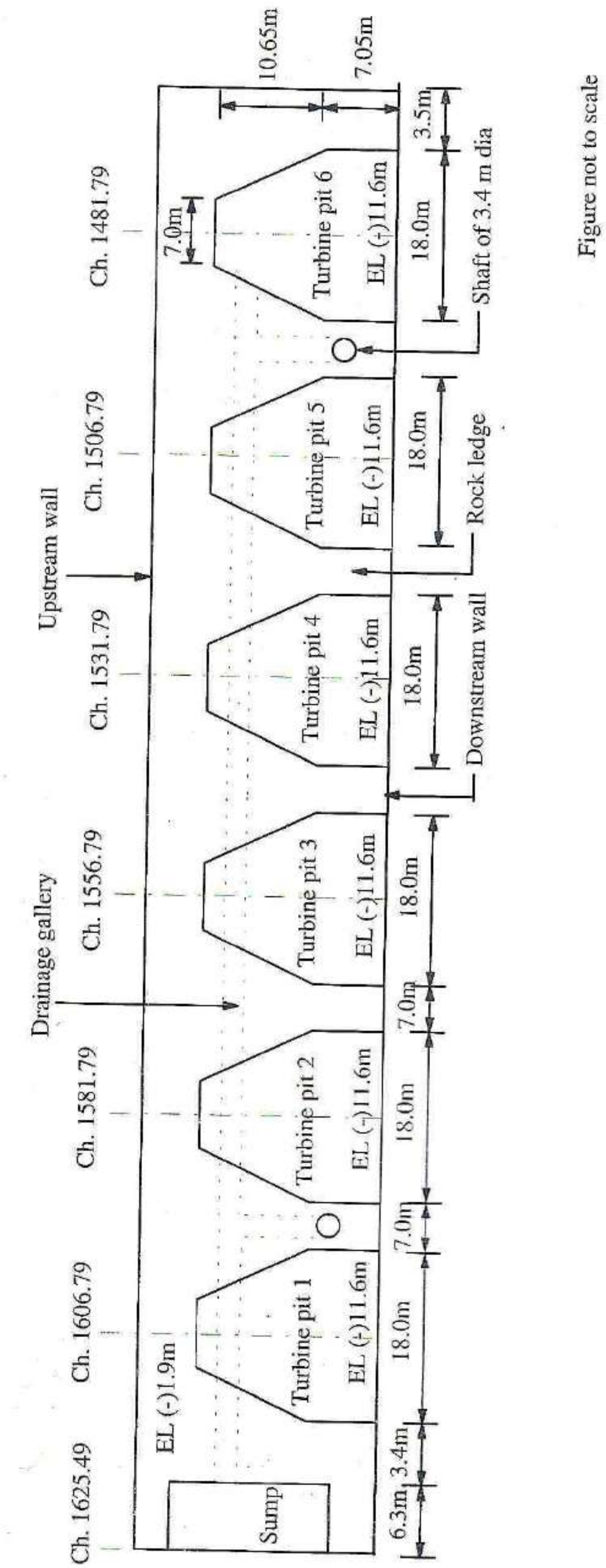


Figure 1 Layout of turbine pits to be excvated in the powerhouse cavern of Sardar Sarovar Project

Table 1 - Physico-mechanical properties of the rock encountered in the turbine pit area

Rock type	Porosity (%)	Specific gravity	Unconfined compressive strength (MPa)
Dolerite (Sill)	2.77	3.0	78
Porphyritic basalt	2.09	2.98	89
Agglomerate	3.79	2.87	64

Three shear zones 'A', 'B' and 'F' were inferred on the basis of core drilling data and geological mapping. The shear zone 'A' came across in unit 4 and 5, shear zone 'B' in unit 2 and shear zone 'F' in unit 6. They are steeply inclined (60 to 80^0) and 0.2 to 1.0 m thick. They mainly consist of rock fragments and associated with calcification and chloritization. The rock mass in the turbine pit area is intersected by four sets of joints. The orientation and spacing of each joint set are given in Table 2.

Table 2 - Orientation and spacing of joints in the turbine pit area

Joint set	Orientation	Spacing (m)
J1	N 30^0 W/80^0 NE	0.4-1.0
J2	N 60^0 E/70^0-80^0 SE	0.8-1.0
J3	N 40^0 E/20^0-25^0 SE	0.3-0.5
J4	N 20^0 E/75^0 NW	0.5-0.8

The foundation of unit 1 rests largely on porphyritic basalt, unit 2 on dolerite and phorphyritic basalt, unit 3, 4 and 5 on dolerite and unit 6 on dolerite and agglomerate.

3. METHOD AND SEQUENCE OF EXCAVATION

3.1 Reasons for Controlled Blasting

For the following reasons, the turbine pits were excavated by controlled blasting.

- The wall rocks of the turbine pits should not be disturbed and overbreak in the pit walls due to blasting should be minimal.
- During excavation of the powerhouse cavern at the Sardar Sarovar Project, distress problem was encountered due to limited amount of cover and the presence of shear zones. After cracks were observed on the cavern walls, further excavation was suspended until additional treatments for the walls and other openings were evolved (Mittal et al., 1999) and completed. The overall stability of the powerhouse cavern was also a matter of great concern and resorting to blasting for further excavation of rock in the powerhouse complex had to be very well controlled.

- The ledge between the turbine pits was only 7.0 m. In addition, the rock forming the ledge/pillar was also weak. Although full-column-grouted rock bolts were provided, before commencing the excavation of the turbine pits, from (-)1.9 m level to (-)11.6 m in the entire rock pillars, controlled blasting was necessary to minimise the damage to these rock pillars.
- Two shafts were also sunk between turbine pit 1 & 2 and 5 & 6 in the ledge of 7.0 m. The diameter of the shafts was 3.4 m which reduced the rock ledge to only 1.8 m between turbine pits 1& 2 and 5 & 6. Apart from the shaft, column footings had to be excavated in the ledge near the downstream wall of the cavern. Since this ledge had to be retained in sound condition, the excavation of the turbine pits was very critical.
- The foundation of the pits should not be disturbed because large turbine units had to be installed at the pit bottom.

3.2 Sequence of Excavation of the Turbine Pits

The excavation of turbine pit 1 commenced first. After excavating it to (-) 7 m, the excavation was suspended, otherwise the access to the machine hall through draft tube tunnel 1 and pit 1 would have been cut off. The excavation was resumed after making another approach to the machine hall from the draft tube tunnel 6 by lowering the river side half portion of the turbine pit 6 to about (-) 6.0 m level. After that the turbine pits 2 to 6 were excavated. Turbine pits 3, 4 and 5 were excavated simultaneously but the excavation of pit 3 was leading pit 4 and that of pit 4 was leading pit 5. The excavated material was removed using excavators with a bucket capacity of 0.9 m^3 of L&T make. The blasted material from the turbine pit 1 and 2 was transported through the draft tube tunnel 1 and 2 respectively. Excavation of turbine pits through draft tube tunnels is the standard practice in other hydroelectric projects (Sharma and Chauhan, 1999). As draft tube tunnels 3 and 4 were not completed before the excavation of turbine pits 3 and 4, the ledge between turbine pits 2&3 and 3&4 were cut to transport the blasted material. Although the cut helped in continuous excavation and transportation of the turbine pits even during monsoon, it increased the excavation and construction cost. When excavation of turbine pits 5 & 6 was started, the draft tube tunnels were already through and hence there was no problem for transporting the material.

4. BLAST DESIGN FOR EXCAVATION OF THE TURBINE PITS

4.1 Selection of Explosive and Initiation System

The explosive used was Superdyne, a cap sensitive small diameter aluminised slurry, manufactured by IDL Industries Limited. Each cartridge of the explosive was 25 mm in diameter, 200 mm in length, weighing 0.125 kg. The density of the explosive was 1150-1250 kg/m^3 and the velocity of detonation was 3400-4000 m/s.

Various alternatives such as using special explosives, polystyrene diluted ANFO, detonating cord and cartridged explosives separated by spacers

(Adhikari and Babu 1994) were considered for charging of perimeter holes. Finally, two cartridges of Superdyne with detonating cord were loaded at the bottom of the perimeter holes. A paper plug was pushed into the hole up to the depth of 0.8 m to create an air gap and the upper portion was stemmed. The detonating cord having 10 g of PETN per meter was used as a decoupled charge in perimeter holes as well as simultaneous firing of a group of perimeter holes.

Two types of electric detonators were used. Short delay electric detonators had delay numbers ranging from zero to ten, with a nominal time interval of 25 ms between successive delay numbers from 1 to 6, 50 ms for 7 and 8, and 75 ms for 9 and 10. Long delay electric detonators had delay numbers ranging from zero to ten, with a nominal time interval of 500 ms between each successive delay number. These detonators were manufactured by IDL Industries Limited, India. The delay periods of either short or long delay detonators alone were insufficient to control blast vibration. Hence, a combination of short and long delay series was used to restrict the maximum charge per delay.

4.2 Blast Design Parameters

The area of the turbine pit was large enough to blast in a single round. Moreover, the available delay detonators were insufficient to limit maximum charge per delay so as to control the blast vibration. Therefore turbine pit was divided into three stages for excavation as illustrated in Figure 2. Blast designs for different stages were prepared separately.

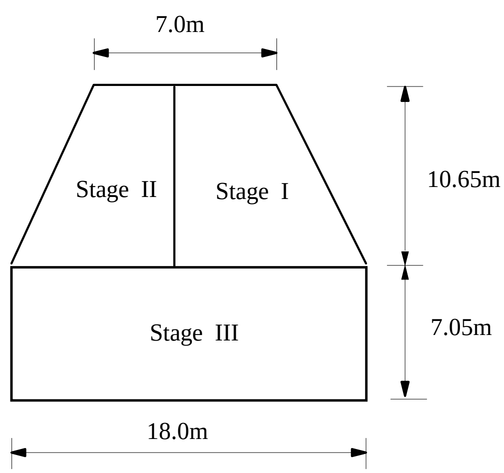


Fig. 2 - Stages of excavation of turbine pits

The blast design was made by integrating fundamentals of controlled blasting (ISEE, 1998; Olofsson, 1991) with the experience obtained while removing the ramp in the same powerhouse cavern (Adhikari et al, 2001b).

The excavation of Stage I started with drilling of wedge cut holes for creating a free face. Ingersol Rand CM 341 mounted on EVL 130 wagon drills were deployed for drilling 51 mm diameter holes. These drills were used for drilling holes for rock bolting. The hole depth was 2.0 to 2.2 m. The perimeter holes were drilled with a spacing of 0.3 m. All production holes were charged with six cartridges per hole, the holes adjacent to the perimeter holes were charged with four cartridges and the alternate perimeter holes were charged with 2 cartridges per hole. Thus the ratio of charges for production, adjacent to perimeter and the perimeter holes was 3:2:1. The drilling, charging and initiation patterns for Stage-I are given in Figure 3.

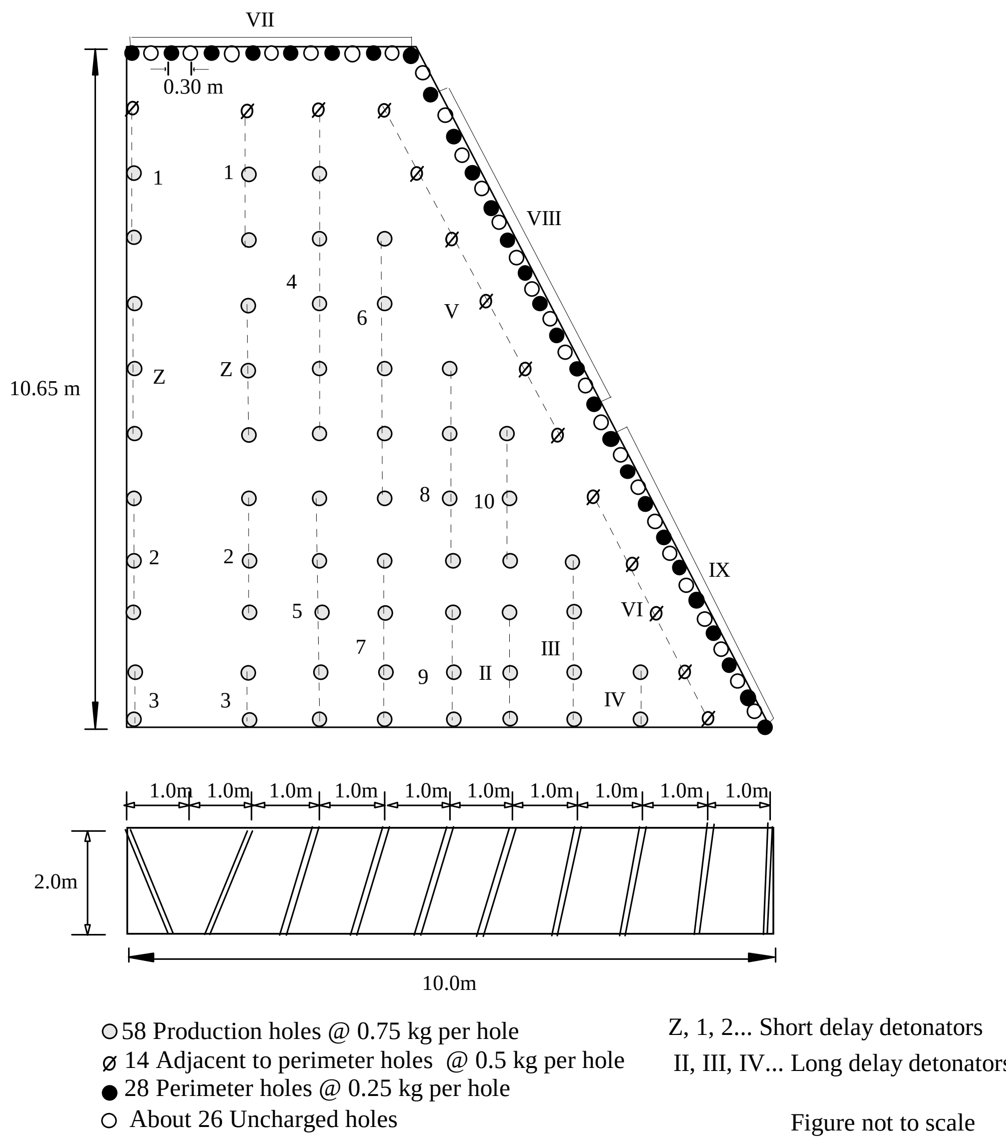
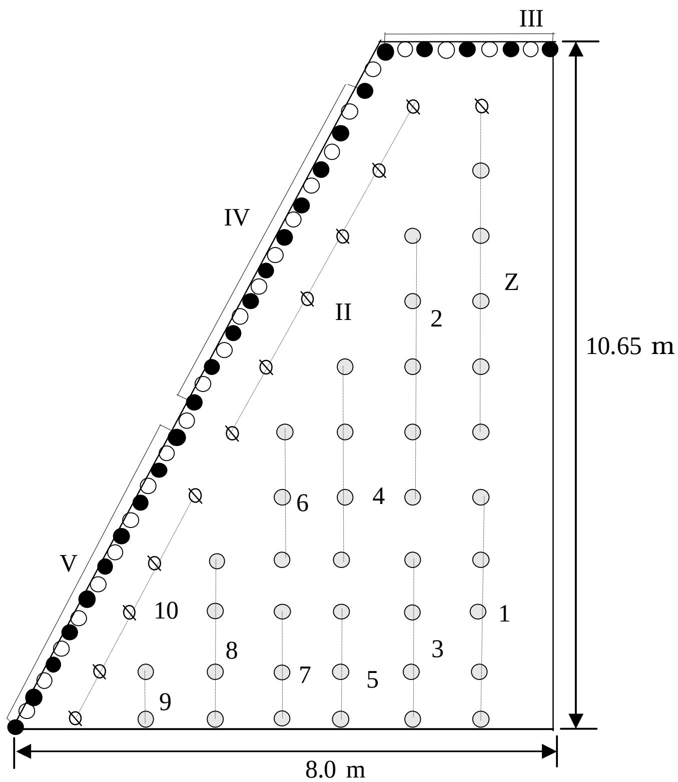


Fig. 3 - Blast design for excavation of turbine pit (Stage-I)

The excavation of Stage-I created an additional free face for Stage-II and therefore wedge cut was not necessary. Vertical holes were drilled on spacing and burden of 1.0 m x 1.0 m. The charging pattern remained same as that of Stage I but the initiation pattern was different on account of the additional free face. The blast designs for Stage-II is given in Figure 4. Blast design for Stage-III (Figure 5) was not different in principle from Stage-II.



○ 38 Production holes @ 0.75 kg per hole
⦰ 12 Adjacent to perimeter holes @ 0.5 kg per hole
● 25 Perimeter holes @ 0.25 kg per hole
○ 24 Uncharged holes

Z, 1, 2... Short delay
II, III, IV... Long delay

Figure not to scale

Fig. 4 - Blast design for excavation of turbine pit (Stage-II)

Further details of the design parameters for different stages are given in Table 3. Based on previous experience (Adhikari et al, 2001b), the maximum charge per delay was restricted to 4.5 kg to control ground vibration.

The technique used differed from line drilling in that alternate holes were charged. The fact that the firing of these charges tended to crack or split the rock between the holes permitted wider hole spacing than line drilling. The spacing of 0.3 m for perimeter holes was much greater than the recommended spacing for line drilling (ISEE 1998). The drilling pattern for holes adjacent to perimeter was different from the recommendation of others (ISEE 1998); that is, the burden and spacing for these holes were not reduced compared those of other holes.

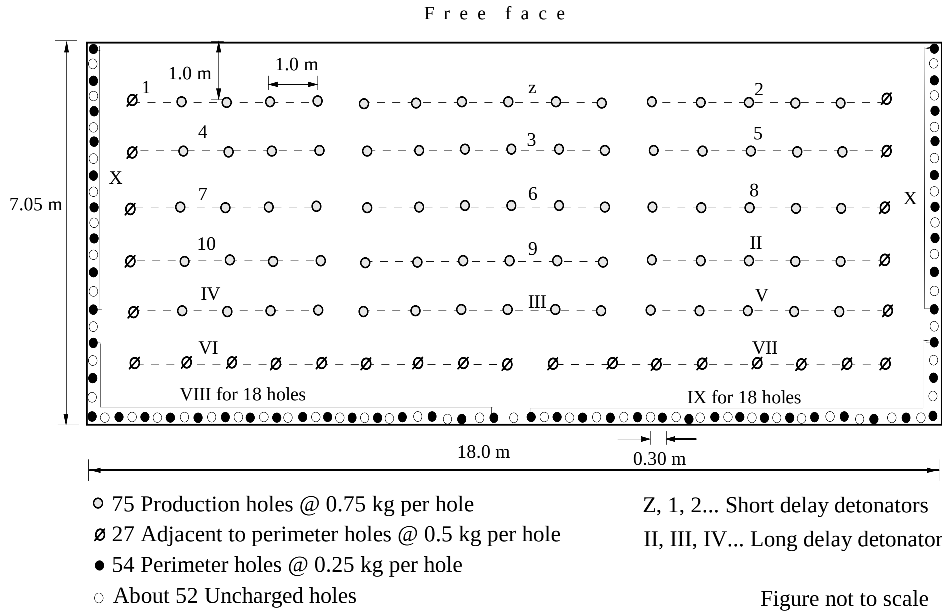


Fig. 5 - Blast design for excavation of turbine pit (Stage - III)

Table 3 - Details of the blast design for different stages of excavation

Parameters	Stage I	Stage II	Stage III
Hole diameter, mm	51	51	51
Drill hole pattern	Wedge cut	Vertical	Vertical
Hole depth, m	2.0-2.2	2.0-2.2	2.0-2.2
Total charge, kg	57.5	42.0	83.25
Maximum charge per delay, kg	4.5	4.25	4.5
Volume of excavation, m^3	155	112	254
Specific charge, kg/m^3	0.37	0.37	0.33
Specific drilling including uncharged holes, m/m^3	1.70	1.94	1.71
Specific drilling excluding uncharged holes, m/m^3	1.35	1.47	1.28

5. RESULT OF BLASTING

The measured ground vibrations were comparable to those of ramp excavation (Adhikari et al, 2001b). Extensometer readings did not indicate any appreciable movement in the walls of the powerhouse cavern. There was no visible damage to underground structures surrounding the turbine pits.

The presence of four sets of closely spaced joints (Table 2) was favourable for fragmentation but unfavourable for controlling overbreak. Some minor slides along the joints were inevitable.

The extent of deviation of the actual line of excavation from the vertical, called off-set was measured by conventional surveying method at different depths. The measurements were made on two perpendicular directions passing through the centre of the pits. Figure 6 shows the plots of the off-set against the depth for four turbine pits on the access tunnel (A/T) side, river side and upstream (U/S) side walls of the pits. The off-sets indicate the amount of overbreak.

It can be seen that the off-sets on any particular side wall are neither higher nor lower compared to other two sides and these off-sets are limited to 0.5 to 0.6m for all the four pits. A few abnormal off-sets were due to sliding of rock blocks along the joints. The average off-set for all pits was 0.30 m, which means that the overbreak in terms of the total volume of excavation of the turbine pits was less than 5 per cent.

The off-sets shown in Figure 6 represent the level of control which could be achieved for the condition of the projects and which may be expected in similar type of rock excavation.

6. SUPPORT SYSTEM USED IN THE TURBINE PITS

The exposed walls of the turbine pits were supported concurrently. The support system included,

- Two layers of 38 mm thick shotcrete, with wire mesh in between.
- 32 mm diameter, 10 to 12 m long fully grouted rock bolts in the upstream side 7 m wide wall at 1.5 m x 1.0 m staggered.
- 25 mm diameter, 6 m long fully grouted rock bolts in the inclined sides of the wall at 1.5 m x 1.0 m staggered.
- 25 mm diameter, fully grouted through bolts varying in lengths (maximum 12 m) on the river side and access tunnel side walls of the pit wall at 1.5 m x 1.0 m staggered.

After reaching (-) 11 m level in the turbine pits, trimming blasts were carried out wherever required and loose rock was scaled manually to the required level. The foundation was provided with 25 mm diameter 3 m long anchors at 2 m spacing in the staggered pattern. After which the foundation area was provided with reinforced concrete for 0.6 m thick. Grouting was also provided in the floor with 52 mm diameter, 1.5 m long grouting holes were drilled at 2.0 m both ways.

The shear zones, which occurred on the floor of the turbine pits 1, 2, 4, 5 and 6, were excavated up to twice the width of the shear zone or minimum 1.0 m with side slopes of 1:0.5 and back filled with concrete.

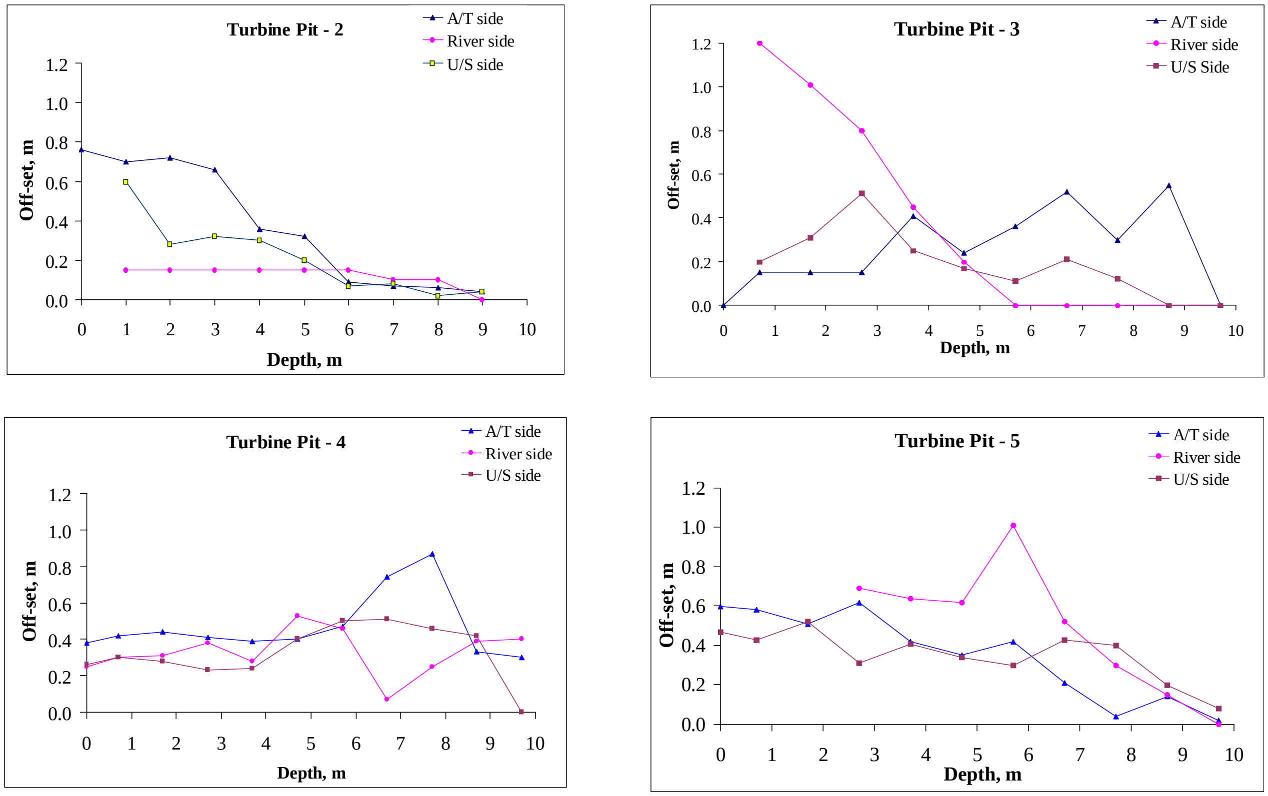


Fig. 6 - Off-set versus depth of turbine pit measured on access tunnel (A/T) side, river side and upstream (U/S) side walls

7. CONCLUSIONS

The paper presents a successful application of controlled blasting techniques for excavation of the turbine pits at the Sardar Sarovar Project. The blast design was arrived by integrating basic principles of controlled blasting and the experience gained while removing the ramp in the same powerhouse cavern. The following conclusions are drawn from this study:

- The damage to the surrounding rock mass due to blast vibration was reduced by excavating the turbine pits in three stages. The maximum charge per delay was kept as minimum as possible using a combination of short and long delay electric detonators and designing suitable initiation patterns.

- The measured ground vibrations were low and did not cause any visible damage to underground structures surrounding the turbine pits. Extensometer readings did not indicate any appreciable movement in the walls of the powerhouse cavern.

- The presence of four sets of closely spaced joints was favourable for fragmentation but unfavourable for controlling overbreak.

- The average off-set, the extent of deviation of the actual line of excavation from the designed vertical walls of the pit was limited to 0.3 m and the overbreak calculated in terms of the total volume of excavation of the pits was less than 5 per cent.

- Application of controlled blasting and suitable treatment of exposed walls led to successful completion of the excavation.

Acknowledgements

The authors are thankful to Mr. J.M. Parmar, Superintending Engineer and to Mr. V.P. Gupta, Executive Engineer of Narmada Project Power Project, Civil Construction circle, Sardar Sarovar Narmada Nigam Ltd. for their support and co-operation in the execution of this work. The co-operation of the site engineers of the Jaiprakash Associates, Kevadia is also acknowledged.

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