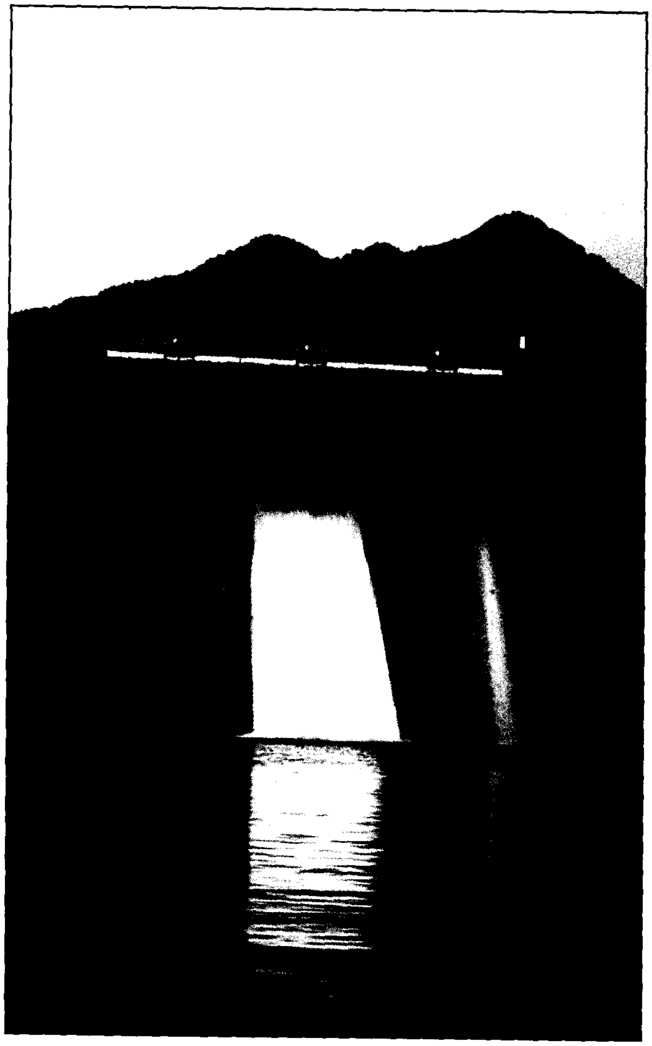


GEOTECHNICAL ASPECTS OF THE DESIGN OF UNDER WATER LAKE TAP IN KOYNA HYDRO ELECTRIC PROJECT STAGE - IV

Water Vison of India

- **Optimal Sustainable Development**
- **Maintenance of Quality**
- **Efficient use of Country's Water Resources to match the growing demands**
- **Active Involvement of all Stakeholders**
- **Achieve Accelerated, Equitable Economic Development of the Country**

Under water lake tapping is a Norwegian technique developed in that country mainly to tap the inland lakes located high up in the mountains below their normal levels for electricity generation and drinking water supply. This technique is used in sub-sea tunnels for oil and gas activities. In this technique, a shaft is sunk on the fringe of the lake/reservoir up to the bottom of the water conductor tunnel from which an intake tunnel is excavated underneath the lake to reach the lake bottom leaving a break-through rock plug which is finally blasted to connect the lake with the pre conceived water conductor system. The blast is designed in such a way that vibration produced in the adjoining rock mass and the resultant hydro dynamic pressure built up in the system are kept at minimum acceptable levels, thus protecting the adjoining structures.

This technique has been used for the first time in India as well in Asian region on Koyna Hydroelectric Project Stage-IV. This paper is a case study describing the various aspects along with geotechnical aspects from investigations to actual execution of this technique on said project.This technique has opened a new avenue on several other projects involving improved utilization of water from the existing reservoirs.

INTRODUCTION

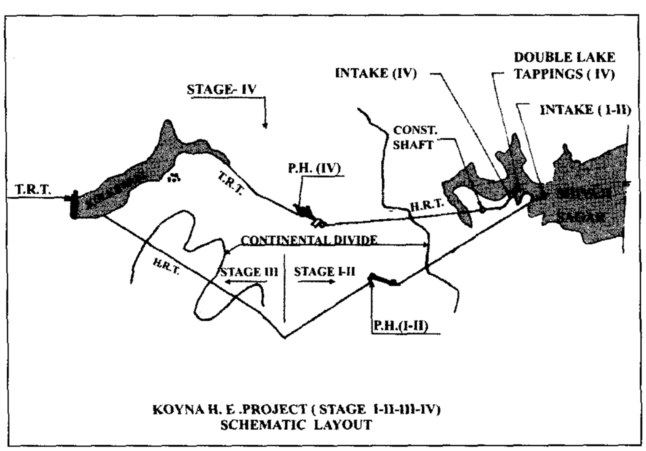
The Koyna Hydroelectric Project (KHEP) is located in the state of Maharashtra at the foothill of the Sahyadri hill range in the peninsular part of India. The project has unique geographical as well as geological features viz. abundant rainfall(+5000mm),the presence of Sahyadri hill range with westerly fall of 500 m,presence of good quality compact basalt making it one of the ideal site for an underground hydro-power project. The hydropower development on this project has taken place in stages over the past 40-45 years.

The project was initiated in late fifties with the construction of 103m high rubble concrete dam across Koyna river with a gross storage of 2797.40 MCM (98.78 TMC).The dam has multiple use with 1918.4 MCM for power generation through west-ward diversion and balance for irrigation d/s on east side along the banks of the Koyna river through a small dam foot powerhouse(2No×20MW). The stage-I&II was completed in 1966 which consists of a 3.748 km long underground head race tunnel taking off from the Koyna reservoir and leading to an underground powerhouse through four pressure shafts utilising the natural head of 475m with the installed capacity of 560MW(4No.×65MW and 4No.×75MW). The stage-III development was completed in 1976. The water released through tailrace of stage-I&II is diverted in the adjoining valley leading to Kolkewadi dam with a dam foot underground powerhouse, having installed capacity of 320MW(4No.×80MW).

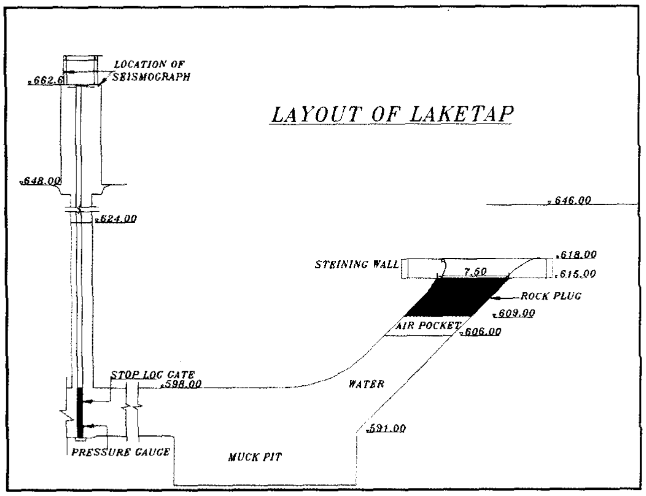
The stage-I&II is developed as a base load station with 60 percent load factor. However, the stage-III is developed as a peaking station with 24 percent load factor. However, over the years since then, the power development in the state is primarily through thermal power stations, it`s share being 80-85 percent today. But the thermal power stations are unable to meet the increasing power demand particularly in the peak hours, the Koyna stage-IV project was taken up in 1990, which has been completed in the year 2000. It is a replica of stage-I&II. It consists of an underground powerhouse with the additional installed capacity of 1000MW(4Nos.×250MW). It has unique feature, of intake structure with twin lake tapping's. After completion of stage-IV all the four stages put together act as peaking stations with the combined load factor of 18 percent but the total water use for Electricity generation remaining unchanged.

In case of KHEP-IV since the source of water is from an existing reservoir, the location of the intake structure was a real challenge. Due to perennial us of the reservoir for power generation, the natural depletion of the reservoir is not easily possible and even the forced depletion is possible some time by end May, just before the onset of monsoon in that area. As such locating the conventional over ground intake tower with approach bridge from the fringe of the reservoir was not possible due to very limited or no period available for consideration.

Thus, in case of stage-IV, an intake structure has been identified on the fringe of the reservoir above full reservoir level. The general layout arrangement for intake structure consists of four shafts, each shaft is 68m deep and has been constructed to house service gate, trash rack and two stop log gates from d/s to u/s towards lake side respectively. From the bottom of the two stop log gate shafts, two intake tunnels 6.5m dia. concrete lined 240m and 180m long each traverse towards lake side underneath the lake. At the end of each intake tunnel a muck pit has been provided from the other end of which an inclined lake tap tunnel of the same size rises at 45 degrees to reach the lake bottom. Break through rock plug of 7.5m dia. and 6m thick was left at the lake bottom for each inclined tunnel.



General arrangement of the Lake Tap is shown in the sketch.



The roll of all these components is functionally interrelated hence all these components are designed considering their interdependence. For KHEP stage-IV design discharge is 260 cumecs, as such instead of providing one large lake tap two lake taps of 6.5m diameter each are planned. These are located 35m apart. Considering the proximity of the lake, the minimum rock cover of 20m(three times diameter) is kept over the crown of the intake tunnel. The inclined shafts are aligned at 45 degree to meet the lake bottom. Further based on Model studies to avoid air entrapment, minimum 12m water cushion above the lake tap is provided. The minimum draw down level is fixed at 630.28m; against the lake floor @618.00m.

GEOTECHNICAL INVESTIGATIONS

The Koyna lake is situated in an area dominated by volcanic rock type. Typically the rock mass comprises basalt lava flows of 15-30m thickness, interlaid by layers of volcanic sediments ,such as brecia turf, agglomerate etc. The basalt layers are generally hard and unweathered at the depths of the tunnels, whilst the layers of brecia/turf display a higher degree of jointing and some tendency of disintegration.

In order to select the proper locations of lake piercing, in addition to the geographical features, Seismic refraction studies were conducted in the area to ascertain the depth of overburden & the rock parameters. The velocities mapped revelled the soundness of rock & the nature of rock mass. After choosing the tentative location & when the lake levels were nearly at the ground levels, actual drilling operations were undertaken to inspect the core recovery. All these drilled holes were immediately plugged by pouring concrete, so that during tunnelling operations ingress of accidental water leakage is avoided. The contract provisions envisaged the removal of overburden in the lake tap area by dredging and under water blasting, however, the first experience in this regard was not found to be encouraging. The lake was forcefully depleted in the last week of May 1995 and the removal of balance overburden, the protection works around the lake tap area, the construction of staining walls around lake tap etc. was undertaken on war footing. At that time, additional geological investigation like bore hole in the lake tap area, permeability test of the adjoining rock mass, rock stabilisation around the lake tap by driving rock bolts etc. was done. Some Norwegian consultants also informally visited the site and based on the rock conditions in the lake tap area viz. hard and unweathered basalt with low joint frequency, they indicated favourable conditions both for dry as well as submerged piercing. Further keeping both options open the balance over ground works were completed in the next working season during May-June 1996 by depleting the lake once again.

In the mean time, the contractors Patel Engineering Ltd. Mumbai were officially instructed to hire the services of Nor consult for planning and designing of submerged lake tapping for KHEP-IV. They submitted their first report in August 1996 to witness the actual lake tapping and had deep and thorough discussion with the Norwegian consultants for underwater piercing to be adopted for KHEP-IV. Nor consult submitted their detailed report in August 1997 describing the detailed methodology, functioning of the designed lake tap, pressure build up on stop log gates, mass transportation after blasting etc. for KHEP-IV.

The work was in progress still keeping both the options open. By March 1998, the progress of both civil and electrical work was such that the first machine was getting ready by December 1998. However , the power generation would have been differed till Oct. 1999, if the dry piercing as envisaged in the contract was to be adopted which was possible only in May/June 1999. A such in September 1998 a final decision was taken in consultation with the panel of experts and the world Bank to go ahead with the submerged piercing as per Norwegian method to accomplish the early generation through first and subsequent units. The contractor was finally allowed to hire the services of Nor consult to supervise the whole exercise right from procurement of material till the final blast. The final blast was successfully & ceremoniously performed on 13-3-1999. The engineering details of this historic event are as follows.

SELECTION OF SITE

Careful investigation is required prior to selection of the site. The selection of site, for lake tap involves number of aspects viz. the geology of the area, location of gate shaft, the length of the intake tunnel, availability of minimum water cushion etc. The first phase will always be a geological survey. Aerial photography gives information of rock structure, cracks and fissures. Seismic refraction studies are more preferable. Visual inspection can be carried out by divers or remotely controlled submarines. Divers are useful in shallow waters. Remotely controlled submarines are recommended for depth of 50m and above. since the Koyna lake was depleted twice, the visual inspection as well as exploratory boring around lake taps was possible. This was an added advantage because such eventually is rare for normal under-water piercing.

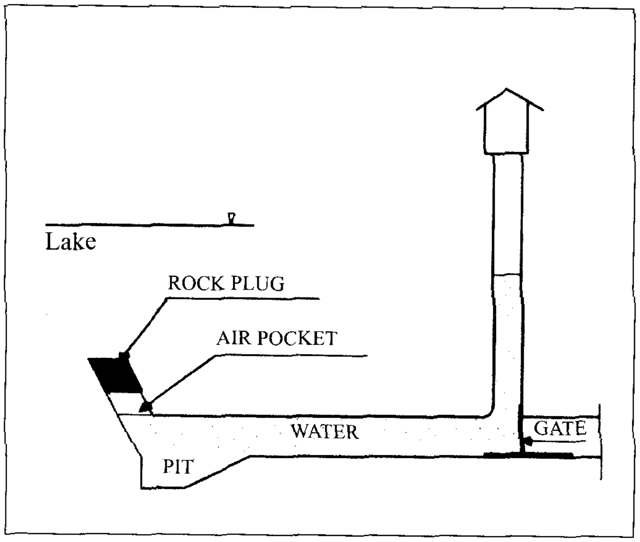
In KHEP stage-IV, as already stated the compact basalt with tight joints was observed. The rock is classified with Barton`s "Q" and Bieniawaski`s "RMR" system. On this system Q & RMR values are 14 & 69 respectively. Initially Under water seismic reflection and refraction survey was carried out by Central Water & Power Station, Pune near the proposed lake tap location to ascertain lake bed levels, probable rock levels and it`s quality. The compression wave velocity of bed rock is 4800m/s. This indicated the rock of very good quality. The overburden was more.

LAKE TAP TECHNIQUE, DIFFERENT METHODS & CHOICE MADE

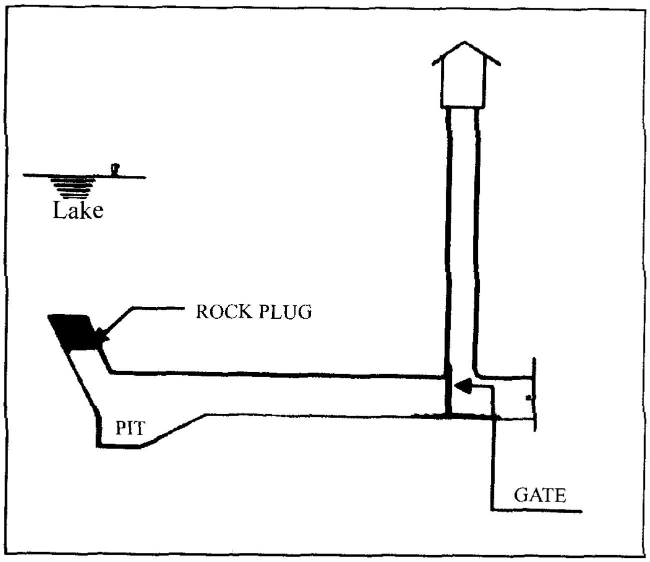
Lake tapping is a technique for connecting the water conductor system to the lake either natural or man made. The lake can be pierced by both dry and wet (submerged) methods. In dry piercing the lake is depleted forcibly and the rock plug is blasted from top (open blasting). In submerged piercing the rock plug is blasted from bottom without depleting the lake. A submerged piercing can be executed by two different methods; viz. closed method and open method.

In closed method, the control gate is on the upstream side of the shaft and thus the tunnel is not connected to atmosphere. The tunnel is dry or partly filled with water. In closed system shooting of the plug can take place shortly after loading. However the hydrodynamic conditions are uncertain. Unacceptable pressure rise at the gate can be generated if the distance between the plug and gate is short. The plug fragments and sediment above it are likely to be carried uncontrolled into the tunnel and can cause damage to the gate. In closed method the tunnel friction plays very important roll. This method is better suited for long tunnel lengths & low reservoir heads.

In open method, the control gate is on down streamside of the shaft, and there is a direct connection between the tunnel face at the plug and the atmosphere, through the gate shaft. The tunnel system is partly filled with water, keeping a sufficient pressurised air pocket underneath the plug. In this system, hydrodynamic conditions are clearly set out and the pressure rise against the gate can be calculated to a fair degree of accuracy. However, the task of water filling is complicated and there is a considerable time lag between explosive loading and shooting. In this system, the velocity of water in the tunnel after blast is low and the debris are easily trapped in muck pit.



Open Lake Tap



Closed Lake Tap

In open method of lake piercing volume of compressed air pocket has a key roll which depends on quantity of explosives. Thus proper estimation of explosives and the sufficiency of air pocket volume are required to be ascertained at layout stage only. Otherwise the dynamic pressures on the gate after plug blasting are excessive and the gate design becomes very complicated.

The design of the KHEP stage-IV intake structure is as per open method of lake piercing.

FINAL DESIGN OF ROCK PLUG

Successfully performed lake taps have in general been carried out on rock plugs with thickness varying from 1m in solid, good rock to 10m at locations with adverse rock mass conditions in combination with large tunnel cross sections. The soil overburden usually varies from 0 to 6 m. Experience has shown that a soil thickness of 1 to 3m may be favourable as the soil seals off joints and fractures in the surface rock mass in the intake area and thus prevents excessive water leakage.

The final design and specifically the rock plug thickness shall be decided based upon experience from the excavation of the intake tunnel and shaft and on results from exploratory drilling from the face through the rock surface at the lake bottom. The final design depends on the following parameters.

- Quality and permeability of the rock mass in the final plug.
- Quality and permeability of the consolidated soil cover.

In Koyna about 2m thick overburden over the top surface of rock was therefore retained. Under normal rock conditions with overhead water depth ranging between 10-80m the rock plug thickness is usually taken as 1.2 times the shorter size of the plug cross section (rectangular) or equal to the diameter of the plug (circular).

For KHEP Stage-IV, based on the overall consideration of the lake tap area a circular rock plug with a thickness of 6m was found to be suitable. Depending upon the total volume of the plug rock mass, a muck pit almost 2 to 2.5 times the said volume is provided to facilitate easy trapping. The shape of the muck pit is such that the further movement of the fallen debris along the flow in to the intake tunnel is prevented. Thus, a rectangular muck pit with vertical sides has been provided.

DESIGN OF AIR VOLUME REQUIREMENT BELOW THE ROCK PLUG

In the open method of submerged piercing for successful final blast, the design requirements are as under :

- An adequate air pocket below the rock plug to prevent transmittal of shock waves to adjoining rock mass after the final blast.
- Sufficient air volume below the plug to receive the gas from the explosion without any excessive pressure rise.
- The water level in the gate shaft after filling to create sufficient air pressure below the plug to squeeze the air through rock plug to the lake.
- The pressure on the control gate within acceptable limits.
- The upsurge in the gate shaft to be contained within the height of the gate shaft.

DEVELOPMENT OF DYNAMIC PRES-SURE AND DESIGN OF GATE

The explosives in the plug on detonation create gas in the air pocket. This gas pressure without any air pocket, would be propagated more or less undamped and most likely to cause great damage to the gate. The gates are required to take this shock loads. One kg of explosives when detonated gives approximately 0.8 Nm^3 of gas (one Nm^3 is the quantity of gas, which will give volume of $1m^3$ at 1 atmosphere of pressure at 0 degree C). The explosion gas expands into the air pocket and the pressure in the pocket increases rapidly. The pressure propagates through the water towards the gate. The rise of the pressure at the gate is twice the amplitude of the pressure wave.

The ratio between quantity of explosives and quantity of entrapped air is decisive for the resulting explosion gas pressure. The quantity of explosives is fixed beforehand, while the quantity of entrapped air is adjusted to control the pressure rise.

In normal condition, maximum static head on the stop log gate is equal to 73m of water. The reservoir level at the time of plug blast is uncertain hence the gates are designed to resist dynamic pressure of 130m of water column.

The gates should be leak proof, otherwise water filling & maintaining the desired water levels in the tunnels becomes difficult task. Hence every precaution even from design stage are required to make the gates watertight.

EXCAVATION TOWARDS THE FINAL ROCK PLUG (MUCK PIT AND INCLINED TUNNEL)

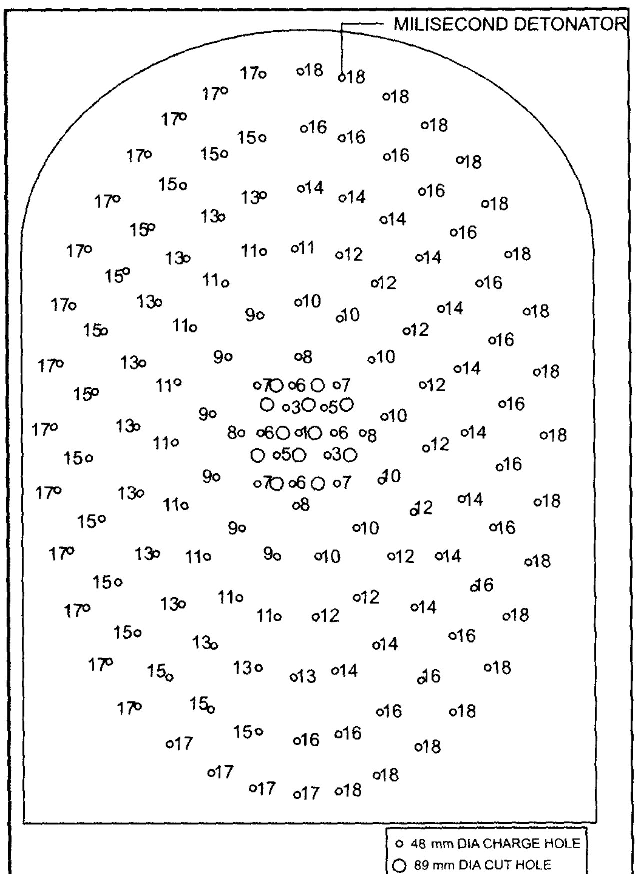
Normal excavation procedure is usually followed up to a point 30 to 100m from the final plug location depending on the quality of rock mass. In case of Koyna, the excavation and concrete lining for the circular tunnels up to d/s face of the muck pit was initially completed. The excavation beyond this point up to face of the rock plug was divided into three main excavation sequences viz. The lake tap tunnel (horizontal portion above muck pit). The piercing inclined tunnel and the muck pit. For all the excavation the blast holes 41mm dia. were used. The lake tap tunnel was excavated with full face by conventional drilling blasting with 2.5 to 3 m long rounds. The muck pit was excavated using bench blasting. The piercing shaft was excavated using under cut pilot and successive roof slashing; but the rounds were gradually reduced from 2m to 1m as well as face was trimmed from being perpendicular to the shaft axis to horizontal at the end. The spot rock bolting during excavation and systematic rock bolting after excavation was done for all the three components. The lake tap tunnel and the muck pit was supported with 50 cm thick M20 RCC lining, so also the piercing tunnel for first 9m only. The lining of the piercing tunnel was stopped well below the bottom of the final rock plug to provide sufficient space for drilling the contour holes of the final blast. It must be kept in mind that sufficient space below the plug was provided for drilling as well as charging the contour holes. It is significant to note that there was no seepage through the rock mass even though the excavation was going on underneath the lake.

DRILLING OF FINAL PLUG

Based on the experience in the koyna rock,139 Nos. of production holes, 48 mm dia. and 16 Nos. of cut holes 89 mm dia. were drilled, limited to 0.3m from the top surface of the rock. These holes were drilled at 45 degrees inclination parallel to the axis of the piercing tunnel.

The excavated face of the plug was at KRL 609.5m. The wooden platform was erected at KRL 607.3m. This platform was specifically designed to take live load of drilling equipment, 20 persons working on it & also for the vibrations during drilling. The unique feature of this platform was that it was totally insulated, so as to safe guard against any electrical current. The platform was elliptical in shape measuring about 10.6m and 7.5m along major and minor axis respectively. The platform structure was formed of 75mm thick timber planks which were supported on 100mm G.I. pipes spanning along minor axis and spaced at about 1.5m interval. The G.I. pipes were supported by 22mm diameter insulated steel rock anchors, which were anchored 2.5m in rock and protruding 1m outside . Braced wooden props from bottom further supported the platform.

M/s Atlas Capco had specially designed the jig on which the BBC 120F drifters were supported in such a way that drilling



CHARGING & DRILLING PLAN

at 45 degrees was possible with convenience & required accuracy. The frame was mounted with air motor operated chain feeds with both longitudinal and lateral movements to conveniently access each drill hole location. The BMS screw feed assembly was permanently fixed on main frame at 45 degrees inclination.

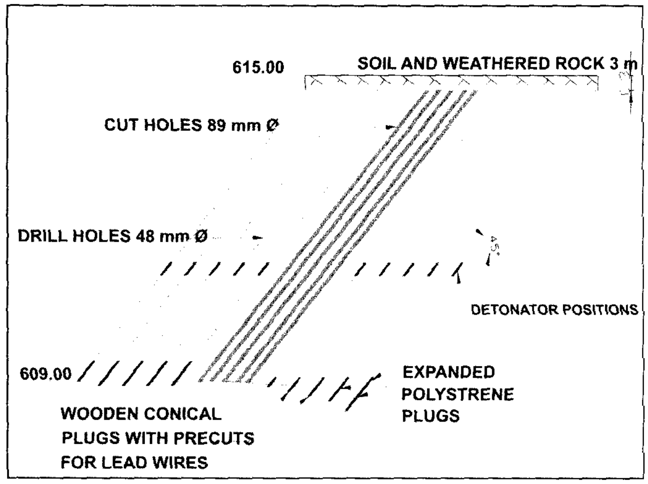
In each lake tap four representative exploratory drill holes were taken to ascertain estimate the top profile of the rock. The rock profile was found to be fairly uniform at K.R.L. 616.81m. The plug thickness at each drill location was estimated from this data and inventory for each bore hole was prepared. The planned drill length was 0.3m less than the estimated plug thickness at each drill location. Rock mass condition was inspected before commencement of drilling. In both the lake taps basalt was heavily fractured with random joints, however the rock mass was more or less dry. Hence initially no rock supports were provided. Only the manual scaling of the rock mass was done prior to the exploratory through- hole drilling.

Prior to the commencement of the final drilling rock fall occurred in one of the lake tap probably due to introduction of drilling water. Hence rock support in the form of 3m long 14 rock bolts was given. In the another lake tap the rock condition was still worst. Hence as a precautionary measures in the form of rock bolting (67 rock bolts) and 25mm thick coat of sealing shotcrete were taken. The alignment of these rock bolts was strictly in plane parallel to the blast hole direction and in between these blast holes. There after the actual drilling was started & completed as per the designed drilling pattern. The drilling time required for each lake tap was about 5 days. For larger diameter hole the pilot and reamer head bits were used. The entire drilling activity was managed with local team of drillers, assisted by foreign drillers and under the expert supervision 7 guidance of the Nor consult. The technicians of Atlas Capco trained the drillers. The common difficulties experienced during drilling were interception of already driven rock bolts, jamming of drill rods, keeping accuracy in drilling due to lack of rigidity in drilling equipment in accurate collaring, the box platform was untidy.

The packers with innovative design & manufactured locally proved to be effective in sealing the leakage of through holes. The water leaking through was never a major problem, however as a precautionary measure grouting agency was kept ready at site. Polyurethane (hardening plastic type Chemical grout)with the capability of expanding at least 10 times its initial volume was attempted. However as the same was found to be toxic causing respiratory trouble, in the first attempt, the same was discontinued. All the drilling activities were closely monitored from control room with closed-circuit T.V. sets. The average length of each drill was @7.8m and the total drilling length of each plug was @1100m.

Explosives

A special type of explosives, detonators & exploders were specified for the under water blast. The important specifications of the same are as under.



Charging Plan

Sl. No.	Particulars	Specifications
1.	Explosives (3500 kg)	Type : Extra Dynamite. Slurry type polythene Cartridge sticks of 35 mm diameter × 400 mm or 600 mm length.
2.	Detonators (650 pieces)	Millisecond delay detonators (1 to 18 no. with protective sheathing)
3.	Shot firing Cable 2 pieces of 300 m & 350 m length.	2 × 2 mm^2 Resistance 2.1 Ohms per 100 m length. Insulation > 5000V. (Minimum 3000V)
4.	Connecting Wire 350 m	0.7 mm diameter. Resistance 4.5 Ohms per 100m length.
5.	Exploder 1 Piece	Cl 160 VA Type. Resistance 4.5 Ohms per 100m length.

The quantity of explosives required depends on plug volume, type of rock, sediment overburden and water pressure on the plug etc. In case of Koyna specific charge of 4.2kg/cum was designed. The specific charge for under water blasting is 50 to 100% higher than the charge for normal tunnelling. Detonator requirement is two per drill hole. The explosives, detonators ,exploder and other accessories were specially imported from Norway Sweden and arrived at site in due time. A pre-test of extra dynamite and detonators stored at 40m water depth was carried at site.

Charging and Ignition Plan

Prior to charging, the length of each hole was measured & also the holes were checked for possible cave in or collapse by inserting plastic stick. All the precautions were taken to avoid any accidental leakage of current. All the electrical connections upstream of the stop log were strictly removed. A lightening conductor was erected on the top of service gate hoist structure. Further to avoid any leakage of static electricity from atmosphere due to storm/lightening an early alarming system capable of giving indications of storm approaching at 160 km was installed. All the explosive loading work was done with battery operated minors lamps.

The drill holes were loaded with explosive sticks. The plastic charging rod was used for pushing the explosives cartridges in to the hole without any hollow in between. In all the charged holes two number of millisecond detonators with identical delay number and normal sensitivity were used. One detonator in the top most cartridge and another in the middle of the outer part of the hole was placed. The charging plan giving the details of appropriate series of detonators to be used in each drill hole was given by Nor consult. As per the charging plan delay numbers of the detonators were increasing from centre to outer periphery. The same was strictly followed. Before placing the detonators in position each detonator was checked for appropriateness of resistivity with Ohmmeter. Last uncharged length of about 0.3 m of each hole was stemmed with expanded polystyrene plugs. Thereafter each hole was packed with wooden conical dowel with pre-cuts through which the lead wires of detonators were taken out. The loading work in both the tunnels was done simultaneously. The loading of the explosives took 4 days.

The connections were made to form two parallel circuits The bottom detonators of all the circuits were connected in one circuit and the top in another circuit. During making connections, after joining of every 10 detonators the total resistivity of completed circuit was checked to detect accidental damage of any detonator during loading. The two circuits were ultimately connected to the shot firing cable in series and the shot firing cable was taken out from stop log gate shaft.

The local workers also did all the charging work. The workers & the experts experienced head-ache as well as vomiting due to fumes of the explosives. Even with the medicines it was not possible to work for more than half hour continuously. Hence the workers were required to be replaced by about every half an hour.

Installation of Monitoring Devices

After completion of loading, following monitoring devices were installed:

- Pressure gauges on second lower element of stop log to measure the dynamic pressure that will develop during plug blasting.
- Two video cameras, specially imported from Scotland, which were capable of recording even under 300m of water head were installed on lining offset of the inclined shaft. The batteries of these cameras were on top, which were made on only after the blast.
- Trigger elements with overflow buckets were fixed at predetermined water filling levels to monitor the water filling level under the plug.
- One transducer was installed in each lake tap tunnel at K.R.L. 608.00m to monitor the air volume underneath the plug. The connection of this transducer was given to the computer.
- The seismographs were installed on stop log shaft at about 90m from the blast site to register the blast induced vibrations

Water Filling

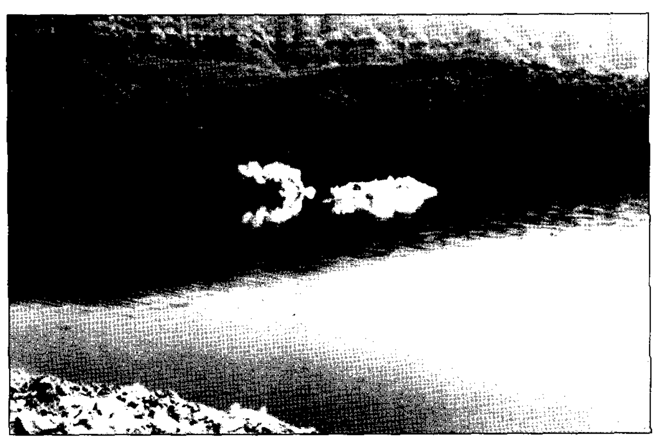
For water filling six 40 HP & two 180 HP pumps were installed on the fringe of the lake. The time required for filling each tunnel was about 22 Hours. It was completed about 5 hours prior to scheduled blast time.

Final Blast

The resistance of the shot firing cables was once again checked & the shot firing cables were connected to the exploders. The electrical current setting calculated was 13 A (6.5 A per circuit). Both the lake tap plugs were detonated simultaneously. The lake tap was successful. The large amount of detonation energy was directed towards the lake forming two mushroom shaped water fountains of about 6m height and creating only moderate dynamic pressure build-up on the stop log gates.

Observations after the Plug Blast

The pressure gauges installed on the stop log gates recorded the pressure of 9.5 bars & 6.5 bars as against the anticipated pressure of 8.6 bars. The seismograph recorded the peak particle velocities 3.73mm/s. & 4.32 mm/s. These are well within the limit of 50 mm/s. The intake tunnels were inspected by deploying the services of the divers and no damage was noticed. The entire muck is collected in the muck pits provided for. The stop log gates were inspected from downstream side & no damage was noticed to the gates. However, the leakage through the sealing's of the stop logs was increased. This may be due to pulsating dynamic loads of the blast.



After few days the cameras installed were removed by the divers. They were safe. The recording revealed that no damage to the concrete lining of the lake tap shaft as well as smooth peripheral blasting.

CLOSING REMARKS AND CONCLUSIONS

The open method of under water lake piercing is more preferable as dynamic pressure can be estimated to fair degree of accuracy & the debris are smoothly collected in muck pit. The high specific charge gives high shock loads on the gate. Reducing the specific charge on the contrary increases the risk of failure of the blast. Hence it is better to be conservative in deciding the specific charge. In open method of under water piercing high degree of quality control is required while manufacturing the control gate. The water tightness of the gate is very important. If leakage starts it is very difficult to maintain the desired water levels. If rock bolting is required then extreme precision is necessary. If the rock bolting is not parallel to the alignment of charge holes, it is extremely difficult to drill the charge holes. The rigidity of the drilling equipment is very essential to carry out the drilling as per the designed drilling pattern. The high degree of precision is required at each & every step especially in drilling the holes to correct alignment, charging, deciding adequate air pocket volume & maintaining it. The innovative packers manufactured locally proved to be extremely successful in stopping the leakage through the through holes.

Misfire during the lake tap, is unrepairable. Excessive seepage, failure of plug during construction may prove to be fatal .Hence, thorough geotechnical investigations with modern techniques is the pre-requisite for lake tapping. This technique of under water lake piercing can be used for using the artificial and existing man made lakes economically for hydro power generation.

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BIOGRAPHICAL DETAILS OF THE AUTHOR

S.N.Huddar, Former Secretary, Water Resources Department, Government of Maharashtra completed his Diploma in Civil Engineering from Government Polytechnic, Nagpur, and joined Irrigation Department as Junior Engineer-in-charge of Survey and investigation of Irrigation Projects from Chandrapur, Nagpur and Bhandara Districts. While in service he completed A.M.I.E. and was selected for the Class I Services by the Union Public Service Commission and joined Central Water Commission as Asstt. Director. He was in-charge of Civil Designs of Hydro Electric Projects from U.P., Jammu and Kashmir and Afghanistan. At the same time he was also selected by the Maharashtra State Service Commission for Class I Services, where he stood first and came back to Maharashtra Service Engineers Class I in 1976

He joined Pench Irrigation Project in 1977 and was responsible for the development of CNS layer in Maharashtra. On promotion as Executive Engineer, he took over charge of underground civil construction of Power House and underground works in the power house complex of Pench Hydro Electric Project, involving construction in a very complex geological set up, at times with the risk to life. He completed the underground construction and commissioning of both the units of 80 MW each in 1986 and 1987. Because of his experience in underground construction, Govt. of Maharashtra entrusted the prestigious Koyna Hydro Electric Project in 1987. Till 1994 he was responsible for the design of all the elements of Koyna Project. In 1994, he took over the construction of Koyna Hydro Electric Project Phase IV, involving new technological developments in the form of Lake Tap and underground construction of 58° inclined pressure shafts which has been completed for the first time in Maharashtra, using modern technologies like bore take, climbers. For the first time in Maharashtra, sophisticated equipment like concrete pumps, laser application for alignment etc. have been used. The famous Lake Tap for the first time, not only in India but in Asia, has been successfully executed by him on 13th March 1999 and all unit of 250 MW has been successfully commissioned.

In recognition of this outstanding work including R & D and the marvel of engineering in the field of hydel development the Central Board of Irrigation and Power presented him with the CBIP Jawaharlal Nehru Birth Centenary Award for the year 1999 on 29th February 2000 at Jabalpur. The FIE foundation Ichalkaranji has also recognised this exemplary achievement and awarded FIE's outstanding contribution award to him and his team of Engineers for under water piercing of Koyna lake without depleting water from reservoir and timely commissioning of KHEP Stage-IV generating 1000 MW of power in phases. This award carries a cash prize of Rs.75000/-.

Source: Proceedings of Workship on Rock Mechanics Tools and Techniques, 13-17 January 2010, Nagpur