Numerical Modeling & use of Latest Technology for Construction of Hydro-electric Projects

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Abstract

Lack of judgment and under/over estimations of the engineering problems, primarily leads to time loss in execution of hydroelectric projects. World over, the emphasis is being made these days by the engineering fraternity to analyze the engineering problems especially related to seepages underneath coffer dams and also the underground caverns intersected by the shear zones through numerical modeling and also the induction of latest technologies for overcoming the complex problems. In Mangdechhu Project (720 MW), Mangdechhu HE Project Authority (MHPA) took two technical decisions which have qualitatively impacted upon the construction of the concrete dam and also the underground power house caverns.

Numerical calculations in underground engineering try to simulate the reality as good as possible. But the numerical modeling process heavily depends on the practical excavation aspects/ sequencing. Numerical analysis results are to be verified by geo-technical measurements/ observation on grounds.

The difficulty in mathematical formulation of a material law is that it must be able to realistically describe the distortion and stress path in rock, gravel, sand and clay matrix without neglecting properties like anisotropy. The simplest material laws are linear or non-linear elastic models. Geo-materials, however, do not show elastic material behavior. Thus, the expectable results will not have much in common with reality quantitatively and qualitatively.

In the context referred above, MHPA has finally succeeded in arriving at proper engineering solutions due to which, the project is proceeding as per construction schedule and shall be getting completed at the Per Megawatt Price which will be the lowest among all contemporary hydro projects being constructed in India / Bhutan.

MHPA has engaged National Institute of Rock Mechanics (NIRM), Bangaluru and also M/s Bauer, Germany for carrying out the Numerical Modeling of the Underground Powerhouse and for construction of Concrete Cut-off Wall in the upstream Coffer Dam respectively.

Hydro Electric Projects located in diverse Himalayan terrain encounter varied engineering problems, treatment of which more often than not lead to cost and time over runs. In order to counter such problems successfully within a given time frame the engineering fraternity needs to closely analyze these problems and adopt modern and latest technology /methodology to ensure successful and timely completion of these projects.
1.0 MHPA is engaged in construction of the 720 MW Mangdechhu HE Project, located in Trongsa Dzong of Central Bhutan. The project comprises a 114m high, 141m long concrete gravity dam located on the Mangdechhu river, a 6.5m dia 13.5km long head race tunnel, an open to air 15m dia 155m deep surge shaft and a 155mm long, 24m wide and 41m high underground Power house cavern.

During the project construction several engineering problems were encountered and successfully handled by adopting latest technology. Notable of these has been adverse foundation conditions met with at the coffer dams and sheared fractured zone intersected in the underground caverns. Both these problems have been successfully dealt with. This paper briefly describes the problems encountered and measures adopted to ensure qualitative engineering resulting in adhering to the construction schedule.

1.1 Construction of upstream Coffer Dam:

The 110m long 22m high upstream coffer dam is founded on a riverine foundation comprising pebble to boulder grade fragments in a mainly sandy/silty matrix. During construction stage investigations the presence of a fine sand/silt lens of 2m to 12m width, having large lateral extension was found to exist within the dam foundation. Gradational analysis of this material indicated high degree of fine constituents which may not have been amenable to the technique of permeation grouting as the methodology earlier envisaged during detailed design stage investigations. In view of the deepest foundation excavation of the main dam receding well below 60m from river bed level and the prevailing high heads upstream of the UCD, it was felt prudent to examine various modern methodologies for creating a fool-proof curtain below the upstream coffer dam. It was felt by the MHPA that the permeation grouting methodology envisaged at DPR stage for the UCD foundation would not be adequate to control the seepages, particularly in view of the changed conditions attributed to the sand/silt horizon. This would invariably lead to high seepages in the ongoing main dam excavation involving continuous dewatering resulting in considerable financial burden and leading to inordinate delays to the project completion schedule. Accordingly, MHPA has involved the expertise of M/s Bauer (Germany) to construct a 57m deep, 110m long, 1.2m wide concrete diaphragm wall/concrete cut-off wall cutting through the central axis of the upstream coffer dam. The curtain thus created through the foundation material upto bedrock level and forms a fool-proof barrier. The entire exercise of construction of the positive cut off spanned a time period of 8 months.

Instrument observations of pore pressure readings measured downstream of the concrete cut-off wall do not indicate significant fluctuations vis-a-vis the river water level existing towards upstream at the Diversion tunnel inlet indicating the barrier is effective against seepage from upstream. Furthermore, in the context referred above, the main dam excavation is proceeding in a controlled manner and as per construction schedule.
1.2 Construction of underground powerhouse caverns:

The powerhouse and transformer hall caverns of the Mangdechhu project comprise a 155m long, 23m wide and 41m high and a 135m long, 17m wide and 23m high cavern respectively. The long axis of both caverns are aligned normal to the foliation strike of the country rock while the overhead rock cover is of the order of approx 200m. The caverns have been excavated in strong quartzite rockmass with interbedded biotite schists and occasional pegmatitic intrusions. During the excavation of the Powerhouse central gullet a 8m wide, 15 to 20 degrees dipping shear/fracture zone was intercepted in the crown of the cavern. The ongoing transformer hall excavation also revealed a similar feature in its crown. Extrapolation of this feature indicated it to be a zone of incompetent rockmass cutting through the width of the 40m wide intervening rock pillar lying between both the caverns and traversing the entire length of the caverns. In view of its disposition and its effect on the stability of the caverns two options were considered. Option of shifting the caverns bodily by 40m towards valley side thereby reducing the affect of the shear zone in the crown of the main cavern or alternately leaving the caverns as they were and treating the zone by engineering methods to improve its insitu properties in addition to revalidating the design rock support. As the former alternative would involve realignment/re-excavation of the TRT and pressure shafts and as some of the associated structures such as horizontal pressure shafts and tail race tunnel had been partially excavated MHPA opted for the later option of treatment of the feature and reassessment of rock support. Furthermore geological projections indicated that even after shifting the caverns the shear zone was expected to continue in the wall and pillars and possibly also be encountered in the turbine foundation, the latter of which would have far reaching consequences. In order to assess the stability of the structures it was felt prudent to carry out periodical 3dimensional stability analysis of the caverns using 3Dec modeling through the services of NIRM who had considerable expertise in this study. It also necessitated extra rock mechanic studies for assessing the engineering parameters of the shear/fracture zone as design inputs for the 3D numerical modeling studies. The studies indicated low FOS along the shearzone intersections, particularly at the bus duct pillars. A detailed instrumentation programme was adopted concurrent with the ongoing excavation to monitor the stability of both caverns and provide design input for reassessing rock support while pregrouting/consolidation grouting was made mandatory for all the shearzone locations to amply strengthen the rockmass utilizing ultrafine cements injected at pressures of upto 30Bar, while sheared material was scooped out and replaced by rich concrete. Similarly the excavation methodology was refined, control blasting adopted and rock bolt length increased to 18m (36mm dia)in the walls and 12m length in the crown. The crown from 0m RD to 40m RD and 100m RD to 155m RD was reinforced with ISMB 350 steel rib support. Presently the main cavern has been excavated to below bus duct level, revised supports have been installed and pregrouting and consolidation grouting measures adopted. Stability analysis is carried out periodically with bench excavation and instrument data examined for observing support behavior. Deformations projected from stability studies are periodically compared with observed displacements and observed to
be in control. Thus MHPA has in its wisdom been able to exercise technically the right choice by adopting latest methodology for both monitoring and support of the caverns thereby controlling financial implication and maintaining construction schedule.

**Conclusion:**

Construction of Hydroelectric Projects requires continuous correction in the design and also in the construction methodology. Mangdechhu Project is the example of such corrections, the seepage free excavation in dam foundation as well as the construction of Underground Powerhouse Caverns are the realities of the day.

Most of the time, the decision making is considering the direct costs without giving a due weight age for the indirect costs including time overruns. Therefore, the initial costing must consider the equivalent benefits getting accrued during execution. These days, powerful numerical modeling tools as well as construction technologies are available which can provide the solutions to our design as well as to construction problems.

**The Author**

A.K. Mishra, took over as Managing Director, Mangdechhu Hydroelectric Project Authority on 27th August 2010. He did his Bachelor's Degree in Civil Engineering in the year 1977 thereafter completed M.Tech (Soil Mechanics & Foundation Engineering) from Indian Institute of Technology, Delhi in the year 1989. He worked for the Development/Commissioning of various Hydroelectric Projects in India and Bhutan. His professional contribution encompasses all the areas of Hydropower Development. He contributed reasonably through his experience in planning, design & engineering, contracts management, execution and monitoring of hydroelectric projects in past 35 years. He has presented various technical papers in National / International Conferences/Seminars. He is also working at the risk mitigation model for hydroelectric power projects for his research work.