REQUISITE OF GEOTECHNICAL EVALUATION FOR AGE OLD DAMS AND APPURTENANT STRUCTURES TO ENHANCE THE EXISTING HEALTH STATUS FOR THEIR LONGEVITY – A CASE STUDY OF SELECTED DAMS IN TAMIL NADU

K. JAYABALAN
Dy. Director General, Geological Survey of India, Mission IV, CHQ, Kolkata

K. ARAVIND
Director, Engineering Geology Division, SU: TNP, Chennai

ABSTRACT

To assess, record and evaluate the present health status of age old dams/Reservoirs and its appurtenant civil structures and also to generate geological documentations, post construction stage geotechnical investigation was carried out at selected dams and reservoirs in Tamil Nadu. Significant observations by means of distress in the foundation media and civil structures with appropriate suggestion of control and corrective measures to avoid further deterioration as per site conditions are briefly dealt in this paper. Distress and complications are not unique in all the project components, it varies from project to project or within the project. The causative factors of distress on defects in each project components have been cautiously assessed to establish the geo-genic or anthropogenic causes and to suggest appropriate mitigation measures for its stability and longevity. Besides, kinematic analysis of discontinuities present in the country rock, reservoir rim and slope stability analysis to delineate the vulnerability, seepages analysis were ascertained and the geo-genic or anthropogenic causes are highlighted with several case studies. In addition, the significance of MEQ studies to delineate RIS by establishing campaign mode semi-permanent geodesy instruments in the areas around dam/reservoir and resultant seismic data interpretations with field validations were used to determine the seismicity around the project site, which has also been briefly discussed. The methodology adopted during the course of investigation would be of immense help to enhance the longevity of dams and as legacy document for research scholars.

Key words: *Dam, Reservoir, Distress, stability, Documentations, Mitigation, Strengthen, longevity, MEQ: (Micro Earth Quake) RIS: (Reservoir induced seismicity)*

1. INTRODUCTION

Post construction stage geotechnical investigation plays a pivotal role to enhance the existing health status of century/decade old dams and reservoirs for their longevity. In general, available technical data related to geology, geomorphology, structural and seismicity of the project sites may not be available, even if available it will be scanty or sketchy. Therefore, to prepare a comprehensive geological and geotechnical report by incorporating the available and gathered data, post construction stage geotechnical investigation was carried out at selected dams/reservoirs on request of Dam Safety Directorate (DSD), PWD/WRO and TANGEDCO, Govt of Tamil Nadu. Amidst, GSI (Geological survey of India) has also been associated with a team comprising of different discipline under the coordination of DSD to evaluate the present health condition of the dams/reservoirs in Tamil Nadu (Balachandran et al 1994). Available data reveals that there are 128 dams/reservoirs in Tamil Nadu under the custodian of WRD and TANGEDCO, of which, dam documentations have been carried out for 103 dams/reservoirs and the documents being prepared for the remaining projects in Tamil Nadu. During the investigation, it was observed that the distress are not unique in all the project components, it varies from project to project or within the project of different components. The chief causative factors of distress in each project components have been judiciously assessed to establish whether the distress are due to geo-genic or anthropogenic for suggesting appropriate remedial measures for the longevity of the project components and also to avoid untoward incidences. Significant observations made during the investigations at selected project sites with unique distress/adverse geological features, causative factor and control and corrective measures suggested for longevity of the existing civil structures are briefly dealt in this paper. In addition, the significance of MEQ studies to delineate RIS by establishing campaign mode semi-permanent geodesy instruments in and around dam/reservoir and resultant seismic data interpretations with field validations were used to determine the seismicity around the project site has also been briefly discussed. Essential inputs made on geological and Geotechnical aspects for strengthening of the following Age old dams/reservoirs and appurtenant structures are briefly discussed herein:

2. ADAVINAINARKOIL RESERVOIR PROJECT, TIRUNELVELI DISTRICT

The Adavinainarkoil reservoir project envisages the construction of a 74.20 m high and 670 m long Masonry dam with uncontrolled central spill way of 100 m length, built across the Hanuman Nadhi (River), a tributary of Chittar River in Tamiraparani basin, with a storage capacity of 174 m c ft. The dam has been provided with three drainage galleries of standard size and shape at different elevation levels. It is abutted against the massive charnockite in the right and weathered charnockite gneiss in the left. The foliation shows N 65°-70°W S 65°- 70° E with steep to moderate dip (50°-65°) due S 20°-25° W. The dam axis oriented almost parallel to the foliation. Achan koil lineament aligned in NW-SE direction is the major tectonic feature which is passing 2.5 km south of the project site. Heavy seepages reported from the foundation by the project authority. To ascertain the source of heavy seepages, investigation was carried in the area around the project site to identify the causative factors for water tightness. The investigation reveals that no visible sign of distress observed on either side of the abutments and d/s foundations. However, seepages observed in the drainage galleries especially the blocks provided between 7 and 9 (500 to 700 LPM) with the corresponding reservoir level of 116.252 to 114.25. In the lowest gallery at El 210.6, the vertical drainage shaft hole No 60,61&63, where the water flows/piped out with heavy force and noise depicts that the seepages may be >1000 lpm and sand particles are also observed in the drainage chute (Fig -1). Besides, the vertical drainage shafts located in different levels of galleries are chocked/ blocked with 50–90 % calcinations (Fig.2), recommended for immediate attention.

Fig. 1 : Ingress of water into drainage gallery by piping

Fig. 2 : Drains are choked with calcinations

(a) Seepage analysis

Seepage data have been collected from the drainage galleries provided at different elevation level in the dam civil structure and lpm has been calculated by adopting the following formula;

- No of "V" notches provided in the galleries at different elevation levels are 26 Nos.
- No of inlets are 5
- Discharge through "V" notch Standard formula 1.42. H5/2M3/sec.

  Where, 1.42 is constant,

  H = Height of water in V notch,

  Conversion of units = 1m3 = 1000 lits

  If the water discharge through the V notch is 2cm = 0.02 m

Seepage analytical data reveals that the "V' notch is provided at exit No 3 from the left end (0 end), seepage water flows over the "V" notch is >17cm with the corresponding reservoir level of 115.25 m (MSL). If the reservoir is full, than the amount of seepage would be multi fold. Systematic seepage analysis by adopting the aforesaid formula would be helpful for the project authority to calculate the water losses from the reservoir (lpm).

The investigation brought out the fact that the *seepages are from the Dam civil structure (Anthropogenic) and not from the foundation (Jayabalan et al 2009).* Significant findings and recommendations were implemented by the project authority for restorations as a result the seepages arrested from the civil structures and the project is intact.

3. PUMPED STORAGE UNDERGROUND HEP, KADAMPARAI, COIMBATORE DISTRICT

To assess the damages to the rock mass due to thermal variations after the devastation of fire accident in the underground powerhouse cavern that had occurred on 19-10-1990 and subsequent rock fall measuring 1.5 ton load reported in the fore bay areas of underground power house cavern, a comprehensive geotechnical investigation has been carried out for various project components to evaluate the causes for deterioration of rock mass and damages to the support measures provided to the existing civil structures and also to suggest an appropriate remedial measures for restoration.

The investigation reveals that the tunnelling media comprises charnockite and its retrograded product of variegated gneisses having an enclaves of pyroxenite and amphibolite traversed by acid intrusive. Foliation in the gneisses with four sets of prominent and three sets of random joints along with two sets of shear/fractures zones are the discontinuities present in the rock mass. The tunnelling medium has been judiciously assessed based on RMR/CSIR's, Barton Q system with relevant BIS codes as per GSI's SOP (Thanavelu et al 2005)

Distress to the civil structures in the form of surficial peeling, crumbling and detachment of rock bolts, wire mesh, shotcrete, widening and prolongation of joint sets, development of criss-cross cracks over the crown and wall of the underground PH cavern, extensively corroded and damaged steel structures in the CCVT (Control cum ventilation tunnel), buckling of steel liner and development of linear cracks along the welded joints in the ferrule of Pressure shaft II, loosening and raveling of rock blocks, wedge failures, shear/crushed zone with seepages resulting corrosion of chain link/wire mesh in the unlined MAT (main access tunnel) and Adits (Jayabalan et al, 2010). Besides, distress in the lined HRT due to reverse pumping and generation mode has been examined reach wise for its rehabilitation. In addition, slope stability problems in the reservoir areas were delineated for restoration. Methodology with innovative ideas adopted during the investigation which includes, and suggestion of control and corrective measure to enhance the present health status for its longevity were implemented in time by the project authority.

4. SARKARPATHY POWERHOUSE, COIMBATORE DISTRICT

Reconnaissance of loosening and *failure of rock mass* into the power house pit was reported from the vertically cut slope by the project authority. Subsequently Geotechnical investigation was carried out to assess the rock mass condition of the cut slope and to find out the causative factors for failure. The investigation reveals that the Charnockite and migmatitic gneiss with enclaves of pyroxene granulite/ amphibolite are the predominant rock types of the area investigated. Pink granite along with a pegmatite and quartz vein, occurs as an intrusive in the host rock. The rock is massive with crude foliation trending ENE-WSW with 60° dip towards SSE. Vertical joints with N-S strike and foliation joint sets are the prominent discontinuities Jayabalan et al 2010) . Significant findings and remedies:

- Precariously perched boulders on the hill slope should be removed by adopting control blasting techniques or by line drilling.
- Construction of retaining wall with weep hole slanting 45°down to resist of sliding
- Development of longitudinal cracks along the road/above the cut slope to be cleaned and packed with RR/concrete to avoid further deterioration.
- In-situ rock boulders of various size ranging between 1.0 – 1.5 m^3 are found on the slope to be anchored with rock mass by using rock bolts.

5. MUKURTHY ARCH DAM, NILGIRI DISTRICT

The Mukurthy Arch dam is first of its kind in India constructed between 1932– 1938, with automatic spillway arrangements. The dam site exposes fresh charnockite in the d/s side of the stilling basin area with 3 sets of prominent joint pattern. Site inspection reveals that the right abutment does not possess hard rock, hence an embankment type of abutment has been provided. Since, it is an arch dam, it takes the maximum load into the abutment, hence it is presumed that arching action of the dam would also involve additional load to the distressed right abutment, as the right abutment has considerable amount of overburden which is already saturated with dam water. Therefore, recommended to monitor the right abutment periodically for any settlement of embankment both in the u/s and d/s face, by **placing sufficient glass tell tales** (Fig. 3). Distress on the u/s face of the wing walls observed on both the abutments with separation, tilting and sinking of blocks. Similarly, the *d/s face of the right abutment sinking is measured about 32 mm.* The d/s portion of the right flank is now being protected with retaining walls with weep holes (Fig. 4) but the slopes have been provide with chain link and concreting without any weep holes. Therefore, recommended to provide random weep holes and placed at 45° angle sloping outwards and also insert with perforated pvc pipes, wherever warranted. Detailed investigation indicated that the slope failures were attributed due to the pore pressure and concomitant excavation at the toe region for siting the power house *(Jayabalan et al 2016).*

Fig. 3 : Broken tell-tale on the right abutment u/s

Fig. 4 : Slope protection/retaining wall with weep holes on the d/s right abutment above PH

6. VAIGAI DAM, THENI DISTRICT

A 3243.07 m long 33.83 m high composite dam with a 231.66 m long central masonry ogee spillway (7 No lift gates 12.19 x 4.7 m)) with a designed discharge capacity of 1674 cumecs was constructed across the river Vaigai. Periyar and Suruli Ar are the main source of water for this dam.

6.1 Significant Observations:

- The left arm abuts against a rocky mound made up of charnockite with an intercalation of quartzite and the right arm abuts in the soil covered gneiss with pyroxene granulite and quartzite.
- No sign of settlement observed in the earthen bund and distress on both the abutments.
- "V" notches provided in the toe drain to be maintained properly for systematic collection of water samples for analysis.
- Termite mounds found in the d/s revetment on the right side of the earthen bund need to be removed to avoid deterioration.
- As such there is no sign of distress in the masonry spillway structure except chocking of few drainage shafts.

7. BHAVANI-KATTALAI BARRAGE-III HEP, NAMAKKAL DISTRICT

Foundation failure of Pier-3, 4 & 14 at Bhavani-Kattalai Barrage-III HEP was reported on 27th June 2017 by the project authority. In response, joint site inspections carried out along with the project authority. Site condition reveals that the entire river bed exposes intermittent outcrops of migmatitic gneiss and charnockite of Archean age. Gneissosity shows parallel to the river course with sub horizontal dip due SW. Longitudinal shear with mylonite encountered on the left bank of the river course with multiple fractures and close spaced joint sets. It was observed that the foundation of piers 3, 4 and 14 are damaged, of which, the foundation of Pier No -3 was completely removed and sand bags were kept below the pier as temporary support (Fig. 5). While verifying the detailed geological/foundation map of the said pier site and core log data indicated that at ch.54 m (pier - 3 location) where fresh rock is available at 13m below ground level and heavy core losses were recorded due to sheared/weathered zone occurred at pier 3 location (Fig 6). Thus, recommended to found the pier at fresh rock level at this particular location (Pitchaimuth et al 2006). Whereas, the present site condition revealed that the rock beneath the pier-3 is sheared and highly weathered fissile gneiss with compressive strength of < 100 kg/cm2 (calculated using Schmidt hammer) and founded on shallow depth (3m below ground level) over sheared/ weathered rock. A raft foundation was made between weathered and massive sheet rock without reinforcement, which has paved way for eroding the sheared weathered bed rock beneath the pier foundation due to water turbulence. This would have been avoided, if geological and geotechnical recommendations implemented during the construction stage of the piers.

Similar type of erosion and foundation failures observed in Pier 4 and 14. If the geological and geotechnical findings pertaining to the adverse gelogenic features (sheared/weathered rock) would have been treated during the construction stage as per the recommendations, this untoward incidences/foundation failures might have been avoided. However, detailed post construction stage investigation was carried out and recommended to lower the foundation up to firm bed rock with proper reinforcement, in view of massive fresh rock exposed an adjacent areas and also recommended to apt design pattern of the piers foundations to sustain the water turbulence (*Asrar Ahmed 2019)*. The recommendations were judiciously executed at the project site and the piers are intact and PH become operational without any distress.

Fig. 5 : Eroded foundation of Pier- 3, view from u/s to d/s facing towards left bank

Fig. 6 : Shear plane day lighted at foundation of pier-3 the sheared/weathered rock scooped out by water action

8. KAMBAM VALLEY, THENI DISTRICT (MULLAI PERIYAR DAM)

The frequent recurrence of low level seismic activities in the area around Mullai Periyar dam (Kambam valley in Tamil Nadu and Idukki district in Kerala) had an apprehension of possible damage to the existing storage dams and also to avoid panic among the public and focus of debate, GSI took up seismic studies as desired by the Empowered Committee by deploying geodesy instruments which includes digital seismic broadband and GPS. Interpretation part of Seismic data collected through seismo-geodetic instruments and past earthquake data are discussed herein:

(a) GPS Geodesy

Campaign mode GPS instruments were installed at different locations to measure the baseline changes, if any, against the established major faults, for which Periyar fault (MP01-MP02), Thekkadi - Kodaivannalur fault (MP04-MP05) and Suruli Ar fault (MP03-MP05) were selected for geodesy studies (Fig.7.) Seismic Instrumental data's were collected with a span of 7 days in each station by using LEICA SR-520 GPS receiver and AT-503 Chock Ring Antennae. Available campaign period data of IGS stations covering the Indian Sub-continent have also been composed for an interpretation. GPS data collected was converted into Receiver Independent Exchange (RINEX) file by using TEQC (ver: 2008 Feb15) software. Site repeatability were estimated using GAMIT/GLOBK ver. 10.35 (Herring et al., 2009). The campaign sites data along with continuously available daily data of permanent IGS sites with 30 seconds sampling intervals and 15° satellite elevation cut-off were used in analysis. The outcome of the analysis reveals that the NE-SW trending Suruli Ar fault indicate high rate of base line changes across Suruli Ar fault accounting for cumulative effect of near vicinity lineaments/faults suggests present day deformation under extensional environment (Som et al 2012). The results obtained from MEQ studies based on 17 selected out of 31 recorded events, ranging between M 1.8-3.3 and the generated 2 composite fault plane solutions suggests *normal faulting with strike slip component.* Besides, the contemporary style of deformation pattern indicate an extensional environment in and around Kambam valley. The results obtained in this study may be taken as only indicative and not conclusive due to limited period of instrumental observations. Since, the Kambam valley exhibits low to moderate level of seismic activity and falls in Zone-III of seismic zonation map of India, it is felt that long term seismic monitoring is needed by using seismo-geodetic instruments along with active fault studies.

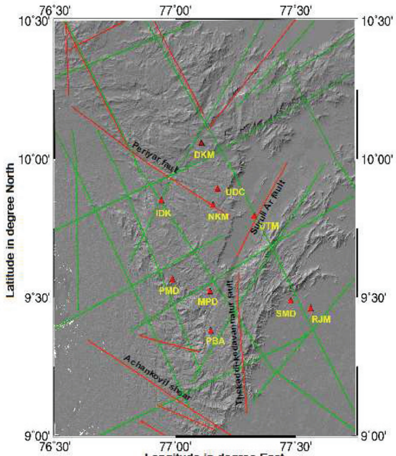

Fig. 7 : Tectonic map of the study area with station location (red triangle), Red lines show major faults and green lines show lineaments. Lineaments and faults are after Dasgupta et al. (2000) and GSI unpub reports.

9. CONCLUSION

Preliminary appraisal has hitherto been made an in-depth analysis like slope stability, reservoir rim stability, reservoir competency, dam break analysis, Reservoir induced seismicity, pore pressure development, reservoir temperature, campaign mode seismic geodesy instrumentation studies on major hydro projects may bring out more information about the documentation which would undoubtedly help the project authority for an implementation of control and corrective measures on time for the project longevity. Besides, frequent interaction between multidisciplinary geoscientist and project authorities with periodic field inspection at the project site to reassess the present health status of the different project components becomes mandatory for timely execution of mitigation in-case of distress if any encountered during the inspection at the project site to avoid untoward incidences.

ACKNOWLEDGEMENTS

The authors are grateful to the Director General, Geological Survey of India for kind approval and according permission to submit this scientific paper to the symposium. Special thanks are due to the Addl. Director General, NMH IV for constant support and encouragement while preparing the paper. Support from the Chief Engineer (Civil-Dam safety), PWD/WRD and TANGEDCO, Govt of Tamil Nadu is thankfully acknowledged. The authors also express their sincere thanks to the PWD/WRD and TANGEDCO project authorities for extending necessary logistic support while carrying out the fieldwork.

REFERENCES

Balachandran,V. & Krishnamurthy, K.S. – Progress Report on Phase I Inspection of 43 Large Dams in Tamil Nadu, GSI Unpublished Progress Report for F.S. 1992-94.

Thanavelu C & Jayabalan. K. – Report No.5 On The Post Construction Stage Geotechnical Investigation At Kadamparai Pumped Storage Hydroelectric Project, Coimbatore District, Tamil Nadu Unpub. Prog.Rep. for F.S. 2004-05

Pitchaimuth & Jayabalan. K. – Geotechnical report on exploration carried out for BKB-II H.E. Project, Namakkal Dist., Tamil Nadu GSI Unpub. Prog.Rep. for F.S. 2008-09 2005 - 2006

Jayabalan. K. & S.Chandrasekaran – Geological Document on Adavinainar koil Reservoir, Sengottai Taluk, Tirunelveli District, Tamil Nadu, GSI Unpub. Prog.Rep. for F.S. 2008-09.

Jayabalan. K. – A Geotechnical Report on Loose Fall From Cut Slope Of Sarkarpathy Powerhouse,Coimbatore District, Tamil Nadu Unpub. Prog.Rep. for F.S. 2009-10.

Jayabalan. K. – Post Construction Stage Geotechnical Investigation on Support Measures To Be Undertaken In Access Tunnel Kadamparai Underground Powerhouse, Coimbatore Distreict, Tamil Nadu, Unpub. Prog.Rep. for F.S. 2009-10.

Som S.K, Moharatra S R. Aravind K, Goutam Kr Chakraborty, K.K. Mukherjee KK, Singh O P, Giridharan T S, Bahadur Ram and Abishek Kumar – A Report On Seismicity In Idukki District, Kerala, Unpub. Prog.Rep. for F.S. 2011-12.

Jayabalan. K. & Aravind K – Dam Safety Phase 1, 5th Cycle Inspection Of TNEB Dams Nilgiri District, Tamil Nadu Unpub. Prog.Rep. for FS 2015- 2016

Asrar Ahmed A & Souvik Acharya – Post-Construction Stage Geotechnical Investigation of Bhavani-Kattalai Barrage-III, H.E. Project Solasiramani, Namakkal District, Tamil Nadu Unpub. Prog.Rep. for F.S. 2018-19