UNDER WATER DIAGNOSIS IN REPAIR AND REHABILITATION OF DAMS – CASE STUDY : THE SHOLAYAR DAM, TAMIL NADU, INDIA

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ABSTRACT

Existing, aging dams are always a treasure for our country. Some part of such a treasure is always under water, which could not be easily accessed earlier. In present scenario, like diagnosing the internal parts of our body with the help of scanning equipment, we engineers use modern, Non-destructive methodologies to investigate the internal portion of the dam, deep underwater inspections are carried out to identify cracks, loss in mortar using ROV (Remotely operated vehicle) and Sonic Tomography.

Underwater investigations were carried out at Sholayar dam, Valparai, Tamil Nadu in 2018. It is a Composite dam. Maximum height of masonry and earthen dam are 345ft and 123ft respectively. Storage capacity at MWL is 5677.09Mcft and Dead storage capacity is 338.89Mcft. Dead storage height is 90ft. By sonic tomography, zones of low velocities were assessed which predicted low density materials and thus concluded seepage in those low density pockets. Visual inspection of submerged portion of U/s face of dam was performed using ROV Nondestructive tests were carried out and measures to reduce the seepage and to increase the stability were suggested.

***Keywords** : diagnosis, non-destructive methodologies, underwater inspections, loss in mortar, ROV, Sonic Tomography.*

1. INTRODUCTION

Fresh, potable water is a Nature's gift to mankind. Making the best use of this natural resource is a pleasure to deal with. The basic science hidden in this is when the solvent (water) reacts with the soluble solutes (sulfates of sodium, potassium, magnesium and calcium present in clay, bricks, mortar,soil,water etc.,) gives a solution containing some quantity of essential solutes which reduces the strength and durability of our ancient hydraulic structures. Increased age of the nation's structures/ Dams as well as the increased importance in regular underwater inspection since the revision of National Inspection Standards in 1988, has increased the need to perform repair to elements located below or in water.

Thus, identifying the quantity of these soluble solutes washed out and replacing them back to the structures without much damage to the adjacent portion, in a most practical and economical way is the challenge we face in this decade.

2. DIAGNOSIS

Type –I – Physical inspection and regular maintenance of the structure.

Dam performance is studied using flow measurement devices in galleries by collecting and measuring the leakage and seepage flows. An increase in flow is often an indicator of a worsening situation. A reduction in flow could also be serious; it might be as a result of a self-healing process but, it could be due to blockage of a drainage system or water being diverted elsewhere. A drainage flow that suddenly becomes dirty or turbid is obviously a good indicator that some sort of erosion process is taking place. If there is a deposit of clay the situation is perhaps even more worrying.

Type – II – Visual and tactile inspections (sense of touch) of structures can typically identify the areas of localized damage.

Advanced Investigations may proceed to additional field explorations by drilling, sampling, and installation of more instruments but this process can be very time-consuming and costly, may be done based on the necessity.

Type – III - Extensive Non Destructive Testing (NDT) can be conducted to determine the thickness of the material and reinforcement remaining in the structure.

NDT uses geophysical testing methods (Ground Penetrating Radar GPR, 2D/ 3D electrical resistivity imaging, sonic tomography and so on) to identify potential leakage paths under earthen, masonry and concrete dams. Sonic Tomography and Non-destructive testing methods are used to identify voided areas and thereby helps to interpret the integrity of dam. Most common method of obtaining is by using the ultrasonic testing equipment.

Various geophysical methods are available to investigate the problems of earthen, masonry, concrete or composite dams to identify the following:

- Leak path detection
- Internal Erosion
- Identification of zone of water accumulation
- Cavity/ sinkhole
- Concrete degradation

Investigations have shown that the rate of deterioration of material that is continuously submerged is less when compared to areas subjected to alternate wetting and drying.

3. CONCRETE DEGRADATION:

Deterioration of saturated concrete due to cycles of weathering (freezing and thawing) occurs in structures. Freezing of water in the pores of concrete give rise to concrete stresses that rupture the cement paste / mortar loss from the joints in between the stones / bricks used in the hydraulic structure. Small air voids in the concrete will become water – filled after a long period of immersion. These voids may also be more easily filled when salts are present. Thus, the resistance given by the hydraulic structure against these pore system within them, with the osmotic effect is normally the stabilityof that particular structure.

When the water with the dissolved salts splashes onto the structure, some of it migrates into the concrete through the cracks, surface voids and pores i.e during wetting (when structure is exposed to water). As the concrete dries, the salts solution is concentrated and eventually crystals are formed. Concrete also deteriorate due to the reaction that takes place between the constituents of the concrete itself. Always the reacted products occupy a volume greater than the original solid materials resulting in increased concrete stresses, cracking and deterioration.

Most common of these internal reactions is the alkali- silica reaction. The alkalis present, primarily in -Portland cement, react with the silica found in certain aggregates. This reaction gel expands when it is moistened, causing tensile stresses in the concrete. Alternate wetting and drying frequently associated with the aquatic splash zone accelerates this reaction.

The splash zone concrete is especially susceptible to sulfates and magnesium ion attack due to frequent wetting and drying cycles caused by the wave action. This action washes away the soft outer layers and replenishes the supply of aggressive chemicals.

4. ABOUT THE PROJECT- HISTORY

Sholayar River is one of the main tributaries of Chalakudi River. It has its source in Valparai Estate and runs in a westerly direction for about 30 miles before it joins the Parambikulam River. The total catchment area of this river up to its in-fall into Parambikulam River is 121.72 sq.km. The upper catchment of this river is situated at an elevation from 3000'. This is influenced by theSouth west monsoon.

The Sholayar Dam was constructed during 1961-1971 (Maximum Height 345 FT) across the river Sholayar as one of the components of the prestigious ParambikulamAliyar Project which has a Capacity of 5385m.cft. Incidentally, this is the highest Dam in Tamil Nadu.

This reservoir, after meeting the requirements of the Kerala State, will divert about 2,500m.cft to the Parambikulam - Aliyar Project System through the Sholayar power Tunnel- I. In addition to this, the waters received from the Nirar and Anamalayar Valleys will also be diverted to the adjacent Parambikulam Valley through the Tunnel. The water thus diverted passes through Power House No. I and is utilized for Power Generation. The Water that is supplied to the Kerala Sholayar Reservoir is also utilized for Power Generation through power House No.II. The installed capacity of Power Generation in Power House No. I is 84M.W and Power House No. II is 25 M.W. The salient features of the Dam are furnished below :

Figure 1 : A view of Sholayar Dam - D/s face

Figure 2 : A view of Sholayar Dam – U/s face

Figure 3 : Spillway portion of Sholayar dam with three gates

5. HYDRAULIC PARTICULARS

LOCATION :

Spillway	:	1592.26 cumecs
Latitude	:	10° 17'52''N
Longitude	:	76° 52'58''E
River	:	Sholayar
River Basin	:	Chalakudi
Taluk	:	Valparai
District	:	Coimbatore
State	:	Tamil Nadu
Earth Quake Zone	:	III
Hydrology : Water spread Area	:	5.26 Sq.km
Catchment Area	:	121.72. sq.km
Flood discharging Capacity provided :		
Spillway	:	1592.26 cumecs
River Sluice	:	56.07 cumecs
Tunnel PH-I	:	21.24 cumecs
Tunnel PH-II	:	21.24 cumecs/
Surplus Escape	:	205.01 cumecs
IMPORTANT LEVELS:		
Tunnel Sill Level (dead storage level)	:	+954.02m
Sill of River Sluice Level	:	+969.26m

Spillway crest level	:	+996.70m
Full Reservoir Level	:	+1002.79m
Maximum Water Level	:	+1004.32m
Top Bund level	:	+1007.36m
CAPACITY :		
Gross Storage Capacity at FRL	:	152.48 Mcm /
Storage Capacity at MWL	:	160.76 Mcm /
Live Storage Capacity	:	142.89 Mcm /
Dead Storage Capacity	:	9.60 Mcm
DAM :		
Type	:	Composite (earth cum Masonry)
Maximum Height of Masonry dam	:	105.16 m
Maximum Height of Earthen dam	:	37.50 m
LENGTH :		
(i) Earth Dam	:	899.16 m
(ii) Masonry	:	345.03 m
Total	:	1244.19 m
(iii) Width at top of dam	:	8.53 m
Spillway:-		
Spillway Type	:	Ogee
No.of bays	:	3
Type of gate	:	Vertical lift
Size of Gate	:	12.80 m (W) x7.62m (H)
Gate Hoisting Arrangement	:	Chain and Sprocket type
RIVER SLUICE:-		
No of Sluice	:	1
Size	:	Height: 1.83 m; Width: 1.52 m
Type of gate	:	Vertical lift
Type of Hoist	:	Screw operated
DRAINAGE GALLERY:-		
No of tiers	:	3
Size of Gallery	:	1.52 m × 2.13 m (5' x 7')
No of notches	:	29

6. INSPECTION AND OBSERVATIONS

Site visit followed by Tomography survey and under water survey were conducted in the year 2018. In the previous inspection the entire length of the dam, operation of gates and the drainage gallery were inspected. The water level at this time of inspection was almost at the maximum water level (i.e 3294.52 ft). Due to continuous rainfall in the catchment area of the reservoir, the rate of inflow was observed to be 10,000 cusecs. One spillway gate was raised by 150mm in order to maintain the water level in the reservoir at the safe operation level.

The drainage galleries on the right flank of the masonry section of the dam were inspected for assessing the seepage water, lime leaching and other structural distress. The specific observations are as follows:

- Permissible Seepage was observed in the right top gallery.
- In the transfer gallery the permissible seepage was observed to be significant.
- Lime leaching was observed in the foundation gallery.
- The overall seepage was less in the dead storage zone when compared to the live storage zone.
- As a whole, the seepage was found to be significant through the drainage conduit located in the spillway blocks.

Figure 4 : Upstream face of Sholayar

7. REMEDIAL MEASURES

A. Cavity Filling

Providing and filling the deeper cavities of the R R masonry which are beyond 5 cm and up to 30 cm using non-shrink, cementitious micro concrete mixed with water at a ratio of 0.16 to fill the gaps where, normal access is restricted and to achieve proper compatibility and placement without vibration. The micro concrete shall contain no chloride admixture and provides minimum compressive strength of 40 N/mm² in 7 days & 50 N/mm² in 28 days when tested in 70.7mm cube. The product had controlled expansion characteristics of 1 to 4% on 12 June 2019 for 20 cubes. (The product shall have controlled expansion characteristics of 1 to 4% when tested as per ASTM C 827– 1987).

Figure 5 : Surface Preparation

Figure 6 : Surface Preparation

Figure 7 : Injection grouting

B. Injection grouting

Treating the internal cavities up to 1 metre deep in the R R masonry using injection pressure grouting by drilling hole of 25mm dia and 300mm deep in triangular pattern at inclined position. Fix PVC nozzles of 12mm dia& 200mm deep using quick setting cement. Mix OPC 43 grade cement with water in ratio 0.35 - 0.4 as per the consistency required and by adding polymer rubber based latex @ 1 litre per bag of cement and plasticized expanding – non shrink grout admixture @ 225 gms per bag of cement and grouting the same by using 40 psi grouting pump. The grouting material shall give min compressive strength of 35 N/mm² in 28 days when tested in 10cm cube. On completion of grouting, the top portion of the PVC pipe shall be cut and seal with cement putty.

C. Pointing

Providing and filling the pointing mortar in the horizontal and vertical joints of R R masonry in the upstream face of Dam to an average depth of 2 times the thickness of joint, (25mm thick and 50mm depth) 50mm depth and finishing with T Joint as done for raised pointing on the faces 20mm on masonry rock surface with 10mm thick by applying a priming coat with solvent free epoxy bonding agent inside the joints with a brush and filling properly these joints with "shrinkage controlled – non shrink, abrasion resistant, UV resistant, impermeable polymer modified cementitious high specification repair mortar system" mixed with water in the ratio of 0.16 should prove fully adequate and will give compressive strength of min 45 N/mm² in 7 days & 70 N/mm2 in 28 days; tensile strength of min 4 N/mm² in 28 days; flexural strength of min 9 N/mm² in 28 days, permeability less than 10-12cm/sec, Water absorption less than 2%, Rapid chloride permeability < 1800 columbs and nicely pointed.

8. GEOPHYSICAL SURVEY METHOD

A. Sonic Tomography Measurements for Transverse Sections

The survey locations, i.e. transverse sections TS-1 to TS-8, and longitudinal section, LS-1, were finalized based on the report of the water seepage rates from the drain holes in the transfer gallery, made available by the Office of the Executive Engineer, Sholayar Basin Division, Valparai, Tamil Nadu. In Phase-I, a total of eight (8) transverse sections have been investigated, with four numbers in the eastern and western non-spillway shoulders of the dam, and four numbers in the spillway segment of the dam. The transmitters were fixed on the downstream face of the dam at a regular interval of one meter. An instrumented hammer was used as the sound source. At the receiver side, three accelerometers were fixed at a spacing of 0.5 m within the transfer gallery of the dam. The downstream side was assessed using a moving winch, specially designed for conducting the survey and fabricated by the authorities of the Dam. The presence of multiple ray tracks that are reciprocally intersected is an essential condition to obtain good quality tomographic results. Therefore for each receiver point, an attempt was made to obtain the largest fan of measurements possible creating a high-density tomography grid.

B. Sonic Tomography Measurements for Longitudinal Section

The longitudinal tomographic section was executed between Block 28 and Block 29 of the dam. A total of eight (8) receivers were fixed on the ceiling of the transfer gallery. The first and the fifth receivers were fixed at a distance of 0.5 m towards either side of thejoint between Block 28 and Block 29. The second and the sixth receivers were fixed at a distance of 1.5 m towards either side of the joint between Block 28 and Block 29. The third and the seventh receivers were fixed at a distance of 2.5 m towards either side of the joint between Block 28 and Block 29. The fourth and the eighth receivers were fixed at a distance of 3.5 m towards either side of the joint between Block 28 and Block 29.

The transmitter points were fixed at the road level. The transmitter points one to twenty-one (1-21) points were fixed at a regular interval of 0.5 m towards either side of the joint between Block 28 and Block 29, and the remaining 38 transmitter points were fixed at an interval of 1.0 m on either side of the transmitter points 1 and 21. Triggered hammering was the sound source, which was produced from theroad level to cover the masonry block of the dam from the top level to the bottom to amaximum possible extent structurally.

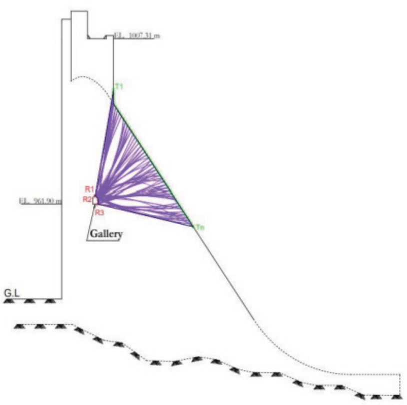

Figure 8 : Sonic Tomography

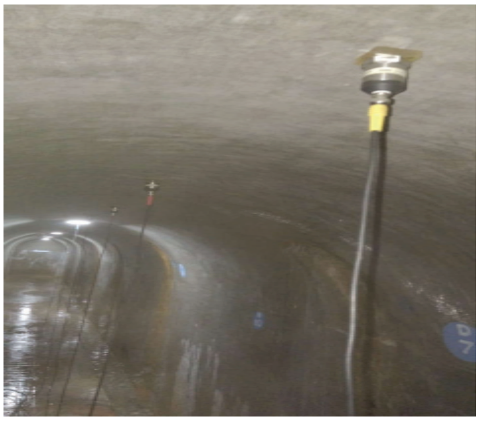

Figure 9 : Receivers –@ceiling of gallery

C. Sonic Tomography Measurements on Non-spillway Segment

In this portion of the dam, four (4) transversal tomographic sections, Sections TS-1, TS-6, TS-7and TS-8 were characterized by 24, 47, 50, 35 transmitters (acquisition) points, respectively, andthree (3) receiver points within the transfer gallery of the dam. The transmitter points were fixed at an interval of 1.0 m on the downstream face. These sections were acquired using an instrumented trigger hammer as the sound source. In addition, the longitudinal tomographic section, LS-1 was executed between Block 28 and Block 29 in the non-spillway segment of the Dam.

D. Sonic Tomography Measurements on Spillway Segment

In the central segment of the dam, a total of four (4) transverse tomographic sections were acquired: TS-2, TS-3, TS-4, and TS-5 are characterized by 34, 45, 46, 45 transmitter points, respectively and the 3 receiver points at the transfer gallery. An instrumented trigger hammer was used as the sound source.

Inferences

The following are the inferences from the tomograms examined:

(1) On an average, the velocity range in the investigated portions of the dam cross sectionsis between 3000 m/s and 5500 m/s. The values encountered from thetomographic investigations are representative ranges expected in random rubble stonemasonry with cement mortar, which is the structural material used in the constructionof the dam.

(2) The average P-wave velocity values are lower in the spillway segment than the nonspillwaysegment, indicating a relatively poorer quality of material in the spillwaysegment, which is on the expected line.

(3) Zones of low velocity also have been identified in non-spillway sections TS-6, TS-7 and LS-1, and these are corroborated by the significant volume of seepage in these blocks,17/29 Blocks 28 and 29, which are possibly most significant. Specific locations of these low velocity zones can be seen in the tomograms.

(4) Pockets of low velocity are seen in sections TS-1 and TS-8, but these may not besignificant to cause seepage. This is corroborated by the low seepage observed fromthe drain holes in these blocks, Blocks 21 and 31.

(5) Significant zones of low velocity are seen in the spillway sections, TS-2, TS-3, TS-4 andTS-5 consist of large regions with low velocity ranges, possibly contributing toseepage. Except for TS-4, which shows a moderate level of seepage through the drainholes, the seepage observations at the other three locations corroborate these findings. In likelihood these identified areas are susceptible to seepage.

(6) From the tomographic sections investigated and the diffused presence of zones of lowvelocities, it can be stated that there is likelihood of seepage within the blocks due tothe presence of low density pockets. This seepage is in addition to that happeningthrough the construction joints between the blocks as observed from the high volume of seepage from drain holes close to the construction joints.

9. UNDER WATER SURVEY

Photos and high-resolution videos of the dam were recorded using ROV Mike. Minor to moderate loss of mortar at the joints of the stone masonry was observed at some sections of the dam submerged in water.

Equipment Details

- 1 × ROV Mike
- 1 × Tether Management System
- 1 × Petrol Electric Generator
- Command Module
- 1 × 0.6kW Power Supply Unit
- 1 × LCD Screen
- 1 × Control Station Processing Unit
- 1 × Keyboard
- 1 × Mouse
- 1 × Wireless Router
- 1 × Remote Control Joystick
- 1 × Laptop

Figure 10 : Remotely operated vehicle

10. STATUS AFTER REHABILITATION

(a) Minimization of the permissible seepage from the upstream face of the dam which was possibly achieved by sealing of the mortar joints (Cavity filling, Injection grouting and pointing) at the upstream face and identifying the pockets after sealing from the results of sonic tomographic survey. The seepage losses were within the permissible limits even before rehabilitation.

(b) The main objective was to ream out the lime leaching from the foundation gallery air vent and from the drainage conduits, which was performed from the gallery prior to the application of sonic tomography. Thus by minimizing the seepage and by arresting leaching the performance of the dam was enhanced.

11. CONCLUSION

The lifespan of any hydraulic structure can never be ascertained, if it is periodically maintained in a good manner. So, let's protect these treasures for generations.

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