# Application of Geo-Physical Survey in Structural audit of Dams in Maharashtra

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***Abstract - Stability and integrity of any dam structure is always of great concern since any possible damage in the structure can affect its operational capabilities and may pose risk to the life and property at downstream of the dam at the time of failure, besides causing huge economic loss. Dam safety is considered an inherent function in the planning, design, construction, maintenance and operation of dams. In spite of taking due care in planning, design and execution stages; many of such dams have shown signs of distress. It has been recognized worldwide that dam safety aspects, particularly of the existing dams, are not receiving adequate attention even as the number of old/existing dams are aging. One of the important aspects of this safety is to assess the nature of likely damage if the proposed dam fails. Lessons from the past have taught us the fact that dams with a perfectly safe design some fifty or hundred years ago are not safe anymore with present dam safety standards. Majority of the present dams therefore need a thorough inspection and subsequent rehabilitation measures, as they have been constructed a century back and gradual wearing of material properties inclusive of some structural distresses of the dams must have taken place during passage of time.***

***To assess the health of the dam, application of Geo-physical survey method found to be reliable and powerful tools for Geo-technical Investigation. They cover the whole range of soils and rocks, independently of particle size, and provide data in the natural state for the characterization atdifferent scales. Assessment of the reliability of the most popular techniques is therefore of primary importance for static and seismic applications. This is also considered to provide an insight on the consequences in the practice of geotechnical engineering.***

***Keywords - Dam. .Dam Safety, Geo-physical survey, soils and rocks***

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## INTRODUCTION

structure built across a stream, a river, or an estuary to retain water. Dams are built to provide water for human consumption, for irrigating arid and semiarid lands, or for use in industrial processes. They are used to increase the amount of water available for generating hydroelectric power, to reduce peak discharge of floodwater created by large storms or heavy snowmelt, or to increase the depth of water in a river in order to improve navigation and allow barges and ships to travel more easily. Dams can also provide a lake for recreational activities such as swimming, boating, and fishing. Many dams are built for more than one purpose; for example, water in a single reservoir can be used for fishing, to generate hydroelectric power, and to support an irrigation system. Water-control structures of this type are often designated multipurpose dams.

Auxiliary works that can help a dam function properly include spillways, movable gates, and valves that control the release of surplus water downstream from the dam. Dams can also include intake structures that deliver water to a power station or to canals, tunnels, or pipelines designed to convey the water stored by the dam to far-distant places. Other auxiliary works are systems for evacuating or flushing out silt that accumulates in the reservoir, locks for permitting the passage of ships through or around the dam site, and fish ladders (graduated steps) and other devices to assist fish seeking to swim past or around a dam.

**Significance:** India has 5334 large dams; the largest number of dams in the world after the USA and China. Constructing dams exposes downstream areas to the risk of catastrophic flooding. Adopting risk-based decision-making systems for making policy, implementation and management decisions regarding dams are crucial for mitigating this risk. Dam Safety Organization, Central Water Commission, Government of India reports a total of 23 major dam failures in the country between 1960 and 2010. Some of them led to a significant number of deaths and damage to property. Dam safety is important for Safeguarding Water security and huge investments in infrastructure. Safeguarding human life, and properties of the people living downstream of the dams. Due to which the structural Audit of existing Dam is very important

## LITERATURE REVIEW

**Georgia S. Mitsika, John D. Alexopoulos, Ioannis Konstantinos Giannopoulos, Nicholas Voulgaris (2023)** presented the preliminary results of a near-surface geophysical research carried out on Lefkada island, for the investigation of the geological setting of Lefkada town.

**Leonides Guireli Netto, Otavio Coaracy Brasil Gandolfo, Walter Malagutti Filho, João Carlos Dourado** (Vol 38, No 1, 2020) found that the application of non-destructive methods of investigation in dams, such as refractive seismic analysis and multichannel surface wave analysis (MASW) are increasingly effective from the point of choosing the best dam site, as well as in the phases of construction and maintenance of the structure.

**Yunsen Wang, Neil Anderson, Evgeniy Torgashov** (Dec 2019) presented foundation survey projects for hotel buildings in Kentucky, assisted by drilling data, an integrated geophysical survey was undertaken. The main goal of the project was to investigate the depth of the top rock and the void locations, if any present. The project used shallow non-invasive geophysical survey methods.

**Abbas Ali, Raafat E. Fat-Helbary, Karrar El-Faragawy, Ahmed Hamed Aswan** (Dec 2019) represents one of the most attractive parts in Egypt, where it contains several historical and archaeological sites such as Abu Simble and Elephantine temples. The present work is mainly concerning with the conducting of Ground Penetrating Radar (GPR) and Multi-Channel Analysis of Surface Wave (MASW) techniques in order to locate any hidden archaeological structures

**Koya Suto, Milovan Urosevic, Milenko Burazer, Snezana Komatina Snezana Komatina** (AEGC 2018: Sydney, Australia) presented risk assessment report by using geo-physical data to prevention of further damage due to severe floods and landslides in the Balkan area.

**Anbazhagan Panjamani, Divyesh Rohit, Athul Prabhakaran, Vidyaranya Bandi** (May 2018) presented the application of integrated geophysical investigation for the identification of cavities at a mega construction site in Kerala State, India. Geophysical survey methods, namely ground penetrating radar (GPR) and multichannel analysis of surface waves (MASWs) techniques, are used to identify the heterogeneities in lateritic soils and localized cavities. The survey areas identified are critical sections of a mega construction project subjected to heavy dynamic and static loads.

The effectiveness of surface methods (MASW and RWM) is compared with PS logging in determining shear wave velocity by study report of **Dewan Mohammad Enamul Haque, Asm Woobaidullah** (2018)**.** For this purpose, shear wave velocity results Vs30 of 12 PS logging and MASW surveys conducted in Mymensingh Municipality in Bangladesh have been utilized. Additionally, the shear wave velocity results of three PS logging have been compared with the refraction profiles of RWM survey conducted in Rooppur nuclear power plant site in Bangladesh.

## OBJECTIVES

To study the Detection of sign of distress on dam body and foundation such as cracks, seepage etc. by visual inspection, review of project files and information database, including records of site condition, dam construction and performance, maintenance records and earlier inspection reports by taking actual case study

To anslysis Review of hydrological data, hydraulic analysis ,Identify weak zone or zone of anomaly by conducting suitable geo-physical survey

## METHODOLOGY

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## DATA COLLECTION

Bhushi Dam, Lonavala is under the management of South-East Division of Central Railway, Mumbai. It was constructed in the year 1876 for the Great Indian Peninsular Railway in order to store and supply water for steam locomotives. The dam crest level was raised in the year 1886 and final raise was made in the year 1906. It was in the year 2014 that Indian Railway announced that Bhushi dam will be developed as a tourist resort and accordingly, further modifications have taken place since then. The site visit and inspection of this dam was carried out during Oct, 2019 and March, 2021. The finding of the inspection was submitted in Report. The location of the dam marked on a Google Earth image is shown in Figure 5.1. The salient features of the dam and with actual dimensions and other details from data received from Dam Authority during inspection visit and from other available sources are presented in Chapter 2: Inspection Report. The chapter also enlists the damages /

distress/ problems in the dam structure and surroundings found at the time of visit.

The area experiences varying weather conditions throughout the year, with monsoons being the most significant season typically lasting from June to September with average annual rainfall ranging from 2500 mm to 3000 mm. The project location lies in that part of Maharashtra which receives high amount of rainfall. The heavy rainfall during this period adds additional stress on the dam structures, which can lead to further damage if not properly maintained. The dam site falls under Zone III i.e. moderate seismic zone, assessment of dynamic stability of the dams during an event of earthquake, also need to be re-assessed

## DATA ANALYSIS

### Geotechnical Report

This report is a compilation of factual data obtained through the geotechnical investigation campaign carried out in the proposed area of development for the project.

## SCOPE OF WORK

The scope of work entails carrying out a campaign of geotechnical investigation works in proposed locations are as follows:

- Mobilization of all equipment & Personnel and execution of the following as per BoQ;
- ➢ Geotechnical Investigation for the 24 nos. of land boreholes at each location using borehole method;
- ➢ Collection of disturbed and undisturbed soil samples and rock samples and water samples;
- ➢ Performing Standard Penetration Test (SPT) at regular depth interval;
- ➢ Carrying out laboratory testing on disturbed and undisturbed soil, rock and water samples;
- ➢ Performing Permeability Tests in soil & rock;
- ➢ Conducting Pressuremeter Tests;
- ➢ Preparation and submission of Report (draft & final).

### Field Investigation

Fieldwork was started from 10th November 2022 and field work completed on 22nd November 2022. The brief description of the activities that comprised the field investigation is presented in thesections below.

### Boring

Rotary drilling is the most rapid method of advancing the boreholes in any type of soil. This method uses rotation of drill bits (tungsten/diamond), with the simultaneous application of pressure to advance the borehole. In core drilling, an annular bit, fixed to the bottom of the outer rotating tube of a core barrel, cuts a core, which is recovered within the inner-most tube of the core barrel assembly and brought to the surface for examination and testing. The core is prevented from dropping out of the core barrel by a core catcher made of spring steel and located just above the core bit. The boring/drilling works at the proposed locations identified and marked by client's representative were performed by the hydraulic rotary drilling rig. Rotary drilling operations were performed to obtain the best possible recovery of undisturbed soil samples in the boreholes. Disturbed soil samples were obtained through a split spoon sampler during execution of Standard Penetration Tests (SPT). The borehole walls are supported by temporary steel casing driven until a hard stratum is encounteredor until reaching of termination depth of the borehole. The summaries of boreholes are presented in below Table. The geotechnical borehole logs with visual lithologs are presented in Appendix C on Plates C1. The location map and plan are presented in Appendix B on Plates B1. The borehole cross sections are presented in Appendix B on Plate B2.

**Table 1: Summary of Boreholes Executed for the Project**

| Sr. No. | Location ID | Field Activity Dates | | Location Co-ordinates | | Termintion Depth, m |
|---|---|---|---|---|---|---|
| | | From | To | Easting | Northing | |
| 1 | BHS BH-01 | 10/11/2022 | 12/11/2022 | 330834.72 | 2070897.62 | 15.00 |
| 2 | BHS BH-02 | 13/11/2022 | 16/11/2022 | 330880.66 | 2070916.03 | 22.00 |
| 3 | BHS BH-03 | 17/11/2022 | 19/11/2022 | 330926.88 | 2070919.16 | 15.00 |
| 4 | BHS BH-04 | 20/11/2022 | 22/11/2022 | 330976.48 | 2070922.25 | 15.00 |

### Sampling

Sampling comprised collection of rock core samples.

### Rock Core Measurements

### Core Recovery

Core recovery defined as the summed length of all pieces of recovered core (whether solid, intact with full diameter, or non-intact) expressed as a percentage of length drilled. The sound rock usually furnishes high recoveries, often about 100 %, seamy and or jointed rock may furnish low recovery and badly broken cores.

**Solid Core Recovery**

**It is the percentage ratio of solid core recovered to the total length of the core run.**

**Rock Quality Designation**

RQD is a modified core recovery percentage in which all the pieces of sound core over 10 cm long are counted as recovery and are expressed as a percentage of the length drilled. The smaller pieces resulting from closer jointing, faulting or weathering are discounted. The RQD has been found to be more sensitive and consistent indicator of general rock quality compared to the gross recoverypercentage. The core quality can be classified as under according to RQD as prescribed in IS 11315 (Part 11):

**Table 2: Rock Core Quality as per, IS 13315 (Part 11)**

| RQD, % | Core Quality |
|---|---|
| 90-100 | Excellent |
| 75-90 | Good |
| 50-75 | Fair |
| 25-50 | Poor |
| < 25 | Very Poor |

**Falling Head Permeability Test**

The Falling Head Permeability Test measures the permeability of a test section by driving a casing to the top of the test section and filling up the borehole with water. The rate of fall of water indicates the flow of water into the test section and is recorded at specific intervals of time to obtain the permeability. The testing was carried out in general accordance with IS 5529 (Part 1).

A summary of the falling head permeability testing conducted for the project is presented below in Table and complete results are presented in Appendix C on Plates C2.

**Table 3: Summary of Falling Head Permeability Test Results**

| Sl. No. | BH No. | Depth, m | Type of Soil | Coefficient of Permeability, cm/s | Degree of Permeability (after Terzaghi &Peck, 1967) |
|---|---|---|---|---|---|
| 1 | BHS BH-01 | 1.50 – 3.00 | Masonry DamMaterial | 6.65E-05 | Very low-low |
| 2 | BHS BH-02 | 1.50 – 3.00 | | 4.08E-05 | Very low-low |
| 3 | BHS BH-03 | 1.50 – 3.00 | | 3.58E-05 | Very low-low |
| 4 | BHS BH-04 | 4.50 – 6.00 | | 9.87E-06 | Very low |

**Pressure-meter Test**

At each test location, a NQ core barrel, producing a nominal hole diameter of 76 mm, was used to form a suitable socket for insertion of the pressure meter. Pressure-meter tests was performed in boreholes as detailed below in Table 3.5 using an OYO Elastmeter-2 (Model-4018), with a rated pressure range of 0 to 200 Bar, for the type of membrane. The test is carried out in general accordance with ASTM D 4719 and IS 12955 (Part 2).

The summary of the Pressuremeter test results are provided below and detailed test records are presented in Appendix C on Plates C4.

**Table 4: Summary of the Pressure-meter Tests**

| Borehole ID | Depth (m) | Elastic Modulus(MPa) | Shear Modulud(Mpa) |
|---|---|---|---|
| BHS BH-02 | 15.00 | 3278 | 1261 |
| BHS BH-03 | 11.00 | 3502 | 1347 |
| BHS BH-04 | 6.00 | 8402 | 3231 |

**Ground Water**

Short-term water levels recorded in open boreholes may not represent a long-term condition since the water level may not have had sufficient time to completely stabilize. Additionally, the groundwater levels will fluctuate with seasonal variations in rainfall, surface runoff. At times during prolonged rainfall ground water level will be higher than in relatively dry periods.

**Laboratory Testing**

The selected rock samples meant for testing were transported to the Reputed laboratory at Navi Mumbai. The laboratory tests were conducted as per relevant parts of Indian Standard, in compliance with the technical specifications of the contract, at laboratory in Navi Mumbai. Tests have been performed as directed by Client.

A summary of laboratory tests carried out is shown below in Table 5 and the complete results of laboratory testing are presented in Appendix D.

**Table 5: Summary of Laboratory Tests carried out for Project**

| Sl. No. | Type of Test | Standard Code followed for carrying out the test |
|---|---|---|
| A | Testing on Rock Samples | |
| 1 | Density | IS 13030 |
| 2 | Water Absorption | IS 1124 |
| 3 | Uniaxial Compressive Strength | IS 9143 |
| 4 | Modulus of Elasticity & Poisson's Ratio | IS 9221 |
| 5 | Rock Triaxial Test | IS 13047 |
| 6 | Tensile Strength | IS 10082 |
| 7 | P-Wave Velocity | ASTM D 2845 |

## SUMMARY

The field and laboratory test data incorporated have been obtained and processed using procedures specified in various codes of practices, good engineering norms and conventions. The field and laboratory test results and records reported here are relevant for the test locations and time at which the tests have been conducted

## CONCLUSION

Based on the study carried out and the importance of the project the following conclusions may be drawn:

- The analysis is carried out for the given section of the dam with Geo-physical and Geo-technical Exploration report along with Hydraulic data. ***The sections are found to be safeas per codal provision.***
- Further through field observation, the critical sections may be assessed again and accordingly analysis may be carried out to check the safety and in case the sections arefound unsafe, retrofitting measures may be adopted.
- The boundary conditions and the parameters used in the analysis may be checked with actual field conditions.
- Final analysis will be carried out based on these data and corrective measures will be suggested.
- Detailed field observation to assess boundary condition, critical section is required for the purposes:
- Critical review of the observations made during site visit.
- Proper instrumentation for health monitoring of dam.
- List of problems associated with the dam.
- Location of visible seepage, probable piping, cracks, vegetation in the downstream.
- Formulation of remedial measures.

## FUTURE SCOPE

In India Most of the dams are not designed properly causing distresses in the dam in the form of cracking, large displacement, heavy leakage, extensive damages during earthquake activities etc. The role engineers, scientist and consultants have increased manifolds for achieving targets of power generation. Proper design, construction and monitoring is essential for smooth functioning of any hydropower project. Structural safety of various components namely dam, head race tunnel, surge shaft, penstocks and powerhouse, of hydropower projects is of vital importance

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