

Investigations existing dam using integrated Geotechnical and Geophysical methods

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ABSTRACT

Most of dams existing in India were constructed long back, with limited technical resources. Information relating to dam foundations and structural components is essential in the evaluation, stability assessment and retrofitting of existing dams. Geotechnical and Geophysical methods can provide direct and indirect information for safety analysis and augment studies for the conditional assessment of dams. This paper presents details for an integrated approach using geotechnical and geophysical methods useful for investigation and rehabilitation of dam and associated structures. Integrated approach of field observation, drilling of boreholes with sample collection, Multichannel Analysis of Surface Wave (MASW) survey, Ground Penetrating Radar (GPR) survey and Resistivity Imaging survey are explained with typical results. Drilling of borehole with Standard penetration test (SPT) N measurement with sampling, static and dynamic properties estimation of the dam and foundation using MASW, water seepage and subsurface layering by Resistivity Imaging survey and weak zone mapping by GPR is discussed in this paper.

INTRODUCTION

Dams, dikes and levees are an important form of hydraulic infrastructure providing protection from floods, water supply for irrigation and domestic purpose, and a source of significant amount of clean energy for billions of people around the world. With ageing and increasing demand it is more likely that these structures will undergo stress in the coming years. Hence it is important to monitor these mega structures continuously for their safety and efficient performance. Failure of dams is usually caused due to poor design, construction quality issues, inadequate maintenance, or a combination of the above. The structural integrity of dams, dikes and levees is critical for the protection of monetary and human life, particularly with the incidence of flooding on the rise. New methods are needed to quantify the structural integrity of dams and levees, given the advancing age and unknown construction/maintenance history for many of these structures. It has been observed in many dam failures disasters could be averted if proper monitoring of the structure would have been done. Continuous monitoring and inspection of these structures helps in identifying potential failure modes as well as in identification of commencement of the same so that appropriate correction measures can be taken to avert failure.

Rigorous assessment and surveillance of dam components including the appurtenant structures and foundation conditions describe the soundness and health of the overall structure. The aim of

the monitoring and inspection exercise is to minimize the potential failure of dams by identification and timely rehabilitation of the cause or mode. With advancement in technology, it is now feasible to identify and monitor health of dam site so that probable anomalies can be identified early and rehabilitation options can be devised. As it is called ‘prevention is better than cure’, an early inspection and identification can save huge amount of retrofitting costs by timely small repairs. Standard dam safety inspection methods using instrumented and visual surveillance approaches are important to ensure safety and stability of the structure. Although visual inspection is easy and quick but it does not give information on internal quality of the dam structure, hence it is recommended to rely on instrumented monitoring and inspection approach for the safety and stability assessment of dam. A number of Geotechnical and Geophysical techniques are utilized to evaluate conditions at existing dam sites (Frontier Geosciences Inc, 2015). These techniques are helpful in determination of mechanical properties of dam structure and its foundation, tracing of leakage initiation, identification of crack or fracture initiation, detection of weak zones or degraded zones of the dam material and foundation.

INTEGRATED INVESTIGATION AND CORE SAMPLING

Subsurface investigation plays an important role by providing suitable data for design and performance assessment of dam structures. The subsurface investigations can be planned based on dam type and preliminary investigations. Detailed investigation can be carried out by an integrated approach using geotechnical and geophysical testing. Here it should be noted that limited drilling and geotechnical testing and more geophysical testing should be carried out to avoid unnecessary drilling of intact dam sections. Drilling and sampling should be avoided and only carried out to assess the strength of the joints and foundation of the dam. Foundation strength can be assessed by drilling and conducting SPT (Standard Penetration) tests at downstream and upstream of dam structure. The boreholes should be drilled as per IS: 1892 (1974) and N-SPT values were measured regularly at 1.5 m interval as per IS: 2131 (1981). Disturbed and undisturbed samples were collected at possible depths as per IS: 2132 (1986). When refusal stratum is encountered, drilling should continue using NX/NXM size Single/double tube core barrel with diamond/synthetic bit. As drilling progresses, core recovery and RQD values should be constantly recorded by the site engineer. Rock cores can be stored in a standard Core Box in Snake Pattern. Collected rock samples can be used to find strength of sample in the laboratory. Specialized horizontal and inclined drilling can be performed to collect core sample in masonry dams for the assessment mortar quality and strength. Typical horizontal drilling in dam section and sample with mortar is shown in Figure 1.

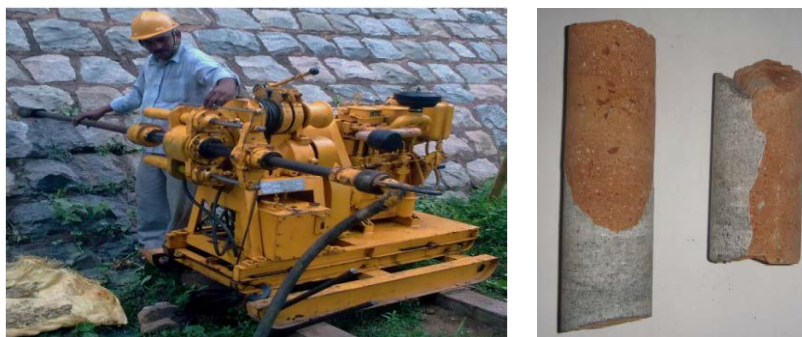


Figure 1: Horizontal Drilling at Downstream for Random Rubble Masonry sample

SEISMIC SURVEY BY MASW

Borehole N-SPT values can give only point subsurface information at drilled locations. In order to measure the average Young's modulus and shear modulus of dam structure, the seismic surface wave survey of MASW (Multichannel Analysis of Surface Waves) can be carried out at required places. MASW first measures seismic surface waves generated from various types of seismic sources such as sledge hammers etc., analyses the propagation velocities of those surface waves and then finally deduces shear-wave velocity (V_s) variations below the surveyed area, inverting the obtained dispersion curve to a theoretical one. V_s is one of the elastic constants and closely related to Young's modulus. Under most circumstances, V_s is a direct indicator of the ground strength (stiffness) and therefore commonly used in deriving the load-bearing capacity. After a relatively simple procedure, final V_s information is provided in 1-D, 2-D, and 3-D formats. MASW is widely used in many geotechnical investigations because of its easiness and non-destructive nature (Park et al., 1999). In dams, MASW can be carried on top, downstream, upstream and also along section to measure shear wave velocity. We have carried out 1-D MASW test at the Thippagondanahalli dam section and waste weir in Karnataka to measure the strength of dam structure. The MASW system consisting of 24 channels Geode seismograph with 24 geophones of 4.5 Hz capacity are used in this investigation. The seismic waves were created by an impulse source i.e. the hitting of a sledgehammer weighing 15 pounds on a 300 mm x 300 mm size hammer plate with ten shots. These waves are captured by the vertical geophones/receivers and further analyzed by inversion. Twenty-four geophones are arranged linearly and the sources are kept on one side of the MASW line. Geophone spacing of 1 m and source distance of 4 m, 8 m and 12 m were being used. Surface wave records are used to extract dispersion curve and to estimate the shear wave velocity. Figure 2 shows MASW survey on dam top and shear wave velocity of dam section.

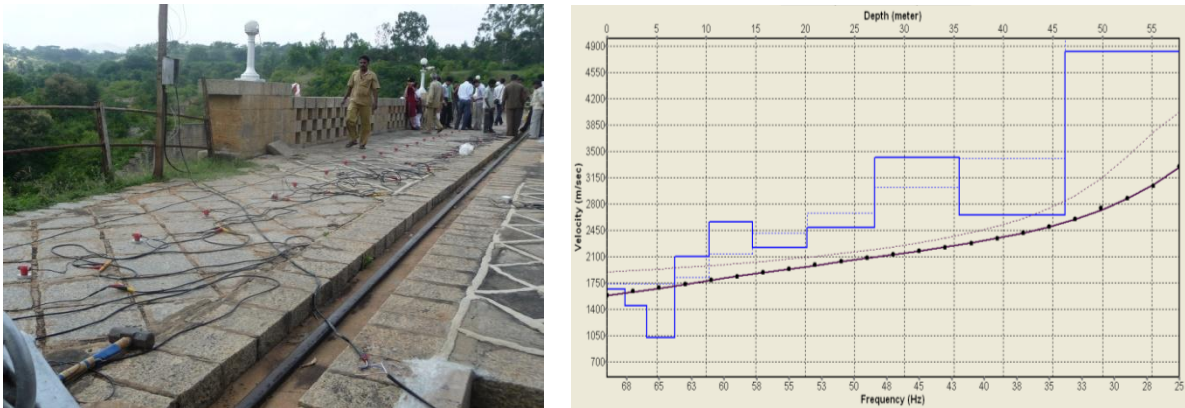


Figure 2: Typical MASW testing at dam site and shear wave velocity

INVESTIGATION OF DAM PROBLEMS BY IMAGING

Old dams pose several hidden problems due to the increase of service years, which may lead to leakage or even break of the dam (Haitao et al., 2010). Crack, Animal burrows and tunnels can lead to erosion and piping phenomenon, which caused approximately half of the world's dam failures (Richards and Reddy, 2010). Though conventional geotechnical investigation may be

cable of deducting hidden problems in the geotechnical structures, the increasingly popular use of geophysical methods for subsurface investigation all over the world and its potential to give an image of the scanning area to identify hidden problems in geotechnical structures (Moustafa et al, 2012) have made geophysical techniques, a prime mode of detecting subsurface anomalies in many structures. In this section, 2- dimensional subsurface imaging techniques of MASW, Ground penetrating radar (GPR) and electrical resistivity tomography (ERT) for identifying subsurface problems are presented.

Ground Penetrating Radar for Dam Study

Ground penetrating radar (GPR) can be used as a powerful tool in dam hidden problem exploration with high resolution and detection efficiency. GPR is an electromagnetic sounding technique that is employed to investigate shallow sub-surfaces which have contrasting electrical properties. The GPR operates by transmitting short electromagnetic waves into the subsurface and recording and displaying the reflected energy. Ground Penetration Radar is an electromagnetic reflection method; in which electromagnetic signal is emitted via an emitter built in antenna into the structure under inspection. The emitted waves are reflected due to the changes in the material properties of the anomalies in the substructure, which will be received by a receiver: inbuilt in an antenna. This wave is recorded in the control unit, displayed in monitor and further analyzed in the computer. Frequency of emitted and received electromagnetic waves plays an important role in the resolution and depth of the information. GPR techniques have been used to identify air filled and water filled cavities in/below geotechnical structures (Hussein et al., 2014). Here ground coupled Mala GPR antennas having a central frequency of 25 MHz, 100 MHz and 500 MHz were used in selected locations and found that 100 MHz is used to image the subsurface. 2-D images are used to interpret the subsurface layering, its homogeneity, densities and air filled voids/cavities. Typical radargram from GPR survey top show layering heterogeneity and cavity signature (air filled) identified by authors are given in Figure 3.

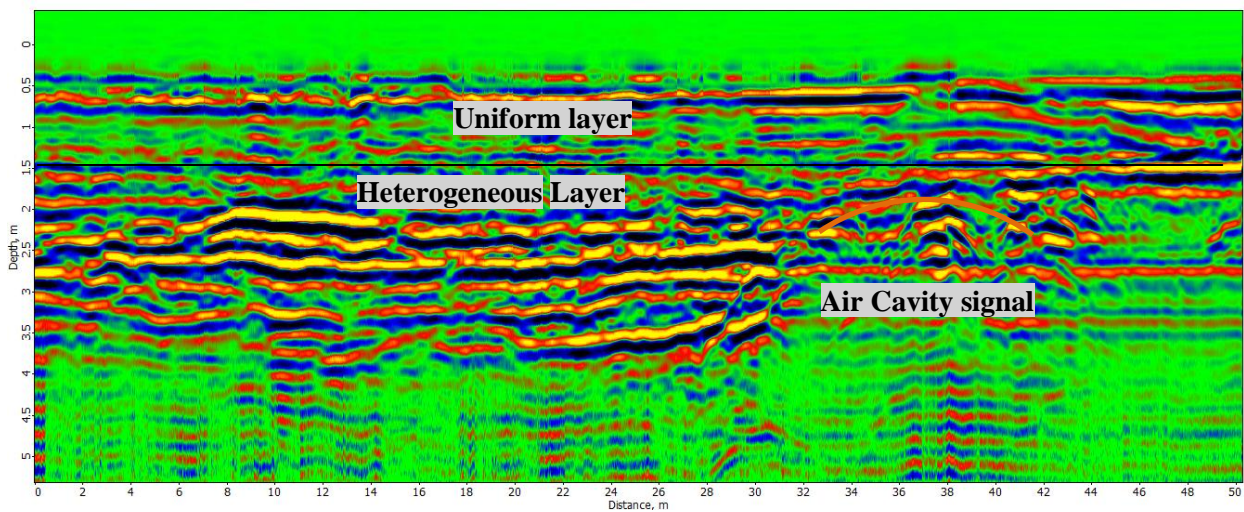


Figure 3: Typical GPR radargram with different layers, heterogeneity and air cavities

Air-filled voids and animal burrows have low dielectric constant (air dielectric constant = 1) and the reflected signal from its boundary will change its polarity relative to the incident signal, in the radar scan across the empty void, a large positive peak can manifest. On the contrary, the water-filled or clay-filled voids have high dielectric constant which results in no change to the polarity of the reflected signal and a large negative peak can be seen in the scan that passes on water- or a clay filled cavity signal (Hussein et al., 2014; Chen and Wimsatt, 2010; Smith and Scullion, 1993; Stott, 1996)

Electrical Resistivity Imaging

Electrical resistivity is one of the age old techniques for monitoring changes of electrical properties in the subsurface and 2-D inversions can provide reliable insight into the subsurface (Loke and Baker 1995; 1996; Chinedu and Ogah 2013). It is very effective in determining depth to water saturated zone and groundwater flow pattern (Loke, 1999; 2004). The resistivity of soils is function of saturation, porosity, permeability, ionic content of the pore fluids, and clay content. This will help to study water seepage through a dam by identifying low electrical resistance. Previous geophysical studies have demonstrated the utility of using electrical resistivity methods to detect and characterize the seepage conditions occurring at dams (Panthulu et al., 2007). Dahlin and Johansson (1995), Johansson and Dahlin, (1996), Aal et al. (2004) and Cho and Yeom (2007), applied the electrical resistivity method to study the embankment of dams. In this study electrical resistivity tomography survey has been carried out using 32 electrode electrical resistivity imaging system. Typical Electrical resistivity tomography is shown in Figure. In Figure 4, it can be noticed that high and low resistivity values (ohm.m) from site, which indicate dense and soft soil layers.

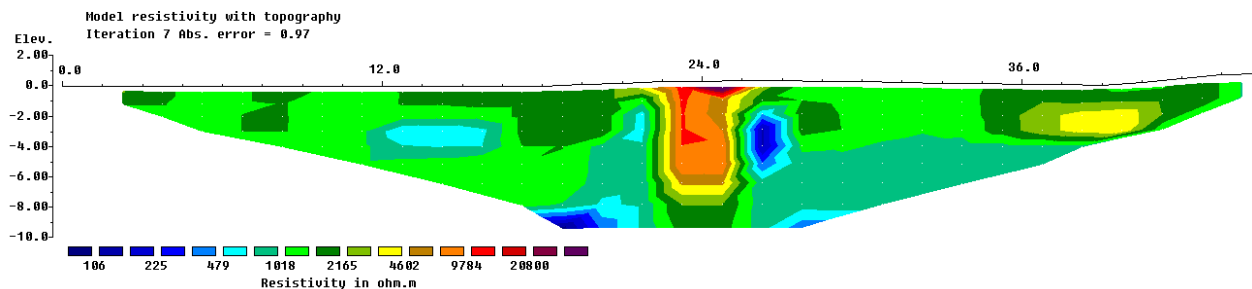


Figure 4. Typical Electrical resistivity tomography.

Summary

The paper presents integrated geophysical and Geotechnical investigation approach. SPT and MASW test results can give static and dynamic properties, which will be useful for the performance analysis of dam. 2- D survey of MASW and resistivity can help to generate 2- D surface profile of dam foundation and dam section. 2- D image of the foundation can be used to understand subsurface profiling and property variation for modeling of the dam foundation. Further shear wave velocity of the dam is useful for the estimation of liquefaction assessment of dam section and foundation. 2-D subsurface images from MASW, ERT and GPR along and across the dam can help to locate unconsolidated and loose ground overburden, which constitutes

most of the high permeable channels of seepage in the dam. Further GPR study can be used to map weak zones, cavities and cracks in the dam and associated structures. Integrated geotechnical and geophysical investigation are useful for condition assessment of existing dam sites.

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