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Seismic response of Concrete Gravity Dam : Case study

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Abstract- **On June 8th 2005, the Koyna region in Western Maharashtra was affected with an earthquake of Magnitude M 4.2. This earthquake was followed by aftershock of M3.6 .For monitoring the deformation of a dam a GPS receiver was set up on the top of the dam by the Indian Institute of technology Bombay [IITB]. And was continuously operation even at the time of Earthquake. The GPS group at the Indian Institute of Technology Bombay has been working over 5 years in this field and analysis of this dam under a research Project funded by Department of Science and Technology. Government of India .The data collected by the receiver on 8 June 2005 was used to analyze the Movement of due to earthquake. Trimble 4000 SSI and Trimble 5700 dual frequency geodetic GPS receiver were also used by GPS team. The Collected Data was processed using Bernese 4.2 software [4]. The dam has withstand many earthquake in past including the devastation 1967 Koynanagar earthquake, resulting in the dam developing some cracks.**

Objective- **The aim of this paper is to analyze the deformation of the dam due to earthquake that occurred at 8 June 2005. This was done by processing and analyzing the continuously recorded GPS data collected before and after the earthquake .The objective is to detect the co-seismic movement of the dam body.**

I. INTRODUCTION

A gravity dam is the one in which the external forces (such as water pressure, wave pressure, silt pressure, uplift pressure etc.) are resisted by the weight of the dam itself. A gravity dam may be constructed either of Masonry or of Concrete. Koyna dam is a Concrete dam. The height of Koyna dam is 84m with 862 sq. km. The main purpose of this dam is to provide hydroelectricity with some neighboring areas. Today the “Koyna Hydroelectric Project” is the largest completed hydroelectric power plant in India, having installed capacity of 1920 megawatt.

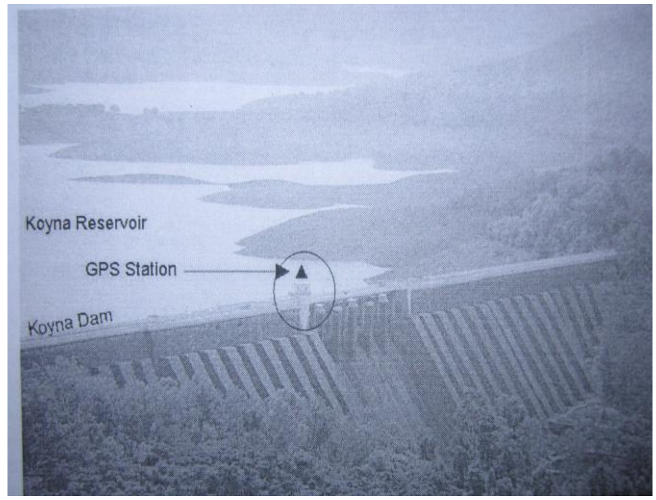
Dam and Crustal deformation studies using GPS are being carried out in this active region of Koyna by the GPS team of Indian Institute of Technology Bombay [IITB], under a research project funded by the Department of Science and Technology [DST], Government of India. GPS data processing using scientific software, estimating parameter responsible for deformation and developing methodologies for checking the stability of the region. A GPS network comprising of 34 stations has been established on the dam and surrounding regions and observed over 12 epochs, from December 2000 to June 2005. Of the 34 stations are established on the dam body, and rest in the area surrounding the dam .Of the 12 stations on the dam, one GPS station is set up on the top of the most point of the dam and runs continuously throughout the day and throughout the campaigns. The remaining stations are generally observed for 6-8 hours.

II. EARTHQUAKE INFORMATION

On June , 8th 2005 at 3 : 02 : 10.7 am IST ,an earthquake with M 4.2 occurred about 20 km southeast of Koyna Dam , Western Maharashtra India. The latitude and longitude of this earthquake was recorded as 17 14.6 and 73 46.7 respectively. This earthquake was followed by an aftershock of M 3.6 that occurred at 4 :34 : 21.2 am [i.e., 1.5 hours after the main shock] at a latitude 17 15.7 and longitude 73 44.5 . The information of the earthquake was collected from the Koyna Dam Authorities.

III. GPS DATA ANALYSIS

The GPS measurements at Koyna Dam area including the dam body itself are usually carried out two - three per year by the GPS team using the Trimble 4000SSI and Trimble 5700 dual frequency geodetic GPS receivers. During the latest campaigns in the June 2005, an earthquake with M 4.2 followed by its aftershock of M 3.6 occurred on the June 8th , 2005. A GPS receiver was set up the previous day on the top of the dam and was continuously operating even during the time of the earthquake. After the occurrence of these earthquakes, the attention was focused to study the co-seismic movement of the dam body due to these earthquake and was done by analyzing the GPS data collected before and after the earthquakes. Data collected 2.5 hours before the earthquake and 2.5 hours including the main shock and the aftershock was considered to study the co-seismic movement of the dam.



3.1. Change in RMS values

The processed data was analyzed and remarkable changes in RMS values of the dam station were noted before, during and after the earthquake (Table 1) .These RMS values were plotted against the time to understand the change in the RMS values for latitude, longitude (Figure 3). The maximum values of RMS for both latitude and longitude were observed from the data collected from 3:02-5:30am (during the occurrence of main earthquake and its aftershock) . These values were found to be shooting up from what was observed just 2.5 hours before earthquake (0:32 - 3:02 am). This increase in RMS values cause movement of the dam and is noted by GPS receiver. The data collected after the earthquake, the RMS values for latitude and longitude were small as compare to the values observed during the earthquake.

To check the reliability of the result obtained for 2.5 hours collected GPS data, the 2.5 hours data collected on 9 June 2005, a day when there was no earthquake in the region, was compared with that of the 24 hours data collected on the same day. The result is shown in table 2.

RMS (m)	2.5 hrs Data	24 hrs data
Latitude	0.0005	0.0002
Longitude	0.0006	0.0002

Date time	RMS(m) (Global)	RMS (m) (Latitude)	RMS (m) (Longitude)
2.5 Hrs before Earthquakes(0:32-3:02 am)	0.0019	0.0006	0.0011
2.5 Hrs including Earthquakes(3:02-5:30am)	0.0019	0.0018	0.0093
Next 2.5 Hrs after Earthquakes(5:30-8:00am)	0.0019	0.0006	0.0006

Table2: reliability check of 2.5 hrs data with 24 hrs data

It was observed that the RMS values of latitude and longitude for 2.5 hours data obtained from 9 June 2005 approximately agree with that of 24 hours data of the same day. This justifies the reliability of the 2.5 hours data and thus the 2.5 hours data collected on 8 June 2005 to study the dynamic movement of the dam is reliable.

3.2. Change in Displacement of Dam Station

Analyzing of the period 2.5 hours before and 2.5 hours including the earthquake shows a displacement of about 2.3 cm (Table 3) in northeast direction (figure 4). This is due to the co- seismic effect of the main shock of M 4.2 and its aftershock M 3.6, which occurred southeast of the Koyna dam (figure 4).

For detecting the change in the movement of deformation of the dam, analysis between the result obtained from the data collected 2.5 hours including the earthquake and the next 2.5 hours after the earthquake were carried out. The analysis shows a displacement of 2.1 cm (table 4) with a southeast direction.

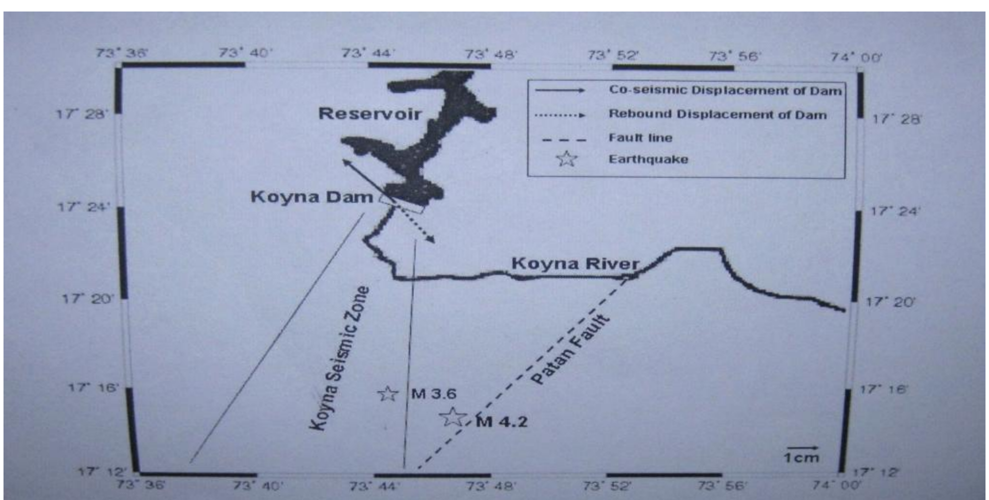


Figure 4: Displacement of the GPS station on Koyna Dam body before and after the earthquakes

Time	2.5 hrs before Earthquake		2.5 hrs including earthquake		Deformation(m)	
Coordinate (sec)	Latitude	Longitude	Latitude	Longitude	Change in Latitude (m)	Change in Longitude (m)
	6.460469	7.746082	6.461223	7.745592	0.017	-0.015

Table3: The resultant displacement of the Koyna Dam GPS station 2.5 hrs before and after June 8th 2005 earthquake

Time	2.5 hrs including earthquake		Next 2.5 hrs after earthquake		Deformation (m)	
Coordinate (sec)	Latitude	Longitude	Latitude	Longitude	Change in Latitude (m)	Change in Longitude (m)
	6.461223	7.745592	6.460656	7.745990	-0.017	0.012

Table4: The resultant Displacement of the Koyna Dam GPS station 2.5 hours after and next 2.5 hours after June 8th 2005 earthquakes

IV. INTRODUCTION

- **Background**

On 11 December 1967, the 103 m high koyna mass concrete dam in India was seriously damaged the magnitude 6.5 earthquake. The damage began with a crack at the change in geometry at the downstream slope, which subsequently spread through the entire cross- section. This event was unique because the Koyna dam is the only concrete dam that has suffered significant damage due to ground shacking, and accelerometers at the site recorded the time histories of the entire event. The Koyna Dam failure is considered a classic problem for experimental studies and to validate numerical procedures for predicting the seismic response of concrete gravity dams.

The University of California at Berkeley previously conducted shake table tests of the Koyna Dam using a 1\150-scale modal, and the Bureau of reclamation, U.S Department of Interior, has conducted shake table tests using a 1\50-scale modal. Scaling material properties to provide appropriate modeling of the damage and failure mechanisms in these types of small-scale modal is always difficult and complex. Unfortunately, the small-scale modal tests referenced above did not provide the amount of comprehensive data required for the symmetric validation of numerical procedures.

The Engineer Research and Development Center [ERDC] Geotechnical and Structures Laboratory [GSL] has conducted extensive linear and nonlinear analyses of concrete gravity dams as part of its mission for the U.S Army Corps of Engineers. The further develop its analytical models; GSL tested a 1\20-scale model of the same Koyna dam. The modal cross-section configuration, as defined by GSL, is shown in Figure 1.

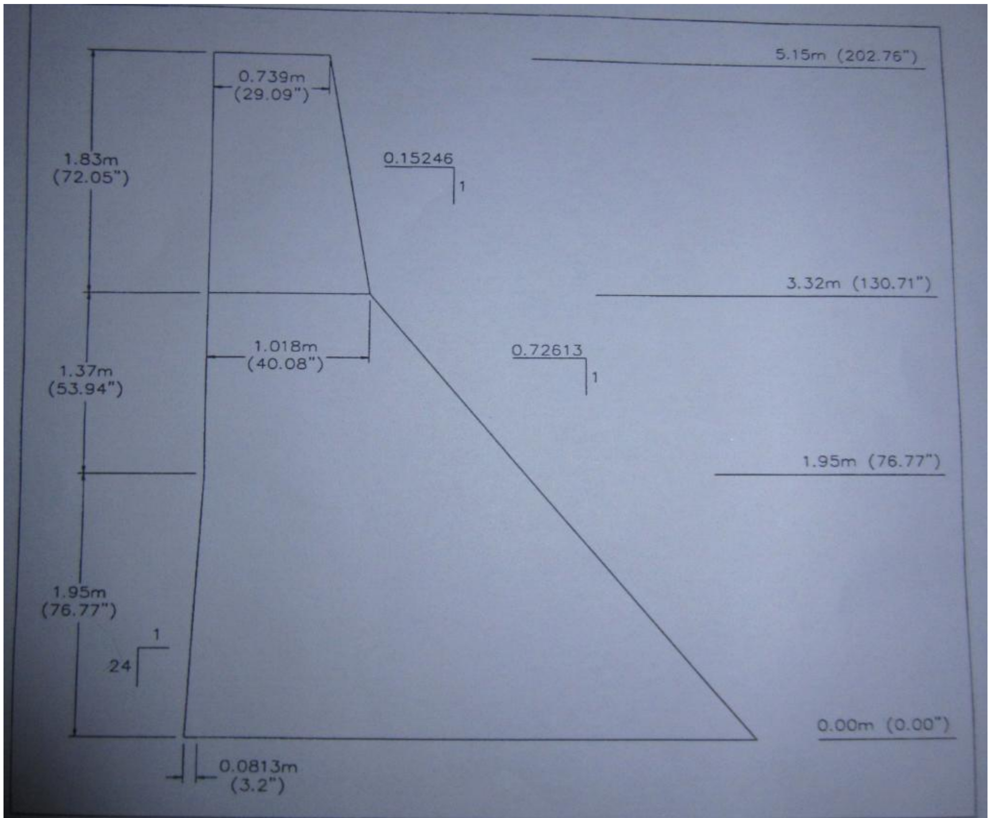


Figure 1. Design dimensions of the Koyna Dam model.

Model Configuration

1. **Model Material Properties**

The material properties for the 1/20-scale dam modal were defined by GSL researchers using material scaling relationships. The material properties of the actual Koyna dam and 1\20 scale modal design values are shown in Table 1.

Material properties	Koyna Dam	1/20-Scale Dam mogel Design	Model avg 28-day Test cylinder	Model cores Near crack	Base
Unconfined Compressive Strength	4000psi 27.6Mps	200 psi 1.38 Mps	253 psi 1.74 Mpa	155 psi 1.07 Mpa	667 psi 4.60 Mps
Modulus of Elasticity	400 ksi,27.6 Gpa	200 ksi,1.38Gpa		200 ksi,1.38 Gpa	500 ksi,3.45 Gpa
Ultimate Concrete Compressive Strain	0.0025	0.0025			0.0060
Density	150 pcf 2403 kg/m^3	150 pcf 2403 kg/m^3	157 pcf 2515 kg/m^3	124.5 pcf 1994 kg/m^3	148.4 pcf 2377 kg/m^3

Casting and Surface Preparation.

Table 1 show that the 1\20-scale Koyna dam modal material [200 psi, 1.338 M Pa] with a low modulus of elasticity [200 ksi 1380 MPa], normal ultimate comprehensive strain [0.0025], and normal density [150 pcf, 2400 kg\m]. Personnel from the Concrete and Material Division of GSL developed the mix design shown in TableB1 to achieve these properties, based on laboratory testing. The principal component of this mix is Baroid API drilling-grade barite [fine 200 meshes] with a specific gravity of 4.25. This material is used in the oil well drilling industry. The barite was delivered to the ready -mix plant in 2508 lb [1138 kg] "super sacks." These large nylon sacks have a chute at the bottom, and they were placed on wood pallets and sealed with a plastic shrink wrap.

Material	Quantities of Materials per the Following		
	1 Cubic Yard	7 cubic Yard ready mix Truck	28 Cubic Yard Total
Type 1 Portland cement	285 lb	1995 lb	7980 lb
Natural concrete Dry Sand	360 lb	2520 lb	10,080 lb
Water	839 lb	5873 lb	23492 lb
Baroid API Drilling Grade Barite	2508 lb	17,556 lb	70,224 lb
3M Polyotetine 25/38 Fibers	7.7 lb	53.9 lb	215.6 lb
Total Weight	4000 lb	27,998 lb	111,992 lb

Casting the Model

This Modal was casted at sight of work.

The ready Mix truck [Concrete Mixing Plant] delivered the material to CERL and discharged into a Concrete pump with a boom connected with a 5inch [1127mm] line. The end of this had a 4inch [102mm] Diameter, 12ft [3.66m] long rubber pump hose. So that the material could be discharge near the bottom of the modal and test block formwork. The Bottom was gradually raised so that the hose remained just below the surface of material as it was. The Hose pipe will help to avoid segregation of material and additional pressure on formwork.

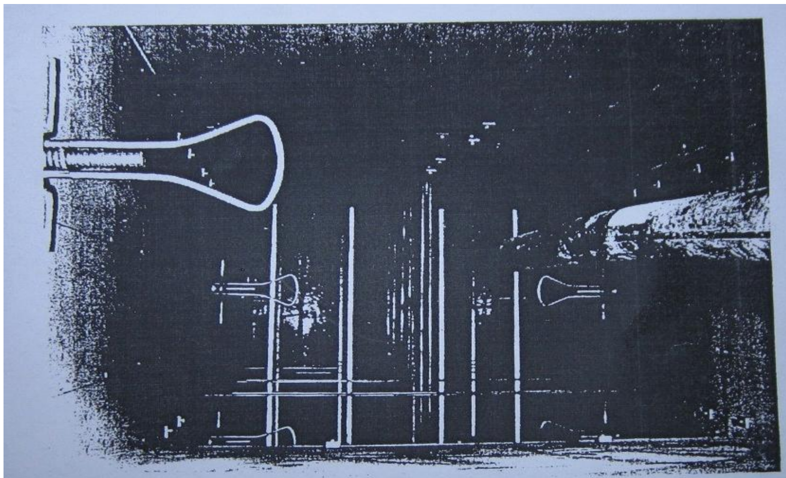


Figure B2. The rubber hose discharging material into the model formwork.

The Picture above shows other inserts, formwork, Coil tiles, Instrumentation Plate with elevator Bolt [shape] attached and EMT Conduit Almost immediately the material Region to settle consolidated clear water rose to surface.

While pumping the truck load of Concrete, the formwork began to leak around toes and other penetration. Initial leaks were essentially clear water, where water has settled out of the mix, but later the material itself began to leak. The leak in on the downstream face where the coil-tie-bolt, used to support an EMT Conduit, penetrate the formwork. A Leak on the downstream face when a coil-tie-bolt, used ot support a water , penetrates the formwork. All then leaks were plugged using rags and woods scraps that were screwed into the formwork. Leaking became much worse as the elevation of material and resulting pressured increased.
During the pumping of 3th truck, considerable leakage took place and pumping stop. The Formwork wooden Board begins to absorb moisture. Along its penetration and soften the wooden formwork so that formwork become more flexible. After leaking was stopped by plugging, remaining material in the 3rd. Truck was pumped into the test block. Further the pumping of material was postponed for 3 hours so as to stabilize the leaks that had been plugged. Then the material from 4th truck was pumped into the formwork. This process continued until the material reached on elevation of about 4inch [0.1m] above the design elevation. As expected that the material to settle with about 9inch [0.2m]. Therefore the final elevation modal top was 4.8inch above the design elevation. Immediately after casting the formwork for modal was redesigned to greatly reduce and to stiffen and strengthen it. These improvements will be incorporated into the modal.

Model Curing, Formwork Removal and Surface preparation

After casting the modal the surface of concrete was not be allowed to drive at all other wise large crack would form therefore the expose surface of modal must be kept moist [wet] by standing water. Plans were made to test the modal at 28 days after casting .The formwork had to be removed in time for surface preparation and sensor installation. Further the test cylinder tests were scheduled for 7 and 14 days after casting, so it was decided to remove the modal formwork after receiving the 14 days cylinder test results to conform that sufficient material strength had developed. Test block formwork was striped first, at 14 days after casting.

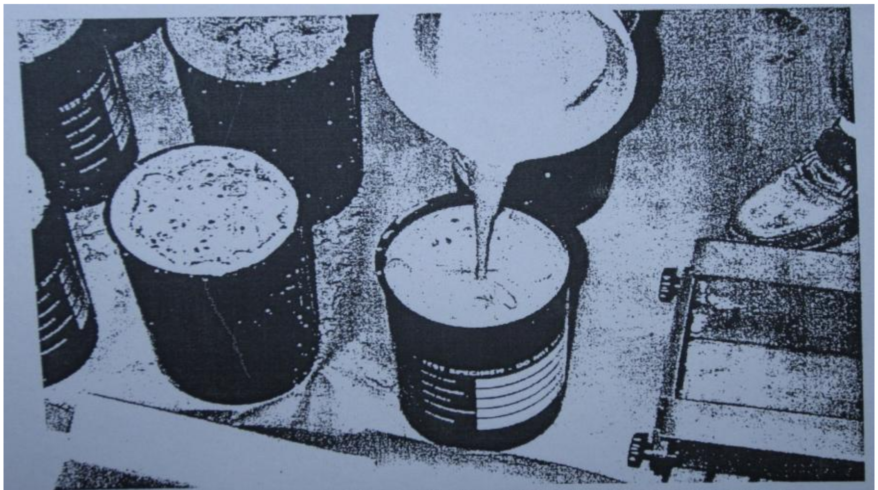


Figure B1. Casting Koyna dam model test cylinders with the very fluid experimental mix.

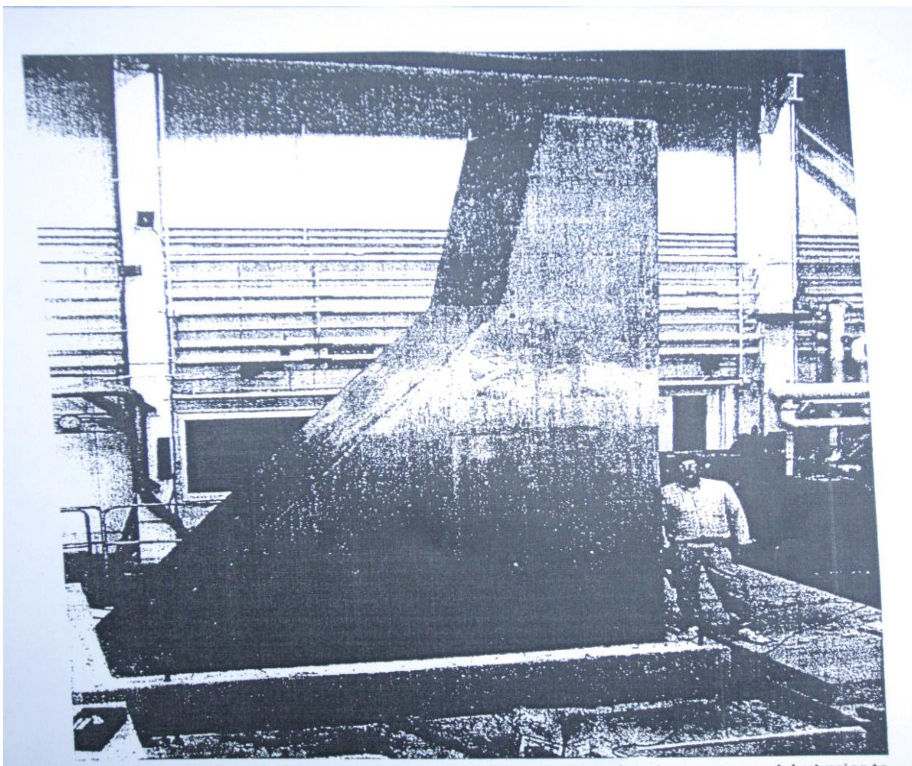


Figure B5. Back face of Koyna dam model after the application of curing compound, but prior to whitewash application.

V. CONCLUSION

This is the first case in India that the co-seismic displacement of a dam body was estimated by using GPS data recorded during the time of occurrence\happening of earthquake and its aftershock. The value of displacement of dam obtained from GPS of 2.3cm observed during the time of earthquakes indicates that effect of the waves on the dam is small. This is because that Koyna Dam has rubble and concrete foundation that might be providing a damping to the seismic waves.

The dam body is stable and not affected by the earthquakes.

It is highly recommended that continuously operating GPS deformation monitoring systems should be set up on all major dams and bridges in India, for monitoring deformations associated with earthquakes, in real time and should be interpreted in combination with response of dam and bridges.

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