EVALUATION OF SEISMIC RESPONSE OF FATEHGADH DAM

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***Abstract*—Earthquake is perhaps, the most dangerous natural disaster. Although it occurs for a few seconds, the aftershocks continue for many days and the damage is progressive. Earthquakes cause severe damage to infrastructure, loss of economy and loss of life. Based on research, it has been seen that damage to life and infrastructure caused due to earthquake accounts to about 50 to 55% of the damages caused by all other natural disasters like floods, hurricanes, volcanic activities etc. Also, the way soil and structure will behave during an earthquake is extremely unpredictable. Hence, studies on the effect of earthquake on the conduct of soil and structure is a necessity.**

During the Bhuj earthquake which occurred on January 26, 2001 almost all the dams which were in 50 km radius from the epicenter of the earthquake were damaged. Around 19 dams of about 10 m to 25 m height experienced damage. Damage was mainly due to longitudinal cracks at the crest and slope failure of upstream and downstream sides of the dam. Hence, in this paper, studies are made to idealize Fatehgadh dam and observe its performance numerically. Fatehgadh dam was among the most affected dams, which is located in Kachchh region in the state of Gujarat, India. In this study we have used PLAXIS software, which is based on finite element analysis and mainly used to analyze the performance of geotechnical structures.

***Key words*— Earth-dam, Earthquake, Seismic Response, Finite Element Analysis, PLAXIS.**

I. INTRODUCTION

January 26, 2001, an earthquake of magnitude 7.7 banged on the Kachchh region of Gujarat, India. It was one of the most devastating earthquakes of Indian history. Around 16,000 people were found dead and more than 1,50,000 were injured [1]. Many small and medium sized earthen dams were damaged. Damage was mainly due to longitudinal cracks at the crest and slope failure of upstream and downstream sides of the dam. Lateral spreading, that mainly happens due to liquefaction of

the soil was also one of the reasons for the damage of the dams. Most of the already existing structures were not safe against earthquake, as it was not designed for the same and that leads the structures to failure during the earthquake. Hence, there is a need to determine safety of such structures and find the exact reason of failure. To find out the exact reason of failure, it is required to analyze the seismic behavior of the dams under earthquake forces. This also guides to take the required remedial measures in future and helps for rehabilitation.

In this paper analysis were carried out using a finite element software, PLAXIS to find the stability of Fategadh dam, which was among the most affected dams during Gujarat earthquake.

It is seen that soil model analyzed by finite element gives us similar static and dynamic conditions as actual and is widely used for analysis of earthen dams and embankments [4]. Even PLAXIS software was introduced for two-dimensional plane-strain analysis and earthquake behaviour of embankments were found out [7][9]. These studies were by using the effective stresses and displacements principles. The analysis of earth dams by PLAXIS allows us to evaluate the conduct of earth dams when it undergoes the changes in stresses, strains, accelerations and displacements at various parts on dam body [3].

II. PROJECT DESCRIPTION

Fatehgadh dam is a multi-zoned earthen dam located in Fatehgadh village of Rapar taluk situated in Kachchh district of Gujarat. It is located on the river Malan and was mainly constructed for irrigation purpose. The dam construction was started in the year 1979 and was finished in the year 1987. The dam has a catchment area of 104 km^2 and receives a mean yearly rainfall of 348 mm. The maximum height of the dam is 11.20m, 3m crest width, and top length of the dam is 4,049m. During Bhuj Earthquake, the reservoir water lever was at the ground level and the foundation soil of the dam section was in saturated condition [5]. When the shaking started, it activated sliding in slopes mainly near the toe of the upstream slope [2]. The reason can be liquefaction of the soil near to the toe of the dam at upstream side. It was found that the cracks were generated mainly at the upstream side of the dam and the depth of the cracks were about 1.5 to 1.7 m. Loss of stability at the upper portion of the downstream slope was also observed after the shaking. Longitudinal cracks were found at the dam crest and the reason may be liquefaction of the foundation soil of the dam. Even the loss of stability at the crown of downstream side is also observed but that may not be the cause of liquefaction of base soils [5]. The reservoir capacity and the area are given in Table I.

TABLE I.: Reservoir capacity and the area

Parameters	Values
Storage capacity (gross)	7.45 Km^3
Storage capacity (effective)	5.92 Km^3
Area at full reservoir level	35 m^2
Length of spillway	1246 m
Discharge (max)	5.42 m^3/s
Maximum yield	7.365 m
Observed flood (max)	86.51 m^3/s

The damaged structure of Fatehgadh Dam is represented in Fig. 1 with the structure prior to failure (as idealized in PLAXIS) shown in Fig. 2 for comparison.

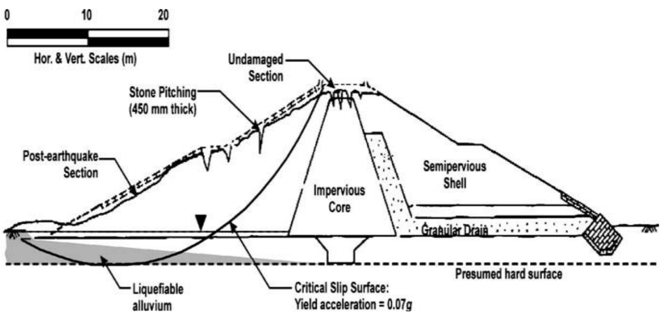

Fig.1. Cross-section of Fatehgadh Dam, R. Singh et al. (2005)[11]

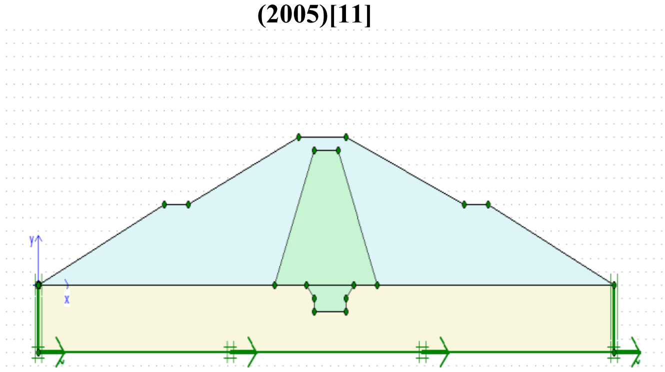

Fig. 2. Cross section of Fatehgadh dam before failure

TABLE II. : Yield acceleration, estimated and noticed Displacement

Dam	Yield Acceleration	Estimated Displacement	Observed Horizontal Displacement
Fatehgadh	0.071g	0.70 m	0.60 m

III. MATERIAL CHARACTERISTICS OF FTEHGADH DAM

Fig. 2 shows the Fatehgadh dam before failure. The dam is divided into 4 stretches. Every stretch represents independent soil material. Different stretches of Fatehgadh dam section have been assembled by Eq. (1). The equation explains how different height of the dam affect the shear wave velocity of different materials at different stretches of the cross section of the dam.

$V_S = 140Z^{0.34}$ (1)

In the equation number 1, V_S represent shear wave velocity and Z is the height of the dam. There is a relationship among shear wave velocity, Young's Modulus and Shear Modulus and that is shown in Eq. (2).

$G=\rho \times V_S{}^2$

$G=E/2(1+\mu)$ (2)

In these equations G denotes Shear Modulus, E denotes Young's modulus, μ denotes Poisson's ratio and ρ is referred as the density of the soil. The parameters of the soil for four different stretches will be calculated using equations [6] and the values are shown in Table 3.These parameters will be used as inputs for further analysis.

TABLE III. : Properties of soil in fatehgadh dam

Layer no	Soil Layers	Unit weight (γ in kN/m^3)	Cohesion (kPa)	φ (degree)	S_u/σ_v'
1	Partially-pervious shell	18	9.8	30.5	
2	Non Pervious core	20	50	0	
3	Foundation soil prone to Liquefaction	18	0.0		0.209
4	Foundation soil not prone to Liquefaction	18	0.0		0.411

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In table III, φ denotes angle of shearing resistance, Su represents as undrained shear strength and $\sigma v'$ represents as effective vertical pressure

DAM SIMULATION

For the generation of mesh there are different sizes of mesh to consider. Like coarse, medium, fine, and very fine. In the convergence test it is seen that there is a significance difference in result when we shift from coarse to medium sized mesh but after that when we consider fine and very fine difference is not noticeable. Hence, medium mesh size is used for the current analysis. Dam simulation consists of identifying the clusters and finding the related properties of those [10]. As discussed earlier, it is observed that Fatehgadh Dam is a combination of 4 clusters.

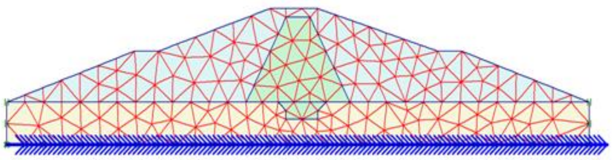


Fig. 3. Mesh generation of Fatehgadh dam

The dam was subjected to an input motion which we have collected from Strong Motion Virtual Data Centre (VDC). The nearest station was IITR station at Ahmedabad, India which was around 239 km distance from the focus. Input motion was applied for a period of 60 seconds. The base acceleration data at Ahmedabad due to Bhuj earthquake (January 26, 2001) is given in Fig. 4 which is used to carry out the analysis.

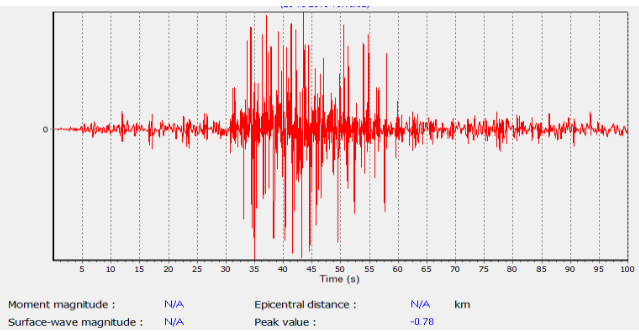


Fig. 4. Acceleration - Time history plot of Bhuj earthquake

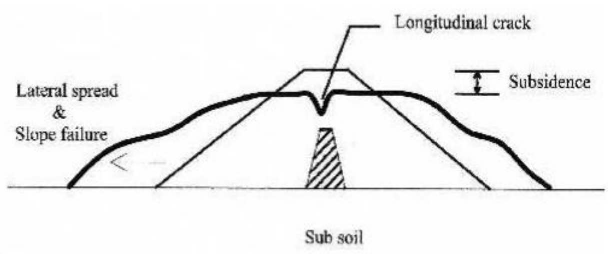
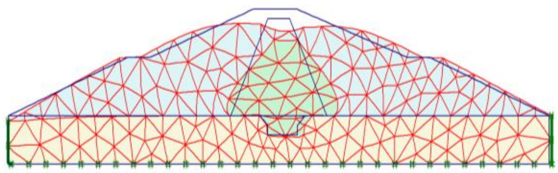


Fig. 5. Failure pattern of earth dams observed in Bhuj earthquake (EERI 2001)

The working pattern of PLAXIS is generally divided into three main steps. In the initial step first the dam will be established and then plastic analysis will be carried out [8]. Then under its own self weight again plastic analysis will be carried out. Then the main dynamic analysis will come. Last step will be the dynamic analysis under seismic loading. Here the data collected from VDC is applied as input. The deformed pattern of Fatehgadh dam after a period 60 sec shaking is given in Fig. 6 and the range of total displacement is presented in Fig. 7.



Deformed Mesh
Extreme Total Displacement 5.16 mm
Displacement scaled up 500 times

Fig. 6. Deformed mesh of Fatehgadh Dam

The deformed shaped is a representation of the finite element mesh in the deformed condition.

Total deformation of the dam was found to be 5.16 mm and total displacement was 4.61 mm. This total displacement is the summation of horizontal displacement and vertical displacement.

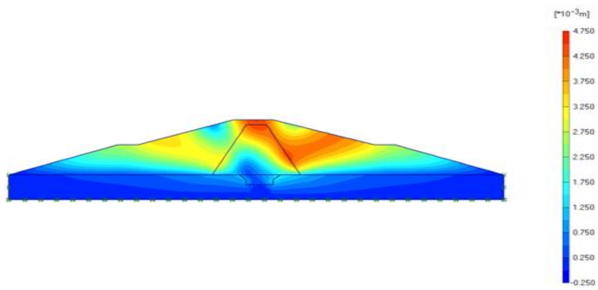


Fig.7. Total Displacements (U_{tot}), Extreme U_{tot} 4.61mm

IV. TIME- DISPLACEMENT ANALYSIS

Several points at which stresses will be found out are selected at different levels at dam cross section. Three different points are selected at base level (three points A, B, and C) as shown in Fig. 8, one point is chosen on the upstream side (Point D), one point is at the middle part (Point E), and one point on the downstream side (Point F), and one point (Point G) at the top of the dam. 7 stress points are hereby shown on the dam (Fig. 8). Load-time curves can be obtained from draw curve option of the software. Fig. 9 shows how time and displacement are related for different points of the dam cross section.

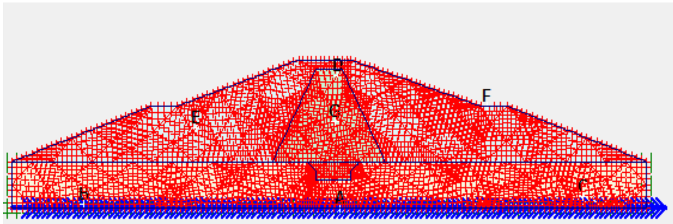


Fig. 8. Points for Time – displacement calculation

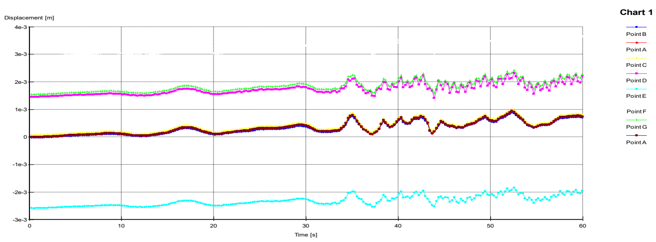


Fig. 9. Time displacement curve at various points

Fig. 9 shows that points A, B, and C (at the base) experienced less horizontal displacement compared to the other points and E and F, which experienced higher level of horizontal displacement in left and right sides increased at 35^{th} sec. The acceleration also showed a steep rise.

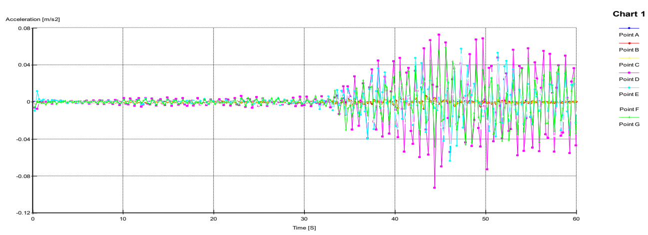


Fig 10. Time Acceleration curves at various points

From Fig. 10 it is seen that after 35sec only there is a steep rise in acceleration. Points A, B, C are chosen at the base. At those points acceleration is lowest and having a uniform acceleration till the 60^{th} sec. At point D (pink colour in the curve), i.e. at the top level of the Dam section, the in acceleration was the highest.

V. STRESS-TIME ANALYSIS

Before the calculation step is started, stress points are selected on the dam cross-section as mentioned earlier. Those points are at base level (three points G, H, and I), one point is chosen on the upstream side (Point J), another one at the middle (Point E), and one point downstream side (Point K) and one point (Point L) at the top of the dam. Stress (σxx)-time curves for the dam can be obtained from draw curve option of the software. Stress-time curves associated to the points mentioned at various portions are shown for Fatehgadh Dam (Fig, 11).

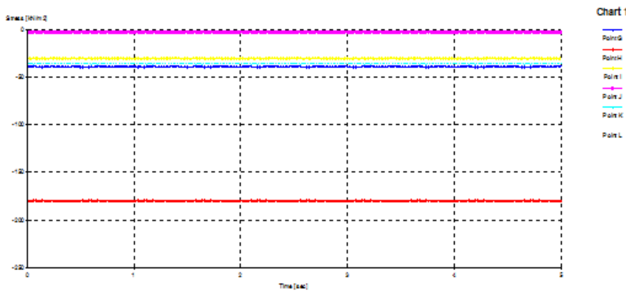
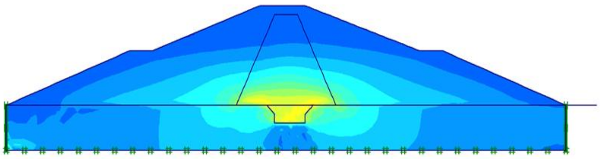


Fig 11. Stress – time curves at various points

Seepage of water generally produces pore water pressure in the dam. Active pressures include total water pressures combining the pore pressure at steady state and the excessive pore pressure. Active pore water pressure was calculated for the dam section as -43.43KN/m^2. Excess pore pressure is mainly due to the excessive load acting on the soil. Here the excessive pore pressure was found to be 0.

During earthquake or shaking, excess-pore pressure generates which causes liquefaction and ultimately the collapse of the dam. However, in this study the active pore pressures remained constant which indicates that no excess pore pressure was generated and hence, no liquefaction had taken place. The pore pressures at crest, middle portion, and at the base of dam have been found to be constant.



Horizontal effective stresses (sig'-xx)
Extreme sig'-xx -262.97KN/m^2

Fig 12. Horizontal effective stress diagram

VI. CONCLUSION

For Fategadh dam, the maximum displacements occurred at the crest with bulging of the side slope causing a horizontal displacement of 5.02 mm and vertical displacement of 4.57 mm and extreme total displacement as 5.16 mm. Maximum stresses were found to concentrate at base of dam. Extreme effective principal stress was found to be 271.05 kN/m^2, extreme total principal stress was found to be 308.51 kN/m^2 and active pore water pressure was found as 43.43 kN/m^2. The peak acceleration recorded was at 44 sec with a maximum acceleration of 0.08 m/s^2.

As mentioned earlier, shaking or earthquake caused liquefaction leading to collapse of the dam due to the generation of excess pore pressures. Compared to the data obtained from the site in which the dam had developed cracks up to several meters, the displacements obtained from the study are found to be comparatively less.

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