Dynamic Analysis of Embankment Dams Under Strong Seismic Excitation and a Case Study

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Abstract

It is a well-known fact that ground motion induced at the dam site by an earthquake located at some distance from the dam can result damages to dams and their appurtenant facilities. Also direct fault movement across the dam foundation can create displacements, which result to more serious problems for embankments and their appurtenant structures. Especially active faults on or near dam sites can cause to damaging deformation of the embankment. Therefore, meaningful seismic parameters are needed to perform a satisfactory evaluation of dam structure. Turkey has so many dams, which are under the influence of near source zone. One of them is Bebekli dam, which has an earth fill embankment having a 34.0 m height from river bed, located at the western part of Turkey. A seismic evaluation of dam site was performed in detail. For the dam site, a seismic–hazard source was obtained as based on local seismic events and a ground motion model was produced by means of the appropriate attenuation relationships. The dynamic analysis of 2-D finite element model of dam-foundation system shows that the maximum value of settlement is 58.5 cm on the crest under the loading of Maximum Design Earthquake.

Keywords: Earthquake, Embankment Dams, Seismic Analysis, Stability Analysis.

1. INTRODUCTION

Earthquakes can result in damages or failures for dam structures. Case studies about the seismic performance of dams under large earthquakes are available in the literature. Tosun [1] states that earthquake safety of dams is an important phenomenon in dam engineering and requires more comprehensive seismic studies for understanding the seismic behavior of dams subjected to severe earthquakes. It is a well-known phenomenon that earthquakes can result damages and failures for dams and their appurtenant structures.

Earthquake effects on dams mainly depend on dam types. Tosun et al [2] stated that safety concerns for embankment dams subjected to earthquakes involve either the loss of stability due to a loss of strength of the embankment and foundation materials or excessive deformations such as slumping, settlement, cracking and planer or rotational slope failures. Safety requirements for concrete dams subjected to dynamic loadings should involve evaluation of the overall stability of the structure, such as verifying its ability to resist induced lateral forces and moments and preventing excessive cracking of the concrete [3].

In the world there are some important cases, which subjected to damages and failures after earthquake, Lower San Fernando Dam in USA is first example failed as a result of liquefaction phenomenon under the earthquake loading conditions. In case of the May 12, 2008 Wenchuan earthquake in China many dams and reservoirs had been subjected to strong ground shaking. So many dams and hydropower plants were damaged. During the 2001 Bhuj earthquake in Gujarat, India, 245 dams had been affected and rehabilitated or strengthened after the earthquake. Also, in the case of the March 11, 2011Tohoku earthquake in Japan, damages were observed about 400 dams and the 18 m high embankment dam failed and 8 people lost their live [1].

In general, strong ground shaking can result in the instability of the embankment and loss of strength at the foundations However, embankment dams, which are well compacted according to the specification, are suitable type for regions having high seismic activity. Well-compacted embankment dam can withstand moderate earthquake shaking, with peak accelerations of 0.2g and more, with no detrimental effects [4,5]. According to Parish and Abadi [6], the well-compacted modern dams can withstand substantial earthquake shaking with no detrimental effects. Performance of well-compacted embankment dams have also been good in general after the 1999-Kocaeli earthquake, Turkey. Recently we have seen from some cases that active faults, which are very close to the foundation of dams, have the potential to cause damaging displacement of the structure.

2. MATERIAL AND METHODOLOGY

The deterministic and probabilistic seismic hazard analyses are commonly used to relieve the seismic activity for a dam site. The deterministic seismic hazard analysis considers a seismic scenario and includes four-step process. It is very simple procedure and gives rational solutions for large dams because of providing a straightforward framework for evaluation of worst ground motions. The probabilistic seismic hazard analysis is widely used and considers uncertainties in size, location and recurrence rate of earthquakes.

ICOLD [7] states that the Maximum Credible Earthquake (MCE) is the largest reasonably conceivable earthquake magnitude that is considered possible along a recognized fault or within a geographically defined tectonic province. In this study, earthquake definitions given by FEMA [8] were considered for seismic hazard analyses. Most of large dams in Turkey were analyzed by using these definitions in past.

The probabilistic hazard calculation was performed to obtain 5 percent damped elastic hazard pseudo-acceleration spectra and to generate the response spectrum compatible acceleration time histories for time domain analyses. The elastic hazard acceleration spectra on the basis of Boore et al [9] were obtained. For generating the acceleration time histories, a software program TARSCTHS was used [10].

Pseudo static analysis was performed for the case study. A 2-D finite element model for the maximum section of the dam and soil profile including bedrock was developed by Plaxis software [11] for the dynamic analysis. Once the model was defined to represent the layered construction technique, then it was modified for dynamic loading conditions. Standard fixity elements were considered along the base and vertical sides of the model. It was assumed that the ground motion acts uniformly along the fixed boundaries.

3. CASE STUDY

Bebekli dam is an earthfill dam, which is situated at the western part of Turkey. The main section of the dam is high from foundation and 35.5 m long. The embankment cross section includes a central core zone flanked on both side by shell zones. The outer slopes of dam are inclined at 3:1 (horizontal: vertical) for upstream and downstream. The cross section includes a transition filter zone between core and shell materials on both sides and a blanket drain system on downstream to collect seepage through the dam and foundation. A toe drain for seepage collection is also included on the downstream toe of dam. The upstream slope of the dam is covered with a layer of riprap to provide wave protection. It rests on the hard bed rock. The alluvium soil on river bed is removed before beginning to embankment constructions.

Table 1. Properties of Bebekli Dam

Properties	Value
Location	West of Turkey
Type	Zoned earthfill
River	
Volume of embankment	348 255 m^3
Beginning to construction	2012
Completion of construction	2016
Crest elevation	684.00 m
Crest length	236.20 m
Height from foundation	35.5 m
Geological formation of foundation	schist
Maximum Water Level	682.60 m
Minimum water level	669.30 m
Reservoir capacity at Maximum Water Level	0.932 hm^3

3.1. SEISMIC HAZARD ANALYSES

The seismic hazard parameters were obtained from the magnitude-frequency relation of Gutenberg-Richter for two different linear seismic zone [12]. The seismic hazard analysis was performed for the dam by means of two separate methods. The deterministic seismic hazard analysis shows that the PGA values for 50 percentile range from 0.193 to 0.327 while those for 84 percentiles they are between 0.338 and 0.491. They average to 0.244 for 50 percentiles and 0.406 for 84 percentiles. These PGA values are high. Because the fault is very close to the dam site. Its distances to the possible fault, the Quaternary fault and the main Holosen fault are 4.07, 6.07 and 9.36 km, respectively (Figure 1).

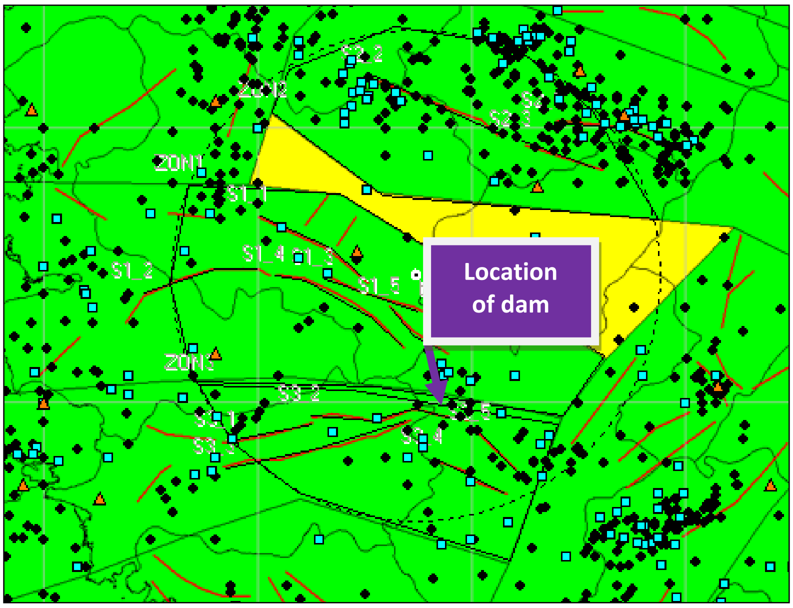

Figure 1. The model used for seismic hazard analyses

The results of probabilistic seismic hazard analysis indicate that peak ground acceleration (PGA) changes within a wide range for all earthquakes levels. For OBE, MDE and SEE, the PGA value averages to 0.300g, 0.405g and 0.566g, respectively. These values mainly depend to the predictive relationships. In this study six separate relationships were considered for determining horizontal peak ground acceleration [12].

As based on this study, Total Risk Factor (TRF) value is 90.5 and it is identified as risk class of II of Bureau method [13]. It means that it has moderate risk potential for downstream life and structures. According to the risk classification adopted by DSI [14], It is categorized as class III with high risk. The seismic hazard analyses performed throughout this study indicates that Bebekli dam is one of the most critical dams within the basin when considered downstream life.

3.2. ANALYTICAL AND NUMERICAL ANALYSES

For this study, earth fill stability of Bebekli dam have been investigated as defining a factor of safety for different loading condition by means of pseudo-static analysis (table 2). At the beginning of this study, seismic coefficient was determined for pseudo-static analysis as based on the approach given in DSI specification [14].

According to this approach seismic coefficient ranges from 0.20 to 0.25. For this study, it was selected as 0.20. Analyses have been executed by means of a software, namely GSTABIL7. The safety factors were calculated by the Modified Bishop Method. The value of seismic coefficient (k) was determined as 0.27 for limit equilibrium condition (F_S= 1.0). An example from analyses is introduced in figure 2.

Table 2. Safety factors of pseudo-static analysis for separate loading conditions

Case	Description	Slope	Factor of Safety	
			Required	Calculated
I	End-of Construction	Downstream Upstream	1.3	2.19 2.92
II	Rapid drawdown	Upstream	1.1-1.3	1.99
III	Operation	Downstream Upstream	1.4-1.5	2.04 2.24
IV	Earthquake	End-of Construction Downstream Upstream Operation Downstream Upstream	1.0	1.38 1.71 1.19 1.28

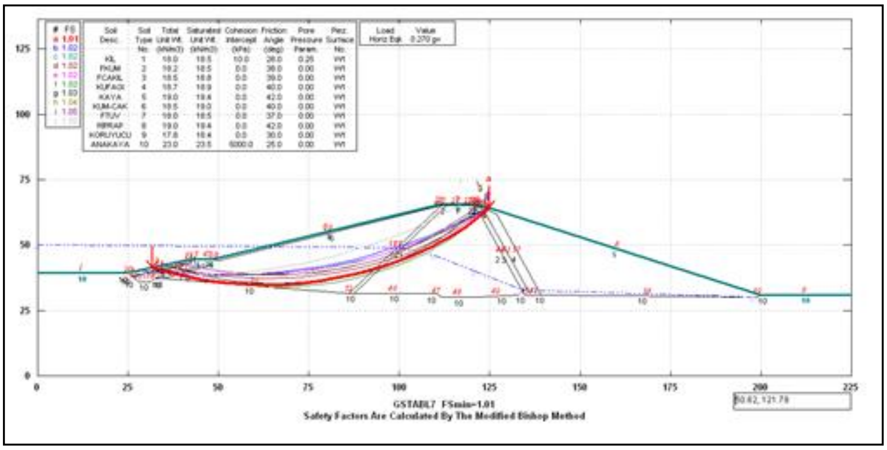

Figure 2. An example of slope stability analyses for Bebekli dam embankment

The parameters of dynamic analysis were selected after defining the OBE and MDE values for the dam site. The probabilistic hazard calculation was performed to obtain 5 percent damped elastic hazard pseudo-acceleration spectra and to generate the response spectrum compatible acceleration time histories for time domain analyses. For generating the acceleration time histories, a software program TARSCTHS was used. The output of time history record of dam site for OBE level is given in Figure 3.

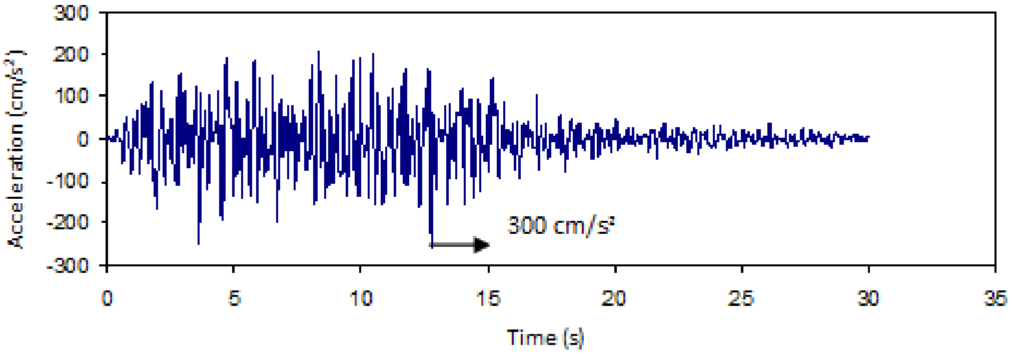

Figure 2. Synthetic acceleration-time history of OBE plot for input motions used in the dynamic analysis of Bebekli dam.

The 2-D finite element model for the maximum section of the dam and soil profile including bedrock and alluvial soil is given in Figure 4. The model consisted of 8905 nodel points and 1090 six-node plane-strain elements. Standard fixity elements were considered along the base and vertical sides of the model. It was assumed that the ground motion acts uniformly along the fixed boundaries. The hardening soil model was selected to define soil properties for all models discussed here.

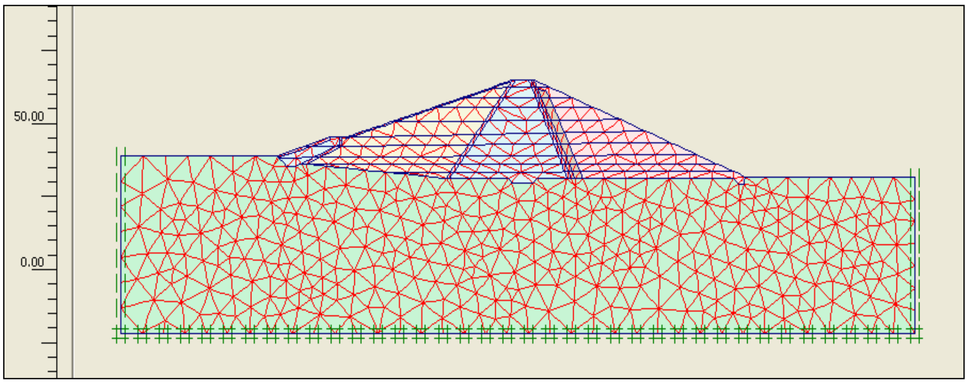

Figure 4. The finite element model of the embankment

The finite element model used in this study is composed of five different materials including the diaphragm wall. The bedrock is also considered as a rigid element with high deformation modulus. The parameters used in the model were considered from the laboratory tests and the literature survey [15,16,17]. For the analysis, the deformation moduli of impervious zone and semi-pervious zone were taken into account as 30 000 and 55 000 kPa, respectively.

As a result of this analysis, maximum vertical settlement was predicted as 40 cm for dynamic loading of MDE level (Figure 5). The horizontal displacements are little greater than vertical displacements. Figure 6 introduces the distribution of horizontal displacement on the model during the dynamic time.

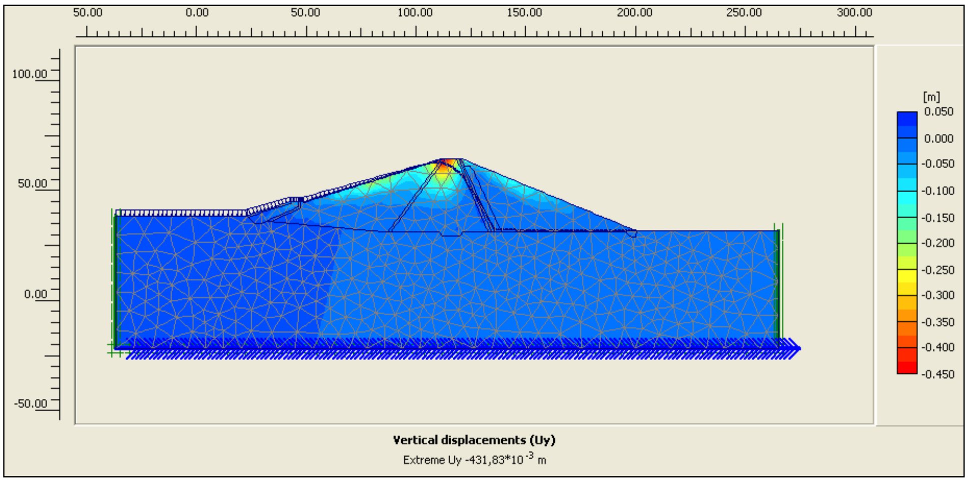

Figure 5. Distribution of vertical displacement for MDE loading condition

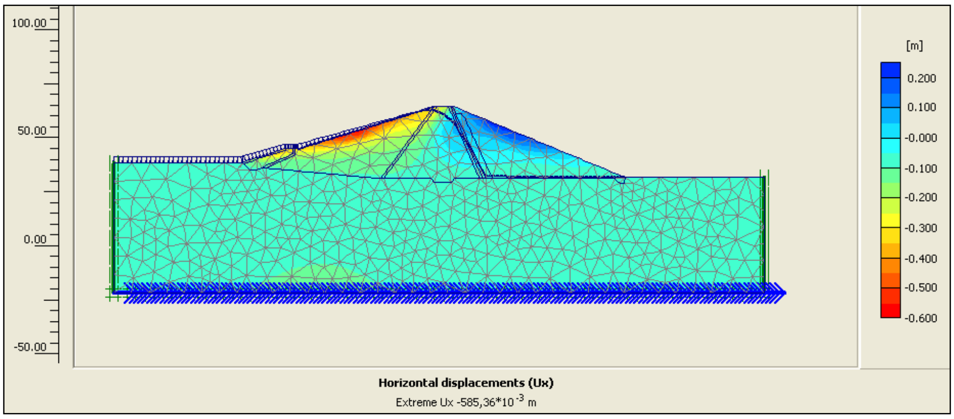

Figure 6. Distribution of Horizontal displacement for MDE loading condition

4. RESULTS AND DISCUSSION

The pseudo-static analysis indicates that both slopes of embankment are safe. The value of seismic coefficient was obtained as 0.27 for limit equilibrium condition. As a result of numerical analysis, maximum vertical settlement was predicted as 43.1 cm for dynamic loading of MDE level, while it obtains as 58.5 cm for horizontal section. The vertical and horizontal displacements are given in table 3 for OBE and MDE conditions.

Table 3. Summary of displacements for different loading conditions

Loading conditions	Vertical Displacement (m)	Horizontal Displacement (m)
OBE	0.195	0.185
MDE	0.431	0.585

As a result of finite element analysis, the horizontal component of acceleration was obtained for different level of embankment. Figure 7 introduces the horizontal acceleration on dam crest with input ground motion. In this figure, red line represents horizontal peak ground acceleration on the base rock, while blue line represents same parameter on the crest of dam, but both for MDE.

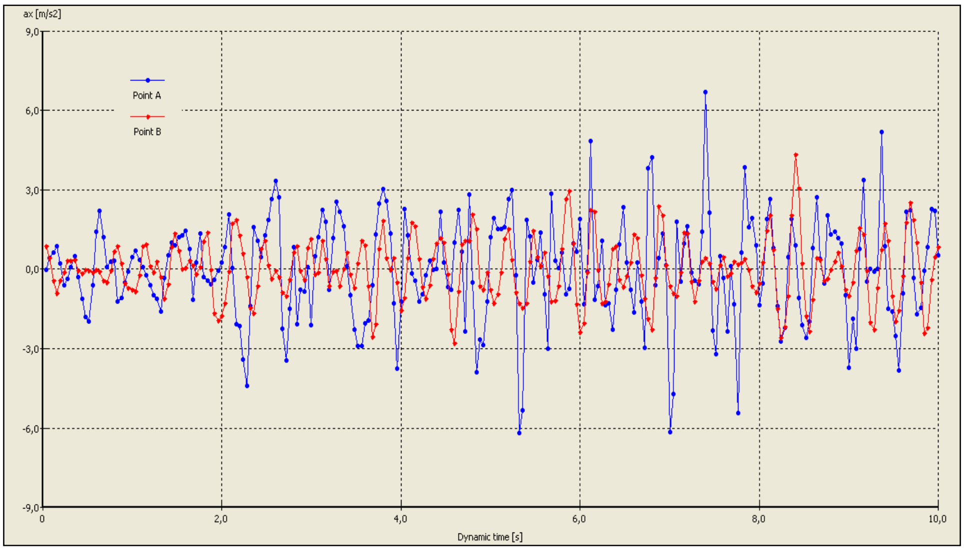

Figure 7. Horizontal acceleration on crest of embankment for MDE.

5. CONCLUSIONS

Bebekli dam site is located on very active seismic region of Turkey. It is under near field motion according to the updated seismic data. The slopes of embankment are safe when considered the pseudo analyses. The dynamic analysis of 2-D finite element model of dam-foundation system indicates that the maximum value of displacement is only 58.5 cm on the crest under the loading of Maximum Design Earthquake. The permanent deformation for this model was obtained between 7 and 15 cm by means of semi-empirical methods. These results indicate that local sliding problem can be seen during the loading of MDE condition, not failure of dam.

6. ACKNOWLEDGMENT

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