Rock Mechanics in Civil and Environmental Engineering – Zhao, Labiouse, Dudt & Mathier (eds)
© 2010 Taylor & Francis Group, London, ISBN 978-0-415-58654-2

Dynamic analysis of Choar earth-fill dam

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ABSTRACT: Owing to the fact that most part of Iran is in the dry region of the world with little water and in other hand the need of water for various requirements is growing extremely fast, one of the most economical solutions is to build earth dams with appropriate safety. In the present study, the stability analysis of Choar earth-fill dam under static and dynamic loads in order to evaluate the effects of earthquake on the stability of the dam by using the numerical simulation have been carried out. This dam is located near the city of Ilam in Iran with a maximum height of 80 meter from the foundation. The stability analyses of Choar dam have been conducted in two stages. In the first step, earthquake hazard analysis to assess the seismic parameters of the area has been reviewed and in the second step, the pseudo-static analysis by limit equilibrium technique. Subsequently the static stability and dynamic responses of the dam were determined under the selected situations by employing two-dimensional distinct element method.

1 INTRODUCTION

The stability of slopes and dam foundations is always of great concern to geotechnical engineers. Numerical modeling is an excellent way to understand the behavior of earth-fill dams and in addition to assess the static stability and dynamic response of these structures. In these methods, the deformation and stress distribution of slopes or dam foundations considering various yielding criteria will be calculated and critical load and failure types or the safety behavior of the structure would be appraised. In the present study, the static and dynamic analyses of Choar earth dam which is located in 20 km northwest of the city of Ilam in Iran has been performed utilizing the Universal Distinct Element Code (UDEC). The purpose of the analyses was to study the behavior of the earth dam, the amount of displacements and also to assess the safety factor of the dam under both static and dynamic loads.

2 GEOLOGICAL AND GEOTECHNICAL SETTING

The Choar dam is positioned in the folded zone of Zagros and is composed of the Paleozoic and Mesozoic sedimentary rocks. This zone is made of thick sediments which generally consist of Limestone, Dolomite, Sandstone and Shale. Rock masses in the area of the dam are comprised of Sarvak formation which is mainly limestone especially in the downstream and grayish shale and marl from Gourpay formation in the upstream and in the left abutment of the dam. There are two main fault systems in the area of the study, the first fault system (reverse fault) is situated in the northeast of the project and the second system (normal fault) is located in the north of the project (Aban pajoh 2007).

Table 1. Geotechnical properties of materials.

	D (kg/m^3)	E(MPa)	C(KPa)	phi	ν
Core	2100	30	10	22	0.35
Filter and drain	2080	75	0	25	0.33
Foundation	2650	5800	1245	33	0.29
Riprap	2080	150	0	40	0.3

*E = modulus of elasticity, phi = friction angle, C = cohesive strength, ν = poison's ratio, D = density.

Altogether ten boreholes with the sum length of 680 m were drilled which deepest borehole with the length of 90 m was drilled in the left abutment. General permeability conditions of rocks shows the higher value in the left abutment in comparison with the right abutment and foundation of the dam. R.Q.D values in the abutments are higher than the foundation.

Joint study was accomplished in the area of the study. In the left abutment two major joint sets and in the right abutment three joint sets were surveyed. The mechanical properties of the various parts of the embankment are listed in Table 1.

3 GROUND MOTION PARAMETERS

The assessment of seismic response of structures requires an understanding of the anticipated ground

Table 2. Design levels of earthquakes.

Earthquakes level	MHA	MVA
DBE	0.2 g	0.15 g
MCE	0.48 g	0.43 g
MDE	0.29 g	0.25 g

*MHA: maximum horizontal acceleration. MVA: maximum vertical acceleration.

shaking as well as an evaluation of the response of the ground and the structure to such shaking (Hasshash et al. 2001). A systematic seismic analysis approach for evaluating the seismic response of underground structures was presented by Hasshash et al. (2001) in the following three major steps that could be used for dynamic design of each structure.

- Definition of the seismic environment and development of the seismic parameters
- Evaluation of ground response to shaking.
- Assessment of structure behavior due to seismic shaking.

The design level of shaking is typically defined by a design ground motion, which is characterized by the magnitudes and characteristics of expected ground motions and their expected return frequency (Kramer 1996).

Assessments of the recorded earthquakes show that Zagros mountains range is one of the active regions of Iran and the regional earthquake hazard analysis yielded an earthquake magnitude of 5–6.5. The maximum recorded earthquake magnitude of 7.4 in the site area from past studies shows the high probability of large earthquake occurrence.

Based on the past studies at the site region, the probability of exceedance in 50 years is an earthquake magnitude of 6.5 (Aban pajoh 2007).

The level of design earthquake has to be defined after seismic analysis. Table 2 lists various design levels of earthquakes namely Design Basic Earthquake (DBE), Maximum Credible Earthquake (MCE) and Maximum Design Earthquake (MDE) which the last one would be used in dynamic design of Choar dam.

4 STABILITY ANALYSIS

Owing to the fact that the stability of earth-fill dams during their life time is very important subject, therefore the stability analysis should be investigated in various points of view and considering several stages and conditions of construction. This job particularly should be performed during and after construction of the dam, rapid drawdown situation and during the earthquake which variety of methods could be employed to evaluate the stability of earth-fill dams.

In this study the stability of Choar earth-fill dam after construction and also during the earthquake has been assessed and the safety factor, displacements of the embankment and foundation were monitored. In the present research, limit equilibrium technique and numerical models were used for aforementioned targets.

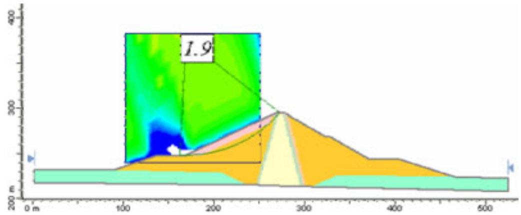

Figure 1. Limit equilibrium model and safety factor of the dam.

4.1 *Limit equilibrium method*

The limit equilibrium technique is a simple method which supposes the surface of rupture and subsequently calculates the safety factor.

This technique was used to analyze the embankment stability under the static and pseudo-static conditions. Safety factors for upstream and downstream of the dam were 1.9 and 1.6 respectively and have been calculated as 1.2 and 1.1 in pseudo-static situation by Slide software. Figure 1 shows the result of static analysis for upstream of the dam.

4.2 *Numerical methods*

In this research, two-dimensional Universal Distinct Element Code (UDEC) which is a great tool for simulation of complex geotechnical projects with different materials and complicated geometries was used to study the behavior of the dam, stress redistribution and displacement in the dam and foundation. In numerical modeling, the maximum shear strain has been evaluated so as to study the surface of failure.

4.3 *Static analysis*

The dimensions of UDEC model for Choar earth dam are 520 m by 130 m. Considering the result, it is clear that the maximum displacement of the foundation is 2.1 cm, the maximum settlements (vertical displacements) of the embankment is approximately 12.71 cm and maximum horizontal displacement of the dam is about 2.1 cm (taking place in the downstream) which is lower than the permissible value regarding the height of the dam. Figure 2 shows the displacement contour in the dam embankment. Concerning the maximum shear strain in slopes of the embankment, local surfaces of rupture were seen but due to the compaction of the earth, the stability (safety factor) of the dam in numerical models was higher than limit equilibrium models.

The minimum safety factor of foundation based on the Mohr-Coulomb failure criteria is 2.75 that confirm the stability of foundation.

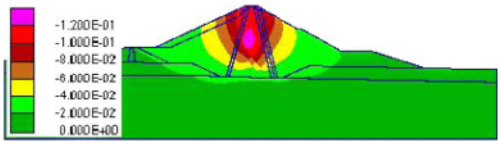

Figure 2. Y-displacement contour of the dam.

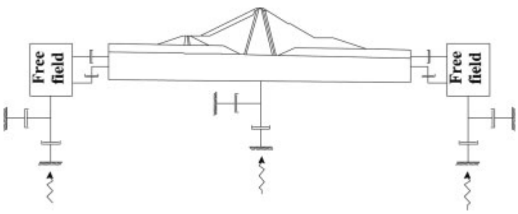

Figure 3. Selected model for dynamic design of the dam.

5 INPUT MOTIONS AND DYNAMIC DESIGN OF CHOAR EARTH DAM

All structures especially earth and rock-fill dams are prone to destruction during an earthquake. Therefore dynamic stability analysis of earth-fill dams should be performed to investigate the behavior of the embankment and also foundation under dynamic loads which is extremely complicated issue.

Figure 3 shows the circumstances of dynamic simulation and the boundary conditions at the sides of the UDEC model.

It is a common practice in earthquake engineering to use accelerograms as they are readily available for different fault systems and earthquake events around the world (Hatzor & Feintuch 2001).

Since seismic hazard analysis focuses on the magnitude of the ground motion and the recorded accelerogram was not accessible, the real accelerogram have been adopted from an earthquake. An artificially generated accelerogram was built regarding magnitude of the reference earthquake, the distance from source to site. The local site geology then adjusts the time history for the analysis. In this method one should choose a recorded accelerogram which has high similarities with the conditions of the site area and subsequently scaling the chosen accelerogram to the site situation (Kramer 1996).

Considering the mentioned factors and due to the shortage of appropriate accelerogram in the site region, the horizontal and vertical accelerograms of 1989 Loma Prieta, California earthquake (magnitude 7.1) has been considered for the present study. Afterwards adaptation was carried out based on the past seismic analyses so as to prepare the input wave for dynamic models.

Figure 4 illustrates the corrected acceleration adopted from the accelerograms of Loma Prieta earthquake and Figure 5 shows the velocity history of the selected earthquake which was prepared utilizing Sismosignal software.

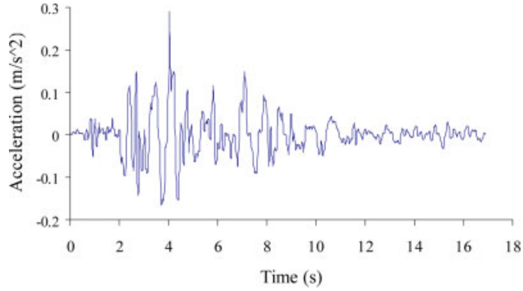

Figure 4. Adopted time histories of selected earthquake.

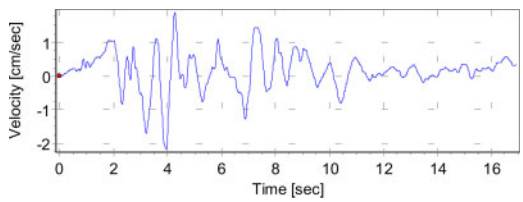

Figure 5. Representation of velocity history of selected earthquake.

Velocity boundary condition cannot be applied along the same boundary as a quiet (viscous) boundary condition. To overcome this problem, velocity record can be transformed into a stress record and applied to a quiet boundary (Itasca 1992).

The dynamic variables for the input shear wave were calculated as follows:

$$V_{max} = \frac{a_{max}}{\omega} = \frac{a_{max}}{2\pi f} \quad (1)$$

where a_{max} is the peak ground acceleration, V_{max} is the peak ground motion velocity, f is the frequency and *w* is the angular frequency, and

$$\tau = \rho c_s V_{max} \quad (2)$$

where τ is the shear stress, C_s is the shear wave propagation velocity and ρ is the rock density. The shear stress calculated from Eq. (2) was doubled in order to compensate for the viscous boundary at the base of the model (Kveldsvik 2009).

Both site response and ground failure are strongly influenced by properties of soil. Site response is primarily influenced by the properties that control wave propagation, particularly stiffness and damping. Ground failure is influenced by those properties, but also by the shear strength of the soil (Bozorgnia & Bertero 2004). In this research, a damping of 0.1% was applied in all the dynamic computations.

As demonsterated in Kuhlemeyer & Lysmer (1973), for accurate representation of wave transmission through a model, the spatial element size must be smaller than approximately one-tenth to one-eight of the wavelength associated with the highest frequency

Table 3. Displacement of upstream and downstream of the dam embankment.

Analyses type	downstream (cm)	upstream (cm)
Static analysis	2.10	1.76
Dynamic analysis	2.17	1.81

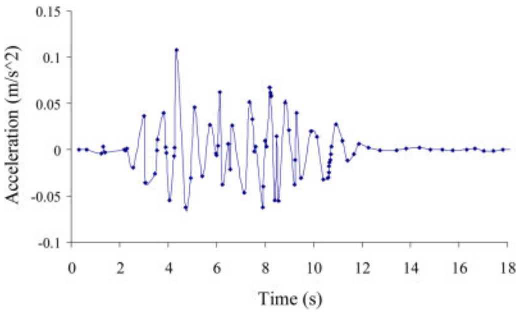

Figure 6. Acceleration response at the crown of the dam.

component of the input wave. The zoning of the models used in this study was adjusted to ensure that the spatial element size is smaller than one-tenth of the wave length associated with the input wave with the highest frequency.

The maximum horizontal displacements of the upstream and downstream of the embankment were calculated for both static and dynamic circumstances and (Table 3). In addition, safety factor of the foundation were 2.75 and 2.27 for static and dynamic analyses respectively.

Figure 6 shows the response acceleration of the dam's crown. Selected wave was applied to the model base and took 0.304 s to propagate upward and reach to the top of the model.

6 CONCLUSION

Numerical studies have been performed to investigate the behavior of Choar earth-fill dam in the west of Iran. Both static and dynamic analyses were carried out to gain an insight into the deformation mechanism, displacement of the embankment and the safety factor of the foundation.

Safety factors for upstream and downstream of the dam in static condition were 1.9 and 1.6 respectively and have been calculated as 1.2 and 1.1 in pseudo-static situation by limit equilibrium method.

In this research, an artificially generated accelerogram had been built by adopting the accelerogram of Loma Prieta, California earthquake (magnitude 7.1) and it has been applied to the model base which took 0.304 s to propagate upward and reach to the top of the model. The maximum horizontal displacements of the upstream and downstream of the embankment were calculated for both static and dynamic circumstances.

Numerical simulations indicated that the safety factor of the foundation reduced from 2.75 in static analysis to 2.27 in dynamic analysis.

ACKNOWLEDGMENT

The authors wish to thank Aban pajoh Consultant Engineers Company for providing access to the Choar earth-fill dam geological study reports.

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