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Seismic Analysis of El–Agrem Concrete Face Rockfill Dam

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ABSTRACT: This paper presents the dynamic analysis of El–Agrem concrete face rockfill dam using the finite element software Plaxis-2D. A parametric study is performed to identify the degree of influence of some parameters such as peak ground acceleration, rockfill shear modulus and constitutive model on the dam behavior. The results indicated that these parameters have an important effect on the response of the dam under seismic loading
Keywords: Behaviour of concrete face rock fill dam, stress - strain analysis, earthquake behaviour, performance of CFR dams.

1. INTRODUCTION

The design of concrete face rockfill dams for earthquake is mainly based on experience and engineering judgement (Cooke, 1984; Cooke, 1997; Núñez, 2007b). For concrete face rockfill dams, performance rather than safety is the main concern, as it is widely accepted that the effect of seismic loading on this type of dams is plastic deformation and settlement but not a slope failure in its classical sense (Cooke, 1984; Makdisi and Seed, 1978; Newmark, 1965). For a given CFRD and earthquake, total settlement of the dam with empty reservoir is larger than the settlement of the dam with full reservoir (Uddin and Gazetas, 1995; Núñez, 2007).

Methods used to estimate dam deformation induced by earthquake range from simple analytical tools (Newmark,1965; Makdisi and Seed, 1978; Núñez, 2007) to three dimensional numerical models. Analytical tools are simple to use but they cannot take into account special features of dam design, like zonification, berms or non uniform slopes. However, the reliability of numerical methods depends on the choice of the constitutive models and the selection of input parameters (Sfriso, 2008).

Materón and Fernandez (2011) reported two major earthquakes occurred in 2008 close to Zipingpu concrete face rockfill dam in China (156 m high, shaken by a magnitude 8 earthquake) and Ishibuchi concrete face rockfill dam in Japan (53 m high, shaken by a magnitude 7.2 earthquake). The severe shaking triggered displacement and cracking at the crest as well as loosening of boulders in the downstream slope, but the performance of the dams from the viewpoint of stability were adequate.

The objective of this paper is to investigate the behavior of El-Agrem concrete face rockfill dam during seismic loading using the finite element code Plaxis 2D (Brinkgreve et al., 2010). The analyses were performed using the linear elastic perfectly plastic model (Mohr Coulomb model). The effect of some parameters on the response of the dam to seismic loading such as seismic acceleration, material shear modulus and constitutive models are also presented in this paper.

2. MAIN FEATURES OF EL-AGREM DAM

The El–Agrem concrete face rockfill dam as shown in figure 1a, is located 15 km south - east of Jijel city (Algeria). The dam reservoir can store approximately 35 million cubic meters of water and provides drinking water to the surrounding region.

The dam is 64 m high and 395 m long with a crest width of 10 m. The embankment volume is 1.6 x 10^6 m^3 and consists of two zones of granitic rockfill materials as shown in figure 1b. Zone E1 comprises the majority of the embankment section with a maximum particle size of 0.6 m and compacted in layers of 0.8 m thick. Zone E2 is a 1 m thick transition zone consists of smaller-size rock, provided between the concrete face slab and the rockfill embankment. The rockfill is compacted to a high density in order to minimize deformations, concrete slab cracks and leakage. The upstream and downstream slopes of the dam were established at 1.7H:1V (Fig. 1b).

The concrete slab on the upstream side provides the watertightness of the dam above the ground together with the perimetric joints and the plinth. The concrete slab has a total area of 31000 m^2 with a variable thickness of 0.5 m at the base and 0.35 m at the top of the dam. The dam foundation consists of granite gneiss rock on the right bank and of marly rock on the left bank. The dam construction was completed in 2000.

Figure 1a General view of El-Agrem concrete face rockfill dam

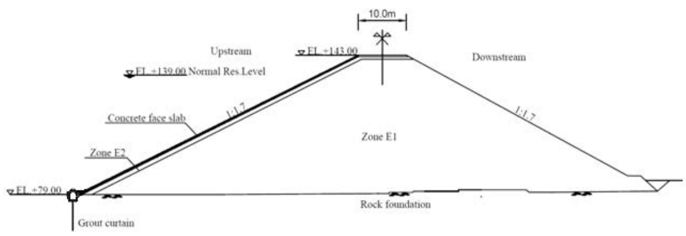

Figure 1b Typical cross-section of El-Agrem concrete face rockfill dam

3. DYNAMIC ANALYSIS

The dynamic analysis was conducted on the maximum cross – section of the dam resting on rock foundation with empty reservoir using Plaxis 2D software. The dam was subjected to the seismic excitation that was recorded during the 2003 Boumerdes earthquake (Algeria) with a peak ground acceleration of 0.34 g in the east-west direction (Fig. 2).

The embankment was modelled using fifteen noded plane strain elements. Figure 3 shows the finite element model having 2228 elements and 18217 nodes.

The deformation of the dam foundation is considered negligible; therefore the model sets fixed displacements along the dam base in contact with the rock foundation. Furthermore, the dam is located in a wide valley (crest length / dam height equals to 6), thus three dimensional effect is negligible.

The concrete slab was modelled as linear elastic with Young's modulus equals to 30000 MPa and Poisson ratio equals to 0.15.

Rockfill materials were modelled with Mohr Coulomb model. Table 1 lists the parameters of the dam materials used in the numerical analysis. The dilation angle was estimated by the relation $\psi=\phi$ - 30 (Bolton, 1986).

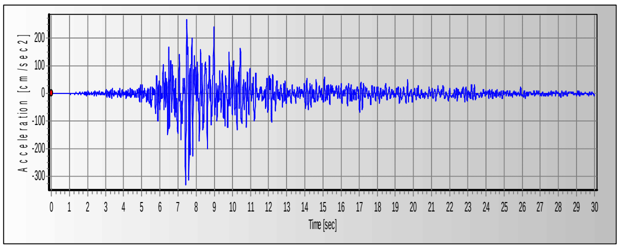

Figure 2 Seismic excitation record in the east-west direction (Boumerdes 2003 earthquake, Algeria)

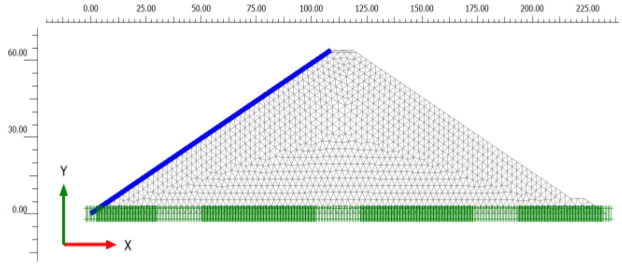

Figure 3 Two dimensional finite element model

Table 1 Rockfill parameters

Layer	Zone E1	Zone E2
Unit weight: γ (kN/m^3)	20.5	21
Cohesion: c' (kPa)	0	0
Friction angle: ϕ'^{o}	45	42
Dilatancy angle ψ^{o}	15	12
Poisson's ratio: ν	0.2	0.2
Shear modulus: G (MPa)	450	450

4. RESULTS AND DISCUSSION

The results indicate that the horizontal displacement of the dam crest is about 320 mm in the upstream-downstream direction and the maximum settlement of the dam crest is about 7mm located on the upstream side. The peak acceleration obtained at the crest (0.66 g) is about 1.94 times the acceleration at the dam base (0.34 g) (Fig. 4). These results are in accord with those obtained by many researchers such as Haciefendiglu (2009); Bayraktar et al. (2011) and Kartal et al. (2011).

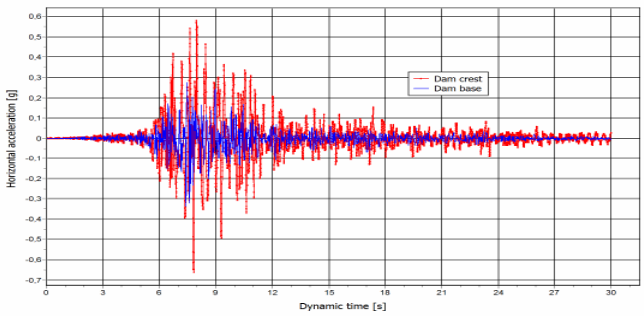

Figure 4 Horizontal accelerations at the base and crest of the dam

4.1 Effect of constitutive model

The effect of rockfill constitutive model on the dam response to seismic loading was investigated using Mohr Coulomb model and elastic model.

The elastic model indicated a crest settlement (2.6 mm) less than that obtained with Mohr Coulomb model (6.8 mm). Moreover, the acceleration at the crest obtained with elastic model (0.92g) is about 1.4 times the acceleration obtained with Mohr Coulomb model (0.66g). Thus the elastic model resulted in a decrease of the crest settlement by about 62% and an increase of the acceleration at the crest by about 39% compared to Mohr Coulomb model.

4.2 Effect of shear modulus

The effect of the rockfill shear modulus on the response of the dam to seismic loading was investigated using shear modulus values of 400 MPa, 450 MPa and 500 MPa. The results shown in Figure 5 indicate that the increase of the shear modulus leads to the decrease of the settlement and increase of the acceleration at the dam crest.

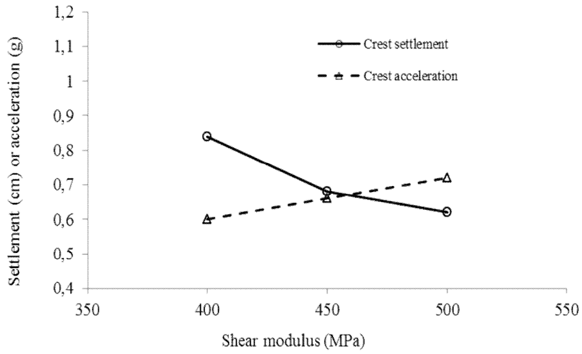

Figure 5 Crest settlement and acceleration versus rockfill shear modulus

4.3 Effect of peak ground acceleration

Acceleration time histories for east-west and north-south directions recorded during Boumerdes 2003 earthquake (Algeria) were used to investigate the effect of peak ground acceleration on the dynamic response of the dam. The peak ground accelerations in the east-west and north-south directions are 0.34 g and 0.25 g respectively.

The analysis results indicate that the increase of the ground acceleration led to the increase of the crest settlement (from 3.6 mm to 6.8 mm) as well as the amplification of acceleration between the base and crest of the dam. The acceleration obtained at the dam crest is about 1.4 times the ground acceleration in the north-south direction and about 1.94 times the ground acceleration in the east-west direction.

5 CONCLUSIONS

The dynamic analysis of El–Agrem concrete face rockfill dam using Plaxis-2D with Mohr Coulomb model indicated that the amplification factor of the acceleration at the dam crest is about 1.94 and this amplification increases with the increase of the peak ground acceleration.

The elastic model resulted in a decrease of the crest settlement and an increase of the acceleration at the dam crest compared to Mohr Coulomb model.

The increase of the rockfill shear modulus led to the decrease of settlement and increase of acceleration at the dam crest.

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