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The effect of foundation's modulus of elasticity on concrete gravity dam's behavior

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Abstract

Investigation on the behavior of dams against the seismic loads is a key factor for safety requirement. One of the most important problems in evaluation of seismic behavior of concrete gravity dams is dam-reservoir-foundation interaction. In this paper, we study the effect of dam-reservoir-foundation interaction on nonlinear behavior of concrete gravity dams, a two-dimensional approach was used including the finite element method and smeared crack approach. Effective parameters in the models are physical properties of concrete such as modulus of elasticity, tensile strength and specific fracture energy. Their importance in the nonlinear analysis was investigated in a parametric study. Different boundary conditions were used in foundation in order to determine the seismic response of concrete gravity dams. Results show that when the nonlinear analysis includes the dam- foundation interaction and the foundation's mass, flexibility and radiation damping, the seismic response of concrete gravity dam will be reduced to a realistic level. Decreasing in ratio of foundation's modulus of elasticity to dam's modulus of elasticity (EF/ES) causes increasing in dam crest displacement. The crack profile is expected to reduce due to mass of foundation and it's damping effects in massed foundation system.

Keywords: Concrete gravity dams, Dam-reservoir-foundation interaction, Smeared crack model

Introduction

Evaluation of nonlinear dynamic behavior and seismic safety of concrete gravity dams has been very attractive to the researchers, because failure of these structures may cause dangerous consequences. It seems to be necessary to select an appropriate numerical model, in the absent of any sufficient practical results. Many researchers worked on developing numerical models to evaluate seismic safety of concrete gravity dams in two and three- dimensional space.

Chopra and Chakrabarti (1972) included linear elastic analysis for predicting the location of crack profiles. In their study, the Koyna dam and the Pine Flat dam were considered, but the dynamic interaction of the reservoir and foundation were excluded. For the first time, Pal (1974) analyzed concrete gravity dams using nonlinear models. He considered the Koyna dam, assuming rigid foundation and excluding the dynamic interaction effect of the reservoir.

Bhattacharjee and Leger (1993) proposed a method that considered the dam-reservoir-foundation interaction using the nonlinear analysis of concrete gravity dam. The reservoir was modeled with matrices for added mass, dampers and springs. Building these matrices in frequency domain analysis, were time consuming and complex. They used smeared crack model in their studies and considered Koyna dam using coaxial rotating crack model (CRCM) and assuming rigid foundation. El-Aidi and Hall (1989) included the smeared crack model for considering the nonlinear behavior of concrete gravity dams. In their research, the reservoir interaction was considered and the foundation was modeled as a rectangular mass less region connected to a semi-infinite visco-elastic half space. Using the size reduced strength criterion (SRS), caused that the crack profiles to be unrealistic. Calayir and Karaton (2005) investigated seismic analysis of concrete gravity dams with considering the effect of dam-reservoir interaction. In their study a co-axial rotating crack model (CRCM), which included the strain softening behavior, was used for analysis of Koyna dam. Mirzabozorg *et al*. (2010) studied nonlinear behavior of concrete dams under non-uniform earthquake ground motion records. Isotropic damage mechanics approach is used to model static and dynamic nonlinear behavior of very concrete in 2D space. They considered the effect of non-uniform excitation of a reservoir bottom on the non-linear response of concrete gravity dams. An anisotropic damage mechanics approach is used to model the non-linear behavior of mass concrete in a two-dimensional space. The reservoir is assumed to be compressible, and the foundation mass is taken into account in analyses conducted utilizing the appropriate boundary condition on the far end truncated boundary of the foundation medium.

Numerical model

The smeared crack model represented by Bhattacharjee and Leger (1993), is used to evaluate the nonlinear behavior of concrete gravity dams with dam-reservoir-foundation interaction using the staggered method of solution that was proposed by Ghaemian and Ghobarah (1998). The Pine flat dam is selected for evaluating the results of computer code, NSAG-DRI (Ghaemian, 2008) that is used to carry out the nonlinear analysis. Basic parameters such as modulus of elasticity, unit weight and Poisson's ratio of concrete dam are chosen as 27.58 GPa, 2483 Kg/m^3 and 0.20, respectively. The modulus of elasticity, unit weight and Poisson's ratio of rock foundation are selected as 22.4 GPa, 2643 Kg/m^3

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and 0.33, respectively. For the purpose of the seismic analysis of dam, Manjil earthquake record is used. (PGA= 0.5g).

Fig.1. Mass less boundary condition

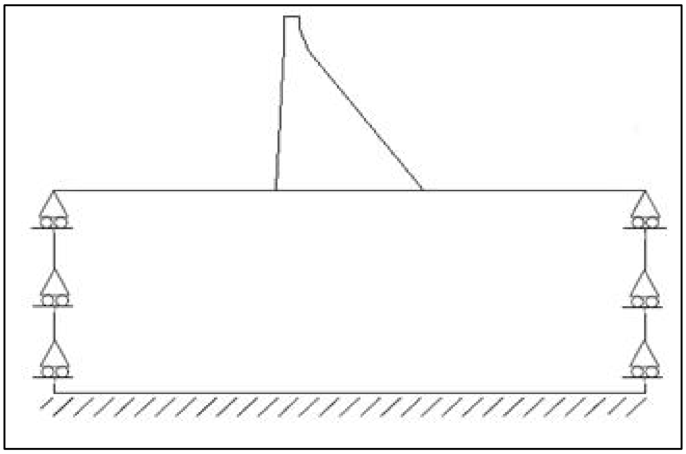
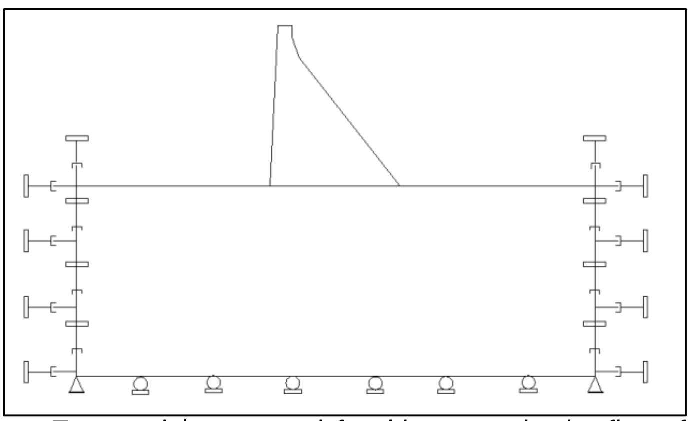


Fig.2. Lysmer boundary condition in massed foundation model



Two models are used for this research, the first of which is flexible mass less foundation with fixed support at base and roller support for sides that is shown in Fig.1 (USACE, 2003 & 2007). The second model is a flexible massed foundation that is shown in Fig. 2, such as Lysmer boundary condition, there are horizontal and vertical dampers in both sides of foundation but at the base only there are rollers. In a finite element model, the damping factor of these dampers can be calculated as follows:

$$C_{11}^{i} = V_P \rho \int_{l_e} N_i dl \quad (1)$$

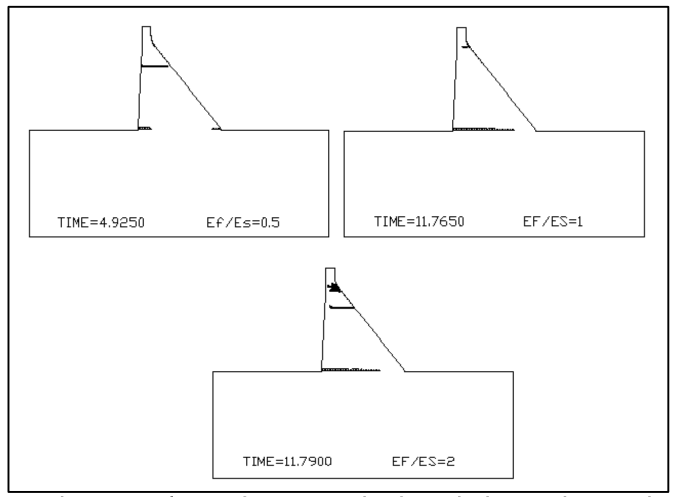
$$C_{22}^{i} = V_S \rho \int_{l_e} N_i dl \quad (2)$$

Where ρ is the rock density; V_P and V_S are the velocity of P and S-waves; C_{11}^{i} and C_{22}^{i} are the damping factors in the normal and tangential directions respectively (Lysmer & Kuhlemyer, 1969).

The effect of foundation modulus of elasticity

In order to consider the effect of foundation's modulus of elasticity, nonlinear dynamic analyses were carried out including variation of EF (EF/ES =0.5,1,2), where EF and ES are foundation's modulus of elasticity and dam's modulus of elasticity respectively. The results of the crack profiles are represented for mass less and massed foundation (Fig. 3 & 4). It is reasonable that the crack profiles are increased due to increase of EF/ES and the maximum displacement of dam crest is decreased in mass less foundation.

Fig.3. Crack profiles of system for mass less foundation by varying EF/ES=0.5,1,2



The results of massed foundation show the increasing of crack profiles and decreasing of maximum displacement of dam crest in Lysmer boundary condition due to increase of EF/ES (Fig. 5 & 6).

Decreasing in ratio of foundation's modulus of elasticity to dam's modulus of elasticity (EF/ES) causes

Fig.4. Time history of dam crest displacement in mass less foundation for different values of EF/ES=0.5,1,2

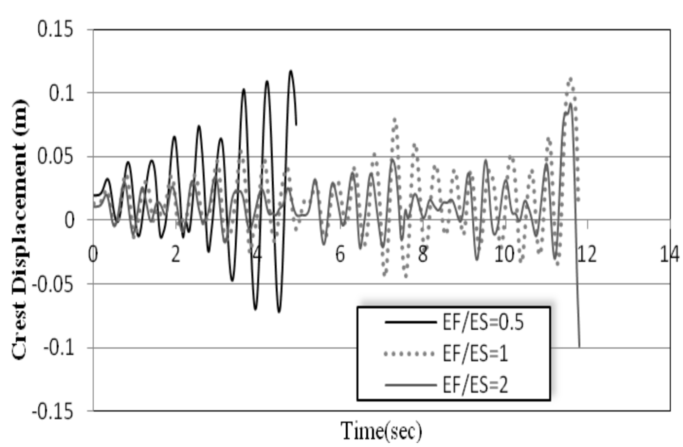


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Fig.5. Crack profiles of system for massed foundation (Lysmer b.c) for different values of EF/ES=0.5,1,2

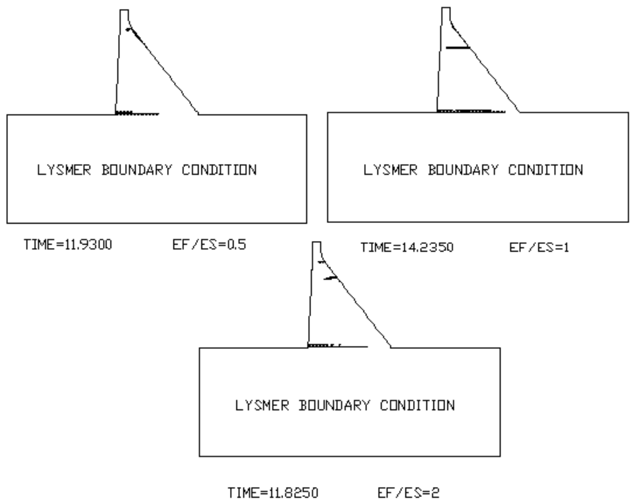
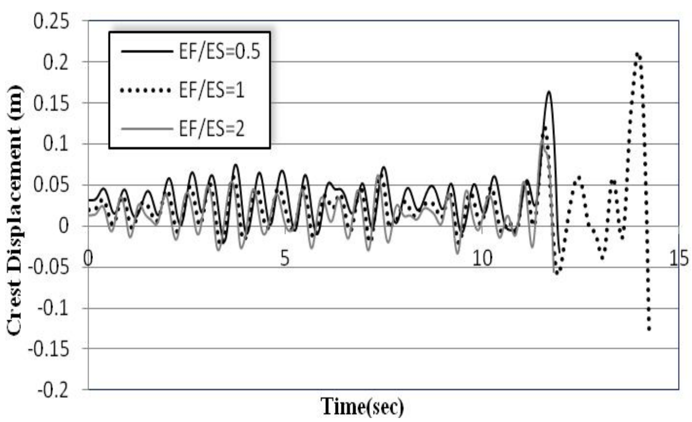


Fig. 6. Time history of dam crest displacement in massed foundation (Lysmer b.c) for different values of EF/ES=0.5,1,2



increasing in dam crest displacement. In nonlinear dynamic analysis, decreasing in ratio of EF/ES causes decreasing crack profiles. Comparing mass less and massed foundation systems, it's concluded that in mass less foundation, it's considered only flexibility and structural damping, neglecting inertia and geometric damping. Then maximum displacement of dam crest increases and it's concluded that nonlinear dynamic analysis of mass less foundation is overestimated. Considering the geometric damping in nonlinear dynamic analysis of massed foundation decreases maximum displacement of dam crest then damage in system is decreased. The crack profile is reduced due to mass of foundation and its damping effects in massed foundation system.

Conclusion

When the nonlinear analysis includes the dam-foundation interaction, the gravity dam's response will be more realistic. In mass less foundation, it is considered only flexibility and structural damping, neglecting inertia and geometric damping. Then maximum displacement of dam crest increases and it's concluded that nonlinear dynamic analysis of mass less foundation is overestimated. Considering the geometric damping in nonlinear dynamic analysis of massed foundation decreases maximum displacement of dam crest then damage in system is decreased. Nonlinear dynamic analysis is depended on EF/ES. Decreasing in ratio of foundation's modulus of elasticity to dam's modulus of elasticity (EF/ES) causes increasing in dam crest displacement. In nonlinear dynamic analysis, decreasing in ratio of EF/ES causes decreasing crack profiles.

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