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Seismic response analysis of concrete gravity dams considering base sliding

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Abstract:. This study presents the seismic response of concrete gravity dams considering welded contact and friction contact and along dam-foundation rock interface. Friction contact is provided using contact elements. Two-dimensional finite element model of Oued Fodda concrete gravity dam, located in Chlef at the northwestern part of Algeria, is used for this purpose. Nonlinear analyses of dam-foundation rock system are performed using ANSYS software. The reservoir water is modeled as added mass using the Westergaard approach. The Druker-Prager model is employed in the nonlinear analysis for dam concrete. The surface-to-surface contact elements based on the Coulomb's friction law are used to describe the friction. These contact elements use a target surface and a contact surface to form a contact pair. According to this study, when the friction contact is considered in joints, sliding displacement of dam base occurs along the dam-foundation rock interface. The dam sliding along its foundation decreases the deformation response in the dam body and shear force at both the heel and toe of the dam.

1. Introduction

Several studies were carried out on the effect of conditions of contact in the interface between the concrete gravity dam and its foundation rock (Leger and Katsouli 1989; Chavez and Fenves 1995; Azm and plautre 2002; Viladkar and Al-Assady 2012). Hall et al (1991) investigated the sliding failure of pine Flat dam during earthquake. The study illustrated tha there is a permanent deformation at the base due to dam sliding. Other investigators studied the seismic sliding at the concrete gravity dam base using analytical methods (Chopra and Zhang 1991) and empirical laws (Danay and Adeghe 1993). Arabshahi and Lotfi (2008) used interface elements to present sliding at dam base. The results shown that sliding reduces seismic response of the dam. Ouzandja and Tiliouine (2016) studied influence of friction coefficient variation at dam-foundation rock on earthquake behavior of Oued Fodda dam. The work demonstrates that the use of contact elements, which represent the friction coefficient, affects the earthquake performance of the dam.

This paper shows the effect of contact friction along the dam-foundation rock interface on the earthquake response of concrete gravity dams. The Oued Fodda dam is taken into account in the numerical analyses. For this purpose, two-dimensional finite element model of dam-foundation rock system is employed. The hydrodynamic pressure of the reservoir water is modeled utilizing the added mass concept (Westergaard 1933). In the nonlinear analysis, the Druker-Prager model (Drucker and Prager 1952) is used for dam concrete. Welded and friction contact are considered in the joints along dam-foundation rock interface. Surface-to-surface contact elements based

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on the Coulomb's friction law are used to describe friction using ANSYS software (2013).

2. Surface-to-surface contact elements

To model a contact problem, we first must identify the parts to be analyzed for their possible interaction. If one of the interactions is at a point, the corresponding component of our model is a node. If one of the interactions is at a surface, the corresponding component of our model is an element: either a beam, shell, or solid element. The finite element model recognizes possible contact pairs by the presence of specific contact elements. These contact elements are overlaid on the parts of the model that are being analyzed for interaction. There are various contact elements. The surface-to-surface contact elements based on the Coulomb's friction law are used to describe the friction. These contact elements use a target surface and a contact surface to form a contact pair (Fig. 1).

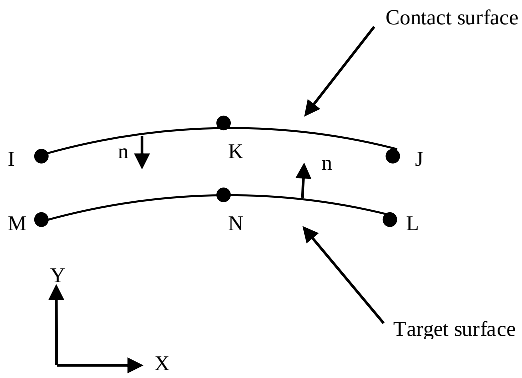

Fig. 1. Target and contact surface elements.

3. Oued Fodda concrete gravity dam-foundation system

3.1. Material properties

The selected dam in this study is located approximately 20 km of Oued Fodda (Chlef), in northwestern Algeria, founded over a massive limestone known as "Koudiat Larouah". The reservoir is mainly used for irrigation purposes. The capacity of the dam is 125.5 hm^3. The maximum height "H" and base width of the dam are 101 m and 67.5 m, respectively. The dam crest is 5 m wide and the maximum height of the reservoir water is considered as 96.4 m. The geometry of the dam-foundation rock system is shown in Fig. 2.

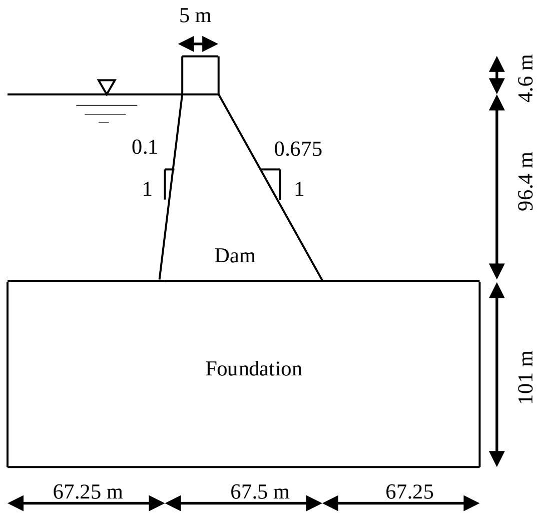

Fig.2. Geometry of dam-foundation rock system.

The material properties for both the concrete gravity dam and foundation rock are reported in Table 1 below. The cohesion and the angle of internal friction of dam concrete requis in nonlinear response according to the Drucker-Prager model (Drucker and Prager 1952) are taken as 2.50 Mpa and 35°, respectively.

Table 1. Material properties of Oued Fodda gravity dam.

Material	Material properties		
	Modulus of elasticity (MPa)	Poisson's ratio	Mass density (kg/m^3)
Dam	24600	0.20	2640
Foundation	20000	0.33	2000

3.2. Finite element modeling of dam-foundation rock system

This study considers two-dimensional finite element model of Oued Fodda concrete gravity dam (Fig. 3). In this model, if the height of the dam is indicated as "H", the foundation rock is extended as "H" in the gravity direction. Besides, foundation rock is extended as "2H" in the width direction. The effect of hydrodynamic pressure is incorporated in the analysis by the added mass concept proposed by Westergaard (1933). The solid finite elements (Plane 82) are used to model the dam and the foundation rock; the structural mass finite elements (Mass 21) are used to model reservoir water. In the finite element model, dam body has 240, and foundation rock has 260 solid finite elements. Besides, reservoir water has 20 structural mass finite elements. 10 contact-target element pairs are employed to model the joints along dam-foundation rock interface. The surface-to-surface contact elements based on the Coulomb's friction law are used to describe the friction. These contact elements use a target surface (Targe169) and a contact surface (Conta172) to form a contact pair.

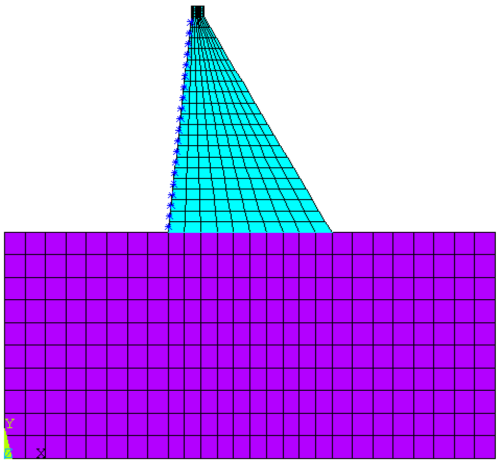

Fig. 3. Finite element modeling of dam-foundation rock system.

4. Nonlinear seismic response of Oued Fodda dam

This study investigates the seismic response of Oued Fodda concrete gravity dam considering base sliding. For this purpose, the 2003 boumerdes earthquake horizontal component with peak ground acceleration (PGA) 0.34 g (Fig. 4) is utilized in analyses. Nonlinear time-history analyses are performed using ANSYS (2013). The horizontal displacements and principal stress components in dam body are presented in both welded contact model and friction contact model.

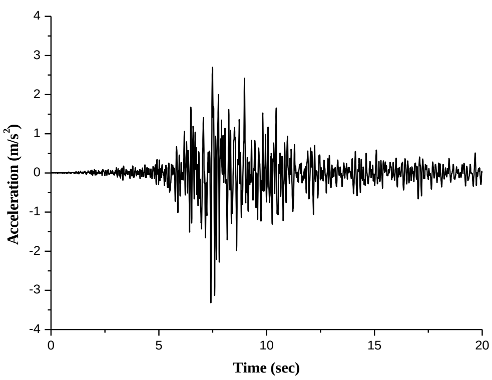

Fig. 4. Time history of horizontal component of the 2003 boumerdes earthquake.

4.1. Displacements

The envelopes of maximum horizontal displacement of the dam are presented in Fig. 5 for welded and friction contact models. Horizontal displacements obtained from friction contact model are slightly smaller than ones obtained from welded contact model. It can be seen in Fig. 5(b) that dam can slide along its foundation having the motion of rigid body in its response. When friction contact is applied at dam-foundation rock interface, sliding phenomenon of dam base is occurred, which is resulted from shear failure.

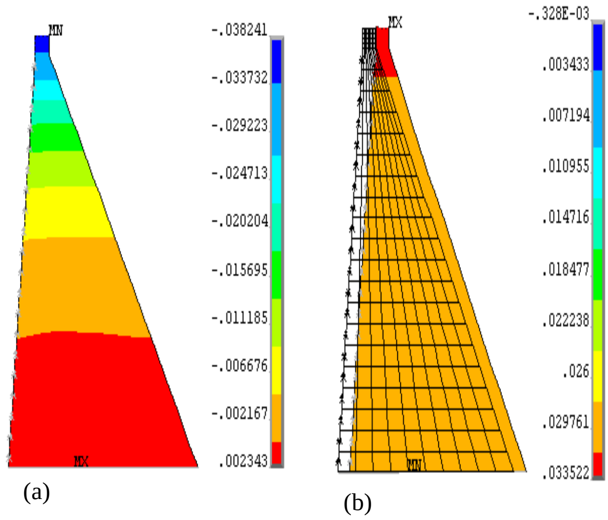

Fig. 5. Maximum horizontal displacement envelopes of the dam: (a) welded contact model; and (b) friction contact model (Unit: m).

Fig. 6 represents the time history of horizontal displacement at the dam crest for both two models. The horizontal displacement at the crest decreases from 3.82 cm for welded contact model to 3.35 cm for friction contact model. On the other hand, the time history of sliding displacement at the dam heel is depicted in Fig. 7. The sliding displacement at the heel is negligible (0.32 cm) for welded contact model, while this is 3.23 cm for friction contact model due to existence of contraction joints along dam-foundation rock interface decreasing the contact zone rigidity.

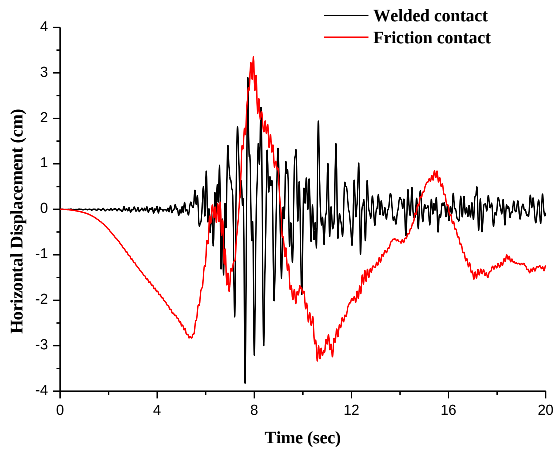

Fig. 6. Time history of horizontal displacement at dam crest for welded and friction contact models.

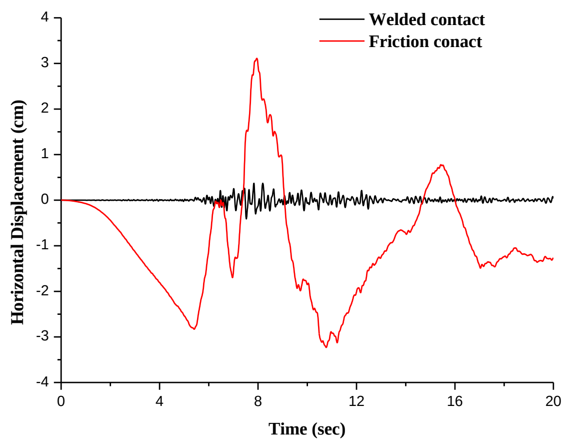

Fig. 7. Time history of sliding displacement at dam heel for welded and friction contact models.

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