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Overturning response analysis of free-standing intake tower subjected to seismic pulses

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ABSTRACT: In this paper, dynamic response of free-standing intake tower is investigated by using the Abaqus software. Briones intake tower is selected and it is modeled in two free-standing and anchored conditions that in the former state, three different frictional conditions are considered between the tower and its foundation. The friction coefficients include: 1)μ=0.58; 2)μ=1.73; 3)μ=∞. The intake towers are modeled 3D in three dry, submerged and semi-submerged states and water-structure interaction is considered by Eulerian-Lagrangian approach. In order to validate the models, the numerical responses of rigid and flexible blocks under seismic load are compared with the obtained results by other researchers. The tower overturning responses include: tower's top relative displacement, sliding, tower's base opening, which are extracted and analyzed under seismic pulses of sinus type, with three time periods of 0.5, 1 and 1.5 seconds, and intensities of 0.2g to 1.0g. It is shown that the presence of water around the intake tower has a significant effect on overturning responses. Also, the tensile stress in the free-standing state decreased by more than 70% compared to the anchored one.

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1. INTRODUCTION

Recent studies on the ancient free-standing columns that have remained stable for thousands of years, have shown that the main reason of this sustainability is the use of a special potential called rocking motion. The research by Housner [1] in 1963 was the beginning of an extensive research on the problem of the overturning of free-standing blocks. Konstantinidis and Makris [2], in2010 , studied the free-standing blocks experimentally, using shaking table, as well as numerically, and extracted the overturning spectrum of the block under pure rocking and sliding motion. In 2014, Vassiliou and Mackie [3] examined the flexibility of free-standing blocks. They found that the intensity and period of the seismic pulse as well as the flexural vibration of the blocks play an important role in their overturning or stability. Intake towers are flexible structures those interaction with reservoir was initially investigated by Liaw and Chopra [4] 1973 as the beginnings of extensive research on this issue. In 1988, Chopra and Goyal [5] presented a method for analyzing the seismic response of intake towers with optional geometry, but with two axes of symmetry in plan, and considering the effects of water-tower and foundation–tower interaction.

In this study, intake tower is modeled by Abaqus in submerged, semi-submerged and solo states with friction coefficient of 0.58, 1.73 and ∞ and overturning responses have been investigated. For solving governing equations on water and structure, Lagrangian and Eulerian approaches are used. The friction coefficient is modeled by Coulomb friction method.

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2. BOUNDARY CONDITION FORMULATION

The boundary conditions are shown in "Fig.1", each of which is described below.

There is no water flow at the interface of the water and tower. This assumption is based on the fact that the surface of the tower is impermeable and leads to a condition that there is no relative velocity in the direction perpendicular to a common boundary between the tower and the water, or in mathematical language:

$$\alpha_n^s = -\frac{1}{\rho}\bar{\nabla}P.\vec{n} \tag{1}$$

At the free surface of the reservoir, the hydrodynamic pressure value is zero, based on which surface waves are neglected in modeling. The Sommerfeld boundary condition is one of the most common ones, which is used at the end of the reservoir to absorb pressure waves going away from the system.

$$\frac{\partial P}{\partial n} = -\frac{1}{C}\frac{\partial P}{\partial t} \tag{2}$$

Where n is the normal vector on the end boundaries of the reservoir [6]. The interaction between contact surfaces

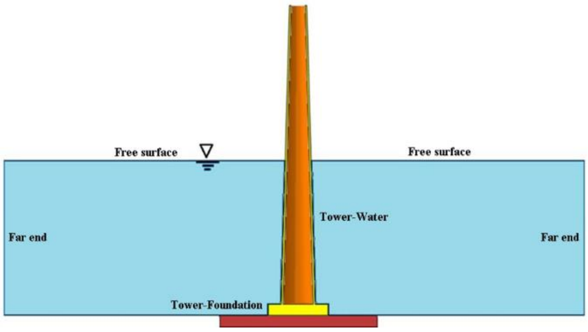

Fig. 1. Boundary conditions of the tower and reservoir

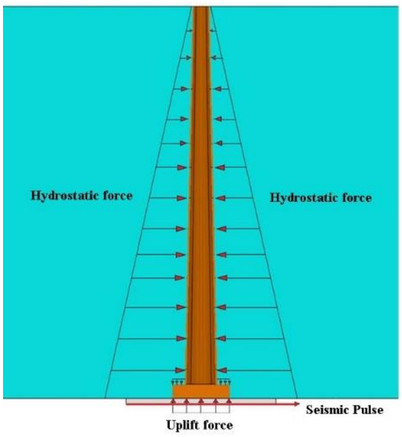

Fig. 2. Loading on the submerged intake tower

Table1.The elastic properties of concrete

unit	value	property
GPa	31	Young'modulus
-	0.17	Poisson ratio
Kg/m3	2430	Mass density

Table2.The properties of water

unit	value	property	
GPa	2.07	Bulk modulus	
Kg/m3	1000	Mass density	

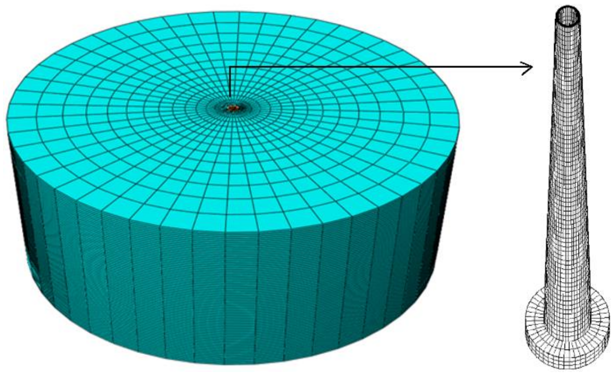

Fig. 3. Finite element model of submerged intake tower

consists of two components: a normal interaction that acts perpendicularly to the surfaces in contact and a tangential interaction that can lead to a relative sliding motion between two adjacent surfaces. The interface between the bottom of the tower and its foundation is modeled by Coulomb friction method, based on which two contact surfaces can transmit certain values of shear stresses before sliding motion begins [7]. In this model, when the sliding motion starts the final shear stress as part of the pressure contact between the two surfaces is described as follows:

$$\tau_u = \mu.\sigma. \tag{3}$$

3. MODELING: GEOMETRY AND LOADING

Briones tower is selected to examine and analyze overturning responses to seismic pulse. In order to simplify the problem, the reinforcement and its structural fittings are neglected in the modeling. In addition, to model the frictional interaction of concrete with soil and rock below it, effective frictional angles of 30 and 60 degrees respectively, which is equivalent to friction coefficient of 0.58 and 1.73, respectively are used. An infinite friction coefficient is also considered to investigate the effect of micro piles.

The tower is made of concrete with material properties according to "Table 1". the loading consists of two static and dynamic steps. The static loading includes the weight of the tower, uplift and hydrostatic load due to the water and the dynamic loading includes seismic pulses. "Fig.2" shows the loading diagram of the intake tower schematically.

The fluid properties are stated in "Table 2 ".

The finite element models of the tower in the submerged state is shown in "Fig. 3". The number of acoustic elements of the surrounding water in the submerged state is 51981.

4. CONCLUSIONS

1- maximum values of the relative displacements of the submerged and anchored intake tower are increased by 38%, 80% and 230% for the period of 0.5s, 1s and 1.5 s, respectively in comparison with the solitary and anchored tower.

2-Increasing the friction coefficient between the bottom of the tower and the underlying foundation, the top relative displacement and the base joint opening displacement are increased; however, the base joint sliding displacements are decreased

3- Overturning responses are increased by increasing the intensity and period of pulses.

4- When the tower is anchored, the contours of the maximum tensile stress are mostly located in the lower half of the tower's height but, for the solitary and semi-submerged free-standing towers, they extend from the lower half of the tower's height to the middle of its height; furthermore, the mentioned contours are advanced to the upper half of the submerged free-standing tower.

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