Seismic performance evaluation of free-standing intake tower using incremental dynamic analysis

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ABSTRACT

Intake towers form the entrance to the reservoir spillway or diversion system and thus play a key role in the seismic resistance of the whole system. safety and proper functioning of the intake towers in the event of a major earthquake is very important, since the release controlled by the reservoir can help to prevent the failure of the dam after an earthquake by reducing the water pressure. In addition, the current seismic assessment based on linear elastic constitutive model cannot adequately describe the seismic capacity of intake towers. Thus, to investigate the proper functioning of intake towers in the event a earthquake, it is necessary to introduce IDA that takes into fully assess the seismic performance of intake towers based on nonlinear dynamic analysis. In this paper by modeling the intake tower of the Briones dam, intake tower in three conditions of the intake tower, the intake tower-reservoir (outside water) and the tower-reservoir-inside water, under the influence of 12 earthquake records, each of which has a magnitude of seven in the earthquake intensity scale, has been investigated. The displacement at the top of the intake tower, damage of the intake tower body and the maximum tensile stress of the rebar in the intake tower were studied in all the three condition are considered as damage measure (DM), and the results were reported in the form of IDA curves. Then based on the results, the function and different limit-states (key points) of the intake tower structure are determined.

KEYWORDS

Intake tower, Seismic performance, seismic capacity, Incremental dynamic analysis, Nonlinear behavior

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Introduction

Safety and proper functioning of the intake towers in the event of a major earthquake is very important, since the release controlled by the reservoir can help to prevent the failure of the dam after an earthquake by reducing the water pressure. The seismic response of intake towers is always a topic of considerable interest. Goyal and Chopra developed a simplified procedure to calculate the added masses accounting for the hydrodynamic interaction of water inside and outside the tower, and the structure-foundation interaction, and it was shown that the structure–foundation interaction had a significant effect on the structural vibration mode [1, 2]. Cocco et al developed a nonlinear static method (capacity spectrum method) to assess seismic performance of intake towers, which, however, did not take into account the seismic capacity of hoist chambers [3]. Incremental dynamic analysis (IDA) is an emerging method that offers a thorough estimation of the seismic demand and limit state capacity of a structure [4]. IDA involves performing nonlinear dynamic analyses of a prototype structural system under a suite of ground motion records, each scaled to several intensity levels designed to force the structure all the way from elastic response to final global dynamic failure. Alembagheri and Ghaemian used IDA to determine the seismic performance and different limit states of hydraulic structures, such as gravity and arch dams [5-7]. Mahmoodi et al used IDA to determine the seismic performance and different limit states of cement dams [8].

In this paper by modeling the intake tower of the Briones dam, intake tower in three conditions of the intake tower, the intake tower-reservoir (outside water) and the tower-reservoir-inside water, under the influence of 12 earthquake records, each of which has a magnitude of seven in the earthquake intensity scale, has been investigated. The displacement at the top of the intake tower, damage of the intake tower body and the maximum tensile stress of the rebar in the intake tower were studied in all the three condition are considered as damage measure (DM), and the results were reported in the form of IDA curves. Then based on the results, the function and different limit-states (key points) of the intake tower structure are determined.

Numerical modeling and Methodology

The intake tower of Briones dam was modeled in 3D in Abaqus software. This reinforced-concrete intake tower, is approximately 70.1 m high, has a hollow circular cross-section of outside diameter of 6.92 m near the base and tapering to a diameter of 3.52 m at the top. The wall thickness is 0.41 m at the base, decreasing to 0.32 m near the top. The tower is supported on a 4.0 m high solid concrete block which has a diameter of 18.3 m at the ground level (Figure 1).

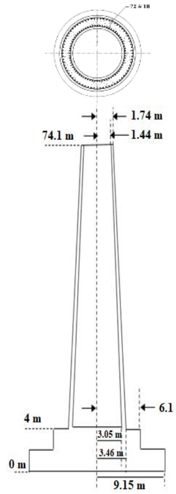


Figure 1. Two-dimensional cross-section and plan of the Briones dam intake tower

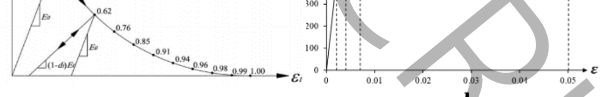
The water in the reservoir surrounding the tower is idealized as a fluid domain that extends to infinity in all radial directions and has a constant depth of 61.3 m. The height of the water inside and surrounding water it is considered the same.

The tower is made of with material properties according to Table 1.

Table 1. Static material parameters

Material	Density (kg/m^3)	Young modulus (GPa)	Poisson ratio
Concrete	2430	31	0.17
Steel	7850	200	0.3
Water	1000	2.2(Bulk modulus)	-

The considered nonlinear behavior of concrete and steel in this study is shown in Figure 2. Also the considered linear behavior of concrete compressive stress.



a b

Figure 2. Considered nonlinear behavior for concrete and steel. a) Concrete b) Steel

The whole FEM model was including 3D solid elements for intake tower, truss elements for rebar, and acoustic elements for water, as shown in Figure 3.

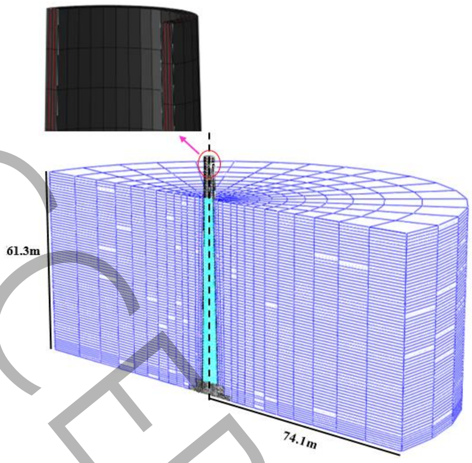


Figure 3. Whole finite element mesh

The loading consists of two stages, static and dynamic. Static loading includes the weight of the tower and hydrostatic load caused by water, and dynamic loading includes the longitudinal component of the earthquake record, which is applied as a boundary condition of the acceleration type to the bottom of the structure.

Twelve earthquake records (Table 2) matched with standard design response spectrum were selected from Pacific Earthquake Engineering Research (PEER)[2] strong motion database.

Table 2. **Selected earthquake records**

No.	Earthquakes	Name	Magnitude (M)
1	Kern County, 1952	KCTAF	7.4
2	Kern County, 1952	KCLIN	7.4
3	Imperial Valley, 1940	IVELC	7
4	Imperial Valley, 1979	IVPTS	6.5
5	Loma Prieta, 1989	LPAND	6.9
6	Loma Prieta, 1989	LPGIL	6.9
7	Loma Prieta, 1989	LPSTG	6.9
8	Morgan Hill, 1984	MHG06	6.2
9	San Fernando, 1971	SFPAS	6.6
10	San Fernando, 1971	SFPPP	6.6
11	Northridge, 1994	NRSAN	6.7
12	Northridge, 1994	NRCOM	6.7

CONCLUSIONS

1. An incremental dynamic analysis method is proposed for assessing the seismic performance and capacity of intake towers based on performance-based seismic design in this study. The IDA results can be used to quantitatively determinate the seismic limit states of the intake tower.

2. Twisted Pattern IDA curves have a wave motion around the elastic slope that follows the law of equal displacements. The twisted pattern of these curves includes successive sections of hardening and softening at different levels of earthquake intensity.

3. The first damage occur in the cases of intake tower alone and intake tower-reservoir at the spectral acceleration level of 0.2g and in the case of intake tower- reservoir-water inside the intake tower at the spectral acceleration level of 0.1g. The first tensile damage created in the body of the intake tower and at these levels of earthquake intensity is caused in the connection section of the intake tower with solid concrete block.

4. Vertical cracks are mainly caused by the earthquake intensity level of 0.3 and 0.4g between horizontal cracks.

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