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Seismic analysis of prestressed concrete cylindrical tanks

A. Shokoohfar [1*], M. Rahai [2], A. Sahrai [3]

[1] Assistant Prof , Faculty of Civil Engineering, Qazvin branch, Islamic Azad University, Qazvin, Iran.
[2] MSc of Structural Engineering of Amirkabir University. of Technology,Tehran, Iran.
[3] MSc of Structural Engineering of Amirkabir University. of Technology,Tehran, Iran

ABSTRACT: The seismic responses of the water-filled prestressed concrete cylindrical tanks have been investigated under earthquake inputs. A series of dynamic-explicit analyses have been performed to study water sloshing phenomena effects on the prestressed concrete tank behavior using ABAQUS software. A shaking table test program has been conducted to validate the numerical analysis. Additionally, the numerical analysis capability to simulate the sloshing waves has been verified using mathematical results. Several numerical models have been prepared with different radius to water height ratios (R/H). The recorded El-Centro, Tabas and Bam accelerations have been employed as the seismic loading in the numerical models. The comparison between the experimental and theoretical results with numerical outcomes demonstrates a reasonable agreement. The seismic excitation effect on the prestressed tendons loss is negligible in the investigated numerical models.

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1. INTRODUCTION

These Prestressed cylindrical tanks are being commonly utilized to store a large volume of water or other various fluids. Damage in the tanks can be considered from economic and environmental points of view. The water resource tanks as a part of the fire-fighting system play a crucial role in risk management. The water sloshing effects may cause a defect in the efficiency of prestressed concrete tanks during earthquake events [1]. Several experimental, analytical and theoretical studies have been performed to describe sloshing phenomena [2]. The Navier-Stokes equations govern the flow inside the tank, but some assumptions such as inviscid or incompressible fluid and irrotational motion have been considered [3]. Panigrahy et al. conducted an experimental program to study the baffle effects on sloshing behavior of rectangular tanks [4]. Ji et al. investigated large lateral oscillation on non-resonant sloshing through a test program [5]. Lacapere et al. carried out an extensive experimental and numerical study on cryogenic liquids storage tanks [6]. Li et al. explored the seismic behavior of prestressed egg-shaped tanks using a shaking table test program and nonlinear numerical analysis with the help of ANSYS software [7].

2. VERIFICATION OF THE DYNAMIC/EXPLICIT ANALYSIS VIA BARRIOS ET AL STUDIES

Barrios et al. developed the Finite Differences Method (FDM) to devise an advanced timesaving numerical method for nonlinear sloshing analysis[8]. They generated Semi-implicit and Crank-Nicholson algorithms and applied them to analyze the sloshing response of rigid cylindrical tanks under the acceleration records of the Mexico earthquakes. A cylindrical tank with radius and water height equal to 5.5 m and 2.5 m are selected among the Barrios et al. numerical examples to verify the applied FE approach in this paper. The semi-implicit method is investigated under the north-south component of the Ciudad Universitaria acceleration record (CU-NS), and the Crank-Nicholson method is considered under north-south and east-west components of the Central de Abasto (CA) acceleration record. The maximum wave height amplitude is about 254 mm and 210 mm for Semi-implicit Dynamic/Explicit methods, respectively.

Divided the Crank-Nicholson method to linear and nonlinear scheme which is referred to linear and nonlinear wave theory [8]. The maximum wave height is about 1740 mm and occurs at 98.75 s in the nonlinear Crank-Nicholson method for the CA-NS record. The corresponding values are 2110 mm and 106.853 s for the Dynamic/Explicit analysis. In fact, the maximum wave height is 2600 mm in the linear Crank-Nicholson method, so it can be inferred that the wave height results of the Dynamic/Explicit analysis are closer to the results of the nonlinear scheme. The Crank-Nicholson solution process failed to continue under the CA-EW acceleration record at t=81.05 s. The Crank-Nicholson schemes use an artificial numerical viscosity to converge the numerical solutions in the responses close to the resonance. Since the dominant period of the EW component is closer to the main sloshing period, the artificial viscosity should be

*Corresponding author's email: ahmad.shokoohfar@qiau.ac.ir

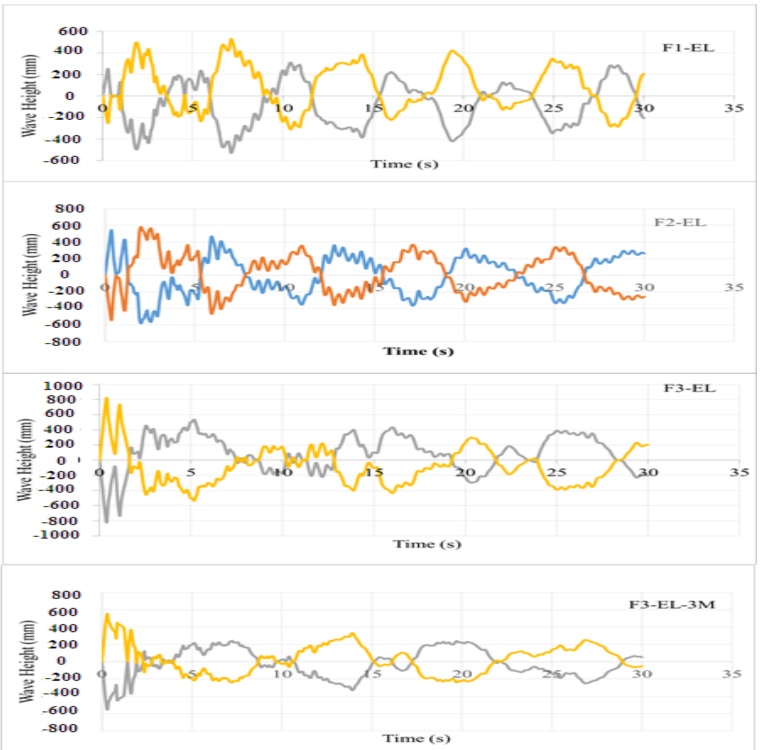

Fig. 1. Wave height history under El-Centro acceleration record.

Table 1. Maximum sloshing wave height in numerical models

Model	F1-EL	F2-EL	F3-EL	F3-EL-3M
Max. Wave Height (mm)	529.76	582.08	824.12	554.67
Occurrence Time (s)	7.12	2	0.38	0.3

amplified to achieve complete results. However, the ABAQUS nonlinear analysis can be carried out to the last moment of the acceleration record but the analysis is very time-consuming. A trustable response of the Dynamic/Explicit method heavily depends on how the selected time increments are small. Naturally, the small-time increments lead to a time-consuming analysis. Also, the time or mass scaling techniques for reducing the analysis time cause large errors and numerical divergence. The maximum wave height is about 2390 mm and occurs at 62.21 s in the Crank-Nicholson method for the CA-EW record. The corresponding values are 2530 mm and 73.38 s for the Dynamic/Explicit analysis. The comparison of results shows good agreement between the current research method and Barrios et al.'s numerical study.

3. DYNAMIC/EXPLICIT MODEL PROPERTIES

SAP 2000 software has been applied to design the numerical model in three ratios of radius to maximum water level (R/H=2,3 and 4) (SAP 2000 Manual, 2015). The mesh size in the tank wall design varies from 275 ×1120 to 275×2240 mm^2 as a result of different R/H ratios. Shell elements have been implemented to model the prestressed concrete containments in SAP 2000 software. The design process includes two stages. The concrete tank has been considered under hydrostatic and hydrodynamic loads to obtain the maximum internal forces and determine the number of tendons and reinforcing bars in the first stage. The seismic base shear of 4483.4 kN, 7580.98 kN and 10690.34 kN have been considered for "F1", "F2" and "F3" models, respectively. The determined tendons have been added to the tank model for controlling the service limits in the second stage.

4. RESULTS AND DISCUSSION

Seismic response analyses were performed under the north-southern component of El-Centro acceleration record for EL-Centro station in May 1940.

The last chart of Fig. 1, show the wave height history of the semi-water filled F3 cases to study seismic performance of the most critical cases with lower water level.

Table 1 summarizes the sloshing wave height results. The maximum sloshing wave height belongs to the model "F3-TAB," and it is about 850 mm occurred in 1.39 sec of the EL-Centro acceleration record. The Numerical results demonstrate that sloshing wave height increases in the higher R/H ratios.

5. CONCLUSIONS

Increasing the R/H ratio leads to a reduction in the upper limit of the maximum envelope and lower limit of the minimum envelope of the tendon stresses. The jumping value of the upper limit of the maximum envelope in the "F3-EL" models are related to developing the tensile structural damage in concrete tank walls. Generally, the nonlinear dynamic/explicit analysis of the prestressed tanks under the selected acceleration records demonstrates that the seismic prestress losses are negligible.

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