JSEE *Vol. 23, No. 4, 2021* *DOI: 10.48303/jsee.2023.1989274.1049*

Research Paper

3D Sloshing of Concrete Cylindrical Tanks under Seismic Conditions

***Mohammad Rahai*[1]*, Ahmad Shokoohfar*[2*]*, Alireza Rahai*[3] *and*
***Mostafa Iraniparast*[4]

1. M.Sc. Graduate in Earthquake Engineering, Department of Civil Engineering, Sharif University of Technology, Tehran, Iran
2. Assistant Professor, Department of Civil Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran, *Corresponding Author; email: ahmad.shokoohfar@qiau.ac.ir
3. Professor, Department of Civil Engineering, Amirkabir University of Technology, Tehran, Iran
4. Ph.D. Student, Department of Civil Engineering, University of Central Florida, Orlando, FL, USA

Received: 06/02/2023
Revised: 09/04/2023
Accepted: 24/04/2023

ABSTRACT

This study aimed to explore the seismic responses of the water-filled prestressed concrete cylindrical tanks. To this end, a number of dynamic-explicit studies are carried out in order to investigate the implications that the water sloshing phenomenon has on the behavior of the prestressed concrete tank when it is subjected to earthquake inputs. Using previous research demonstrates that our numerical analysis is capable of representing the sloshing waves. In addition, a shaking table test is carried out to verify the accuracy of the numerical analysis. The main highlight of the numerical simulation method is to consider all components and elaborate detailing of prestressed tanks. The novelty of this study is to model the 3D sloshing of the liquid in the prestressed concrete tanks. Comparing the experimental and numerical results demonstrates a reasonable agreement between them. Also, in this research, the dynamic-explicit method is applied accompanying the Arbitrary Lagrangian-Eulerian (ALE) adaptive meshing to enhance the numerical model for nonlinear sloshing wave simulation. An experiment is performed on a prestressed concrete containment sample in the shaking table of the Amirkabir University of Technology to assess the efficiency of numerical analysis. The numerical results show the robustness of the water simulation method in which almost shows realistic motions of water mass points in the ALE method.

Keywords:
Seismic Excitation; Water Sloshing; Prestressed Concrete; Water Tank; Shaking Table Test

1. Introduction

Prestressed Concrete cylindrical tanks are utilized to store a variety of liquids in various sectors (e.g., in the oil and gas industry, nuclear power plants, and water supply facilities) and have a key role in human lives. Tanks that undergo damage may lose their liquid contents, which could result in economic losses and could also potentially pollute the surrounding area over the long run. In addition, water storage tanks are an important element of a city's fire-fighting infrastructure and serve a crucial function in urban areas. Because of the potential dangers of their collapse, the seismic response of cylindrical storage tanks has been the subject of a great deal of research. As a result, the safety of liquid storage tanks through an earthquake is important and a lot of research has been done on the topic.

During earthquakes, the effects of water sloshing about inside the tank might reduce the effectiveness of the tank made of prestressed concrete (Virella, Prato, & Godoy, 2008). Concerning the sloshing problem, simulating the fluid's free surface is a crucial topic that must be addressed. There have been a few different approaches taken to approximating the free-surface (Rebouillat & Liksonov, 2010). As stated by (ASCE, 1984) the influence of tank flexibility does not modify the pressure distribution on the walls for the sloshing component of cylindrical steel tanks. This was because there were substantial differences between the basic periods of the earthquake excitation and the durations that were required to generate sloshing waves. Consequently, the assumption of a rigid tank is a good approximation to use when calculating hydrodynamic pressures in cylindrical tanks caused by the sloshing component of the liquid. The seismic response of above ground floating roofed steel tanks, with deformable walls and fully anchored at their base, is studied numerically in (Ozsarac, Brunesi, & Nascimbene, 2021). The main advantage of the system is that it controls the sloshing of the stored liquid and reduces the maximum wave height under seismic excitation, thereby preventing/ minimizing possible liquid spillover, as well as potential sloshing-related damage and sink of floating roof. The flexibility of the tank can enhance the sloshing response, as found by Koh et al. (1998), who in-vestigated the dynamic response of three-dimensional (3D) liquid storage rectangular concrete tanks using linear wave theory. A reaction that was comparable to that of the rigid tank was seen for the tanks with the thicker wall thickness. Estekanchi & Alembagheri (2012) used the endurance time (ET) approach for seismic analysis of steel tanks, and their findings were compared to conventional codification design methods. The provided method was shown to be beneficial in assessing the seismic reactions of both anchored and unanchored steel tanks. Hashemi et al. (2013) presented analytical solution methods for the analysis of the dynamic behavior of a partially filled three-dimensional fluid container when subjected to horizontal ground seismic excitation. Additionally, a simplified model was proposed for evaluating the pressure along the walls of a two-dimensional tank. Both of these contributions can be found in the paper. To validate numerical models for seismic FSI analysis in finite element codes, a comprehensive set of experiments was performed on a liquid-filled cylindrical vessel in (Mir, Yu, & Whittaker, 2020). Results in terms of sloshing frequency, damping ratio in sloshing modes, and hydrodynamic responses for multi-directional earthquake simulator inputs are reported and compared with analytical solutions for liquid-filled vessels.

Various analytical methods such as Smoothed Particle Hydrodynamics, hybrid finite element explicit finite element (Moslemi & Kianoush, 2012), implicit Lagrangian-Eulerian (Rawat, Mittal, Chakraborty, & Matsagar, 2019) and volume of fluid (VOF) are suggested for analyzing fluid structure interaction problems (Eswaran & Reddy, 2016). Edwards (1969) was the first person to propose using a technique based on finite elements to estimate the seismic response of ductile liquid storage tanks. The finite element method was applied to the study of a tank for the storage of liquids that was cylindrical in shape and had a height to diameter ratio that was less than one. The FE model that was presented was capable of taking into consideration the coupled interaction that occurred between the liquid that was being stored and the elastic tank shell. Moslemi & Kianoush (2012) studied the dynamic behavior of cylindrical tanks by focusing on the interaction between effective parameters on the dynamic response. Nicolici & Bilegan (2013) investigated the impacts of combined implications of computational fluid dynamics (CFD) analysis and the FE stress analysis on the sloshing that occurs in a cylindrical tank. Recent research conducted by Eswaran and Reddy (2016) utilizes partitioned strong fluid-structure coupling as a means of achieving two-way mechanical contact of both a fluid and a structure. They used the VOF modeling technique to represent the free surface of the liquid. In their investigation, the fluid was analyzed using the finite volume approach, while the structure was analyzed using the finite element model (FEM). In the FEM study of tanks with rigid and flexible walls and variable parameters, Rawat et al. (2019) employed a coupled acoustic-structural (CAS) method as well as a coupled Eulerian-Lagrangian (CEL) method.

Lin & Zhang (2017) presents a safety analysis for a of the prestressed concrete containment vessels (PCCVs) under strong earthquake excitations. They evaluated safety of these structures based on the two specified limit states include service and ultimate states. Their numerical analysis result proves that the Chinese PCCVs remain in service limit state for the acceleration record with peak ground acceleration (PGA) range from 0.8 g to 1.1 g, and pass the ultimate state for PGAs 1.2 g to 1.7g. Song et al. (2017) focused on passive containment cooling system (PCS) of the PCCVs. They performed an innovative numerical analysis with considering fluid structure interaction (FSI) in the water tank and soil structure interaction (SSI) in overall system. According to the findings, the FSI impact cannot be used to reduce the seismic response in a simple method; rather, it should be included in the design and analysis of structures. They proposed a simplified method to consider FSI for design purposes based on the numerical results of the finite element models.

In this research, the dynamic-explicit method is applied accompanying the ALE (Arbitrary Lagrangian-Eulerian) (Rebouillat & Liksonov, 2010) adaptive meshing to enhance the numerical model for nonlinear sloshing wave simulation. An experiment is performed on a prestressed concrete containment sample in the shaking table of Amirkabir University of Technology to assess the efficiency of numerical analysis. The numerical method is verified based on other valid studies in this domain.

2. FE Modeling Approach

ABAQUS software has two main modules ABAQUS / Standard and ABAQUS / Explicit for problem analysis. The ABAQUS / Standard module is a general finite element instruction that can analyze various linear or nonlinear problems, including the static, dynamic, electrical response, or thermal of the components of a model. ABAQUS/ Explicit module is a special instruction for solving finite element problems that uses explicit dynamic method in numerical solution. This method is suitable for analyzing transient and short dynamic problems such as collisions and explosions. ABAQUS Explicit package is used in this study in order to perform dynamic analysis.

C3D8R element is used for concrete part, which is compatible with all analyzes. The interaction between concrete and rebar is specified using the Embedded Region technique, which is enabled by the usage of the T3D2 element to represent common and pre-stressed rebars. To model the prestressed reinforcing, a technique similar to the process of defining rebars is used, which allows the definition of Prestressing through initial conditions (Initial Condition-Type: Stress). The "Prestress Hold" Python command is used to define the post-tensioning state. It was examined several scenarios and from a special mesh size had no effect on the responses, so it ultimately took into account the largest size that had no effect on the responses.

A frictionless normal contact is applied as interaction between the outer surface of water elements and the inner surface of concrete elements. A free surface boundary condition is considered to form sloshing modes with no restrictions. The sloshing wave described by Equation (1):

$$d_S = \frac{P}{\rho g} \tag{1}$$

where P represents pressure (positive in compression), ρ is water density, and d is wave height. As a consequence of Equation (1), the sloshing waves that observed in the models are induced by gravity; hence, in the absence of gravity, no sloshing waves would arise at the liquid surface as a result of the stimulation (Virella, Prato, & Godoy, 2008).

An initial condition called "Geostatic stress" is implemented to introduce vertical and lateral hydrostatic pressures at the beginning of the Dynamic/Explicit analysis. Water self-weight is assigned to water solid elements as a body force. The lateral hydrostatic pressure of water is defined using a FORTRAN subroutine "VDLOAD" during the Dynamic/Explicit analysis. Acceleration records are applied as modified boundary conditions to the tank foundation. Because large changes in the surface of fluid may occur as it moves, it is necessary to consider deformation in the system using mesh with compatibility in the solution process in ABAQUS. Therefore, Arbitrary Lagrangian-Eulerian (ALE) adaptive meshing is used to provide the required sloshing system conditions (ABAQUS 6.14 documentation. (n.d.)). In the ALE method, computational mesh nodes, same as the Lagrangian behavioral model, can be moved with continuous mass or mass particles, and can also remain constant similar to Eulerian behavior, and the mass particles moving on the mesh grids.

The uniaxial stress-strain diagram generator model proposed by Chang and Mander has been used in the form of the concrete damage plasticity (CDP) method to define the concrete material in this research. In the definition of this generalized model, the more laboratory information, the closer the obtained stress-strain diagram is to reality (Shokoohfar & Rahai, 2016). Figure (1) presents a confined and unconfined concrete stress-strain diagram for the tank foundation and wall.

As material behavior for steel components of the numerical models, a strain rate independent plasticity model was used. The strain rate independent material may be described as follows:

$$q = \sigma^0 \tag{2}$$

where $\sigma^0(\tilde{\varepsilon}^{pl})$ is the yield stress and depends on the equivalent plastic strain. The plastic strain increase causes the yield stress to have uniform variations in all directions, which is described as isotropic hardening in reference (Abaqus 6.14 documentation. (n.d.)). Figure (2) shows the stress-strain diagram for rebar and tendon.

When high-amplitude sloshing waves shape on the liquid surface, they will have a nonlinear impact on the pressure distribution on the rigid walls, hence nonlinear wave theory must be included in the tank-liquid system's hydrodynamics. When high-amplitude sloshing waves develop on the liquid surface, this need arises. The main material properties for concrete, steel, and tendon of the RC studied tank were summarized in Table (1).

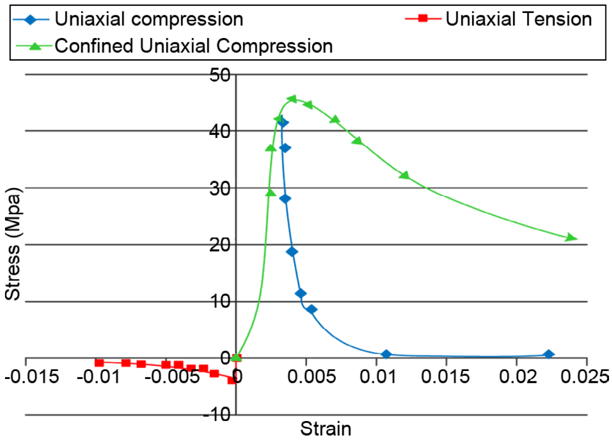

Figure 1. The Chang and Mander concrete model.

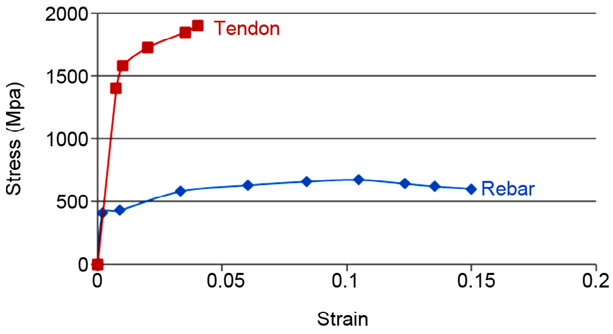

Figure 2. The stress-strain relationship of steel components.

Table 1. Material Properties.

Material	Properties	Value
Concrete	E (MPa)	32702.906
	ε_{co}	0.0022
	f_{co} (MPa)	40
	ε_t	0.00032
	F_t (MPa)	5.31
Rebar	E (MPa)	198632
	f_u	740.8867
	ε_{true}	0.002052
	ε_{pl}	0.1363
Tendon	E (MPa)	186666
	f_y	1410
	f_u	1976
	ε_y	0.00747
	ε_u	0.0392

The equations of state in the tank-liquid model provide a hydrodynamic material model that calculates the volumetric strength of the material and the pressure (which is positive in compression) as a function of fluid density and specific energy (internal energy per unit mass). The Mie-Gruniesen equations (Lemons & Lund, 1999) are linear equations of state that employ a linear relationship between the shock velocity (Us) and the particle velocity (Up).

$$P = k\eta \tag{3}$$

where $\eta = 1 - (\rho_0 / \rho)$, and ρ_0 reference density. This constitutive relation is the same as $P = \kappa\varepsilon_v$ in the acoustic medium. Introducing geometric nonlinearity into nonlinear kinematic relations is the source of the nonlinearity that is present in the model. This nonlinearity is caused by the computation of the volumetric strain. Due to the fact that water has a high bulk modulus (K = 2.07 GPa), it is nearly impossible to compress this liquid. ABAQUS recommends choosing an elastic bulk modulus that is two or three orders of magnitude lower than the real value while still assuming that the material is practically incompressible. A bulk modulus of 2.07MPa, three orders of magnitude less than the actual bulk modulus of water has been adopted here, as recommended in ABAQUS. Therefore, ρ_0 and c_0 is assumed to be 938 kg/m^3 and 45 m/s which leads to $\kappa = 2.07$ MPa. The Navier-Poisson Law is applied with a very low shear viscosity (υ = 0.0013) to simulate the shear behavior of water as an inviscid fluid based on Equation (4).

$$S = 2\nu e_p \qquad (4)$$

where S is the deviatoric stress and e_p is the deviatoric part of the strain rate [1].

3. Validation of Numerical Method

In 2007, Hernandez-Barrios proposed a numerical method for analyzing the seismic response of cylindrical tanks taking into account the effects of nonlinear hydrodynamics. The equations of motion are transferred from the physical domain to the processing domain using variable variation so that there is no need to rewrite the processing domain in the processing of progress response in time. They developed the Crank-Nicholson and Semi-implicit algorithms and used them to conduct an analysis of the sloshing response of rigid cylindrical tanks subjected to the acceleration data of the Mexico earthquakes. A cylindrical tank with a radius of 5.5 meters and a water height of 2.5 meters was chosen as one of the numerical examples provided by Hernandez-Barrios (2007)to verify the FEM approach that was utilized in this particular piece of research. This method is investigated under the acceleration records that are illustrated in Figure (3).

Figure (4) shows that the maximum wave

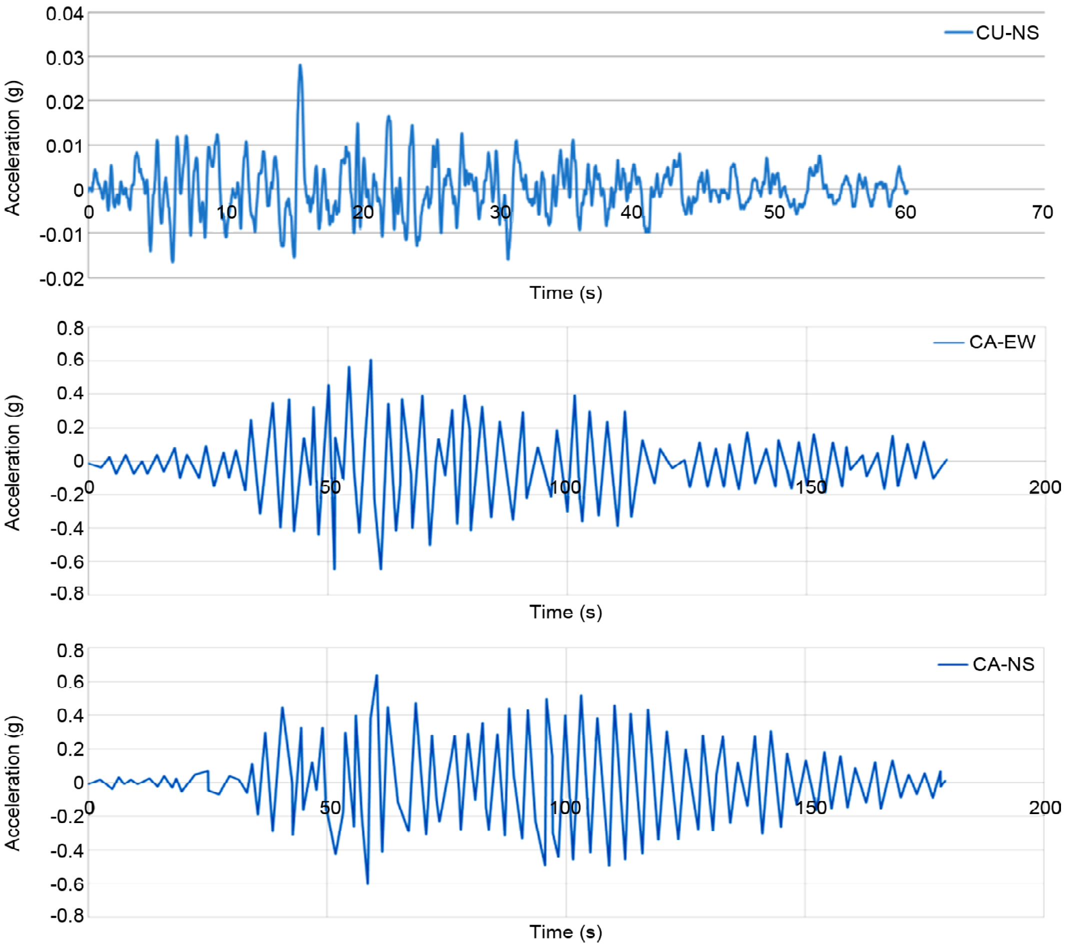

Figure 3. CU(Ciudad Universitaria) and CA(Central de Abasto) acceleration records.

height amplitude is about 250 mm and 205 mm for Semi-implicit and Dynamic/Explicit methods, respectively.

Figure (5) shows the comparison of the wave height histories in the Crank-Nicholson and the current study method. The Crank-Nicholson method was subdivided into a linear and a nonlinear scheme by Barrios et al., and these two approaches are now known respectively as linear and nonlinear wave theory (Hernandez-Barrios, Heredia-Zavoni, & Aldama-Rodraguez, 2007). Figure (5) presents the wave height history for the nonlinear scheme of the Crank-Nicholson method in the selected geometry. According to the nonlinear Crank-Nicholson method applied to the CA-NS record, the wave height that reaches its maximum at 98.75 seconds is approximately 1740 millimeters. According to the Dynamic/Explicit analysis, the corresponding values are 2110 millimeters and 106.853 seconds. In fact, the maximum wave height is 2600 mm in the linear Crank-Nicholson method, therefore it can be deduced that the wave

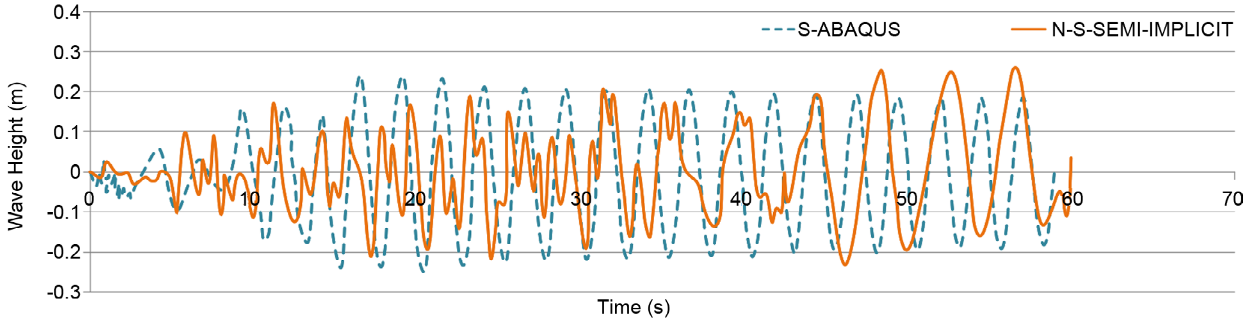

Figure 4. Wave height histories for CU-NS record.

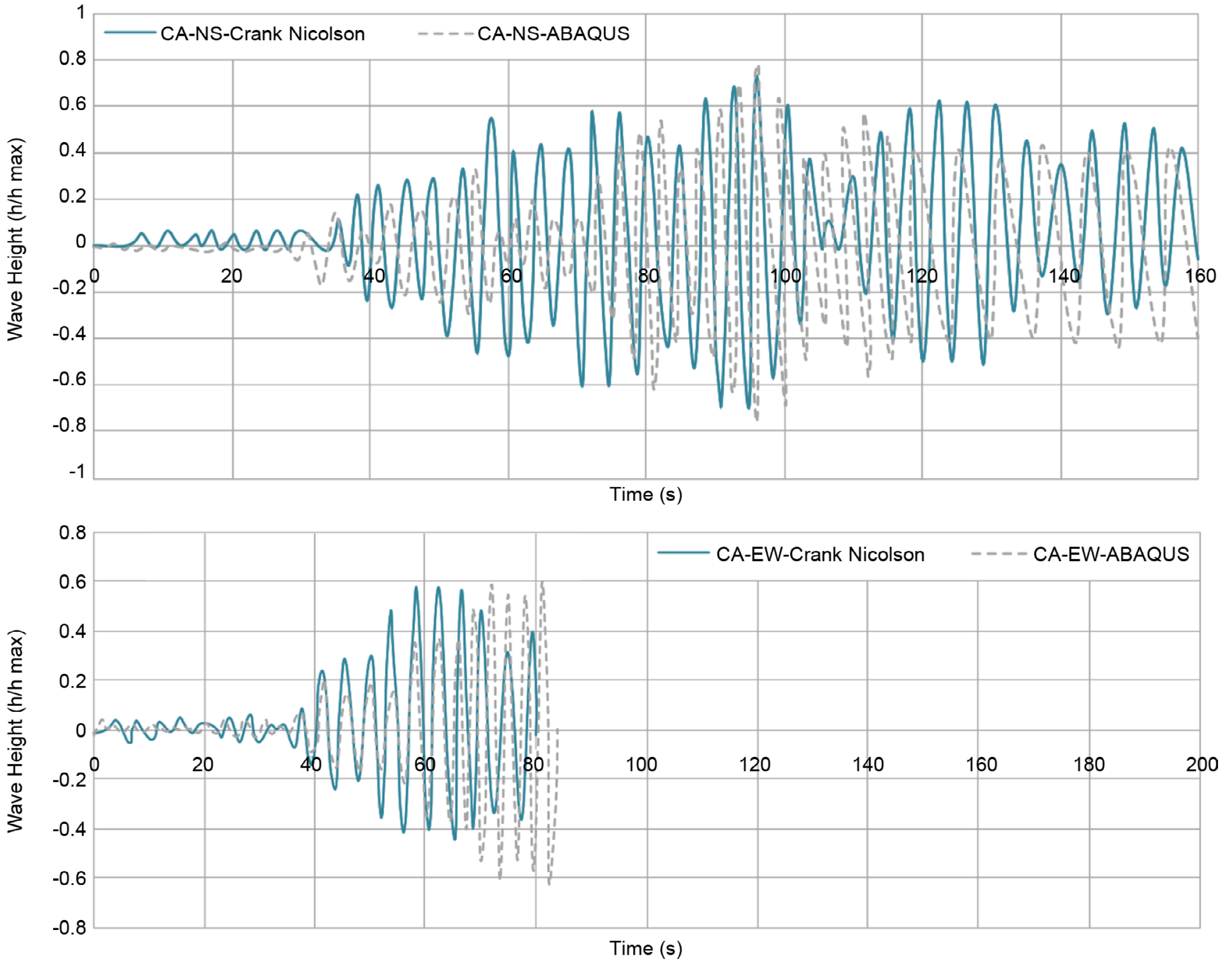

Figure 5. Wave height histories for CA records.

height results of the Dynamic/Explicit analysis are pretty close to the outcomes of the nonlinear scheme.

4. Experimental Validation

A shaking table experiment was designed to test the efficiency of the nonlinear analysis approach. A cylindrical prestressed concrete tank was constructed and subjected to several seismic records in Amirkabir University of Technology (AUT). The geometric features of the prestressed concrete tank are given in Figure (6). The post-tensioning system of the concrete tank includes six vertical and two circumferential tendons. The height of the tank wall is 1.5 meters. The tank was filled with water to one meter. The mix design of the concrete of SCC type is presented in Table (2).

The shaking table limitations led to applying artificial accelerations instead of real earthquake input data. The artificial accelerations El-1 and N-1 were employed as seismic excitations. Figure (7) presents these two acceleration records. Since the shaking table was unidirectional in one direction of input, the earthquake we experienced was also unidirectional and we also

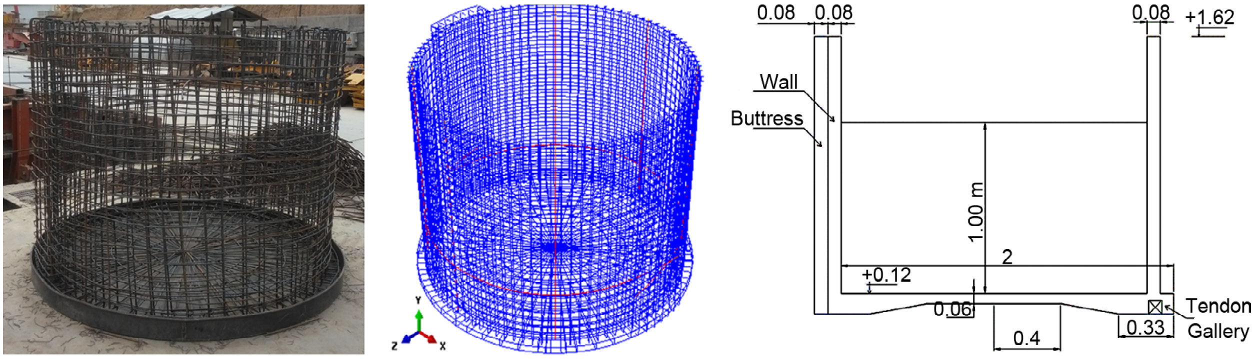

Figure 6. Geometric and Reinforcement details of the Prestressed Tank.

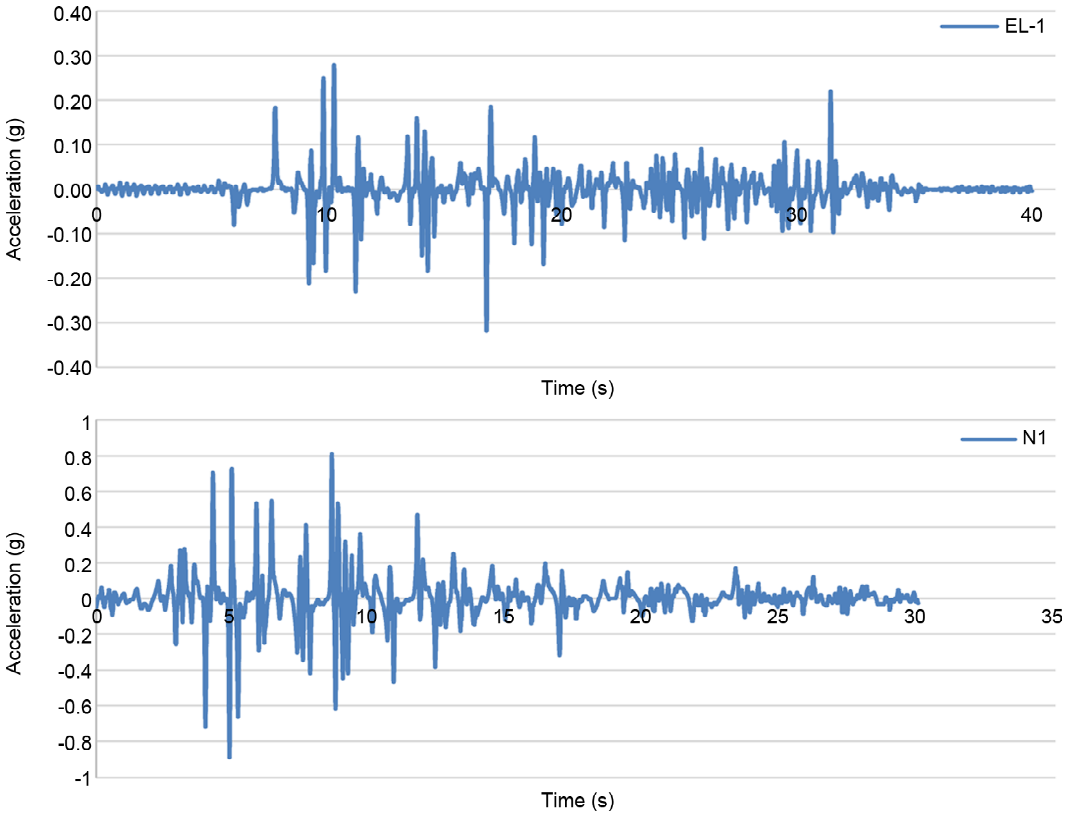

Figure 7. Artificial acceleration records for shaking table test.

Table 2. Concrete mixture.

Material (kg)	Mix Proportions (kg/m^3)
Cement	430
Fine Aggregate	985
Coarse Aggregate	643
Limestone Filler	110
Admixture	2.5
Water	163.4
Total	2334

observed it numerical model in one direction. The application of the earthquake was also in the form of acceleration with amplitude presented in the experiment. Therefore, four records were applied to the bottom of the tank.

The method used to create artificial ground motion records involves synthesizing a time history of ground motion using mathematical models that simulate the seismic wave propagation through the earth's crust. This can be done using either deterministic or stochastic methods. Deterministic methods involve modeling the earthquake source and wave propagation using known physical laws and parameters. Stochastic methods involve generating random signals that have statistical properties similar to those of real earthquake recordings. The response spectra for these artificial records can be calculated by applying a Fourier transform to the time history of ground motion and then calculating the spectral acceleration at different periods. The resulting response spectra can be compared to design spectra for the site to assess the potential seismic hazard. In this study, the shaking table used could not precisely apply the earthquake records, so the records have been adjusted and filtered by Maple software so that the device can accept them as input.

Figure (8) illustrates the numerical and experimental wave height histories under both acceleration records. As you see, due to limitations of the "Wave-Probe" detection, positive wave heights are more precise than the negative ones.

Figure (9), the positioning state of the tank sample on the shaking table was selected in a way that the maximum stress due to hydrodynamic pressure was obtained. The experimental investigations indicate that ABAQUS Dynamic/Explicit analysis is a reasonable method to simulate the seismic performance of the Prestressed concrete cylindrical tanks.

The vibration periods of a liquid storage tank

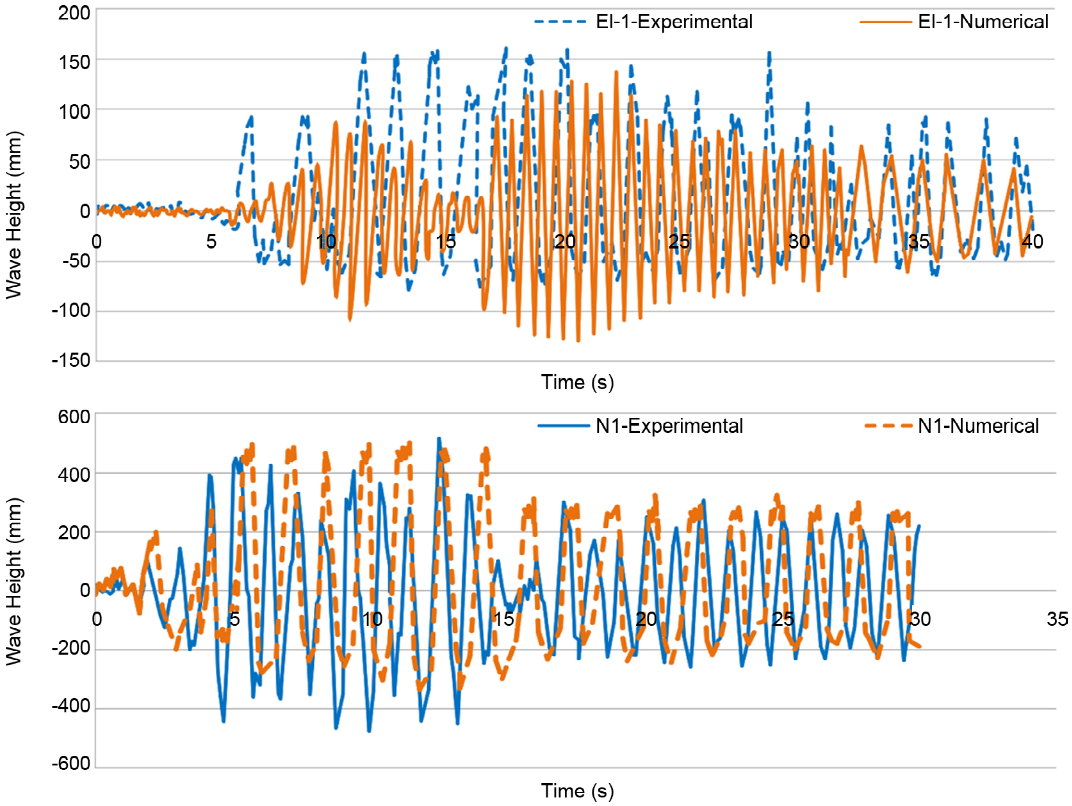

Figure 8. Nonlinear sloshing of water surface.

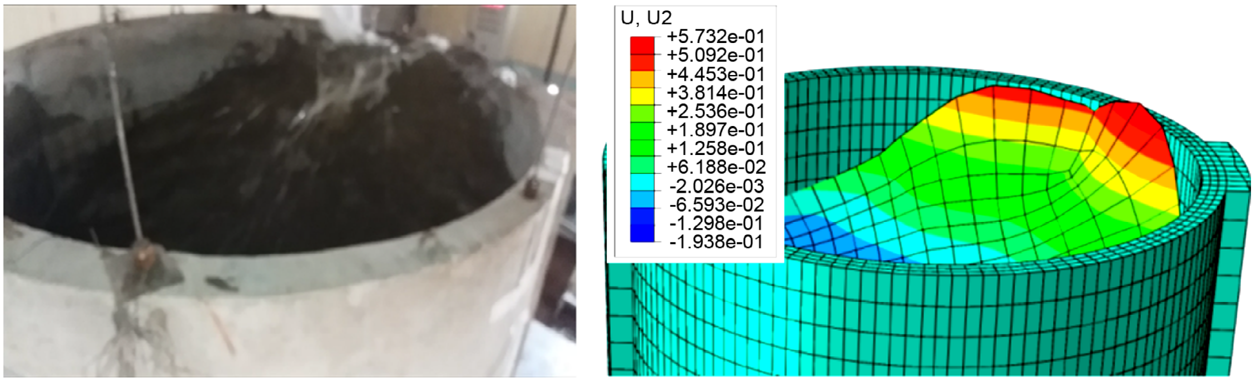

Figure 9. Maximum water height under artificial acceleration record N-1 (U2 in meters).

depend on various factors such as the size and shape of the tank, the type of liquid stored, and the level of liquid in the tank. Generally, the vibration periods range from a few seconds to several minutes. We selected the vibration period in such a way that most of the main sloshing modes are captured.

Damping is modeled in liquid storage tanks to reduce or eliminate vibrations caused by external forces such as wind or seismic activity. Damping can be achieved through various methods such as adding viscous dampers, installing energy dissipation devices, or using fluid viscous dampers. In this study, two types of damping were considered. One was defined for the water material viscosity Newtonian and dynamic viscosity was equal to 0.0013 and linear rebar viscosity parameter was 0.06, and quadratic viscosity parameter was 1.2. And the other one is related to numerical damping that was considered 0.05 defined in the software for the analysis of explicit dynamics.

5. Conclusion

Seismic responses of prestressed concrete cylindrical containments are studied using the tendon stress variation, the exerted stress because of the hydrodynamic pressure in the wall and sloshing wave height parameters. The shaking table test program was conducted on the pre-stressed concrete tank model to validate the Dynamic/Explicit nonlinear analysis. The numerical simulation method is verified using the Barrios studies (Hernandez-Barrios, Heredia-Zavoni, & Aldama-Rodraguez, 2007) and experimental results. The verification using the Barrios study results indicates that the current study's nonlinear analysis method leads to similar results as the Crank-Nicholson scheme. The experimental validation demonstrates the capability of the Dynamic/Explicit nonlinear analysis to present different sloshing wave height results under acceleration records with diverse acceleration amplitudes. Overall, by studying tendon stress variation in a pre-stressed liquid storage tank, it is possible to optimize the tank's performance and ensure its long-term integrity and durability. But any changes were not observed.

The numerical research outcomes can be stated as follows:

1. The numerical results show the robustness of the water simulation method in which almost shows realistic motions of water masses in the ALE method. The differences of the results may be caused by experimental condition errors.
2. The known methods of the Crank-Nicholson scheme and Semi-implicit methods are selected to assess the explicit/dynamic results in this domain. The results demonstrate that the results of the presented method are so close to nonlinear form of these recognized numerical methods.

References

ABAQUS 6.14 documentation. (n.d.). (n.d.). Retrieved from http://130.149.89.49:2080/v6.14/

ASCE (1984). *Guidelines for the Seismic Design of Oil and Gas Pipeline Systems*. ASCE. Retrieved from https://cedb.asce.org/CEDBsearch/record.jsp?dockey=42895

Edwards, N.W. (1969). A procedure for the dynamic analysis of thin walled cylindrical liquid storage tanks subjected to lateral ground motions. University of Michigan. Retrieved from https://worldcat.org/en/title/68278579

Estekanchi, H.E. & Alembagheri, M. (2012). Seismic analysis of steel liquid storage tanks by Endurance Time method. *Thin-Walled Structures*, *50*(1), 14-23, doi: https://doi.org/10.1016/j.tws.2011.08.015

Eswaran, M. & Reddy, G.R. (2016). Liquid sloshing in fuel storage bays of advanced reactor subjected to earthquake loading. *Procedia Engineering*, *144*, 1278-1285, doi: https://doi.org/10.1016/j.proeng.2016.05.118

Hashemi, S.S., Saadatpour, M.M. & Kianoush (2013). Dynamic behavior of flexible rectangular fluid containers. *Thin-Walled Structures*, *66*, 23-38, doi:https://doi.org/10.1016/j.tws.2013.02.001

Hernandez-Barrios, H., Heredia-Zavoni, E., & Aldama-Rodraguez, A. A. (2007). Nonlinear sloshing response of cylindrical tanks subjected to earthquake ground motion. *Engineering Structures*, *29*(12), 3364-3376, doi: https://doi.org/10.1016/j.engstruct.2007.08.023

Koh, H., Kim, J.K. & Park, J. (1998). Fluid-structure interaction analysis of 3-D rectangular tanks by a variationally coupled BEM-FEM and comparison with test results. *Earthquake Engineering & Structural Dynamics*, *27*(2), 109-124.

Lemons, D.S. & Lund, C. (1999). Thermodynamics of high temperature, Mie-Gruneisen solids. *American Journal of Physics*, *67*(12), 1105-1108. doi: https://doi.org/10.1119/1.19091

Lin, F. & Zhang, L. (2017). Safety analysis of nuclear containment vessels subjected to strong earthquakes and subsequent tsunamis. *Nuclear Engineering and Technology*, *49*(5), 1079-1089, doi: https://doi.org/10.1016/j.net.2017.03.008

Mir, F.U., Yu, C. & Whittaker, A.S. (2020). Experimental and numerical studies of seismic fluid-structure interaction in a base-supported cylindrical vessel. *Earthquake Engineering & Structural Dynamics*, *50*(5), 1395-1413, doi: https://doi.org/10.1002/eqe.3402

Moslemi, M. & Kianoush. (2012). Parametric study on dynamic behavior of cylindrical ground-supported tanks. Engineering Structures, 42, 214-230, doi: https://doi.org/10.1016/j.engstruct.2012.04.026

Nicolici, S. & Bilegan, R.M. (2013). Fluid structure interaction modeling of liquid sloshing phenomena in flexible tanks. *Nuclear Engineering and Design*, *258*, 51-56, doi: https://doi.org/10.1016/j.nucengdes.2012.12.024

Ozsarac, V., Brunesi, E. & Nascimbene, R. (2021). Earthquake-induced nonlinear sloshing response of above-ground steel tanks with damped or undamped floating roof. *Soil Dynamics and Earthquake Engineering*, *144*, 106673, Retrieved from https://doi.org/10.1016/j.soildyn.2

Rawat, A., Mittal, V., Chakraborty, T. & Matsagar, V. (2019). Earthquake induced sloshing and hydrodynamic pressures in rigid liquid storage tanks analyzed by coupled acoustic-structural and Euler-Lagrange methods. *Thin-Walled Structures*, *134*, 333-346.

Rebouillat, S. & Liksonov, D. (2010). Fluid-structure interaction in partially filled liquid containers: A comparative review of numerical approaches. *Computers & Fluids*, *39*(5), 739-746, doi: https://doi.org/10.1016/j.compfluid.2009.12.010

Shokoohfar, A. & Rahai, A. (2016). Nonlinear analysis of pre-stressed concrete containment vessel (PCCV) using the damage plasticity model. *Nuclear Engineering and Design*, *298*, 41-50. doi:https://doi.org/10.1016/j.nucengdes.2015.12.019

Song, C., Li, X., Guoliang, Z. & Wei, C. (2017). Research on FSI effect and simplified method of PCS water tank of nuclear island building under earthquake. *Progress in Nuclear Energy*, *100*, 48-59, doi: https://doi.org/10.1016/j.pnucene.2017.05.025

Virella, J.C., Prato, C.A. & Godoy, L.A. (2008). Linear and nonlinear 2D finite element analysis of sloshing modes and pressures in rectangular tanks subject to horizontal harmonic motions. *Journal of Sound and Vibration*, *32*(3), 442-460, doi: https://doi.org/10.1016/j.jsv.2007.07.088.