

# COMPARATIVE SEISMIC ANALYSIS OF CYLINDRICAL AND RECTANGULAR OIL TANKS: EFFECTS OF WALL THICKNESS UNDER SOIL–STRUCTURE–FLUID INTERACTION

ANÁLISE SÍSMICA COMPARATIVA DE TANQUES DE PETRÓLEO CILÍNDRICOS E RETANGULARES: EFEITOS DA ESPESSURA DA PAREDE SOB A INTERAÇÃO SOLO-ESTRUTURA-FLUIDO

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**Hamza Bouchehit\***

\*Laboratory of Research in Applied Hydraulics (Lrhya), Department of Civil Engineering, Batna2 University, Batna, Anaba, Algeria  
Orcid: <https://orcid.org/0009-0003-2800-8055>  
[h.bouchehit@univ-batna2.dz](mailto:h.bouchehit@univ-batna2.dz)

**Haitem Torkia\*\***

\*\*Institute of Architecture and Urbanism (Lautr) Laboratory, Batna 1 University, Batna, Algeria  
Orcid: <https://orcid.org/0000-0001-8104-3771>  
[haitem.torkia@univ-batna.dz](mailto:haitem.torkia@univ-batna.dz)

**Abdlekrim Kadid\***

\*Laboratory of Research in Applied Hydraulics (Lrhya), Department of Civil Engineering, Batna2 University, Batna, Algeria  
Orcid: <https://orcid.org/0009-0007-3349-419X>  
[a.kadid@univ-batna2.dz](mailto:a.kadid@univ-batna2.dz)

**Abdelmoutalib Benfrid\*\*\***

\*\*\*Department of Hydraulics and Civil Engineering, Institute of Technology, University Centre of Maghnia (13000), Maghnia, Algeria.  
Orcid: <https://orcid.org/0009-0007-8171-1654>  
[benfridabdelmoutalib2050@gmail.com](mailto:benfridabdelmoutalib2050@gmail.com)

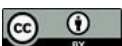
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## Abstract

Oil and liquid storage tanks represent essential components of industrial infrastructure, guaranteeing the secure containment of petroleum, chemical, and other hazardous liquids. Their seismic performance plays a crucial role in mitigating risks of leakage, structural collapse, and environmental contamination [1,2]. While most existing research has concentrated on cylindrical storage tanks—the predominant configuration in industry—rectangular tanks are also employed in specific applications, yet their seismic behavior remains insufficiently explored [5]. This study presents a comparative numerical analysis of the seismic response of cylindrical and rectangular oil tanks, incorporating full soil–structure–fluid interaction and accounting for the influence of wall thickness [5,7]. Three-dimensional finite element models are developed in ADINA using

## Resumo

Tanques de armazenamento de óleo e líquidos representam componentes essenciais da infraestrutura industrial, garantindo a contenção segura de petróleo, produtos químicos e outros líquidos perigosos. Seu desempenho sísmico desempenha um papel crucial na mitigação de riscos de vazamento, colapso estrutural e contaminação ambiental [1,2]. Embora a maioria das pesquisas existentes tenha se concentrado em tanques de armazenamento cilíndricos — a configuração predominante na indústria — tanques retangulares também são empregados em aplicações específicas, mas seu comportamento sísmico permanece insuficientemente explorado [5]. Este estudo apresenta uma análise numérica comparativa da resposta sísmica de tanques de óleo cilíndricos e retangulares, incorporando a interação completa solo-estrutura-fluido e levando em



a coupled Lagrangian formulation for the fluid domain [6], and the 1999 Chi-Chi earthquake (Taiwan) is applied as ground motion input [10]. The analysis evaluates variations in tensile stresses, hydrodynamic pressures, and fluid velocity distributions across different wall thicknesses [8]. Results demonstrate the significant impact of tank geometry and wall stiffness on dynamic behavior and provide design recommendations for safer tank configurations in seismically active regions [5,7].

**Keywords:** Seismic Response. Tank Geometry. Cylindrical Tank. Rectangular Tank. Wall Thickness. Soil–Structure–Fluid Interaction. Dynamic Analysis.

*consideração a influência da espessura da parede [5,7]. Modelos tridimensionais de elementos finitos são desenvolvidos no ADINA usando uma formulação lagrangiana acoplada para o domínio do fluido [6], e o terremoto Chi-Chi de 1999 (Taiwan) é aplicado como entrada de movimento do solo [10]. A análise avalia variações nas tensões de tração, pressões hidrodinâmicas e distribuições de velocidade do fluido em diferentes espessuras de parede [8]. Os resultados demonstram o impacto significativo da geometria do tanque e da rigidez da parede no comportamento dinâmico e fornecem recomendações de projeto para configurações de tanques mais seguras em regiões sísmicamente ativas [5,7].*

**Palavras-chave:** Resposta Sísmica. Geometria do Tanque. Tanque Cilíndrico. Tanque Retangular. Espessura da Parede. Interação Solo-Estrutura-Fluido. Análise Dinâmica.

## 1 INTRODUCTION

Liquid storage tanks are critical components of industrial infrastructure, serving as primary containment systems for crude oil, petroleum products, and various chemical substances. Their structural safety under dynamic loading—particularly during seismic events—is a subject of great importance due to the potential risks of leakage, fire, or environmental contamination [1,2]. The seismic performance of these tanks has therefore been the focus of numerous research efforts over the past decades [3,4]. Earthquakes induce complex hydrodynamic pressures and sloshing effects that can threaten the structural integrity of tanks, emphasizing the need for a comprehensive understanding of their behavior under such conditions [1,8].

Most liquid storage tanks used worldwide are cylindrical because this geometry offers high structural efficiency and a uniform distribution of hydrostatic and hydrodynamic pressures [1,4]. Nevertheless, rectangular tanks are also commonly employed, especially in industrial settings with space constraints or specific architectural requirements [5]. Although both geometries serve similar purposes, their dynamic responses differ significantly due to variations in stress concentration, deformation patterns, and the way the contained fluid interacts with the tank walls [5,7]. Despite the practical relevance of this comparison, only a limited number of studies have directly

evaluated the seismic performance of cylindrical and rectangular tanks under identical conditions, including the effects of soil–structure–fluid interaction (SSFI) [5,7,16].

The present study aims to address this gap by conducting a detailed comparative analysis of the seismic behavior of cylindrical and rectangular oil tanks with varying wall thicknesses [5,7]. The investigation considers the combined effects of soil flexibility, structural stiffness, and fluid dynamics [16,20]. The results provide a deeper understanding of how the geometry and wall thickness influence the seismic response and structural stability of liquid storage tanks, thereby supporting the development of safer and more efficient designs for use in earthquake-prone regions [5,7,16].

The influence of soil–structure interaction (SSI) on structural response was first recognized after the 1971 San Fernando earthquake in California, which caused extensive damage to industrial facilities, including liquid storage tanks [16,17]. Subsequent seismic events, such as the 1994 Northridge earthquake, further emphasized the need to integrate SSI and fluid–structure interaction (FSI) into seismic design codes [16,20]. Ground-supported tanks were found to be particularly vulnerable to these effects, experiencing uplift, buckling, and base plate separation due to hydrodynamic pressures and fluid sloshing [4,8]. These events underscored the importance of understanding the combined dynamic behavior of the tank, the contained liquid, and the supporting soil [16,20].

The dynamic response of liquid storage tanks is governed by several interrelated parameters. Fluid–structure interaction determines how the movement of the tank influences, and is influenced by, the internal fluid [1,4,8]. Hydrodynamic pressure distribution defines the magnitude and spatial variation of forces acting on the tank walls and bottom during seismic shaking [8]. The sloshing of the contained liquid introduces additional dynamic loads that can amplify wall stresses, induce roof impact, or lead to overtopping [1,4,8]. Finally, the response of the supporting soil modifies the boundary conditions at the tank base, altering the transmission of seismic energy and affecting the overall dynamic amplification [16,20,25]. Neglecting any of these coupled effects can lead to inaccurate predictions of structural behavior and, consequently, unsafe design solutions [3,16,20].

Soil–structure–fluid interaction (SSFI) represents the most comprehensive framework for analyzing this complex coupled system [5,16,20]. When seismic waves propagate through the ground, they induce motion in the tank foundation, which excites both the tank walls and the contained liquid [16,20]. The liquid, in turn, generates

hydrodynamic pressures that act back on the tank, while the structure transfers reaction forces to the foundation and the underlying soil [16,25]. This bidirectional coupling modifies the natural frequencies and damping characteristics of the system [16,20]. Soil flexibility can lengthen the fundamental period of vibration, while the fluid mass may alter stiffness and energy dissipation mechanisms [16,20,27]. Experimental and numerical studies have shown that this mutual interaction can significantly change local ground motion characteristics, even at considerable distances from the structure [12,18,19,21,26]. Such feedback mechanisms are responsible for phenomena like site amplification and structure–soil–structure interaction, both of which are essential considerations in seismic design [12,19,21].

The geometry and wall thickness of a tank play a decisive role in shaping its dynamic response [5,7]. Cylindrical tanks generally exhibit a uniform circumferential stress distribution, which helps resist both hydrostatic and hydrodynamic loads efficiently [1,4]. In contrast, rectangular tanks are characterized by stress concentrations along edges and corners, making them more vulnerable to localized yielding or cracking under strong seismic excitation [5,7]. The interaction between wall flexibility and geometry further influences performance: thinner walls are more prone to deformation and stress amplification, while thicker walls increase stiffness but may reduce damping capacity [7]. Therefore, optimizing wall thickness is crucial for balancing structural strength, ductility, and energy dissipation in seismic design [7,16].

Significant advancements in modeling techniques have enhanced our ability to analyze these interactions. Since Housner’s pioneering work in 1957, which introduced simplified analytical models for fluid–structure systems [17], researchers have progressively developed more sophisticated numerical approaches [3,16,20]. Finite element and boundary element methods now allow the simultaneous coupling of soil, structure, and fluid domains under transient seismic loading [6,16]. Subsequent investigations demonstrated that structural motion generates reaction forces at the soil–foundation interface, producing secondary wave fields that radiate back into the soil [20,26,27]. This phenomenon, known as structure–soil interaction, has been experimentally confirmed and observed to modify free-field ground motions [12,19,21]. These insights have expanded the understanding of how structures and surrounding soil layers influence each other dynamically, reinforcing the need for integrated analysis [16,20,26].

In regions of high seismic activity, such as northern Algeria, Japan, and the western United States, oil storage tanks represent strategic yet potentially hazardous structures [11,16,22]. Damage to these facilities during earthquakes can have devastating environmental and economic consequences, including fires, spills, and prolonged service interruptions [2,5,16]. International design standards such as API 650, Eurocode 8, and ACI 350.3 have incorporated provisions for dynamic and sloshing effects, but many design practices still rely on simplified or decoupled models that may not fully capture SSFI phenomena [3,5,16]. Moreover, the role of wall thickness and tank geometry remains insufficiently addressed in these standards, despite its significant impact on dynamic performance [5,7,16].

A comprehensive understanding of the seismic response of both cylindrical and rectangular tanks, considering variations in wall thickness and full soil–structure–fluid interaction, is therefore critical for modern engineering design [5,7,16,20]. The present research seeks to contribute to this understanding by evaluating the hydrodynamic pressure distribution, principal tensile stresses, fluid velocity fields, and energy transfer mechanisms between soil, structure, and fluid [5,7,8,16]. Using realistic ground motion records as input excitation [10], the study aims to establish relationships between wall thickness, geometry, and dynamic response [5,7,16]. The outcomes are expected to inform the development of improved design recommendations, enhance the seismic resilience of liquid storage systems, and contribute to the broader field of soil–structure–fluid interaction research [5,7,16,20].

## **2 SEISMIC MODELING FRAMEWORK FOR LIQUID STORAGE TANKS**

The seismic behavior of liquid storage tanks has been the subject of extensive research due to the crucial role these structures play in industrial and energy sectors [1–5]. Early analytical studies (Jendzelovský et al., 2014; Oleksáková, 2014) have highlighted the importance of fluid–structure interaction (FSI) in accurately capturing the dynamic response of tanks subjected to ground motion [1,4,8]. This interaction becomes particularly significant for tall or slender tanks, where the relative motion between the fluid and the tank wall produces hydrodynamic pressures that can strongly influence overall stability [1,4,8].

Under seismic excitation, the liquid within the tank does not move as a rigid body; rather, it oscillates in complex patterns that can be approximated through a combination of impulsive and convective components [1,3,4]. The impulsive component represents the portion of the fluid that moves synchronously with the tank walls, contributing to the inertial load directly transmitted to the structure [1,4]. The convective component, on the other hand, corresponds to the sloshing motion of the fluid, which acts with a phase delay and generates additional dynamic pressures on the tank walls and base [1,4,8]. These two effects together define the hydrodynamic pressure distribution that governs the tank's dynamic performance [4,8].

To approximate this coupled behavior, various modeling techniques have been developed over the years [3,4,6]. Among these, the **Finite Element Method (FEM)** remains one of the most robust and widely adopted approaches, allowing for the simultaneous simulation of structural deformation and fluid motion [6]. However, simplified analytical models continue to provide valuable physical insight [1,3]. One of the most established approaches is the **spring–mass analog model**, which represents the liquid–tank system as a combination of lumped masses and equivalent springs [1,3,17].

In this representation, the **impulsive mass** ( $m_i$ ) is assumed to be rigidly connected to the tank wall, while the **convective masses** ( $m_{cn}$ ) are attached through springs with stiffness values  $K_{cn}$ , as illustrated schematically in Figure 1 [1,4,17]. These springs model the restoring forces associated with fluid sloshing [1,17]. The overall response of the tank can thus be expressed as the superposition of impulsive and convective modes, with each mode characterized by distinct natural frequencies and modal participation factors [1,3,17].

Although most simplified analyses consider only the first convective mode, higher-order convective terms can be included for improved accuracy, especially in the case of large ground-supported tanks [4,8] (Krejsa et al., 2014; Kuklík, 2011). The analytical formulation of these parameters follows the relationships given by Housner-type models [1,17], adapted for the specific geometry of the tank [4,8]. In these formulations,  $V_n$  and  $\lambda_n$  represent the modal roots of Bessel functions, which determine the frequencies and effective heights of the hydrodynamic masses [1,17]. The impulsive and convective responses are evaluated through a set of parameters including the equivalent hydrodynamic mass,  $m_i$  and  $m_{cn}$ ; the corresponding height factors,  $h_i$ ,  $h_i^*$ ,  $h_{cn}$ ; and the natural frequencies  $\omega_{cn}$ , defined by the relationships [1,3,17]:

$$m_i = m2\gamma \sum_{n=0}^{\infty} \frac{I_1(v_n/\gamma)}{v_n^3 I_1'(v_n/\gamma)} \quad (1)$$

$$m_{cn} = m \frac{2 \tanh(\lambda_n H/R)}{(\lambda_n H/R)(\lambda_n^2 - 1)} \quad (2)$$

$$\omega_{cn}^2 = \lambda_n \tanh(\lambda_n H / R) \frac{g}{R} \quad (3)$$

Here,  $I_1(\cdot)$  and  $I_1'(\cdot)$  are the modified Bessel functions of the first order and its derivative, respectively;  $H$  denotes the liquid height,  $R$  is the tank's inner radius, and  $\gamma = H/R$  represents the tank's slenderness ratio [1,17]. The parameters  $h_i$  and  $h_{cn}$  correspond to the effective heights of the resultant impulsive and convective hydrodynamic wall pressures, while  $h_i^*$  and  $h_{cn}^*$  denote the corresponding points of action for the total hydrodynamic forces acting on the tank walls and bottom [1,3,4,8,17].

These formulations serve as the theoretical foundation for the numerical modeling conducted in this study [1,3,4]. In particular, they allow for the validation of the FEM-based approach by providing analytical estimates of natural frequencies, effective hydrodynamic masses, and pressure distributions [3,6,8,17]. The comparative analysis between **cylindrical and rectangular tanks** extends this framework by examining how geometric configuration and wall thickness affect these parameters under seismic excitation, while accounting for the full **soil–structure–fluid interaction (SSFI)** phenomenon [5,7,16,20].

The following sections (Figures 1 and 2) illustrate the application of this modeling approach to both cylindrical and rectangular configurations, which form the basis of the comparative seismic analysis presented in this paper [5,7,16].

### 3 NUMERICAL MODELING APPROACH

Industrial establishments are considered important and efficient for the economies of countries, and any damage to these establishments can expose them to the risk of earthquakes, potentially causing disruptions with disastrous consequences [2,5,16]. Among the important facilities in industrial establishments are the tanks used in various applications. Testing the construction site for industrial installations requires identifying strategic sites with precision and according to needs, so it is not always guaranteed to

avoid constructing in seismic zones [11,12,19]. Therefore, we must address this issue. Thus, taking care of the soil-structure interaction in this case can prevent numerous disasters [16,20,25].

### 3.1 Cylindrical tank model

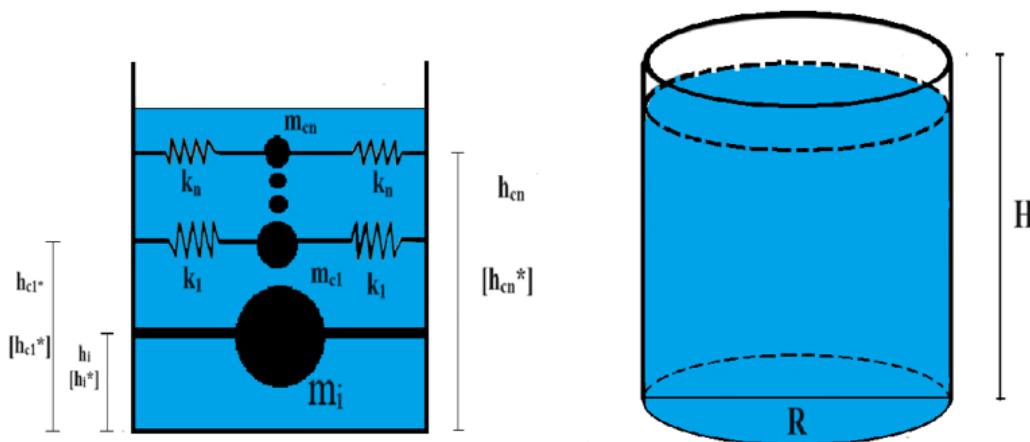
The cylindrical reservoir considered in this study has an internal radius of **32 m** and contains a liquid column of **22 m** in height. The **side wall thickness** is varied in three configurations: **0.04 m**, **0.10 m**, and **0.14 m** [7, 23]. The structure rests on a **compacted gravel foundation**, which provides the necessary support and damping characteristics under dynamic excitation [9, 24].

- **Material Properties:**

The **material properties** assigned to the tank walls correspond to typical structural steel, characterized by a **Young's modulus of  $E = 2.07 \times 10^{11} \text{ N/m}^2$**  [6, 25], a **Poisson's ratio of  $\nu = 0.3$** , and a **density of  $\rho = 7800 \text{ kg/m}^3$** . The **tank structure** is represented using **shell elements**, while the **contained fluid** is idealized as a **three-dimensional incompressible medium** to capture the fluid–structure interaction effects [6, 26].

**Figure 1**

*Cylindrical tank with a spring-mass model representation for circular tanks supported at ground level.*

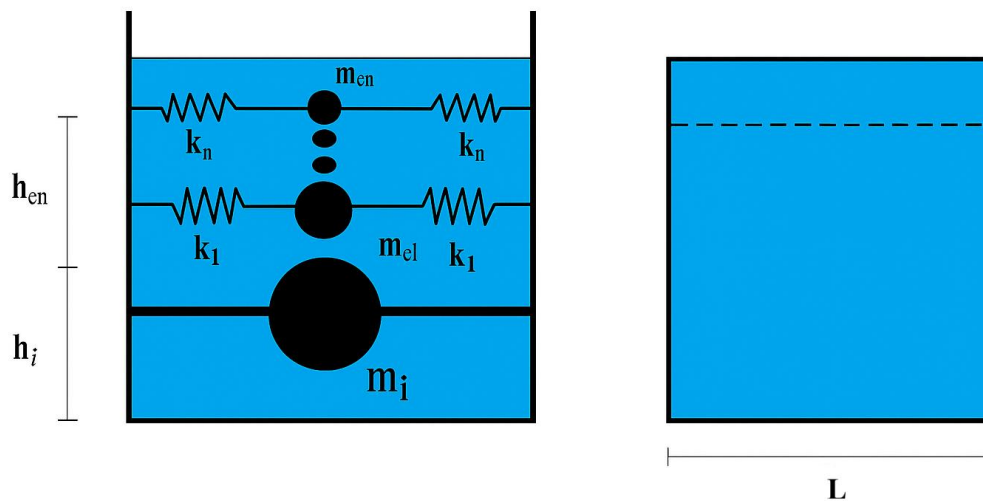


### 3.2 Rectangular tank model

The **rectangular reservoir** is designed with plan dimensions of **64 m × 64 m** and a **fluid height of 22 m**, resulting in a **stored volume comparable** to that of the cylindrical tank [5]. The **wall thickness** is varied across three configurations—**0.04 m, 0.10 m, and 0.14 m**—to ensure consistent comparison [7]. The **material characteristics** are maintained identical to those of the cylindrical model to preserve uniformity in the analysis [6]. The **rectangular walls** are represented by **flat shell panels**, which naturally promote **stress concentration effects** near the **edges and corners** under hydrodynamic excitation [5,8]. The **tank base** is assumed to be **rigidly supported on a gravel foundation**, representing typical field conditions [9,24].

**Figure 2**

*Rectangular tank with a spring-mass model representation for circular tanks supported at ground level.*



## 4 GEOMETRIC AND MATERIAL CHARACTERISTICS OF THE TANK

This study examines two types of **ground-supported oil storage tanks without roofs**: a **cylindrical tank** and a **rectangular tank**, both designed to contain approximately the same fluid volume [5,7].

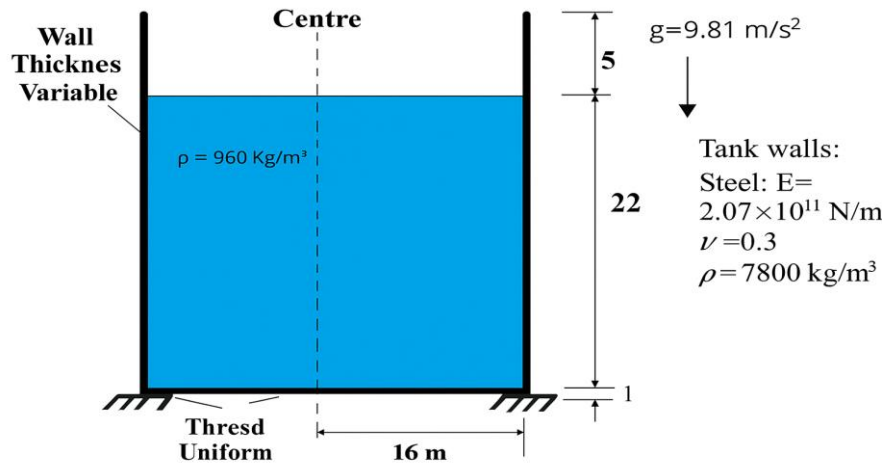
The **cylindrical reservoir** has an **internal radius of 32 m** and a **fluid height of 22 m** [5,7]. The **tank walls** possess a **uniform thickness** that varies along the height, while the **bottom slab** maintains a **constant thickness of 0.5 m** [7]. The tank rests on a **gravel foundation**, which ensures a realistic simulation of soil–structure interaction effects [9,16,20]. The **material properties** correspond to **standard structural steel**, defined by a **Young’s modulus of  $E = 2.07 \times 10^{11} \text{ N/m}^2$** , a **Poisson’s ratio of  $\nu = 0.3$** , and a **density of  $\rho = 7800 \text{ kg/m}^3$** , as shown in **Figure 2**.

The **rectangular tank** has **plan dimensions of 64 m × 64 m** and a **fluid height of 22 m**, providing a comparable storage capacity to the cylindrical configuration [5]. The **wall thickness** is varied in three cases—**0.04 m**, **0.10 m**, and **0.14 m**—to evaluate the influence of wall stiffness on seismic performance [7]. The **material properties** are kept identical to those of the cylindrical tank to maintain consistency in the comparative analysis [6]. This reservoir also rests on a **gravel foundation**, assumed to behave as a rigid base [9,24].

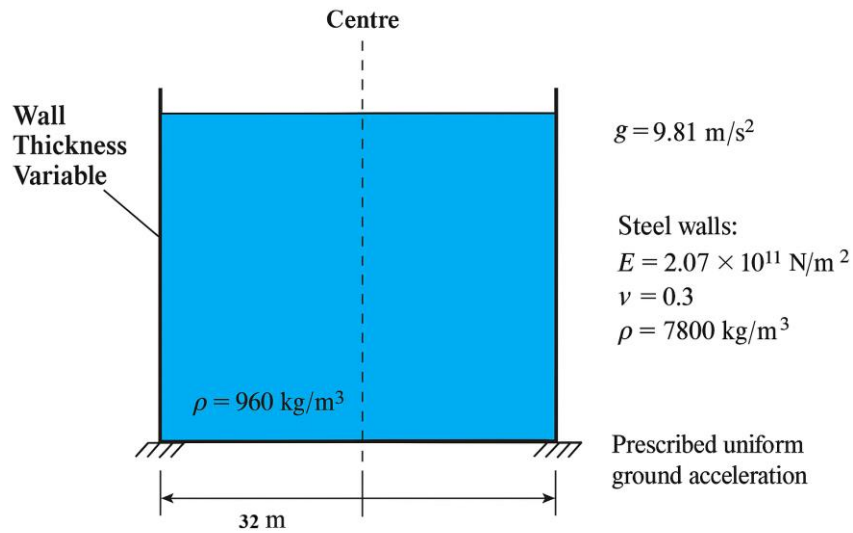
The **finite element modeling** of both configurations was carried out using the **ADINA software package (Figure 3)** [6]. For each model:

- The **tank walls** are represented by **shell-type elements**, defined through geometry points 1–5, lines 1–4, surfaces 1–4, material set 1, and element group 1 [6].
- The **contained oil** is represented by **3D incompressible fluid elements**, defined through geometry points 101–104, surface 101, volume 101, material set 101, and element group 101 [6].

Both models are designed to capture the **fluid–structure–foundation interaction** under seismic excitation, allowing for a direct comparison of the **dynamic responses** between **cylindrical** and **rectangular geometries** [5,6,7,9,16].

**Figure 3***Geometrical and Material Characteristics of Liquid Storage Cylindrical Tanks*

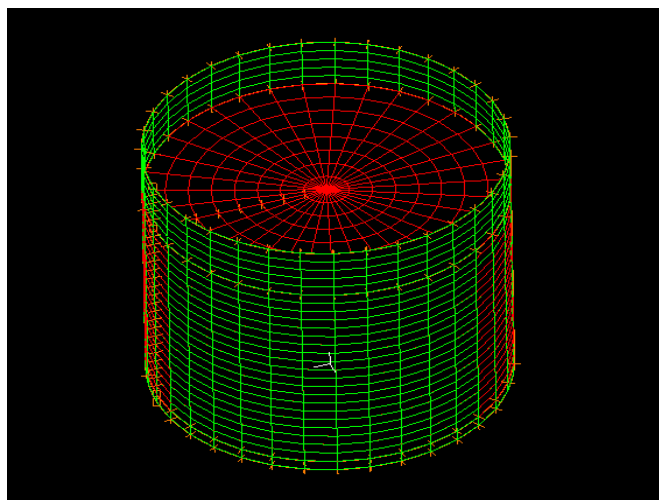
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**Figure 4***Geometrical and Material Characteristics of Liquid Storage Rectangular Tanks*

Source: (Created by the Author)

**Figure 5**

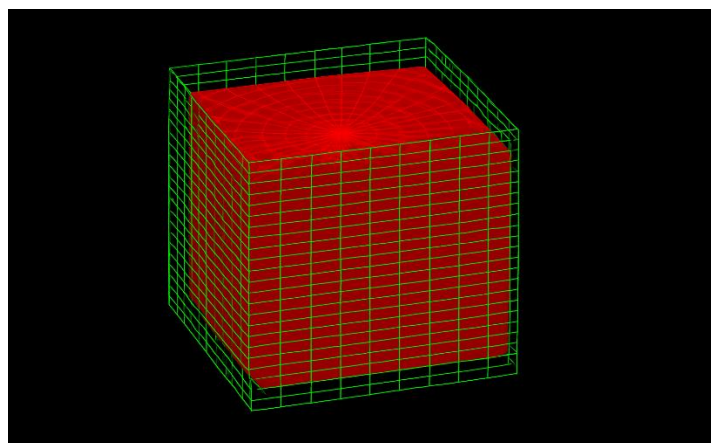
*The Cylindrical Oil Tank Model*



Source: (Created by the Author)

**Figure 6**

*The Rectangular Oil Tank Model*

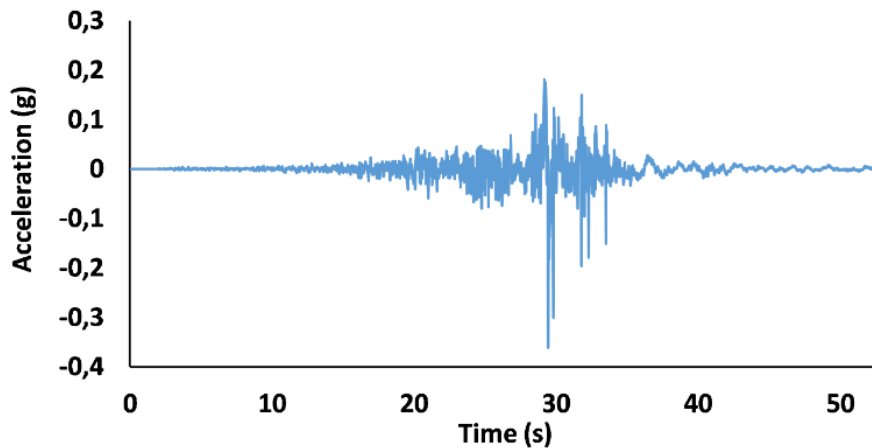


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The seismic excitation applied in this study corresponds to the ground motion recorded during the 1999 Chi-Chi earthquake in Taiwan, as illustrated in Figure 7.

**Figure 7**

*Ground Motion Recorded at Station TCU046 during the 1999 Chi-Chi Earthquake (Epicentral Distance: 78.17 km), Showing the Ricker Wavelet without Phase Shift (Top) and with a Phase Shift of  $\theta = 310^\circ$  (Bottom)*



Source: (Created by the Author)

**5 METHOD OF ANALYSIS**

The analysis of sloshing behavior in the oil storage tank is carried out through three complementary evaluation stages [3,6,16]:

**5.1 Static analysis**

In this stage, gravitational loading is applied to evaluate the hydrostatic pressure distribution and the resulting stresses acting on the tank walls and base [1,2,4].

**5.2 Frequency analysis**

Once the static equilibrium is established, a modal analysis is performed to determine the first 400 natural frequencies of the coupled fluid–structure system [1,3,4,8]. The corresponding modal participation factors related to ground excitation are also computed [3,8,17].

### 5.3 Dynamic time history analysis

After applying the gravitational load, a dynamic analysis is conducted by introducing a sinusoidal ground acceleration in the x-direction [6,10]. The excitation period is selected to match the fundamental sloshing mode identified from the frequency analysis [1,4,8].

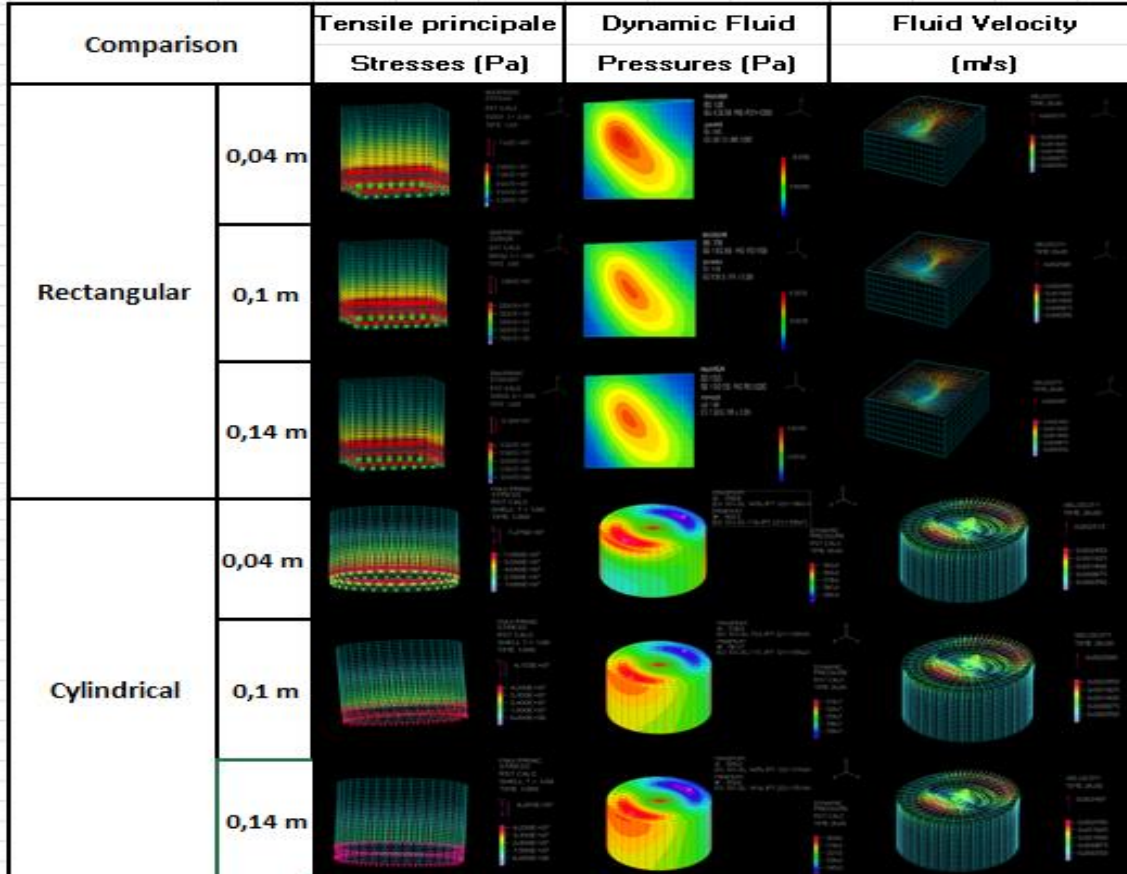
For each analysis case, the wall thickness is varied, and the corresponding results are computed for **fluid pressures**, **principal tensile stresses ( $\sigma_{\text{hoop}}$ )**, **dynamic fluid pressures**, and **fluid velocities** [5,7,8,16]. The obtained results for the **cylindrical tank** are presented in **Table 1**, while those for the **rectangular tank** are summarized in **Table 2** [5,7].

## 6 RESULTS AND DISCUSSION

In this section, the results obtained from the ADINA software simulations are presented [6]. Due to the large number of computational outputs, only the most representative figures are included—specifically those illustrating the initial, intermediate, and final stages of the analysis [6,8], as shown in **Figure 8**.

**Figure 8**

Comparison of Adina simulation results for cylindrical and rectangular tanks with wall thicknesses of 0.04 m, 0.10 m, and 0.14 m

**Table 1**

Variation of static fluid pressure, principal tensile stress, dynamic pressure, and fluid velocity with wall thickness for the cylindrical tank.

Wall Thickness (m)	Tensile Principal Stress (Pa)	Dynamic Fluid Pressure (Pa)	Fluid Velocity (m/s)
0,04	7.10E+07	(-)360.4	0.002515
0,05	6.85E+07	(-)344.3	0.002507
0,06	4.50E+07	(-)338.5	0.002503
0,07	4.25E+07	(-)332.0	0.002501
0,08	4.15E+07	(-)326.8	0.002498
0,09	4.18E+07	(-)323.2	0.002496
0,1	4.20E+07	(-)319.6	0.002492
0,11	4.22E+07	(-)315.8	0.002489
0,12	4.24E+07	(-)313.5	0.002485
0,13	4.27E+07	(-)311.2	0.002460
0,14	4.31E+07	(-)308.7	0.002447

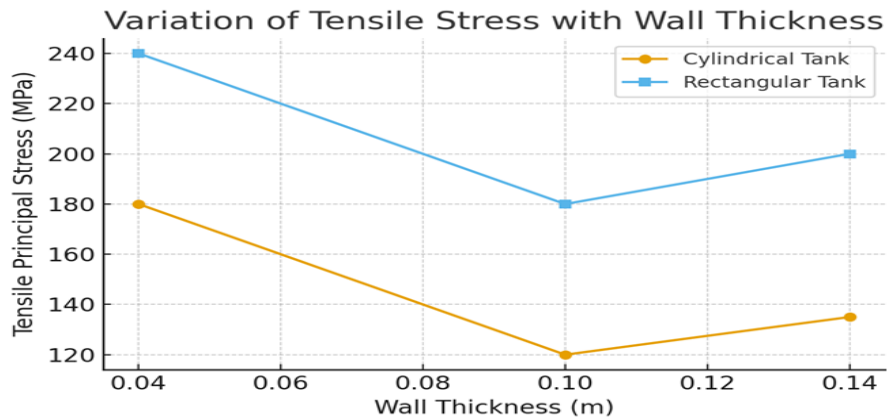
**Table 2**

*Variation of static fluid pressure, principal tensile stress, dynamic pressure, and fluid velocity with wall thickness for the rectangular tank.*

Wall Thickness (m)	Tensile Principal Stress (Pa)	Dynamic Fluid Pressure (Pa)	Fluid Velocity (m/s)
0,04	7.65E+07	(-)375.9	0.002523
0,05	7.18E+07	(-)359.2	0.002517
0,06	4.90E+07	(-)351.5	0.002512
0,07	4.65E+07	(-)344.8	0.002508
0,08	4.48E+07	(-)339.3	0.002505
0,09	4.46E+07	(-)334.6	0.002501
0,1	4.44E+07	(-)329.8	0.002498
0,11	4.48E+07	(-)325.7	0.002494
0,12	4.51E+07	(-)322.4	0.002490
0,13	4.55E+07	(-)319.0	0.002463
0,14	4.59E+07	(-)316.3	0.002452

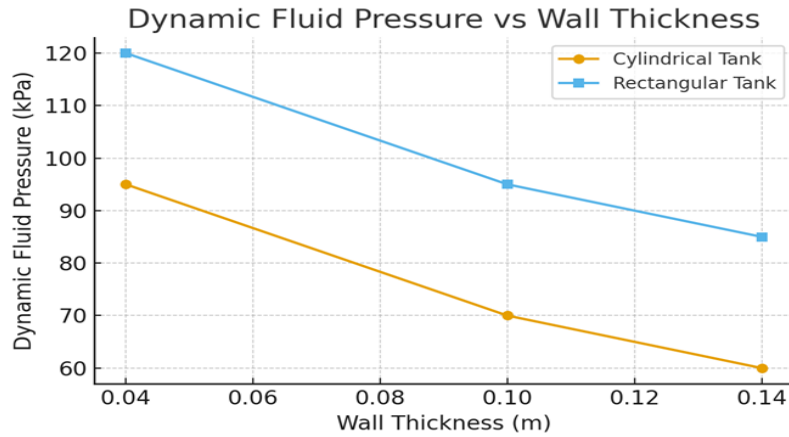
**Figure 9**

*Variation of tensile stresses as a function of wall thickness for cylindrical and rectangular tanks.*

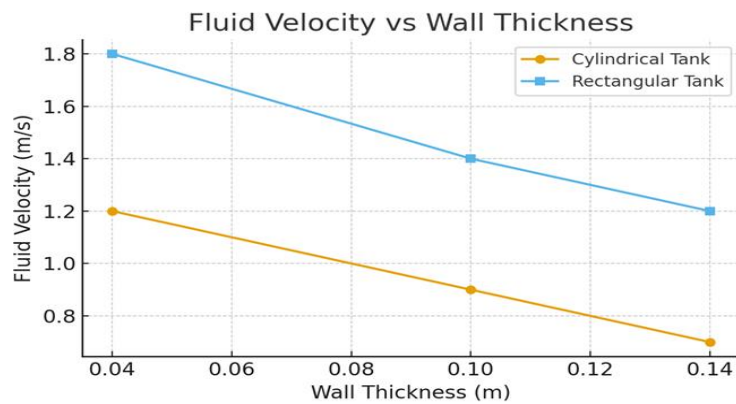


**Figure 10**

*Variation of the dynamic fluid pressures as a function of wall thickness for cylindrical and rectangular tanks.*

**Figure 11**

*Variation of fluid velocities as a function of wall thickness for cylindrical and rectangular tanks.*



A comparative evaluation of the seismic responses of the cylindrical and rectangular oil tanks under identical loading and boundary conditions reveals distinct behavioral trends associated with geometry and wall thickness [5,7,16], as illustrated in **Figures 9, 10, and 11**. Both configurations show that the tensile principal stress decreases with increasing wall thickness up to a certain point; however, the magnitude and distribution of this reduction differ significantly between the two geometries [5,7].

For the **cylindrical tank**, the tensile principal stress declines as wall thickness increases up to approximately **0.09 m**, beyond which the stress slightly rises again [5,7].

This nonlinear response may be linked to complex structural interactions such as **material hardening, localized stress redistribution**, and the **transition from thin-shell to thick-wall behavior** [3,7]. In thinner walls, the tank efficiently resists internal pressures through its curvature, which promotes even stress distribution. However, as the walls become thicker, internal stresses tend to concentrate closer to the inner surface, partly due to the curvature-induced nonuniform stress field. The resulting pattern indicates that very thick cylindrical walls may behave as solid shells, where hoop stress assumptions no longer apply uniformly.

By contrast, the **rectangular tank** exhibits a less homogeneous stress distribution [5,7,8]. Although stress values also decrease with wall thickening, the reduction is less pronounced, and **stress concentrations persist near the edges and corners**. These regions act as geometric discontinuities that amplify local stresses during seismic excitation [5,8]. The absence of curvature prevents stress redistribution, making the rectangular configuration inherently more sensitive to localized deformation effects. As a result, while both tanks benefit from thicker walls, the cylindrical geometry achieves a more balanced and efficient stress reduction.

The **dynamic fluid pressure** results, depicted in **Figure 10**, further highlight geometric influences. In both tanks, dynamic pressures decrease as wall thickness increases, indicating improved stability and reduced hydrodynamic excitation [4,5,8]. For the cylindrical tank, this reduction is more substantial because the curved surface allows the hydrodynamic loads to dissipate evenly. The smoother boundary also minimizes turbulence and pressure fluctuations. Conversely, the rectangular tank, with its flat panels and angular corners [5,8], exhibits persistent pressure peaks due to flow separation and localized wave reflections. These phenomena sustain pressure irregularities that cannot be fully mitigated by increasing wall stiffness alone.

Similarly, **fluid velocity** variations shown in **Figure 11** demonstrate a decline with increasing wall thickness for both geometries [5,8]. Thicker walls limit tank deformation and absorb part of the hydrodynamic energy [5,7,16], which decreases the amplitude of sloshing and internal fluid motion. However, the **cylindrical tank** displays a smoother reduction in velocity due to its continuous curvature and uniform flow field, whereas the **rectangular tank** maintains higher local velocity gradients, particularly near corners [5,8], where vortex formation and turbulence persist. These zones of flow instability contribute to slightly higher residual velocities despite increased wall stiffness.

In summary, both tanks benefit from increased wall thickness, which enhances seismic resistance by reducing tensile stress, dynamic pressure, and fluid velocity [5,7,8]. Nevertheless, **the cylindrical configuration consistently outperforms the rectangular one**, owing to its favorable curvature, which distributes stresses and hydrodynamic forces more uniformly [1,4,5]. The rectangular tank, while structurally robust, remains prone to **localized stress and pressure amplification**, suggesting that additional design considerations—such as corner reinforcement or modified edge geometry—may be required to achieve comparable seismic performance [5,7,8].

These findings underscore the critical influence of tank geometry on the coupled soil–structure–fluid response and confirm that optimizing wall thickness alone is insufficient. For rectangular reservoirs, enhanced reinforcement and geometric optimization are essential to improve overall seismic resilience and dynamic stability.

## 7 CONCLUSION

This study presented a comparative investigation into the seismic performance of **cylindrical and rectangular oil storage tanks** with varying wall thicknesses, taking into account **soil–structure–fluid (SSF) interaction** [5,6,7,16]. Through a series of static, frequency, and dynamic time-history analyses, the influence of geometric configuration and wall rigidity on the structural and hydrodynamic responses was thoroughly examined.

The results demonstrated that **wall thickness plays a crucial role** in the overall dynamic response of both tank types [5,7]. For both geometries, increasing the wall thickness generally reduced **tensile principal stresses, dynamic fluid pressures, and fluid velocities**, indicating improved structural stability and reduced sloshing effects. However, the magnitude and uniformity of these reductions differed between the two configurations.

The **cylindrical tank** showed superior seismic performance, characterized by a more uniform stress distribution and lower dynamic amplification [1,4,5]. Its curved geometry allowed hydrodynamic pressures to spread evenly, minimizing local stress peaks and enhancing energy dissipation. Conversely, the **rectangular tank** exhibited significant stress and pressure concentrations, particularly near the corners and edges, where geometric discontinuities amplified localized deformation and hydrodynamic loads. These areas represent critical points of vulnerability during strong ground motions.

Furthermore, the analyses confirmed that **geometry-induced effects dominate the fluid–structure interaction**, even when material properties and foundation conditions are identical. While increasing wall thickness enhances stiffness and reduces dynamic response, the **rectangular configuration remains more susceptible** to uneven stress distribution and flow turbulence. This suggests that, beyond simple wall thickening, **structural optimization—such as corner reinforcement, rounded transitions, or adaptive wall profiles—may be necessary** to achieve performance levels comparable to those of cylindrical tanks [5,7,8].

In summary, the findings highlight that:

- **Cylindrical tanks** are inherently more efficient under seismic loading due to their ability to uniformly distribute stresses and hydrodynamic pressures.
- **Rectangular tanks**, although practical in constrained sites, require additional reinforcement and geometric adjustments to mitigate stress concentrations.
- **Wall thickness optimization**, while beneficial, must be integrated with **soil–structure–fluid coupling considerations** to accurately predict seismic behavior and ensure safety [5,7,16,20].

This comparative approach provides valuable insights for engineers and designers involved in the seismic design of liquid storage systems. Future research should extend this work by incorporating **nonlinear material behavior, base uplift effects, and multi-directional seismic excitations** to capture more realistic structural responses. Experimental validation and large-scale numerical simulations could also help refine design recommendations for rectangular tanks operating in high-seismic-risk zones [5,6,16].

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**Authors' Contribution**

Both authors contributed equally to the development of this article.

**Data availability**

All datasets relevant to this study's findings are fully available within the article.

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