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# Seismic analysis of oil storage tanks with different geometries

# *Farklı geometrilere sahip petrol depolama tanklarının sismik analizi*


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# Seismic Analysis of Oil Storage Tanks with Different Geometries

## *Highlights*

- *Seismic analysis was performed on a numerical model of steel material tank containing oil.*
- *To investigate the sloshing response under seismic effect using oil reservoirs.*
- *To study the effect of tanks height and investigate the modes based on natural frequency.*
- *The tank structure deforms in particular shapes*
- *The results observe a clear relationship between the oil level, tank shape, and modal shape.*

## *Graphical Abstract*

*The simulation results confirmed previous studies based on the swash response and presented numerical results of the seismic impact, including the types of deformation in the tank structure and the mode of failure.*

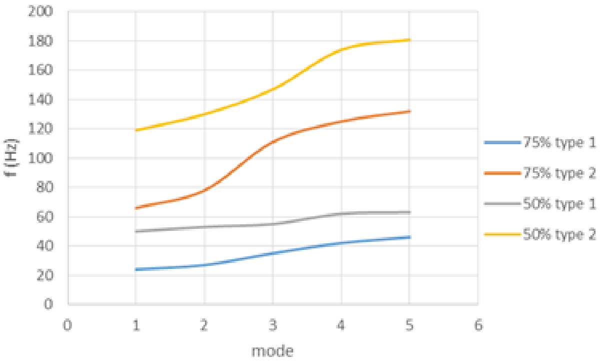


**Figure.** Comparison of impulsive frequencies for different types of tanks

## *Aim*

*To investigate the swash response under seismic action using oil reservoirs and examine the effect of tank height, as well as to investigate natural frequency-based modes.*

## *Design & Methodology*

*ANSYS software was used in this paper. By observing the sample responses such as acceleration and deformation of the tested models, the results were compared and confirmed with previous studies.*

## *Originality*

*Storage tanks with different geometries with three variants levels of occupancy were analysed using FEM.*

## *Findings*

*Due to the different responses, based on differences in tank size and oil level, these differences are significant especially when investigating the hydrodynamic oil pressure and tank size.*

## *Conclusion*

*The tank structure vibrates or deforms in particular shapes which are named mode shapes when expressed by their natural frequencies. The higher oil level presented a higher natural frequency in all cases.*

## *Declaration of Ethical Standards*

*The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.*

# Seismic Analysis of Oil Storage Tanks With Different Geometries

*Araştırma Makalesi/Research Article*

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**ABSTRACT**

Oil storage tanks must be designed to withstand dynamic and seismic loads. It is very important to ensure the safety of oil tanks with large volumes under earthquakes. During the earthquake, the land surface moves in all directions and as a result, the tank is exposed to vibrations. Especially the movements parallel to the land surface create vibrations in the tank and cause unexpected deformations on the tank walls. In this study, possible deformations that may occur in oil tanks with three different geometries under seismic conditions are investigated depending on their filling ratios. In the study, a package program based on the finite element method was used. By observing the sample responses such as acceleration and deformation of the tested models, the results were compared and confirmed with previous studies. The results revealed a clear relationship between oil level, tank shape and mode change. The higher oil level offered higher natural frequency in any case. The response spectrum model observed an increase when the oil level increased.

**Keywords: Oil tanks, dynamic loads, earthquake effect, finite element method.**

# Farklı Geometrilere Sahip Petrol Depolama Tanklarının Sismik Analizi

**ÖZ**

Petrol depolama tankları, dinamik ve sismik yüklere dayanacak şekilde tasarlanmalıdır. Büyük hacme sahip petrol tanklarının depremler altında güvenliğinin sağlanması oldukça önemlidir. Deprem süresince arazi yüzeyi bütün yönlere doğru hareket etmekte ve bunun sonucu olarak tank titreşimlere maruz kalmaktadır. Özellikle arazi yüzeyine paralel hareketler tankta titreşimler meydana getirmekte, tank duvarlarında beklenmedik deformasyonlara neden olmaktadır. Bu çalışmada, sismik koşullar altında üç farklı geometriye sahip petrol tanklarında meydana gelebilecek muhtemel deformasyonlar doluluk oranlarına bağlı olarak incelenmiştir. Çalışmada sonlu elemanlar yöntemi temeline dayanan bir paket programdan yararlanılmıştır. Test edilen modellerin hızlanma ve deformasyon gibi numune tepkileri gözlemlenerek sonuçlar önceki çalışmalarla mukayese edilmiş ve doğrulanmıştır. Sonuçlar, yağ seviyesi, tank şekli ve mod değişimi arasında net bir ilişki olduğunu ortaya koymuştur. Daha yüksek yağ seviyesi, her durumda daha yüksek doğal frekans sundu. Tepki spektrum modeli, yağ seviyesi arttığında bir artış olduğu gözlemlendi.

**Anahtar Kelimeler: Petrol tankları, dinamik yükler, deprem etkisi, sonlu elemanlar yöntemi.**

## 1. INTRODUCTION

In global industrial development and improvement of production efficiency, the improvement of safety in industrial and storage facilities using novel technical resources considered an essential target. The importance of this process is to ensure effective prevention of large industrial accidents. Tanks for oil and liquid systems are commonly used in the storage of various sectors of industry [1]. Large capacity tanks are assessed in terms of vulnerability against seismic effects.

Failure of these reservoirs through earthquake may cause different troubles such as fire or other health risks and economic loss. The good understanding of the seismic behaviours is a crucial issue due to the need to integrity of objectives correlated with the costs and developments of constructions. Normally, they are constructed of steel alloy metals in the form of circular configurations or spherical shape. These tanks structure can be built in different configurations; they can be high rise tanks, supported and structured configuration, half or completely buried under the ground. Cylindrical configuration considered structurally better for tank construction, while spherical tanks are used for particular purposes such as liquid gas and some special tanks. The seismic analysis based on the oil effect in the large storage tanks need a special design consideration such as the hydrodynamic forces and pressure. These forces are extracted by two groups, the tank wall effects and bottom [2].

These effects are essential in the design of the seismic tank. Inadequately designed tanks in the past exposed to strong ground motions led to ruptures, damage and failures of tank accessories. Furthermore, when tanks store flammable or disastrous effects, toxic liquids, such as uncontrolled fire, explosion or toxic dispersion arose.

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Therefore, tanks must be designed to maintain their integrity in initial state, during and after a seismic event to prevent negative future effects. Many studies observe the impulsive effect of liquid component on tanks structure due to seismic response. The typical storage tank failures such as diamond shape, buckling types and elephant foot are commonly related to the impulsive component [3, 4].

Through the earthquake, the land surface proceeds in all trends. The influence of vibration on tank structure are mostly the movements in a trend parallel to the land surface because of the actuality that structures are already designed based on vertical loads and effects. The influence of the earthquake provided for, in most issues, by the usual factor of safety for vertical loading, and most of structures take in the design consideration the lateral forces. Moreover, the horizontal forces effectiveness of essentially all reservoirs caused a litter effect of displacement due to earthquake ground motion, therefore, all points of the reservoir will be subjected to differential displacements of the construction and the stresses will be developed. Therefore, no particular earthquakes provisions for structural ingredient of the quake are usually considered in codes of horizontal impose. The storage tanks are relatively rigid and not able to deform in concrete with the ground [4, 5].

Seismic researches of oil storage started from 1930s, and have drawn a lot of interest in the field of tanks construction. The related works typically concerns into three categories; the first category is the theoretical computational models, the second category is numerical simulations, and the third category is experimental analysis. The dynamic response of simplified models which studied the liquid storage tank was the mass-spring model. This model proposed by Housner et al., which considered the rigid tank walls and developed to improve the impact of the flexible walls of the tanks. The improvement was to enhance the tanks resistance on seismic responses when it full with liquid [6]. As seen in Figure 1, the effect of impulsive part represents the lower portion of the liquid along with the wall and produce impulsive hydrodynamic pressure on tank wall and on the tank base. The main aim of the previous studies was to develop methods to investigate earthquake resistance under different conditions and provide codes for engineers for liquid storage tanks construction processes [7].

Liquid containing tanks are an important component device in distribution and transmission systems. It can be constructed in different geometric and material constraints and this can present different effects on the dynamic behaviour of tanks along with the different patterns of the hydrodynamic pressures from the stored liquid and the possible consequences of a seismic event. During operation these reservoirs can be subjected to different types of loading. Based on the subjected loads, the tank design can capture all failures possibilities [1, 3 and 7]. Seismic analysis can be performed on numerical model of steel material based on vertical ground-situated model tank containing oil. There are few researches to investigate the specifications of different types of tanks under the seismic effect [8]. For that, this study intends to perform a seismic analysis on the model of different types of oil storage tanks to investigate the responses of tank walls reliability. Also the sloshing effect is phenomenon that must be investigated based on different types of oil tanks. Seismic analysis is one method which should be carried out to provide satisfactory performance of tanks. The storage reservoirs analysis has been the topic of many studies. In this chapter, modes of analysing reservoirs under seismic loading are reviewed. The analysis of oil, soil interactions and code provisions on seismic analysis are also briefly reviewed. The loads on oil reservoirs may result from many resources and their influence depend on the type and mass of the oil tank structure related to those loads [9, 10]. An earthquake is a vibration or oscillation of the surface of the earth reasoned by transient disturbance of the centripetal force or elastic equilibrium of the crags at or beneath the superficies. In an earthquake, the earth proceeds in a nearly random fashion in all trends, both horizontally and vertical [11]. The studies about oil tanks structure concern the dynamic behaviour of 3D Fluid containers using the Rayleigh-Ritz method [12, 13]. The present approach is convenient and simple to apply for practical purposes. They used only a pair of walls, orthogonal to the ground direction and applied motion is assumed to be flexible while the other pair considered rigid and the effects of sloshing are not taken into account. Al-Zeiny et al., investigated the effects hydrodynamic pressures of oil affected on thin-walled based on earthquake motions. The model analysis of the tanks when the separation contact occurs on the foundations and tank base, large deformations appear in the soil-tank interaction and material yielding, also the free surface sloshing observed a large-amplitude. Thus, applying significant methods to investigate the tank characteristics are inappropriate to capture the complex seismic response. The efficient methods such as finite element approach suitable to handle the complexities to improve the effects resistance of the aforementioned factors on the seismic response of the tanks [14]. Jadhav et al., proposed a study of two-dimensional finite element analysis. They adopted for the sloshing analysis of spherical tank filled with oil using the velocity potential formulation in addition to the linear oil wave theory. The slosh frequencies of spherical tank are evaluated. The slosh frequencies of oil are computed for different positions and dimensions. The results obtained the slosh response of oil in a spherical tank is studied under steady state sinusoidal base excitation. The displacement of oil slosh reduced noticeably by putting baffle in spherical tank [4]. Chen and Kianoush computed the hydrodynamic pressures in spherical tanks. They applied the sequential method based on the effect of the tank flexibility. In this study, two-dimensional model has been used to investigate the tank wall considered, the time-history analysis impact. Both of tall tanks and shallow tanks are considered. The results of analysis observed a good response and compared with those obtained results on the current design based on practice codes and standards. The Housner's model takes into account the mass of stored oil which considered one of the rigid wall boundary condition and hydrodynamic pressure calculations. A comparison presents that the mass approach overestimates the base shear. The flexibility of the wall and tank displacements effects are also discussed [15]. Vathi et al., used numerical two-step methodology. They applied a detailed finite element of the tank for static analysis deformation at different levels of loading and a simplified tank model as a spring-mass system for dynamic analysis, enhanced by a nonlinear spring. They analysed two cylindrical liquid storage tanks with different aspect ratios for local performance. The results observed a better understanding of tank uplifting mechanics in existing seismic design provisions [16]. Pascal et al., applied a mathematical model of a steel roundabout ground-arranged model tank loaded up with oil. Tanks are thought to be fixed to an inflexible establishment. The barrel-shaped steel tank reactions are dissected utilizing Time History Analysis connected with Modal investigation by applying limited component programming. Variety in mode shapes with stature changing is noticed. A parametric report is directed by stature and henceforth the varieties of greatest sloshing wave tallness, regular frequencies, typical pressure, comparable pressure, and the mode are not really set in stone. What's more, it is observed that sloshing tallness increments with an expansion in fluid stature. In any case, the divider locking happens in all fill conditions as the little thickness of the shell divider [8]. Sivy et al., studied the seismic analysis of circular cross section. The used model is considered aboveground, vertical liquid storage tanks with different slenderness parameters. The researchers computed the natural frequencies and respective modes in addition to the response of the flexible tank using the response spectrum method [1].

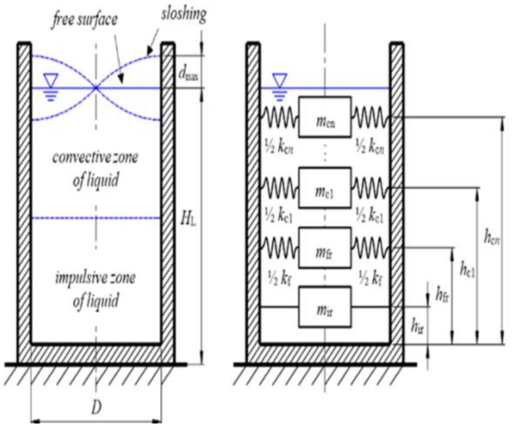



**Figure 1.** Spring mass equivalent model [7]

Annam and Sastry conducted a geotechnical seismic site response analysis with a network model of soil layers and piles. Time-dependent site-specific seismic acceleration analyzes were performed. Swing forces were taken into account for both full and empty tank conditions in the analysis. A 3D FEM seismic analysis of pile movement and forces during and after the earthquake was made and the piles were checked for structural adequacy [17]. Miladi and Razzaghi analyzed the dynamic loading situation by using the acceleration values created by the 6.1 magnitude earthquake in Iran in 2006. They carried out a parametric study to evaluate the effect of the amount of stored liquid on the seismic behavior and performance of the tank [18]. Çelik et al. They proposed an epoxy-carbon coating method to improve the seismic performance of cylindrical steel tanks. They stated that the Equivalent (von-Mises) stresses decreased significantly after the tank was covered with epoxy-carbon composite material [19]. Rawat et al. The swash displacement and bottom shear time history responses were evaluated for 3D tanks subjected to harmonic unidirectional ground motions. They concluded that the turbulent displacement is not affected by the tank flexibility, but the impact hydrodynamic pressure and the impact component of the bottom shear increase with the tank flexibility [20]. Maraveas compared the existing steel oil storage tanks used in practice with the finite element method and examined specific issues related to seismic design. He stated that although the current design methods failed to describe the exact behavior of the two cylindrical tanks he was comparing, they did not violate basic safety considerations [21]. Zhao et al. They used the Smoothed Particle Hydrodynamics-Finite Element Method (SPH-FEM) algorithm, a less computational algorithm, to simulate liquefied natural gas (LNG) tanks. They stated that the Von Mises tension increased at the bottom of the tank, and that strong earthquakes could seriously compromise the structural integrity of large LNG tanks [22].

In this present study, by observing the sample responses such as acceleration and deformation of the tested models, the results were compared and confirmed with previous studies. The main objective of this study is: To investigate the swash response under seismic action using oil reservoirs and examine the effect of tank height, as well as to investigate natural frequency-based modes. The main objective of this study is: To investigate the swash response under seismic action using oil reservoirs and examine the effect of tank height, as well as to investigate natural frequency-based modes.

## 2. METHOD

### 2.1. Mechanical model

A mechanical model replaces the reservoir-oil system based on the spring-cluster conditions and considered them as a spread the evaluation of hydrodynamic imposes. In these mechanical model it is recognized that vibrating fluid inside the vessel has two ingredients, one that proceeds in unison with the reservoir (recalled impulsive ingredient) and another one which undergoes sloshing proposal (recalled convective ingredient).

Figure 2 schematically demonstrates such a mechanical model.

Mechanical model was first progressing for reservoirs with rigid walls. ACI 350.3, indicates parameters of mechanical model for round reservoirs. NZSEE guidelines use mechanical model of Veletsos and Yang [8] for rigid orbicular reservoirs and that of Haroun and Housner for supple reservoir. For rigid round reservoirs, it suggests use of rigid orbicular reservoir model wherein, radius is replaced by half extent of reservoir. It states that in most issues, such an approximation for round reservoirs is expected to give base clips within 15% of worth's from more exact theory. For flexible round reservoirs, it suggests the same execution as that of rigid round reservoirs. This document also offers procedure for evaluating dashing and mechanical cluster of horizontal orbicular cylindrical reservoirs [14].

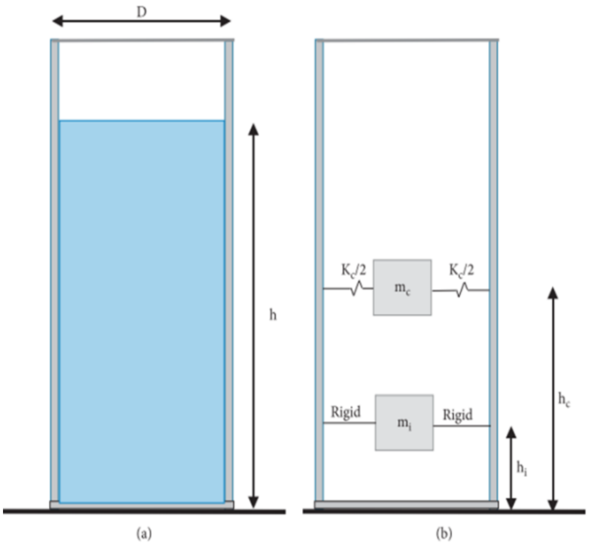



**Figure 2.** Description of reservoir [23]

## 2.2. Time Period of impulsive mode

Impulsive style refers to the lateral effect mode subjected on the reservoir-oil system. The impact of lateral seismic forces on reservoir depends on the impulsive style time period. Time period of reservoir -fluid system depends on the resilience of support also. Table 1 gives specifics of the expressions used in various icons to evaluate the impulsive style time period. For settled base orbicular reservoirs, ACI 350.3 uses formula specific by Veletsos, whereas NZSEE instructions have adopted the shape response from Haroun and Housner [6, 24]. Euro code 8 has pursued the expression specific by Sakai et al, [4, 25].

## 2.3. Hydrodynamic compression

Distributions due to lateral excitation stresses in the reservoir wall depend on allocation of hydrodynamic compression along the wall height. Veletsos et al, has also gained the distribution of hydrodynamic compression on rigid as well as supple wall. It may be mentioned that flexibility of reservoir wall does not affect the convective hydrostatic compression. However, it does affect the rushing hydrodynamic compression distribution, particularly for the slender reservoirs [7, 14]. Evaluation of impulsive compression distribution in flexible reservoirs is quite involved and can be done only through iterative executions. Expressions for distribution of dashing and connective hydrodynamic compression from various codes are specific in Table 2 [26, 27].

## 2.4. Response to vertical base excitation

Under the influence of vertical excitation, oil exerts axisymmetric hydrodynamic compression on reservoir wall. Knowledge of this compression is essential in duly assessing the safety and might of reservoir wall against buckling. In all the codes leverage of vertical rev is considered only for orbicular tanks, and there are no provisions on round reservoirs. Response to vertical excitation is mainly governed by the time while of fundamental breathing of vibration of reservoir -oil system. It may be noted that this style is for the issue of orbicular reservoirs only. Expression for perfect time period of a style of reservoir is quite involved. All codes do have provisions to consider reservoir response under vertical excitation [25, 28]. Expressions for time period of vertical style (breathing style), from various codes are specific in Table 3 [29].

## 2.5. Sloshing of height

The sloshing ingredient of oil cluster undergoes vertical displacement and it is needful to provide sui table free assembly to prevent spilling of oil. All the icons give explicit expressions to evaluate extreme sloshing ground-swell height. The safety of tank base under seismic effects can produce an internal energy impact if it elevated with liquid. This phenomenon produces a structural failure due to the potential liquid effect. The structural failure will affect the tank ring upper the base or the upper liquid level in the tank head [30, 31].

The difficulties in determining mathematical issues of the elevation of the unknown movement under free surface and in evaluating the non-linear boundary conditions based on geometry are the main problems. Many applied programs used the geometric and the large amplitude of sloshing materials. The simulation involved the following features the principle of variation is fully-coupled nonlinear liquid-structure interaction challenges with sloshing based on free surface. A finite element method used to investigate the structures using the concept of degeneration. Sloshing based on free surface modelling considered as the nonlinear wave theory formulation. The tensionless springs is used as a model for foundation. This method approved to be efficient in representing the nonlinear problem. The efficient time integration technique is used to solve the nonlinear governing equations. This method has been developed specifically to solve liquid-structure interaction problems [1, 30]. These expressions are specific in Table 4. Further, it may be aforesaid that NZSEE guidelines behold contribution of higher sloshing styles also. ACI 350.3 and Euro code 8 suggest higher of ground-swell height

**Table 1.** Expressions for dashing time period specific in various codes

| Tank type | Reference | Expression |
|---|---|---|
| Obricular reservoirs with settled base | ACI 350.3 | $T_i = \frac{0.628\, h\sqrt{P_c/E}}{C_w\sqrt{t/R}}$ ; $C_w$ is a coefficient specific as function of $h/R$ in graphical from ACI 350.3 |
| | NZSEE Guidelines | $T_i = \frac{5.61\pi\, h\sqrt{P/E}}{K_h}$ ; $K_h$ is function of $h/R$ and $t/R$ to be obtained from specific graphs. |
| | Euro code 8 | $T_i = \frac{2R}{C_i}\sqrt{\frac{ph}{Et}}$; $C_i = 0.01675(h/R)^2 - 0.15(h/R) + 0.46$ |
| Obricular reservoirs with supple base | ACI 350.3 | $T_i = \sqrt{8\pi(W_i + W_W + W_R)/(gDk_p)}$ |
| | NZSEE Guidelines | No expressions are specific |
| | Euro code 8 | |
| Round reservoirs with settled base | ACI 350.3 | $T_i = 2\pi\sqrt{W_i + W_w/(gk)}$ ; k= flexural stiffness of reservoir wall |
| | NZSEE Guidelines | $T_i = 2\pi\sqrt{d/g}$ ; d= deflection of Wall due to a uniformly distributed load of size $q = mfg/4Bh$ |
| | Euro code 8 | |

**Table 2.** Expressions for distribution of hydrodynamic compression due to lateral excitation specific in various codes

| ACI 350.3 | |
|---|---|
| • Obricular reservoirs<br>Impulsive compression<br>$P_i = 0.58A_i\,\gamma \tan h(1.732\ R/h)\,[4h - 6h_i - (6h - 12h_i)\,y/h]$<br>Convective compression<br>$P_c = 0.4A_c\,\gamma \tan h(R/h)^2(1.732\ h/R)\,[4h - 6h_i - (6h - 12h_i)\,y/h]$<br>y: Oil standart at which wall is investigated measured from rule | • Round reservoirs<br>Impulsive compression<br>$P_i = 0.58A_i\,\gamma \tan h(1.732\ L/h)\,[4h - 6h_i - (6h - 12h_i)\,y/h]$<br>Convective compression<br>$P_c = 0.132A_c\,\gamma \tan h(L/h)^2(1.732\ h/L)\,[4h - 6h_i - (6h - 12h_i)\,y/h]$<br>y: Oil standart at which wall is investigated measured from rule |
| **NZSEE Guidelines** | |
| Explicit expressions are not specific, however grapically distribution of hydrodynamic compression is shown. These graphs are specific for orbicular as well as round reservoirs. Distribution for orbicular reservoir is possessed from Veletsos (1984). | |
| **Euro code 8** | |
| Expressions from Veletsos are specific. | |

**Table 3.** Codes for distribution of hydrodynamic compression due to lateral excitation give in various codes

| | |
|---|---|
| **ACI 350.3** | $P_v = A_i\gamma hb\,(1 - y/h)$<br>b: Ratio of columnar and horizontal rev, b should not be minus than $2/3$ |
| **NZSEE Guidelines** | $P_v = A_i\gamma h\,(1 - y/h)$ |
| **Euro code 8** | For rigid reservoirs: $P_v = A_i\gamma h\,(1 - y/h)$<br>For flexible reservoirs:<br>$P_v = A_i\gamma h\,(1 - y/h) + 0.815A_i\gamma h \cos\left[\frac{\pi}{2}\left(1 - \frac{y}{h}\right) f(\frac{h}{R})\right]$<br>$f\left(\frac{h}{R}\right) = 1.078 + 0.274\ln(y/h)$ for $0.8 < h/R < 4.0$<br>$= 1.0\ for\ h/R < 0.8$ |

**Table 4** Expressions for extreme sloshing ground-swell height specific in various codes [29]

| Code | Sloshing ground – swell heihgt |
|---|---|
| **ACI 350.3** | A.R. |
| **NZSEE Guidelines** | 0.84 A.R. (Considering only first style) |
| **Euro code 8** | 0.84 A.R. |

### 2.6. Modal analysis

In designing a structure under dynamic load Structural shapes of mode and natural frequencies are crucial problems in this field. These problems can be considered as the initial conditions of the analysis process. The modes represent the structural response of the body which is used to evaluate its characteristics. Modal analysis can be found in ANSYS Workbench software and can be produced based on the mesh generation of the tanks body using finite element method. One of the important sties in this condition presented a six mod and frequency plots of open tank model as shown in Figure 3 [31].

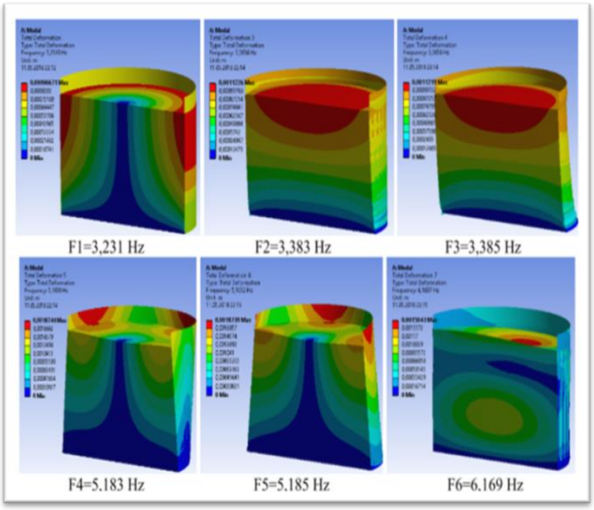



**Figure 3.** Samples of modal analysis [31]

Provisions for consideration of soil interaction are provided only in NZSEE guidelines and Euro code 8. First savings pertains to influence of soil flexibility on time period of reservoir. Expressions for time period of lateral and vertical style of reservoir, including the leverage of soil flexibility are supply [24]. Secondly, inclusion of ground also increases the damping of the build. Expressions are also provided for equivalent damping of reservoir – fluid – soil system.

## 3. FINITE ELEMENT METHOD (FEM)

Today, observations and approximate solution methods have gained great importance with the widespread use of high-capacity computers in engineering applications. Particularly, the Finite Element Method (FEM) is widely used in solving problems due to its high accuracy [32-34]. The FEM is a critical procedure for numerical investigation of engineering problems in civil engineering as well as other engineering branches. The numerical investigation of the oil tank structure response is performed on the basis of a detailed FEM model and tested with the help of the available ANSYS. In order to apply the continuity conditions of the shell media and fluid at the tank boundary, the nodes of coincident the fluid and shell element are constrained to be coupled in the normal direction of the interface, while relative forces are allowed to occur in the tangential directions. The uniaxial effects of the subjected forces are simulated using the ANSYS features based on the modal and spectral responses of the tank. The procedures utilized throughout this project as shown in the flow chart in Figure 4.

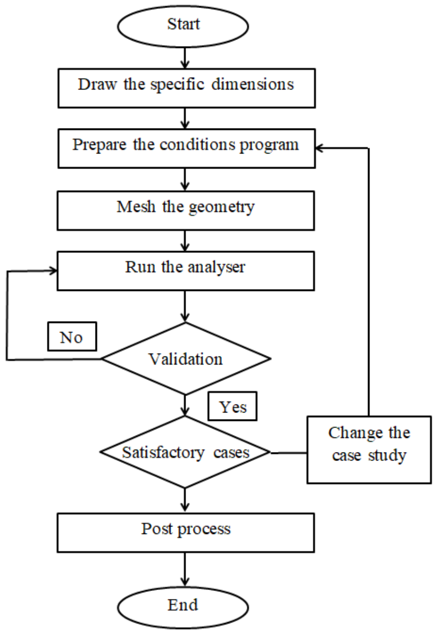



**Figure 4.** Flowchart of the project

Modelling is a sample of the building construction and also presenting some system of concern. A model is comparable to the system it signifies but simpler than it. The most important aim of a modelling is to allow the analyst the prediction of the effects on the system by making changes. A good model is a wise balance between practicality and ease.

The procedure of parameters identification of the selected material model from ANSYS file was carried out in the ANSYS setting via numerical calculation of the database of the model. Initial data of materials parameters represents the basis for the optimization or the evaluation process. The required for initial studies depend on the constraints and goals of study.

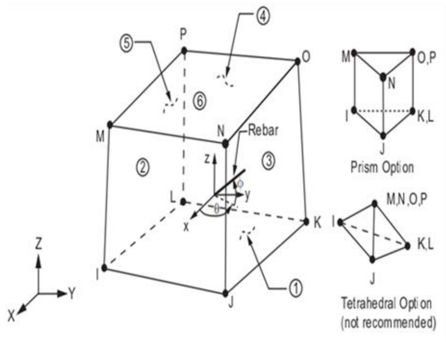



**Figure 5.** Solid input representations in ANSYS

There are many options that contribute to build the model, where the three-dimensional model is considered, which may consist of one or more materials (in this study the sample was considered to consist of steel structure materials filled with oil), be evaluate the inputs on the basis that the oil tanks consists of specific proportions of steel material. The selected model is made of three vectors, and the change in the effect of forces on the model used in these three vectors as a directional base (Figure 5).

In additional oil tanks data and technical specifications such as shear transmission coefficients, tensile stress, and compressive values are entered as indicated in the Table 5 for solid oil tanks materials. Tank material is 304L stainless steel.

**Table 5.** Solid oil tanks material options

| Mechanical properties | Symbol | Steel |
|---|---|---|
| Young's modulus (GPa) | $E$ | 193 – 200 |
| Poisson's ratio | $v$ | 0.3 |
| Density (kg/m$^3$) | $\rho$ | 8000 |
| Tensile Strength, Yield (MPa) | $S_y$ | 210 |
| Tensile Strength, Ultimate (MPa) | $S_z$ | 564 |

Steel bars of steel reinforcement modelling approach were introduced for linear isotropic model with 2×105 MPa and poison ratio of 0.3 and nonlinear inelastic with yield stress preliminary values 1581. The models have an integral form based on classical linear viscoelastic cases and nonlinearity was incorporated by linear interpolation of the material parameters with respect to stress. The viscoelastic model generated corresponds to the traditional rheological linear viscoelastic modelling approach.

ANSYS has two essential features to build geometry: they are; Nodes, which can be defined as a coordinate location in a field where the Degrees of Freedom (DOF) are described. The DOFs for the point shows the possible movement of this point due to the loading of the structure. The DOFs also represent which forces and moments are moved from one element to the next. The second feature is the elements which can be defined as the primitive building block of finite element analysis. It is a mathematical relation that defines how the degree of freedom of node is related to the next node. There are several basic types of elements. These elements can be lines (trusses or beams), areas (3D model) or solids (bricks or tetrahedral). Different element types are chosen based on the type of analysis which is going to be performed.

The next step is to mesh the geometry. In order to generate a computational mesh throughout the slab volume, it must be use the ANSYS Meshing application to create a mesh for the structural analysis. The procedure for generating a mesh of nodes and elements should process of setting the element qualities and setting Mesh controls. The 3D mesh elements can be of two types namely triangular and quadrilateral. Use of triangular element creates an unstructured mesh whereas; the use of a quadrilateral element creates a structured mesh. To create a mesh, either the element count (number of elements) or the element size can be specified. The size functions allow us to control the size of mesh-element edges for the geometric edges and for faces or volumes that are meshed. Meshing results propose a discretization of the case study. It is the most important part of an analysis and can determined the efficiency and effectiveness of an analysis because it gives the finite elements analysis. It can be easily build a model by employing linear curves and planar surfaces that is almost impossible to mesh. For that the metric can be used to identify invalid as well as potential poor quality elements, which may cause larger solution. The standard ANSYS mesh quality presents that (0.5 to 0.8) can be considered as a good result based on skewness statues, and the researcher achieve (0.79) mesh quality [35].

Mesh structure tetrahedral mesh model is made. Tetrahedral meshes are adaptive to the scene geometry and do not need to be rebuilt under certain type of deformations. Tetrahedral meshes are considered as an alternative acceleration structure in the literature.

The next process of applying the loads on the model is one of the most important processes in building the simulation, as the value, type, location, and direction of the load are essential in studying the behaviour of the model response. It is possible in the ANSYS program to determine the type, quantity, and locations of loads before or after the Mesh process. The loading process is filled with objects that have physical properties. In the model for this study, the place of loading was determined in the middle of the model and according to the actual model that was adopted. The forces will be distributed on the elements and nodes of the Mesh in the body and thus transfer the effect of the forces to those elements by a series of calculations based on the infinite elements of the body to find the effect of the load on both sides.

## 4. RESULTS AND DISCUSSION

The oil tank is analysed based on various liquid conditions and specified the sloshing height effect which studied to investigate the vulnerability condition. The various oil level specified in this study are 25%, 50%, and 75% fill. The test type of each group and the number of tests needed and the required variations are presented in Table 6. A circular and cylindrical constant thickness ground supported steel oil storage tank is modelled using ANSYS 15. The tank has an inner thickness of 10mm. The properties of oil and steel are shown in Table 7.

In order to ensure that the simulation model built in right conditions and will be solved in a good representation of reality, the validation technique used by comparing the results based on specific selected model. The modal analysis deals with the dynamics behaviour of the tanks structure. The modal analysis is used to determine the dynamic characteristics of a system such as natural frequency, mode shapes etc. It helps to point out the reasons of vibrations that cause damage of the integrity of tanks components. Using it, we can improve the overall tanks characteristics in certain operating conditions. The experimental modal analysis deals with measurements input data from which a mathematical model is derived by previous studies. The researcher uses the results of previous experiments which are developed by previous studies as a validation model and the results have been performed by finding the sloshing of oil in circular tanks. To validate the analysis, for simply supported one cylindrical tank, the values of sloshing are compared with the analytical results obtained from previous studies by using ANSYS software using cylindrical tanks, by taking the effect of foundation into consideration, the values of sloshing are compared with the analytical results of the other studies as shown in Table 8.

**Table 6.** Test groups

| Group | Tank Dimensions | Mode testes | Water level |
|---|---|---|---|
| Tank type 1 | Height: 21800 mm = 21.8 m<br>Diameter: 80000 mm = 80 m<br>Volume:109523.2×$10^9$ $mm^3$ = 109523 $m^3$ | 5 modes | 25%<br>50%<br>75% |
| Tank type 2 | Height: 11920 mm = 11.92 m<br>Diameter: 18980 mm = 18.98 m<br>Volume: 3370.84×$10^9$ $mm^3$ = 3370.84 $m^3$ | 5 modes | 25%<br>50%<br>75% |
| Tank type 3 | Height: 11920 mm = 11.92 m<br>Diameter: 22800 mm = 22.8 m<br>Volume: 4864.25×$10^9$ $mm^3$ = 4864.25 $m^3$ | 5 modes | 25%<br>50%<br>75% |

The simulation results observe a comparison between independent data of previous numerical results and ANSYS tests based on the same conditions. The results show the variation in values of sloshing of oil magnitudes. There is an agreement with the results obtained in this study they are compared and found that the minimum differences values. It observes a similarity values in all cases results which indicate that the model is valid.

**Table 7.** Tanks and oil properties

| Properties | Tank | Oil |
|---|---|---|
| Density | 7850 kg/$m^3$ | 890 kg/$m^3$ |
| Poisons ratio | 0.3 | - |
| Youngs modulus | 210 GPa | - |
| Bulk modulus | - | 1.2 GPa |

**Table 8.** Numerical comparison of sloshing v/s oil level

| Oil level | Pascal et al. | Present study |
|---|---|---|
| 25% | 0.3608 | 0.33267 |
| 50% | 0.3315 | 0.32646 |
| 75% | 0.3735 | 0.3604 |

### 4.1. Model analysis of cylindrical tanks with oil level 75%

Modal analysis is the investigation of the unique properties of frameworks in the recurrence area. It assists with deciding the vibration qualities (normal frequencies and mode states) of a mechanical design or part, showing the development of various pieces of the construction under powerful stacking conditions, for example, those because of the sidelong power produced by the electrostatic actuators. The normal frequencies and mode shapes are significant boundaries in the plan of a design for dynamic stacking conditions. Modal investigation, or the mode-superposition strategy, is a direct unique reaction technique which assesses and superimposes free-vibration mode shapes to describe dislodging designs. Mode shapes depict the arrangements into which a design will normally dislodge. Normally, parallel removal designs are of essential concern. A design with N levels of opportunity will have N comparing mode shapes. Every mode shape is an autonomous and standardized uprooting design which might be intensified and superimposed to make a resultant relocation design. The Modal space is one point of view for understanding underlying vibrations. Structures vibrate or twist specifically shapes called mode shapes when being invigorated at their regular frequencies. Under commonplace activity conditions a construction will vibrate in an intricate blend which comprises of all mode shapes. In addition, modal examination moves an intricate construction that isn't difficult to see, into a bunch of decoupled single-level opportunity frameworks that are easy to comprehend. In this research, the first test was to find out the response of the cylindrical tanks and results shown in the figures below (Figure 6).

### 4.2. Model analysis of cylindrical tanks with oil level 50%

The second step of modal analysis is the by taking a cylindrical tank with 50% oil level. The natural frequencies and mode shapes are taken based on the same conditions and shape of tank. Structures vibrate or deform in particular shapes when being excited at their natural frequencies. Under typical operation conditions a structure will vibrate in a complex combination which consists of all mode shapes. Modal analysis of this condition presents different frequency numbers and different shapes of deformation as shown in Figure 7.

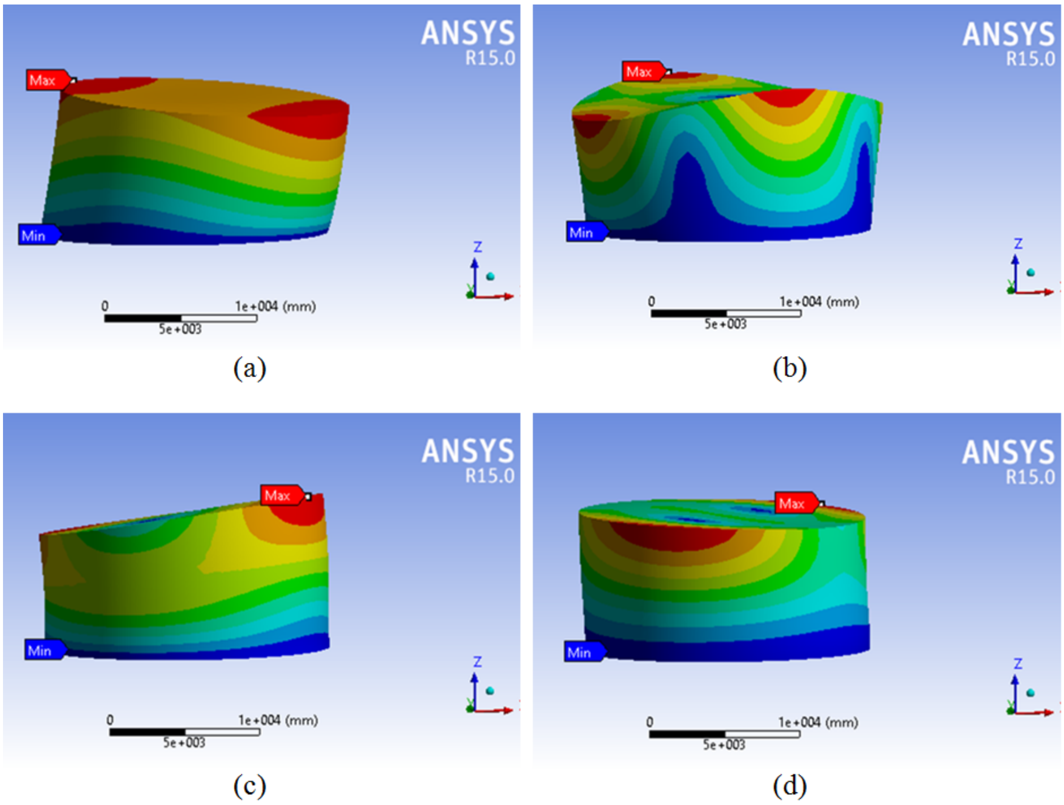



**Figure 6.** 75% Oil level deformation (a: mode 1, b: mode 2, c: mode 3, d: mode 4)

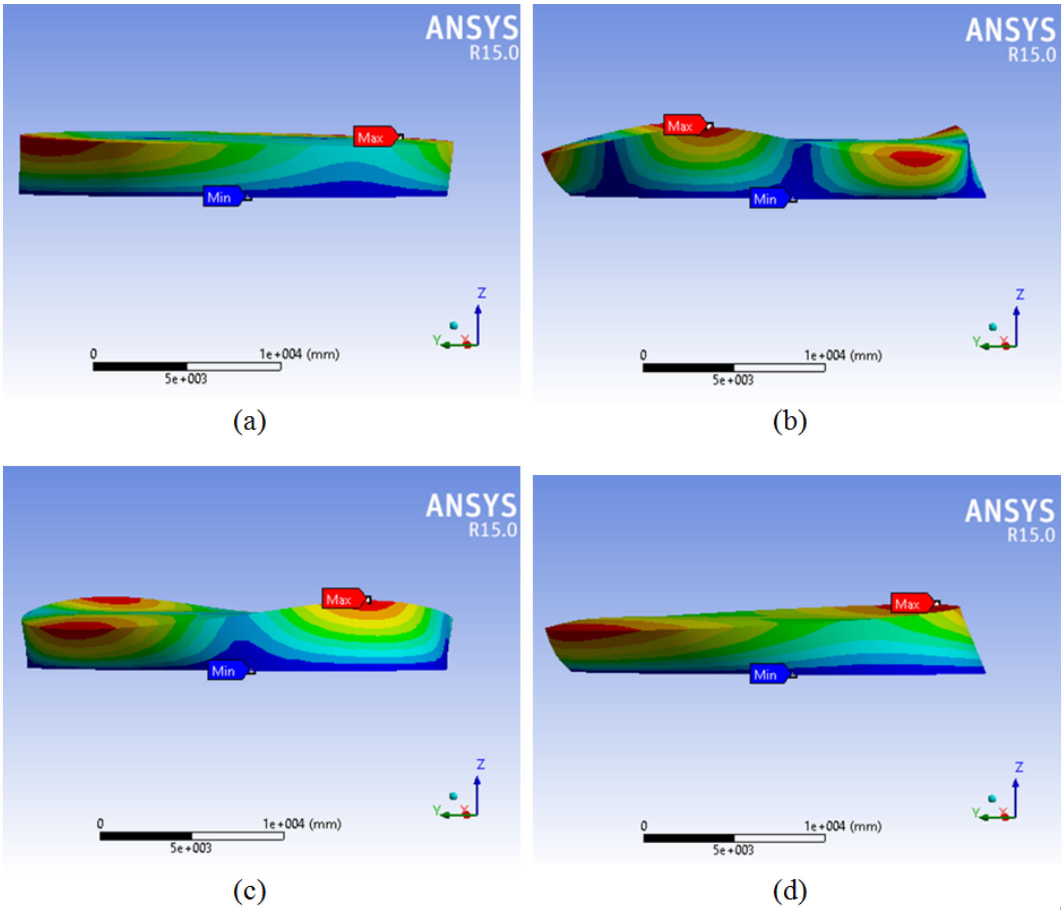



**Figure 7** 50% Oil level deformation (a: mode 1, b: mode 2, c: mode 3, d: mode 4)

### 4.3. Model analysis of cylindrical tanks with oil level 25%

The third step of modal analysis is the by considering a cylindrical tank with 25% oil level. The natural frequencies and mode shapes are taken based on the same conditions and shape of tank. The oil vibrates in particular shapes based on typical operation conditions and the surface structure will vibrate in a complex combination which consists of all mode shapes. Modal analysis of this condition presents different frequency numbers and different shapes of deformation as shown in Figure 8.

The comparison of impulsive frequencies for different boundary conditions is shown in Figure 9 and Figure 10. As the depth of fluid increases, the frequency of tank decreases for all the types of tanks. Also Figure 11 presents a clear comparison between the small tank in type 2 and large tank in type 1. The frequency in large tanks is less than the small one

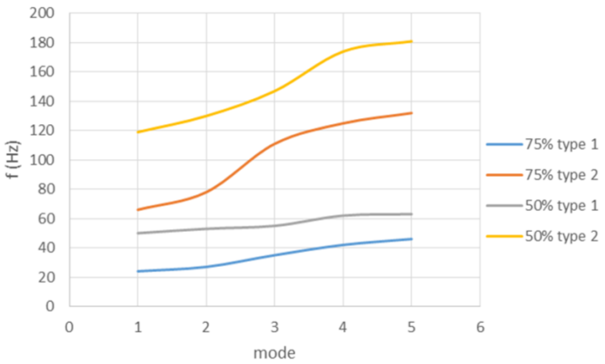
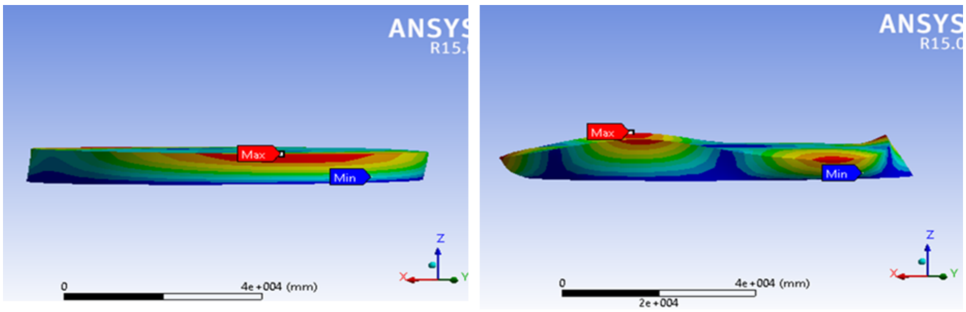



**Figure 11.** Comparison of impulsive frequencies for different types of tanks

### 4.4. Results of response spectrum

Response spectrum method for determining the overall responses of the investigated tank liquid systems fixed to a rigid foundation was performed. The seismic response




(a) (b)

**Figure 8** 25% Oil level deformation (a: mode 1, b: mode 2)

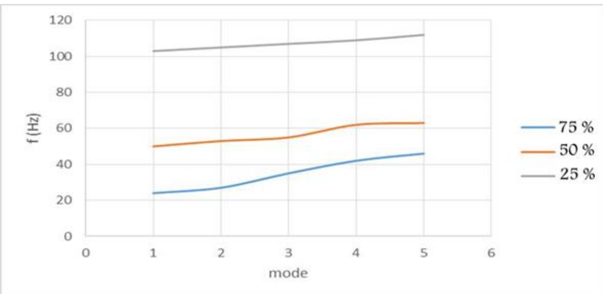



**Figure 9.** Comparison of impulsive frequencies for different oil level type 1.

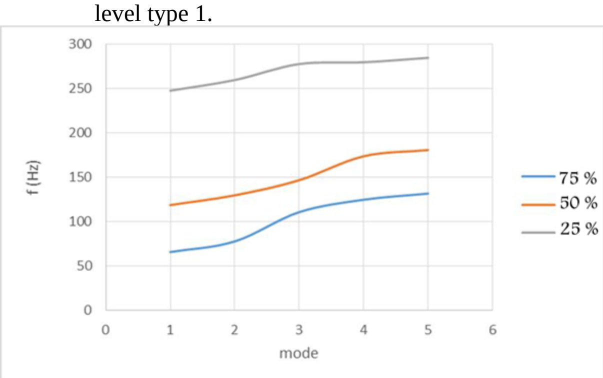



**Figure 10.** Comparison of impulsive frequencies for different oil level type 2.

was described by response spectrum curves; figures (Figure 12, Figure 13, Figure 14 and Figure 15) shows the overall responses of oil storage tanks to the earthquake response spectrum modal is one of the most common methodologies for describing the behaviours of structural system subject to seismic excitation.

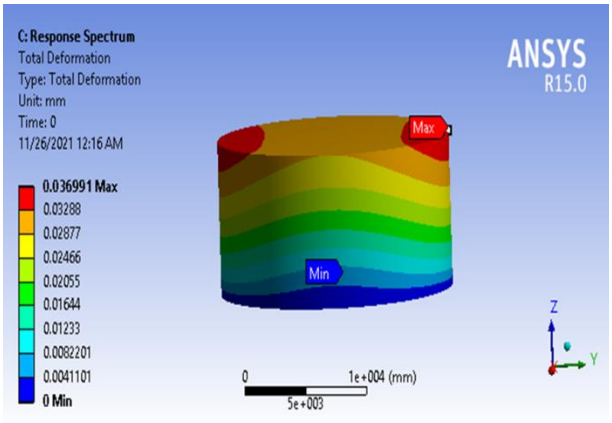



**Figure 12.** Responses of oil storage tanks to earthquake (tank type 1)

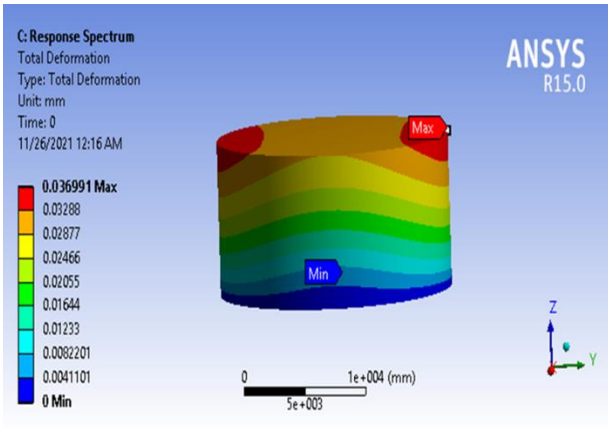



**Figure 13.** Acceleration responses of oil storage tanks to earthquake (tank type 1)

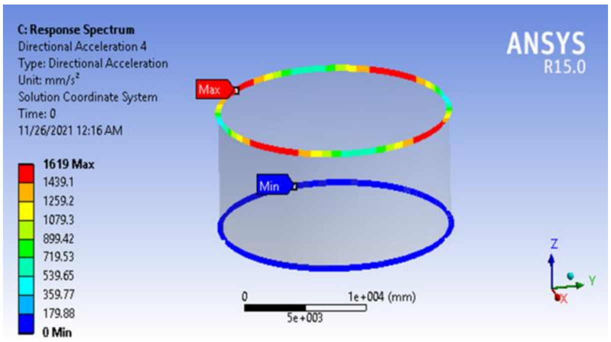



**Figure 14.** Directional acceleration responses of oil storage tanks to earthquake (tank type 1)

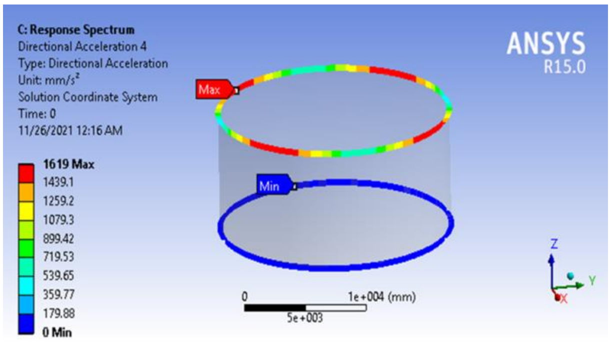



**Figure 15.** Deformation responses of oil storage tanks to earthquake (tank type 1)

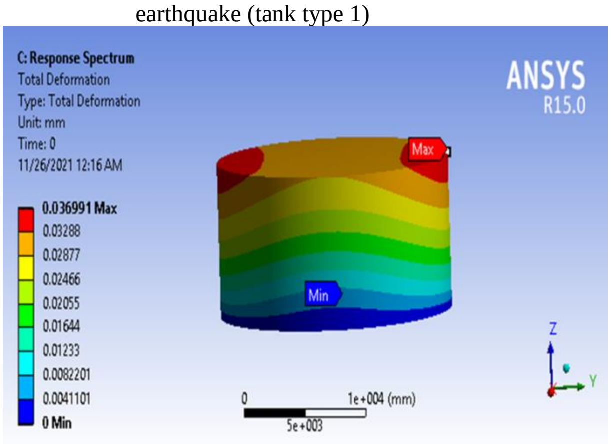



**Figure 16.** Responses of oil storage tanks to earthquake (tank type 3)

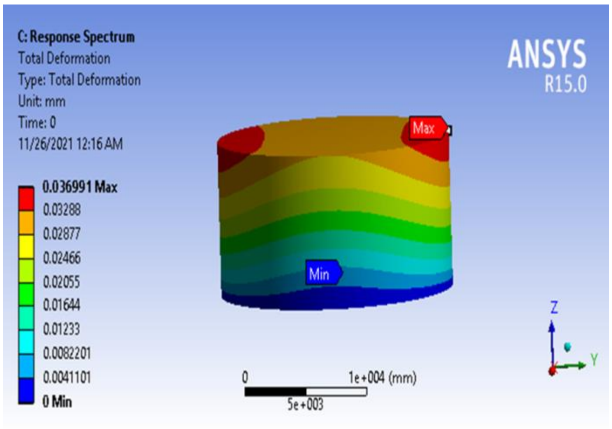



**Figure 17.** Acceleration responses of oil storage tanks to earthquake (tank type 3)

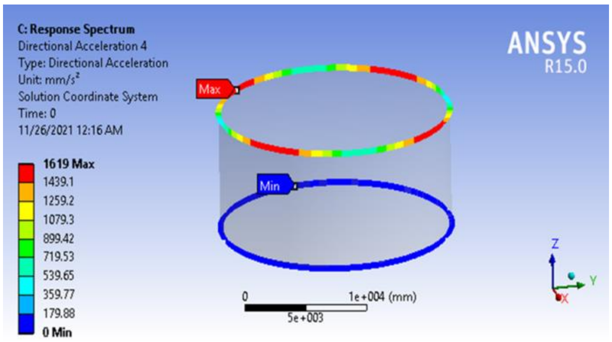



**Figure 18.** Directional acceleration responses of oil storage tanks to earthquake (tank type 3)

This method is often used instead of a time-history analysis to calculate the response to time-dependent loading. For computation of response of the tank filled with liquid, analysis is performed as shown in the results below. The tank-liquid system is excited with a corresponding response spectrum with proportional damping in the x-direction. Based on results from the modal analysis, this method is used for the combination of maximum modal response and this combination rule is used due to closely spaced modes of oscillation. As shown in the Figures, the overall response of the tank-liquid system to the response spectrum, the maximum response of the liquid-structure system presents the deformation type and acceleration, as shown in figures (Figure 4.23, Figure 4.24, Figure 4.25).

Due to the different responses, based on differences in tank size and oil level, these differences are significant especially when investigating the hydrodynamic oil pressure and tank size. On the other hand, the response of the oil mass and its contribution to hydrodynamic pressure are affected by the wall's upper position.

## 5. CONCLUSION

The main contribution obtained in this research is to investigation the earthquake effect subjected on tanks structure based on different oil level. The practical basis for this thesis is to find out the sloshing response and present the numerical results of seismic effect including deformation types and shape of failure in the tank structure. The results observed a similarity between independent data of previous numerical results and ANSYS tests and the case study published in previous studies. The results show the variation in values of sloshing of oil magnitudes. There is an agreement with the results obtained in this study they are compared and found that the minimum differences values. It observes a similarity values in all cases results which indicate that the model is valid. Also, the modal domain presented one perspective for recognizing liquid tanks structural vibrations.

The tank structure vibrates or deforms in particular shapes which are named mode shapes when expressed by their natural frequencies. Under the typical operation of oil tanks, the conditions of structural vibrations in x-axis mode shapes and the modal analysis observes a degree of freedom systems that are simple to be recognized the results observe a clear relationship between the oil level, tank shape and modal shape. The higher oil level presented a higher natural frequency in all cases. Finally, the overall oil tank response subjected to earthquake effect and spectrum modal show the deformation shape and the acceleration. The response spectrum modal observes an increment when the oil level increases. For that, the researcher recommends supporting the tank structure with a column in the deformation points.

Seismic analysis of buried and ground-supported storage tanks are recommended to be studied.

- To study the dynamic behaviour of storage tank when is roofing.

- Effect of the uplift due to pressure of the surrounding soil is important problems.

- It is recommended also to study the atmospheric pressure upon the tank.

A Pressure vessel is a device designed as a closed container that holds gases or liquids at a pressure considerably different from the ambient pressure. Due to differential operating conditions of pressure vessels, they are potentially dangerous and accident involving can be deadly and poses lethal dangers. The main aim of this work is to design and analyze a pressurized lube oil tank for working under varying operating conditions and to identify the most contributing parameter that controls the efficient working of the oil tank. Generally pressure will be developed inside the oil tank and also it has to withstand several forces developed due to both internal as well as external pressure acting on it, making the design critical. Hence for safety purpose, the pressure vessel was designed as per ASME standards. Further validation of PV-ELITE software was made by comparing its results with that of manually calculated design values. Efforts are made to understand the various stresses developed in pressure vessel. Generating a 3D model and analyzing it using a suitable FEM solver. Comparison of the result is made with PV-ELITE software results and found to be with agreeable range. The error percentage is 4.99% which is well within the permissible range showing 95 % accuracy.

In future studies, the response of oil storage tanks to seismic forces can be evaluated with different network structures, oil types and different tank geometries.

## DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

## AUTHORS' CONTRIBUTIONS

**Hussein neamah abualshun JANABI:** Literature review, finite element analysis.

**Hüseyin GÖKÇE:** Obtaining the necessary data for finite element analysis and writing the article.

**Ender SARIFAKIOĞLU:** Interpretation of results, final check.

## CONFLICT OF INTEREST

There is no conflict of interest in this study.

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