Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 5, Issue 09, September -2018

PLASTIC DEFORMATION OF CYLINDRICAL STEEL TANK BOTH UNDER THE KOCAELI AND EL-CENTRO EARTHQUAKE

Ali İhsan Çelik[1], [2]Tahir Akgül, Ahmet Celal Apay[2]

[1]*Besni Vocational High School, Adiyaman University, Turkey*
[2]*Civil Engineering, Sakarya University, Turkey*

Abstract —*This article is about the plastic deformation of cylindrical steel storage tank. Finite Element Method analysis was performed via Explicit Dynamic analysis tool of ANSYS Workbench software. A Lagrangian mesh was used for the tank body, and a Eulerian mesh technique was used for the water in the tank. One second acceleration values of Kocaeli and El-Centro earthquake were used as a displacement record. Maximum total deformation was 5.453 m under the Kocalei earthquake and it was 2,464 m under the El-Centro earthquake. By means of explicit dynamic analysis with two different seismic recordings, buckling shapes very close to real buckling were obtained. This study is a reference for determined plastic deformation risk of cylindrical steel tanks.*

Keywords*-cylindrical steel tanks; Eulerian mesh; seismic analysis; plastic deformation*

I. INTRODUCTION

Cylindrical steel tanks are significant thin walled engineering structures. Their prominence is increasing day by day especially for nuclear power plants areas. They may include dangerous chemical and petrol as well as firefighting water. If their mechanical behavior is well known, they can be protected under the devastating of earthquake loading. Qing-shuaiCao and YangZhao were performed buckling strength analysis of cylindrical steel tanks under the harmonic settlement, they indicated form the results that ultimate harmonic settlement and buckling mode of the tank are closely correlative geometric parameters [1]. When a tank containing liquid is subjected to earthquake movement, the liquid is subjected to horizontal acceleration. The tank walls will be exposed to hydrodynamic pressure. The liquid at the bottom of the tank behaves like a mass that is rigidly attached to the tank wall. The fluid mass moving along the wall is called as the impulsive mass. Impulsive hydrodynamic pressure acts on tank walls due to this impulsive liquid mass. The concept of separation of the response to the contribution of a single impulsive mode and a number of convective modes are followed, as originally advocated by Housner [2]. The liquid mass in the upper part of the tank experiences a sloshing motion which is called as convective fluid. For this reason, the hydrodynamic response is divided into impulsive and convective components in order to accurately investigate the dynamic behavior of the tanks. Housner proposed two mass models for a cylindrical tank. Housner's two mass models are widely used by many international codes such as API650, IITK-GSDMA Guidelines for Seismic Design of Liquid Storage Tanks [3,4]. J.M. Spritzer and S. Guze was reviewed by comparing the design provisions in API 650's Annex E with other well-known design documents around the world, including that of New Zealand and Japan. The liquid in the tank accelerates horizontally and compel forces on the tank wall during the earthquake. In addition, in the standards they are compared, damage situations such as hydrodynamic hoop stress, uplift, base buckling, freeboard, stress and overturning were taken into consideration. According their results, API 650 Annex E can be considered to adequately account for all the major failure states when compared to New Zealand and Japanese design documents [5].

In recent years, the tendency towards finite element modeling (FEM) of steel storage tanks involving tank wall and foundation flexibility issues have been increasing. One of these studies, was about the modeling of partially filled steel liquid tanks. Nicolici S. and Bilan R. M. focused on the computational fluid dynamics (CFD) analysis to estimate the effect of sloshing wave amplitude, convective mode frequency, pressure applied to walls. As a result of the analysis, it was found that the fluid structure interaction affected the sloshing effect and the wall elasticity strengthened the impulsive pressure [6]. In this study, impulsive and convective masses were evaluated together as a single mass to perform an explicit dynamic analysis.

Field investigations have been performed by various researchers to determine the type of damage that occurred in liquid in earthquakes and the factor causing these damages. In the field surveys, it has been revealed that liquid tanks are performing poorly under the influence of earthquakes and it has become necessary to develop new methods for increasing earthquake resistance. According the Preveen et al, when subjected to strong shaking, tanks respond in a non-linear fashion and experience some damage. However, no generally acceptable methods perform a non-linear seismic analysis of tanks. Therefore, the damage sustained by tanks underground motions of different intensities cannot be quantified easily [7]. Because of the simplicity design and low cost, very-thin-perimeter walls are used in construction of steel storage water tanks [1]. However, these cylindrical steel tanks are thin-shelled structures that are subject to internal pressure from stored liquid alongside lateral pressure that can arise from roof loads, horizontal loads such as earthquakes and the frictional drag of stored materials on the walls [8]. There are two important factors that impact the steel tanks' deformation after earthquake: the characteristics of the earthquake's force and the dynamic characteristics of the structure. Steel structure is affected by ground components that comprise two lateral components, a vertical component and three tensional components [9]. Steel storage tanks take several deforms under the earthquake loads. Large axial compressive stresses due to beam-like bending of the tank wall can cause elephant-foot buckling of the wall. Their roof and top can be damaged due to the sloshing liquid [10].

The finite element method has advantages during solving general problems with a complex structure shape. The ANSYS explicit dynamic package allows to capture the physics of short-term events for products exposed to highly nonlinear, transient dynamic forces. Custom, accurate and easy-to-use tools are designed to maximize user productivity. With ANSYS, it can be learned how a build reacts to heavy loads. Algorithms based on the first principles correctly predict complex reactions such as large material deformations and failures, interactions between objects, and fluids with rapidly changing surfaces.

In this paper, Explicit dynamic analysis was performed with Kocaeli and EL-Centro earthquake short one second data being used for the non-linear analysis. In order to carry out the analysis, 1 second earthquake value which is between 9 and 10 second date was selected both earthquake. As a result, total deformation and directional deformation were compared for both Kacaeli and El-Centro earthquake. In addition, the plastic deformation patterns obtained by the finite element method are very similar to the deformations that have occurred in previous earthquakes. International code standards for cylindrical steel tanks continue to evolve in the light of scientific work being done. In this study, plastic deformations that may occur in tanks during severe earthquakes were determined by the finite element method, contributing to both the literature and cylindrical steel tank standards. This work also will be able to a reference for the determination of the different buckling damages of cylindrical steel tanks at risk.

II. PARAMETERS of TANKS

The cylindrical steel storage tank and fluid body were modelled with ANSYS Workbench. The materials used to model the water storage tank are the structural steel and water element. The density of structural steel was 7850 kg/m^3, Young Module 210 GPa and Poisson Ratio 0.3. Water density of water 1000 kg/m^3 and bulk module 2.2 GPa were determined.

Diameter of tank is 15,08 m, height is 11,31 m and shell thickness is 0,06 m. Explicit dynamic analysis was performed with water levels of 10 m. The problem of the interaction between the shell and the liquid is modelled using the interaction between Eulerian and Lagrangian bodies to provides an ability to interact tightly in a bidirectional fluid structure in the Explicit Dynamics system. Design size and mesh models of tanks are shown in Figure 1.

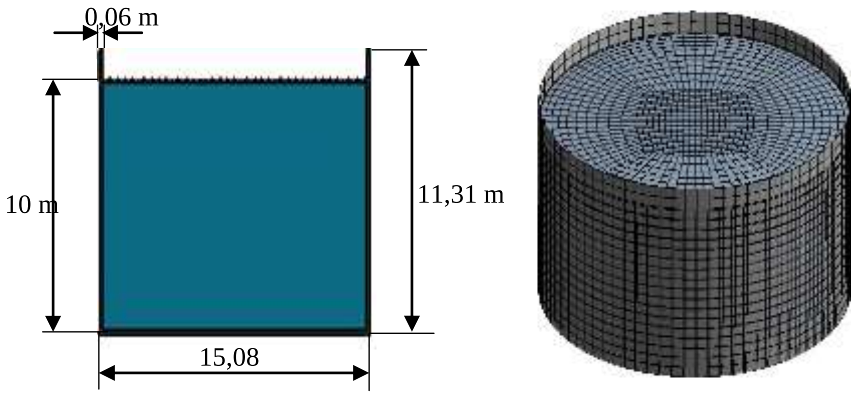


Figure 1. Design Size and Meshed View of Tanks

III. FLUID-STRUCTURE INTERACTION

Solid bodies can be either Lagrangian reference frame or Euler reference frame in the Explicit dynamic system. The reference frames can be simulated to allow the best solution technique to be applied to each modeled item. During the simulation, the organs represented in the two reference frames are automatically interact with each other. For instance, if a body is filled with steel using a Lagrangian reference frame and another body filled with water using the Euler reference frame, the two bodies will automatically interact with each other if they are in contact. The interaction between Eulerian and Lagrangian bodies provides the ability to interact tightly in a bidirectional fluid structure in the Explicit Dynamics system.

As in the following simple example, a body with a Lagrangian reference frame (gray) moves from left to right on a body with Euler reference frame. As the body moves, Euler cells act as a moving border in the Euler region, progressively covering their volumes and faces. This leads to a material flow in the Euler Domain. At the same time, a stress field will develop in the Euler region resulting in external forces applied to the moving Lagrangian body. These forces will return to the movement and deformation (and stress) of the Lagrangian body. Simulation of Eularian reference frame is shown in Figure 2.

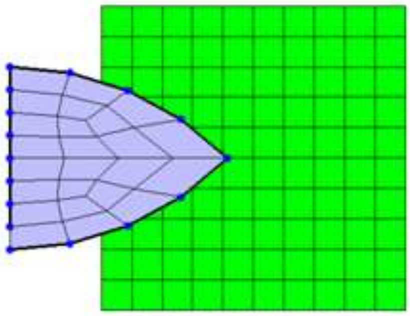


Figure 2 Eulerian reference frame [11]

In more detail, the Lagrangian body covers areas of the Euler area. The intersection between Lagrange and Euler bodies leads to an updated control volume in which the conservation equation of mass, momentum and energy is solved. In Figure 3 is more detailed Eulerian reference frame.

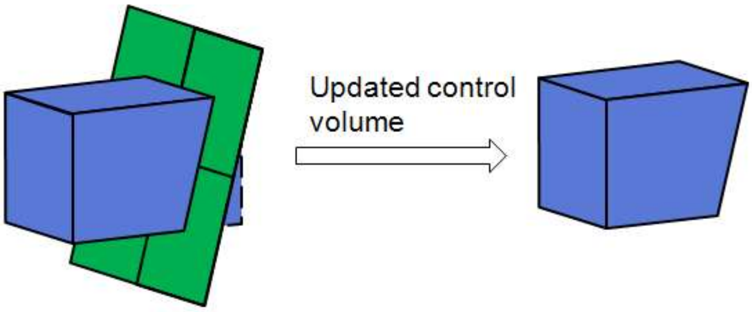


Figure 3 Eulerian reference frame [11]

At the same time, normal stress on the intersecting Euler cell will move over the intersecting area of the Lagrangian surface. Interaction of the Lagrangian cells and normal stress are presented in Figure 4.

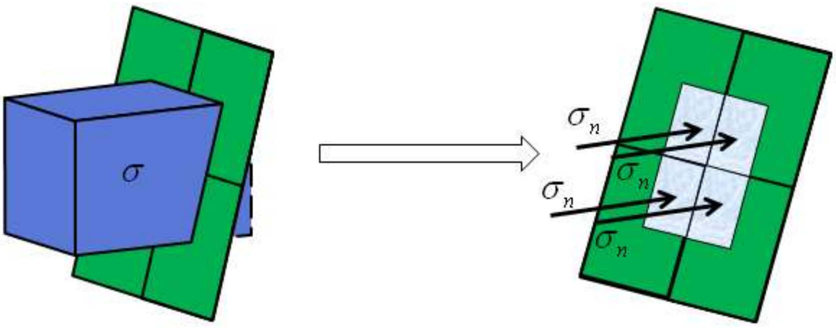


Figure 4 Normal stress in the intersected Euler cell [11]

This provides a bidirectional interconnected fluid structure interaction. During a simulation, the Lagrangian structure can move and deform. Large deformations can cause erosion of elements from the Lagrangian body. In such cases, the connection interfaces are automatically updated.

To achieve precise results when combining Lagrangian and Euler objects in Explicit Dynamics, it is necessary to ensure that the size of the cells of the Euler dominant is smaller than the minimum distance along the thickness of the Lagrangian objects. If this is not the case, material leakage can be seen in the Euler region with the Lagrange structure [11].

Body interaction between tank's shell and water was performed automatically as frictionless. Interaction of bodies are shown in Figure 5.

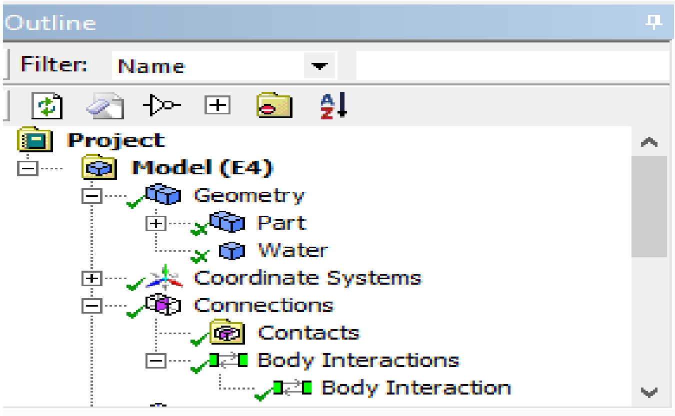


Figure 5 Interaction of bodies

IV. SETTING UP PROCEDURE 3D EXPLICIT DYNAMIC ANALYSIS

Setting-up process is composed of three consecutive steps named as pre-processor, execution and results. First step begins with create an Explicit Dynamics Analysis system by double-clicking on the system as shown in Figure 6.

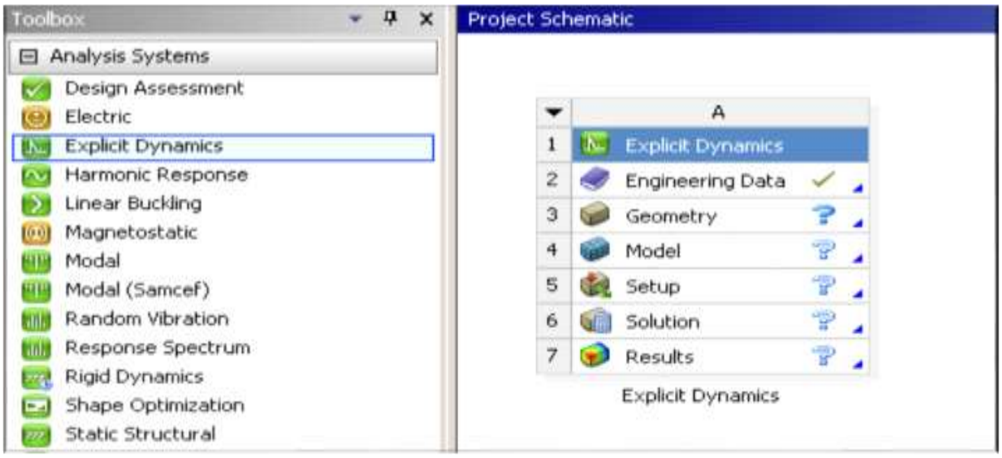


Figure 6 Established Explicit Dynamic Analysis

Properties of water material can be defined the under "Engineering Data" option. Density and Isotropic are added the following and physical properties can be defined by dropping and drop them to the specified material. While defining Poisson ratio of water should be defined as in the Figure 7.

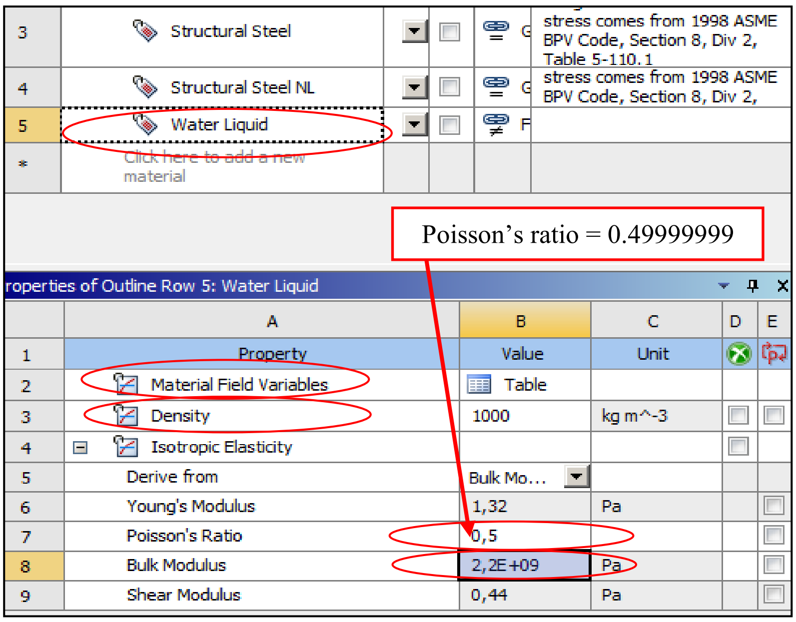
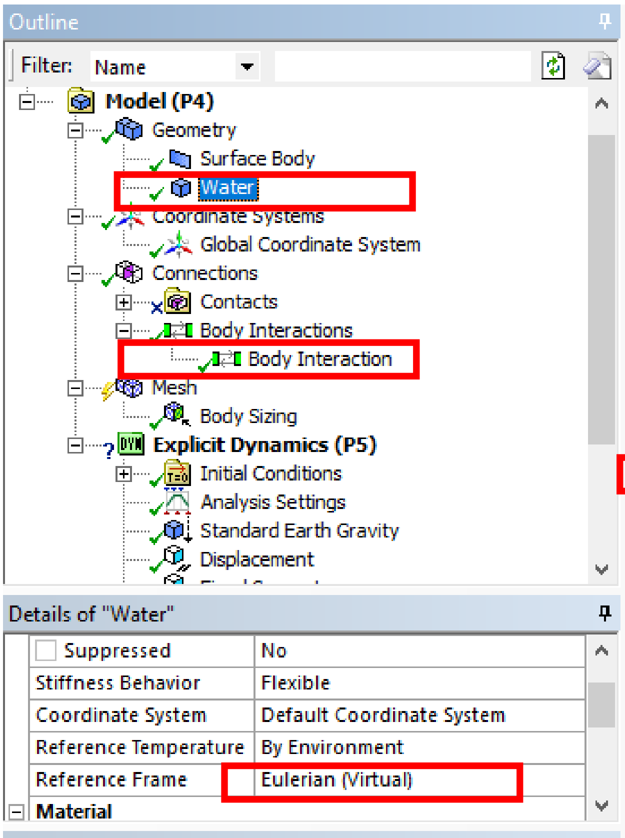
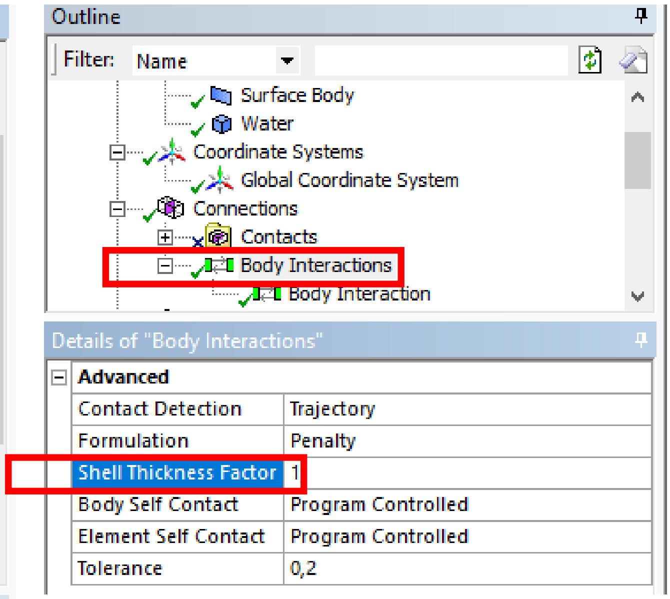


Figure 7 Definition of Material Properties

In the following Figure 8. (a and b) defines are significantly vital. Reference frame define “Eularian (Virtual)” for water and shell thickness factor should be 1.



a) Define Eularian (Virtual)



b) Define Shell Thickness Factor

Figure 8 Specify Materials

In Figure 9 shows of the Scope. The scope should be changed to “Eulerian Bodies only” (there is no need to extend the Euler mesh to cover the tank shell). Total cells should be reduced the from 250000 to 25000 (this is a simple model, so a very fine Euler mesh is not needed).

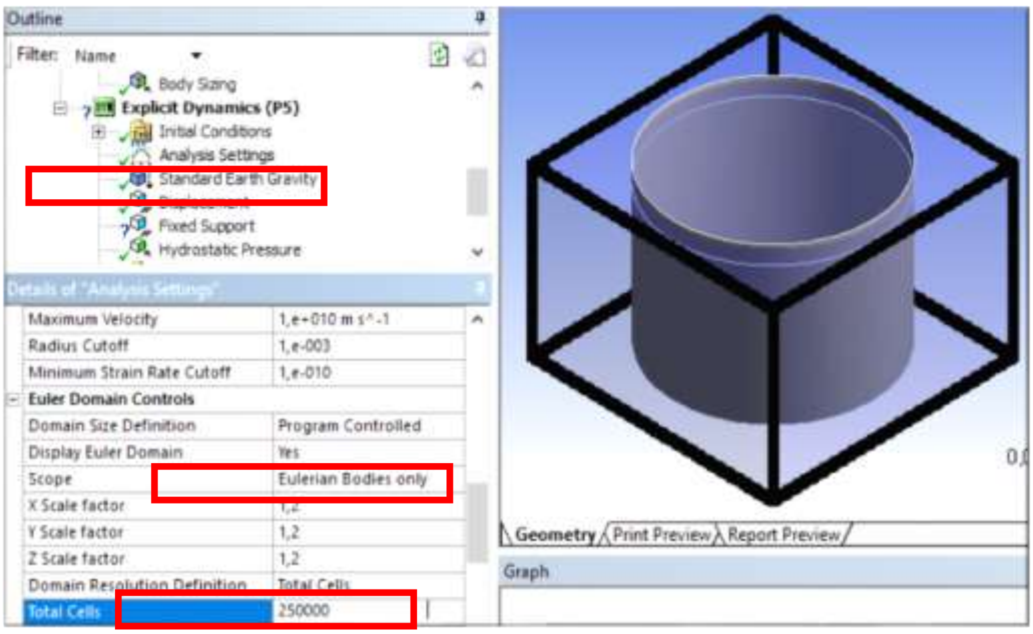


Figure 9 Define Eulerian Bodies only

After setting accurately explicit dynamic of water tank, it can be meshed. The mesh body size defined 1m. Mesh model of tank is shown in Figure 10.

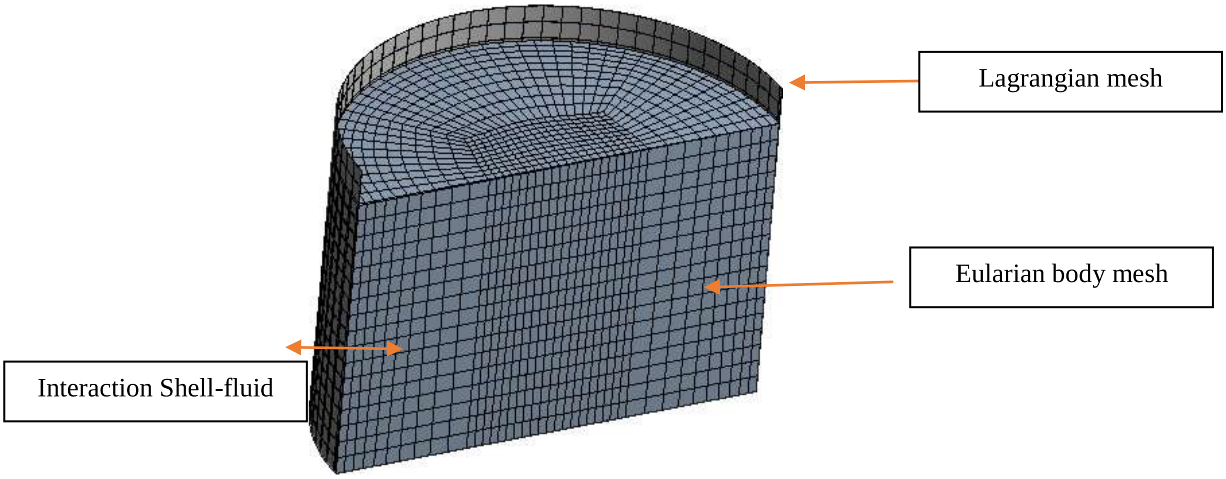
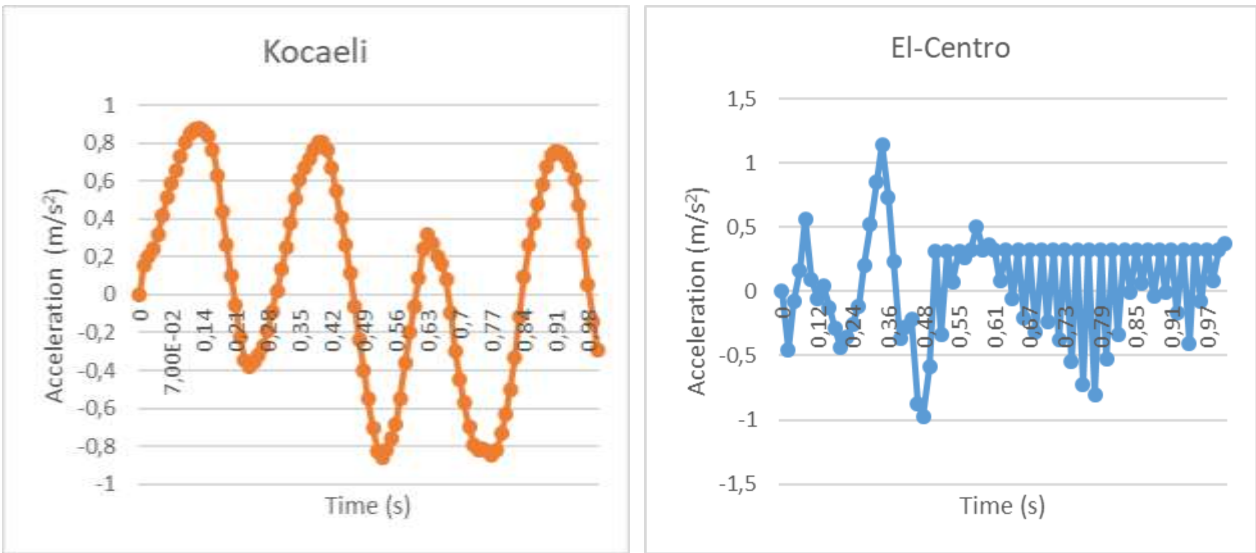


Figure 10 Mesh models of tanks

Figure 11 shows Kocaeli and El-Centro earthquakes acceleration graphics for 1 second time which are used for plastic deformation of cylindrical tank. Both earthquake include acceleration between -1 and 1 second time intervals. While the Kocaeli acceleration behavior is similar to the parabolic curves, the El-Centro acceleration contains stricter and sharp lines. Those values were selected from Kocaeli and El-Centro earthquake accelerations records to see plastic deformations.



a) El-Centro Acceleration b) Kocaeli Acceleration

Figure 11 Accelerations selection

The explicit dynamic analysis is used to determine the dynamic response of a structure due to stress wave propagation, impact, or time-dependent loads due to rapidly varying time. The momentum change between moving objects and inertial effects is often an important aspect of the type of analysis performed. This type of analysis can also be used to model highly nonlinear mechanical events. Nonlinear materials can be caused by material contact and geometric deformation. Events with less than 1 second time scales are simulated with this type of analysis effectively [11]. In the analysis, explicit dynamic, 1 second earthquake values were defined as displacement force. Some determines are shown in Figure 12.

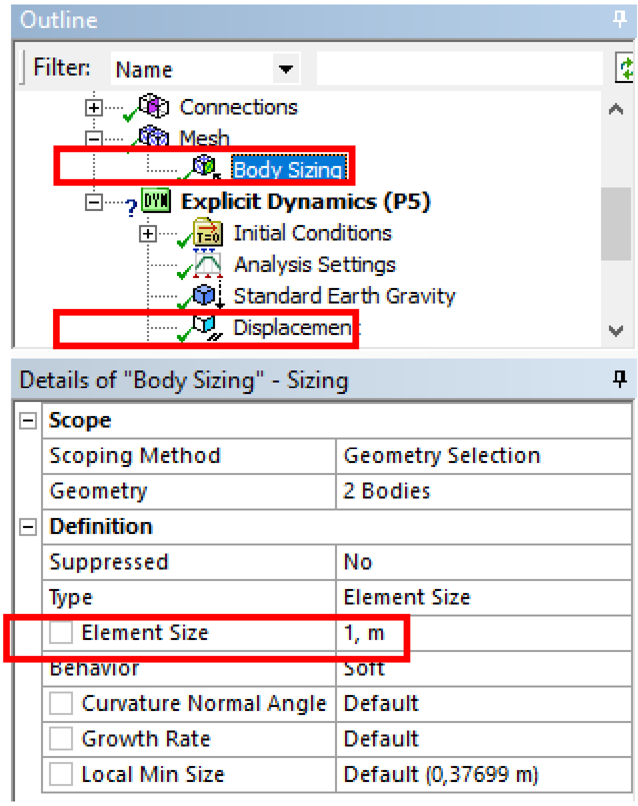
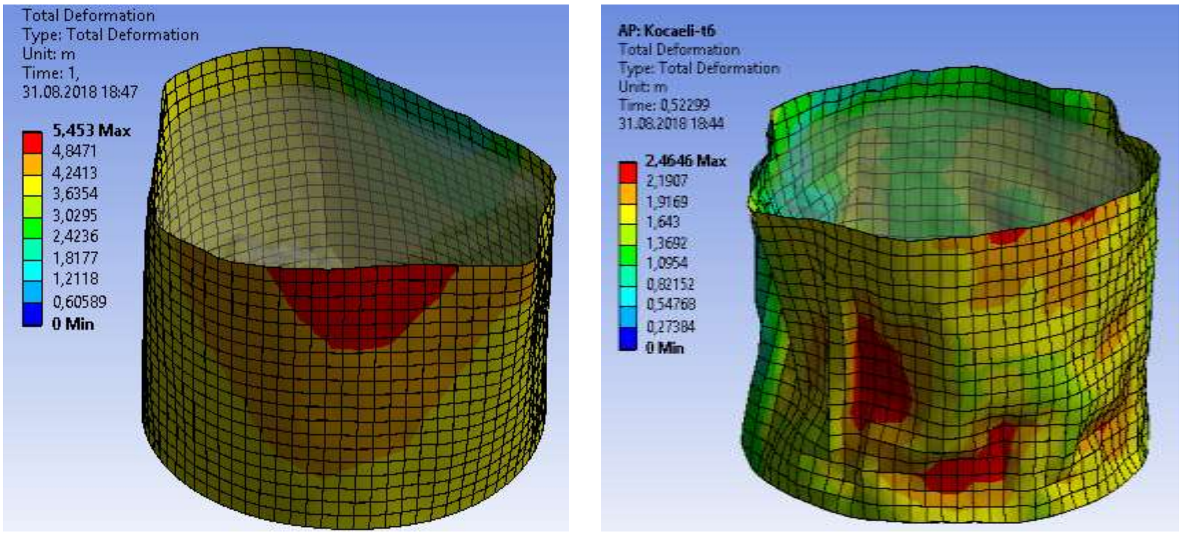


Figure 12 Define Eulerian Bodies only

V. DISCUSSION AND CONCLUSION

4.1. Evaluation of Total Deformation

It was observed that the effect of total deformation due to the hydrodynamic pressure on the upper side of the steel tank was observed in images given both Kocaeli and El-Centro earthquake to see the impact of water on the walls. Red color shows maximum deformation and blue color shows minimum deformation. The maximum total deformation under Kocaeli earthquake is approximately twice as much as the El-Centro earthquake. The maximum total deformation reached around 5.453 m under the Kocaeli earthquake in Figure 13 (a) and it was happened as 2.464 m under the El-Centro earthquake in Figure 13 (b). When the tank wall was examined, it was observed that the deformation was more common in the lower regions under the El-Centro seismic loading, but the maximum deformation occurred on the upper side of the tank walls with sloshing effect under the Kocaeli earthquake.

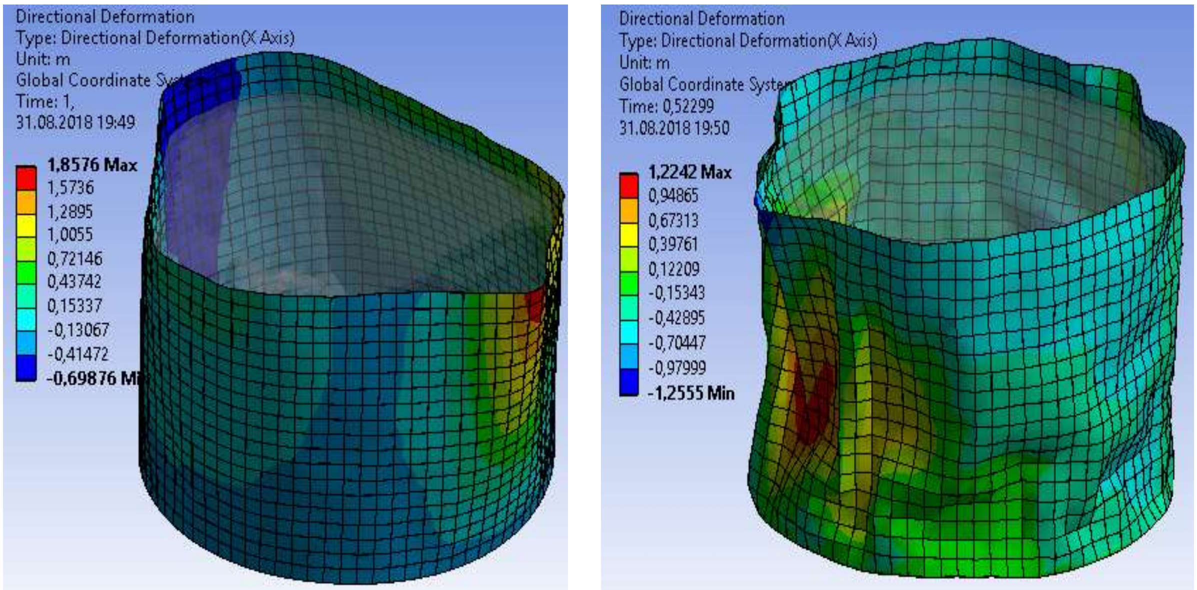


a) Total Deformation of Kocaeli b) Total Deformation of El-Centro

Figure 13 Total Deformation of Open-top tank

4.2. Evaluation of Directional Deformation

Figure 14 (a) and (b) is illustrated directional deformation. The maximum directional deformation reached around 1.8576 m in Figure 14 (a) and it was 1.242 in Figure 14 (b). When the directional deformation was compared with total deformation, it was observed that the directional deformation was lower especially under the Kocaeli earthquake.



a) Directional Deformation of Kocaeli b) Directional Deformation of El-Centro

Figure 14 Directional Deformation of Open-top tank

Figure 15 shows damages of cylindrical steel tanks because of the previous seismic events. In fact, the buckling obtained by the finite element method is very similar to the buckling that occurred during the previous seismic events. In particular, Figure 15 (a) is similar to Figure 15 (a) and also Figure 15 (b) to Figure 15 (b).

a) Roof and shell buckling b) Shell buckling

Figure 15 Buckling shape due to earthquake

VI. RECOMMENDATION

By means of explicit dynamic analysis with two different seismic recordings, buckling shapes very close to real buckling were obtained. These results show the risk situations of cylindrical tanks in earthquake zones. These studies can be further augmented to determine the seismic performances of the tanks in the earthquake zone and also it can be studied to strengthen of low seismic of performance tanks. In addition, that the Eulerian mesh technique, which is often used in impact analysis in ANSYS software, it can be used to simulate, nonlinear behaviors better in the analysis of containing liquids steel tank.

REFERENCES

[1] Qing-shuaiCao and YangZhao, "Buckling Strengh of Cylindrical Steel Tanks under Harmonic Setlement," Thin walled Sturcures. Volume 48, Issue 6, Pages 391-400, June 2010

[2] G. W. Houser, "Earthquake Pressures on Fluid Containers", Eighth Technical Report under Office of Naval Research, Project Designation No. 081 - 095, California Institute of Technology, Pasadena, California, pp. 02-16, Aug 1954.

[3] G. W. Houser, "Dynamic pressures on accelerated fluid containers", *Bull Seismol Soc Am*, vol 47, no 1, pp 15–35, 1957.

[4] G. W. Houser, "The Dynamic Behavior of Water Tanks", *Bull Seismol Soc Am*, vol 53, no 2, pp 381–387, 1963.

[5] J.M. Spritzer, S. Guzey, "Review of API 650 Annex E: Design of large steel welded abovegroun storage tanks excited by seismic loads", *Thin-Walled Structures*, vol 112, pp 41–65, 2017.

[6] S. Nicolici, R.M. Bilegan, "Fluid structure interaction modeling of liquid sloshing phenomena in flexible tanks", *Nucl. Eng. Des.*, vol 258, pp 51–56, 2013.

[7] P. K. Malhotra, T. Wenk, M. Wieland, "Simple Procedure for Seismic Analysis of Liquid-Storage Tanks", *Struct Eng Int*, vol 10, no 3, pp 197–201, 2000.

[8] K. R. Sunitha, B. Jacob, "Dynamic Buckling Of Steel Water Tank Under Seismic Loading", International Journal of Civil Engineering../KSÜ/KSÜ-Strenghtening1.docx - _msocom_1 IJCE, vol 4, no 6, pp 81–90, 2015.

[9] M. Mohamadshahi, A. Afrous, "General considerations in the seismic analysis of steel storage tanks", *Journal of Scientific Research and Development*, vol 2, no 6, pp 151–156, 2015.

[10] C. A. Brebbia, V. Popov, *Thirty-third international conference on Boundary Elements and Other Mesh Reduction Methods XXXIII*. Southamption: WitPress, 2011, 286, web link: https://books.google.com.tr/books?id=bOwoKUfWONIC&printsec=frontcover&hl=tr#v=onepage&q&f=false

[11] **SASIP inc.** https://www.sharcnet.ca [Çevrimiçi]. - 2018. - 01 08 2018. - https://www.sharcnet.ca/Software/Ansys/17.0/en-us/help/exd_ag/exp_dyn_theory_expl_flui_struct_582.html.

