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Strengthening of Cylindrical Steel Water Tank Under the Seismic Loading

Sismik Yükleme Altında Silindirik Çelik Su Tankının Güçlendirilmesi

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ABSTRACT

Cylindrical steel tanks are widely used to water store and for cooling in nuclear power plants. The seismic behaviour of liquid storage tanks is very complicated due to the hydrodynamic pressures of the fluids in them. In this paper, the epoxy-carbon coating method is suggested to improve of seismic performance of cylindrical steel tanks. Composite epoxy-carbon materials are widely used for winding thin walled cylindrical steel structures. After tank had coated with epoxy–carbon composite material, it was observed that Equivalent (von-Mises) stresses significantly decreased. The maximum hoop stress in the unprotected tank is 81.92 MPa, while the maximum stress is reduced to 44.77 MPa after it was coated with the epoxy-carbon.

Keywords: Cylindrical Steel Tank, ANSYS, FEM, Seismic Analysis

ÖZET

Silindirik çelik sıvı tankları nükleer enerji santrallerde su depolamak ve soğutma amacıyla yaygın olarak kullanılmaktadır. Sıvı depolama tanklarının sismik davranışları, içlerdikleri akışkanların hidrodinamik basınçlarından dolayı çok karmaşıktır. Bu makalede, silindirik çelik sıvı tanklarının sismik performansının iyileştirilmesi için epoksi-karbon ile kaplama yöntemi önerilmiştir. Kompozit epoksi-karbon malzemeler, ince duvarlı silindirik çelik yapıların sarılması için yaygın olarak kullanılmaktadır. Deponun epoksi-karbon kompozit malzeme ile kaplanmasından sonra, Equivalent (von-Mises) stresin ciddi şekilde azaldığı gözlemlenmiştir. Korunmasız tanktaki maksimum çember gerilimi 81.92 MPa iken, maksimum çevre gerilimi epoksi-karbon ile kaplandıktan sonra 44.77 MPa'ya düşmüştür.

Anahtar Kelimeler: Silindirik Çelik Tankı, ANSYS, SEM, Sismik Analiz

1. INTRODUCTION

Cylindrical steel tanks are widely used to store water and for cooling in nuclear power plants. Due to their importance, they should not be damaged during earthquakes. The seismic behaviour of liquid storage tanks is very complicated due to the hydrodynamic pressures of the fluids in them. Several researches have been performed in the literature to determine the seismic performance of cylindrical liquid storage tanks, considering dynamic fluid-structure interaction (FSI). Because of the simplicity design and low cost, very-thin-perimeter walls are used in construction of steel storage water tanks [1-6]. 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 [7]. The liquid mass in the upper part of the tank experiences a sloshing motion which is called as convective fluid. Thus, the hydrodynamic response is divided into impulsive and convective components to accurately investigate dynamic behaviour of tanks. Housner proposed a two mass model for a cylindrical tank. Housner's two mass model has been commonly used by many international codes such as API 650, IITK-GSDMA Guidelines for Seismic Design of Liquid Storage Tanks [8,9].

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

* This study was derived from PhD thesis in Natural & Applied Science Institute in Hasan Kalyoncu University.

resistance. According the Preveen et al, when the tanks are subjected to strong shaking, they react nonlinearly form and some damage. However, there is not a generally acceptable methody which performs a nonlinear seismic analsysis of tanks. Therefore, the damage to tanks exposed to ground motions of different densities cannot be easily determined [10]. Nonetheless, as thin walled structures the cylindrical steel tanks are subjected to internal pressures from stored fluid with axial compression that can arise from roof loads, horizontal loads such as earthquake and the frictional drag of stored materials on the walls [11]. 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 [12]. Cylindrical steel liquid tanks take several deformations 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 [13].

In general, there are two methods for seismic analysis of tanks, such as the API 650 formulation and the finite element method. The API 650 formulation method takes the study of Housner as a reference [8,9]. A useful tool was developed by Housner which was referred to as the spring-mass analogy to analyses aboveground storage tanks experiencing seismic forces by characterizing the system into two main components. Naghdali et al., examined several existing tanks using API 650 rules and FEM model with ANSYS software. Their results demonstrated that, in some cases, there are some imperfections in the API 650 specification that require further investigation [14].

Spritzer and Guzey compared the design provisions in API 650's Annex E with widely known design documents throughout the world, including 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, damage situations such as hydrodynamic hoop stress, uplift, base buckling, freeboard, stress and overturning were taken into consideration. According their to results, API 650 Annex E sufficiently considers all the major failures states unlike New Zealand and Japanese design documents [15].

There are many type of earthquake damage on the steel liquid storage tanks such as shell buckling (elephant foot buckling, diamond shape buckling), roof damages and connecting pipes. Elephant foot buckling usually occurs near the base of the tank and on the side of the shell wall which is an outward bulge at the bottom of the tank. Researchers asserts that elephant foot buckling is influenced by the level of tensile ring tension, where an increase in ring tension increases the possibility of the onset of elephant's foot buckling. [16]. Niwa and Clough concluded that such a failure mechanism is aresult of the combined effect of vertical compressive stresses exceeding critical stresses. This mechanism usually leads to pipe fracture and welding failure, resulting in loss of tank contents [17].

Altun expressed that the elephant foot buckling is a nonlinear behaviour due to seismic excitation. It occurrs under the critical buckling load with small amplitude The first shell material may begin to emerge in the event of a possible failure. For this reason, firstly damage may be occured in the structure then failure can be also become. In this manner, the possible failure may have an elastic character. In fact, this failure behaviour may be requested for earthquake resistant structure design because the seismic energy can be absorbed while the structure is damaged [18]. Elephant foot buckling damage is shown in Figure 1.

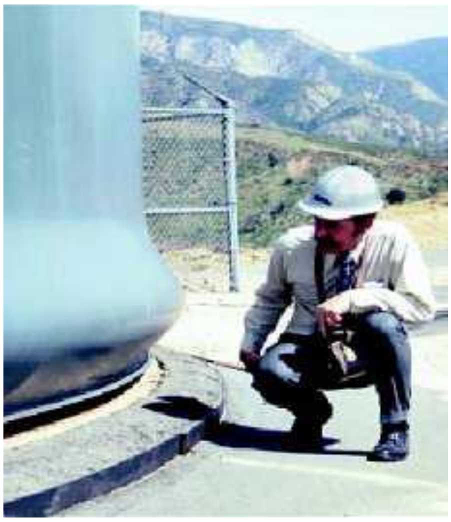

Figure 1. Elephant Foot Buckling

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 and Bilan 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 by sloshing effect and the impulsive pressure being amplified by the wall elasticity [19].

The finite element method has advantages during solving general problems with a complex structure shape. In this article, some basic seismic values were calculated by the API 650 standard, followed by the first sixty seconds of the North-South component of El-Centro accelerogram of 1940 data being used for the non-linear analysis.

The aim of this study is to perform earthquake analysis with ANSYS engineering software and to develop a new reinforcement technique on the cylindrical steel storage tanks. At the end of this study, variations seismic element of cylindrical steel liquid storage tank can be defined in the ANSYS Workbench software as well as effect of the tank strengthening techniques will be presented. Additionally, remedial measures of tanks to against earthquake may be understood. Finally, safely design and preserving of storage tanks will be able to suggestible for new industrial plants.

2. FINITE ELEMENT APPROACH

In this study, open-top of cylindrical steel tank is modeled using finite element technique. The ground-supported cylindrical steel water storage tank is assumed to be rigidly anchored to the rigid ground. Diameter of tank is 15.08 m, height is 11.31 m, shell thickness is 0.06 m and level of water is adjusted as 10 m.

Many type of construction requires the ability to predict the dynamic properties of engineering structures because of increasing demands for quality and reliability. This need can only be satisfied by the availability of appropriate mathematical representations of the structures studied and the advanced finite element technology which resolves the problem with different levels of success [20]. In finite element analysis, mesh density is an important issue that is closely related to the accuracy of finite element models and directly determines the levels of complexity. According to the FEA theory, fine-mesh of FE models achieve high accuracy results, but can take longer computing time. Conversely, having a rough network, FEM can result in less accurate results, but it saves more computing time. In addition, the small element size will increase the complexity of the finite element model and which is used only when high accuracy is required [21].

In order to refine acceptable mesh model, different element size was used. The aim here is to narrow the mesh to achieve the required accuracy precision by using as many degrees of freedom as necessary. The cylindrical water storage tank is modeled using 1984 shell elements and 4640 fluid elements are employed in FE modeling of the tank. According to Moslemi, as the mesh size increases, the number of elements decreases and the accuracy of the solution increases [22]. To adjusted a density mesh, a study on the FE solution convergence is conducted for rigid tank mesh model considering different numbers shell elements. The discretization error can be defined as:

$$E(\%) = \frac{P_{(EX)} - P_{(EF)}}{P_{(EX)}} * 100 \tag{1}$$

The mesh density refinement is continued until the difference between the results obtained from one mesh and the previously refined mesh becomes negligible. Graph of refinement mesh is presented in Figure 2.

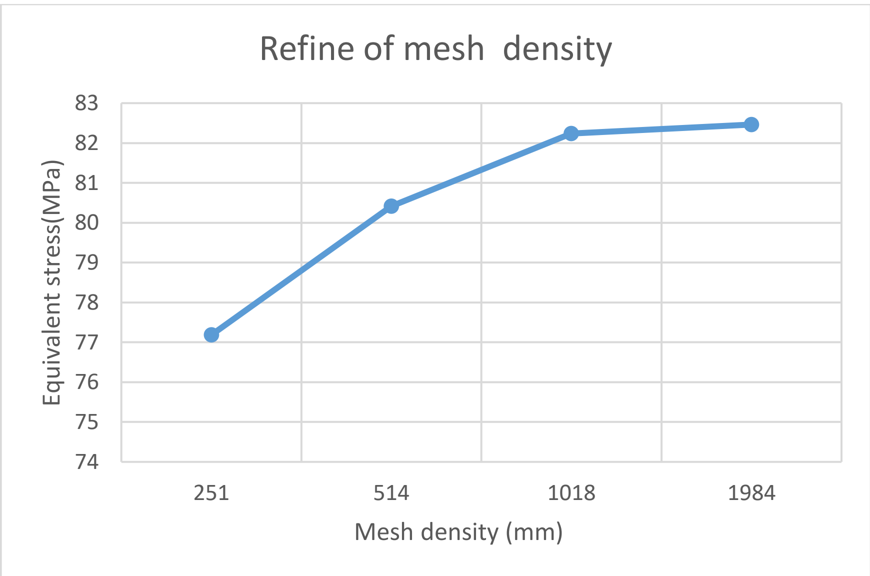

Figure 2. Refinement of Mesh Density

The problem of the interaction between the shell and the liquid is modeled using Shell 281, Solid 186, Contact 174 and Target 170 elements. Design size and the best refinement mesh model of tank are shown in Figure 3. Numerical verification is necessary to show that numerical models can predict responses with reasonable accuracy and precision. For this reason, a static and dynamic modal analysis of tank model is performed a result API 650. Modal analysis generally is used to understand the behaviour of a structure without any loads. 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/m3, Young Module 210 GPa and Poisson Ratio 0.3. Water density of water 1000 kg/m3 and bulk module 2.2 GPa were determined.

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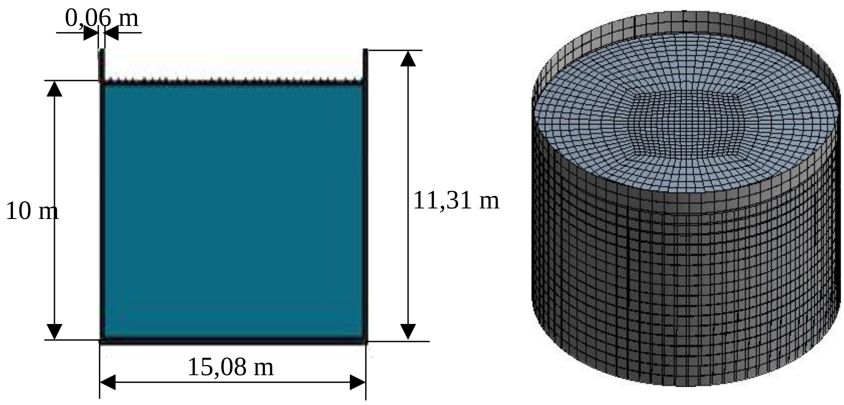
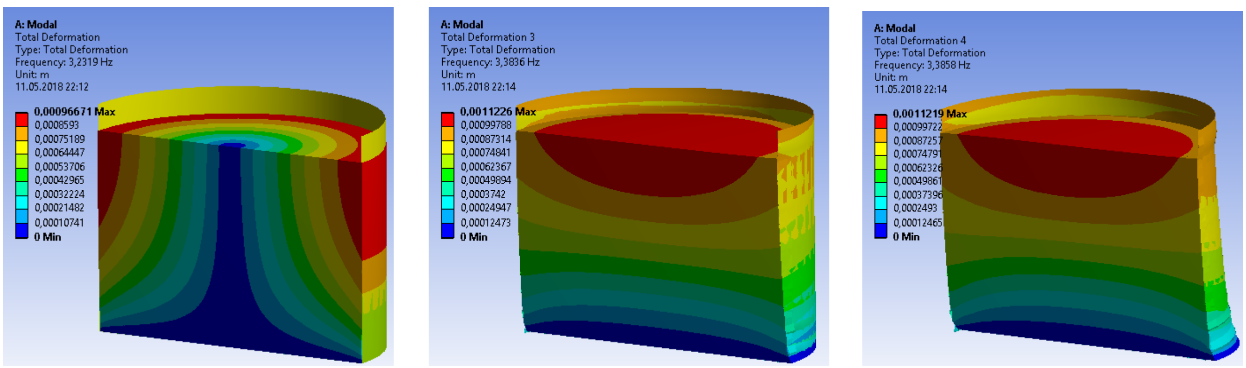


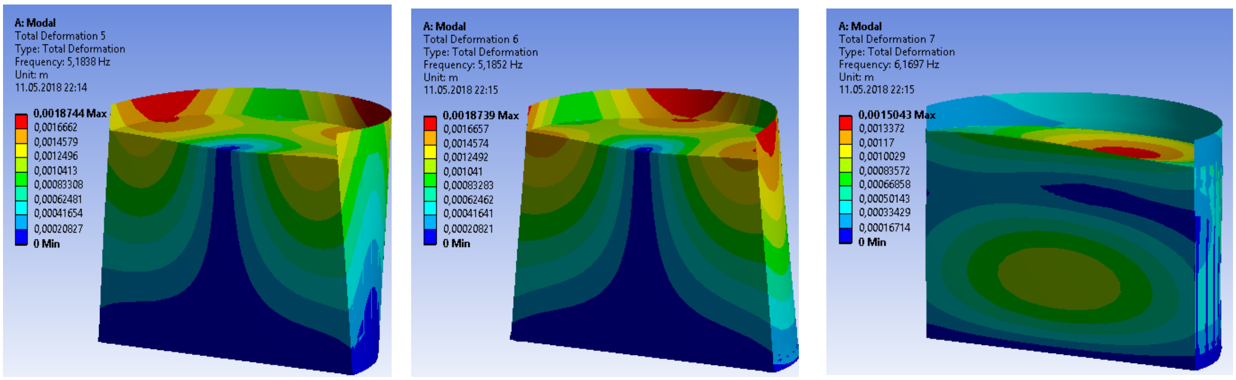
Figure 3. Mesh Model of Cylindrical Steel Water Tank

2.1. Modal Analysis of Tank

In designing a structure that is exposed to a dynamic load, the natural frequencies and mode shapes of a structure are very important. It can be considered as a starting point for a transient dynamic analysis. Generation and meshing of the finite elements for the shell of the tanks are based on the width of the plates used to form them. It is assumed that the damping factor is 2% for tank. The first 6 mode and frequency values of the open tank model are shown in Figure 4.



F1=3,231 Hz F2=3,383 Hz F3=3,385 Hz



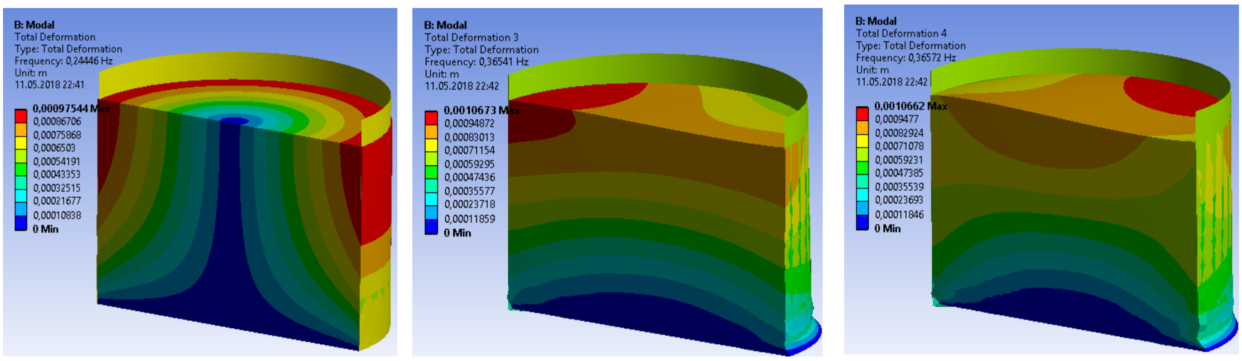
F4=5,183 Hz F5=5,185 Hz F6=6,169 Hz

Figure 4. Impulsive Modal Analysis Results and Frequencies

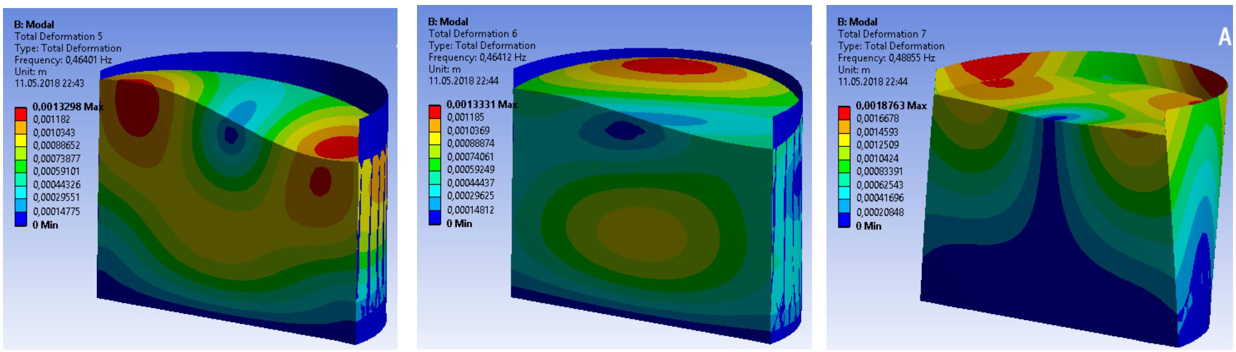
The motion of contained fluid in vertical cylindrical tanks with fixed based may be expressed as the sum of two separate contributions, called 'impulsive' and 'convective', respectively. When the water tank is accelerated under seismic conditions, a part of the liquid mass moves in same direction in harmony with the tank. This part of the liquid mass is known as the impulsive mass. The vibration modes set up by this mass are called the impulsive modes. Other parts of the liquid mass may be exposed vibration due to inertial properties and cause sloshing. This part of the liquid mass is called the convective mass and the vibration modes set up by this mass are called the convective modes.

The convective mass is located at the position indicated by h_c in the upper part of tank, and represents the liquid mass causing the liquid face sloshing. The point mass moved with the liquid mass and the tank was exposed to the sloshing the face of water.

The interaction between structure and liquid has vital importance. Great effort was made to accurate the interaction between the shell and the liquid. The results of the modal analysis performed in the ANSYS workbench software using the finite element method were compared with the analytically calculated method. The first 6 convective modes are shown in Figure 5.



F1 = 0.24446 F2 = 0.36541 F3 = 0.36572



F4 = 0.46401 F5 = 0.46412 F6 = 0.48855

Figure 5 Convective Modal Analysis Results and Frequencies

In fact, modal analysis is not directly related with this study, but in order to crosscheck finite element model of cylindrical steel tanks, first free vibration frequencies were calculated using API 650 formulation and compared with finite element frequencies values. Table 1 compares the results between the FEM analysis frequencies and the API 650 formulation calculated first frequency values respectively. The natural frequency of impulsive and convective mass can be calculated with follow equations 2 and 3.

$$\omega_i = \frac{2\pi}{Ci * hi} * \sqrt{\frac{E * t}{p * r}} \quad =20.51 \text{ rad/sn} \quad =3.23119 \text{ Hz} \tag{2}$$

$$\omega_c = \frac{2\pi}{Cc * \sqrt{r}} \quad = 1.54 \text{ rad/sn} \quad =0.24446 \text{ Hz} \tag{3}$$

Table 1. Modal Analysis Results of the Circular Steel Water Tank

Modal No	Impulsive Frequency (Hz)		Convective Frequency (Hz)	
	FEM Model	API650	FEM Model	API650
Mod1	3.2319 Hz	3.26 Hz	0.24446 Hz	0.246 Hz
Mod2	3.3836 Hz	NA	0.36541 Hz	NA
Mod3	3.3858 Hz	NA	0.36572 Hz	NA
Mod4	5.1838 Hz	NA	0.6401 Hz	NA
Mod5	5.1852 Hz	NA	0.46412 Hz	NA
Mod6	6.1697 Hz	NA	0.48855 Hz	NA

3. STRENGTHENING OF CYLINDRICAL STEEL TANK

One of the considerable aims of this paper is to strengthen the tank exposed to deformation under the loads of the earthquake. It is possible to replace the steel tank with the new undeform able tank made of thicker shell, but this will increase the cost considerably. Strengthening of existing tank at low cost has great importance.

Reinforced composite materials are widely used to coated cylindrical shells which may be the structural elements in storage tanks, reservoir for transportation pressure vessels, rocket components. Many researchers discribed the teory of cylindrical shell and its application to the analysis of cylindrical structures [23]. Stress-Strain graphics of composite materials is given in Figure 6.

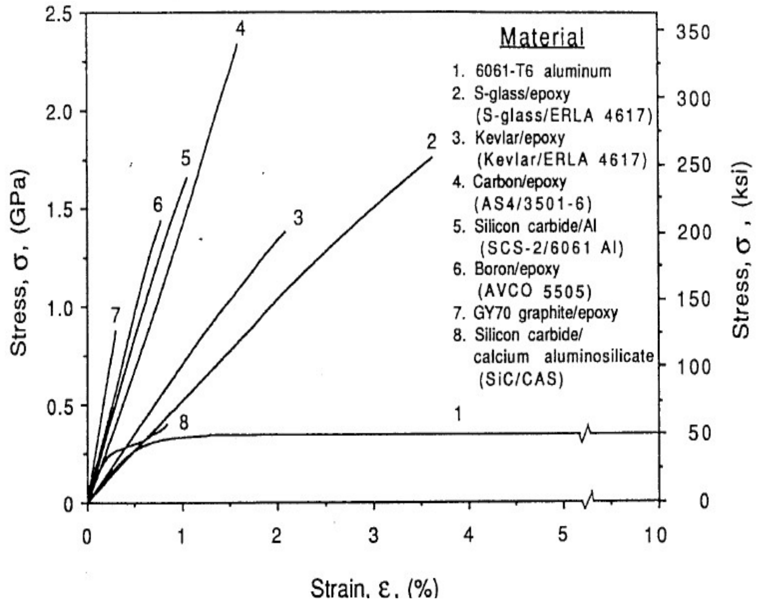


Figure 6. Stress-Strain Graph of Some Composite Materials [24]

Composite material consists of the combination of two different and insoluble materials. These materials remain discernible on a microscopic scale. Although each individual phase has its own properties, the properties and structural strength of the composite are superior to each other's own movement [25]. The materials consist of a fiber reinforcement coupled with a matrix material. Allow the hardness and strength of the material to change with the loading direction. Composition of composite material is shown in Figure 7.

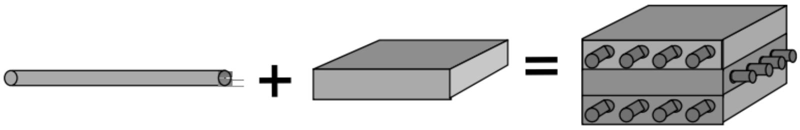


Figure 7. Composition of Composites Materials [26]

Composite materials allow the hardness and strength of the material to change with the loading direction due to the fact that it consists of a fiber reinforcement combined with a matrix material. Some mechanical properties of composite materials and composition materials are showed in table 2.

Table 2. Proporties of Composite and Composition Materials

Fiber/Filament Reinforcement.	Matrix	Composite
High-strength	Good-shear properties	High-strength
High-stiffness	Low -density	High-stiffness
Low-density	Good-shear properties	Low-density

Composite materials are widely used in aerospace structures and pressure vessel tanks, especially to protect against high air pressure. Composite materials application is seen in Figure 8.

Figure 8. Application of Epoxy Carbon Area [26]

The ANSYS Composite Prepost (ACP) module was used to perform the structural analysis of the composite wrap around the cylindrical water tank and the analyses were carried out. ANSYS is able to model and examine composite structures in more detail in this module. Relationship between transient analyses and ACP (pre) is shown in Figure 9.

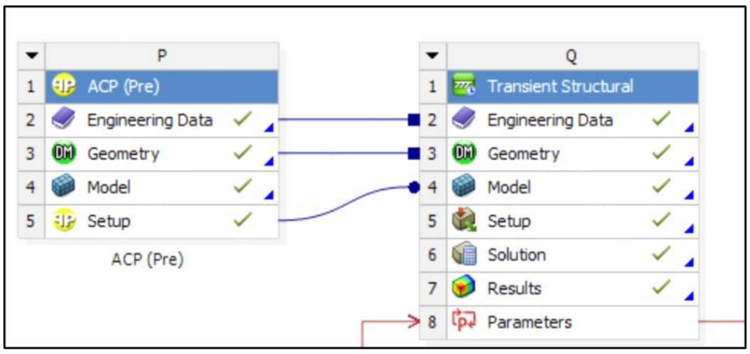


Figure 9. Relationship ACP and Transient Structural

Figure 10 shows materials properties. Composite modelling in Workbench provides the ability to account for variability in the mechanical properties of composite materials due to any scalar user-defined quantity. Temperature, Shear Angle (defined through ACP-Pre draping), and Degradation Factor are predefined variables in Workbench Engineering Data to be used for refining a composite material's behaviour.

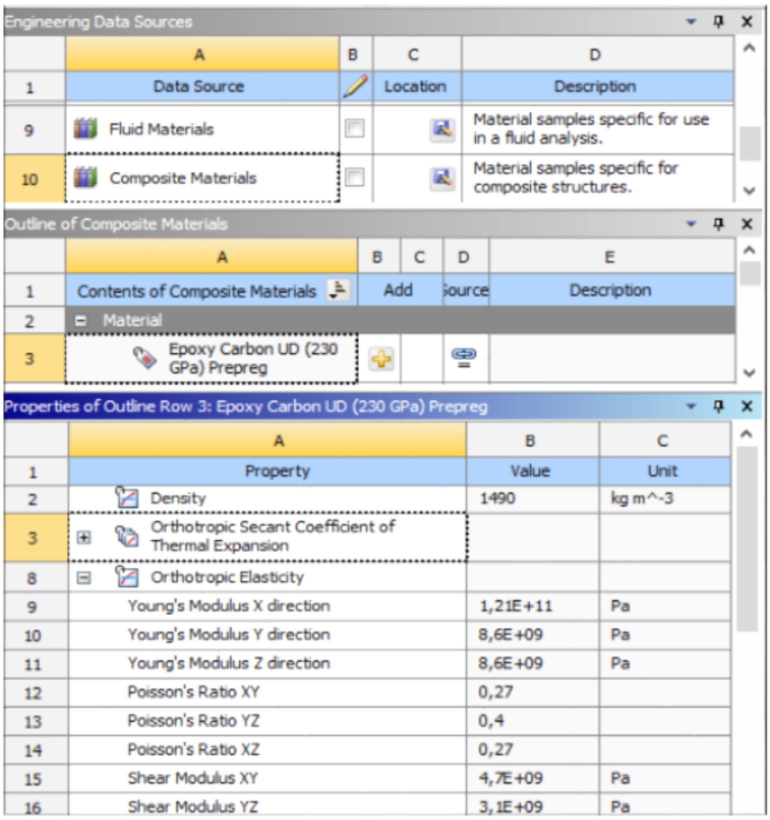
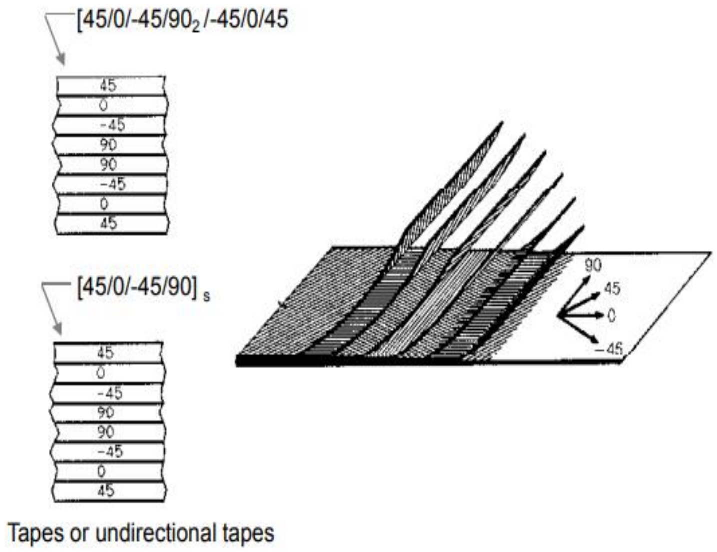


Figure 10. Fabrics and Tapes

Winding technique of laminates on cylindrical surface strengthening is very important. Laminates should be symmetric to while wrapping on surface of cylindrical tank to reduce the complexity of the design for which there are an infinite numbers of orientations possible. Because of the more damage resistant and more amage lolerant than satcks of similarly oiented plies of squencies, they are applied on the cylindrical outher surface as 45,90,-45 angles. This also includes the load carrying similarly oriented stackings in the laminate and helps prevent the separation of the layers under loading [27]. The winding technique of the lamina is described in detail below;

- The fabric's angle warp is used as the layer (plies) direction angle, when layers are used in a laminate. The angle is enclosed in brackets to determine the ply as a fabric ply.
- The laminate is composed of both fabric and tape layers which are hybrid laminates. The brackets around the fabric layers separate the fabric layers from the tape layers.
- If laminates are symmetrical and there are odd-numbered layers, the middle layers are primed to indicate that they are mid-plane.

Not only each lamina should be labeled with a layer orientation, but also the laminae are listed sequentially with the first number representing the laminate to which the arrow points. If laminae angles are different, individual adjacent laminae are separated by a slash. Adjacent layers which the same angle are showed with a numerical subscript indicating the total number of layers sequenced at that angle. Figure 11 presents the angles of laminas



. **Figure 11.** Laminas and Application Angles [28]

A suitable winding thread and thickness are important to reduce manufacturing difficulties and increase structural efficiency. For the winding to occur, the epoxy resin was arranged at 90 degrees and the fibers were arranged in a diagonal manner with 45 degree angles. The cylindrical tank was wrapped in a single layer with an epoxy-carbon composite material of 2 mm. The composite material is considered full bounded on the cylindrical steel surface.

In fact, in some industrial zones, tanks are wound with various composite materials to protected the from corrosion. However, there are deficiencies related to any strengthening effects against the earthquake. Figure 12 shows one of these tanks.

Figure 12. An Example of Coated Cylindrical Tank [29].

These specified angles are the helical of the fibers that it is spirally wrapped. In the program, fiber angles can be changed parametrically. The adjustment of the ideal angle of the layers is effective in strengthening. Determining of angles are shown in Figure 13.

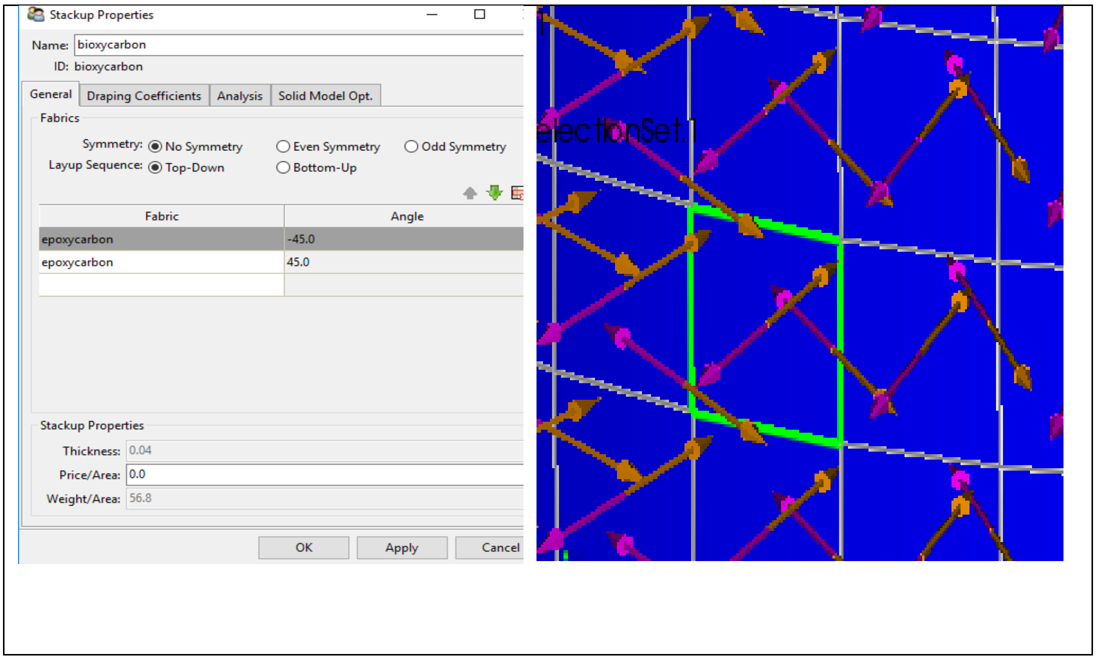
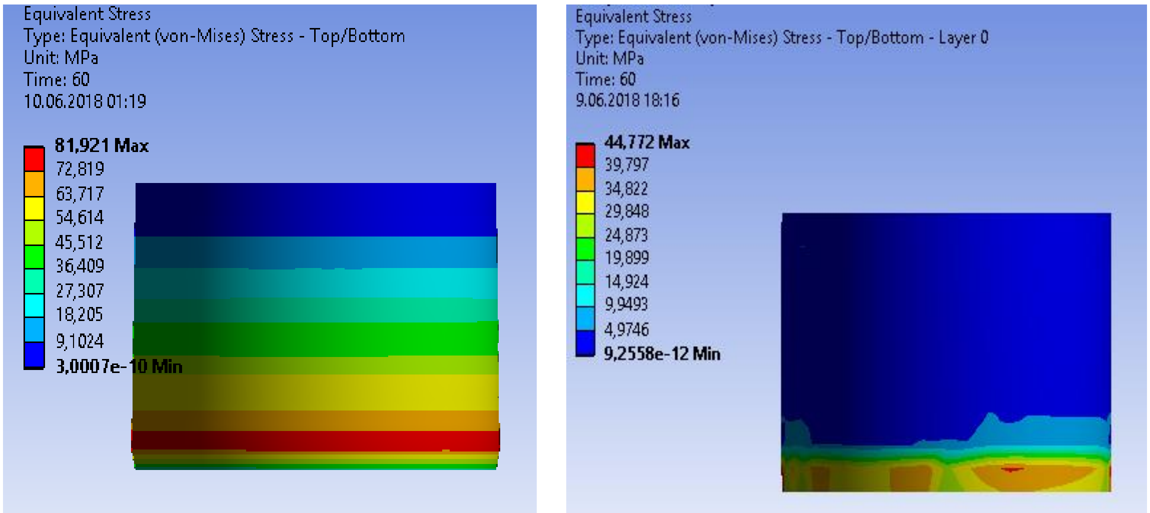


Figure 13. Application of Epoxy Carbon in ACP.

3.1. Result of Strengthening Tanks

After tank had coated with epoxy–carbon composite material, Equivalent (von-Misses) stresses seriously was decreased. In Figure 14 shows distribution of the equivalent stress before and after strengthening open-top tank. Analysis was performed as impulsive under the El-Centro earthquake loads. The red colors show the maximum hoop stress and, blue color show the minimum stress. It is observed that after strengthening with epoxy-carbon in the cylindrical steel tank in Figure 15 (b), there is a serious decrease in the hoop stress. In addition, it appears that the elephant foot buckling in the bottom of the tank disappears due to the stress reduction. The maximum hoop stress in the unprotected tank is 81.92 MPa, while the maximum hoop stress is reduced to 44.77 MPa after it was coated with the epoxy-carbon.



a) Before strengthening stress b) After strengthening stress

Figure 14. Strengthening of Cylindrical Open-Top Tank

Figure 15 shows distribution Equivalent stress as determined different shell thickness of open-top tanks. It is seen that, it is protected the cylindrical steel tank with epoxy-carbon composite material, it provides better protection than increasing its thickness. As shown in Figure 15, the maximum stress of the tank with a shell thickness of 4 mm is almost same with the stress of the unprotected tank of 8 mm thickness.

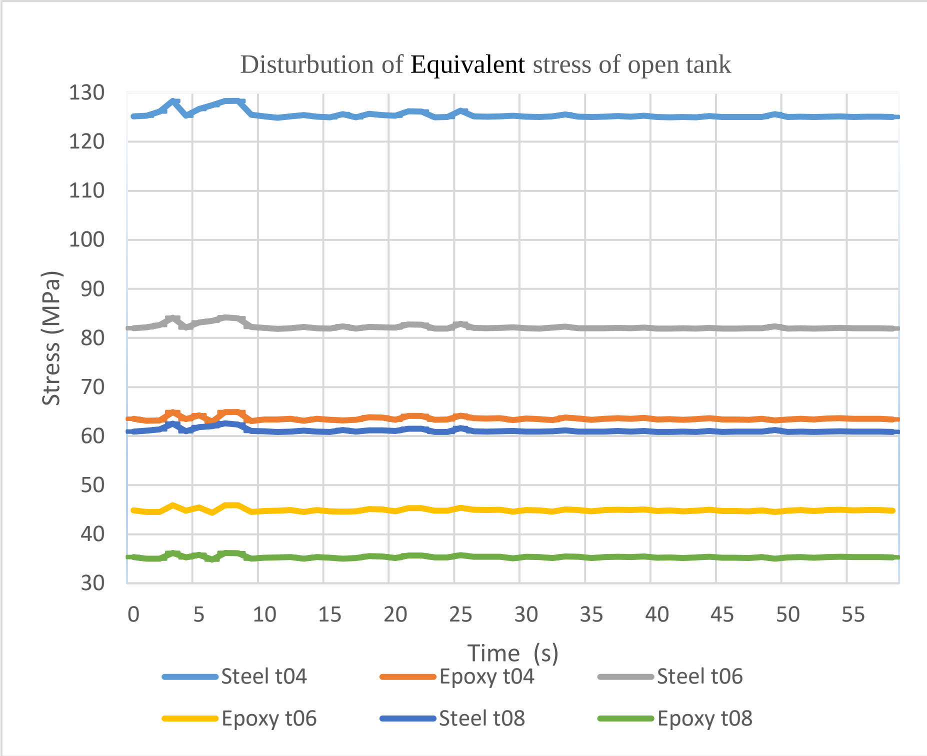


Figure 15. Comparison of Equivalent Stress

4. CONCLUSION

The strengthening technique with epoxy-carbon via ANSYS finite element analysis is an effective analysis technic in the short time duration since it reduces stress in the base of tank. Strengthening of cylindrical steel tanks were performed with epoxy-carbon composite material. Due to stresses in the bottom of the cylindrical steel tank; base shear force, overturning moment and elephant foot buckling are occurred. These risks will be eliminated with the reduction of the stresses in the bottom of the tank subjected to earthquake loads. As a result, the maximum von-Misses stress in the unprotected tank is 81.92 MPa, while the maximum equivalent stress is reduced to 44.77 MPa after it was coated with the epoxy-carbon in open-top tank. According to the standards, the tank thickness should be 6 mm, but after the strengthening of the tank, the equivalent stress at the shell thickness of 4 mm has been proven to be reduced. Moreover, the stretching of the 4 mm tank is at the same level as the stress in the 8 mm tank. Accordingly, the existing thin-walled tanks can be reinforced with epoxy carbon and also the new manufactured tanks can be strengthened by epoxy-carbon capping with thinner walls. This technique will also protect against wear and tear for longer life.

5. REFERENCES

[1] A. Bayraktar, B. Sevim, A. C. Altunışık, T. Türker, “Effect of the model updating on the earthquake behavior of steel storage tanks”, *J Constr Steel Res*, vol 66, pp 462–468, 2010.

[2] F.H. Hamdan, “Seismic behaviour of cylindrical steel liquid storage tanks”, *J. Constr. Steel Res*., vol 53, no 3, pp 307–333, 2000.

[3] M.A. Haroun, G.W. Housner, “Earthquake response of deformable liquid storage tanks”, *J. Appl. Mech. Trans ASME*, vol 48, no 2, pp 411–418, 1981.

[4] B. Hunt, N. Priestley, “Seismic water-waves in a storage tank”, *B Seismol. Soc. Am.*, vol 68, no 2, pp 487–499, 1978.

[5] Y. Tang, “Dynamic-response of tank containing 2 liquids”, *J. Eng. Mech. ASCE*, vol 119, no 3, pp 531–548, 1993.

[6] A.S. Veletsos, Y. Tang, H.T. Tang, “Dynamic-response of flexibly supported liquid storage tanks”, *J. Struct. Eng. ASCE*, vol 118, no 1, pp 264–283, 1992.

[7] 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.

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

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

[10] 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.

[11] K. R. Sunitha, B. Jacob, "Dynamic Buckling Of Steel Water Tank Under Seismic Loading", *International Journal of Civil Engineering IJCE*, vol 4, no 6, pp 81–90, 2015.

[12] 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.

[13] 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

[14] N. Hosseinzadeh, H. Kazem, M. Ghahremannejad, E. Ahmadi, N. Kazem., "Comparison of API650-2008 provisions with FEM analyses for seismic assessment of existing steel oil storage tanks", *J Loss Prevent Proc Ind*, vol 26, no 4, pp 666-675, 2013.

[15] 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.

[16] J.M. Spritzer, S. Guzey "*Nonlinear numerical evaluation of large open-top aboveground steel welded liquid storage tanks excited by seismic loads*", *Thin-Walled Structures 119 (2017) 662–676*

[17] Niwa, A., and Clough RW., 1982: Buckling of cylindrical liquid storage tanks under earthquake loading. Eartquake engineering and structural dynamics, 10, 107-122

[18] Altun, H. A. (2013), Sesimic Analysis of Steel Liquid Storage Tanks by API-650" // M.Sc. Thesis, *Department of Civil Engineering, Structural Engineering Programme, Istanbul Technical University, Graduate School of Science Engineering and Technology*

[19] 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.

[20] Ewins, D. J. and Imregun, M (1986), State-of-the-Art Assessment of Structural Dynamic Response Analysis Methods (DYNAS), Shock and Vibration Bulletin, Vol. 56 (I),

[21] Liu, Y. and Glass, G., 2013, "Effects of Mesh Density on Finite Element Analysis," SAE Technical Paper 2013-01-1375, https://doi.org/10.4271/2013-01-1375

[22] Moslemi, M. (2005) Seismic Response of Ground Cylindrical and Elevated Conical Reinforced Concrete Tanks // *PhD Thesis. - Tehran, Iran, : Master of Applied Science*

[23] V. V. Vasiliev and E. V. Morozov, *Composite materials and structure materials,* Elsevier, no. 685, Published Date: 4th July 2013.

[24] I.M. Daniel, O. Ishai, *Engineering Mechanics of Composite Materials.* New York: Oxford University Press, 1994.

[25] https://quizlet.com/110694842/ch-9-flash-cards (erişildi: 01 11, 2018).

[26] D. S. Cairns, L. A. Wood, "Composite Materials for Aircraft Structures", 2009. http://www.montana.edu/dcairns/documents/composites/MSUComposites2009.pdf (evaliable date: 01 11, 2018).

[27] http://www.ist.edu.pk/downloads/amss/lecturers/design-guidelines.pdf

[28] Jared W Nelson, *"Composite Materials for Aircraft Structures: A Brief Review of Practical Application"*, Department of Mechanical and Industrial Engineering Montana State University ME 480 Introduction to Aerospace, Spring 2010

[29] https://img.diytrade.com/smimg/229183/45971184-7862682-0/FRP_VESSEL/2dee.jpg