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Full Length Research Paper

Stability of Petroleum Storage Tanks considering the effect of Helical Stair Beams

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ABSTRACT

Liquid storage steel tanks are vertical above-ground cylindrical shells and as typical thin-walled structures, they are very sensitive to buckling, especially when they are empty or at low liquid level. This research is to study the buckling behavior of oil storage tank And study the effect of adding helical stair beams to the shell and check for the benefits we can obtain after adding the stair beam in the F.E Model. Methodology to be mentioned Using FEM and Computational Fluid Dynamic, two models were examined under the same condition, the first model is steel Tank shell with Diameter of 16 m and height of 14 m, while the other is with the same geometry, and we just added a helical steel beam over the half circumferences of the shell. Attention is given to the load definition in each case, each loading case is first explained followed by comparison of the two tanks models. Finite element analysis was performed considering the stresses come from CFD computation for wind load as well as all the case of loading for Oil storage Tank according to the standard of welded Tanks API 650.

Introduction

Benefits of using steel tank

Tanks employed to store oil and fuels have significantly increased during the past two decades it can be loaded up to 60,000 m3.Steel tanks are common used for this purpose, according to the flexibility of their construction as it can be painted and / or insulated to meet with the requirements of their stored material. [1] For example Methyl/Ethyl tanks can react with epoxy so in case it is required to store Gasoline the inner face of the tank should be lining with amine-cured epoxy coating not painting to avoid such react. Storage tanks serve two major purposes. One is to provide storage volume and the other is to provide pressure to the distribution system.

A particular tank can serve one or both purposes depending on its location within the system and its type. There are a variety of tank types, the major type are ground storage, elevated, and hydro pneumatic tanks. Construction materials for the various types of tanks are generally concrete and steel although some tanks for small storage volumes and special uses could be constructed of fiberglass. [2] Glass fused to steel system can be applied also for water and waste water storage tanks and it consist of glass flake epoxy [3] applied over the prepared surface of the steel and heating sheets up to a degree of temperature exceeds the melting point for glass 850 C.

Steel tanks in this decade are the key of the construction projects. Storage tanks are often cylindrical in shape, perpendicular to the ground with flat bottoms, and a fixed or floating roof. There are usually many environmental regulations applied to the design and operation of storage tanks, often depending on the nature of the fluid contained within.

Buckling and failure types in Oil storage tank

Most of steel tank designers are concerned about this behavior, which is a process by which a structure cannot withstand loads with its original geometry, so that it changes into a new shape in order to find a new equilibrium configuration. This is an undesired process and occurs for a well-defined value of the load. The consequences of buckling are basically geometric.

Fig 1. a,b,c Buckling Shapes

Above ground storage tanks are vital facilities in PuertoRico and in the Caribbean Islands. Large thin-walled tanks are employed by various industries to mainly store oil, water, and petrochemical products. Tanks are complex structures, frequently built with a cylindrical body clamped at the base, a roof, and an additional structure to support the roof. Usually, they have a fixed conical or dome roof. It is also common to find floating roofs or tanks open at the top. Tanks are frequently constructed as part of "tank farms" or large industrial plants with dozens or even hundreds of tanks.

Figures 1.1 and 1.2 show typical tank farm configurations in Puerto Rico and Saint Lucia. Damage in steel tanks has been identified each time a hurricane affects the Caribbean. During hurricane Hugo (1989), severe damage and collapse of oil tanks were detected in St. Croix (Figure 1.6) with consequences for the production, the local economy, and the environment.

Damage of tanks in Antigua occurred during hurricane Luis in 1995, followed a week later by hurricane Marilyn leading to damage of a number of tanks in St. Thomas. Hurricane Georges (1998) produced local buckling of tanks in Yabucoa and Guayanilla, in southern Puerto Rico. Although damage was not severe, repairing was needed to reestablish the storage capacity and optimal operation conditions. Figure 1.7 illustrates some examples of local buckling of the cylindrical shell and collapse of a dome roof in Puerto Rico. During hurricanes, the occurrence of moderate damage to total failure was mainly associated to buckling of the cylindrical shell of the tank. In some cases, the top enclosure of a water storage tank failed and left the short cylindrical shell to resist wind loading, so that a second failure occurred in the form of buckling of the top part of the shell. Buckling was detected in St. Croix during hurricane Hugo, with large distortions in the shape of the shell Figure 1.6.Most studies on the effect of wind pressures on cylindrical shell have beencarried out in short open top tank models or in silos that are taller than the tanks previously described. It has been usual to assume that the wind pressure is constant in time.

In previous studies models were analyzed using static approaches and did not pay attention to the possibility of dynamic effects induced by wind. Observing the damaged tanks, one may wonder if wind gusts with very high speeds associated to hurricanes are capable of inducing transient vibrations in the shell during short times, which may eventually lead to dynamic buckling. This is one of the questions that this thesis can answer.

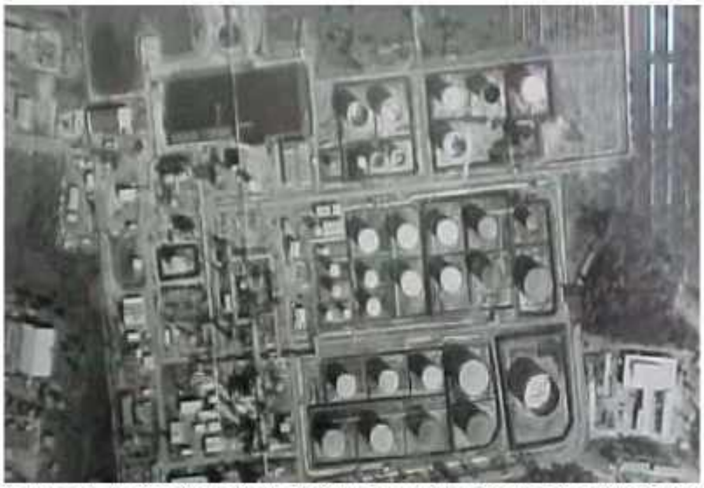


Figure 1.1. Aerial view of a tank farm located in Puerto Rico (Caribbean Petroleum).

Figure 1.2. Tank farm located in Saint Lucia, during construction.

Figure 1.3. Tank farm located in Puerto Rico (Caribbean Petroleum).

igure 1.4. Cone roof tanks connected to pipelines (Caribbean Petroleum

Figure 1.5. Cylindrical tanks in Yabucoa, Puerto Rico.

Figure 1.6. Collapsed tanks in St. Croix after hurricane Hugo (1989).

Figure 1.7. Local buckling and collapsed dome roof tank after Georges (1998), Puerto Rico.

Other identified source of failure in tanks is the loss of the soil foundation strength. Such failure is sometimes due to severe windstorms with heavy rains or to excessive compressibility of the soil deposit due to other reasons. This leads into differential settlements in some part at the base which cause buckling to the shell.

Thin Shell strengthen phenomena

The strengthening effects of stiffening rings top and intermediate wind girder have been investigated and recommended by American Petroleum Institute Such girders have been taken into account and most of the previous researches and studies refer to the distance between top and intermediate wind girder as the top wind girder is a must according to American Petroleum Institute [4] .

Research Objective

Use of helical stiffeners spiral stairs on half of the tank circumferenceto improve buckling behavior Effort towards improving design shall be mentioned and advised by the Author.

Research Methodology

Analysis Objects

Two models were examined under the same condition, the first model is steel Tank shell with Diameter of 16 m and height of 14 m, while the other is with the same geometry, and we just added a helical steel beam over the half circumferences of the shell.

Table 1. Design Consideration

Tank Material Standard	EN 10025-2:2004
Steel grade	S235JR
Poisson's ratio	0.3
Young's modulus	206700 Mpa
Yield Strength	235MPa
Tensile Strength	350MPa
High Liquid Level	13.450 m

Table 2. Material Properties

Wind Velocity	53 m/sec
Risk Category	II
Site Class	D
Specific Gravity of the stored Liquid	0.84
Selected Time History	El_Centro Earthquake
D/H	1.42

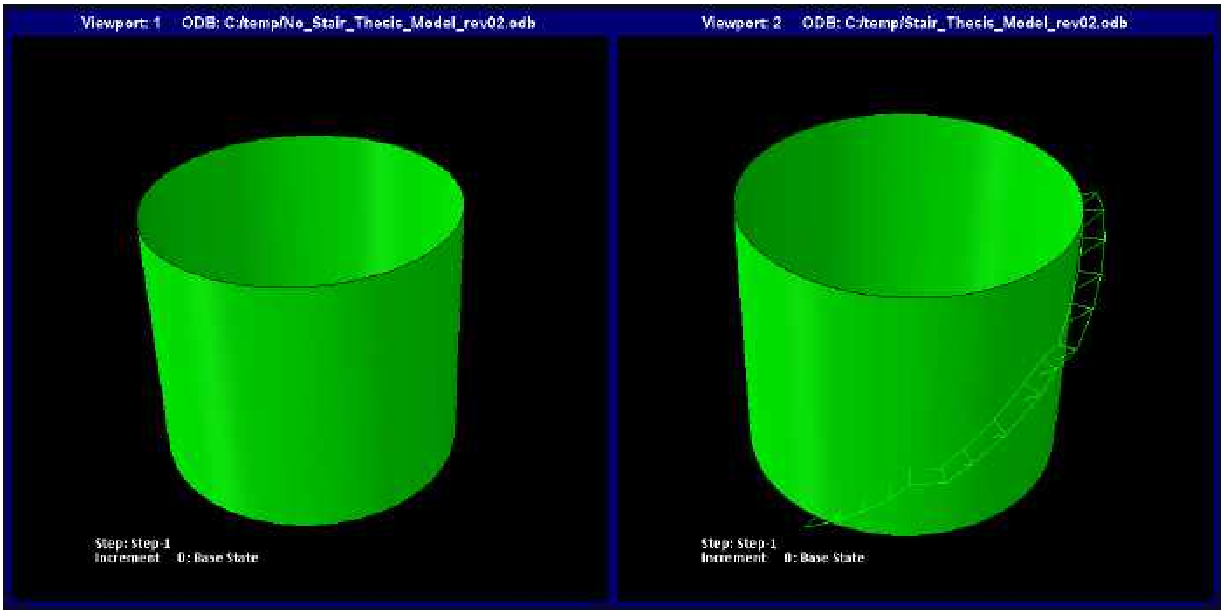


Fig 2. Two Analytical Models with and without stairs

Analysis Method and Analytical Model

In this Chapter the reader can see all the load cases that were considered in the design and structural analysis of the oil tank [5]. It is made of three different thicknesses 10, 8 and 6mm thick steel. The loads for the API standard 650 Eleventh edition have been considered.

Geometry and FEM Meshing

The tank was modeled as a cylinder and meshed with shell finite elements. The thickness was assigned to these finite elements. Two models were built, one with stairs and one with no stairs. The FEM model without stairs can be seen on the figure 2 and with stairs on figure 3

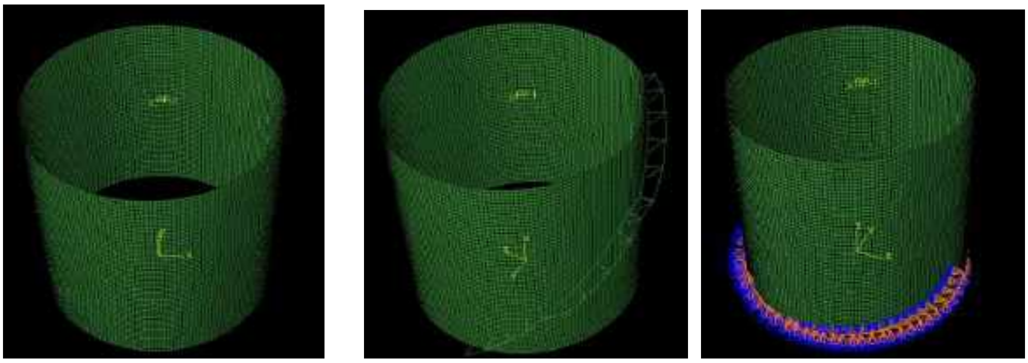


Fig. 3, 4, 5.: FEM model of oil tanks

Boundary Conditions

The boundary conditions were the same for all the load cases. The bottom of the structure was constrained in all 6 degrees of freedom as presented on the figure 4.

Load Definition.

Table 3. Design Loads

Dead Load (*D*)	Roof Structure Weight is 7.930 ton while the roof Plates weight is 10.115 ton
Stored Liquid (F)	ρ*g*HL.L=0.11531 MPA
Hydrostatic Test (Ht)	ρ*g*H =0.13734 MPA
Wind (W)	According to CFD
Design External Pressure(Pe)	0.25 KPA
Design Internal Pressure(Pi)	0.5 KPA
EQ	El-Centro Earthquake Time history
Test Pressure (Pt)	4.35 KPA

Load Cases.

Table 4 Design Load cases

1.	**FluidandInternal pressure**	DL+F+Pi
1	**Hydrostatic Test**	DL+Ht+Pt Where ; P= (A*Fy*tanα/200 D^2) + (0.00127 DLR/D^2)=4.35 Kpa
2	**Wind and Internal Pressure**	DL+W+(Fp)*(Pi) &FP=0.4
3	**Wind and External Pressure**	DL+W+0.4*Pe
4	**Gravity Load**	DL+Lr+0.4*Pe
5	**Gravity Load**	DL+ Pe+0.4 Lr
6	**Wind Load**	W

Shell Course 01
Product Design Stress (Sd) = 137.0000 MPa
Hydrostatic Test Stress (St) = 154.0000 MPa
Corrosion Allowance (CA): 2.0000 mm
Shell Height: 2.0000 m

$$td = ((4.9)(13.45 - 0.3)(16)(0.84))/137) + 2.0 = 8.3212\ mm$$

$$tt = ((4.9)(13.45 - 0.3)(16))/154) = 6.7\ mm$$

t=10 mm

Shell Course 02
Corrosion Allowance (CA): 1.0000 mm
Shell Height: 2.0000 m

$$td = ((4.9)(11.45 - 0.3)(16.00)(0.84))/137) + 1.00 = 6.3612\ mm$$

$$tt = ((4.9)(11.4500 - 0.3)(16.0000))/154.0000) = 5.67\ mm$$

t=8.0 mm

Shell Course 03
Corrosion Allowance (CA): 1.0000 mm
Shell Height: 2.0000 m

$$td = ((4.9)(9.45 - 0.3)(16.00)(0.84))/137) + 1.00 = 5.398\ mm$$

$$tt = ((4.9)(11.4500 - 0.3)(16.0000))/154.0000) = 4.6582\ mm$$

t=6.0 mm

Wind Load According To Computational Fluid Dynamic
[6] ,[7] Tank has been analyzed in CFD OpenFOAM Program according to velocity of 53 m /sec . Stress due to wind load over 11427 nodes on the tank have been inserted into FEM-Abaqus .

Shell Course 04
Corrosion Allowance (CA): 1.0000 mm

$$td = ((4.9)(7.45 - 0.3)(16.00)(0.84))/137) + 1.00 = 4.437\ mm$$

$$tt = ((4.9)(7.45 - 0.3)(16.0000))/154.0000) = 3.64\ mm$$

Shell Course 05 Corrosion Allowance (CA): 1.0000 mm
Shell Height: 2.0000 m

$$td = ((4.9)(5.45 - 0.3)(16.00)(0.84))/137) + 1.00 = 3.4756\ mm$$

$$tt = \frac{((4.9)(7.45 - 0.3)(16.0000))}{154.00} = 2.6218\ mm$$

t=6.0 mm

Shell Course 06
Corrosion Allowance (CA): 1.0000 mm
Shell Height: 2.0000 m

$$td = ((4.9)(3.45 - 0.3)(16.00)(0.84))/137) + 1.00 = 2.514\ mm$$

$$tt = ((4.9)(7.45 - 0.3)(16.0000))/154.000 = 1.60\ mm$$

t=6.0 mm

Shell Course 07
Corrosion Allowance (CA): 1.0000 mm
Shell Height: 2.0000 m

$$td = ((4.9)(1.45 - 0.3)(16.00)(0.84))/137) + 1.00 = 1.5528\ mm$$

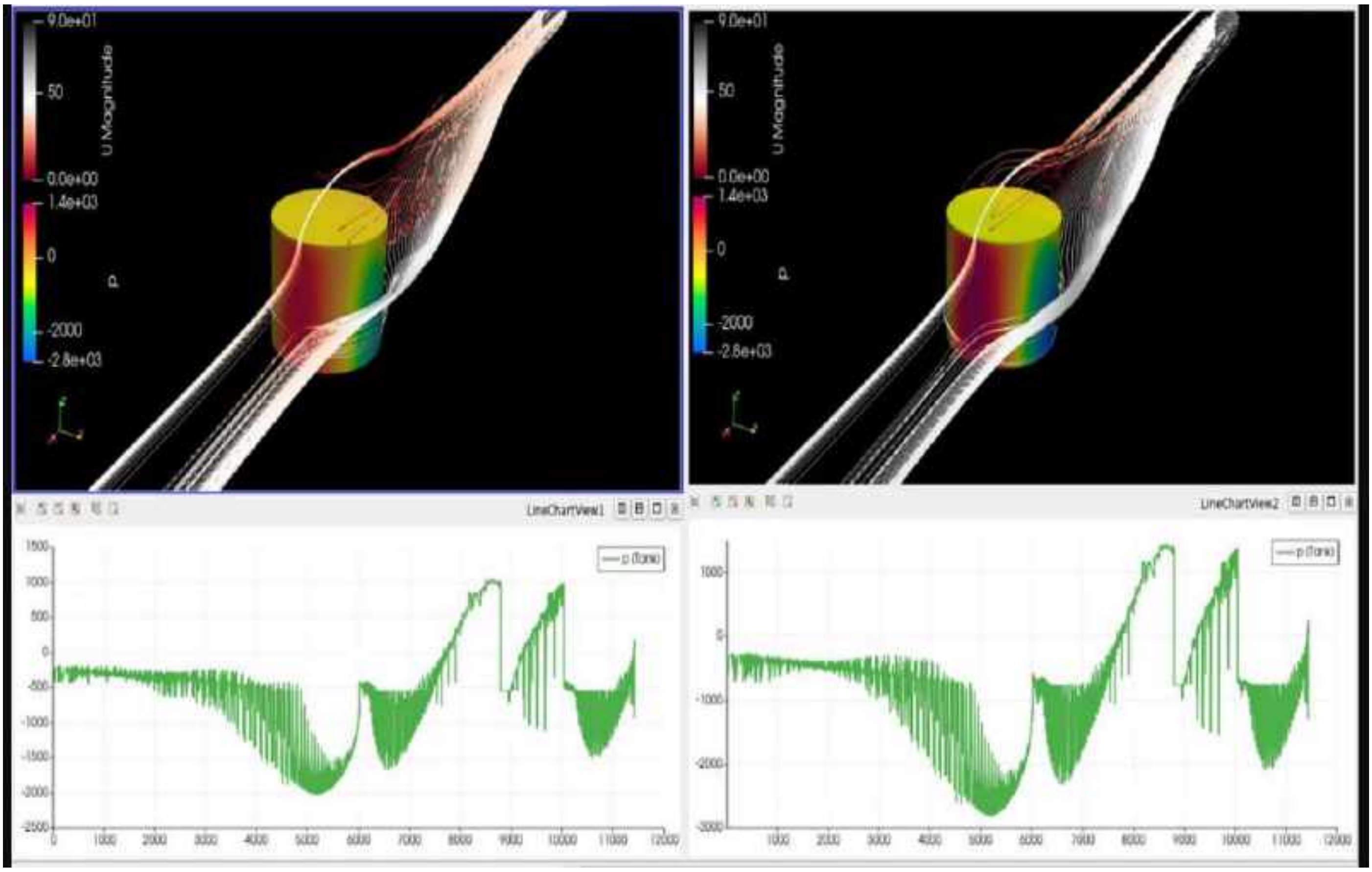
$$tt = ((4.9)(7.45 - 0.3)(16.0000))/154.0000) = 0.5855\ mm$$

t=6.0 mm

Shell Courses Design.
Product Design Stress (Sd) = 137.0000 MPa**,** Hydrostatic Test Stress (St) = 154.0000 MPa Corrosion Allowance (CA): 2.0000 mm for the 1st course and 1 mm for the rest
Shell Height: 2.0000 m as the total height is 14 meter, thereby we have 7 courses [5]

Course (from bottom)	**Shell Thickness -mm**
1	10
2	8
3	8
4	6
5	6
6	6
7	6

Table 5 Shell course Thickness considering corrosion Allowance



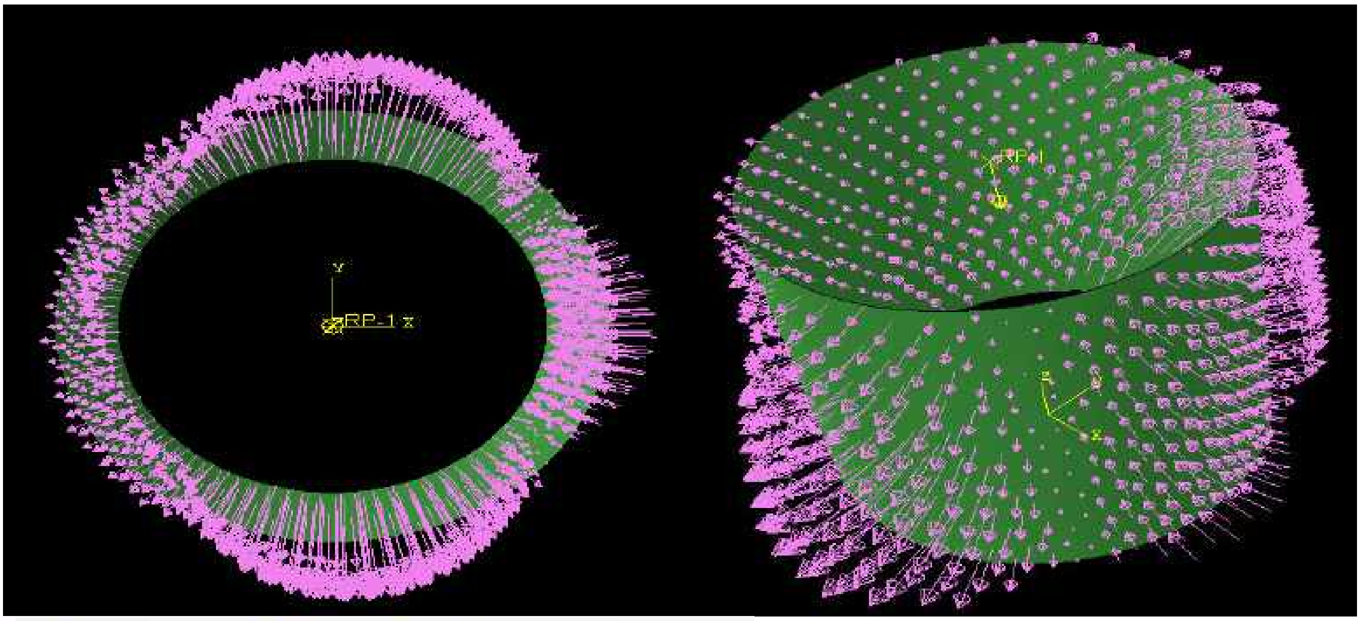


Fig 6, Fig 7, Fig 8 show the inserted wind load in FEM-Abaqus from CFD Program

Results and Discussion

It is divided into two sections, first one for the FEM results of the two cases for each case of loading and a brief from the author and his analysis on the results .The second section is the summary and observation.

FEM Results

For all load cases the results are presented first as the Deformation(U) inmmandalteras Stress (S) In MPa. Results will show two options of each load case in the same Slice, Left of the slice shall display the stiffened tank while the right of the slice shall display the other tank. The meridional design stress obtained from Abaqus can be seen in Figures.

Case of Loading DL+F+Pi

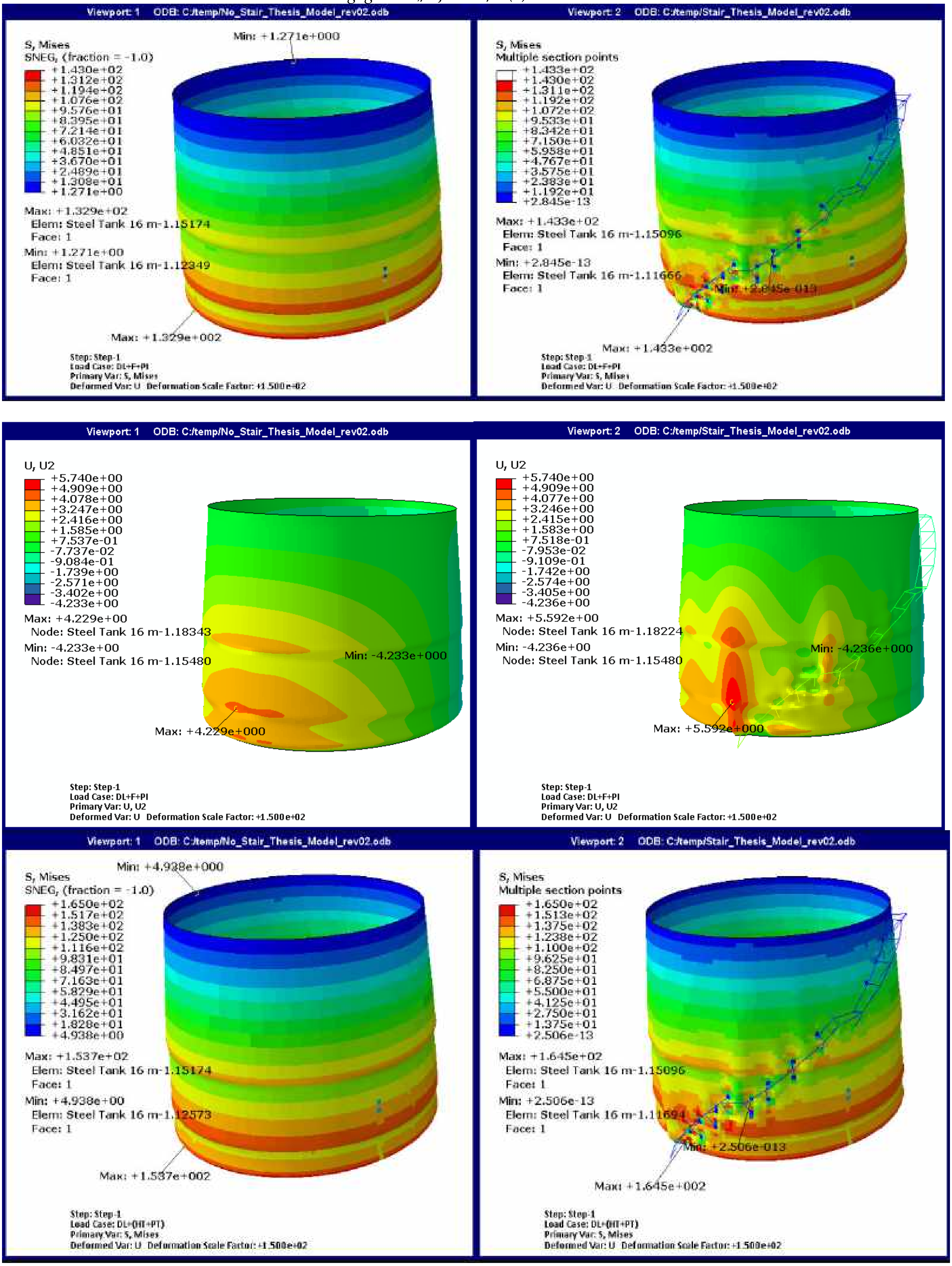
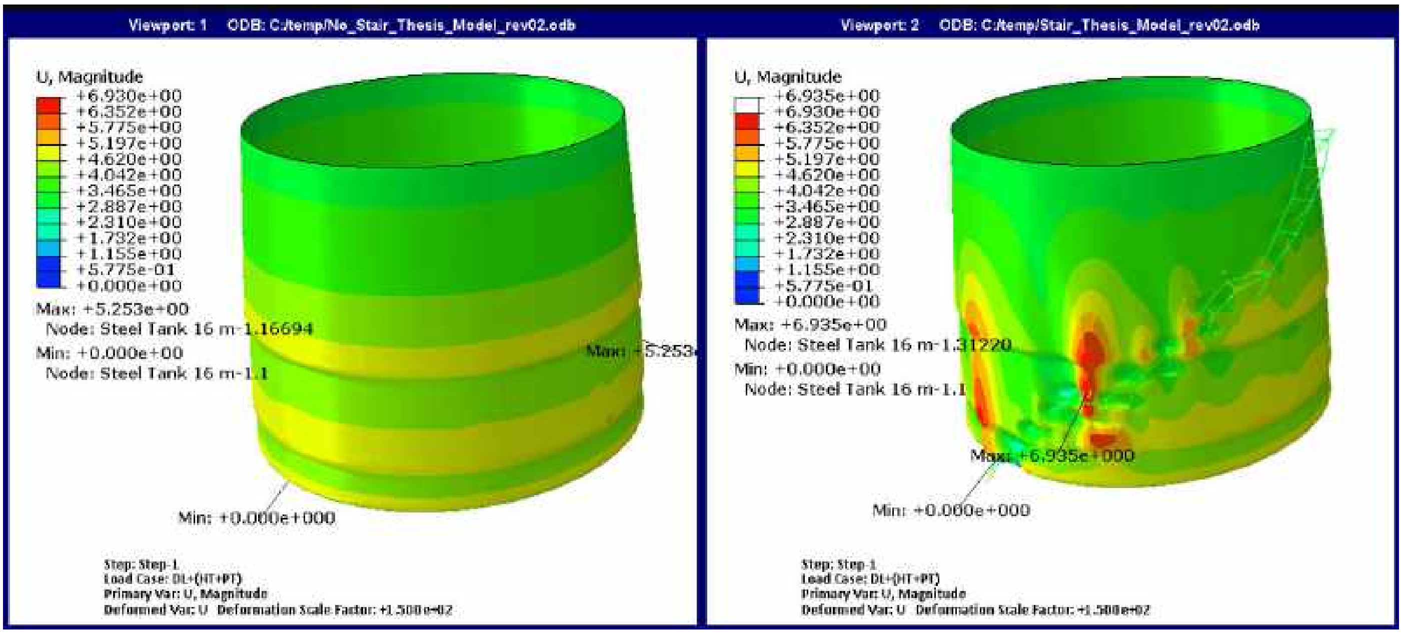

Viewport: 1 ODB: C:/temp/No_Stair_Thesis_Model_rev02.odb
S, Mises
SNEG, (fraction = -1.0)
+1.430e+02
+1.312e+02
+1.194e+02
+1.076e+02
+9.576e+01
+8.395e+01
+7.214e+01
+6.032e+01
+4.851e+01
+3.670e+01
+2.489e+01
+1.308e+01
+1.271e+00
Max: +1.329e+02
Elem: Steel Tank 16 m-1.15174
Face: 1
Min: +1.271e+00
Elem: Steel Tank 16 m-1.12349
Face: 1
Min: +1.271e+000
Max: +1.329e+002
Step: Step-1
Load Case: DL+F+PI
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +1.500e+02
Viewport: 2 ODB: C:/temp/Stair_Thesis_Model_rev02.odb
S, Mises
Multiple section points
+1.433e+02
+1.430e+02
+1.311e+02
+1.192e+02
+1.072e+02
+9.533e+01
+8.342e+01
+7.150e+01
+5.958e+01
+4.767e+01
+3.575e+01
+2.383e+01
+1.192e+01
+2.845e-13
Max: +1.433e+02
Elem: Steel Tank 16 m-1.15096
Face: 1
Min: +2.845e-13
Elem: Steel Tank 16 m-1.11666
Face: 1
Min: +2.845e-013
Max: +1.433e+002
Step: Step-1
Load Case: DL+F+PI
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +1.500e+02
Viewport: 1 ODB: C:/temp/No_Stair_Thesis_Model_rev02.odb
U, U2
+5.740e+00
+4.909e+00
+4.078e+00
+3.247e+00
+2.416e+00
+1.585e+00
+7.537e-01
-7.737e-02
-9.084e-01
-1.739e+00
-2.571e+00
-3.402e+00
-4.233e+00
Max: +4.229e+00
Node: Steel Tank 16 m-1.18343
Min: -4.233e+00
Node: Steel Tank 16 m-1.15480
Min: -4.233e+000
Max: +4.229e+000
Step: Step-1
Load Case: DL+F+PI
Primary Var: U, U2
Deformed Var: U Deformation Scale Factor: +1.500e+02
Viewport: 2 ODB: C:/temp/Stair_Thesis_Model_rev02.odb
U, U2
+5.740e+00
+4.909e+00
+4.077e+00
+3.246e+00
+2.415e+00
+1.583e+00
+7.518e-01
-7.953e-02
-9.109e-01
-1.742e+00
-2.574e+00
-3.405e+00
-4.236e+00
Max: +5.592e+00
Node: Steel Tank 16 m-1.18224
Min: -4.236e+00
Node: Steel Tank 16 m-1.15480
Min: -4.236e+000
Max: +5.592e+000
Step: Step-1
Load Case: DL+F+PI
Primary Var: U, U2
Deformed Var: U Deformation Scale Factor: +1.500e+02
Viewport: 1 ODB: C:/temp/No_Stair_Thesis_Model_rev02.odb
S, Mises
SNEG, (fraction = -1.0)
+1.650e+02
+1.517e+02
+1.383e+02
+1.250e+02
+1.116e+02
+9.831e+01
+8.497e+01
+7.163e+01
+5.829e+01
+4.495e+01
+3.162e+01
+1.828e+01
+4.938e+00
Max: +1.537e+02
Elem: Steel Tank 16 m-1.15174
Face: 1
Min: +4.938e+00
Elem: Steel Tank 16 m-1.12573
Face: 1
Min: +4.938e+000
Max: +1.537e+002
Step: Step-1
Load Case: DL+(HT+PT)
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +1.500e+02
Viewport: 2 ODB: C:/temp/Stair_Thesis_Model_rev02.odb
S, Mises
Multiple section points
+1.650e+02
+1.513e+02
+1.375e+02
+1.238e+02
+1.100e+02
+9.625e+01
+8.250e+01
+6.875e+01
+5.500e+01
+4.125e+01
+2.750e+01
+1.375e+01
+2.506e-13
Max: +1.645e+02
Elem: Steel Tank 16 m-1.15096
Face: 1
Min: +2.506e-13
Elem: Steel Tank 16 m-1.11694
Face: 1
Min: +2.506e-013
Max: +1.645e+002
Step: Step-1
Load Case: DL+(HT+PT)
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +1.500e+02

Fig. 9, 10, 11.

Author observation in case of loading DL+F+Pi Figures 9, and figure 10 show FEM model, Two Cases with stair and without stair S- Misses and U2 .Obviously considering the stair in the design induct the presence of stress values of -2.845 e-13 MPA which is very low compared with the inducted value from the other case (without stair) which is 1.27 MPA .On the other hand the Maximum stress value in stair case model is higher than the other case due to the weight of steel beam it self.

Case of Loading DL+HT+PT



Step: Step-1
Load Case: DL+(HT+PT)
Primary Var: U, Magnitude
Deformed Var: U Deformation Scale Factor: +1.500e+02

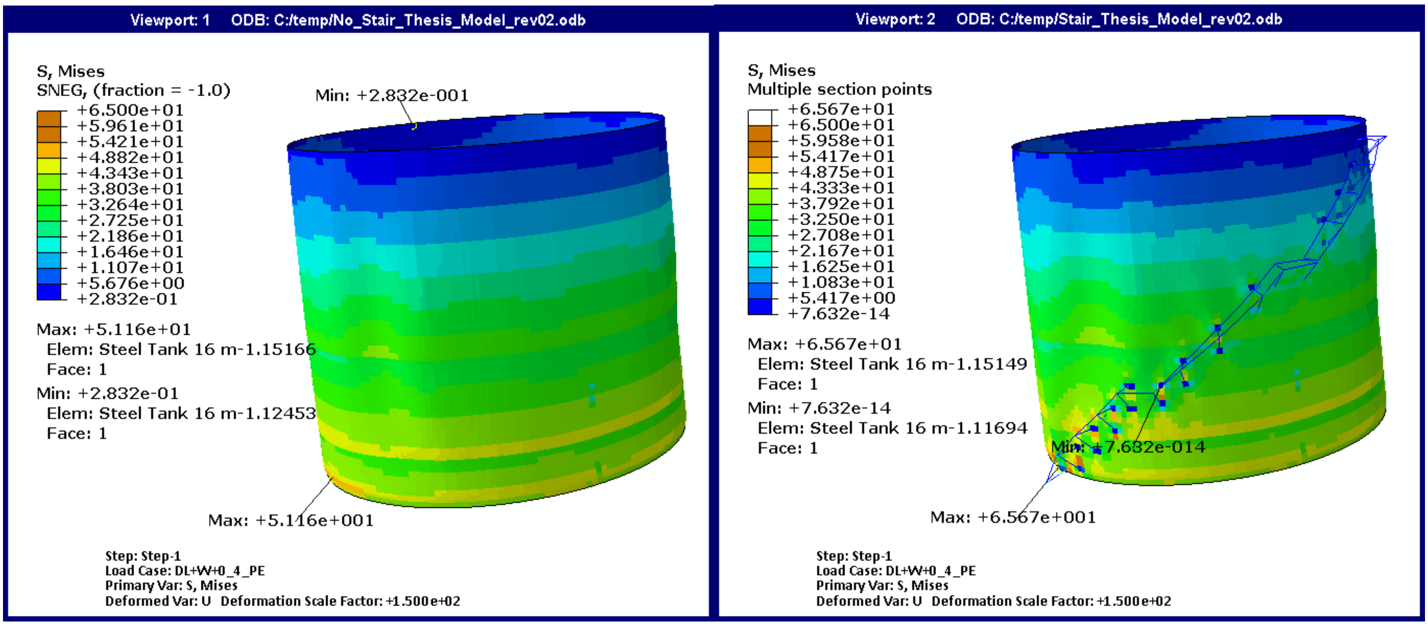
Step: Step-1
Load Case: DL+(HT+PT)
Primary Var: U, Magnitude
Deformed Var: U Deformation Scale Factor: +1.500e+02

Fig. 12

Author observation in case of loading DL+HT+PT

Figures 11,12 shows FEM model, Two Cases with stair and without stair S- Misses and U2.This case of loading HT+PT is the most effective case of loading in our model as it gives the maximum stress value .If we look in deep in the results we will notice that thepresence of the stair induct the min stress values 2.5 e-13 MPA in the nodes around the stair as it is very low value compared with the minimum value from the other case (without stair).Maximum stress in stair case still higher than the other case due to the weight of stair beam .

Case of Loading DL+W+(FP)*Pi



Step: Step-1
Load Case: DL+W+0_4_PE
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +1.500e+02

Step: Step-1
Load Case: DL+W+0_4_PE
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +1.500e+02

Fig. 13

Author observation in case of loading DL+W+(FP)*Pi

Figures 13, 14 show FEM model, Two Cases with stair and without stair S- Misses and U2. Unlike 650 tanks, most of the stresses on tanks is from internal pressure rather than environmental loads such as snow, Earthquake and wind. Therefore, combining environmental loads with tank fluid and pressure loads is less significant in design. However the presence of the stair always make the elements around its area have less stress values than the other case as well as U2.

Two Cases of Loading DL+Lr+0.4Pe & DL+0.4Lr+Pe

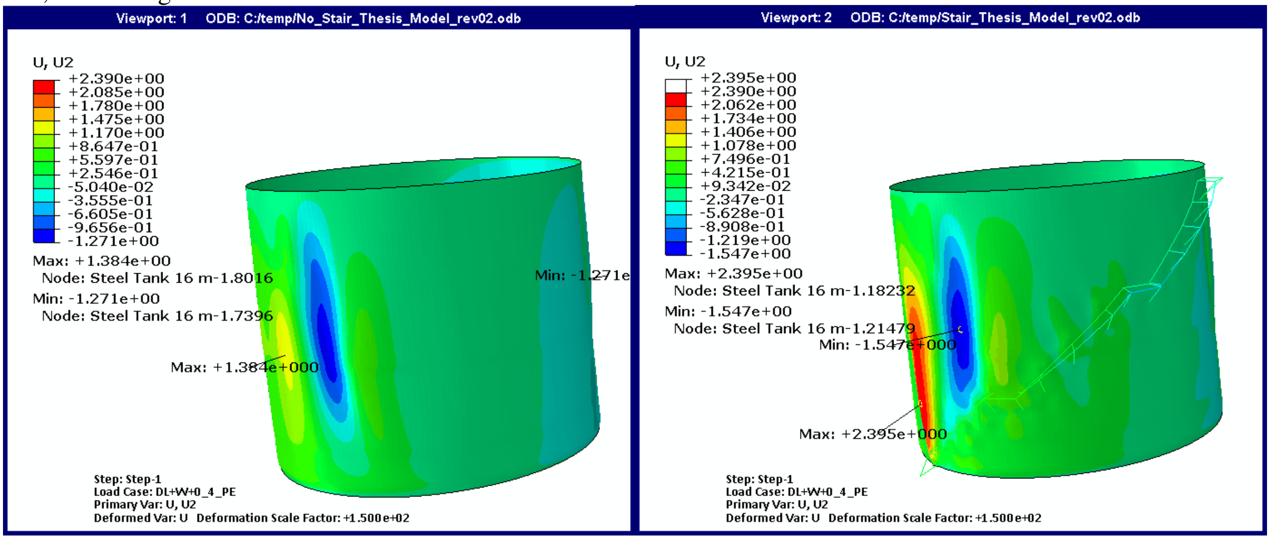


Fig. 14

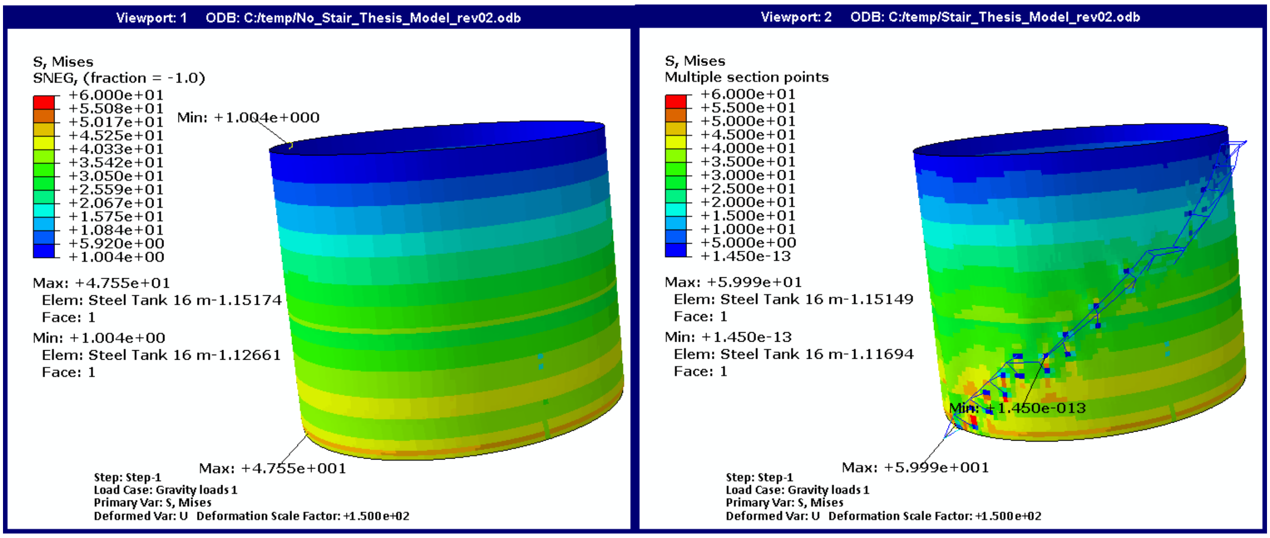


Fig. 15

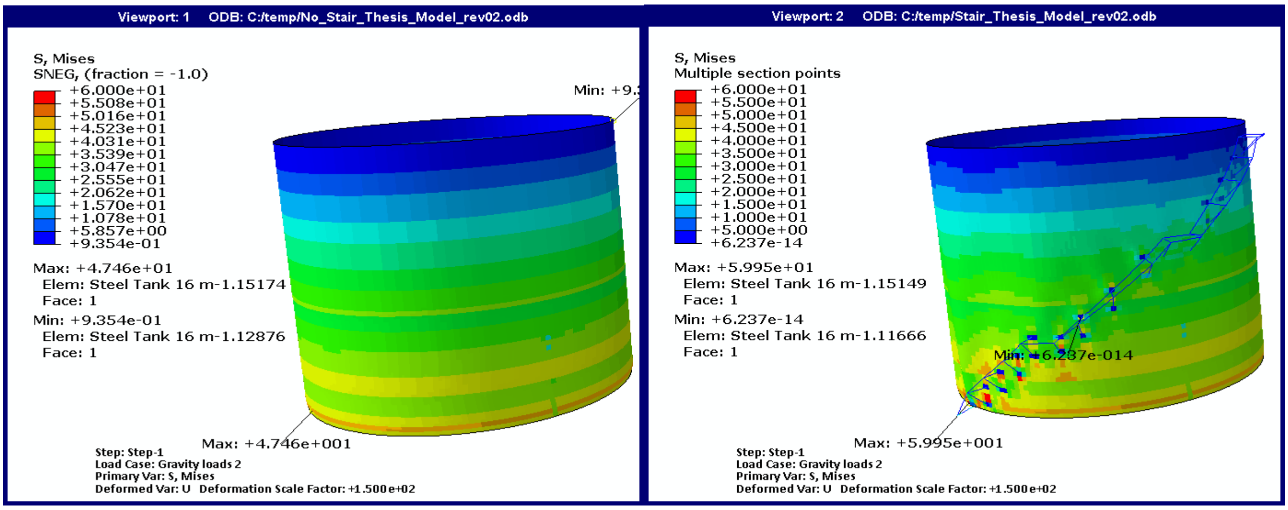


Fig. 15a

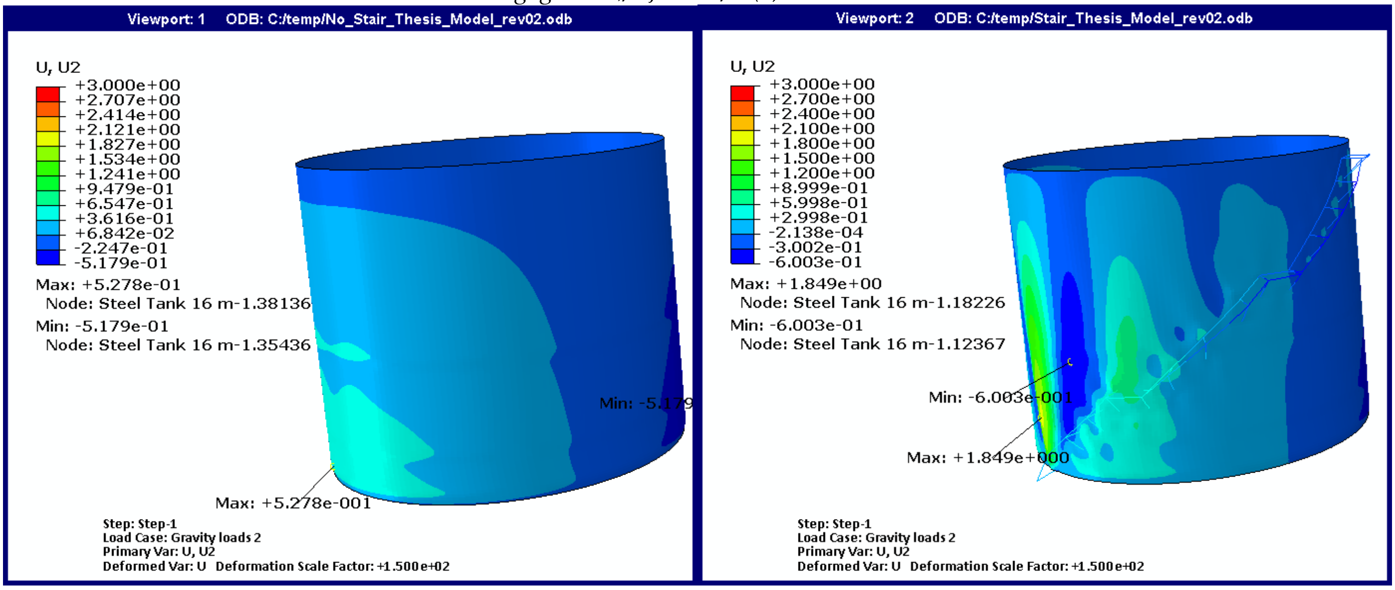


Fig 16

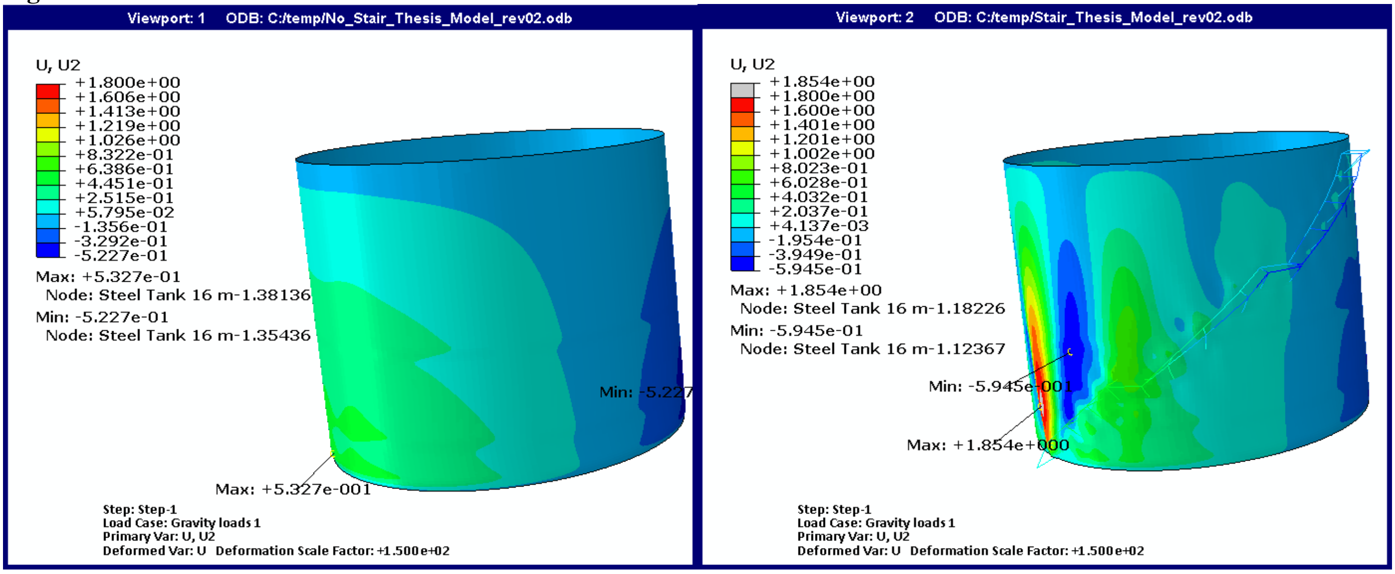


Fig 16 a

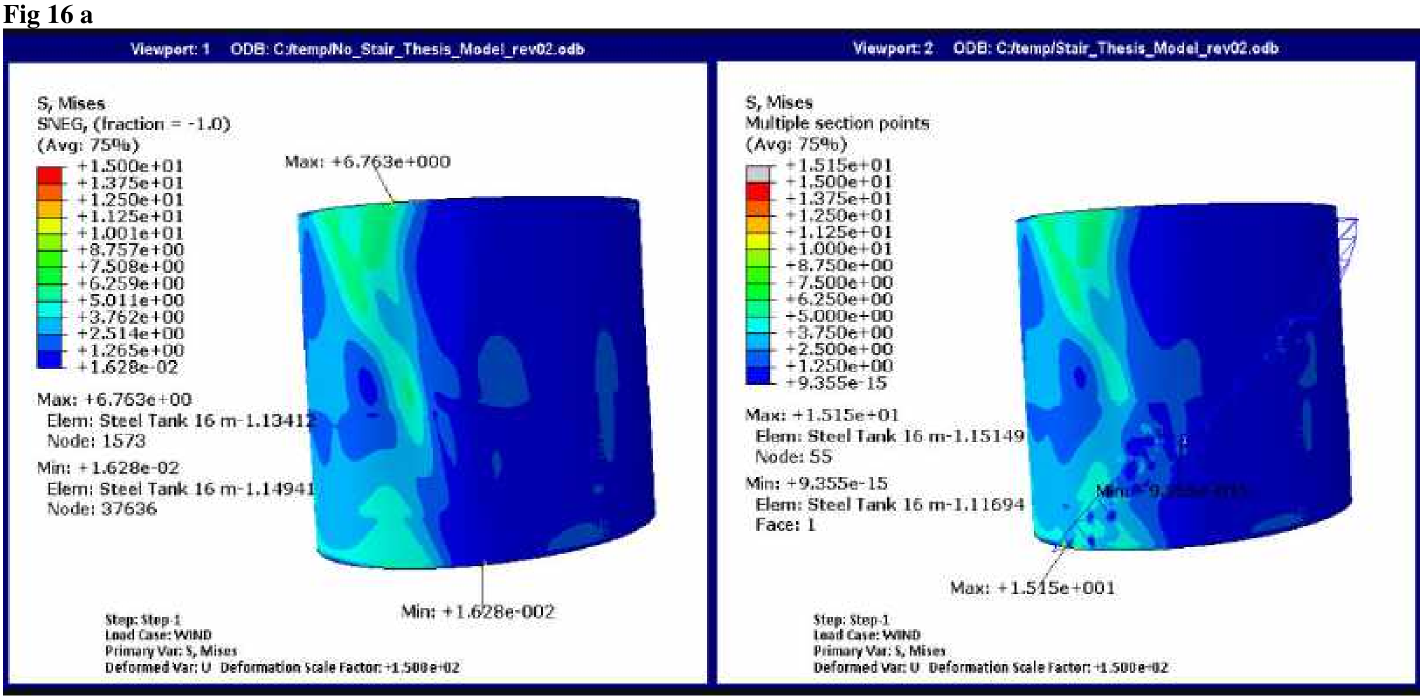


Fig17

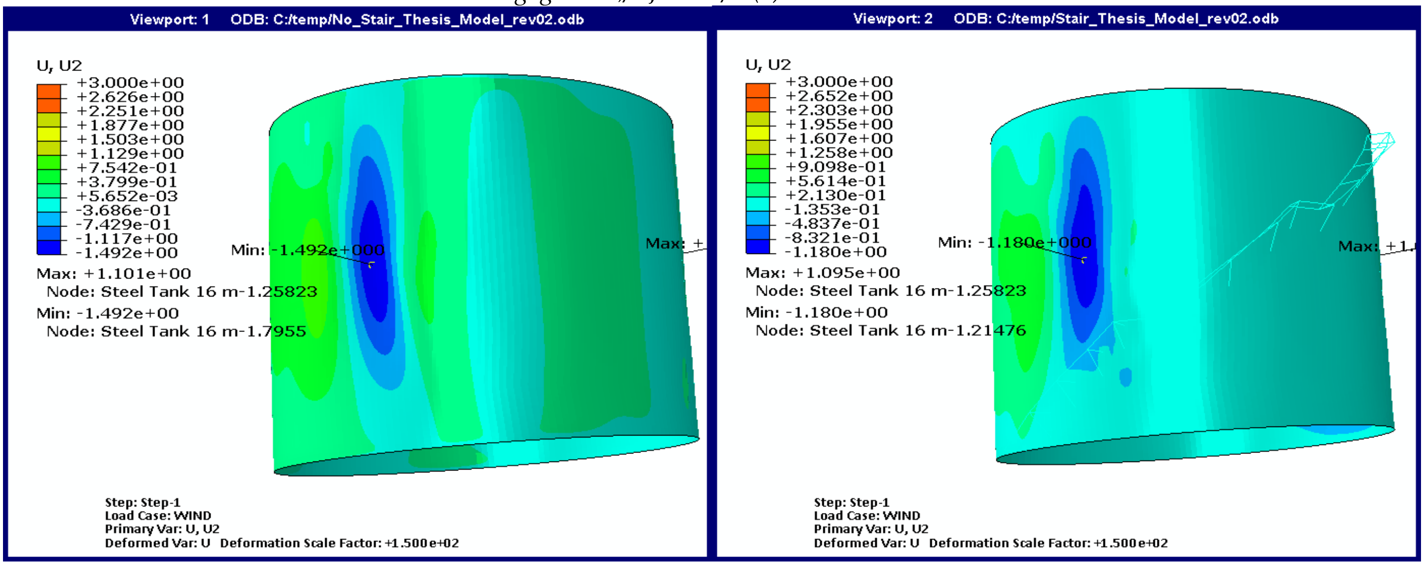


Fig 18

Author observation in cases of loading DL+Lr+0.4Pe & DL+0.4Lr+Pe

Figures 15,16,15 a,16 a shows FEM model, Two Cases for Two cases of loading 5 and 6 as mentioned in Table 3.1

Wind Load

Author observation in case of loading Wind Load

Figures 17,18 shows FEM model, Two Cases of wind loading S- Misses and U2. If we have wind load we will obtain benefits from the presence of the stair. Minimum displacement values are exist over all the area of the shell in presence of the stair.

Conclusions and future work

The wind is more or less influential in a given structural design case ,in this paper we investigated that the helical stair which already exist in most kind of above ground storage tank has a great influence in the design and it can be a reason to reduce the thickness of tank shell. Helical stair acts as an oblique stiffener especially in case of wind load as it decreases the displacement by 5 % .Although the helical stairs and due to its weight increase the maximum stress, it decreases the stress in the area surrounded the stair by great values. We highly recommend another study in presence of helical stair surround all the circumference of the tank not only half of it and we do believe thus will reduce the shell thicknesses by more than 15 %.On the other hand the calculated wind load due to CFD is completely different than the typical methods in standards and codes. As in CFD computation we obtain real stress values which are extremely similar to the values we get from Wind tunnel.

References

[1]KDeana,W.DCookaP,Burchillb, MZipperc Curing behaviour of IPNs formed from model VERs and epoxy systems: Part II. Imidazole-cured epoxy,2001

[2]Kamila Hrabovská,Jitka Podjuklová,Karla Barčová,Katerina Pelikánová Vitreous Enamel Coating on Steel Substrates ,2009

[3] A. V. Ryabova, ,E. A. Yatsenko, ,V. V. Khoroshavina & L. V. Klimova Glass-Enamel Corrosion-Resistant Coatings for Steel Pipelines ,2017

Gravity cases S- Misses and U2.It is extremely obvious that if we have wind load we will obtain benefits from the presence of the stair ,especially in displacement resistant .

[4] Amir R. Shokrzadeh, Strengthening effects of spiral stairway on the buckling behavior of metal tanks under wind and vacuum pressures,2016.

[5] American Petroleum Institute. Welded Tanks for Oil Storage. API Standard 650, 11th edition. API Publishing Services, Washington, D.C. (2007).

[6] Carlos A. Burgos, Wind buckling of tanks with conical roof considering shielding by another tank, 2014.

[7] Yang Zhao n , Yin Lin, Buckling of cylindrical open-topped steel tanks under wind load;2014.

[8] Luis A. Godoy, Buckling of vertical oil storage steel tanks: Review of static buckling studies; 2016.