FINITE ELEMENT ANALYSIS OF COMPOSITE WATER BUFFER DRUM

By

CHINMAY SHRIKRISHNA GODBOLE

Presented to the Faculty of the Graduate School of

The University of Texas at Arlington in Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

MAY 2018

Acknowledgement

I would like to thank Dr. Andrey Beyle for giving me this opportunity to work under his guidance. His encouraging and problem-solving nature helped me a lot throughout this journey. He always had time to discuss and solved my problems by giving valuable input.

I would like to thank Dr. Dereje Agonafer and Dr. Kent Lawrence for finding time from their busy schedule to be on my thesis defense committee.

I would like to thank all my friends, colleagues for being there and supporting me. Their motivation helped me along all the way to crack every problem.

I would also like to thank my family, especially my father, my mother for their support all these years. It was their continued support and belief that I have been able to do all that I have done so far.

Lastly, I would also like to offer my regards to all those who have supported or helped me in any regards to this journey.

Abstract

FINITE ELEMENT ANALYSIS OF COMPOSITE WATER BUFFER DRUM

Chinmay Shrikrishna Godbole, MS

The University of Texas at Arlington, 2018

Supervising Professor: Andrey Beyle

Composite materials offer many advantages for to many industries and developments based on their low density, corrosion resistance, and high strength to weight ratio. In addition, the use of composites allows for more design flexibility for products, the properties to meet specific design requirements, thus promoting better system oriented and cost-effective solutions. However, on a high performance equated basis, the economic incentive to use composite components can often be demonstrated based on their capability to reduce system and life cycle costs.

Water buffer drum which is a pressure vessel holds a specified volume of fluid with desired temperature and pressure. Its function is to provide water with certain temperature to equipment facility. For smooth working large number of piping is attached to this. These conditions create critical nozzle loading on the pressure vessel. This paper gives an idea about comparative study between carbon steel and combination of carbon steel and composites. Composites such as Glass fibered reinforced are used for the study. Pressure vessel with a combination of different boundary conditions such as Pressure, Nozzle loading, Wind, Seismic is analyzed for carbon steel and the combination of carbon steel and composites. Various thickness combinations of composite and carbon steel are used for design study. While analyzing water buffer drum components stress induced in various components are compared. By replacing some

thickness of carbon steel there will be percent reduction in weight which will save many costs related to the weight of water buffer drum.

Table of Contents

List of Illustrations

List of Tables

Chapter 1 Introduction

The pressure vessel is one most important equipment for the smooth functioning of many industries such as oil and gas, pharmaceutical, healthcare, HVAC. The pressure vessel is nothing but equipment to hold the desired volume of gas or liquid at required temperature and pressure. The pressure vessel is generally made of carbon steel, stainless steel or metals. There are very few cases where non-metal is used for manufacturing of pressure vessel. Pressure vessel construction is very costly for its service time considered. Corrosion is one of a factor that cost many lots in construction. But there are ways to reduce the overall cost of the pressure vessel.

To reduce pressure vessel cost, the weight of pressure vessel should decrease, and lifespan should increase. The decrease in weight will affect vessel transportation, operation, and maintenance cost. Reducing weight is very tedious job due to complexity in pressure vessel operation. For this new material with low density and high strength and stiffness can be used.

In recent years, composite materials with these properties are evolved. Also, extensive research on various materials and improvising their properties are going on. Many materials with such properties are easily available in the market.

1.1 What is water buffer drum

Water buffer drum is pressure vessel used for water flow circulation to increase system efficiency in chillers, reactors, boilers. Depending upon application temperature range of fluid in water buffer drum is decided. As per process requirement capacity of the drum, more factors are taken into consideration for design. It is used in fluid circulation vessel so the major piping system is attached to this.

Chilled water buffer drums are designed for use of chilled water system with insufficient water volume capacity, in relation to chiller capacity. Chilled water buffer drum increases system volume and reduces the rate of temperature change in return water, resulting in improved temperature control, consistent system operation and controlled compressor cycling.

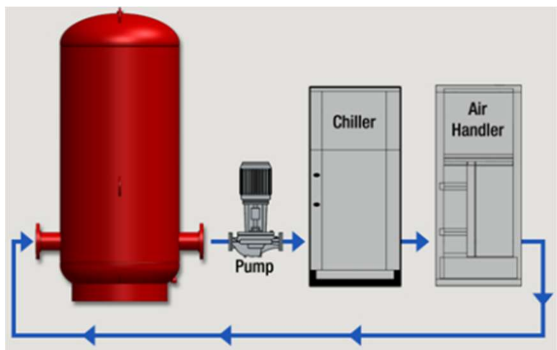


Figure 1-1 Chilled water buffer drum

Hot water buffer drum is designed for use of high temperature, a high-efficiency system that incorporates small, modular low mass boiler. It adds necessary thermal mass to the system to dampen fast transitions and minimize boiler cycling that occurs during zero or low domestic load conditions.

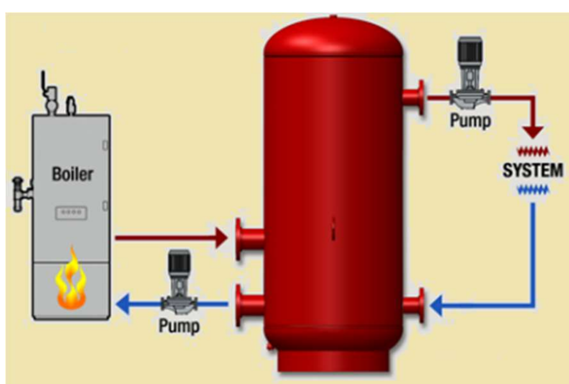


Figure 1-2 Hot water buffer drum[1]

1.2 Research Objective

The objective of this study is to analyze water buffer drum which is used in industry for storing water with desired temperature and pressure. For smooth functioning of the drum, piping is attached to it. For most of the cases, piping loads are affecting design thickness of drum. In this study, we are analyzing buffer drum with various thickness combination of composite and carbon steel. We will be keeping same design conditions for the composite model as that of original carbon steel model to withstand combined loads like internal pressure, nozzle load, wind load, seismic load.

We aim to show stress generated due to loading condition various parts with variation in a combination of thickness with carbon steel and composite. As using composite will be beneficial for weight reduction of whole geometry.

1.3 Composites

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite, you can easily tell the different materials apart as they do not dissolve or blend into each other. Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibers or fragments of the other material, which is called the reinforcement. Composite materials are high in strength to weight ratio[2]. Composites are a combination of two or more constituent materials with significantly different physical and chemical properties. When two or more materials combine it give other material which is completely different from individual materials.

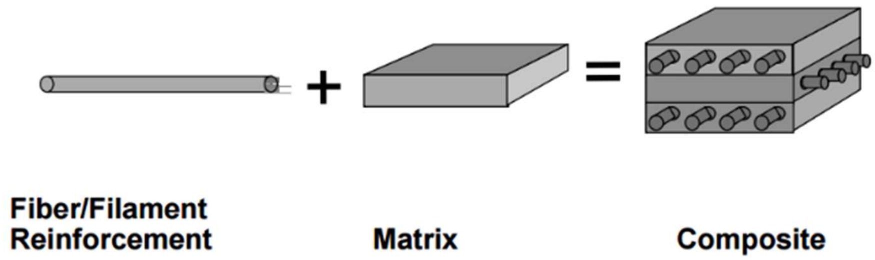


Figure 1-3 Composites[3]

In this study we considering E-glass fiber. E-glass fiber is having some distinct properties to be considered, those properties are listed below:

- High stiffness
- Low cost
- Corrosion resistant
- Thermal resistance
- Low density
- Design flexibility
- Low manufacturing constraints

Also, while analyzing composite some factors should consider:

- Delamination in ply
- In Plane shear due to deflection
- Shear due to out of plane deformation

Chapter 2 Geometry

In this chapter, we will discuss about water buffer drum geometry used for analysis. Overall length of 7150 mm with TL to TL length 4100 mm and internal diameter of 1450 mm. 8 mm thickness is used for geometry for shell and head. For this study, carbon steel material is used for preliminary analysis.

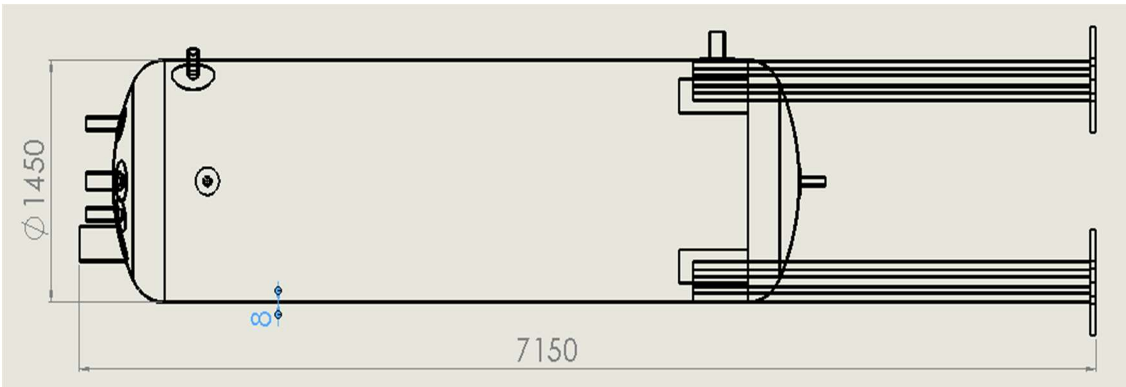


Figure 2-1 Overall Dimensions

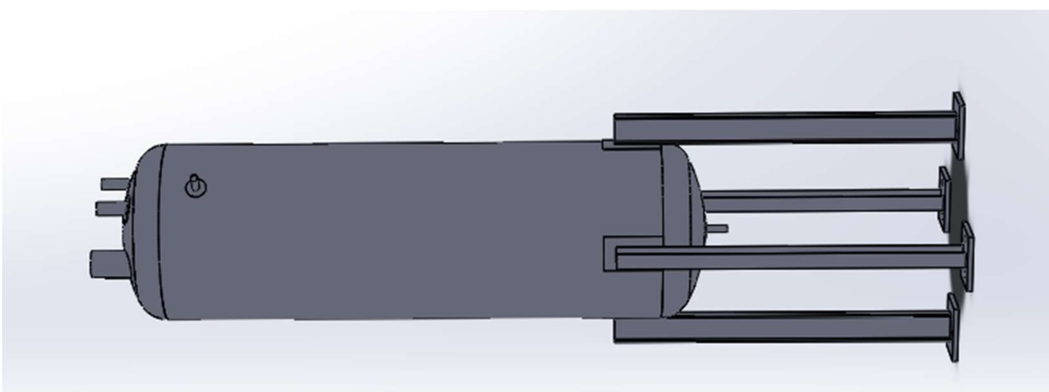


Figure 2-2 Overall Geometry

For working of water buffer drum various nozzles are attached to water buffer drum. Nozzle orientation with nozzle properties is mentioned below.

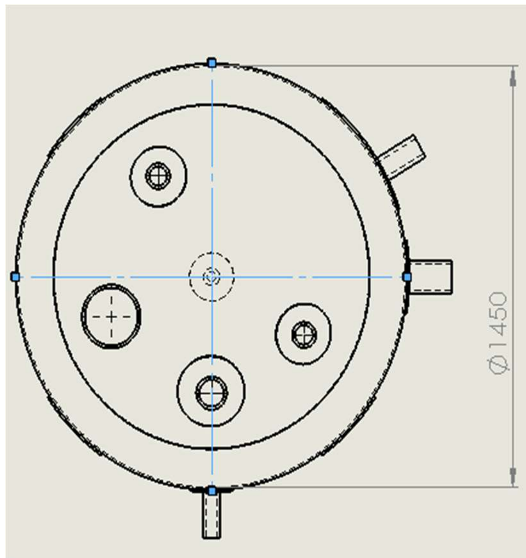


Figure 2-3 Nozzle orientation

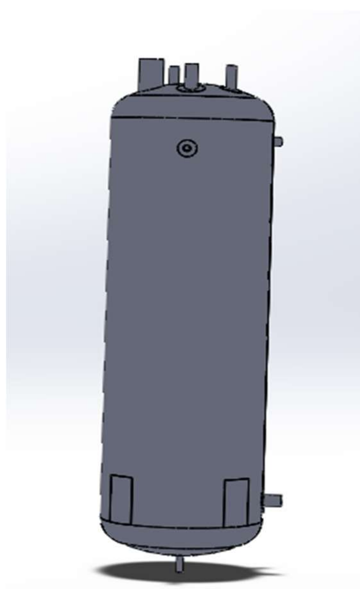


Figure 2-4 Water buffer drum with nozzles

Form nozzle table other details for nozzles like nozzle projection, nozzle size, nozzle thickness, reinforcement pad can be obtained. Nozzle thickness is nothing but nozzle schedule. Nozzle is a pipe, so thickness of nozzle varies with schedule, but the outer diameter remains the same for every size. Nozzle table is mentioned below.

Description	**Pipe size (inch)**	**Schedule**	**RF Pad (mm)**	**Projection (mm)**
Water Inlet	3”	Sch 160	t8 x 210	550 from TTL
Drain	2”	t13.6	t8 x 165	550 from BTL
Minimum flow	2”	Sch 160	t8 x 165	910 from CL
Water Outlet	4”	Sch 160	t8 x 250	910 from CL
Vent	3”	Sch 120	t8 x 210	550 from TTL
Overflow	3”	Sch xxs	t8 x 300	910 from CL
Handhole	8”	Sch 60	-	600 from TTL
Recirculation Line	4”	Sch 120	t8 x 250	550 from TTL

Table 2-1 Nozzle properties

Nozzles are welded to the pressure vessel and then mentioned thickness reinforcement pads are welded to pressure vessel.

According to pressure vessel, elevation and functioning type of supports are decided. Supports types for vertical pressure vessel are generally Leg, Lug, and Skirt. Legs are nothing but typical cross sections like I beam, angle beam, channel beam or pipe. In this study cross-section of leg is I beam. Water buffer drum is supported by legs which are welded to reinforcement pad on pressure vessel shell. Legs are welded to baseplate which is attached to foundation with help of foundation anchor bolts. Reinforcement pad with width of 285 mm and height of 450 mm is welded on shell with 45°, 135°, 225°, 315° orientation. For baseplate foundation bolts BCD is 1724 mm.

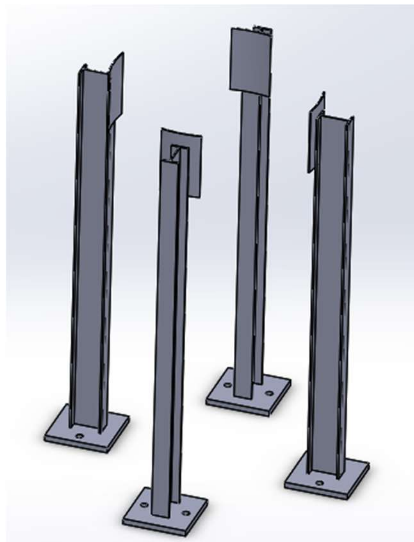


Figure 2-5 Leg support with reinforcement pad

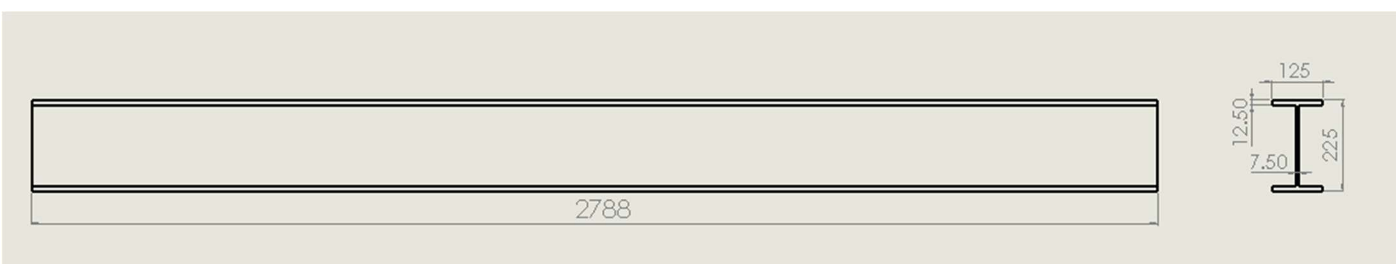


Figure 2-6 Leg cross section

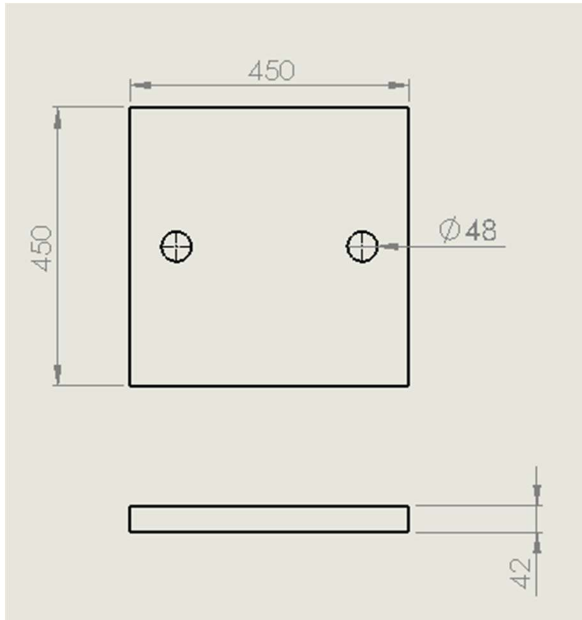


Figure 2-7 Baseplate cross section

Chapter 3 Design Parameters

Pressure vessel design generally based on functioning, surrounding conditions, working zone and many more. In this chapter, we will discuss about design conditions, material properties of carbon steel.

3.1 Design conditions

Factors affecting the design of water buffer drum are:

- Internal pressure
- External pressure
- Design temperature
- Corrosion allowance
- Welding joint type & efficiency
- Materials
- Insulation
- Testing conditions

Depending upon these conditions pressure vessel manufacturing constraints can be obtained. In this case, we are considering basic design parameters to obtain pressure vessel basic geometry. Pressure vessel consists of various parts which are welded to shell and head. Welding details are a very important criterion in the manufacturing of pressure vessel. Most of the time welding details are defined by the manufacturer. In this case, required design parameters are listed below:

Parameter	Value	Unit
Internal Pressure	Atmospheric Pressure (101325)	Pa
External Pressure	Atmospheric Pressure (101325)	Pa
Design Temperature	75	°C
Density of fluid	997	Kg/m^3
Corrosion Allowance	1.5	mm
Joint Efficiency	1.0	-
Radiography	100%	-

Table 3-1 Design Parameters

3.2 Material Properties

In pressure vessel design various components are included which can be manufactured from various manufacturing procedures like casting, machining, forming, forging etc. Materials are of various types like a plate, rod, pipe. As the strength of a material depends on its manufacturing process. According to process requirement material for various components to be decided. Also, while choosing materials there is one more factor to be considered. That factor is the type of fluid pressure vessel will hold. Fluid inside is also causing corrosion. By considering all these factors materials needed to be considered for design. Generally, standard materials are considered for design from ASME section II part A & B. Material properties are taken from ASME section II part D. Material list and material properties considered for this case are mentioned below:

Component	**Material**
Shell & Head	SA 516 Gr.70
Reinforcement Pad	SA 516 Gr.70
Support Leg	SA 36
Baseplate	SA 36

Table 3-2 Material List [4][5]

Properties	**Value**	
	SA 516 Gr.70	**SA 36**
Young’s Modulus	200 GPa	200 GPa
Yield Tensile Strength	260 MPa	250 MPa
Ultimate Tensile Strength	485 MPa	400 MPa
Poisson’s Ratio	0.29	0.26
Density	7800 kg/m^3	7800 kg/m^3
Allowable stress	138 MPa	114 MPa

Table 3-3 Material Properties[6][7][8]

Chapter 4 Design Calculations & Loading Conditions

The loadings to be considered in designing a vessel shall include those from:

a) Internal or External pressure

b) the weight of the vessel and normal contents under operating or test conditions

c) superimposed static reactions from the weight of attached equipment, such as motors, machinery, other vessels, piping, linings, and insulation

d) cyclic and dynamic reactions due to pressure or thermal variations, or from equipment mounted on a vessel and mechanical loadings

e) wind, snow, and seismic reactions

f) impact reactions such as those due to fluid shock

g) temperature gradients and differential thermal expansion

h) abnormal pressures, such as those caused by deflagration

i) test pressure and coincident static head acting during the test[9]

These are several loading conditions that one should take into consideration while designing the pressure vessel. In every pressure vessel according to surrounding or process conditions types of loadings vary. Multiple loadings can simultaneously act on the pressure vessel. While designing pressure vessel multiple loading cases should be considered. First, we will find individual loads acting on pressure vessel according to design parameters. In this design study, we are considering Pressure, Piping, Wind and seismic loading. In this chapter, we are discussing detail load calculations for factors mentioned.

4.1 Weight

Weight is a most important factor while designing pressure vessel especially supports the vessel. Empty weight and operating weight needs to be considered for load cases. For this case, empty weight of water buffer drum is 2220 kg. This weight is obtained from ANSYS properties. Component wise weight distribution is given below:

Component	**Material**	**Density (kg/m^3)**	**Weight (kg)**
Shell	SA 516 Gr.70	7800	1524
RF Pads	SA 516 Gr.70	7800	36
Support Leg with Base plate	SA 36	7800	660

Table 4-1 Empty weight distribution

For designing pressure vessel, we must consider the real-time scenario. Real time scenario for a pressure vessel is nothing but an operating condition. To obtained operating weight we need to add fluid weight enclosed by water buffer drum to empty weight. First, we need to find volume enclosed by pressure vessel.

Water buffer drum volume = Cylinder volume + Head volume

Cylinder volume = $\pi R^2 H$ [10]

R = Internal radius = 0.725 m

H = TL to TL length = 4.1 m

Cylinder volume = 6.7703 m^3

Head Volume = $\frac{\pi di^3}{24}$ [10]

di = Inside diameter = 1.45 m

Head Volume = 0.399 m^3

Total Volume = 7.5683 m^3

For operating weight, we need to calculate weight fluid enclosed and adding it to empty weight.

Weight of fluid = Volume x Density

= 7.5683 x 997

= 7560 kg

Operating weight = Empty weight + Fluid weight

= 9780 kg

4.2 Pressure & Static Head

Water buffer drum is used for storing fluid so from given design condition internal and external pressure is atmospheric pressure. There is no pressure difference between inside and outside conditions, so we are considering design pressure as zero. This vessel is for storage and recirculation purpose. It always consists of a mighty volume of fluid. Due to that on every component, there is acting pressure static head of fluid is applied. In this section, we will calculate static head acting on each component.

Static head = $\rho g h$

ρ = Density of Fluid = 997 kg/m^3

g = Acceleration due to gravity = 9.81 m/s^2

h = Height of fluid column acting on component

Static head acting on each component is calculated and shown in the table given below:

Component	h = Height of fluid column acting (m)	Static Head (Pa)
Top Head	0.365	3570
Shell	4.465	43670
Bottom Head	4.83	47240

Table 4-2 Static head

In analysis pressure applied on respective components will be Internal Pressure + Static Head.

4.3 Nozzle Loads

Every engineering project involving the design of pressure equipment, including pressure vessels, heat exchangers, and the interconnecting piping requires that the interface loads between the equipment and piping be established for the pressure vessel nozzle design and the limitations on piping end reactions. The vessel or exchanger designer needs to know the externally applied loads on nozzles and the piping designer needs to know the limiting end reactions on any connected equipment. However, the final loads are not known until the piping design is completed. This requires a very good estimate of the piping end loads prior to completing the vessel or piping design. The challenge is to develop a method of determining the optimum set of design loads prior to design. If the design loads are too low, the piping design may become too costly or impractical. If the design loads are too high the vessel nozzle designs will require unnecessary reinforcement and increased cost. The problem of the stresses at a nozzle to vessel intersection due to internal pressure and external forces and moments is one of the most complex problems in pressure vessel design. The problem has been studied extensively; however, each study has its own limitations. Numerous analytical and numerical simulations have been performed providing guidance with associated limitations. The objective is to establish allowable nozzle load tables for the piping designer and the vessel designer. The loads and load combinations must be based on a technically accepted methodology and applicable to all nozzle sizes, pressure classes, schedules and vessel diameters and thicknesses and reinforcement designs within the scope of the tables. The internal design pressure must also be included along with the 3 forces and 3 moments that may be acting on the nozzle and the nozzle load tables must be adaptable to all materials of construction.

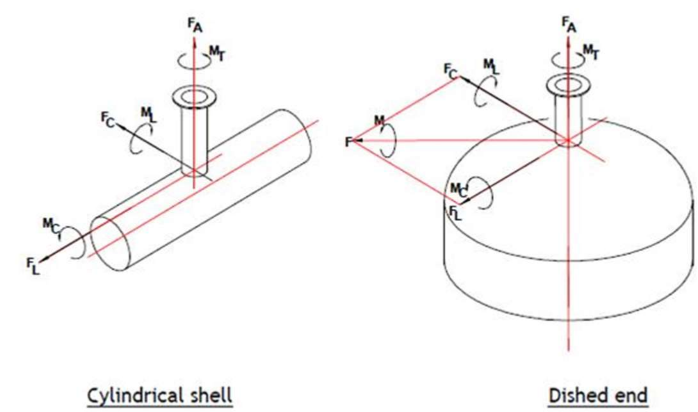


Figure 4-1 Direction of applied nozzle Loads

In Figure 4-1, the direction of each load and moment is shown. These loads vary with nozzle pipe size and nozzle flange rating. The maximum allowable loads which the nozzle can withstand without failure. However, depending on the configuration of the connected Piping system or due to the various design conditions analyzed, the loads imposed on the Nozzle may exceed these allowable values[11].

Design allowable nozzle loads are shown below:

Nozzle pipe size (inch)	Equipment allowable nozzle loads for 150 Flange rating					
	Force (N)			Moment (Nm)		
	F_L	F_A	F_C	M_C	M_T	M_L
2	2400	2400	1800	240	360	320
3	3600	3600	2700	540	810	710
4	4800	4800	3600	960	1440	1250

Table 4-3 Nozzle Loads

F_L – Longitudinal shear force

F_C – Circumferential shear force

F_A – Axial tension or compression force

M_L – Longitudinal bending moment

M_C – Circumferential bending moment

M_T – Torsional moment [11]

In the analysis, nozzle loads specified in Table 4-3 as per nozzle size are applied on respective nozzles in respective global directions.

4.4 Seismic Loading

Seismic loading condition is one of the essential criteria for pressure vessel design. Seismic load failure of the pressure vessel with toxic, pressurized gas or fluid may be catastrophic. Seismic loading in nothing but the vibration of the pressure vessel for some period. This vibration creates some deflection near the attachment of supports and pressure vessel. Due to vibration, there will vertical and horizontal forces acting. And these forces create moments. Moments acts as an overturning moment on leg. In this chapter, we are calculating overturning moment acting per leg according to given process conditions. All the calculation work is done from “Pressure vessel design manual” by Dennis Moss.

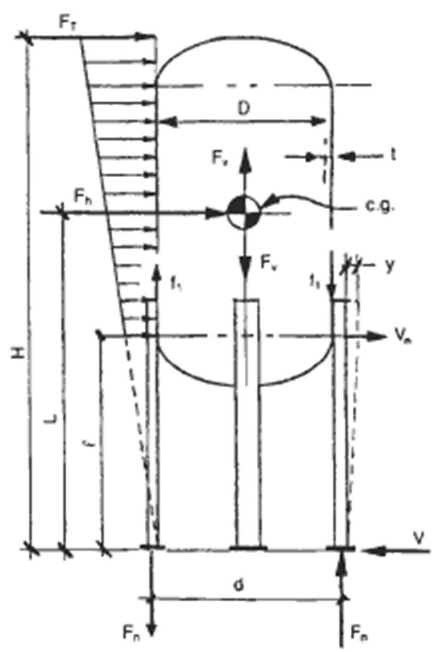


Figure 4-2 Seismic Loads & Reactions for a vessel with unbraced legs[12]

Calculations for moments are shown below:

Operating weight (W_o) = 21613 lb

Modulus of Elasticity (E) = 29007600 Psi

No of Legs (N) = 4

I_x = 100.8 in^4

I_y = 10.2 in^4

Distance from BTL = 92.52 in

Deflection (y) = $\dfrac{2\,Wo\,l^3}{3NE(Ix+Iy)}$

y = 0.88 in

Period of Vibration (T) = $2\pi\sqrt{y/g}$

T = 0.3 sec[12]

Defining some coefficient required for further calculation:

Importance factor (I) =1.0

Numerical Coefficient (R_w) = 2.2

Seismic Zone Factor (Z) = 0.075

Coefficients (C_a) = 0.06

Coefficients (C_v) = 0.06

R_w = coefficient

self-supporting stacks	2.9
vertical vessel on skirt	2.9
spheres and vessels on braced legs	2.2
horizontal vessel on pier	2.9
vertical vessel on unbraced legs	2.2

Figure 4-3 Coefficient R_w

Seismic Coefficient C_a*

Soil Profile Type	Seismic Zone Factor, Z				
	$Z = 0.075$	$Z = 0.15$	$Z = 0.2$	$Z = 0.3$	$Z = 0.4$
S_A	0.06	0.12	0.16	0.24	$0.32N_a$
S_B	0.08	0.15	0.20	0.30	$0.40N_a$
S_C	0.09	0.18	0.24	0.33	$0.40N_a$
S_D	0.12	0.22	0.28	0.36	$0.44N_a$
S_E	0.19	0.30	0.34	0.36	$0.36N_a$
S_F	See Footnote 1				

Seismic Coefficient C_V*

Soil Profile Type	Seismic Zone Factor, Z				
	$Z = 0.075$	$Z = 0.15$	$Z = 0.2$	$Z = 0.3$	$Z = 0.4$
S_A	0.06	0.12	0.16	0.24	$0.32N_v$
S_B	0.08	0.15	0.20	0.30	$0.40N_v$
S_C	0.13	0.25	0.32	0.45	$0.56N_v$
S_D	0.18	0.32	0.40	0.54	$0.64N_v$
S_E	0.26	0.50	0.64	0.84	$0.96N_v$
S_F	See Footnote 1				

Figure 4-4 Coefficients C_a & C_v

Calculating base shear (V)

$V_1 = 0.56\ Ca\ I\ Wo$

= 726.2 lb

$$V_2 = \frac{Cv\ I\ Wo}{Rw\ T}$$

= 1964.8 lb

$$V_3 = \frac{2.5\ Ca\ I\ Wo}{Rw}$$

= 1473.6 lb

As V must be greater of V_1 & V_2 but it should not exceed V_3.

Seismic design is based on allowable stresses rather than yield or ultimate strength so base shear may be reduced by factor of 1.4.

$V = V_3/4$

= 1052.5 lb

As T< 0.7 sec, percent of shear applied on top is zero.

Overturning Moment at Base,

M = L V[12]

Where L is distance of CG of vessel from base

M = 124136 lb.in

Overturning moment per leg,

M_S = 31034 lb.in OR 3500 Nm

4.5 Wind Loading

Wind pressure is one of the most important factors in designing of pressure vessel. Wind loads exert pressure on the projected area of the pressure vessel which can cause bending of supports. Wind consideration is important for the structural stability of the vessel. It is essential to find out wind forces and moments for elevations of the pressure vessel. Also, one of the factor to check is vessel thickness adequacy. Apart from thickness it generates overturning moment at base anchorage due to lift. For this study, wind load calculations are based on American Society of Civil Engineers (ASCE) 7-95 obtained from “Pressure Vessel Design Manual‟ by Dannis Moss.[13]

Defining factors and coefficients need to be considered for wind calculations:

Structure category = II

Exposure category = D

Table 3-2
Structure Categories

Buildings and structures that represent a low hazard to human life in the event of failure	Category I
All buildings not covered by the other 3 categories	Category II
Buildings and other structures containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released. . .REFINERIES	Category III
Buildings or structures where the primary occupancy is one in which more than 300 people congregate in one area	Category III
Schools, non-emergency health care facilities, jails, non-essential power stations	Category III
Essential facilities	Category IV

Exposure Categories

The following ground roughness exposure categories are considered and defined in ASCE 7-95 Section 6.5.3.1:

- *Exposure A:* Centers of large cities.
- *Exposure B:* Urban and suburban areas, towns, city outskirts, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single family dwellings or larger.
- *Exposure C:* Open terrain with scattered obstructions having heights generally less than 30 ft (9.1 m).
- *Exposure D:* Flat, unobstructed coastal areas directly exposed to wind blowing over open water; applicable for structures within distance from shoreline of 1500 ft or 10 times the structure height.

Figure 4-5 Structure Category & Exposure Categories from Moss[12]

Wind Load calculation factors depending structural & exposure category from "Pressure vessel design Manual" by Dannis Moss are listed below:

Description	Symbol	Value	Unit
Basic wind speed	V	72	mph
Effective Diameter	$D_e = 1.4D$	6.71	ft
Importance Factor	I	1.15	-
Force Coefficient	C_f	0.9	-
Gust Factor	G	0.85	
Velocity pressure exposure coefficient	K_z	1.12	-
Topographic factor	K_{zt}	1.0	-
Height	H	23.45	ft
Projected Area	$A_f = L_e D_e$	64.7	Sq ft

Table 4-4 Wind calculation coefficient from Moss

First to determine vessel is rigid or flexible

a) If h/D < 4, then vessel is rigid.

b) If h/D > 4, then vessel is flexible.

Calculate h/ D ratio = 23.45/6.71 = 3.49 < 4, Hence vessel is rigid.

Wind Load (F) = $q_z\ G\ C_f\ A_f$

Velocity Pressure at height z above the ground (q_z) =0.00256 $K_z\ K_{zt}\ V^2$ I [12]

qz = 0.00256 (1.12) (1.0) $(72)^2$ (1.15)

= 17.09 pound per square feet

F = (17.09) (0.85) (0.9) (64.7)

= 846 lb

The overturning moment at the base,

M = 121400 lb in

Effective overturning moment per leg,

M_w = 30350 lb in OR 3435 Nm

4.6 Loading Combinations

In this analysis, a combination of mentioned loadings is used as load cases. While combining load case mainly testing, transportation and operating conditions are considered. While transportation of buffer drum or for maintenance all nozzle will be blinded. In that case, there will be a vacuum created inside buffer drum. On that note, external atmospheric pressure will act on drum. We considered wind and seismic loadings for drum. Ideally, it should be designed for worst case like wind and seismic loads at same time. But it is not needed to consider such a rare case. In all the cases there is fixed support is considered on anchor bolt surface on base plate. Typically, we are analyzing four cases with load combination mentioned as below:

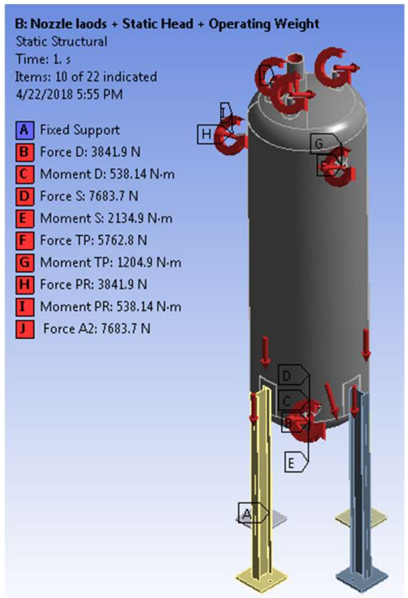
Case 1: Internal Pressure + Static Head + Operating Weight + Nozzle Loads

Case 2: External Pressure + Empty weight

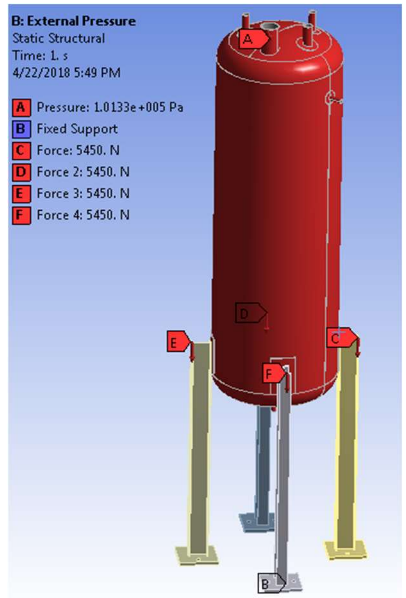
Case 3: Internal Pressure + Static Head + Operating Weight + Nozzle Loads + Seismic Load

Case 4: Internal Pressure + Static Head + Operating Weight + Nozzle Loads + Wind Load

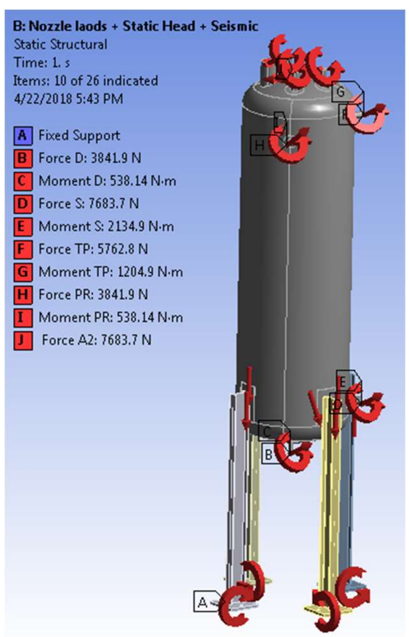
Actual ANSYS applied load case is shown below:



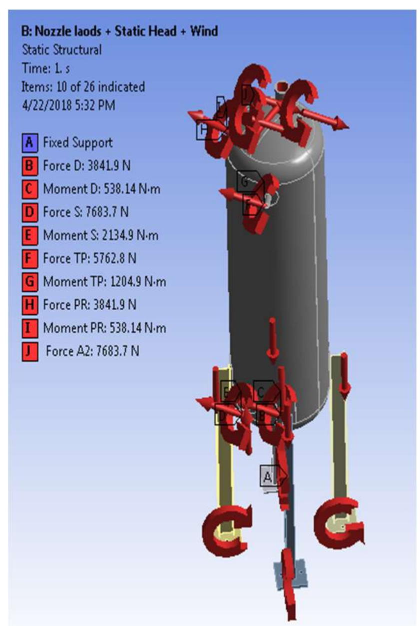
(a)



(b)



(c)



(d)

Figure 4-6 (a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4

Chapter 5 Carbon Steel Results

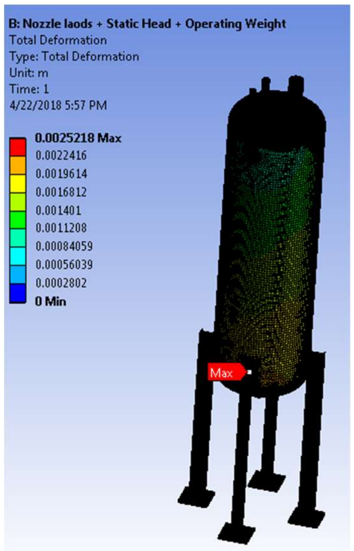
From loading conditions, results for four cases are obtained. In this chapter, we will compare all load case results. All the results are obtained with simulation software ANSYS 17.2 For each case we are comparing overall stress, stress induced in support leg, stress induced in reinforcement pad. By comparing results, we can obtain most stringent case for the pressure vessel.

From ANSYS, we have obtained equivalent von misses stress at every component. As legs are welded to RF pad and RF pad is welded on the shell. So, we are considering stress values of these components. As near welding connection, there will be more stress concentration. For results in each case, the maximum point of stress generation for each component are shown in results.

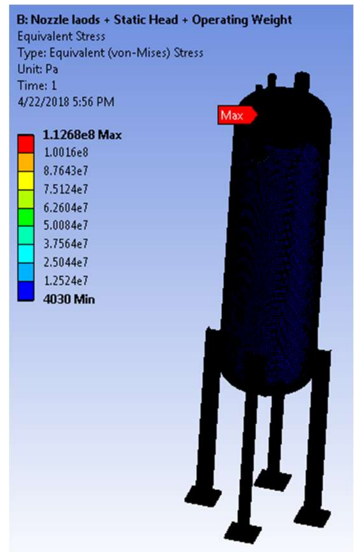
Results for deformation, Maximum Stress induced, Stress-induced in legs and RF pad for every case is shown.

5.1 Load Case 1

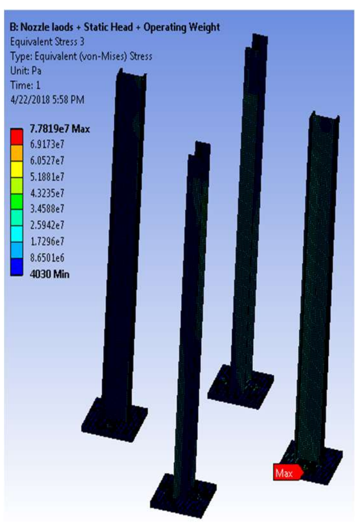
Results for load case 1 are shown below:



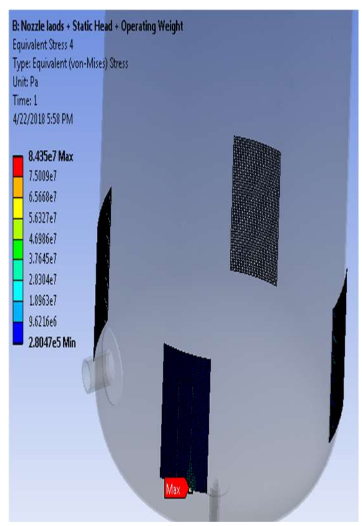
(a)



(b)



(c)

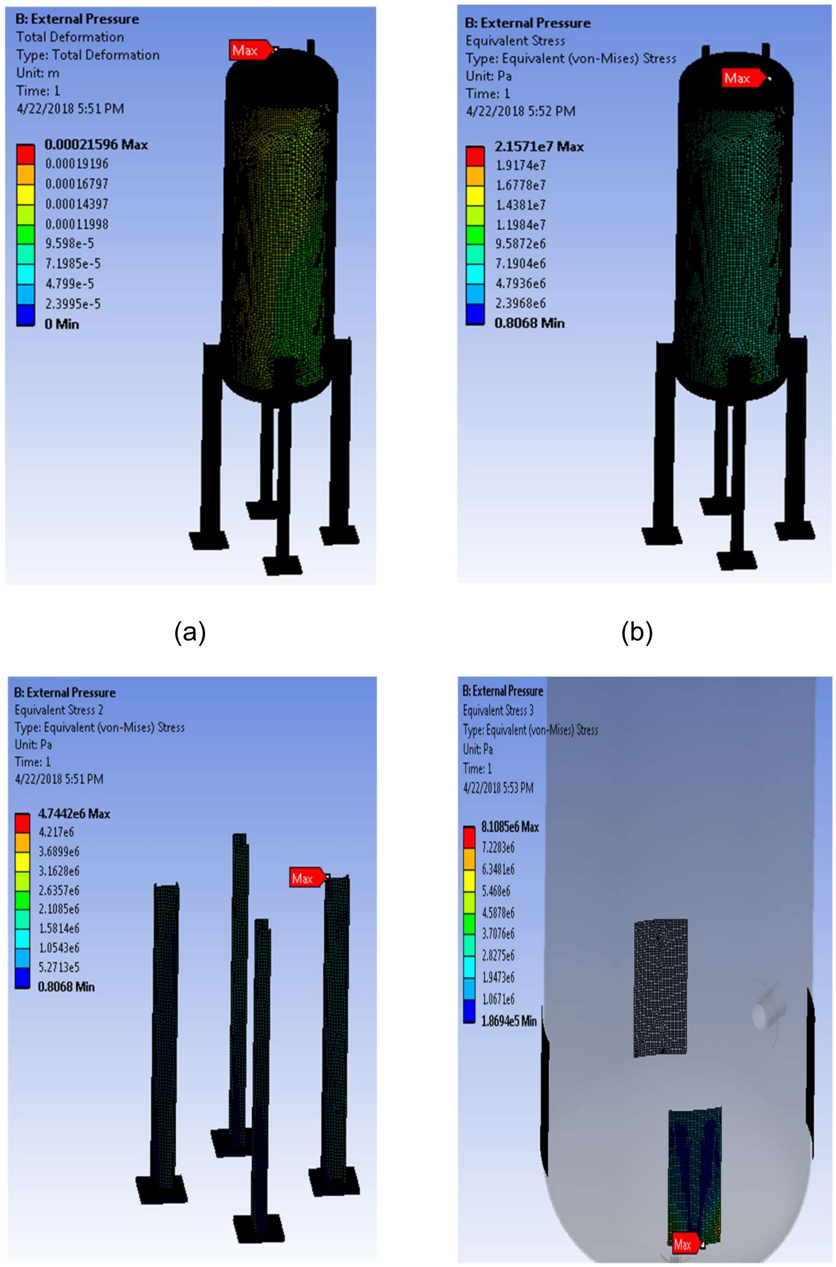


(d)

Figure 5-1 Case 1 Results (a) Total Deformation (b) Overall Stress (c) Legs (d) RF Pad

5.2 Load Case 2

Results for load case 2 are shown below:

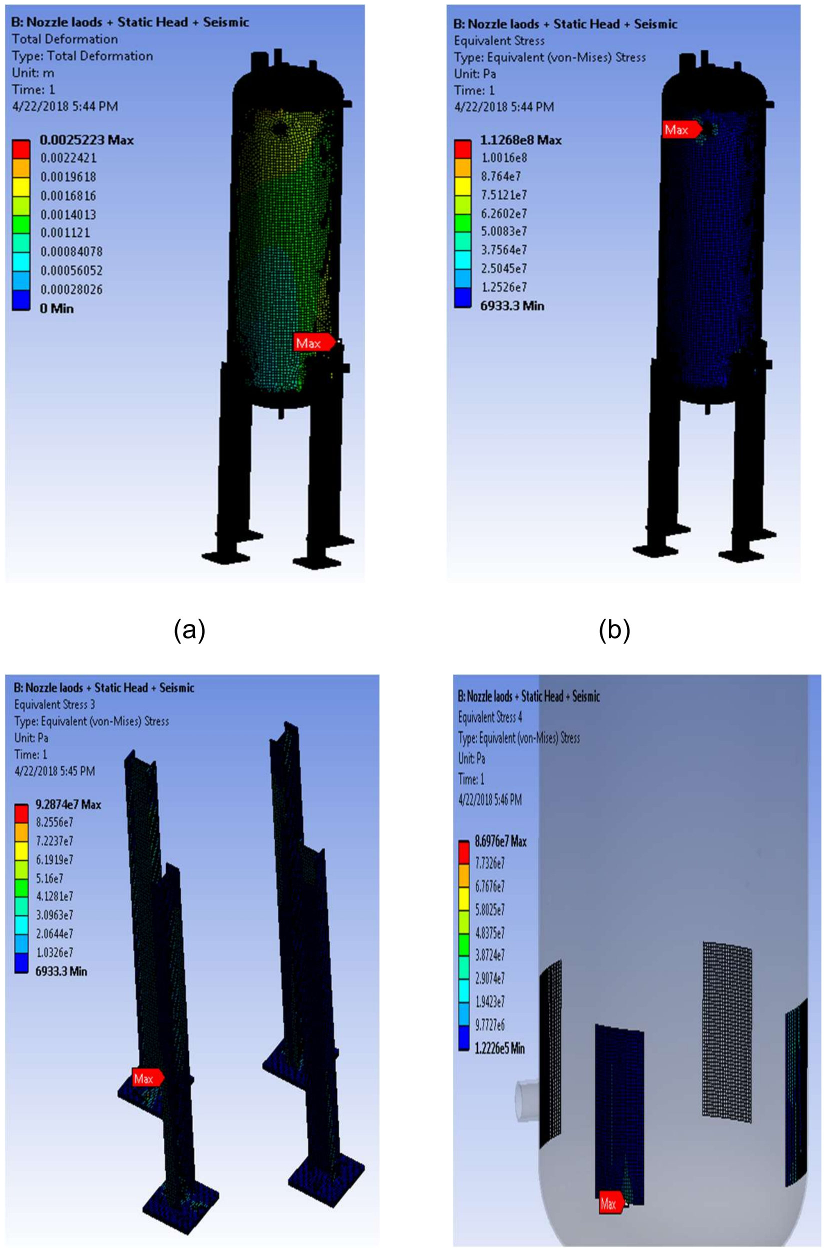


(a) (b) (c) (d)

Figure 5-2 Case 2 Results (a) Total Deformation (b) Overall Stress (c) Legs (d) RF Pad

5.3 Load Case 3

Results for Load Case 3 are shown below:

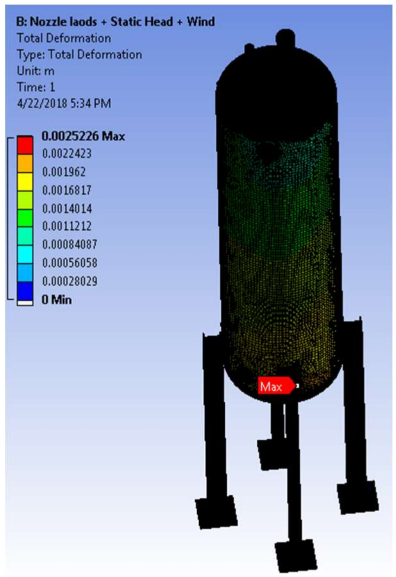


(b) (d)

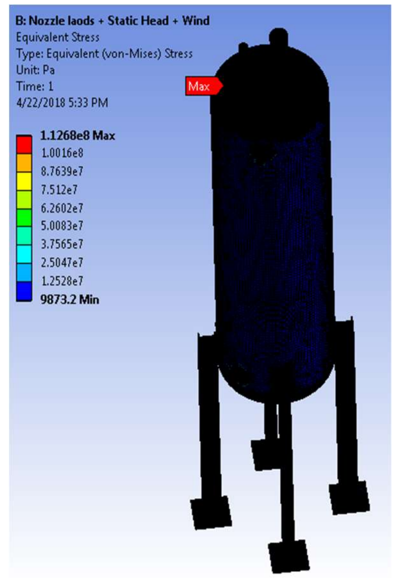
Figure 5-3 Case 3 Results (a) Total Deformation (b) Overall Stress (c) Legs (d) RF Pad

5.4 Load Case 4

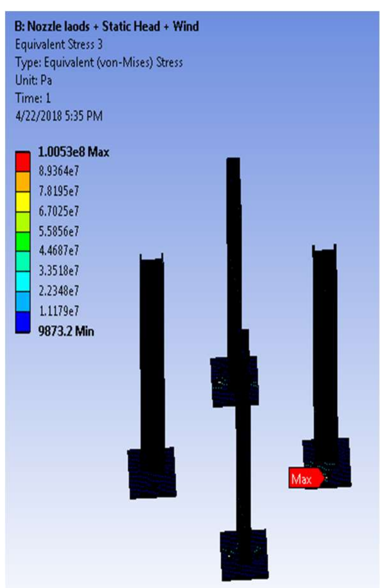
Results for Load Case 4 are shown below:



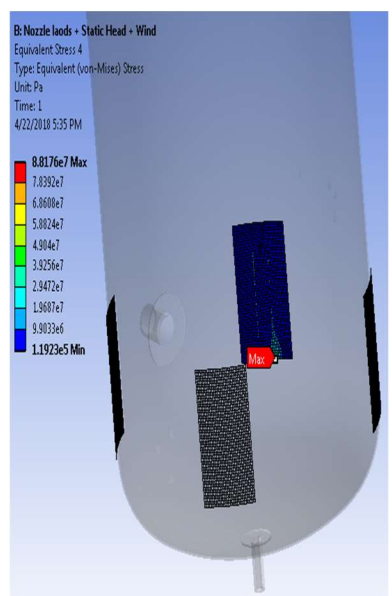
(a)



(b)



(c)



(d)

Figure 5-4 Case 4 Results (a) Total Deformation (b) Overall Stress (c) Legs (d) RF Pad

5.5 Comparison of Load cases

From all load cases comparing data of stress induced in shell, Leg, RF pad to find dominant case amongst all. Stress-induced by various components are tabulated below:

Stress (MPa)	Case 1	Case 2	Case 3	Case 4
Shell	112.68	21.57	112.68	112.68
Leg	77.82	4.74	92.87	100.53
RF Pad	84.35	8.11	86.97	88.17

Table 5-1 Comparison of stress-induced for all load cases

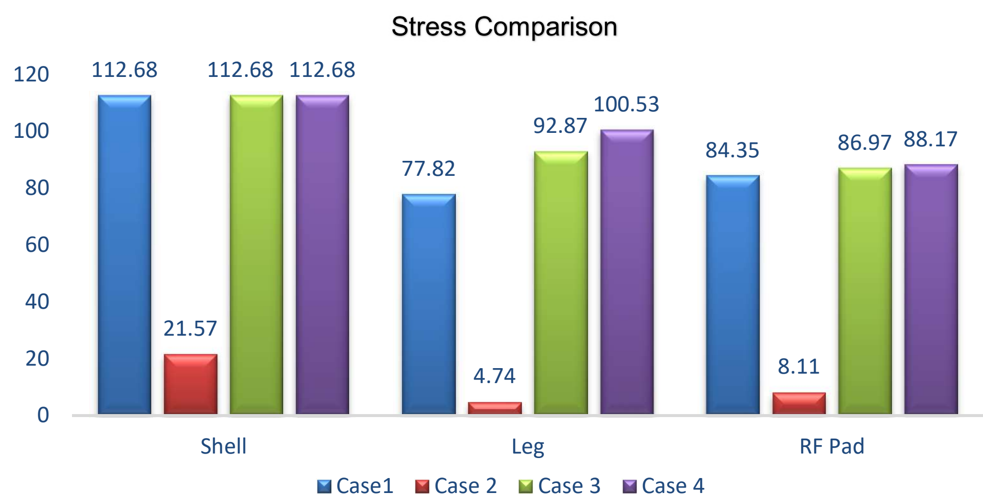


Figure 5-5 Stress comparison chart

From above comparison, we have noticed that value on shell remains same in almost all the cases as nozzle loading is a critical factor for causing maximum stress around nozzle reinforcement pad on shell. And stress generated in legs and RF pad varies with each load case. From above data, we can say load case 4 which is Internal Pressure + Static Head + Nozzle load + Wind load is critical case for water buffer drum.

Chapter 6 Composites

In this chapter, we will discuss material properties, how composite analysis is done in ANSYS. This study includes comparison between carbon steel and combination of carbon steel and composites. Various cases with different thickness combinations are considered for this study. For this study, we are replacing some part of shell thickness by composite material. Support leg and RF pad remain same as that of carbon steel.

In this case we are considering three thickness combinations. These combinations are:

a) 4 mm of carbon steel + 2 mm of E-glass
b) 4 mm of carbon steel + 4 mm of E-glass
c) 6 mm of carbon steel + 2 mm of E-glass

6.1 E-glass properties

Mainly E-glass is used for this study due to its extensive properties for this type of application. As mentioned earlier, E-glass is orthotropic in nature. As its material properties are not same in every direction. We need to mention every single property required for analysis. E-glass unidirectional material is used for simulation. Default E-glass UD material mentioned in ANSYS in used. Material properties Material properties of E-glass are mentioned in the table below:

Properties	Value
E_{11}	45000 MPa
E_{22}	10000 MPa
E_{33}	10000 MPa
V_{12}	0.3
V_{23}	0.4
V_{31}	0.3
G_{12}	5000 MPa
G_{23}	3847 MPa
G_{31}	5000 MPa
Tensile strength in X direction	1100 MPa
Tensile strength in Y direction	35 MPa
Tensile strength in Z direction	35 MPa
Compressive strength in X direction	-675 MPa
Compressive strength in Y direction	-120 MPa
Compressive strength in Z direction	-120 MPa
Shear strength in XY	80 MPa
Shear strength in YZ	47 MPa
Shear strength in XZ	80 MPa

Table 6-1 E-glass Properties

6.2 Simulation

ANSYS Processing is divided into three steps:

Pre-processing: In this step, the material is defined and assigned to geometry. Model is generated. Also, the meshing of the model with different mesh parameters is done.

Solution: In this step, all loading conditions to geometry such as forces, moments are defined and applied. Solution control tool is available to control various steps in solution module.

Post-processing: In this step desired results can be produced. There are multiple options to generate results.

ANSYS composite PrePost is a tool for analyzing composite models ply by ply. As composite solid consists of several plies to make one solid model. This creates engineering complexity to define a thickness, orientation, materials. Ply angle or fiber orientation is one of the major factors in a composite layup. In this module, positive or negative fiber direction angle can be given to ply as per layup requirement. Numerous layer with different orientation and thickness can be set one below other to generate thickness.

Engineering layered composites involve complex definitions that include numerous layers, materials, thicknesses, and orientations. The engineering challenge is to predict how well the finished product will perform under real-world working conditions. Simulation is ideal for this when considering stresses and deformations as well as a range of failure criteria. ANSYS Composite PrepPost software provides all necessary functionalities for finite element analysis of layered composite structures. You can choose to work with either shell theory (thin-composites) or move to modeling solid composites in the case of thicker parts[14].

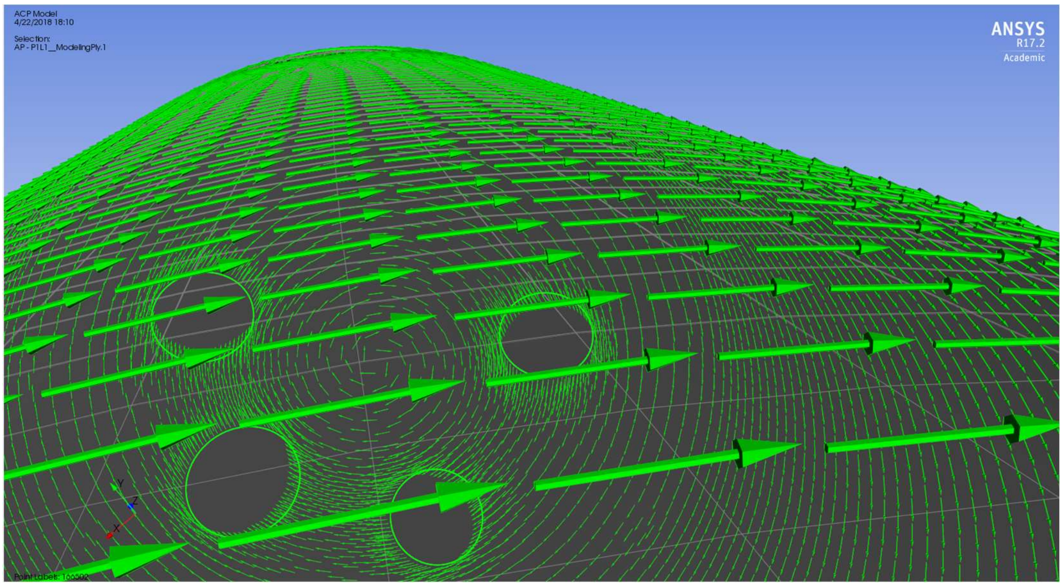


Figure 6-1 0° Fiber direction

In Figure 6-1, 0° Ply fiber direction is shown for this case. Apart from 0°, we can give any angle for fiber direction of ply. With same or varying ply thickness we can generate a solid model of the required thickness. For generating the solid model, we should give layup direction to generate thickness[14][15][16].

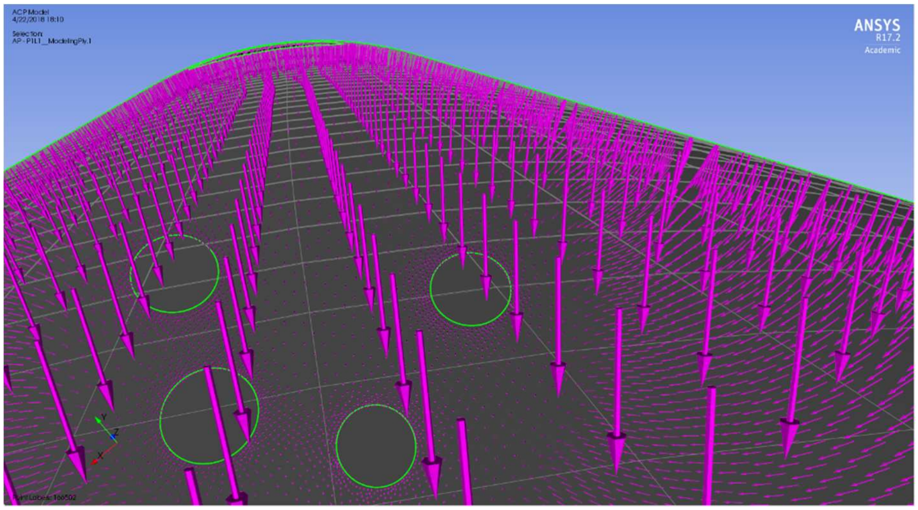


Figure 6-2 Lay up direction

Nozzle loading is most critical loading for this case. Resultant force and moment for all nozzles vary because of difference in x, y, z component of each nozzle. For this type of loading, we are considering quasi-isotropic ply sequence.

Ply sequence for all the cases remains same which is [0/90/45/-45/-45/45/90/0]. Ply thickness for each case is different. For case (a) & (c), ply thickness is 0.25 mm and for case (b), ply thickness is 0.5 mm.

Chapter 7 Composite Results

Simulations for cases described for load cases and thickness combination are analyzed. In these cases, all boundary conditions, material properties specified earlier are used. In this chapter, we are comparing component-wise results for all load case described before. Also, how composite material reacts to loading conditions are described. From the carbon steel results, we got that case 4 Internal Pressure + Static Head + Operating Weight + Nozzle Loads + Wind Load is most critical one. Stress generated in every component due to thickness variation is compared case wise.

7.1 Results for shell

As we discussed, results for critical load case Internal Pressure + Static Head + Operating Weight + Nozzle Loads + Wind Load are shown below:

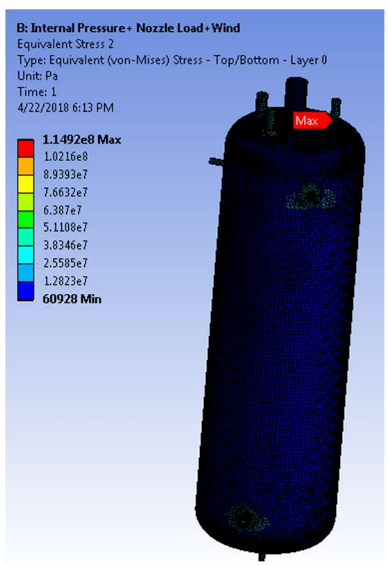


Figure 7-1 Stress generated in shell for combination 4+2

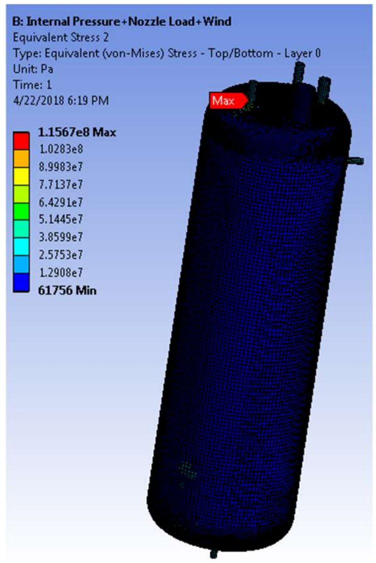


Figure 7-2 Stress generated in shell for combination 4+4

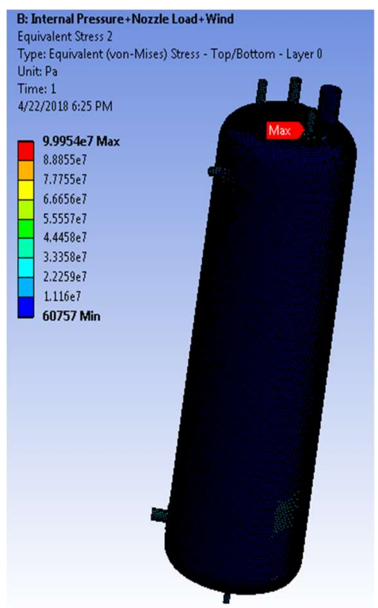


Figure 7-3 Stress generated in shell for combination 6+2

Results for stress generated in shell are compared below:

Stress (MPa)	Case 1	Case 2	Case 3	Case 4
Carbon steel	112.68	21.57	112.68	112.68
4+2	114.92	53.07	114.92	114.92
4+4	115.67	50.97	115.67	115.67
6+2	99.95	43.97	99.95	99.95

Table 7-1 Comparison of stress generated in shell

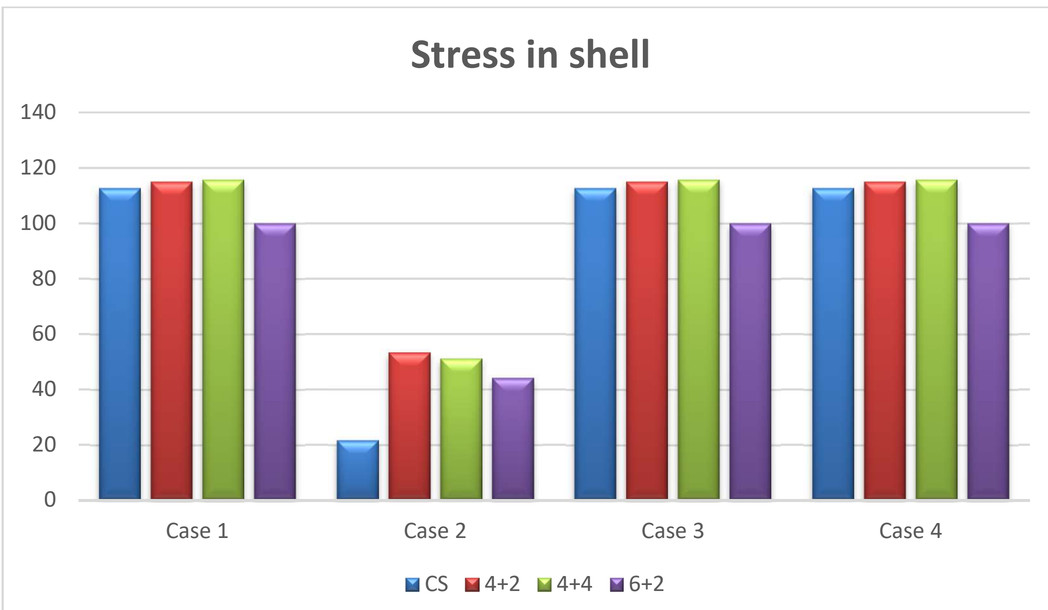


Figure 7-4 Stress comparison for shell

Here you can see stress generated in 3 cases is same that is because of nozzle load is governing in that cases.

7.2 Results for Support Leg

As we discussed, results for critical load case Internal Pressure + Static Head + Operating Weight + Nozzle Loads + Wind Load are shown below:

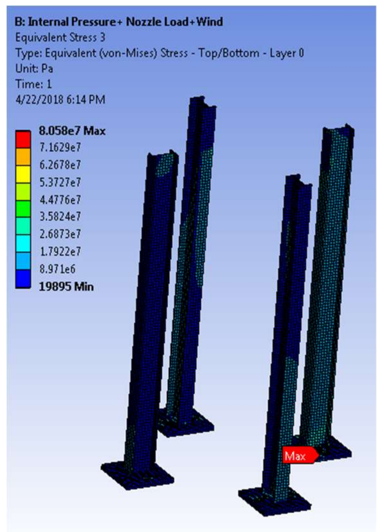


Figure 7-5 Stress generated in leg for combination 4+2

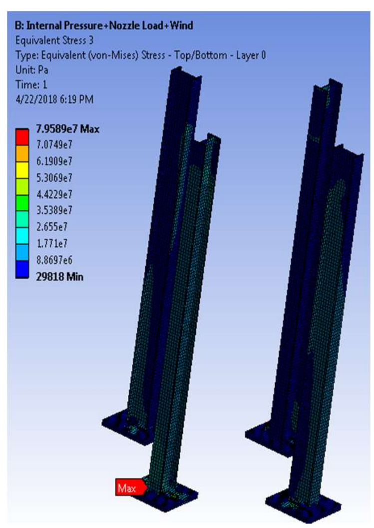


Figure 7-6 Stress generated in leg for combination 4+4

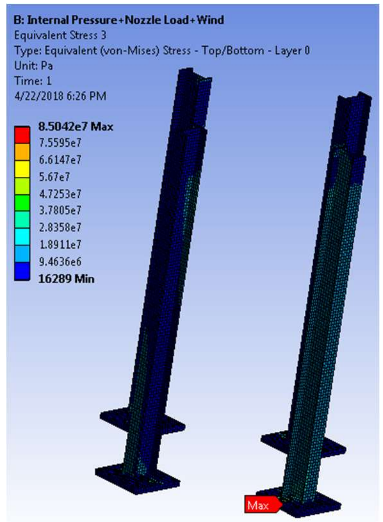


Figure 7-7 Stress generated in leg for combination 6+2

Results for stress generated in Leg are compared below:

Stress (MPa)	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Carbon steel	77.82	4.74	92.87	100.53
4+2	59.57	10.22	73.59	80.58
4+4	59.62	9.66	72.65	79.58
6+2	63.07	10.72	78	85.04

Table 7-2 Comparison of stress generated in Leg

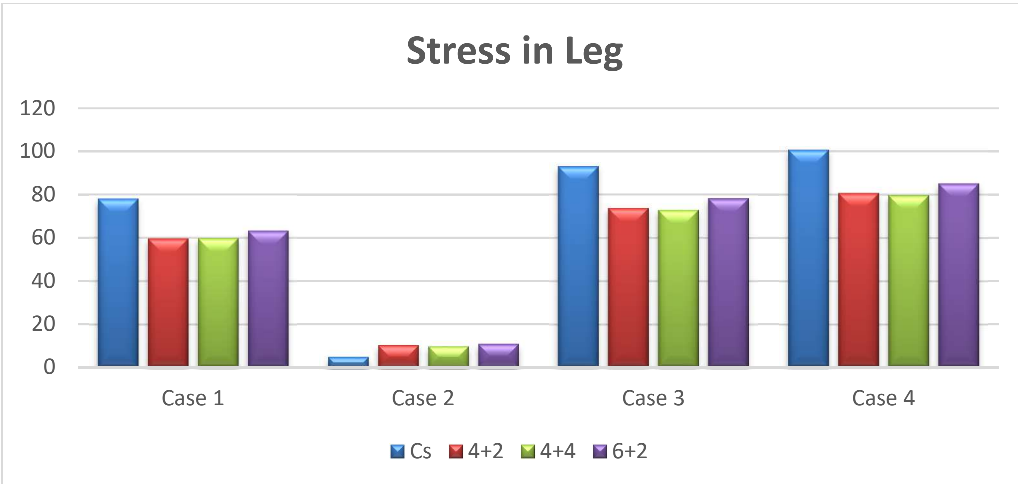


Figure 7-8 Stress comparison for Leg

7.3 Results for RF Pad

As we discussed, results for critical load case Internal Pressure + Static Head + Operating Weight + Nozzle Loads + Wind Load are shown below:

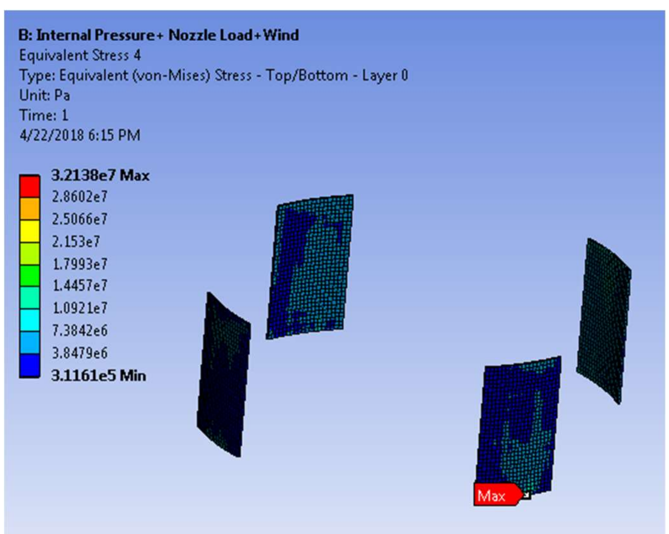


Figure 7-9 Stress generated in RF Pad for combination 4+2

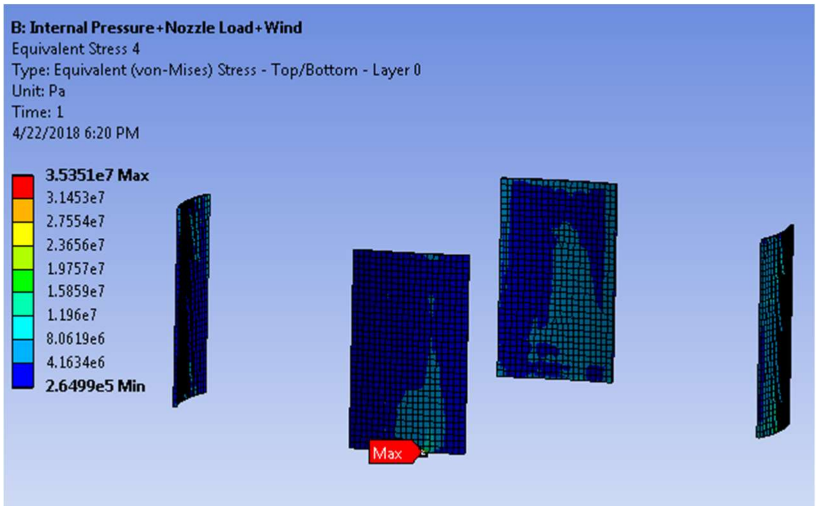


Figure 7-10 Stress generated in RF Pad for combination 4+4

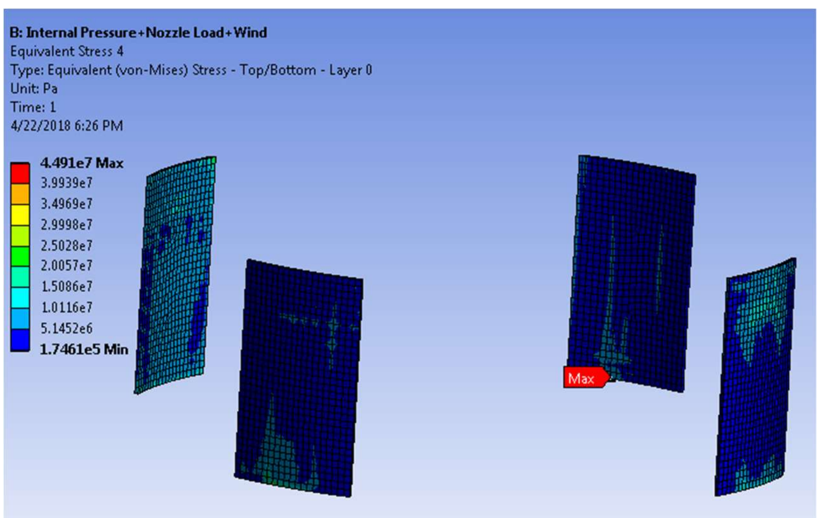


Figure 7-11 Stress generated in RF Pad for combination 6+2

Results for stress generated in RF Pad are compared below:

Stress (MPa)	Case 1	Case 2	Case 3	Case 4
Carbon steel	84.35	8.11	86.97	88.17
4+2	31.08	32.76	31.33	32.18
4+4	32.43	32.73	34.44	35.35
6+2	41.93	35.91	43.98	44.91

Table 7-3 Comparison of stress generated in Leg

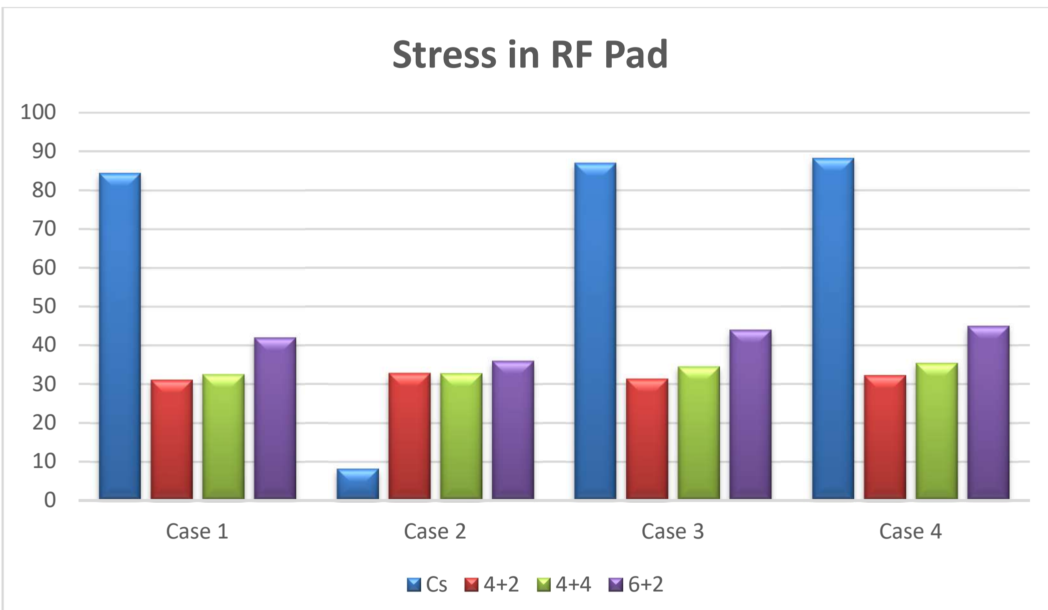


Figure 7-12 Stress comparison for RF Pad

7.4 Results for E-glass

Results for E glass are shown below with stresses in composite solids. Composite E-glass is wrapped around shell. On the shell, critical nozzle loads are acting. Stresses in composite solid for nozzle loading for each thickness combination are shown below:

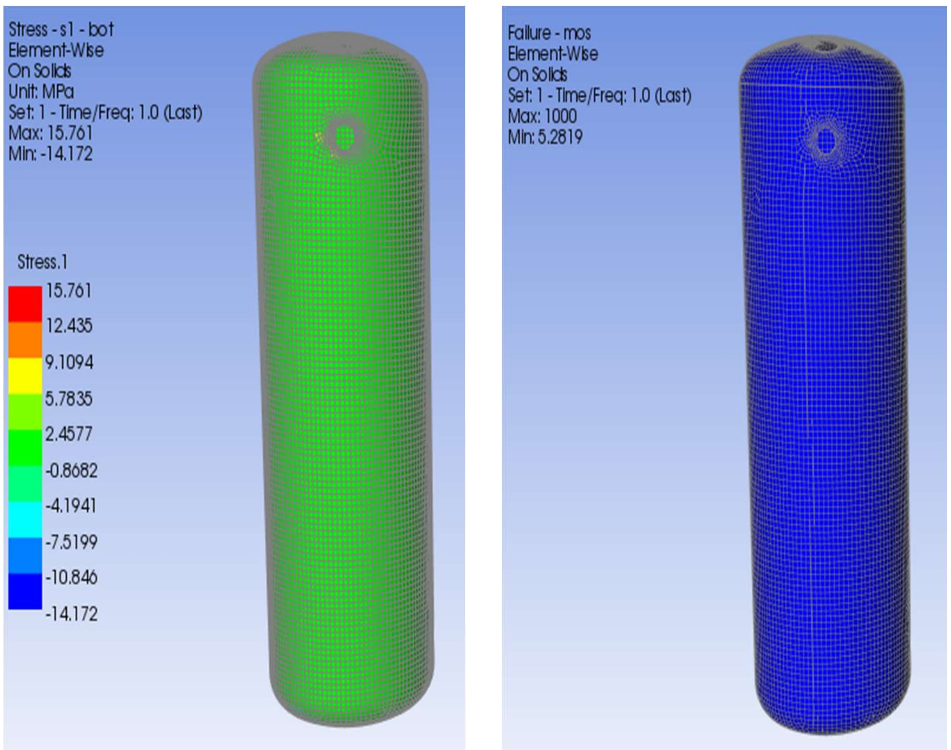


Figure 7-13 Stress & MOS in solid composite for combination 4+2

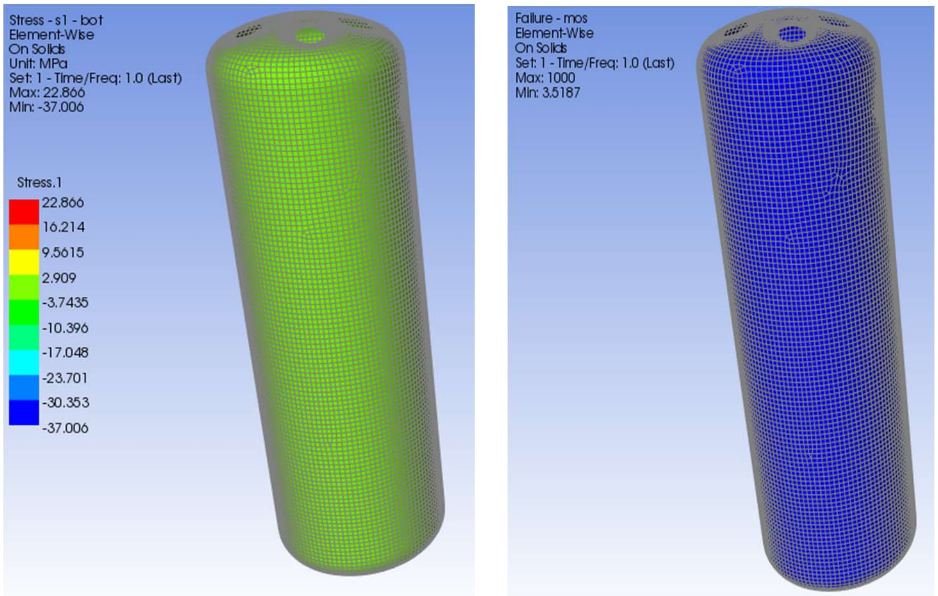


Figure 7-14 Stress & MOS in solid composite for combination 4+4

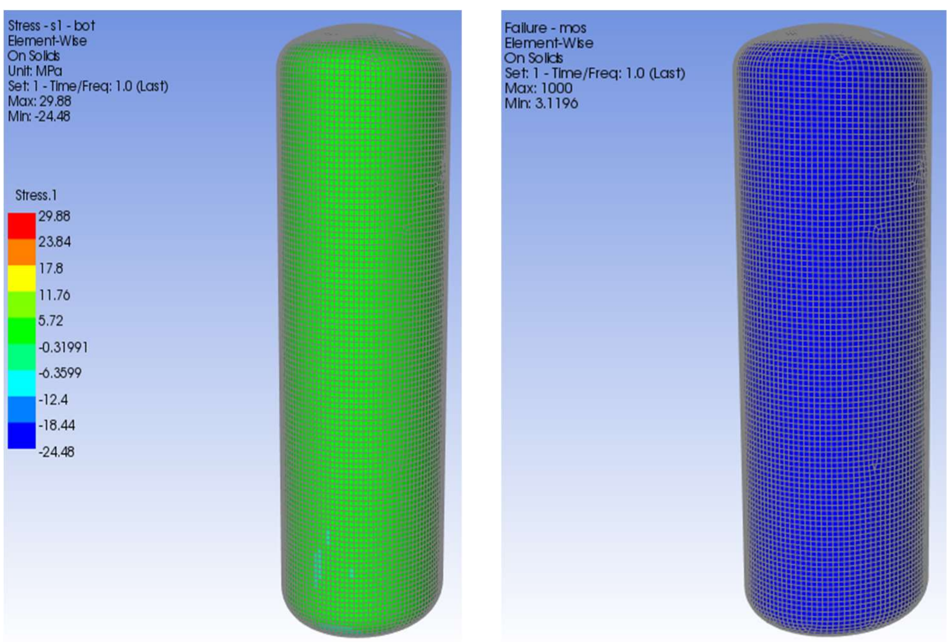


Figure 7-15 Stress & MOS in solid composite for combination 6+2

In composites, most of the times ply failure occurs due to excessive load on single ply. The margin of the safety of each ply for nozzle loading is mentioned below:

MOS	4+2	4+4	6+2
0	5.28	6.2	6.53
90	8.51	7.64	3.11
45	9.46	9.5	4.56
-45	8.39	5.21	4.87
-45	8.92	4.34	5.36
45	7.02	4.8	6.96
90	7.306	3.51	5.38
0	5.75	4.96	6.7

Table 7-4 Margin of safety for Ply sequence

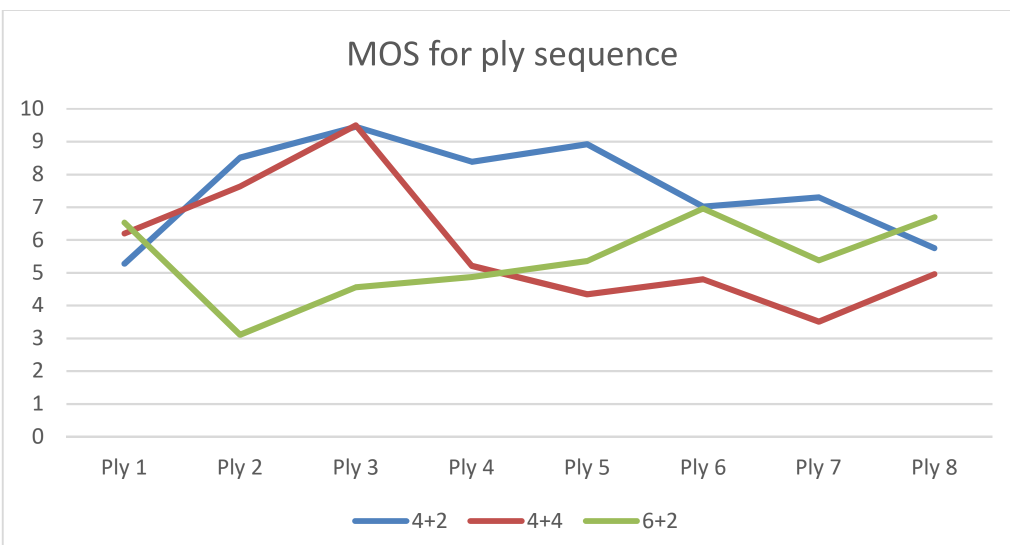


Figure 7-16 Comparison of MOS for ply sequence

7.5 Weight Difference

There is large difference in densities of two materials. Weight comparison for each case along with graph is shown below:

Weight (kg)	Shell	E-glass	Total	% reduction
CS	1524	-	1524	-
4+2	825	93.03	918.03	39.76%
4+4	825	185.72	1010.72	33.66%
6+2	1191	93.03	1284.03	15.68%

Table 7-5 Weight Comparison

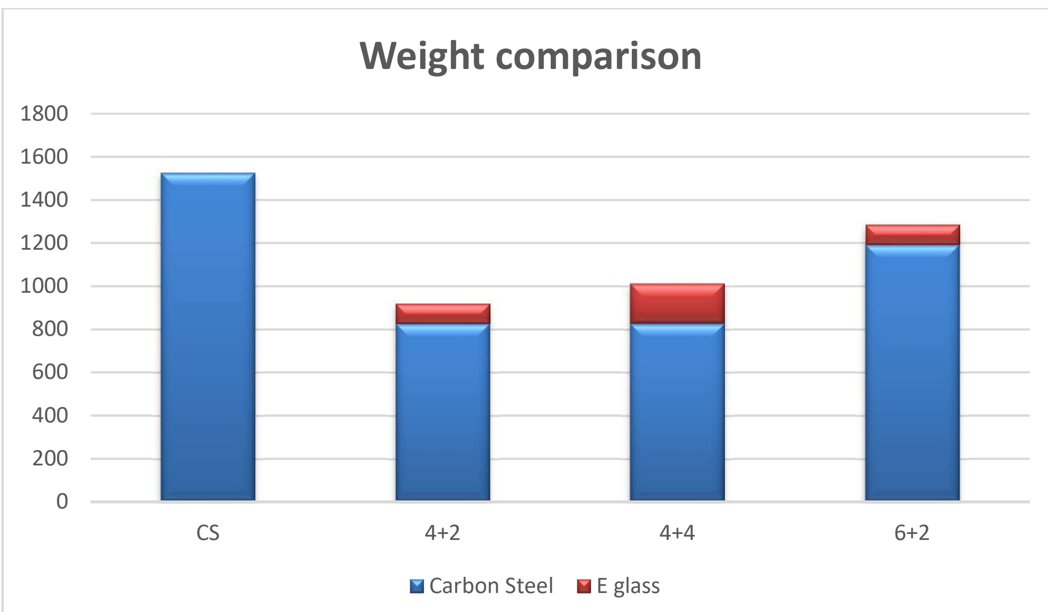


Figure 7-17 Weight Comparison with a different combination

Chapter 8 Conclusion

From the analysis results, we can say replacing some thickness of carbon steel by E-glass it gives more stability and less stress concentrated areas in overall water buffer drum. E-glass is lightest than carbon steel, but it is having some manufacturing limitations.

When it comes to stress generated in the shell, combination 6+2 is having lowest value. As for other thickness combination stress value almost remains same. As for nozzle loading, the same kind of stress results occurred in each case.

As far as stress in support leg concerned, it is having more variety of loadings like wind, seismic. Carbon steel geometry of legs remains same but due to replacing thickness in shell geometry stress induced in legs for all load cases decreases. Stress-induced in legs is almost reduced by 15%.

RF pad is main connection between supports and process condition of buffer drum. In stress results of RF pad, there is a tremendous amount of decrease in stress value in each thickness combination. For life cycle of water buffer drum, it is important to reduce stress generation near RF pad. By change in thickness stress value reduces to half of its value in carbon steel.

Reduction in stress indicates increase in factor of safety and life cycle of water buffer drum. There is less deformation in every case that will give good results to piping attached to drum. It will be good fit for smoothing of carrying piping loads throughout the line.

In this study, weight of shell reduced by 15% to 40%. Reduction in weight will achieve cost saving in transportation, handling, maintenance. By overall results for replacing one can choose one of the combinations according to requirement of client or process requirement.

Future Work

Few study cases can be made to further study this topic,

- Different materials other than E glass can be used for analysis.
- Different ply sequence other than quasi-isotropic can be used for analysis.
- How prestressing of fibers will affect the strength of composite and overall design.
- Composite material reinforcement pads can be used for reduction of metal from this design.
- Thermal analysis can be done with various thickness combination of composites to know outside wall temperature. By this, there is chance of eliminating extra insulation thickness provided on vessel.
- Vibration analysis can be done for this vessel as it may consist case of agitator working on the top head.

References

[1] "buffertanks.pdf." [Online]. Available: https://westank.com/wp-content/docs/brochures/buffertanks.pdf.

[2] Composite, "No Title." [Online]. Available: http://www.rsc.org/Education/Teachers/Resources/Inspirational/resources/4.3.1.pdf.

[3] "Composite." [Online]. Available: http://www.keyshone.com/9-interesting-facts-know-aircraft-composite-materials/.

[4] B. ASME, *Sec. II Part A Ferrous Material Specifications (Begining to SA-450)*. 2014.

[5] A. Boiler, "Part A Ferrous Material Specifications (SA-451 to End)," 2014.

[6] P. V. Code, "Part D Properties (Metric)," 2013.

[7] "SA 516 Gr 70 Material Properties." [Online]. Available: http://www.matweb.com/search/DataSheet.aspx?MatGUID=9ccee2d0841a404ca504620085056e14&ckck=1.

[8] "SA 36 Material Properties." [Online]. Available: http://www.matweb.com/search/datasheet.aspx?matguid=afc003f4fb40465fa3df05129f0e88e6.

[9] P. V. Code, "Rules for Construction of Pressure Vessels," 2013.

[10] A. V. Barderas and B. S. S. G. Rodea, "HOW TO CALCULATE THE VOLUMES OF PARTIALLY FULL TANKS," vol. 2, no. 1, pp. 1–7, 2016.

[11] "Nozzle loads." [Online]. Available: http://www.piping-engineering.com/nozzle-loads-part-1.html.

[12] D. Moss, *Pressure vessel design manual*. .

[13] P. D. B. S. Mr. Jiger Modia, Prof. S J Joshib, "Pressure Vessel Design against

Wind and Seismic Load," no. November 2013, 2014.

[14] "ANSYS Composite PrePost." [Online]. Available: https://www.ansys.com/Products/Structures/ANSYS-Composite-PrepPost.

[15] "Robert M. Jones Mechanics of Composite Materials.pdf." .

[16] V. Valery and I. Evgeny, *Mechanics and Analysis of Composite Materials*. .

Biographical Information

Chinmay Shrikrishna Godbole was born in Kalyan, Maharashtra, India in October 1992. He received his Bachelor of Engineering in Mechanical Engineering from the University of Mumbai, India in August 2014. He worked at Jacobs Engineering India Pvt. Ltd. In Navi Mumbai as a Design engineer from November 2014 to June 2016. He enrolled into Master of Science in Mechanical and Aerospace Engineering program at the University of Texas at Arlington in Fall 2016. From March 2017, He started working under the guidance of Dr. Andrey Beyle, mostly working on the topics related to Analysis Composite materials. He is proficient in ANSYS, Hypermesh, Solidworks. He graduated in May 2018.