AUTOMATION OF
FINITE ELEMENT ANALYSIS
FOR PRESSURE VESSEL

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AUTOMATION OF
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IN

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NIRMA UNIVERSITY

Year: 2020-21

Declaration

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- The thesis comprises my original work towards the degree of Bachelor of Technology in Mechanical Engineering at Nirma University and has not been submitted elsewhere for degree.
- Due acknowledgement has been made in the text to all other material used.

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I Parmar Akashkumar Prakashchandra give undertaking that the Major Project entitled "Automation of Finite Element Analysis of Pressure Vessel" submitted by me, towards the partial fulfilment of the requirements for the degree of Bachelor of Technology in Mechanical Engineering of Nirma University, Ahmedabad, is the original work carried out by me. I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Approval Sheet

The Project entitled **Automation of Finite Element Analysis for Pressure Vessel** by **Parmar Akashkumar Prakashchandra (17bme065)** is approved for the degree of Bachelor of Technology in Mechanical Engineering

Examiners

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Firstly, I would like to thank Larsen and Toubro Limited, Hazira and Nirma University, Ahmedabad for providing me an excellent learning opportunity in one of the finest manufacturing facilities in the country. Being in the center of technical innovations and working among the people who aim for maximum efficiency in every manufacturing process, provided a great amount of practical knowledge, exposure to which has helped me to understand the concepts of Engineering with more clarity.

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Lastly, I am grateful all my friends and family for their constant support.

Name and signature of student

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ABSTRACT

With increasing demand and competition every manufacturer today aim for the maximum productivity achievable i.e. to maximize the output, meeting the required functional and dimensional accuracies. One of the ways of improving productivity is by automatizing the process to reduce the time. Automation not only reduce the time but also eliminates the worker fatigue. Generating program for automation in one-time investment, once done then user has to enter data only. Thus, many manufacturing companies are investing in automation to meet their demands.

This project aims at automatizing the manual analysis process for pressure vessels at Larsen and Toubro Ltd, Hazira. The proposed work would not only decrease time by more than 90% but also ensure accuracy due to elimination of manual errors.

The workbench project is generated such that pressure vessels having different dimensions can be analysed in the same project. In addition, pressure vessels having different type of nozzles at any angle can be analysed.

Key words: Automation, Productivity, Accuracies, Analysis, Pressure vessels, Nozzles

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CHAPTER 1

Introduction

1.1 About the project

Productivity is a major concern for any company due to increasing rivalry in manufacturing industries. It aims of getting the best of the available resources to maximize output and therefore every company are constantly putting efforts in the direction of achieving maximum productivity. Analysis of the product is one of the most commonly used productivity enhancing tool used in industries today. Before manufacturing the actual product, it is really important to virtually analyse the product and check for failures.

The critical process of analysis takes a huge amount of time. The problem focuses on generating a program that automates the modelling of pressure vessels and developing a workbench project that reduces the manual work by a great factor.

1.2 About the L&T, Hazira

Larsen and Toubro Ltd. founded by Henning Holck-Larsen and Søren Kristian Toubro, two Danish Engineers, is an Indian Multinational Company headquartered in Mumbai, Maharashtra, India. It has over 80 years of unparalleled experience in providing world class consumer centric solutions, gaining them unmatched capabilities across Technology, Engineering, Construction and Manufacturing making them market leaders in major lines of business [1].

Figure 1. 1: L&T – West, Hazira [1]

The Hazira facility spreads over more than 750 acres of land along with waterfront facility of 1.6 km lengthwise. The whole Hazira plant is divided into two segments – East and West.

Whole plant houses facilities for critical, large sized ultra-heavy equipment for Nuclear and Process Plants. It has heavy thick rolling machines of 6000 MT capacity which can roll the plates of 4500 mm wide and 250 mm thick. In addition, the plant has CNC plasma/gas cutting machines, water jet cutters, floor mounted horizontal boring machines, vertical boring machines, forming press, digital welding stations based on IOT, heat treatment furnaces, quenching facilities, hydro test beds and some more heavy-powered equipment. [2]

CHAPTER 2

Literature Review

2.1 Pressure Vessel definition

A Pressure Vessel is a container that is designed to hold the fluids at substantially higher or lower pressure from the ambient pressure. [3]

The primary function of a fixture is to hold the fluid at some pressure irrespective of the purpose of the fluid.

2.2 Design and Analysis of pressure vessels

Due to pressure acting, there is a chance for the fluid contained in the vessel to leak out, which can cause accidents and may harm lives. For the same reason it is important that the design, fabrication and testing techniques are controlled a few legislation organizations like ASME, BS and API standards etc. All pressure vessels manufactured by industries must be certified by either of the legislatures.

2.2.1 History of ASME codes for Pressure Vessel [4]

In 1905, a boiler explosion came out to be a disaster in a shoe factory in Massachusetts and killed 58 people, injuring 117 others and caused nearly about quarter million of dollars. Then, the decision to implement a code to formulate regulations and rules for pressure vessel design have come in to act. The first edition of the ASME Rules to construct pressure vessels, known as the 1914 edition, was adopted in the spring of 1915.

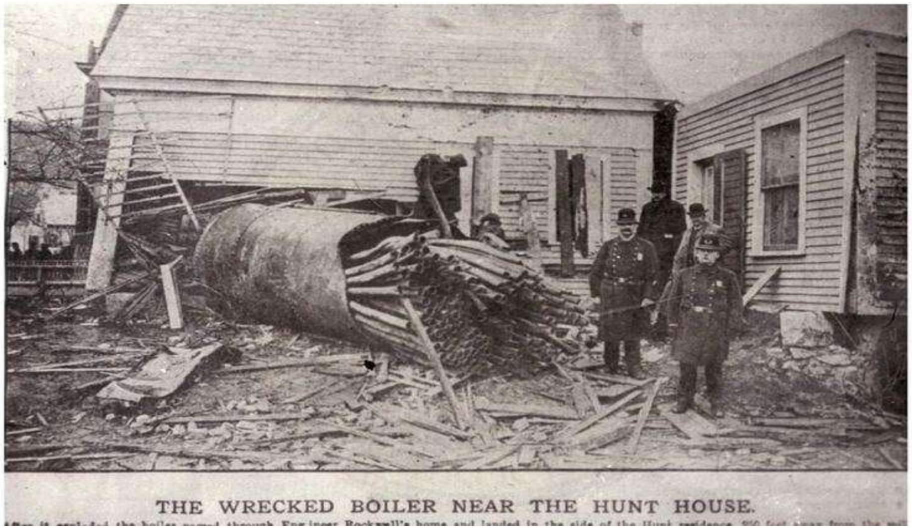

Figure 2. 1: Massachusetts Shoe factory explosion [5]

With time, the new editions came into implementation. The new ASME Boiler & Pressure Vessel Code, Section VIII, Division 2 was published on July 1, 2007. This 2007 Edition became mandatory for vessel design in July, 2009.

2.2.2 Manufacturing of Pressure Vessels

Overall Manufacturing Process includes[6]:

1. **Design and Analysis:**
    1. Design drawings are made considering forces, moments, inertia and affecting criteria.
    2. Developed designs are analysed using computer software and necessary changes are made in design.
2. **Fabrication:**
    1. After analysis, actual fabrication is done. Includes required processes like – Forming, Forging, Welding, Assembling, etc. and then heat treatments are carried out.
3. **Testing:**
    1. Post heat treatments, various testing processes are done based on requirements, i.e. – Visual inspection, Liquid penetrant test, Radiographic test, Ultrasonic tests, Hydrostatic tests.

2.2.3 Analysis of Pressure Vessels

As per ASME design and analysis procedure, below mentioned are the required steps:

1. Finite Elemental Analysis:
    a. Design data
    b. Material properties
    c. Geometric modelling
2. Load considerations
3. Acceptance criteria

2.2.3.1 Load considerations [7]

1. Thermal Loads: Due to heavy temperature handling
2. Mechanical Loads: Due to…
    1. internal pressure
    2. Nozzle/piping loads
    3. Wind/seismic loads
    4. Dead weight

Out of which, below mentioned are the Load combinations, which will be set as loading criteria.

1. Mechanical loads(Internal pressure + Static head + Dead weight + Nozzle loads)
2. Mechanical + Wind/seismic loads (90% Internal pressure + Static head + Dead weight + Nozzle loads + Wind loads)
3. Mechanical + Thermal loads(Internal pressure + Static head + Dead weight + Nozzle loads + Wind loads)

2.2.3.2 Acceptance criteria [7]

1. Membrane Stress < S
2. Membrane + Bending Stress < 1.5*S
3. Sum of the Principal Stresses < 4*S

    S = Yield Tensile Strength of the material

2.3 Objectives of the project

The primary objective of this project is to generate a program that can model the pressure vessels as per dimensions and develop a workbench project that can reduce the manual input to minimal.

Stages of approach:

I. Perform manual Analysis.
II. Develop a program to automate the process.
III. Compare the results.

CHAPTER 3

Methodology

Analysis is done using FEA software – '**Ansys**' manually to understand the working of the software. As there are Thermal and Mechanical load considerations, using steady state thermal and static structural features, **Thermostructural analysis** has been carried out.

After completions of manual analysis, mechanical scripting for automation of the process is carried out using **Python** programming language.

From all of the pressure vessels having different types of nozzles, one of them is taken for manual analysis and the results are compared with automatized results afterwards.

3.1 Manual Analysis

3.1.1 Engineering Data

Design Data	
Design Code	ASME Sec VIII Div. 2 Ed' 2017 Cl.2
Operating pressure and temperature	5.335 MPa at 319°C
Min. Site ambient temperature	12°C
Corrosion allowance	NIL

Table 3. 1: Design Data [8]

Material of Construction	
Shell & Top head	SA-542M Type D Cl. 4a
Manway	SA-336M Gr. F22V

Table 3. 2: Material of Construction [8]

Material properties			
Temperature (°C)	Elastic Modulus (*10^3 MPa)	Thermal Conductivity (W/m°C)	Mean linear thermal Expansion coeff. (*10^{-6} °C^{-1})
25	210	36.3	11.5
100	206	36.9	12.1
150	202	37.1	12.4
200	199	37.2	12.7
250	196	37.1	13.0
300	192	36.7	13.3
350	188	36.2	13.6
400	184	35.4	13.8

Table 3. 3: Material Properties [8]

3.1.2 Geometry

Geometric Model	
ID of Shell	3800 mm
Thickness of Shell	51 mm
IR of top head	1903 mm
Thickness of top head	45 mm
Thickness of crown	45 mm

Table 3. 4: Geometric Model [8]

3.1.3 Meshing

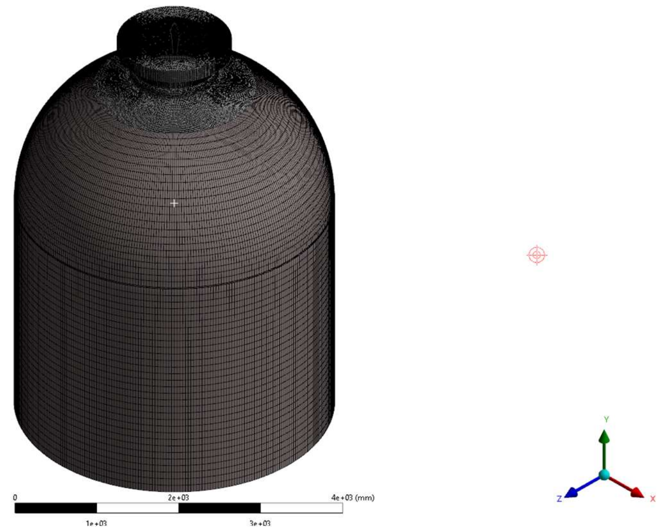

Figure 3. 1. a : Meshing

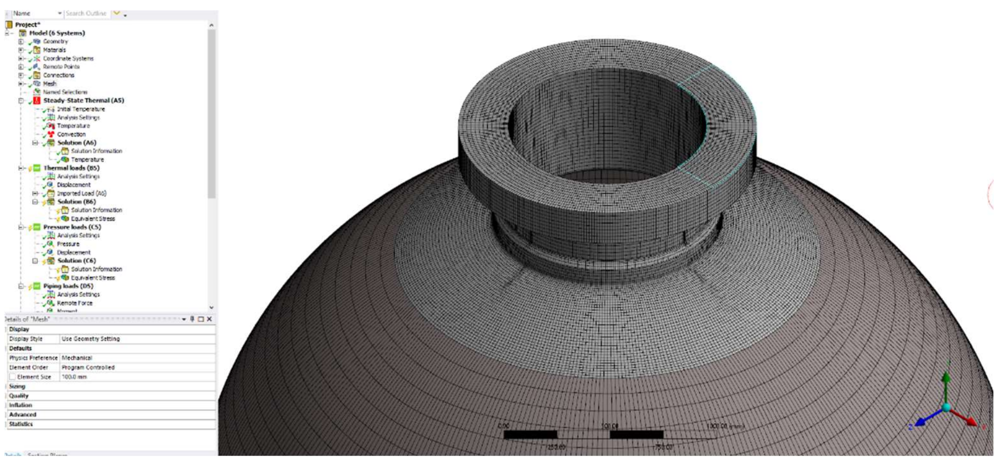

Figure 3. 1. b : Meshing

3.1.4 Boundary Conditions

1. Thermal Boundary Conditions:

   Heat transfer co-efficient between operating fluid and vessel inner surface is considered as infinity.

   Therefore, vessel inner temperature is same as operating fluid temperature.

- Vessel Exterior Temperature: 12°C
- Vessel Inner Temperature: 319°C

2. Thermal Loads:

h_{eqv} = Equivalent heat transfer co-efficient in lieu of air and insulation.

t = Thickness of the material

K = Thermal conductivity of the material

$$h_{eqv} = \frac{1}{\left[\frac{1}{h_{eqv}} + \frac{t}{K}\right]}$$

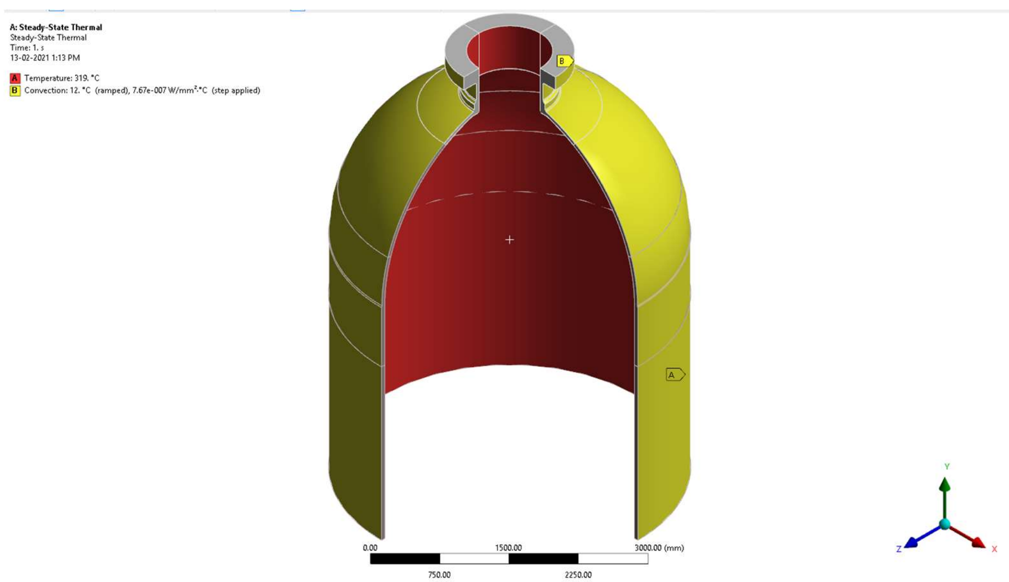

Figure 3. 2 : Thermal Boundary Conditions

3. Internal Pressure:

For making a safe design, design pressure is taken higher than operating pressure.

Design pressure: 6.276 MPa (as per ASME SEC VIII Div. 2 Ed' 2017 Cl. 2)

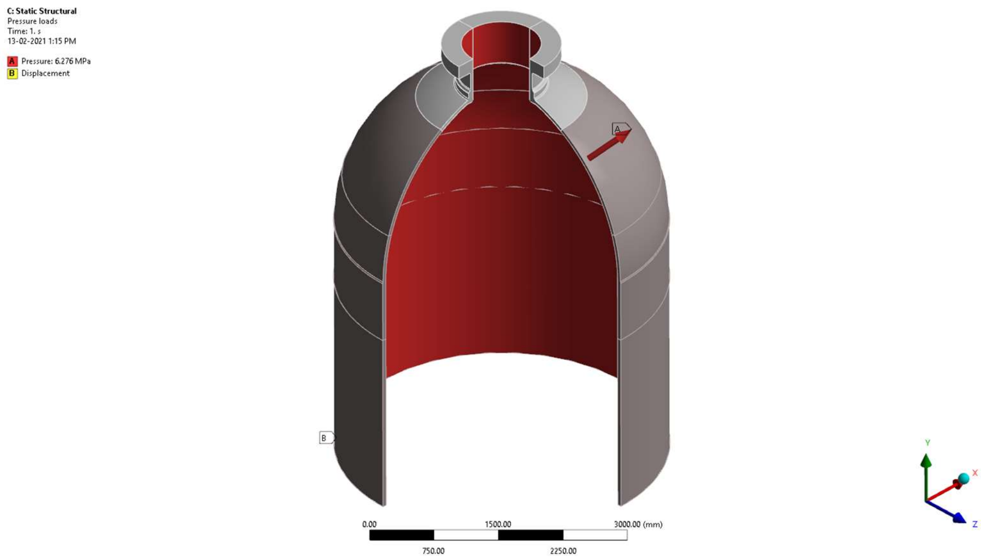

Figure 3. 3 : Internal Pressure

4. Nozzle/Piping Loads:

Direction	Force(N)
F_x	98885
F_y	98885
F_z	98885
M_x	129492000
M_y	129492000
M_z	-129492000

Table 3. 4 : Nozzle/Piping Loads

Figure 3. 5 : Nozzle/Piping Loads

5. Wind/Seismic Loads:

Shear force: 197,712 N

Moment: -211,092,970 N-mm

Figure 3. 6 : Wind/Seismic Loads

6. Dead weight:

   Weight: 19,948 kg

Figure 3. 7 : Dead weight

3.2 Automation of the process

Engineering data can vary based on different projects, therefore entering material properties dimension is manual process.

3.2.1 Geometry

Geometry may differ based on types of nozzles. There are total 6 different types of nozzles, by merging based on their similarity, total 3 different codes are generated for geometry generation. Below is the depiction of the nozzles categorization.

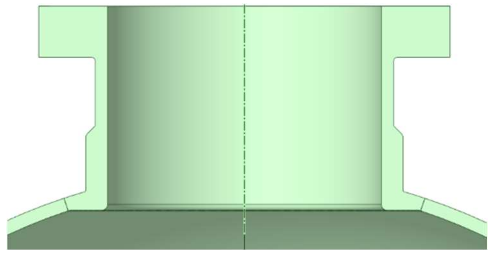

Figure 3. 8. : Manway with flange (Type - 1)

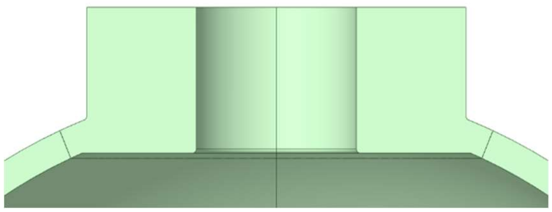

Figure 3. 9. a : Manway with straight face without neck

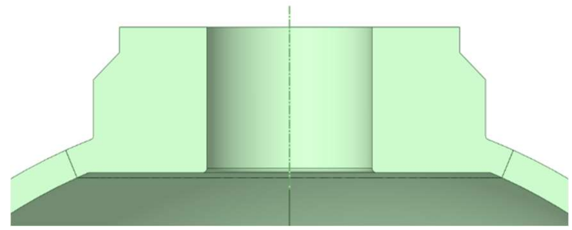

Figure 3. 9. b : Manway with straight face and neck

Figure 3. 13. : Manway with straight face (Type - 2)

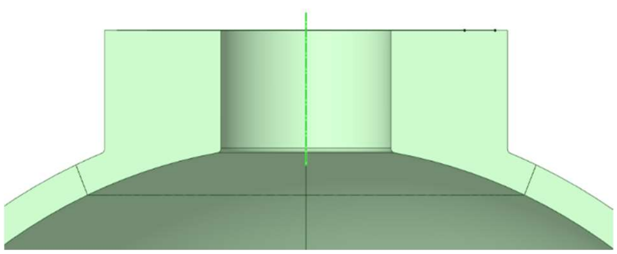

Figure 3. 14.a : Manway without straight face without neck

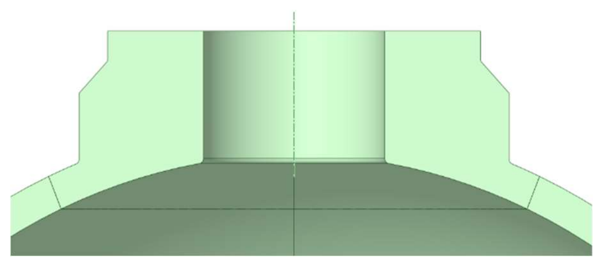

Figure 3. 14.b : Manway without straight face with neck

Figure 3. 10. : Manway without straight face (Type - 3)

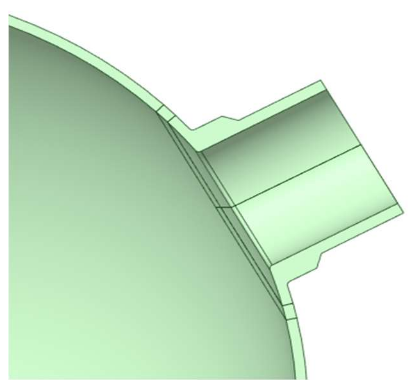

Figure 3. 11. : Radial Nozzle (Type - 4)

Out of total 6 different types of nozzles, 4 types are derived as per their geometric similarity. In addition, it is clearly seen that type-2 and type-3 are more or less similar. Therefore, a combined script for type 2 and 3 is generated.

To sum up, total three codes are generated for different geometries.

1. Type - 1
2. Type – 2 and Type – 3
3. Type – 4

Also, it is evident from industrial uses that the units which are widely used are millimetre and inch. Therefore, in every script there is an option provided to use the unit system in mm or in.

Below mentioned are the inputs required for geometry generation along with sample input parameters…

Unit	1
Shell_BMID	3809
Shell_Thk	51
Head_BMIR	1907.5
Head_Thk	45
Nozzle_Projection_from_TL	2514.4
Nozzle_BMID	932.4
Neck_OD	1016
Hub_OD	1080
Hub_Min_Height	115
Hub_to_Neck_Angle	45
Lip_OD	1200
Flange_OD	1400
Flange_Thk	173.4
BCD	1250
Bolt_Hole_Dia	79.3
Total_Nozzle_Height	693.6
Weld_Overlay_on_Flange_Face	8
Nozzle_Head_Inside_Fillet	19
Nozzle_Head_Outside_Fillet	19
Neck_Flange_Fillet	14
Hub_Neck_Fillet	19

Table 3. 5. : Geometry Input Parameters

3.2.2 Meshing

Below mentioned are the required parameters to generate mesh in the model. Depending upon dimensions, mesh size can differ. User can provide the mesh sizing, edge sizing and face sizing values in the parameter set that are required to generate the mesh.

Nozzle_To_Head_Edge_Sizing Number of Divisions	3
Nozzle_Inner_Fillet_Edge_Size Number of Divisions	3
Nozzle_Outer_Fil_Sizing Number of Divisions	3
Nozzle_neck_Flange_Fillet_Size Element Size	15
Nozzle_Face_Size Element Size	15
Nozzle_Body_Sizing Element Size	15
Nozzle_Circular_Edge_Size Element Size	15
Head_Transition_Edge_Size Element Size	25
Nozzle_Head_Transition_Body Element Size	25
Head_Transition_Edge_Size_2 Element Size	35
Head_Body_Sizing Element Size	35
Head_Shell_Junction_Body_Sizing Element Size	35
Shell_Tansition_Edge_Size Element Size	45
Shell_Transition_Meshing_1 Element Size	45
Shell_Transition_Meshing_2 Element Size	45

Table 3. 6. : Mesh Input Parameters

To provide the sweep in the mesh generation, different naming selections are provided. Below is the sequence of the named selection and its depiction.

Step	Named Selection
1	Nozzle_Meshing_1
2	Head_Transition_Meshing_1
3	Head_Meshing_1
4	Head_To_Shell_Junction_Meshing_1
5	Shell_Meshing_1
6	Shell_Meshing_2
7	Nozzle_Meshing_2
8	Head_Trasition_Meshing_2
9	Head_Meshing_2
10	Head_To_Shel_Junction_Meshing_2
11	Shell_Meshing_1_2
12	Shell_Meshing_2_2

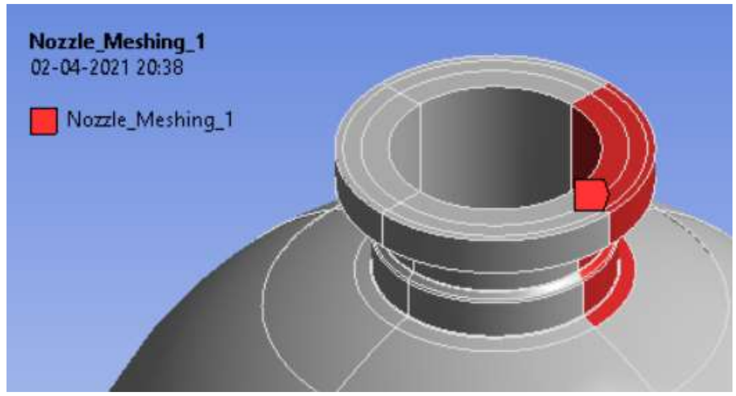

Figure 3. 12. : Nozzle Meshing 1

Step	Named Selection
1	Nozzle_Meshing_1
2	Head_Transition_Meshing_1
3	Head_Meshing_1
4	Head_To_Shell_Junction_Meshing_1
5	Shell_Meshing_1
6	Shell_Meshing_2
7	Nozzle_Meshing_2
8	Head_Trasition_Meshing_2
9	Head_Meshing_2
10	Head_To_Shel_Junction_Meshing_2
11	Shell_Meshing_1_2
12	Shell_Meshing_2_2

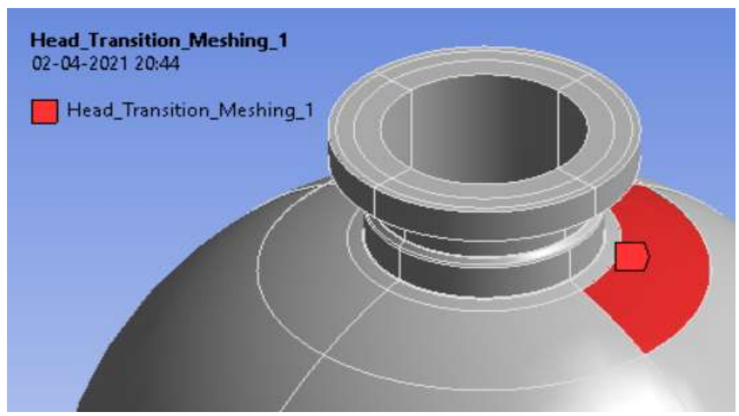

Figure 3. 13. : Head Transition Meshing 1

Step	Named Selection
1	Nozzle_Meshing_1
2	Head_Transition_Meshing_1
3	Head_Meshing_1
4	Head_To_Shell_Junction_Meshing_1
5	Shell_Meshing_1
6	Shell_Meshing_2
7	Nozzle_Meshing_2
8	Head_Trasition_Meshing_2
9	Head_Meshing_2
10	Head_To_Shel_Junction_Meshing_2
11	Shell_Meshing_1_2
12	Shell_Meshing_2_2

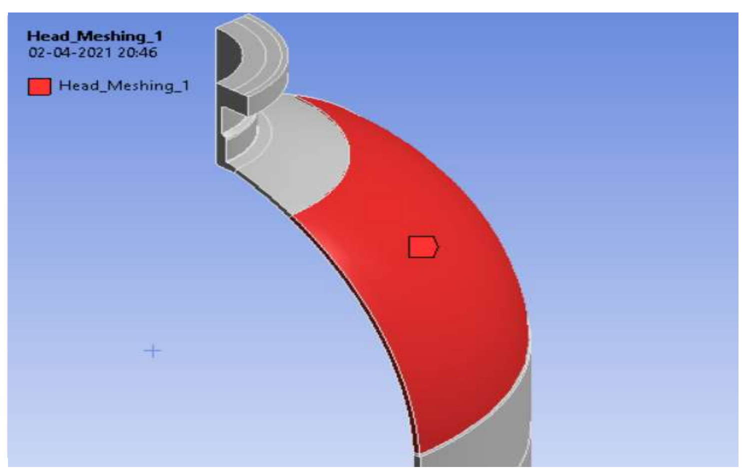

Figure 3. 14. : Head Meshing 1

Step	Named Selection
1	Nozzle_Meshing_1
2	Head_Transition_Meshing_1
3	Head_Meshing_1
4	Head_To_Shell_Junction_Meshing_1
5	Shell_Meshing_1
6	Shell_Meshing_2
7	Nozzle_Meshing_2
8	Head_Trasition_Meshing_2
9	Head_Meshing_2
10	Head_To_Shel_Junction_Meshing_2
11	Shell_Meshing_1_2
12	Shell_Meshing_2_2

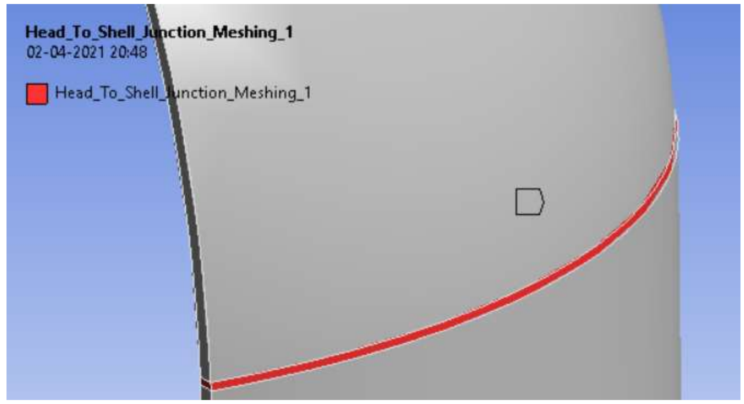

Figure 3. 15. : Head to Shell Junction Meshing 1

Step	Named Selection
1	Nozzle_Meshing_1
2	Head_Transition_Meshing_1
3	Head_Meshing_1
4	Head_To_Shell_Junction_Meshing_1
5	Shell_Meshing_1
6	Shell_Meshing_2
7	Nozzle_Meshing_2
8	Head_Trasition_Meshing_2
9	Head_Meshing_2
10	Head_To_Shel_Junction_Meshing_2
11	Shell_Meshing_1_2
12	Shell_Meshing_2_2

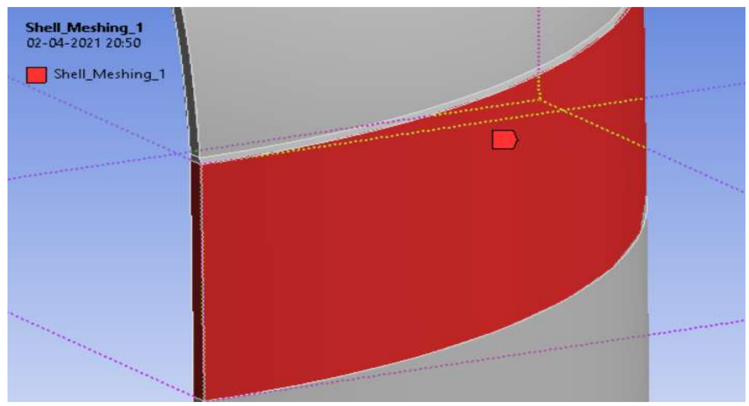

Figure 3. 16. : Shell Meshing 1

Step	Named Selection
1	Nozzle_Meshing_1
2	Head_Transition_Meshing_1
3	Head_Meshing_1
4	Head_To_Shell_Junction_Meshing_1
5	Shell_Meshing_1
6	Shell_Meshing_2
7	Nozzle_Meshing_2
8	Head_Trasition_Meshing_2
9	Head_Meshing_2
10	Head_To_Shel_Junction_Meshing_2
11	Shell_Meshing_1_2
12	Shell_Meshing_2_2

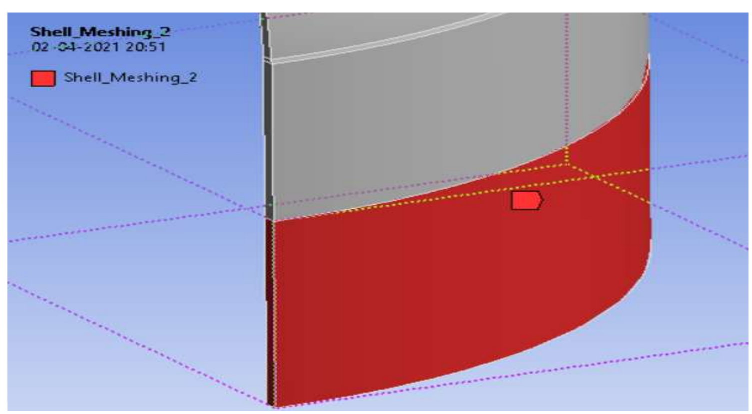

Figure 3. 17. : Shell Meshing 2

Above shown images are for named selection 1 to 6, which is for quarter of the whole model. Named selection from 7 to 12 are for the rest of the third quarter part. This way, the software can catch a sweeping path and a continuous and uniform mesh can be generated easily.

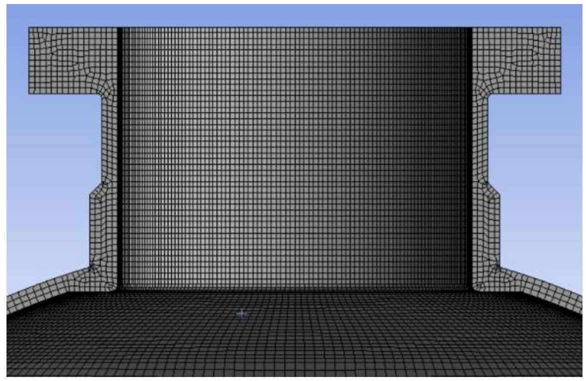

Figure 3. 18. : Mesh Cross-section

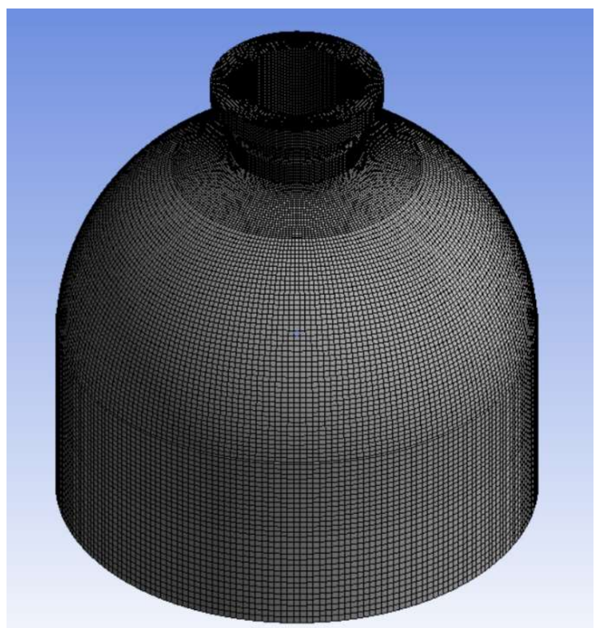

Figure 3. 19. : Mesh Iso-metric view

After meshing process, boundary condition set-up is required. Now, the workbench project is already set for boundary conditions for displacement, internal pressure, pressure thrust, nozzle loads and nozzle moments using named selection approach. Only loading values are required to set-up the conditions.

3.3.3 Boundary Conditions

Below mentioned are the inputs that are required to set-up the boundary conditions.

P210	Remote Point Y Coordinate	-67.28
P211	Internal Pressure Magnitude	6.276
P212	Pressure Thrust Magnitude	0
P213	Nozzle Loads Y Component	98885
P214	Nozzle Loads X Component	98885
P215	Nozzle Loads Z Component	98885
P216	Nozzle Moments Y Component	1.2949E+08
P217	Nozzle Moments X Component	1.2949E+08
P218	Nozzle Moments Z Component	-1.2949E+08

Figure 3. 20. : Boundary Conditions input

CHAPTER 4

Results

The last step of the analysis is checking results. Here, the results for both Manual and Automated analysis are depicted. The viability of the project can be evaluated based on comparison between the results.

4.1 Manual Analysis

1. Temperature Profile:

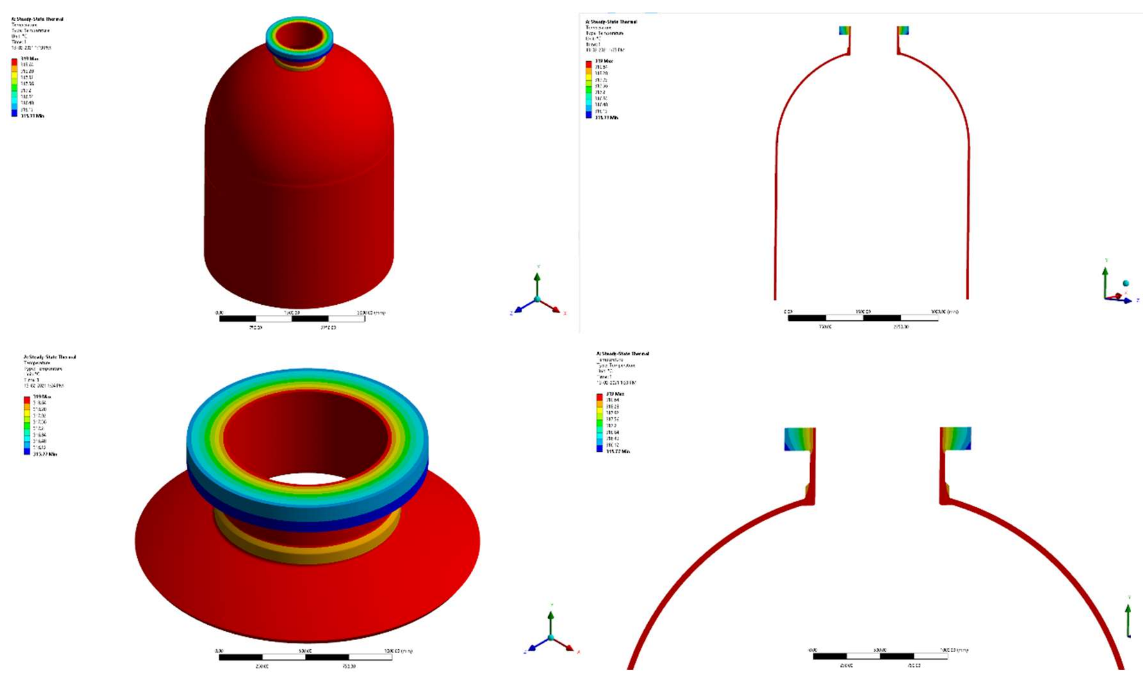

Figure 4. 1. : Temperature Profile

2. Thermal Load Stresses:

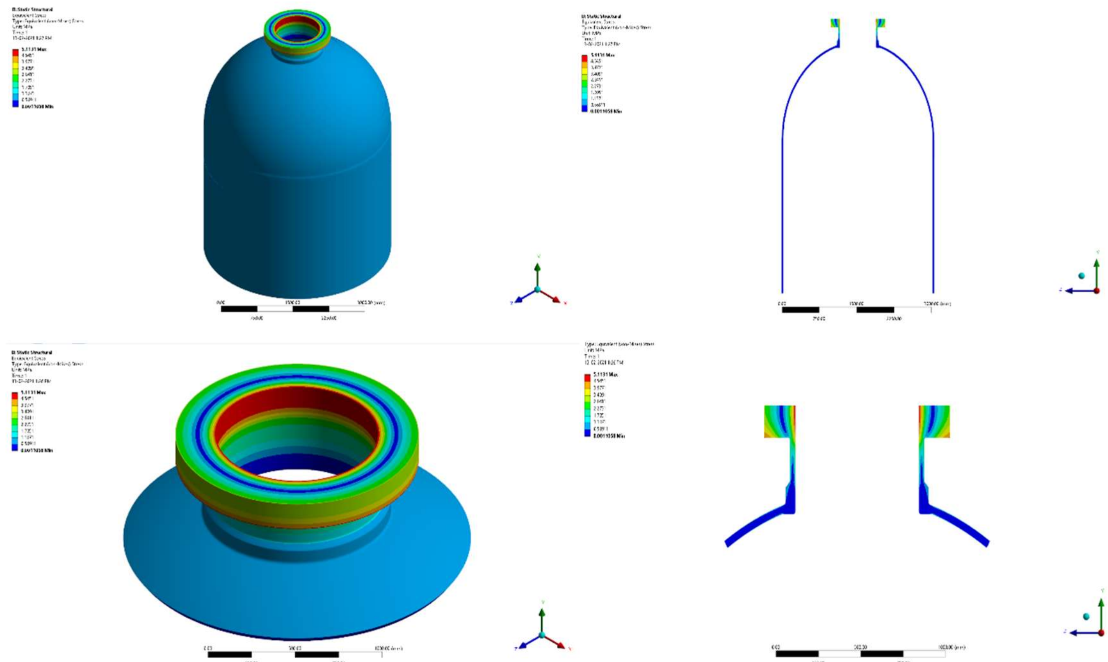

Figure 4. 2. : Thermal Load Stresses

3. Pressure Load Stresses:

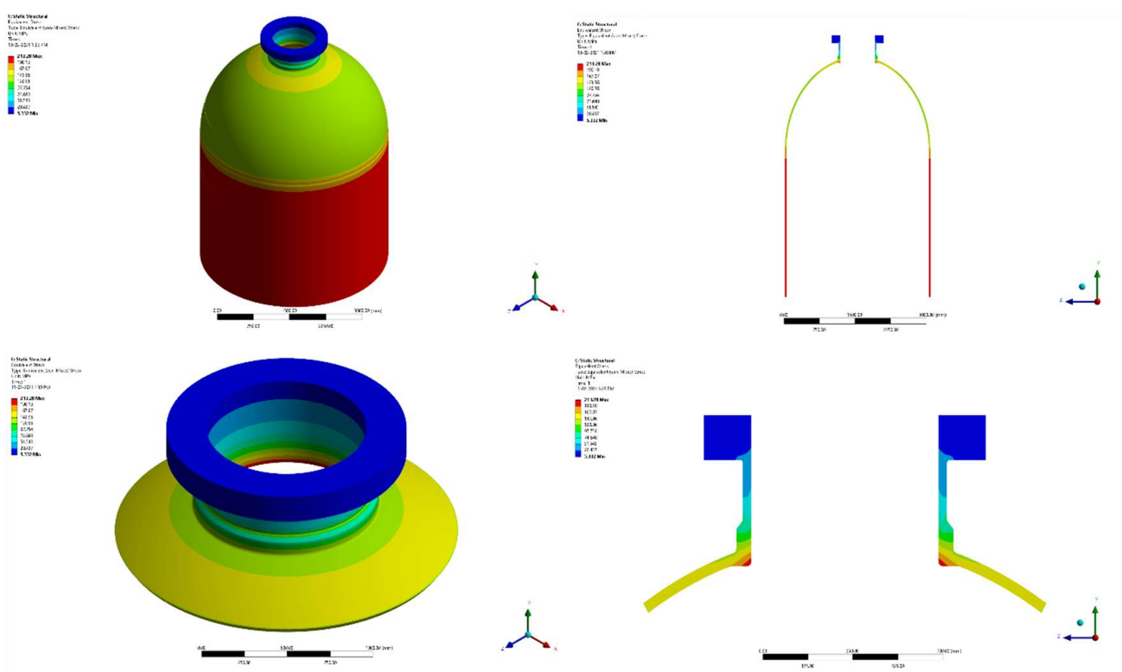

Figure 4. 3. : Pressure Load Stresses

4. Piping Load Stresses:

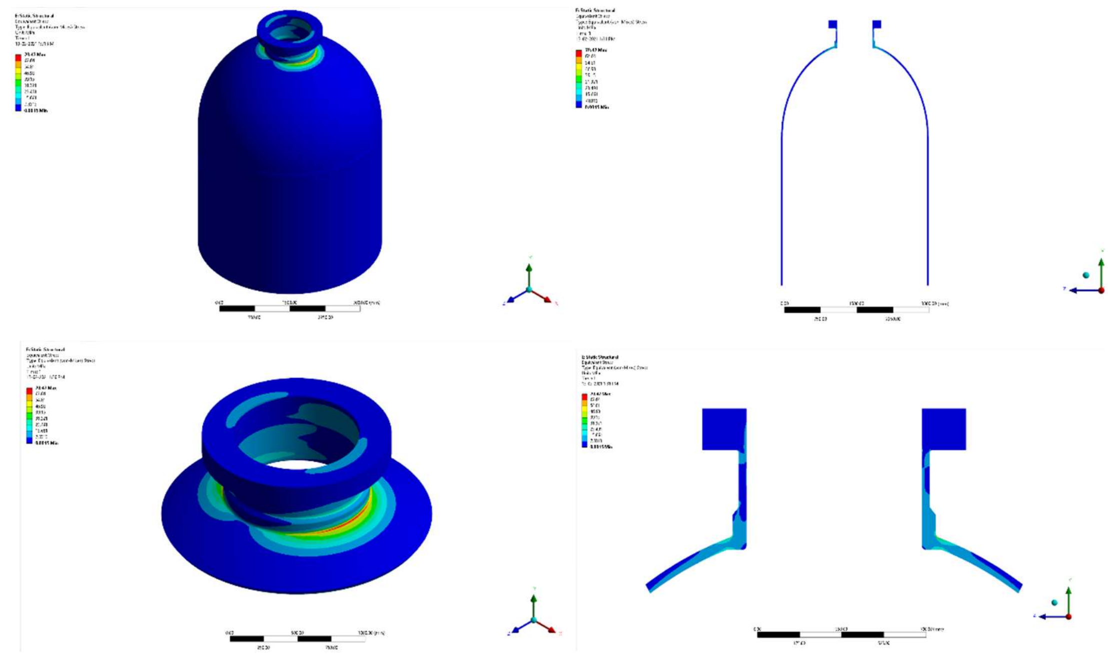

Figure 4. 4. : Piping Load Stresses

5. Dead weight stresses:

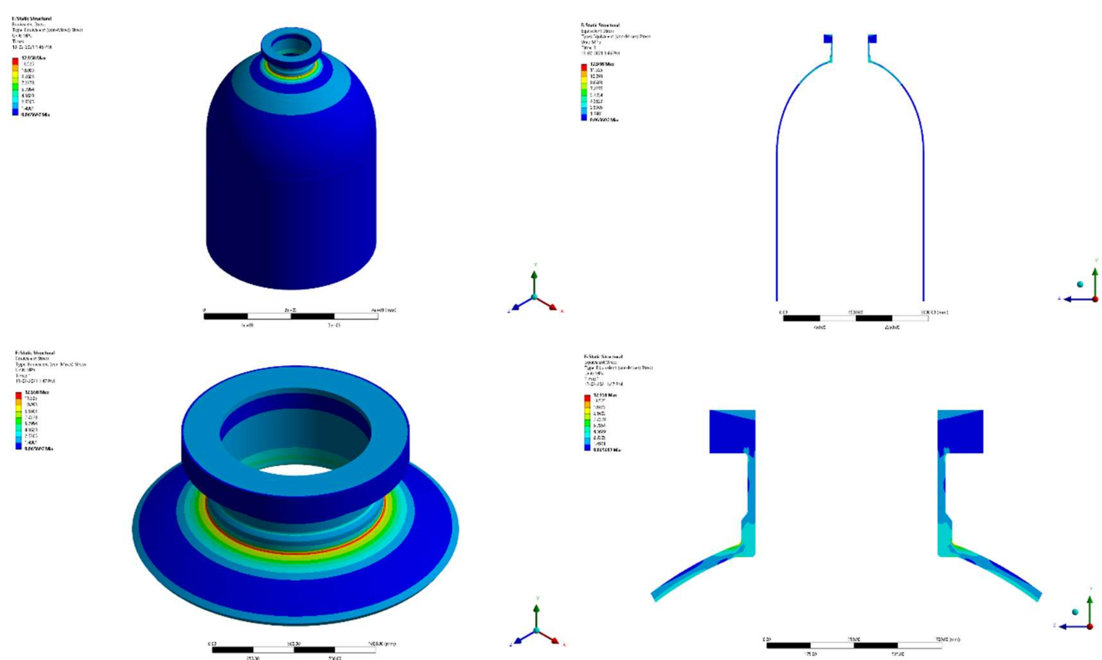

Figure 4. 5. : Dead weight Stresses

4.2 Automated Analysis

1. Temperature Profile:

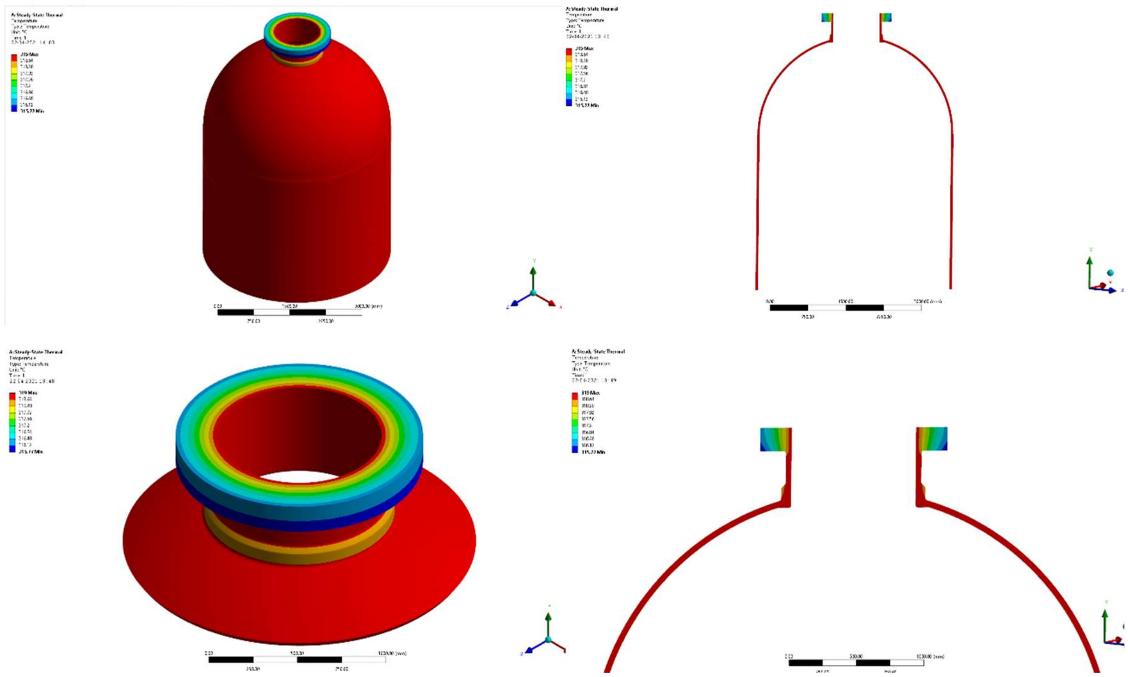

Figure 4. 6. : Temperature Profile

2. Thermal Load Stresses:

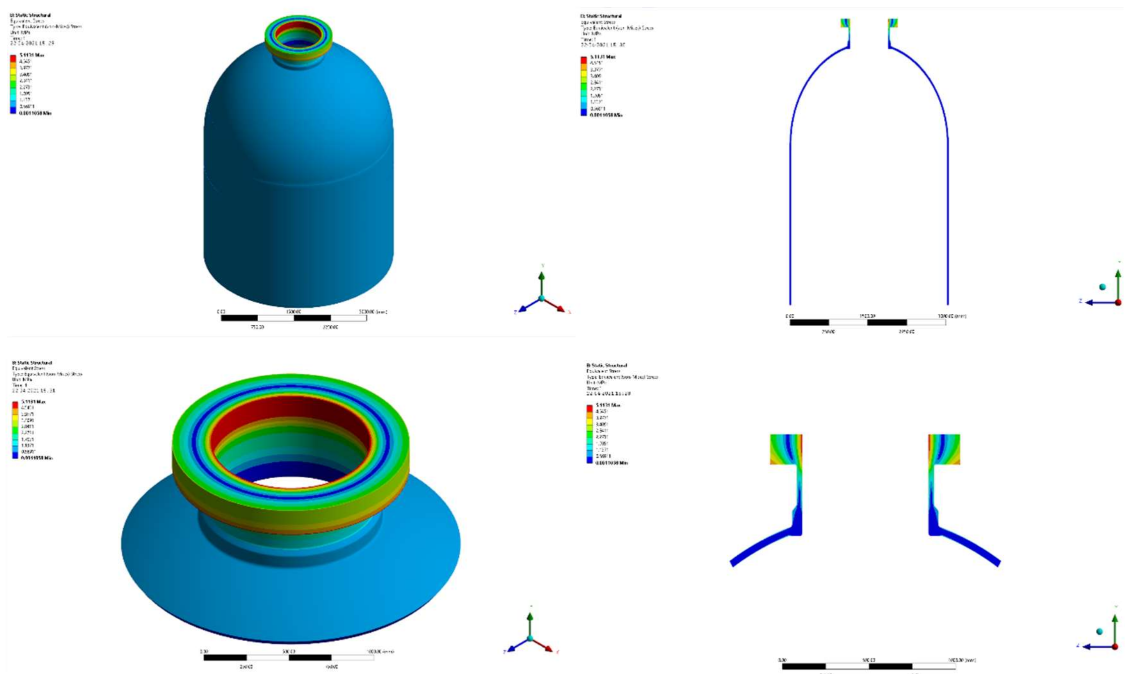

Figure 4. 7. : Thermal Load Stresses

3. Pressure Load Stresses:

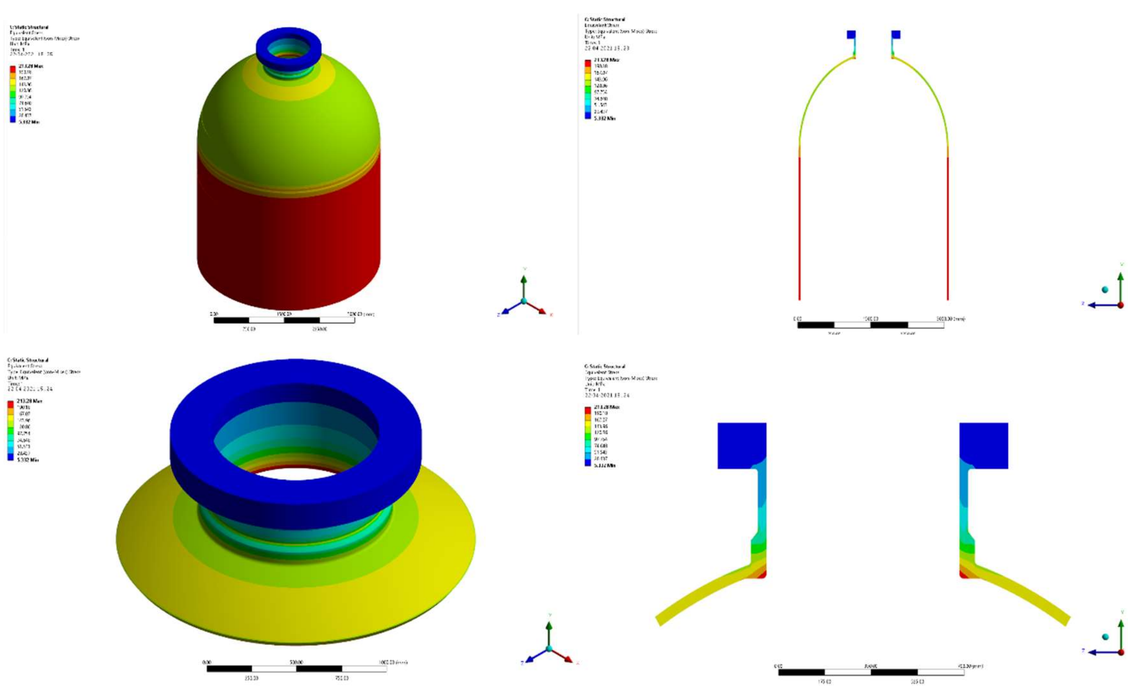

Figure 4. 8. : Pressure Load Stresses

4. Piping Load Stresses:

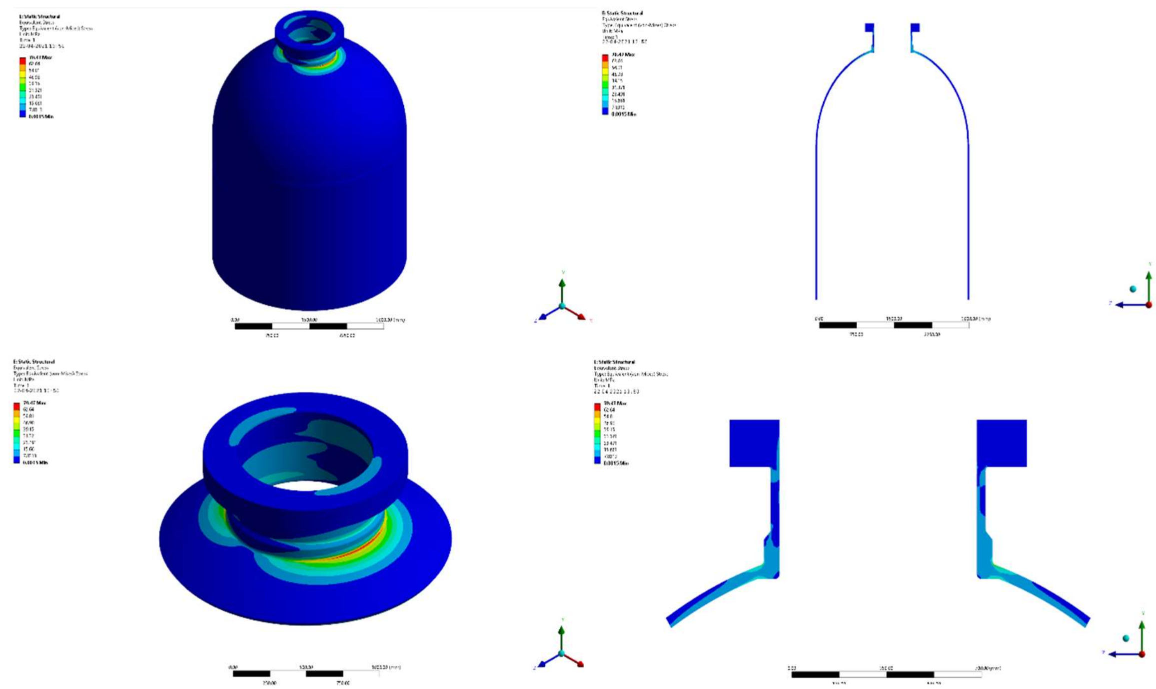

Figure 4. 9. : Piping Load Stresses

5. Dead weight stresses:

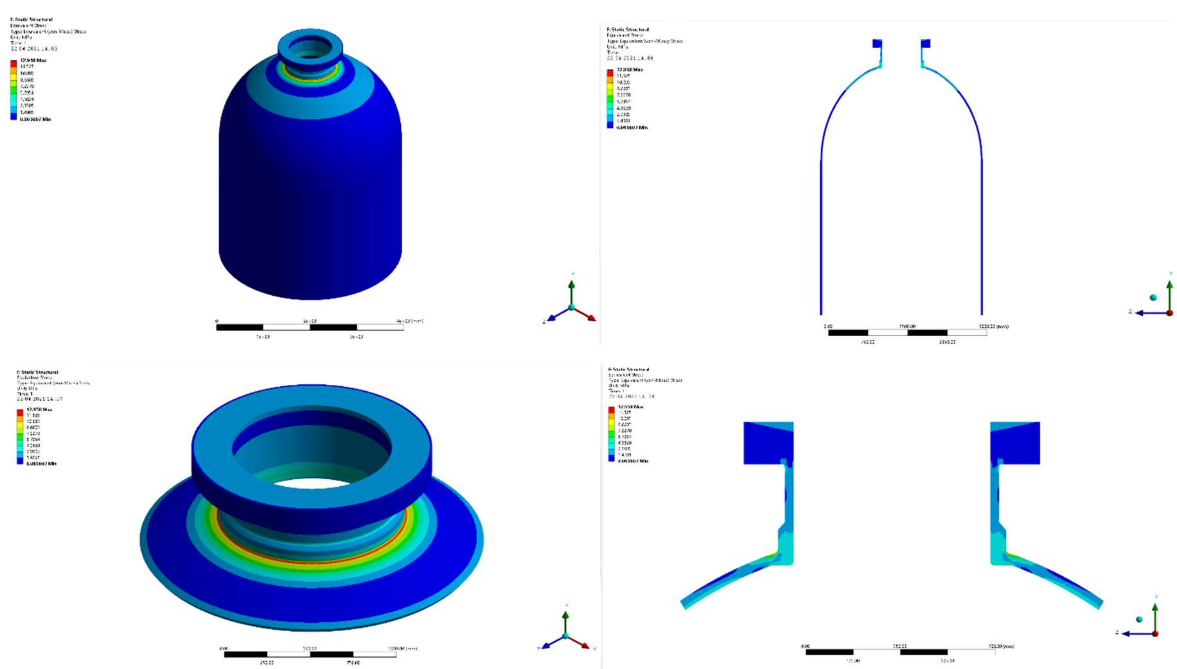

Figure 4. 10. : Dead weight Stresses

CHAPTER 5

Summary and Conclusion

5.1 Manual Analysis

From manual analysis, it is concluded that the design is safe based on given loading criteria. Also, the analysis process is lengthy and time consuming, which may also cause worker fatigue and may result in errors.

5.2 Automated Analysis

It is evident from the results that stress plots obtained from automated process are exactly same as manual process. Therefore, this project is viable to be implemented in industries. In addition, manual process took more than 50+ hours for the same process while automated project only took about 20-25 minutes to generate the results.

5.3 Conclusion

With the use of automation, a workbench project is successfully designed. Manual analysis is tedious, lengthy and time consuming. This project eliminates the worker fatigue and errors due to fatigue. From a rough estimation, the project decreases the time by more than 99% and therefore, it directly affects the volume of work and increase the productivity by a great factor.

Also, this project will affect the future workers. For instance, without this project, a new employee to the company must know the basics of analysis software (i.e. Ansys) and must be familiar with the operating processes. If not, then the employee has to learn the basics and then perform the analysis. In such case, the analysis would take even more than 100 hours. On the other hand, with the successful implementation of this idea, the employee does not need to learn about software. Just by putting the values, he can get the results in approximately 20 minutes.

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