

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Volume 6, Issue 4, April 2017

Design and Analysis of Hatch Door for Submerged Container

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ABSTRACT: The hatch door is designed and analyzed for the determination of thickness to sustain the underwater pressure. This process is use to obtain dimensions of the door model of hatch for failure situations. Objective of this paper is to calculate the thickness by design procedure and then comparing it with solution obtained from analytical model. In the design stage the thickness of hatch is calculated with known factor of safety and in the analysis stage the hatch model is created with known thickness and comparison between both has been done. The stresses generated can be lowered by increasing or decreasing the dimensions, using appropriate material. The analysis is done with the help of software tools like 1) Solid Works 2) ANSYS, which helps to determine the factor of safety of hatch and then further optimization can be done.

KEYWORDS: Hatch, Torispherical, Thickness, Head, SOLIDWORKS, ANSYS, Duplex steel, Pressure, Optimization.

I. INTRODUCTION

A submerged container has a hatch, which protects the vessel from the water pressure on the submerged container, and an outer surface of hatch, which provides a streamlined shape for the submerged container. The hatch of container is made of duplex steel, an alloy made from nickel, molybdenum and chromium that protects the submerged container from the high pressures exerted upon it at greater depths. There are different types of hatch head considered are: **Hemispherical:** It is the strongest type of the formed head. Due to shape it allows to withstand more pressure than any other formed head. These types of heads have minimum thickness, weight and hence low material cost. **Semi-Ellipsoidal:** These types of heads are also called as semi-elliptical head. They are also free from discontinuities. **Torispherical:** The torispherical heads are commonly used as end closures in wide variety of pressure vessel. While this kind of hatch ends has been widely used in wide range of industries from air space, land to undersea structures. The heads are formed by using two radii, the crown radius and the knuckle radius.

II. LITERATURE SURVEY

[1] Bhaskar Patil, Ravi G Lingannavar, "Structural Analysis and Optimization of the Hatched Door" The stress analysis is used for the design of hatch of the Submarine. This process is successfully used in an industrial field and which is proven to be able to give more efficient component designs. It also helps to eliminate actual prototypes for analysis. The objective is to investigate the stresses on hatch operating mechanism of submarine. The effects of stresses on the assembly were calculated when hatch was in closed position. The effects of stress on the hatch operating mechanism, which was based on the results of finite element and by the calculations of the stress analysis, were observed. The load cases of the maximum stresses were compared with the yield stress and ultimate stress of Stainless Steel 302 alloy which was observed to be safe and within limit.

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[2] Behzad Abdi, Hamid Mozafari, Amran Ayob, "Find the Optimum Shape Design of Externally Pressurized Torispherical Dome Ends Based on Buckling Pressure" The four-centered ellipse method was used because it is easy and appropriate method for depicting the shape of the torispherical dome end and it makes the dome optimization step

very easy. In this method there is usage of only two important variables: thickness and the ratio of minor to major axis. The optimization of hatch is done by the usage of imperialist competitive algorithm.

III. MATERIAL SELECTION

A) Material Selection

The different material considered for the design of the hatch is

1) **Stainless steel SS-316:** Chromium 16%, Nickel 14%, Manganese 2%, Silicon 1%, Carbon 0.03%, Sulphur 0.03%, Molybdenum. 3%.

2) **25Cr Duplex Stainless Steel:** Chromium 25%, Nickel 7%, Silicon 0.80%, Carbon 0.02%, Nitrogen 0.27%, Molybdenum. 3%.

B) Specifications

1) Material used: Stainless Steel 316

Chromium content of the Stainless steel: 0.16

Ultimate stress Stainless steel 316 =515 MPa

Young's modulus: 1.90×10^5 MPa

Poisson's ratio: 0.29

Density = 8×10^{-6} Kg/mm³

2) Material used: Duplex Steel

Chromium content of the Duplex steel: 0.16

Ultimate stress Duplex steel =799 MPa

Young's modulus: 1.99×10^5 MPa

Poisson's ratio: 0.27

Density = 7.75×10^{-6} Kg/mm³

The high amount of chromium and molybdenum content of duplex steel make it highly resistant to uniform corrosion in organic acids i.e. formic, acetic acid etc. It also provides high resistance to inorganic acids, especially those containing chlorides. In dilute sulfuric acid combined with chloride ions, duplex steel has better corrosion resistance than 904L, which is a highly alloyed austenitic steel grade which is specially designed to resist pure sulfuric acid. Stainless steel of type 316L cannot be used in hydrochloric acid due to the risk of localized and uniform corrosion. However, it can be used in dilute hydrochloric acid. It also gives resistance to intergranular corrosion, pitting corrosion, stress corrosion cracking, and crevice corrosion. Because, duplex steel is more preferred material than SS316 hence, it is selected for hatch design.

IV. DESIGN OF HATCH

Problem statement: Design and analysis of hatch for a submerged container which should withstand the water pressure at 300 m depth with the pressure on convex side of 3 MPa, under ambient temperature.

Geometry of Torispherical Head

Consider a torispherical hatch door with constant thickness t (figure 1) under external pressure. It can be assumed that the torispherical head is fully clamped at the edges and there is not any flange on it. The four-centered ellipse method is used to create the torispherical head, the radius of spherical cap R and the radius of toroidal knuckle r have definite relations, which can be expressed as functions of the ratio (K) and the angle of spherical cap θ . Then, the geometry of torispherical head can be constructed by using the four-centered ellipse method (figure 2).

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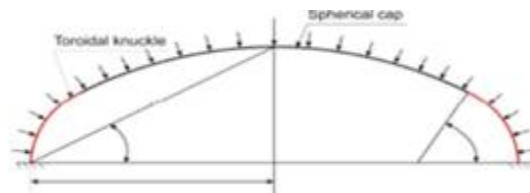


FIGURE 1: Pressure acting on Hatch

This figure shows the pressure operation on the hatch. In figure 1 the external pressure is acting on the hatch. This helps us for the calculation of the thickness of hatch

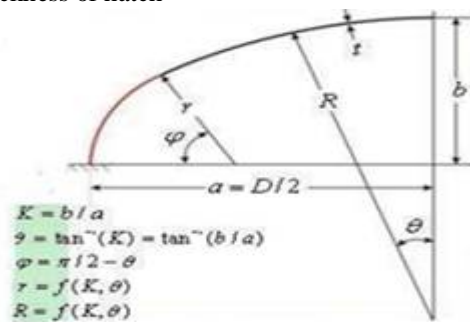


FIGURE 2: Geometry of Hatch

This figure depicts the geometry of the hatch. It helped us in the calculation for the crown radius and the knuckle radius. The figure shows the various notations of torispherical hatch

We know the ratio $K = b / a$,

$$a = \text{radius} = \frac{D}{2}$$

$$b = \text{height}$$

$$\theta = \tan^{-1}\left(\frac{b}{a}\right)$$

$$r = \text{radius of toroidal knuckle} = \frac{a}{2} \left[\frac{1 + \sin \theta - \cos \theta}{(\cos \theta)^2} \right]$$

$$R = \text{radius of spherical cap} = \frac{a}{2 \sin \theta} \left[1 + \frac{1 - \sin \theta}{\cos \theta} \right]$$

1. Calculation of Hatch Thickness by Four Centered Ellipse Method (With Internal Pressure)

$$a = \text{radius} = \frac{D}{2} = 1095 \text{ mm}$$

$$b = \text{height} = 500 \text{ mm}$$

$$\theta = \frac{b}{a} = \frac{500}{1095}$$

$$\tan^{-1} \theta = 24.95 \approx 25^\circ$$

$$r = \text{radius of toroidal knuckle} = \frac{a}{2} \left[\frac{1 + \sin \theta - \cos \theta}{(\cos \theta)^2} \right]$$

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$$= \frac{1095}{2} \left[\frac{1 + \sin 25 - \cos 25}{(\cos 25)^2} \right]$$

$$\therefore r = 344.16 \text{ mm}$$

$$R = \text{radius of spherical cap} = \frac{a}{2 \sin \theta} \left[1 + \frac{1 - \sin \theta}{\cos \theta} \right]$$

$$= \frac{1095}{2 \sin 25} \left[1 + \frac{1 - \sin 25}{\cos 25} \right]$$

$$\therefore R = 2120.81 \text{ mm}$$

Thickness calculation,

$$t = \frac{0.855 p_i R}{\sigma_t \times \eta - 0.1 p_i}$$

Internal Pressure, $p_i = 3 \times 1.67 \text{ Mpa} = 5 \text{ Mpa}$ (By Reference ASME CODE, Int. Pressure=1.67 times of External Pressure)

$\eta = 100\%$ (for seamless)

$$\sigma_t = \frac{S_{ut}}{f.o.s} = 295 \times 10^6 \text{ N/mm}^2$$

$$\therefore t = \frac{0.855 \times 5.01 \times 2120}{295 \times 1 - 0.1 \times 5.01} = 31.85 \approx 32 \text{ mm}$$

2. Calculation of Hatch Thickness by ASME Code, Graphical Method (With External Pressure)

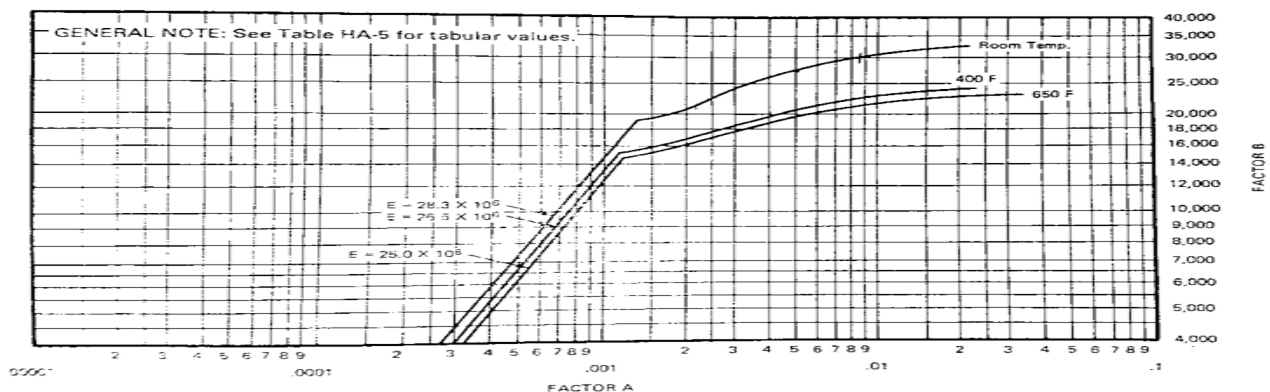
The required thickness of torrispherical head having external pressure is dependent on two factors namely A, B. Where factor A is dependent on outer radius of crown portion of head and the minimum required thickness of head after forming. Here the thickness is presumed to be 57mm for the calculation of factor A.

$$A = \frac{0.125}{R_e/t}$$

$$A = \frac{0.125}{2120.81/57}$$

$$\therefore A = 2.94 \times 10^{-3}$$

Now, the Factor B is obtained with the help of **chart** for "determining shell thickness of components under external pressure". It depends on diameter at large end of torispherical section, thickness and the external working pressure.



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With the help of Factor b, which is obtained from chart external pressure is to be calculated by the following formula for required permissible limit.

$$P_a = \frac{4B}{3(D_L/t_e)}$$

Where $B = 24500$ (From chart)

$$P_a = 438.94 \text{ PSI} = 3.026 \text{ MPa}$$

For thickness of 57mm the hatch withstands the external pressure up to 3.026 MPa, which is greater than the required limit.

V. MODELLING AND ANALYSIS

MODEL NO. 1

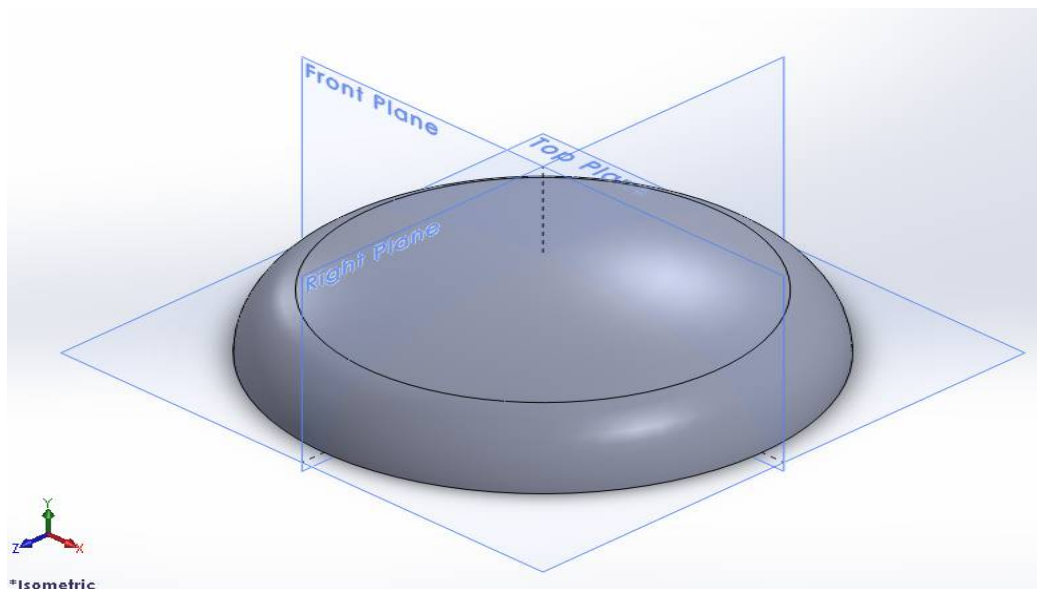


Figure III. 3D model of hatch

3D model of hatch is designed with the help of SOLIDWORKS.

The Diameter of hatch is, $D=2190$ mm, the Knuckle radius is, $R=2120.81$ mm, the Crown radius is, $r=344.16$ mm. The thickness of hatch is, $t=32$ mm

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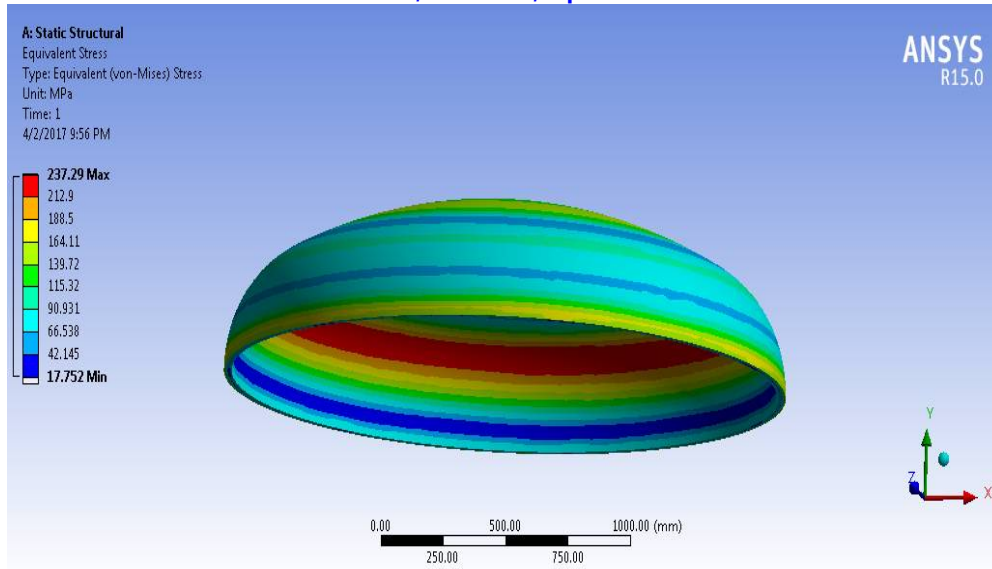


Figure IV. Stress distribution of hatch

In this figure static structural analysis of model I for equivalent (von-mises) stress is obtained in ANSYS Software. Stress distribution of model 1 is shown in above figure IV. The maximum stress is 237.29 MPa.

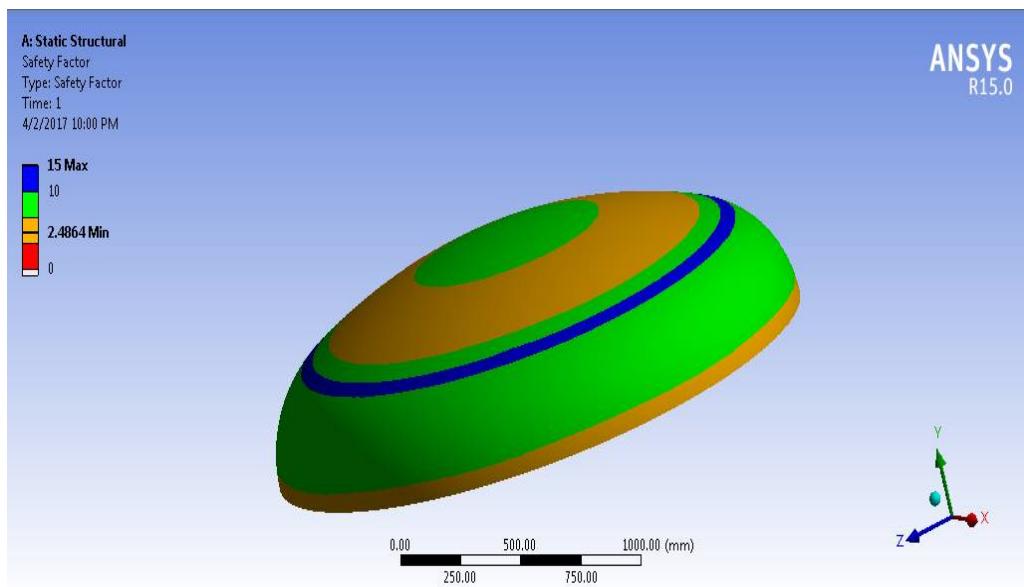


Figure V. Factor of Safety of hatch by ANSYS

In this figure static structural analysis of model I for Factor of Safety is obtained in ANSYS Software. Factor of safety of model 1 is shown in above figure V. The Factor of Safety is obtained as 2.4864.

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MODEL 2

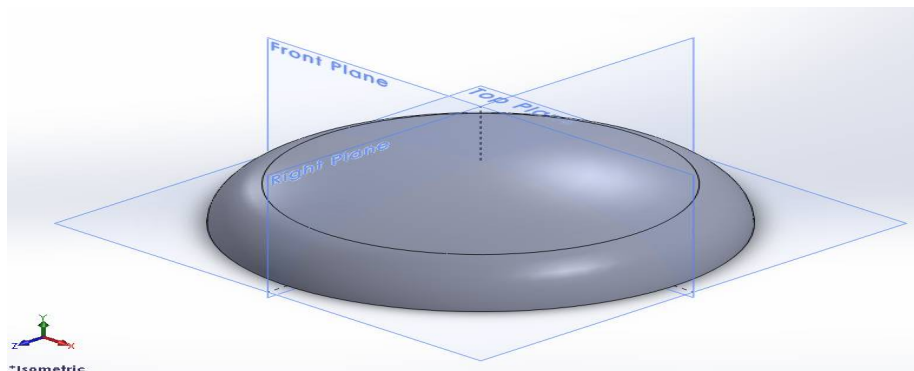


Figure VI. 3D model of hatch

The Diameter of hatch is, $D=2190$ mm, the Knuckle radius is, $R=2120.81$ mm, the Crown radius is, $r=344.16$ mm, and the Thickness of hatch is, $t=57$ mm

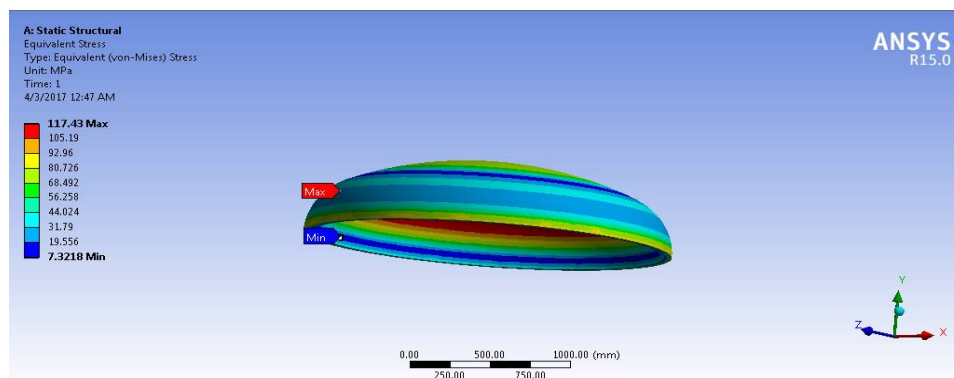


Figure VII. Stress distribution of hatch

In this figure static structural analysis of model 2 for equivalent (von-mises) stress is obtained in ANSYS Software. Stress distribution of model 2 is shown in above figure VII. The maximum stress is 117.43 MPa.

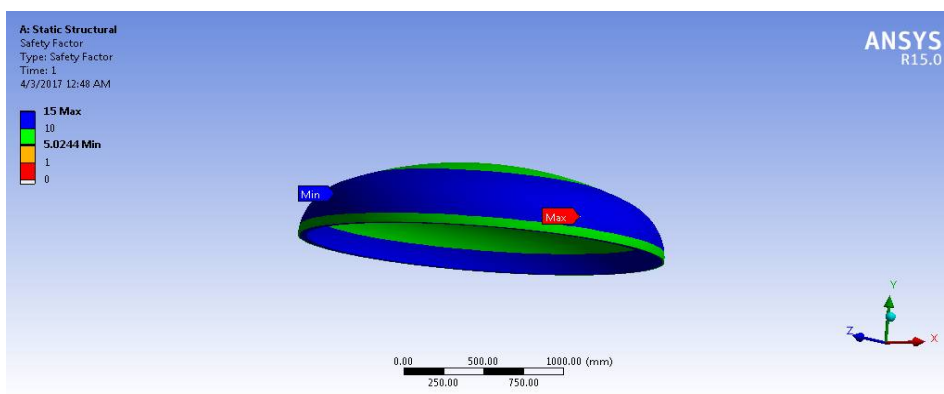


Figure VIII. Factor of Safety of hatch by ANSYS

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In this figure static structural analysis of model 2 for Factor of Safety is obtained in ANSYS Software. Factor of safety of model 2 is shown in above figure VIII. The Factor of Safety is obtained as 5.0244.

MODEL 3 – Optimized Model (With F.O.S 4 Trial and error to get minimum thickness)

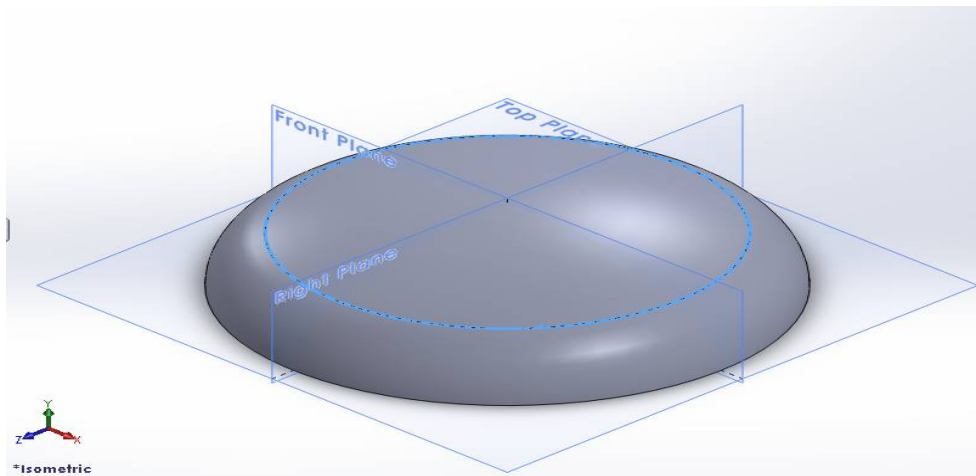


Figure IX. 3D model of hatch

The Diameter of hatch is, $D=2190$ mm, The Knuckle radius is, $R=2120.81$ mm, The Crown radius is, $r=344.16$ mm
And the Thickness of hatch is, $t=49$ mm

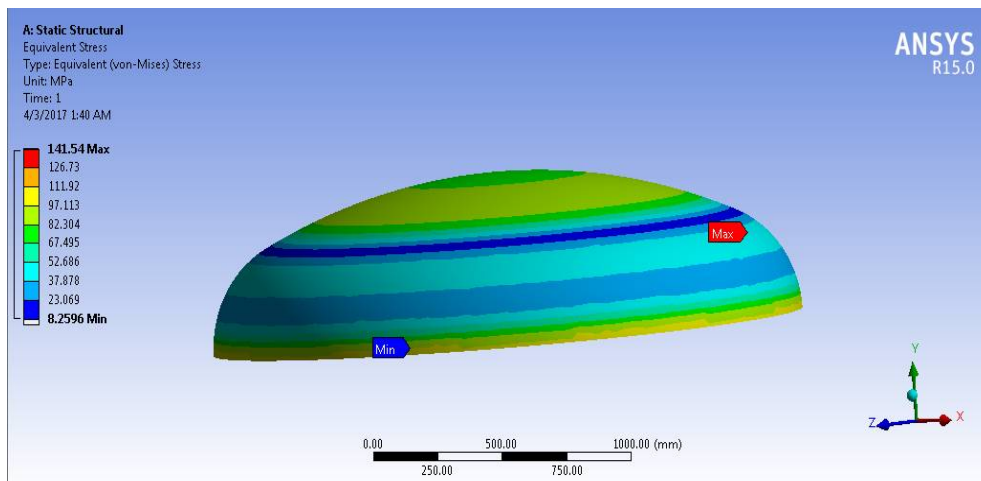


Figure X. Stress distribution of hatch

In this figure static structural analysis of model 3 for equivalent (von-mises) stress is obtained in ANSYS Software. Stress distribution of model 3 is shown in above figure X. The maximum stress is 141.54 MPa.

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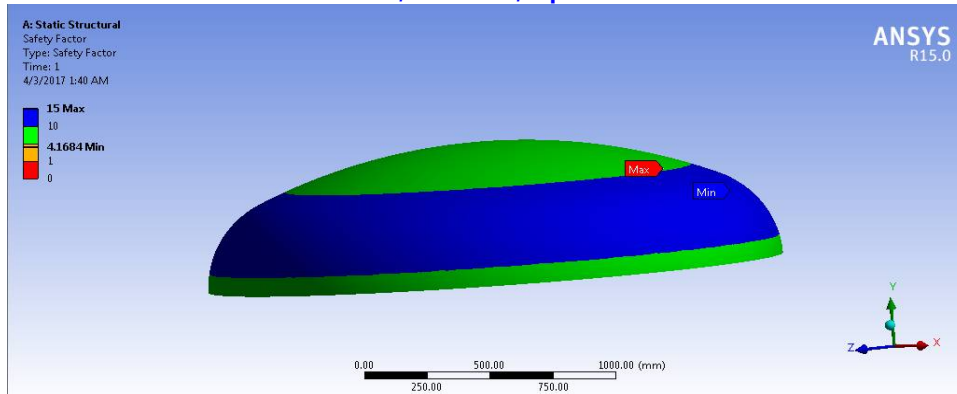


Figure XI. Factor of Safety of hatch by ANSYS

In this figure static structural analysis of model 3 for Factor of Safety is obtained in ANSYS Software. Factor of safety of model 3 is shown in above figure XI. The Factor of Safety is obtained as 4.1604.

VI. RESULTS

In the four centred method for designing of torispherical head, the thickness obtained is 32mm and maximum stress obtained is $237.29N/mm^2$ for 2.486 factor of safety. Similarly for the graphical method under external pressure, the thickness obtained is 57mm and it gives maximum stress as $117.43N/mm^2$ with factor of safety 5.0244.

TABLE I. COMPARISON OF RESULTS OBTAINED FOR VARIOUS THICKNESSES.

Method	Thickness (mm)	F.O.S	Weight (Kg) (Volume × Density)	Stress (MPa) (Max)
Four Centered Ellipse Method	32	2.486	1305.8	237.29
Graphical Method	57	5.0244	2387.5	117.43
Optimized Model	49	4	2035	141.54

Then, the hatch thickness is optimized using finite element method (ANSYS Software). For the optimised hatch the factor of safety is 4 and the minimum thickness to withstand the given external pressure of 3 MPa is 49mm and the weight of hatch obtained.

VII. CONCLUSION & FUTURE WORK

The present work illustrates that for torispherical hatch thickness calculation, two methods are studied i.e. four centered method and ASME graphical method for pressure on convex side of hatch. From calculation and analysis of respective hatch, it is observed that ASME Code graphical method for vessel hatch end design gives more stable results. The stress obtained on hatch is less and factor of safety is high, which is our prime objective. During optimization of hatch thickness, the factor of safety is kept constant and thickness is obtained from ANSYS software. This also helped us to reduce the weight of hatch designed.

For future study, the optimum design of torispherical hatch for submerged container may be consider for factor like buckling pressure, strength, space use, weight, manufacturing cost, safety, etc.

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