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The structure design of type-C independent tank on LNG ship

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ABSTRACT

This paper based on the "International Carriage of liquefied gases in bulk ship construction and equipment rules" and "Pressure Vessel Standards". The internal pressure of single cylinder tank calculates by the principle of two-dimensional calculation method and obtains the thickness of cylinder and head by a computer program. Finally, take consideration of the interaction of internal pressure and the thermal stress, gravity, Hydrostatic pressure; verify the design thickness on ANSYS software. And the conclusion shows that theoretical design results meet the strength requirements.

1. INTRODUCTION

Liquified natural gas (LNG) is a clean energy and has attracted more and more attention in the world. LNG tank is a pressure container of LNG, according to the "International Carriage of liquefied gases in bulk ship construction and equipment rules" and "Pressure Vessel Standards", LNG tank can be divided into 4 categories (SIGTTO 2000), Integral tanks, Membrane tanks, Semi-membrane tanks and Independent tanks. Membrane tanks and Semi-membrane tanks are widely used in the construction of large LNG ships and construction process is complex. For the small LNG ships, C-type Independent has more advantages, such as low cost, simple design, high stability, etc (EDUARDO PEREZ ORUE).

The structure size of C-type independent is decided by the internal pressure, we can acquire it by general design principle (Ding Lin. 2009). Firstly, we should be sure the internal pressure of the container in longitudinal and transverse and choose the larger one, after that we can get the basic thickness of the wall and head. This procedure has a direct impact on the succession work.

When a small LNG ship is travelling on the sea, the internal pressure will be influenced by the surge, swaying, heave, roll, pitch and yaw (Pei Yiqun 2012). This article is based on the traditional two-dimensional acceleration ellipse synthesis, compile a VB program to calculate the thickness of the wall and head in the C-type independent LNG tank. In the end, verify the value of thickness on ANSYS.

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2 REASEARCH ON STRUCTURE DESIGN OF C-TYPE INDEPENDENT TANK

2.1 Design steam pressure P_0

According to the IGC rule (IMO 1993), C-type Independent tank comply with the pressure vessel standard, and the design stem pressure is larger than the value calculate by Eq. (1) and Eq. (2)

$$P_0 = 0.2 + 0.1AC(\rho)^{1.5} \tag{1}$$

$$A = 0.0185 \times (\sigma_m / \sigma_A)^2 \tag{2}$$

Here, P_0 is the design steam pressure. C is the tank's feature sizes which is the maximum of the following values, h (Height of the tank), $0.75b$ (0.75 times of the tank width), $0.45L$ (0.45 times of the tank length); ρ is the density of the cargo at design temperature, Kg/m^3; σ_m is the allowable stress of material, MPa; σ_A is the allowable dynamic stress of material.

2.2 Internal design pressure P_{eq}

The internal design pressure P_{eq} is the sum of vapor pressure P_0 and internal liquid pressure P_{gd} but not include the effect of liquid sloshing. We can get the internal design pressure P_{eq} by Eq. (3)

$$P_{eq} = P_0 + (P_{gd})_{max} \tag{3}$$

The internal liquid pressure P_{gd} is produced by the liquid height Z_β and dimensionless acceleration α_β, which can be calculated by Eq. (4)

$$P_{gd} = \alpha_\beta Z_\beta \left(\frac{\rho}{1.02x10^5} \right) \tag{4}$$

Where, α_β is the dimensionless acceleration produced by gravity and motion load at the β direction; ρ is the density of the cargo at design temperature, Kg/m^3; Z_β is the maximum liquid height, which measured from the pressure point to the tank's shell plate at β direction.

2.3 Dimensionless acceleration α_x, α_y, α_z

Vertical motion acceleration α_z produced by heave, pitch and roll is defined as:

$$\alpha_z = \pm\alpha_0 \sqrt{1 + \left(5.3 - \frac{45}{L_0}\right)^2 \left(\frac{X}{L_0} + 0.05\right)^2 \left(\frac{0.6}{C_b}\right)^{1.5}} \tag{5}$$

Transverse motion acceleration α_y produced by swaying and yaw is defined as:

$$\alpha_y = \pm\alpha_0 \sqrt{0.6 + 2.5\left(\frac{X}{L_0} + 0.05\right)^2 + K\left(1 + 0.6K\frac{Z}{B}\right)^2} \tag{6}$$

Longitudinal acceleration α_x produced by surge and pitch is defined as:

$$\alpha_x = \pm\alpha_0 \sqrt{0.06 + A^2 - 0.25A} \quad (7)$$

Here, L_0 is the length of the ship (m); B is the width of the ship (m); C_b is the Square coefficient; X is the vertical distance from boat to the center of gravity of tank (m), the front direction is positive, behind is negative; Z is the vertical distance from actual ship waterline to the center of gravity of tank (m), the above direction is positive, bellow is negative; K is a constant $K = 1$.

2.4 Resultant acceleration α_β and liquid height Z_β at Transverse direction

When we calculate the internal pressure of the liquid P_{gd} in Eq (4), we should firstly determine the resultant acceleration α_β, we can acquire the α_β from the three dimensionless acceleration $\alpha_x, \alpha_y, \alpha_z$, the resultant acceleration (TABAKOV 2013) α_β on Y-Z plane can be described as Fig. 1.

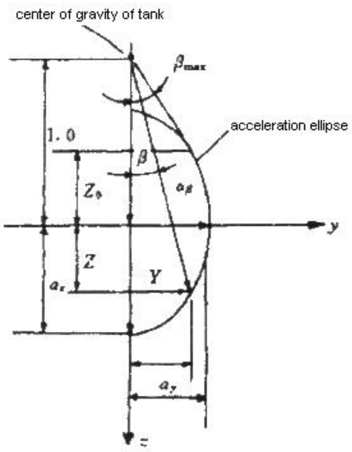


Fig. 1 resultant acceleration ellipse on Y-Z plane

$$\alpha_\beta = \frac{\alpha_y{}^2 \cos\beta_r + \alpha_z\alpha_y\sqrt{\alpha_y{}^2\cos^2\beta_r + \alpha_z{}^2\sin^2\beta_r - \sin^2\beta_r}}{\left(\alpha_y{}^2\cos^2\beta_r + \alpha_z{}^2\sin^2\beta_r\right)} \quad (8)$$

The structure of pressure vessel can be described by analysis method. The liquid height Z_β (DING Ling 2010) can be can be descripted as Fig. 2.

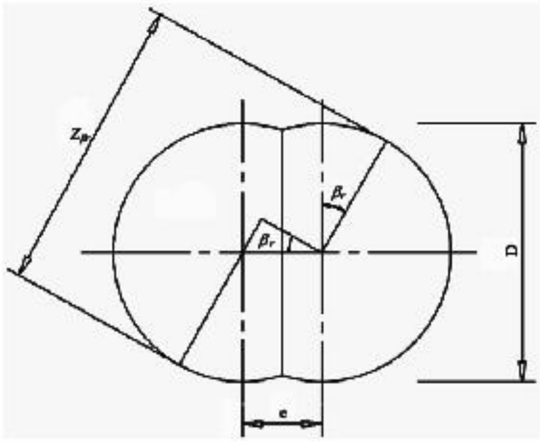


Fig. 2 Liquid height on transverse plane

$$Z_{\beta} = d \times \sin\beta_{\mathrm{r}} + D \tag{9}$$

Here, d is the center distance of double cylinder, if it's a single cylinder, $d = 0$; D is the inside diameter of the tank.

In the same way, we can acquire the resultant acceleration α_{θ} and liquid height Z_{θ} at longitudinal direction, and the internal pressure P_{θ} can be described by Eq. (10)

$$P_{\theta} = \alpha_{\theta} Z_{\theta}\left(\frac{\rho}{1.02x10^{5}}\right) \tag{10}$$

Here, the acceleration ellipse on X-Z plane, so the α_{θ} and Z_{θ} can be written as Eq. (11)

$$\alpha_{\theta} = \frac{\alpha_x{}^2 \cos\beta_p + \alpha_x\alpha_z\sqrt{\alpha_x{}^2\cos^2\beta_p + \alpha_z{}^2\sin^2\beta_p - \sin^2\beta_p}}{\left(\alpha_x{}^2\cos^2\beta_p + \alpha_z{}^2\sin^2\beta_p\right)} \tag{11}$$

The structure of pressure vessel can be described by analysis method. The liquid height Z_{θ} (DING Ling 2010) can be descripted as Fig 3

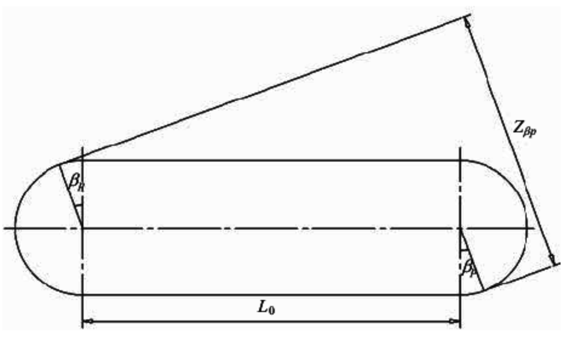


Fig 3 Liquid height on longitudinal plane

$$Z_{\theta} = D + L_0 \times \sin\beta_p \tag{12}$$

Where, D is the diameter of the tank, m; L_0 is the length of the tank(not include the head).

Then, we can calculate the internal pressure of the tank by Eq.(13)

$$P = Max[P_0 + (P_\beta)_{\max}, P_0 + (P_\theta)_{\max}] \tag{13}$$

2.5 Determine the thickness of the wall σ_1 and head σ_2.

The thickness of the wall σ_1 can be defined as

$$\sigma_1 = P \times D / (2 \times \sigma \times e - P) + \mathrm{t} \tag{14}$$

Where, P is the Internal design pressure, MPa; D is the cylinder inside diameter, m; e is the Welding coefficient, $e = 1$; σ is the allowable stress of material, MPa; t is the Corrosion allowance, $\mathrm{t} = 0.5 \sim 1$.

The thickness of the head σ_2 can be defined as

$$\sigma_2 = P \times D \times y / (2 \times \sigma) + \mathrm{t} \tag{15}$$

Here, y is the shape coefficient for spherical head, we set it as 0.55.

3. CALCULATE THE THICKNESS OF WALL σ_1 AND HEAD σ_2

From the equations above, we can calculate the thickness of the wall σ_1 and head σ_2.Enter the relevant data into the program, and we get the result of the thickness of the wall σ_1 and head σ_2 shown as Fig. 4

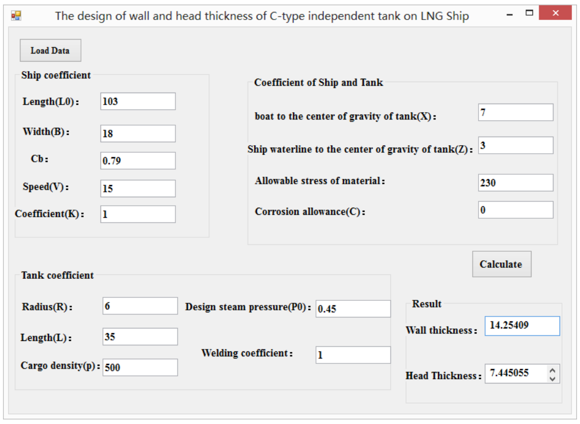


Fig. 4 the results of the program

From Fig. 4, we obtain the wall thickness $\sigma_1 = 14.25mm$ and head thickness $\sigma_2 = 7.45\mathrm{mm}$. But we should set a safety factor n for the thickness. Commonly, $n = 2$, after correction, the wall thickness $\sigma_1 = 2 \times 14.25 = 28.5\mathrm{mm}$ and head thickness $\sigma_2 = 2 \times 7.45 = 14.9mm$.

4. VERIFY σ_1 AND σ_2

4.1 Strength analysis of the tank

In this article, taking the C-type independent tank on small LNG Ship as an example, calculate the wall thickness σ_1 and head thickness σ_2 in a VB program. The design steam pressure is 0.45MPa, Maximum volume 5000m3, Spherical head, set the Q345R as the material of the tank. Main parameters of the ship and tank show as Tab.1 (Liu Wen-hua 2012).

Table 1 Main parameters of the ship and tank

Parameter(ship)	Length/m	Width/m	Square coefficient	Speed/kn
value	103	18	0.79	15
Parameter(tank)	Radius/m	Length/m	Cargo Density(Kg/m3)	Welding coefficient
value	6	35	500	1

This C-type independent tank is subjected to multiple load conditions, Main load distribution are shown as Table 2(Liu Wen-hua 2012).

Table 2 Main load distribution of the tank

number	Load	Operation value
1	Gravity(m/s2)	g
2	Temperature(^{0}F)	100
3	Transverse acceleration(m/s2)	0.12g
4	Longitudinal acceleration(m/s2)	0.12g
5	Hydrostatic pressure(MPa)	90% Volume
6	Steam pressure(MPa)	0.45

The environmental temperature is 700F, Thermal expansion Coefficient 1.2E-5/^{0}C, Tank density 8000kg/m3, Cargo density 500kg/m3, Young's modulus 2.03e11, Poisson ratio 0.3.

In the analysis process, we should firstly analysis the different load separately and record the maximum stress value then gets the maximum stress at 6 loads combine operating condition.

The tank is supported by two supports, and distance 11m from top of the head, which is shown as Fig. 5

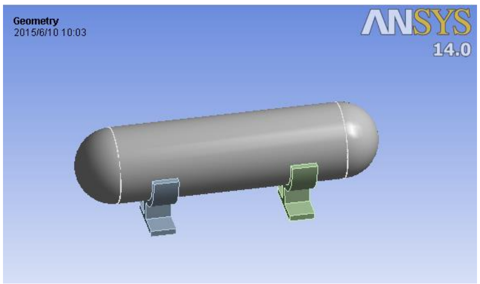
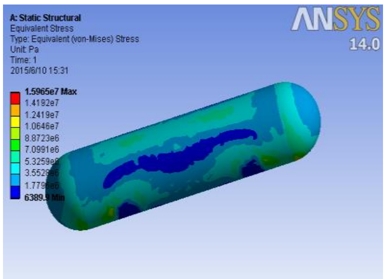
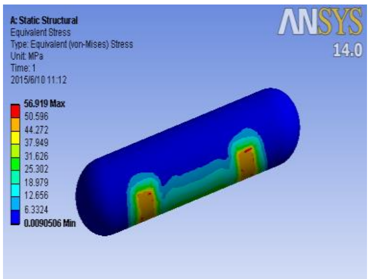


Fig. 5 Finite element analysis model

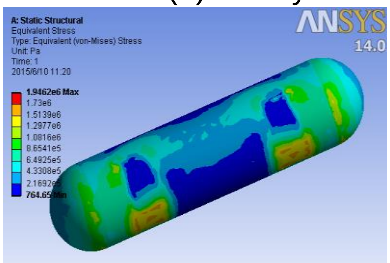
Boundary conditions: Impose fix constraints on two supports, restrict the slip and rotation. The supports and tank are bonding contact, so the tank is restricted. Stress analysis of tank under different load conditions are shown as Fig 6



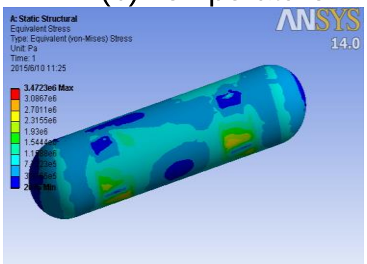
(a)Gravity



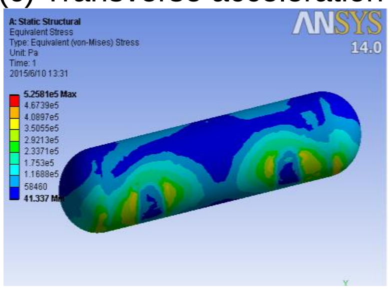
(b) Temperature



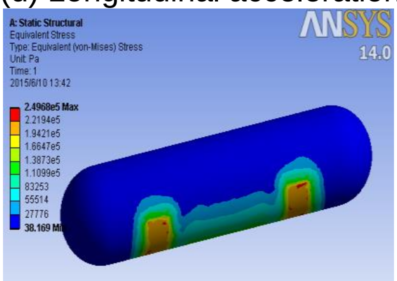
(c) Transverse acceleration



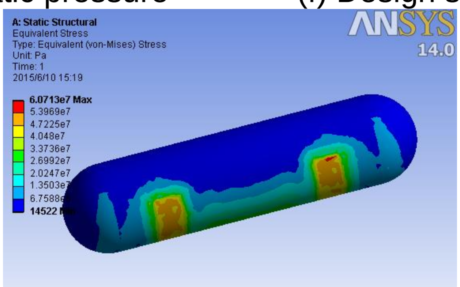
(d) Longitudinal acceleration



(e) Hydrostatic pressure



(f) Design steam pressure



(g) 6 loads combine

Fig. 6 Stress analysis of tank under different loads

We can obtain the maximum stress value of the tank under different condition, which was shown as Table 3

Table 3 Max Stress and Max Deformation under different load condition

Load	Max Stress(MPa)	Max Deformation(mm)
Gravity	15.9	5.79
Temperature	56.9	4.79
Transverse acceleration	1.95	0.69
Longitudinal acceleration	3.47	1.16
Hydrostatic pressure	0.53	0.15
Design steam pressure	0.25	0.08
6 loads combine	60.7	7.55

The maximum allowable stress of material Q345R is 230MPa, The Maximum Stress in 6 different load conditions is Temperature load, which is 60.7MPa < 230MPa.

4.2 Strength analysis of the joint between cylinder and head

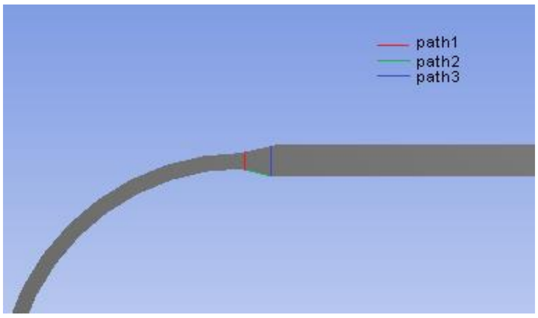
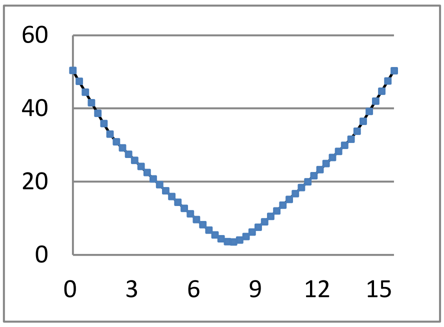


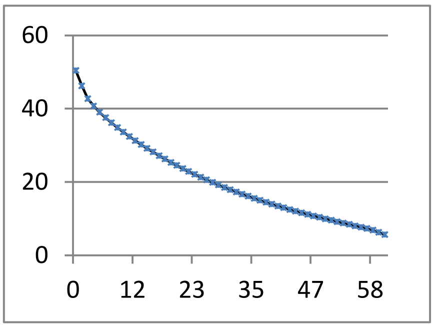
Fig. 7 Joint between cylinder and head

The joint between cylinder and head shown as Fig 8, for 2D analysis, axisymmetric model, the thickness of wall and head are 28.5mm and 14.9mm respectively, Transition length is 60mm. The design pressure is the sum of Design steam pressure (0.45MPa) and Hydrostatic pressure (0.53MPa).

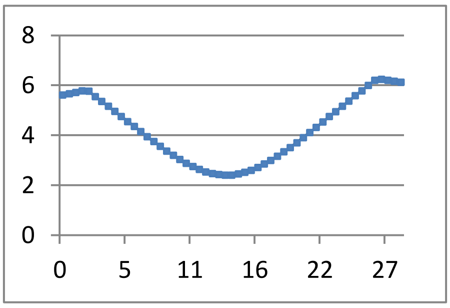
There are three paths in elbow, which are represented by three lines of different colors as shown in Fig 8, the red one is path1, green one is path2 and blue one is path3. These three paths probe the stress along with the path at the post process, stress distribution along the three paths are shown as Fig 8.



(a) Stress distribution along path1



(b) Stress distribution along path2



(c) Stress distribution along path3
Fig. 8 Stress distribution along three paths

The maximum stress in the three paths is 50.35MPa, which is much less than the allowable stress of the material 230MPa, so this structure is safe in elbow.

5. CONCLUSIONS

Acceleration ellipse theory is applied in this article, and to verify the theory value of wall and head thickness on ANSYS. The following conclusions are drawn.

1). we get the resultant acceleration then determine the internal pressure and compare the internal pressure in Longitudinal and Transverse and obtain the maximum value.

2). Read the main information of the ship and tank, calculate the thickness of wall and head in the V program.

3). Verify the thickness of wall and head by 6 different kinds of load condition then check the dangerous point in elbow. Though analysis, the thickness of wall and head are meet the strength requirements.

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