Side Space’s Impact on Stress of the Inner Pressure Tank
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Abstract. This paper analyzes the side space’s impact on deformation and stress of the inner pressure tank shell under different load cases, depending on the stress law of the outer pressure tank. The results indicate that: the smaller side space is good for the longitudinal stress at the shell above the pressure tank under two conditions. As the side space increases, the stress decreases. The stress’s changing law of the inner pressure tank’s shell is the same with the outer. However, the changing law of the hull’s stress is different. The stress computational formula of the outer pressure tank can’t be applied to the inner directly and it need be modified.

Introduction
The research on the inner pressure tank’ structural and mechanical properties is hardly taken for the sake of using the double shell submarine for a long time in our country. There are no much experiences for building, employing and systems of calculating. However, the research on the outer pressure tank has been done by experts and scholars maturely and many results have been obtained. Xie Zuoshui analyzed the stress of hull shell in the floor pressure tank area [1]. He pointed out the stress concentration problems of shell plates and pressure tank structure of submarine-quasi-homocentric type [2]. He developed the method of calculating pressure tanks’ stress with the four space shell mechanical model and finite element analysis [3]. In the research of inner pressure tank. Mao Yunsheng [4], designed the new structure of inner adjusting water tank in the single shell submarine based on the former Soviet union’s "pressure tank strength and stability calculation method". He determined the main parameters and made some FE calculating for the pressure tank, the pressure hull, and floor structure. Wu Fan [5] analyzed the inner pressure tank’s stress under two different loading conditions and concluded that when the fluid hold is connected, the condition is more dangerous and the stress level is higher.

The above literatures’ research for pressure tank is of significance to the study of that in China. However, as a new structure, the mechanical properties of inner pressure tank have not been studied as the side span is important structural parameters of pressure tank. The purpose of this article is to analyze the stress law of typical structures with the changing of side span under different ballast conditions in order to find out the better side span in the inner pressure tank and the outer pressure tank’s stress calculation formula’s adaptability to the inner pressure tank stress calculation.
Calculation Model and Condition

Calculation Model

Built-in annular pressure tank, based on its mechanical characteristics, is divided into three regions: the monolayer pressure shell at the top of the tank, pressure shell at the bottom of the tank area, and the pressure shell of tank area.

As shown in figure (a), the basic input parameters of the structure (the actual value/shell thickness) include the radius of pressure cylinder shell relative value $R_1 / t_1 = 188.3$, the annular pressure tank diameter relative value $R_2 / t_1 = 155$, the side spacing relative value $lR = (R_1, R_2)/t_1 = 33.3$, annular pressure tank length relative value $L/t_1 = 325$, frame and floor spacing relative value $l/t_1 = 21.7$, the longitudinal spacing the relative value of $b_1 / t_1 = 11.67$, the tank circumferential size $\theta$.

![Figure 1. model of pressure hull and tank.](image)

Taking the annular pressure tank with longitudinal type model as an example (figure 1b). The component size includes: tank shell $t_1 = 1$, floor thickness $t_2 / t_1 = 0.67$, the tank side bulkhead $t_3 / t_1 = 1.3$, top shell $t_4 / t_1 = 1$, keel plate thickness for $t_5 / t_1 = 0.67$. The 20a ball flat steel is selected as tank shell longitudinal and the 24a ball flat steel is selected for the bulkhead stiffeners and floor reinforcement. Parts in pressure shell, thickness of tank is $t_6$.

The relative value of thickness of the bottom of the tank area and that at the top $t/t_8$ is 1.5. The frame at the top of tank area $\frac{1.5 \times 15}{1.67 \times 4.33}$, frame outside the tank area $\frac{1.33 \times 13.3}{1.5 \times 4.33}$.

Using ansys modeling [5] for calculation, the shell plate and frame adopt shell63 element modeling. web frame panels, tank shell longitudinal bulkhead stiffeners, floor and end adopt beam188 unit modeling.

Calculating

Calculating model boundary conditions: rigid fixed pressure of one shell side and the other end in addition to the axial freedom, constraining other degrees of freedom.

![Figure 2. loads under different conditions.](image)
The linear load is employed along axial line of hydrostatic pressure $1/2P_cR_1$. Respectively from the following two kinds of load cases: (1) load the pressure hull calculating pressure $P_c = 1$ unit under pressure of static water pressure, state of not connecting between the liquid chamber and tank disconnected; (2) load 2, the whole tank shell (including tank shell, the top pressure shell, tank roof and side bulkhead) and pressure shell of tank area calculation under pressure $P_c = 1$ unit of hydrostatic pressure, state of connecting between the liquid chamber and foreign tank.

**Stress Analysis of the Outer Pressure Tank**

The paper[6] analyzes the stress distribution with the longitudinal strengthened outer pressure tank model of the same volume under the same load.(Figure 3)

There into,

$$R_{01} = \sqrt{R_1^2 - \frac{\theta}{360} (R_1^2 - R_2^2)}$$

(1)

$$R_{02} = R_{01} + (R_1 - R_2)$$

(2)

Based on the reference [7] and [8], the stress of pressure tank and shell is calculated with the changing of side span.

(1) The longitudinal stress of floor root in the inner and outer surface of shell ("+" means outer surface, "-" means inner surface).

$$\sigma_i = \left\{ -k_i^* - 1.815 \frac{Q_i}{I} \sqrt{\frac{D_i}{D_i^*}} \frac{\rho_i}{\rho_{max}} F_i(u_i', y_i') \pm \frac{6K_i b_i^*}{R_i t_i} P_R \right\}$$

(3)

There into, (1) $k_i^* = \frac{b_i t_i}{b_i t_i + F_i} \cdot \frac{1}{6} (1-m)(2+m)$; (2) $m = \frac{R_{01}}{R_{02}}$; (3) $D_i = \frac{Et_i}{12(1-\mu^2)}$;

$$D_i^* = \frac{Et_i}{12(1-\mu^2)} + \frac{E}{b_i} \left[ \left( y_i + \frac{t_i}{2} \right) \frac{b_i t_i}{b_i t_i + F_i} \right]$$

(4)

$$(y_i, y_i') = t_2' = t_2 + A_i / b + A_i / (R_{02} - R_{01})$$

(5)

$$u_i = \frac{0.642}{\sqrt{R_{02} t_i}}$$

(6)
In the formula, $W_{max}$ means the maximum modulus of longitudinal section with attachment shell ($b1$ means breadth); $F_1$ means section area of the longitudinal, mm$^2$; $i_1$ means inertia moment of longitudinal, mm$^4$; $t$ means the discounting thickness of the floor plate, mm; $A_r$ means the total section area of longitudinal stiffeners in the floor, mm$^2$; $b$ means the space between radial stiffeners at, mm; $A_s$ means the total section area of floor stiffeners, mm$^2$; $t$ means the thickness of the pressure hull shell.

(2) The circumferential stress of the shell’s longitudinal root in the middle of span between floors.

$$\sigma_2 = -1 + \frac{Q_i}{t} \left( \frac{D_1}{D_i} F_1(v, \gamma_0) \right) - 0.545 \frac{Q_i}{t} \left( \frac{D_1}{D_i} \frac{t}{h} \left( D_i - t \right) R_{11} \right) - \frac{6kR_{11}^2}{R_{11}} P_{R_{11}}$$

(3) The longitudinal stress of the shell’s outer surface at the root of floors.

$$\sigma_1 = -k_0 + 1.815 \frac{Q_i}{t} F_1(v, \gamma_0) \left( \frac{P_{R_{11}}}{t} \right)$$

$$\sigma_0 = \frac{\mu k R_{01}^2}{Et} \left( \frac{k + g_0}{k - g_0} \right) + \frac{\left( 1 - \mu k_1^2 \right) R_{01}^2}{M}$$

(4) The longitudinal stress of the shell’s inner surface in the middle of span between floors.

$$\sigma_3 = -k_0 - 1.815 \frac{Q_i}{t} F_1(v, \gamma_0) \left( \frac{P_{R_{11}}}{t} \right)$$

Results are obtained in Figure 4.

In the calculation of outer pressure tank:

(1) when the radius of liquid tank is unchanged, with the increase of side space the parameters ($k_1$, $\nu$, $k_0$, $\gamma_0$) of the root shell of liquid tank are gradually increased, $D_1$ and $D_i$ remain the same but the parameters ($\gamma_1$, $u^*$, $k$, $L$) diminish. However, because of increase of side distance, the above parameter variables also show a trend of increase. It can be seen from the figure 4 that liquid tank shell stress get little and the diminish trend of shell stress of root of longitudinal is gentler, but the longitudinal stress in middle surface that
shell is located in the root of liquid tank plate floor diminish faster. So, the stress of liquid tank shell get small, when distance of side is added and shell stiffness has no variation.

![Figure 4](image.png)

Figure 4. Stress of outer pressure tank’s shell varies with $l_R$.

(2) In pressure tank, the parameters ($\nu$, $k_0$, $\gamma_0$) at the root shell of plate floor have a trend of increase, but $Q_0$ gets little with side span changing, so, with side span increasing pressure hull shell of the outer pressure tank longitudinal stress at the root outside surface of plate floor and at the across inner surface of adjacent plate floor grows slowly.

It means chang of side span has a smaller effect on pressure hull shell longitudinal stress at the root outside surface of plate floor and at the across inner surface of adjacent plate floor; but adding the distance of side is benefit from decrease of stress at the root of plate floor in the outer pressure tank.

The Inner Pressure Tank’s Calculation and Analysis

When calculating inner pressure tank with longitudinal strengthen by the finite element software, checking and analysising stress value of typical place where location is same to the outside pressure tank under two kinds of load conditions.

The following shows five kinds of the maximum stress and the biggest stress surface situations that relative amounts (lR) of pressure tank typical parts in side space is 26, 30, 33.3, 36, 7, under the action of two kinds of load, as is shown in table 1~3.

### Finite Element Analysis of Liquid Tank Top Pressure Shell Maximum Stress

| Load | $l_R=26$ | $l_R=30$ | $l_R=33.3$ | $l_R=36.7$ | $l_R=40$ |
|------|----------|----------|------------|------------|----------|
| Longitudinal stress | The across end | Middle surface | 1 | -67 | -68 | -69 | -70 | -71 |
| Circumferential stress | The across | Outside surface | 1 | -86 | -86 | -87 | -87 | -88 |
|                       | 2         |           | 2          | -87       | -87       | -88   | -88   | -89   |
According to the analysis it can be seen that when relative amounts of the side span is from the change of 26 to 40, with the increase of side span, longitudinal stress and circumferential stress of the liquid tank top pressure shell all showed a trend of increase; At across of top pressure shell the maximum circumferential stress is closed to the allowable stress values \( \sigma_s = 87 \) unit pressure, the longitudinal and circumferential stress of the tank top pressure shell under two kinds of load is generally same and increment is not big, the variation of longitudinal stress increased by 2.8%, and the circumferential stress increase by just 2.2%.

Therefore, reduce of the side span is helpful to reduce the stress of the top pressure shell.

3.2 Finite element analysis of liquid tank bottom pressure shell maximum stress

| Name of stress | Stress location | Stress surface | Load \( l_R \) =26 | \( l_R \) =30 | \( l_R \) =33.3 | \( l_R \) =36.7 | \( l_R \) =40 |
|---------------|-----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Longitudinal stress | The across | Inner surface | -104 | -107 | -109 | -111 | -112 |
|                 | Outside surface | 2 | -112 | -111 | -108 | -106 | -104 |
| Circumferential stress | The across | Inner surface | -91 | -91 | -91 | -90 | -89 |
|                 | Middle surface | 1 | -82 | -82 | -81 | -80 | -80 |
|                 | Outside surface | 2 | -109 | -108 | -105 | -104 | -101 |
|                 | Middle surface | 1 | -79 | -79 | -77 | -76 | -75 |

Under two kinds of loading, maximum longitudinal stress and circumferential stress at the bottom of the shell under the load 1 is in the inner surface, that is transformed to the outer surface under the load 2, this is mainly caused by different stress patterns, inner surface compression of pressure shell frame around the cross end and the pressure at the bottom of the tank shell surface compressive stress ribsend. It means to consider its maximum stress state, in different working conditions of the tank, it is same as the analysis of the maximum stress on the tank shell of external pressure when considering the dangerous situation [4]

With the increase of side span, the circumferential stress at bottom of the tank pressure shell all showed a trend of decrease. Under the action of load 1, stress caused by the change of the side span curve is flat, under the action of load 2, changes of side span caused the stress value of the gap is bigger, when it is under load 1 condition, circumferential stress caused by the change of side span is not obvious.

![Figure 5. Stress of tank’s bottom area varies with \( l_R \).](image-url)
According to table 2, absolute value curves are drawn in Figure 5. The visible, when the relative amount of side spacing is 33.3; stress values are same under load 1 and load 2. It shows that the value is the optimal fender spacing between the two kinds of load. In the case of load 1, when side spacing increases, circumference stress from 26 to 33 remains unchanged, but the maximum circumferential stress is decreased and the maximum longitudinal stress increases; Under the condition of load 2, when the side spacing increases, the maximum circumferential stress and maximum longitudinal stress decrease.

Variation of the longitudinal stress at the bottom of the pressure hull under two kinds of load is different, but the stress values are linear change with side spacing, indicating that at the bottom of the pressure hull, the moment also will appear in a linear relationship with side spacing change. Under the action of load 1, with the increase of side spacing, longitudinal stress showed an upward trend; under the action of load 2, longitudinal stress showed a downward trend. In the case of load 1, at the bottom of the hull directly affected by load, side spacing is more, the deformation driven of the tank shell is more obvious under the action of load 2, tank shell is affected directly by the load and the deformation driven of plate deformation, then driving the change of bottom pressure hull plate. Therefore, under the action of load 1, the increase of side spacing increases the longitudinal stress. 3.3 Finite element analysis of maximum stress of shell plate in liquid tank

| Name of stress         | Stress location       | Stress surface | Load   | $l_R = 26$ | $l_R = 30$ | $l_R = 33.3$ | $l_R = 36.7$ | $l_R = 40$ |
|-----------------------|-----------------------|----------------|--------|-----------|-----------|-------------|-------------|-----------|
| Longitudinal stress   | The across end        | Inner surface  | 1      | -52       | -50       | -49         | -47         | -46       |
|                       |                       |                | 2      | -91       | -88       | -85         | -81         | -79       |
| Circumferential stress| Root of longitudinal bone | Inner surface  | 1      | -93       | -92       | -90         | -87         | -85       |
|                       |                       | Outside surface| 2      | -109      | -108      | -106        | -104        | -102      |

The longitudinal stress at the end of tank shell under two kinds of load have big difference, with side spacing increasing, the vertical stress show a trend of decrease, but it is not obvious, it suggests that it is not sensitive to changes of side spacing. Under the action of load 1, the stress value of the inner surface of the tank plate is smaller than that of the allowable stress, and is partial to safety.

At the root shell plate, the maximum circumferential stress is transferred from the inner surface of the load 1 to the outer surface of the 2 state, which is different from that of the external pressure tank.

The circumferential stress [7] of the inner surface at the longitudinal root shell of the external pressure tank:

$$|\sigma_2| \leq 1.15\sigma_s = 101$$

From the table we can see that circumferential stress value in the outer surface at the root of longitudinal bone of pressure liquid tank exceeds the allowable stress range. Therefore, when analyzing the stress at the root shell of longitudinal bone of inner pressure liquid cabin shell to pay special attention to the circumferential stress in the outer surface.
From the analysis of Table 3, it can be known that the two kinds of load:

1) Under the action of load 1, large stress position is in the longitudinal stress on the outer surface of the across end of liquid tank bottom hull, the circumferential stress of the top and bottom of the hull surface; Under the action of load 2, the liquid tank bottom shell also appears a larger longitudinal stress with a larger circumferential stress, while at the same time, larger circumferential stress also appears in the longitudinal root surface of tank shell, it shows that under the two kinds of load tank bottom pressure hull generates larger stress. We should pay special attention to the design and production.

1) Therefore, it is known that the connection of the component and the thickness of the shell plate appear the maximum stress value, which is mainly caused by the difference of the thickness of the shell plate.

2) With the change of side spacing, the variation law of maximal stress is inequality under two kinds of load.

3) At the top and the cross end of the tank, the surface of maximum longitudinal stress has not changed, which is still maintained at the cross end on the top of the tank and the inner surface of the tank plate.

Concluding Remarks

In this paper, the finite element method is used to build model of the inner pressure tank, in the case of two kinds of load and different side spacing, calculating the maximum stress distribution and stability of the inner pressure tank. The analyses indicate that there are some conditions about the inner pressure tank’s changing with side space.

The side space is advantageous to reduce the stress at top of the hull under two types of loads.

With increasing of the side space, the longitudinal stress at bottom of hull pressure shell increases under load 1 and decreases under load 2. The two stress curves are intersected when the side space is 33.3, which indicates that it’s good for the longitudinal stress.

The circumferential stress and longitudinal stress at the shell of two types have the similar changing law with the outer pressure tank.

1) As for the shell, the longitudinal stress at the shell of the outer pressure tank increases with the increasing of side space. But the amplitude is not big.

2) The stress at top of the shell in the inner pressure tank has the same changing law with the outer. However, the circumferential stress and longitudinal stress decrease with the increasing of side space, which is different from that of the outer.

3) The longitudinal stress at shell of the inner pressure tank decreases with the increasing of the side space, which is the same with the outer.

The analysis shows that the mechanical properties of the inner pressure tank are similar to the outer. The calculation formula of the outer pressure tank can be adjusted to the inner pressure tank after being modified. The formula can be deduced in the following studying.

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