

Chapter 85

Perlite Pressure Calculation and Finite Element Simulation Study of LNG Storage Tank



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Abstract Because perlite has good cold insulation effect and is widely used in LNG full capacity tanks, in this paper, the final perlite lateral pressure can be obtained by repeated iterative calculation using Janssen formula, and the perlite lateral pressure is applied to the inner tank of LNG full capacity tanks for statics finite element simulation. The results show that the deformation of the inner tank is within a reasonable range. At the same time, the perlite lateral pressure buckling analysis is carried out for the inner tank of the LNG tank under the empty tank state. The results show that the tank does not buckle under the empty tank state, and the critical buckling pressure of the inner tank is 3.14 times of the applied pressure, which verifies the rationality of the tank design.

Keywords Perlite · Pressure calculation · LNG storage tank inner tank · Buckling analysis · Finite element simulation

85.1 Introduction

As a clean energy, natural gas plays a more important role in modern industry. LNG is easy to store within a relative small volume, so it has obvious advantages in storage and transportation. At present, the full-capacity storage tank has become the mainstream storage tank for liquefied natural gas due to its safety and reliability. Therefore, its importance is self-evident [1–7]. At present, researchers have conducted a lot of research on the structure of the full-capacity storage tank [8, 9]. Large-scale LNG full-capacity storage tanks have high requirements for cold insulation. Perlite is usually used for cold insulation between the inner and outer tanks. Some researchers have conducted related research on the cold insulation performance and pressure calculation of perlite [10–12].

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The initial filling of perlite in the full-capacity storage tank has a compressive effect on the elastic felt in the storage tank. This initial pressure can be calculated using the Janssen formula for calculating granular materials [13–15]. The initial pressure causes the elastic felt to shrink, which can be obtained from the compression curve of the elastic felt. The amount of compression causes changes in the thickness of the annular perlite, so the lateral pressure can be recalculated according to the Jensen formula, and this iterative process is repeated until the calculation results converge to obtain the final lateral pressure of the perlite.

85.2 Relevant Dimensions and Material Parameters

Diameter of inner tank in cold state ($-165\text{ }^{\circ}\text{C}$) (Table 85.1):

$$D' = D - D \times \alpha \times \Delta T \quad (85.1)$$

When the inner tank is cold, the radius shrinks:

$$d = (D_i - D')/2 \quad (85.2)$$

According to the Quietflex material data, the temperature change of the inner tank causes the compression of the elastic felt to be 0.235 mm/mm, and the compression of the elastic felt to be df , which can refer to the chart provided by the supplier, as shown in Fig. 85.1.

Table 85.1 Relevant dimensions and material parameters

Inner tank diamete	D_i
Inner diameter of outer tank	D_o
Extreme maximum temperature X7Ni9 steel linear expansion coefficient	$\alpha = 9.2 \times 10^{-6}$
Elastic felt compression caused by temperature changes in the inner tank	0.235 mm/mm
Density of perlite	$\rho = 66\text{ kg/m}^3$
Friction coefficient of perlite	$\mu = 0.70$
Gravitational acceleration	$g = 9.81\text{ m/s}^2$
Shrinkage of elastic felt	df
Elastic felt thickness	tab

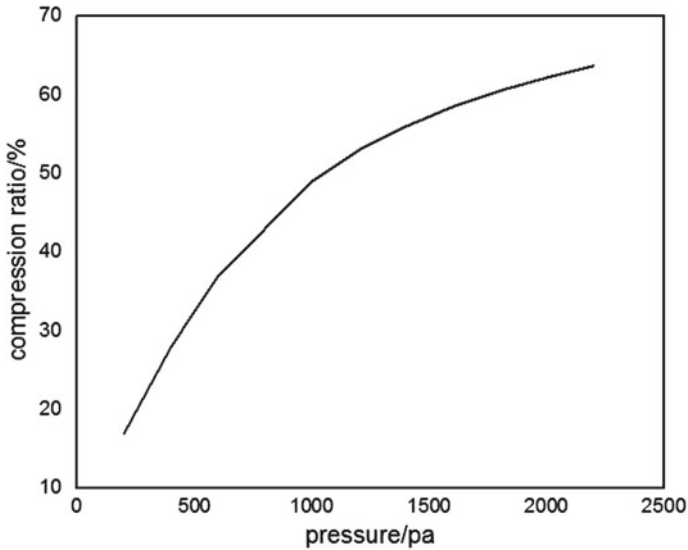


Fig. 85.1 Typical elastic felt curve

85.3 Calculation Method

85.3.1 Calculation Method

The initial pressure is calculated using the Janssen formula for calculating granular materials. The initial pressure causes shrinkage of the elastic felt, which can be obtained from the compression curve of the elastic felt. The amount of compression causes the thickness change of annular perlite, so the lateral pressure can be recalculated according to Janssen formula. Repeat this iterative process until the results converge. The calculation steps are as follows:

- (1) Determine the inner diameter of outer tank (i.e. outer diameter of perlite) and inner tank, as well as the initial thickness of elastic felt, so as to determine the initial inner diameter of perlite (i.e. outer diameter of elastic felt);
- (2) The pressure of perlite is obtained from the outer diameter and inner diameter of perlite according to Janssen formula. This pressure acts on the elastic felt, and the compression rate of elastic felt is obtained from the pressure according to the following figure;
- (3) From the compression rate, we can get the new thickness of elastic felt and the new inner diameter of perlite, calculate the Janssen pressure again, get the new pressure of perlite, and check the compression rate of elastic felt again;
- (4) In this way, until the compression rate of the elastic felt is constant, this compression rate is the final compression rate under the pressure of perlite.

Iterative calculation:

Inner tank radius $R_i = D_i/2$

Outer diameter of perlite $R_o = D_o/2$

Initial value of inner diameter of perlite $R_{pi}(0) = R_i + \text{tab}$.

Janssen formula calculates pressure:

$$p = \frac{(D_o - D_i)\rho g}{4\mu} \left[1 - \exp\left(\frac{-4\mu kh}{D_o - D_i}\right) \right] \quad (85.3)$$

P —pressure of perlite (kPa);

K —lateral pressure coefficient, $k = (1 - \sin \theta)/(1 + \sin \theta)$, θ is the internal friction angle of perlite, generally 30° ;

H —Inner tank height (m).

The Janssen formula is simplified as:

$$P = \rho * g * (R_o - R_{pi})/2\mu \quad (85.4)$$

Iteration formula of original perlite inner diameter:

$$R_{pi(n)=R_{pi}(n-1) - d - \text{tab} * d_f \quad (85.5)$$

When using the original iterative formula for calculation, misunderstandings can easily occur, and it is easy to include d_f as the total compression amount in the calculation, resulting in non convergence of the calculation results.

Improved iteration formula of perlite inner diameter:

$$R_{pi}(n) = R_{pi}(n-1) - d - \text{tab} * df(n=1) \quad (85.6)$$

$$R_{pi}(n) = R_{pi}(n-1) - \text{tab} * \Delta df (n > 1) \quad (85.7)$$

In which, Δdf represents the increase in compression amount.

85.3.2 Trial-Calculation Case

In which, Δdf represents the increase in compression amount.

According to the results of the calculation example, the improved formula is similar to the previous results, and the calculation results converge. Some deviations are due to the former not considering the radius contraction of the inner tank when it is cold.

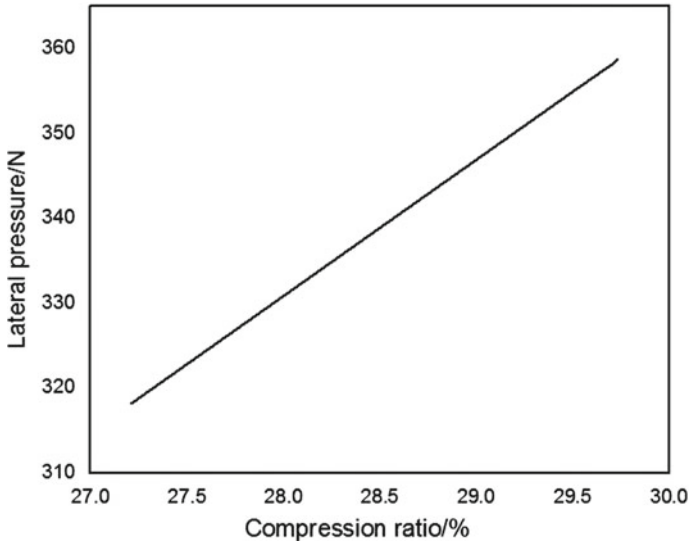


Fig. 85.2 Iterative calculation process of a domestic project

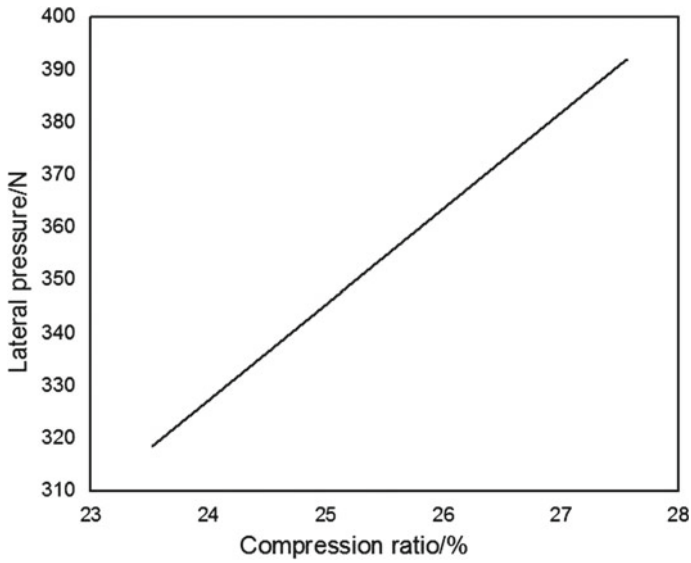


Fig. 85.3 Improved iterative calculation process

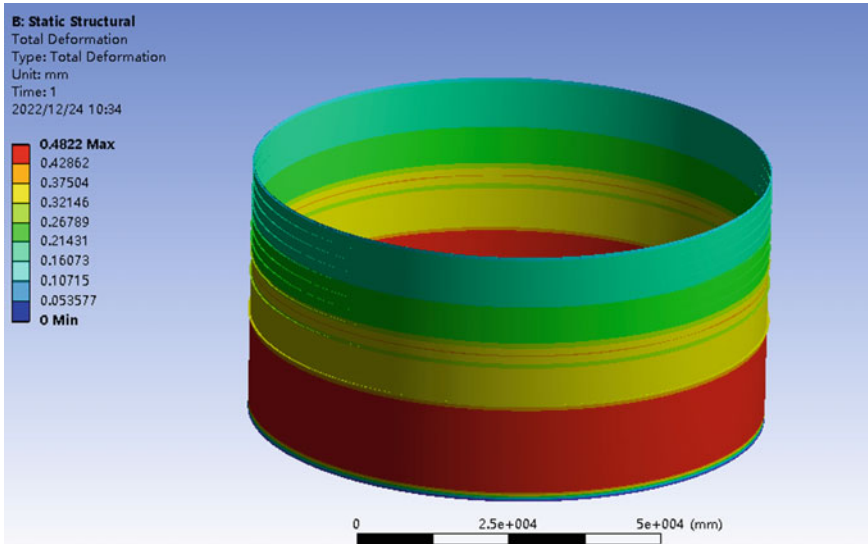


Fig. 85.4 Statics analysis results

85.4 Finite Element Analysis

85.4.1 Statics Analysis

According to the iterative calculation, the final side pressure of perlite is obtained. In order to analyze the deformation of the inner tank of LNG tank under this side pressure, an equal proportion model of the inner tank of LNG tank is established. The deformation of the inner tank under the action of perlite side pressure is shown in Fig. 85.4. According to the deformation results, the deformation of the inner tank under this maximum side pressure is within a reasonable range, so the tank design is reasonable.

85.4.2 Buckling Analysis

Due to the thin-walled cylindrical structure of the inner tank, this type of structure is prone to buckling in engineering. To verify whether the inner tank of LNG storage tanks will buckle, buckling verification analysis should be conducted. The inner tank is only subject to perlite pressure in the empty tank state. During the buckling analysis, perlite pressure is applied to the outside of the tank for buckling analysis. The results are shown in Fig. 85.5. According to the buckling analysis, under this scheme, the critical buckling pressure of the inner tank is 3.14 times of the applied

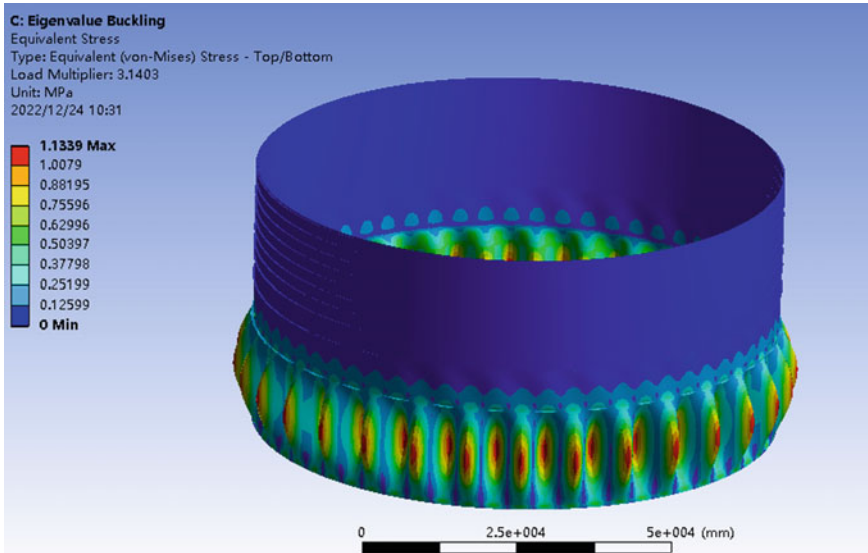


Fig. 85.5 Buckling analysis results of inner tank

pressure, which is greater than the safety factor 3. Therefore, the inner tank will not buckle under this working condition, meeting the design requirements.

85.5 Conclusion

- (1) By using the improved Janssen formula through iterative calculation, convergence and correct results can be obtained;
- (2) Through finite element analysis, it is verified that the deformation of the inner tank under the pressure of perlite is within a reasonable range and will not buckle when the tank is empty.

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