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Experimental study on wall pressure of grain silo with large diameter

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Abstract. Through the field test of a warehouse in the national grain reserves in three big diameter squat silo, the author obtained by numerical lateral pressure value of silo wall under grain weight, and the results are compared with theoretical analysis of several commonly used method to calculate and draw some conclusions, provide a reference for the design of the light silo.

Key words. shallow silo, side pressure, bin test.

1. Introduction

Shallow silo is a kind of new type in recent years by China's grain warehouse construction, the diameter of each warehouse is at 23-30 meters , grain height is 12-25meters, storage capacity is more than 10000 tons, which is more suitable for Chinese situation with large capacity, small occupied area, tons of grain, low cost, is the development direction of China's granary construction.

The shallow silo with large diameter, large capacity, so the stress state of the shallow silo under grain weight are different from the warehouse and traditional silos, so the design and construction of it is also different from the warehouse and silos. There is no one country making specification for design and construction of the shallow silo in the world, so that designers lack reliable basis in the design of this type of storage, only dealing with these problems according to their own understanding.

At home and abroad, people usually use the following four methods to calculate the silo wall pressure: Janssen formula, Rankine formula, Column formula and Reimbert formula. The Janssen formula is based on the analysis of establishment of differential equation of the static balance in any tiny thin material silo in the vertical direction, and then the integral equation in the whole cabin and the practice proves that it is suitable for calculation of deep silo wall pressure; Rankine formula and Column formula is deduced according to the theory of limit equilibrium of the retaining wall; Reimbert formula and Column formula theory is similar, only using

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internal friction angle and instead of outer friction angle between the silo wall and the angle of the approximate grain. Because the research at home and abroad for the shallow silo is little, silo design according to the above four kinds of methods of safety and rationality has no theoretical basis and the corresponding test data to prove it. For this purpose, we research of warehouse warehouse load in-depth through the trials of this new type and compare the results with calculated with the above four methods, and think that the Column formula is suitable for calculating shallow silo wall pressure.

2. Several commonly used formulas for calculating side wall pressure

There are four methods for calculating the side wall pressure of a shallow silo.

(1)Janssen formula

The formula for calculating the lateral pressure of the Janssen formula is as follows:

$$p_h = \frac{\gamma R}{\mu' k}\left[1 - e^{-\mu' {}^{kY}/R}\right] \tag{1}$$

p_h is lateral pressure of bulk to silo wall; $\gamma$is the gravitational density of particles; $k$is ratio of lateral pressure to vertical pressure; μ' is the friction coefficient between the bulk and the silo wall; Y is depth height of bulk; R is hydraulic radius of silo;$R = F/U$, $F$is Cross-sectional area of silo;$R$is the cross section of the perimeter of the silo.

The Janssen formula is mainly used to calculate wall pressure of deep silo. According to statistics, standard silo in all 14 countries is on the basis of the Janssen formula. Some scholars believe that the shallow silo is a special case of deep silo, whose is similar with top force status of deep silo. So the pressure of the materials should be calculated through deep bin formula.

(2)Rankine formula

The active earth pressure formula of Rankine is also widely used to calculate the wall pressure of a shallow silo:

$$p_h = k_a \gamma Y \tag{2}$$

γ, Y are the severe and buried depth of bulk;$k_a$is the active pressure coefficient of Rankine bulk,$k_a = \tan^2(45^\circ - \varphi/2)$.

(3)Column formula

Column theory is based on the retaining wall after sliding wedge. Limit equilibrium is derived, the formula is:

$$p_h = k_a \gamma Y \tag{3}$$

k_a is the active pressure coefficient of Rankine bulk

$$k_a = \frac{\cos^2(\varphi - \rho)}{\cos^2\rho\cos(\varsigma + \rho)\left[\sqrt{\frac{\sin(\varsigma+\varphi)\sin(\varphi-\beta)}{\cos(\varsigma+\rho)\cos(\rho-\beta)}}\right]^2}$$

The parameters are as shown in Figure 1.

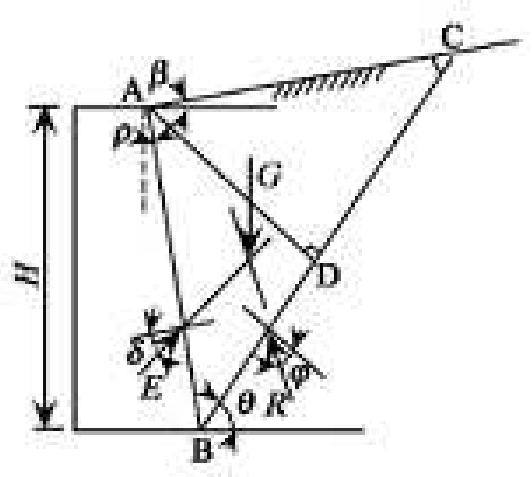

Fig. 1. Calculation of active earth pressure of Coulomb

(4)Reimbert formula

accordance to the method of derivation of the Column theory, Reimbert structures balance equation considering the wall sliding grain, but as to friction, the friction between the wall and the angle of grain approximation is replaced by grain internal friction angle. the following formula is obtained:

$$P_a = p^{'}\cos\varphi = \frac{\gamma H^2}{2}\left[\frac{\tan\beta}{\tan\varphi + \tan(\beta+\varphi)}\right] = \frac{\gamma H^2}{2}\cdot K \tag{4}$$

Then according to the test results of their real positions, k is reduced to:

$K = \tan^4(\pi/4 - \varphi/3)$, Therefore, the lateral pressure at the top of the grain body is horizontal:

$$p_h = \gamma Y \tan^4(\pi/4 - \varphi/3) \tag{5}$$

$$p_h = (1 + 2\alpha/\pi)\,\gamma Y \tan^4(\pi/4 - \varphi/3) \tag{6}$$

φ, β are the angle of internal friction and the angle between the rupture surface and the wall of the silo.Reimbert angle and fracture surface and silo wall because of its approximate grain in theory when the internal friction angle instead of external friction between the wall and the grain body angle, which lead to lateral pressure calculation small, but the error through the test results that warehouse the adjustment of the parameters in the formula has been made up. However since then test

whether the diameter or height calculation are not compared to tall silo, therefore its use remains to be verified.

3. Chamber test

At present, many scholars at home and abroad do test study on the mechanical characteristics of the silo, either a warehouse test or a model test. The model test is convenient to be conducted, according to a certain proportion of the real income reduced another prototype which has the basic characteristics of the real object. However, it is well known that the size of the silo can be reduced, granular materials arranged in the internal granule is very small, which is not reduced by the same proportion, it is inevitable that the bulk material is in the same scale, so the majority of granular materials comes into powder material, and the characteristics of powder and granular material also have great difference. Therefore, model test prone cylinder and the loaded materials are not reduced according to the same scale, that so-called size effect, obviously, this is a fatal defect of model test, the results will lead to be unreliable, many foreign research proves it. The real warehouse test needs great manpower, material and financial resources, but the result is direct and reliable. Therefore, we use the warehouse experiment.

(1)Test

Experiments were carried out in a grain depot in Jiangsu province. The library includes 10 reinforced concrete silo, silo grain diameter is 30m, height is 15m, height from the bottom to the top of is trestle bridge of the top of the Bin is 25.5m, underground passage in the depth is 3.5m, the single warehouse capacity is up to 9 000t.

(2)Test instruments

Steel string type pressure sensor readings of TYJ20 is choosed in the civil engineering instrument factory production in Jintan city of Jiangsu Province. All instruments were calibrated before test, considering the temperature compensation.

(3)Test plan

According to the test content, and understanding of the grain order, using three seat cabin of 8 shallow silo in the chamber. In order to enable comparability between each measurement, the three seat cabin layout is employed with different schemes, including the warehouse wall arranged two rows of each row of pressure gauge 9, angle of 30 degrees, two rows layout mainly in order to reduce the error due to construction and other causes of wall stiffness throughout the inconsistent test results; the other two seat cabin was furnished with a row of 9 shallow silo. The pressure gauge spacing is shown in figure 2.

(4)Test results

Measurement results of three positions is compared to the results of conventional methods, which is shown as Figure 3, figure 4 and Figure 5. Y-axis is height of H for each measuring point to grain top intersected with the silo wall, X-axis shows lateral pressure of each point value by pH. It can be known from different grain height measured results and formula comparisons: 1) lateral pressure by Janssen formula and Rankine formula of shallow silo wall is too conservative, the calculated

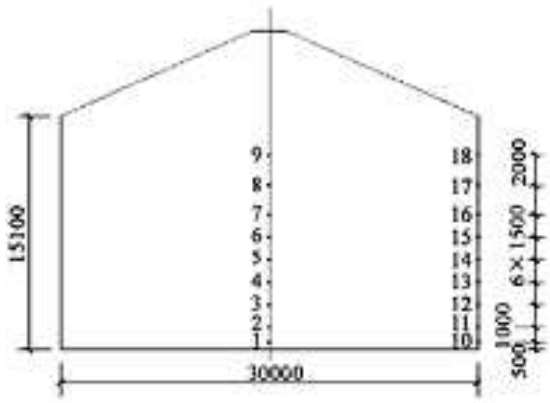

Fig. 2. pressure sensor layout (mm)

values exceed the measured value of more than 30%; 2) the actual results is close to calculated by Reimbert formula and Column formula, mostly less than 10%. But the result of the Re-imbert formulais less than measured results, it is dangerous; and the values of column are larger than the actual results, which is more secure.

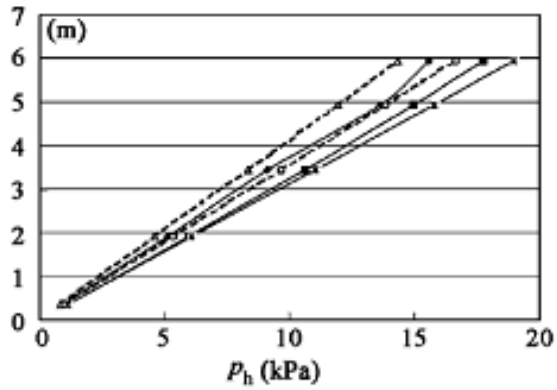

Fig. 3. grain loading height is 6.35 meters

4. Conclusion

Using the Column formula in the grain silo lateral pressure is reasonable, other methods are not reasonable.Janssen formula simplycompares shallow silo to upper of deep silo is not exact, because of their high aspect ratio, structural stiffness, constraint conditions are not similar. But Rankine does not take friction formula into account, and it does not the applicable conditions of the Rankine formula, resulting in large deviation results; Due to extensive application conditions of the

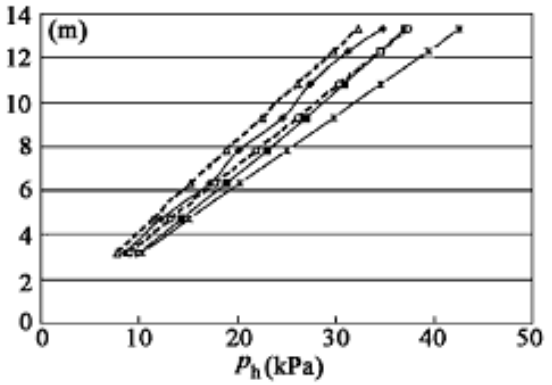

Fig. 4. grain loading height is 13.71 meters

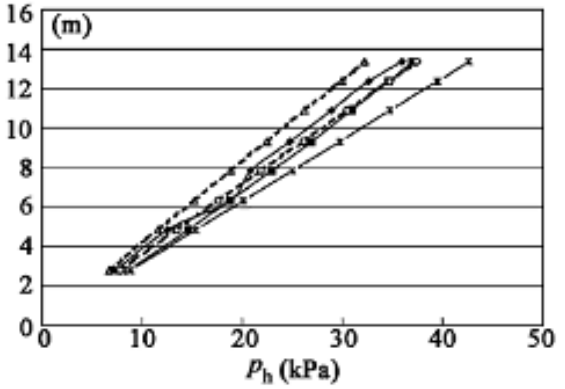

Fig. 5. grain loading height is 13.77 meters

Column formula, and verified by the test results, using it to calculate the large diameter of silo wall pressure is more reasonable, so it is suggested that the formula used in the design of large diameter silo.

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