Experimental research on friction coefficient between grain bulk and bamboo clappers

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Abstract. A silo is an important piece of storage equipment, especially in the grain industry. The internal friction angle and the friction coefficient between the grain and the silo wall are the main parameters needed for calculating the lateral pressure of the silo wall. Bamboo is used in silo walls, but there are no provisions about the friction coefficient between bulk grain and bamboo clappers in existing codes. In this paper, the material of the silo wall is bamboo. The internal friction of five types of grain and the friction coefficient between the grain and the bamboo clappers were measured with an equal-strain direct shear apparatus. By comparing the experimental result values with the code values, the friction coefficient between the grain bulk and bamboo clappers is lower than that between grain and steel wall and that between grain and concrete wall. The differences in value are 0.21 and 0.09, respectively.

1. Introduction
Silos are vital when they come to grain storage. The lateral pressure of the silo wall and the friction are the main factors in silo design [1-3]. Grain’s internal friction angle and the friction coefficient between the grain and the silo wall are the parameters needed for calculating lateral pressure. The physical characteristics of the five types of bulk grain used in this experiment are shown in Table 1. Their information is given according to Code for design of grain steel silos [4].

| bulk    | gravity density $\gamma$ [kN/m$^3$] | internal friction angle $\varphi$ [°] | friction coefficient concrete wall | friction coefficient steel wall |
|---------|--------------------------------------|---------------------------------------|-----------------------------------|---------------------------------|
| paddy   | 6.0                                  | 35                                    | 0.50                              | 0.35                            |
| rice    | 8.5                                  | 30                                    | 0.42                              | 0.30                            |
| corn    | 7.8                                  | 28                                    | 0.42                              | 0.32                            |
| wheat   | 8.0                                  | 25                                    | 0.40                              | 0.30                            |
| soybeans| 7.5                                  | 25                                    | 0.40                              | 0.30                            |

There are two types of silos for grain storage: the reinforced concrete silos and the steel silos. The steel silos have been more widely applied due to their advantages such as light weight, low cost, short
construction period, waterproof property, and outstanding permeability. But, according to the domestic status quo and the development trend, silos now have improved insulation performance, reinforced energy saving, and reduced emissions. Bamboo is a kind of fast-growing and high-yield plants, renewable in a short time frame, and possesses substantial mechanical properties with high strength and stiffness [5]. Reinforced concrete silos and steel silos are insufficient in these three areas, so bamboo has been gradually introduced as a structure material. The previous research about a truncated cone-shaped steel-cable-bamboo grain silo has been patented [6]. However, there is no prior research regarding the friction coefficient between the bulk grain and the bamboo clappers in existing codes, according to Table 1.

In this paper, the silo wall is made of bamboo. The main research aims are as follows:

(1) Grain’s internal friction angle was measured by experiments and compared with the code value.
(2) On the basis of a feasible experimental method, through experiments regarding the friction coefficient between grain bulk and bamboo clappers, the recommended friction coefficients were concluded.

2. Experimental principle
The laboratory direct shear test, based on the More-Coulomb strength theory, is the most common method to ensure the grain’s internal friction angle. The theory of the common direct shear test is shown in Fig.1. Firstly, the samples were placed in the top and the bottom shear boxes and load vertical stress on top of the sample. Then, the horizontal stress was loaded on the bottom shear box; the shearing process last until the destruction of the samples Finally, according to the experimental data of different vertical stress to calculate the shearing strength of the sample and drawing the relationship curve of \( \tau - \sigma \) as shown in Fig.2, and the equation \( \tau = C_0 + \sigma \tan \phi \), according to linear regression is created. [ \( \phi \) —— internal friction angle of sample (inclination of the curve); \( c_0 \) —— cohesion of sample (intercept in the direction of \( \tau \) of the curve)].

![Figure 1. Theory of common direct shear test](image1)

![Figure 2. Relationship curve of \( \tau - \sigma \)](image2)

The experimental principle for measuring the friction coefficient between the grain bulk and the bamboo clappers is quite similar to the way in which the internal friction angle is measured. The only distinction is that the sample in the bottom shear box is replaced with bamboo clappers. Repeating the above steps, the external friction angle \( \phi_0 \) is obtained and \( \tan \phi_0 \) is the friction coefficient between the grain bulk and the bamboo clappers.

3. Experimental methods
The equal-strain direct shear apparatus used in this experiment is produced by Nanjing NingXi soil instrument Co., LTD, as shown in Fig. 3. It controls shear velocity automatically.

The materials of the samples according to code are: paddy, rice, corn, wheat, and soybeans, and the material of silo wall is bamboo. Measuring gravity density and particle diameter of five grains before the experiment is necessary, for improving the reliability of the experimental results. For friction angle
and friction coefficient experiments, the authors divided each type of grain into three groups, and each group had four samples. The four samples in each group were placed under different vertical pressures and then loaded the horizontal thrust on the bottom box. The authors then measured the shear stresses at the time of the samples’ destruction. The experimental results are an arithmetic mean of the 3 groups. For each test, the quality of the samples in the shear box is equal for each group. We put grain into the shear box in 2 or 3 times, ensuring the same times of vibration when put the grain every time from the same height.

Figure 3. Equal-strain direct shear apparatus

According to the statistics of the equal-strain direct shear apparatus and the characteristics of the grain as well as the basis of the code, the vertical stress rates were set to 50KPa, 100KPa, 200KPa and 300KPa. The authors used the existing 0.765 kg and 1.53 kg weights to achieve vertical stress.

Grain is a non-viscous body, so when we consider the characteristics of the grain itself, as well as the shear velocity of similar materials, the shear velocity for the internal friction angel experiment and for the friction coefficient experiment is 12r/min and that is 4r/min respectively.

4. Results and discussion

4.1. Samples determination

The grains’ origin, gravity density, and particle diameter are shown in Table 2.

| Table 2. Grain’s original country, gravity density and particle diameter |
|--------------------------------|----------|----------|----------|----------|----------|
| bulk origin                   | paddy    | rice     | corn     | wheat    | soybeans |
| HuNan                         | 6.0      | 8.5      | 7.8      | 8.0      | 7.5      |
| JiangSu                       | 5.3      | 8.7      | 7.4      | 7.6      | 7.0      |
| Shandong                      | 9.72     | 4.90     | 12.98    | 6.26     | 7.26     |
| Shandong                      | 2.41     | 2.98     | 8.66     | 3.52     | 6.95     |
| Shandong                      | 1.99     | 2.16     | 4.46     | 3.13     | 6.23     |

4.2. Calculate shear stress $\tau$

\[
\tau = k_iR
\]
\[ k_1 \quad \text{— test-force-ring correction coefficient, } k_1 = 1.88 \text{ KPa} / 0.01 \text{ mm}, \] 
\[ R \quad \text{— dial indicator degree, 0.01 mm}. \]

4.3. Calculate internal friction angle \( \phi \) and friction coefficient \( \tan \phi \)

The shear stress under four different vertical stresses \( \sigma (50\text{ KPa}, 100\text{ KPa}, 200\text{ KPa}, 300\text{ KPa}) \) of each group is \( \tau = C_0 + \sigma \tan \phi \). The internal friction angle \( \phi \) and the friction coefficient \( \tan \phi \) can be obtained by \( \sigma \) and \( \tau \), according to least square method.

\[ \tan \phi = \left( n \sum \sigma \tau - \sum \sigma \sum \tau \right) / \left[ n \sum \sigma^2 - \left( \sum \sigma \right)^2 \right] \]

\( n \) — the number of measured value in each group

4.4. Result of experiment data

According to the calculations and the arrangement of experimental data, the internal friction angles and friction coefficients between the different kinds of grain and the bamboo clappers are shown in Tables 3 and 4.

**Table 3. Internal friction angle of grain bulk**

| bulk  | group 1  | group 2  | group 3  | average/° | Standard deviations | code value/° |
|-------|----------|----------|----------|-----------|---------------------|-------------|
| paddy | 30.54    | 29.68    | 30.67    | 30.30     | 0.44                | 35          |
| rice  | 30.64    | 28.91    | 31.09    | 30.21     | 0.94                | 30          |
| corn  | 26.05    | 26.26    | 27.21    | 26.51     | 0.50                | 28          |
| wheat | 17.00    | 17.76    | 18.07    | 17.61     | 0.45                | 25          |
| soybeans | 28.89   | 27.27    | 27.49    | 27.88     | 0.72                | 25          |

**Table 4. Friction coefficient between grain bulk and bamboo clappers**

| bulk  | group 1  | group 2  | group 3  | average  | Standard deviations | Recommended value |
|-------|----------|----------|----------|----------|---------------------|-------------------|
| paddy | 0.28     | 0.29     | 0.29     | 0.29     | 0.006               | 0.25              |
| rice  | 0.18     | 0.19     | 0.17     | 0.18     | 0.008               | 0.20              |
| corn  | 0.24     | 0.22     | 0.19     | 0.22     | 0.021               | 0.22              |
| wheat | 0.22     | 0.22     | 0.23     | 0.22     | 0.006               | 0.20              |
| soybeans | 0.21   | 0.21     | 0.19     | 0.20     | 0.010               | 0.20              |

Table 3 and Table 4 show that:

(1) The internal friction angle and the friction coefficient measured in the experiment are consistent in all three groups. In the experiment regarding internal friction angle and friction coefficient, the standard deviations of paddy, rice, corn, wheat, and soybeans are low, indicating that the experiment method is reliable.

(2) Fig.4 indicates the differences between the experimental data and the code values about internal friction angle. The experiment data of paddy, corn, and wheat are lower than the code value. The experiment data of rice and soybeans are higher than the code value. These differences may be caused by the idea that the grains’ basic characteristics and experimental environment are different from the demand of code.

(3) The friction coefficient between the grain bulk and the bamboo clapper is smaller than that between the grain and the steel wall, and that between grain and concrete wall. These difference values
are 0.21 and 0.09 respectively. Considering the experimental material and the experimental environment, the friction coefficients shown in Table 4 are recommended.

![Graph showing internal friction angle comparison](image)

**Figure 4.** The differences between experimental data and code values about internal friction angle

5. Conclusion

The experimental investigation focused on the friction coefficient between grain bulk and bamboo clappers. Based on this research, the following conclusions could be drawn:

1. Comparing the experimental data with the code value, the result shows that the internal friction angle and the friction coefficient measured in the study are consistent within the three groups. Therefore, the experiment was reliable.

2. Due to the differences between grains’ basic characteristics and experimental environment, experimental data and the code values about internal friction angle are different.

3. The friction coefficient between the grain bulk and the bamboo clappers is lower than that between the grain and steel wall and that between the grain and concrete wall.

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References

[1] R. O. Uñac, A. M. Vidales, O. A. Benegas and I. Ippolito, Experimental study of discharge rate fluctuations in a silo with different hopper geometries, Powder Technology, 225 (2012) 214-220.

[2] J. F. Chen, J. M. Rotter and J. Y. Ooi, Correlation between the flow pattern and wall pressures in a full scale experimental silo, Engineering Structures, 29 (9) (2007) 2308-2320.

[3] Z. Zhong, J. Y. Ooi and J. M. Rotter, the sensitivity of silo flow and wall stresses to filling method, Engineering Structures, 23 (7) (2001) 756-767.

[4] Code for design of grain steel silos, Beijing, GB 50322-2011.

[5] J. Liu, J. L. Zhang, J. Guo, Y.S.Li, The Development Status of the Modern Bamboo Structure Buildings, Forest Engineering, 29 (5) (2013). (In Chinese).

[6] L.F. Yin, G. Tang, A Truncated Cone-shaped Steel-cable-bamboo Grain Silo, People’s Republic of China Ministry of Construction: ZL201310160057.3 (in Chinese).