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# Experimental and numerical investigation of the effect of temperature patterns on behavior of large scale silo

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ABSTRACT

With the requirement of environmental protection, reinforced concrete silos with large diameter for coal storage were built. In view of less literatures on the effect of temperature patterns, this paper presents the experimental study and 3D FEM simulation of a reinforced concrete silo with 136.5 m in diameter and 19.35 m in height. The stresses of circumferential and vertical steel bars were measured by the vibrating string strain gauges installed under different circumstances of temperature patterns due to sunshine and season changing. The data were collected and transmitted with GPRS transmission system for a period of more than 1000 days. Meanwhile, finite element model was built by ABAQUS software, in which the Drucker-Prager elasto-plastic criterion and the elasto-plastic damage model were used to modify the nonlinearity of soil and reinforced concrete. The test data agree well with the numerical simulation results. The effect of temperature patterns on silo wall was scrutinized. The results of this paper provide a crucial basis for the design of large scale silos.

## 1. Introduction

Silo failures are relatively common in many countries, which cause a significant economic loss. Maj [1] indicated that the appearance of horizontal and vertical cracks due to temperature, pressure of stored material, live loads etc. reduces the carrying capacity of the silo walls to be lower reliability. Ooi et al. [2] studied the pressures on the walls of a prototype reinforced concrete silo subject to both concentric and eccentric flow, the silo built in Sweden is 7 m in diameter and 46 m in height, the systematic and random components of pressure were extracted by experiments. They also presented the finite element studies on the wall pressures of a circular silo affected by a local axisymmetric wall imperfection [3,4], and the flow pattern and wall stresses affected by filling process [5].

The effect of temperature variation of stored material on silos has also attracted the attention of some scholars. Jia et al. [6] presented a 2D FEM non-linear heat transfer model to describe the transient temperature distribution in a cylindrical grain bin. Carson et al. [7] indicated that unusual loading conditions existed as a result of temperature fluctuations or moisture effects, which led to much higher hoop stresses than expected. Most of the expansion took place in horizontal direction, resulted in the greatly increased lateral pressures on silo wall. Moran [8] studied the effect of thermal variations on plastic and elasto-plastic behaviors of silo by using FEM. Jian et al. [9] monitored the temperatures and moisture contents of 20 t wheat filled in a metal silo from Aug. 2003

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to Oct. 2004 in Western Canada. Larsson et al. [10] monitored temperatures by using temperature sensors spatially spread in six large scale silos built in Canada for wood pellet storage over 7 months, the flat bottom bins were 21.9 m in diameter and 23.2 m in height. Ren et al. [11] established a 3D numerical model to study the temperature variation on outdoor squat silo and large size horizontal warehouse in quasi-steady-state. However, most of the researches are focused on the temperature variation of stored material on silos with relative small diameters within 20 m [12].

Based on theoretical and empirical methods, different standards and rules existed for silo design [13]. In order to compute the overpressure factor and compare the results of pressure estimations by different standards, Martinez [14] presented a new contribution to the dynamic continuum simulation on the discharge of cylindrical silos by using FEM.

In the past two decades, FEM has been widely used to simulate silos structure. Karlsson et al. [15] simulated granular material flow in plane silos, the FEM numerical examples of transient stress fields had good agreement with analytical solutions and experiments. Briassoulis [16] studied the behavior and the state of stress developing in a silo shell under real asymmetric pressure concerning both storing and discharge, and suggested that the design of silos may not neglect the asymmetric features of the real pressures of stored material. Sanad et al. [17] studied granular flow and pressures in a flat-bottomed silo, in which finite element and discrete element models were used collaboratively. Guaita et al. [18] applied an elasto-plastic constitutive law to cylindrical silos with eccentric hoppers and rigid walls by using the Drucker-Prager criterion. Dooms [19] explained the differences between results obtained with a model that exploits symmetry and a 3D model. Goodey [20,21] outlined the development and verification of a finite element model for the filling pressure distribution in a square platform silo with flexible walls, and found that rectangular silo differs from square silo due to the different mean pressure and degree of pressure variation on the two walls.

In recent years, concerning about the storage capacity of silos, many large scale silos were built, some even have diameter more than 100 m. Fu et al. [12] indicated that the scale of silo takes important effect on wall pressure, and the wall pressures at the end of filling are much higher than static wall pressures near silo bottom. However, less study was carried out about the effect of temperature patterns on the behavior of silo with large diameter. This is an issue induced structural damage sometimes and even destruction.

As mentioned earlier, wall pressure, a governing factor in the design of silos, has a significant effect on the safety and efficiency of silos. In this research, a case study was finished caring about the effect of temperature patterns on the behavior of large scale silo by experiments and FEM numerical simulations. The numerical simulation results agree well with the stresses of steel bars measured for a period of more than 1000 days. The effect of temperature patterns due to sunshine and season changing on silo wall was scrutinized. This provides a crucial basis for the design of large scale silos.

## 2. Experimental investigation

### 2.1. Description of experimental test

As an intuitional method, experiments were often used to study the wall pressure of silos. In this study, the experimental investigation of the large scale silo built in Xinjiang, China, was conducted more than two years. Fig. 1 shows the photo of part silo, which has a diameter of 136.5 m and a height of 19.35 m without considering the upper steel frames on silo wall. The thickness of silo wall remains 0.7 m constant from the top surface to the height of 3 m, and then gradually increases to the bottom of wall. Fig. 2 exhibits the layout of 12 vibrating string strain gauges in circumferential direction and 18 gauges in vertical direction, in which the identifier DQH means the gauges were installed in circumferential steel bars and the identifier DQS means the gauges were installed in vertical steel bars. These gauges were made in China with model number JTM-V1000. The stresses of steel bars were calculated by converting the measurement of vibrational frequency and the simultaneous temperatures were measured by thermistor contained in

**Fig. 1.** Photo of part silo.

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