Measurements of ambient temperature effect on wall pressures imposed by stored solids in silos

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Earlier studies of silo pressures generally suggested that wall pressures would be symmetrical if the filling and discharging were both symmetrical. However more careful measurements showed that wall pressures can vary significantly around the circumference and can be unsymmetrical even in symmetrical silos which appear to be symmetrically filled and discharged. The loss of symmetry may be traced back to in-homogeneity and anisotropy developed in the initial packing during filling. An axi-symmetrical silo is no guarantee to obtain an axi-symmetric discharging pattern. In some cases, even a minor disturbance of the flow pattern can cause a serious loss of symmetry in the wall pressures.

Thermally induced stresses along the walls of silo may also become critical in some cases, and are recognised as being important (DIN, 1987; ASAE Standards, 1989). Most codes and standards require that silo shall be designed to resist thermal stresses due to temperature differences between stored material and outside air. One of the first analytical approaches to this subject was introduced by Andresen. The expression derived by Ahdresen is based on the membrane theory for thin shells, assuming that behaviour of grains is linearly elastic for the incremental strain associated with thermal contraction. Britton measured strain increases of nearly 25% near the bottom of a model bin filled with sorghum when temperature declined 16 °C in 3 hrs. Puri et al. examined the effect of en masse stored material properties on the thermally induced lateral pressures. A linear regression relation was used for the thermal overpressure as function of temperature. Blight conducted field experiments on a full-size steel bin to study the effect of temperature change on pressures in a bin filled with shelled corn. Blight's test results showed that 1), bin wall lateral pressures increase as the temperature increase; and 2), repeated application of a constant amplitude temperature cycle resulted in an equilibrium lateral pressure profile within a couple of cycles. Blight also observed that the temperature effects can cause a doubling of horizontal pressure on the bin wall.

Preliminary experiments were carried out to investigate the storage pressure along the walls of a full scale axi-symmetrical silo in response to the variation of thermal loads imposed. The dimensions of this silo are shown in Figure 1. As seen, the barrel of silo has a dimension of ϕ2500 x 7850 mm; it is attached with a shallow hopper of a 45° inclination. The outlet of hopper is ϕ100 mm. The thermal loads were induced by changes in the ambient temperature - the heating-up from the Sun, which was however usually uneven on the walls along circumference as shown in Figure 2 as a typical example. The representatives of pressures exerted on the walls by stored solids were measured with four pressure transducers mounted at designated locations on the silo walls as shown in Figure 1, i.e., distributed evenly along a circumference just below transition of silo. The transducers were designed for both normal pressure and frictional traction measurement, and were incorporated with a data acquisition logger Hydra, which would register and collect data in real time to be analysed later.

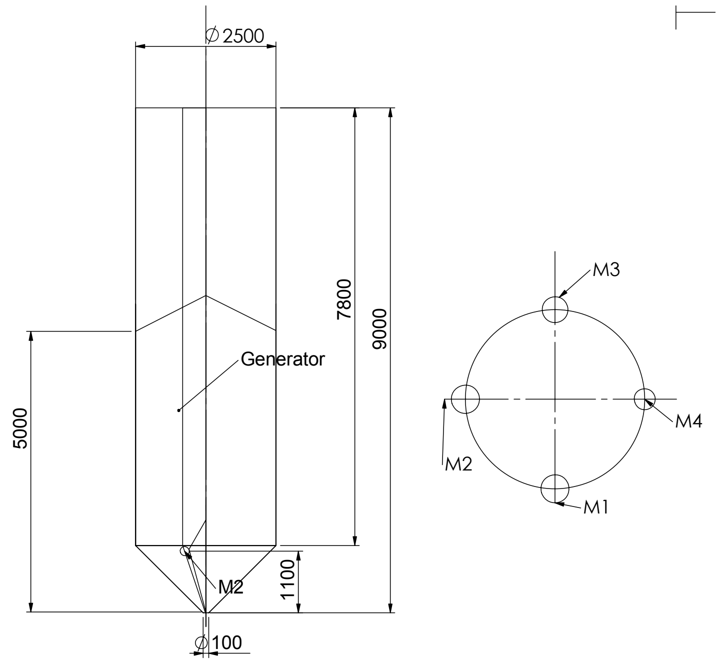

Figure 1. A full scale axi-symmetrical silo, and locations of pressure transducers

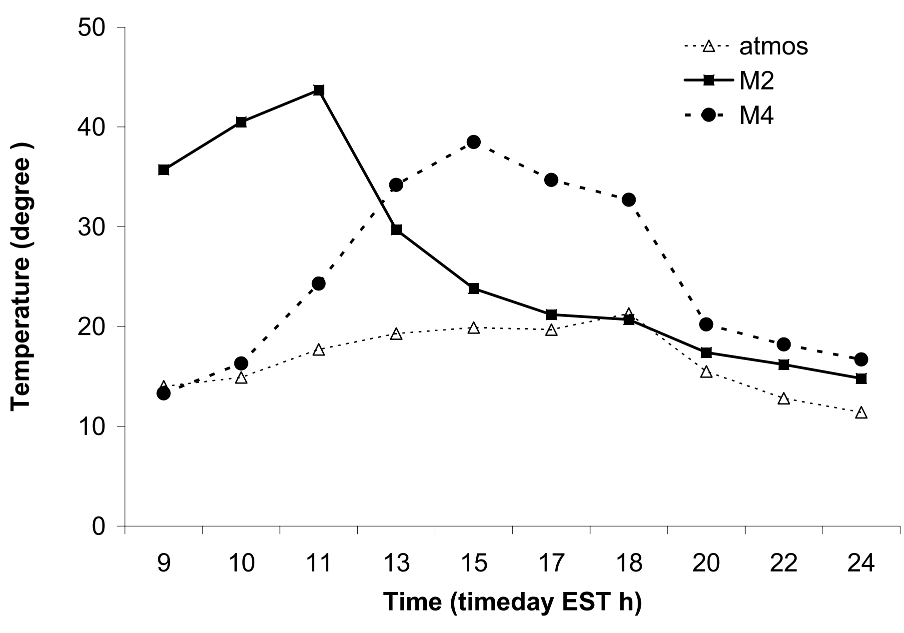

Figure 2 Variation of temperature on the walls along generators M2, M4 in response to the ambient temp. (M2 diametrical opposite to M4).

The silo was filled with sand. The sand had a bulk density of 1370 kg/m^3, its internal frictional angle was 36°. The friction angle with the wall of silo was 26.9° ($\mu = 0.51$).

During filling, a forced concentric filling was conducted in order to achieve symmetrical fillings. In the present test, an amount of such solids mass was fed into silo to a level around 5000 mm from the outlet, and left as in storage. Measurements were carried out to measure variation of loads exerted on pressure transducers during storage over a span of three days, and the result are shown in Figure 3.

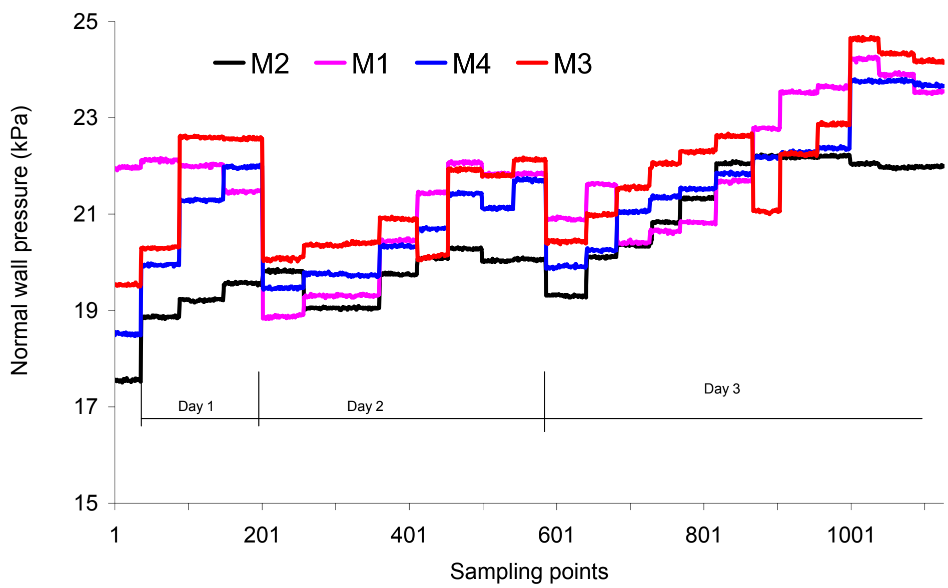

Figure 3. The development of pressures on transducers (the data in each step was obtained in two minutes measurement, each step with a two-hour interval)

As seen in Figure 3, the pressures measured on the four transducers were quite uneven at the end of filling. Measurements on day one (from 9:00 to 15:00) found that the pressures increased (except M2) with the warming up of wall. Such increases were actually considerable; but unfortunately the variations of temperature in atmosphere were not recorded.

Measurements were carried out from 9:00 to 21:00 on day two. At first, it was found that the pressures dropped overnight, and its distribution along circumference also tended to be more even. Similar trends were observed during measurements at the beginning, that is, the pressures increased with the warming up of ambient temperature; however it was also noticed that the pressure continue to increase even though the temperature in atmosphere decreased.

Prolonged measurements were carried out on day three; the variations of atmosphere temperature were also recorded, along with temperature variations on the walls at locations closed to M2 and M4 as shown in Figure 2. It was seen that the pressures on the transducers started to increase from the overnight drop when the atmosphere was warmed up. At the some time, the walls of silo were also heated up-- its temperature could reach much higher than that in atmosphere (see Figure 2). Correlated with the results in Figure 2 and Figure 3, it could be observed that the pressures on transducers would continue to increase if there were differences between the temperatures of walls and of the atmosphere, such pressures decreased when the temperature differences were getting closer.

Measurement results obtained so far showed that the pressures exerted on the transducers varied considerably in response to the thermal variation on the walls. It is suggested that the walls expand or contract, and turned the stored sands sunk or compressed, a situation of either an active state or a true passive state, to which the walls are in return subjected. As a result, the loads on the wall might vary significantly. More measurements of pressures on transducers, correlated with temperature measurement, are required to address the development and its distribution of loads on the walls further.