Model Bin as a Measuring Element of Grain Pressures

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RINGKASAN

Masalah mengukur tekanan biji-bijian dalam belubur telah dianalisa. Kesulitan yang timbul di masa-masa yang lepas dikaji sepenuh-penuhnya dan satu percubaan telah dibuat untuk mengurangkan kesulitan ini. Langkah-langkah penting dalam peralatan semasa memasang, dan kesan ke atas keputusan-keputusan telah dinyatakan. Pemeriksaan juga telah dilakukan ke atas belubur model yang telah dipasang dengan gage-gage tarekan untuk mengukur tekanan biji-bijian dan taksiran telah dibuat ke atasnya sebagai unsur pengukur yang mudah dan senang.

Adalah didapati bahawa gage-gage tarikan rintangan letrik sebagai alat mengukur tegasan ufuk dan pugak pada dinding belubur selindar adalah berguna untuk memerhatikan perubahan tekanan biji-bijian pada dinding.

SUMMARY

The problems of measuring grain pressures in a grain bin are analysed. The difficulties in measurements in the past are critically studied and an attempt is made to minimise them in the present set-up. The important steps in instrumentation while fabricating and their effect on the results are indicated. The model bin with strain-gages affixed is examined for the measurement of grain pressures. Its use as a proper and convenient measuring element is evaluated.

It is found that the electric resistance strain gages for measuring the horizontal and vertical strains in the wall of a cylindrical bin are useful in observing pressure changes of the grain pressures on the wall.

INTRODUCTION

In the design of grain storage structures like bins and silos, it is necessary to know the pressure characteristics of grains. Determining the static and dynamic pressures exerted by grain on the walls and floors of bins continues to be a difficult task for the design engineer. The theoretical models by Janssen and Airy do not take into account the variables arising out of the new practices in storage, and different methods of loadings and unloadings. Experimental methods on models and proto types are required for a better understanding of these variables in efficient design and management practices.

Reimbert and Reimbert (1976) stress the importance of theoretical and experimental studies in the silo design, and particularly, the experimental determination of material-behaviour including the pressures exerted. The data on grain storage loads and pressures are assembled for the use of engineers as basic data for design of the structures for storing grain in ASAE data D240, Agricultural Engineers' Year Book (1977). They are based on Janssen's Theory and not on experimental results. More experiments with as many variables involved are needed to correctly predict the pressures in static and dynamic states. Manbeck *et al.* (1978) report the measurements of dynamic circumferential strains in models of thin-walled, flat bottomed grain bins during centric discharge. They verify that no significant overpressures develop in shallow bins ($\frac{H}{D} = 1.25$) and that significant overpressures develop in deep-bins ($\frac{H}{D} = 5.0$). Moysey (1978) presented a method of estimating increased pressures during emptying. The ratio of lateral to vertical pressure adjacent to a bin wall is shown to depend on wall friction as well as internal friction.

Experience has shown that many silo failures could have been avoided had proper use been

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made of the available theoretical and experimental data on static and dynamic grain pressures in the design.

A model bin with affixed strain gages and auxiliary instrumentation (Saxena, 1970) is studied in detail with respect to grain pressures at different temperatures. The instrumentation employed presents a convenient determination of grain pressures for different variables with the least measurement errors.

There have been two rather serious short-comings in measuring grain pressures in the past. The first was measuring the pressure by mounting cells in special apertures in the bin wall. The presence of such a device, unless its physical properties are identical with those of the bin wall, alters the pressure. Movement of wall or sensing device a few hundredths or perhaps thousandths of a millimeter will affect the pressure. (Jenike and Johanson, 1968). The second short-coming was that measurements were made at only one or two locations at the bottom of the structure and pressures measured at various depths of fill (Collins, 1963). That is pressures were not measured at various grain depths for a given loading.

Both shortcomings are overcome in the present experiments by measuring grain pressures in a simple circular bin of light gage steel and using the cylinder wall itself as the measuring element. This is accomplished by applying electric resistance strain gages to the cylinder wall at several locations. Horizontal and vertical stresses are determined from the biaxial strain data.

TEST STRUCTURE

The test structure is a cylindrical bin 0.75m in diameter and 1.5m high *(Fig. 1)*. It is made of two courses of 28 gage (00.4mm) galvanized steel sheets, each with a vertical soldered joint; the bottom course is 0.9m and the top 0.6m high. Six S-shaped hooks are used to join the two courses at the horizontal joint.

To ensure measurement of the true strain in the steel wall sections the zinc coating were removed over wide vertical strips on both sides of the wall sheet. Three applications of a dilute hydrochloric acid reagent were made. The surfaces were washed with water and wiped dry to prevent rusting of the exposed surfaces.

The strain gages were located diametrically opposite and at six levels on both sides of the bin wall. To maintain the circular shape of the
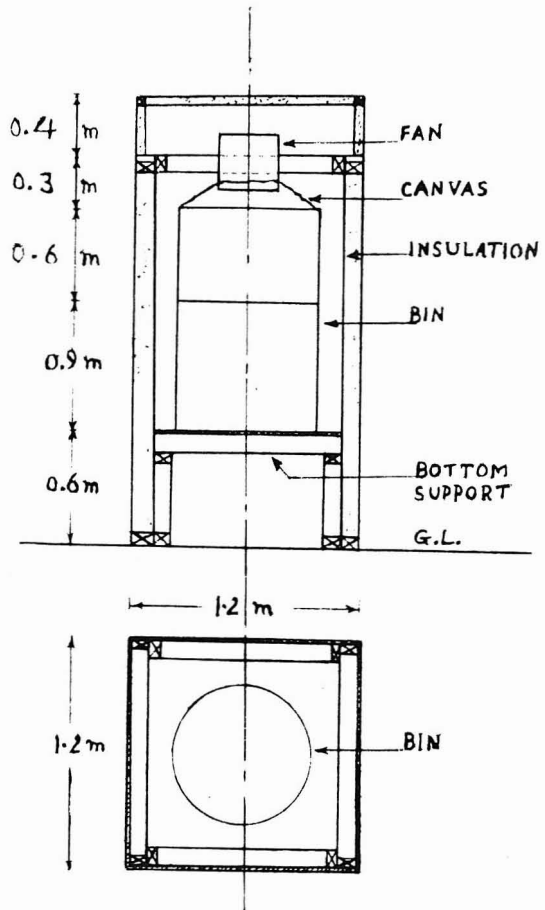

Fig. 1: Details of test bin within temperature controlled enclosure.

model bin and to avoid movement from the fixed position in filling and emptying, a 0.75m by 0.75m wooden square is fitted in the bottom. The left and right painted marks on this square fix the directions of the strain-gage locations.

The model bin rests on a wooden frame 1 m square and 0.6m high. The bin has a capacity of 640 kg of soy beans. A 6mm thick pressed wood 1m square with perforations is nailed over the wooden support. A 225mm square opening provided with a slide gate in the pressed wood is used for emptying the bin.

The model bin together with the support is totally enclosed in a 1.2m square and 2.4m high double walled insulated chamber. All four panels are detachable to permit easy access to the chamber. These are insulated with owens – corning fiberglass aluminium foil backed building insulation of 6mm nominal thickness.

A 300mm 373 watt tube axial fan is supported on a suitable wood frame in the top of the chamber for circulating air through the soybeans. An air tight connection is made between the fan and the top of the bin with light canvas shaped into a frustum of a cone. The upper portion of the chamber is enclosed with insulated panels. All lead wires from strain gages, heater, fan and thermocouples pass through openings in the chamber walls for connection to the instruments.

TEST MATERIAL

The experiment was conducted with soybeans because they are round and uniform in shape unlike the other grains such as wheat and corn. The variety of the soybeans is wayne. They are yellow in color and contain one per cent of brown, black and bicolored soybeans. Their grade designation is No. 1. The kernels are round and have only 10 per cent splits. The damage in the kernels is only two per cent. The foreign material amounts to only one per cent. The moisture content is 13 per cent (wet basis).

INSTRUMENTATION

Twenty four BLH strain gage rosettes (thin – paper-backed type A-5-A) are applied at each of the 14 locations in such a way that 8 rosettes of lot B-32 E 993 U 4 are on the upper section of the bin model, and 16 rosettes of lot B 32 E 993 W 4 are in the lower section *(Fig. 2)*. On the recommendation of the manufacturer, two dummy gages from each of these two lots are used, taking each dummy gage for the same lot gages. A pair of rosettes at each location, one inside and the other outside of the wall, is essential for the biaxial measurement of strain. This arrangement separates the direct strain from the bending strain due to the local bending in the thin walls of the model bin.

Applying The Strain-Gages

Before mounting the strain-gages, the surface is first rubbed gently with ordinary sand paper and then washed with a dilute solution of hydrochloric acid. A moist cloth is used to remove traces of acid and the surface is wiped with a dry cloth. The surface is roughened slightly with medium grade emery paper and wiped to obtain a moisture-free and clean surface. A cross is etched at each location where a strain gage rosette is to be mounted. The surface around each location is washed with gasoline until a clean swab shows no discoloration. Finally, before the rosette is applied, the surface is again cleaned with carbon-tetrachloride.
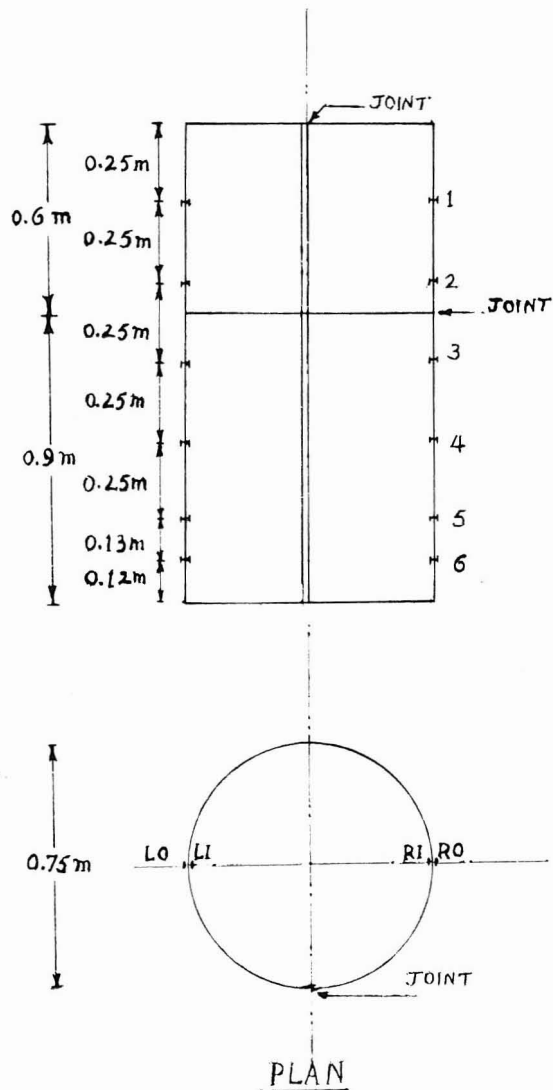

Fig. 2 : *Model Bin showing locations of strain-gage rosettes.*

To improve adhesion, SR-4 cement precoat is applied on a clean area (75 × 75mm) and left to dry for fifteen minutes. Then the precoat is covered liberally with a fast drying SR-4 cement. The rosette is firmly applied immediately as the same time the cross marked on the gages is adjusted to match that etched on the surface in such a way that one pair of lead wires point downward and the other in counter-clock wise direction. Adhesive tape is applied to keep the rosette positioned while the cement is drying. A piece of strain gages, wiring terminals type TR-50 is simultaneously installed below the strain-gage rosette without trimming the copper and teflon backing. The whole assembly is held in place

with a weight of two pounds. As recommended in the BLH folder for rosettes for air drying, the rosettes are air dried for 52 hours without application of any heat.

After installation, the copper terminals are cleaned and brightened with fine sand paper. The wire from the strain gage and the stranded lead wires are joined and twisted together, placed on copper terminals, and soldered with an electric Pencil Soldering Iron. Extreme care is taken not to over-heat and over-solder the joint, lest the copper terminals are dislodged from the teflon backing or a short circuiting occurs. After soldering, the joint is allowed to cool and to become firm. For water proofing, ordinary vaseline is generously applied over each of the rosettes.

Checking Strain Gages

The instrument used for testing the strain gage is a triplett model 2405 Volt-Ohms-milliammeter which measures ohmic resistance over a wide range. This instrument which applies a maximum of 22.5 volts for resistance measurement is specially selected. Instruments with higher maximum readings, on the other hand, would cause a gage insulation damage to occur and ruin the gage. The gages are tested for resistance after the cement has completely set. It is found that each of the lot U gages has 120.00 ohms and each of the lot W gages has 119.00 ohms, falling exactly within the range prescribed by the manufacturer. The test for leakage resistance for each gage to the metal (steel) underneath shows that the leakage resistance is more than 300 megohms required for proper installation and drying for gages. Each gage has more than 50 megohms resistance to ground which shows the satisfactory condition of all the gages. A test of air pockets or imperfect bonding is also made. Each gage is connected to the strain indicator; the entire surface over the gage is gently pressed with a thin pencil; the strain indicator shows a slight rise of about 0.0002 per cent which becomes zero when the pencil is removed. This shows that each gage is sound and properly bonded.

A remote sensing thermostat with a range of −10°C to 45°C and a fixed differential of 3°C is used to control the temperature in the Chamber. It is mounted just below the perforated floor of the test bin. The thermostat is connected in series with 1500 watts F-A-15 model Electromode Heater and the electric power source through a modified switch box. The heating capacity is increased by putting two coil-type heating elements in front of the heater. Each coil is 3000 watts, connected in parallel to a 240 Volt power source.

Copper constantan thermocouples are used for measuring the temperature inside the enclosure such that six are placed in the grain bulk, four on the bin wall and one each in the top and bottom air spaces. All the thermocouples are connected to an L-N, speedomax-G, copper-constantan T-C type recorder reading to 0.5°C with a response time of fifteen seconds.

Measuring Pressures On The Bin Wall

The lead cables from rosettes were carefully taken out of the insulated chamber so that the gages were not damaged when the leads were pulled or connected. The dummy gages were so connected that lot U dummy rosettes were with lot U rosettes and lot W dummy rosettes were with lot W rosettes.

To increase the measuring sensitivity the gages were connected to a close external wheatstone bridge circuit having two active and two compensating gages placed alternately around the bridge loop. The indicated strain was twice the actual strain since the two active gages produced an additive effect in unbalancing the bridge. The advantage of the external circuit was that it minimizes the effect of variations in cable and terminal contact resistances upon the strain measurements because both sources of error were external to the gage bridge. Each bridge circuit from the model bin was connected to the four-arm bridge terminals on the type 20 strain indicator. The gage factor dial was set to 2.00.

The insulated chamber was checked for tightness and all connections to the instruments verified. After a temperature of 21°C was obtained by circulating air in the chamber, initial readings of all twenty-four bridges were taken.

Following the readings of all gages with the bin empty, the bin was filled carefully so that the rosettes were not disturbed by impact of the grain. The soybeans were levelled and a canvas connection was put in position. The chamber and the soybeans were ventilated for three hours until the thermocouples recorded an average temperature of 21°C throughout. After approximately an hour the indicator was read. The thermostat was then set at 27°C and the chamber ventilated for three hours until the average temperature reached 27°C throughout. Readings were then taken. The same procedure was repeated for temperatures at 32°C, 38°C and 43°C.

The chamber was then opened and the bin emptied. The chamber was closed again; the thermostat set at 21°C; and the fan was run until this temperature was reached. A set of readings was taken with the bin empty for comparison with the initial readings.

To check the consistency of the readings, the experiment was repeated for temperatures at 21°C, 32°C and 43°C.

After the reading at 43°C the grain was heated further to 46°C; the chamber was then opened, the bin emptied and refilled with soybeans, and the chamber was closed. Ventilation was continued until the average temperature of 43°C was recorded throughout. The readings were taken at temperatures of 43°C, 32°C, 27°C and 21°C during the cooling period of the bin filled with soybeans.

The chamber was again heated and two sets of readings were taken at 24°C and 43°C. The bin was opened and the canvas was disconnected. The fan cooled the bin walls to 27°C while the temperature of the grain was at 38°C. Readings were taken. The canvas was reconnected to the bin and the whole chamber was brough. to 24°C af.er which readings were taken again.

Hoop stresses in the walls of the bin were calculated from the strains (measured by the strain-gages) using Hooke's Law for a biaxial state of stress:

$$S_a = \frac{E}{1-\gamma^2} (e_a + \gamma e_b)$$

where
E = modulus of elasticity of steel
γ = poisson's ratio of steel = 0.33
e_a, e_b = Strain in the direction of 'a' and 'b' which are at right angles
S_a = Stress in the direction of 'a' (horizontal)

The mean stress values for inside and outside members were averaged. From these the hoop tension was calculated. The lateral pressure was computed from:

hoopstress × thickness, divided by bin-radius

An ideal model is difficult, if not impossible, to construct. Certain facts regarding the model were assumed. Similarly, since it is difficult to create an ideal situation in the laboratory the following assumptions were made in the experimental stage.

1. The bin remains circular in section throughout its height before and after careful filling of the grain.
2. The lead cables connecting pressure transducers and the strain-gage rosettes, along with thermocouple wires do not disturb the grain pressure distribution.
3. The presence of strain-gage rosettes inside the grain bulk also does not disturb the grain pressure inside the model bin.
4. The soldered joints, the zinc removed surfaces inside and outside the model bin, and the loose horizontal joint with 'S' shaped hooks are assumed to be a part of the homogenous bin.
5. Since the bin has to be emptied and filled several times, the depth of grain is assumed to be 1.5 meters each time without any conical or other surcharge.
6. The bin is emptied and refilled carefully and it is assumed that any dynamic or impact loads are negligible.

RESULTS AND DISCUSSION

The observed lateral pressures on the bin walls at each of the four temperatures while heating are given in Fig. 3. The shapes of the curves for 21°C, 27°C, 32°C and 43°C are similar. But, as the temperature of the grain bulk is increased from 21°C to 43°C, the lateral pressures on the wall decrease rapidly at first and then more gradually.
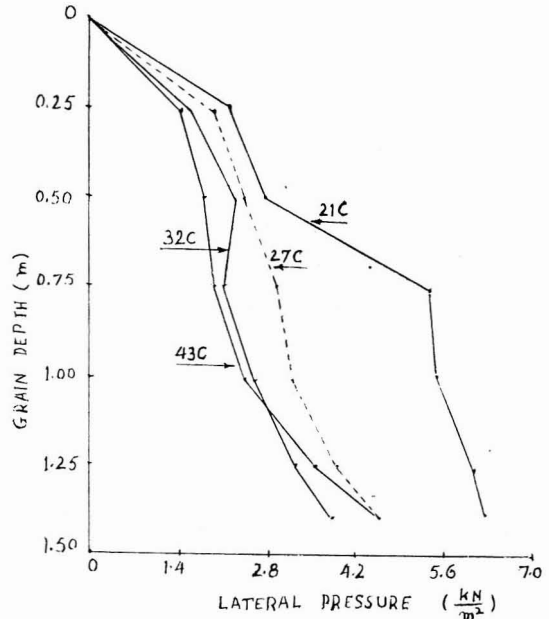

Fig. 3: *Observed lateral pressures while heating from 21°C to 43°C (grain filled at 21°C).*

The lateral pressures on walls decrease when the temperature of the grain is raised from 21°C to 43°C due to packing of the grains in the initial stages of heating.

The bin was emptied and refilled with soybeans at a temperature of 43°C, and cooled to 21°C. The lateral pressures are shown in Fig. 4. They fall sharply at first and then decrease more gradually. Nearer the bottom of the bin, the decrease in the lateral pressure is much less than that at the top of the bin; this may be due to friction of the floor.
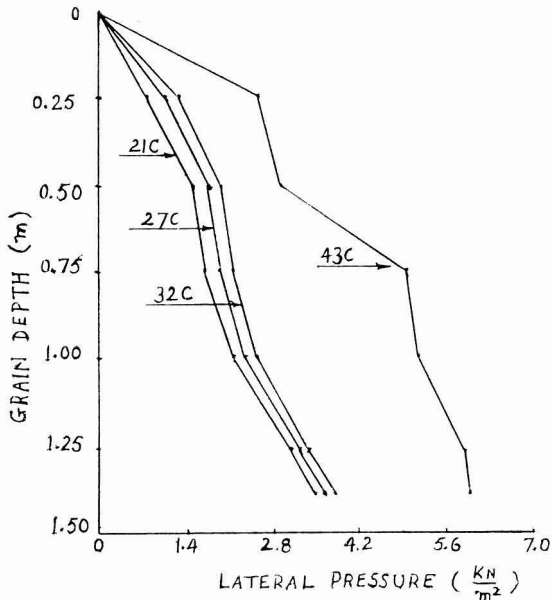

Fig. 4: *Observed lateral pressures while cooling from 43°C to 21°C (Grain filled at 43°C).*

The drop in pressure, in general, is attributed to the fact that the grain shrinks as temperature falls. An adjustment takes place with a decrease in volume of the bulk. The steel shrinks also but less than the soybean bulk. Accordingly, the wall moves relatively outward causing the lateral pressures to drop. The bulk of soybean has less porosity and behaves more or less like a solid mass. On heating from 24°C to 43°C, lateral pressures increase because the bulk has more thermal expansion than steel.

Janssen's curve along with the experimental values at 21°C are given in Fig. 5. These experimental values are higher than Janssen's. As the lateral pressures vary with increasing or decreasing grain temperatures, Janssen's equation is not sufficiently inclusive for determining lateral pressures.

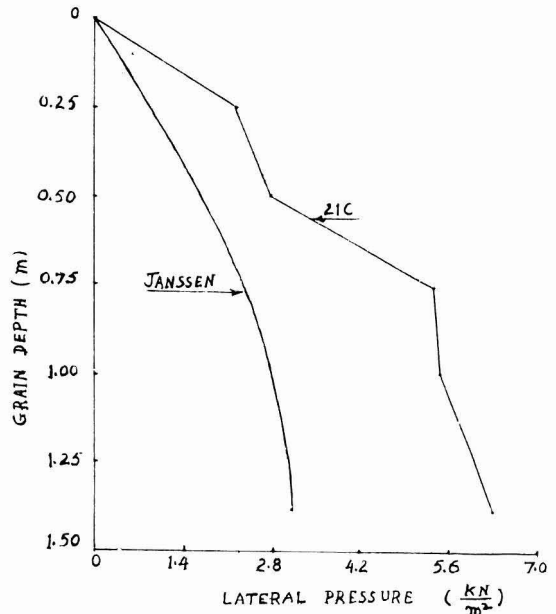The measurement of lateral pressures involves the interaction of the linear coefficients of thermal

Fig. 5: *Comparison of theoretical and experimental curves.*

expansion of soybean and steel, the former being three times that of the latter. When heating the grain, the individual expansion of each kernel is absorbed in the bulk itself. This accounts for the soyabean bulk not being affected while expansion of the component unit is taking place.

The lateral pressures may be active and passive depending upon the relative movement of the bin wall. The measuring element, that is, the bin as a whole, records the respective active and passive state of pressures.

The bin, with electric resistance strain gages, proves to be a useful research instrument for measuring grain pressures under different conditions.

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