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INFLUENCE OF FILLING METHOD ON RADIAL DISTRIBUTION OF VERTICAL PRESSURE OF RAPESEED ON BOTTOM OF A MODEL BIN*

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A b s t r a c t. The packing density and spatial arrangement of individual grains influence the mechanical behaviour of granular material. The method of bin filling influences the spatial arrangement of solid particles and, as a consequence, the pressure distribution. This paper outline an effect of preferred orientation of normal directions in contact points of particles on radial distribution of vertical pressure on the bottom of a model bin.

K e y w o r d s: bin, pressure distribution, rapeseed, anisotropy

INTRODUCTION

The method of bin filling influences mechanical properties of granular solids. Various methods of bin filling result in a varied density of the granular material, and in a different spatial arrangement of individual granules. Both density and spatial structure of a granular material influence the load distribution in a bin. Porosity, permeability, pressure distribution and flow pattern depend on the packing density and internal structure of bulk solids [1,3,4,6]. Stream filling creates a less compacted structure of granular material than sprinkle filling, and contributes to mass flow during discharge. In contrast to stream filling, sprinkle filling increases density of granular material and contributes to plug flow during discharge [8]. Increased in-bin density creates a higher angle of internal friction, which results in a decrease in the lateral to vertical pressure ratio [4,6].

Boruszak and Sygulski [1] have found that the sprinkle filling of rapeseed decreases static and dynamic wall pressure, as compared to stream filling. The total vertical wall load during filling and rest was smaller for sprinkle filling than for stream filling but was high during discharge. Kamiński [4] have used three methods of bin filling: central stream, circumferential and sprinkle to study the influence of filling method on pressure distribution. The author found the highest lateral pressure of wheat grain for central filling and the lowest for circumferential. The different radial distribution of density for central and circumferential filling methods was considered as a reason of obtained difference in pressure distribution.

The objective of this research was to determine the influence of filling method on radial distribution of vertical pressure on the bottom of a model bin.

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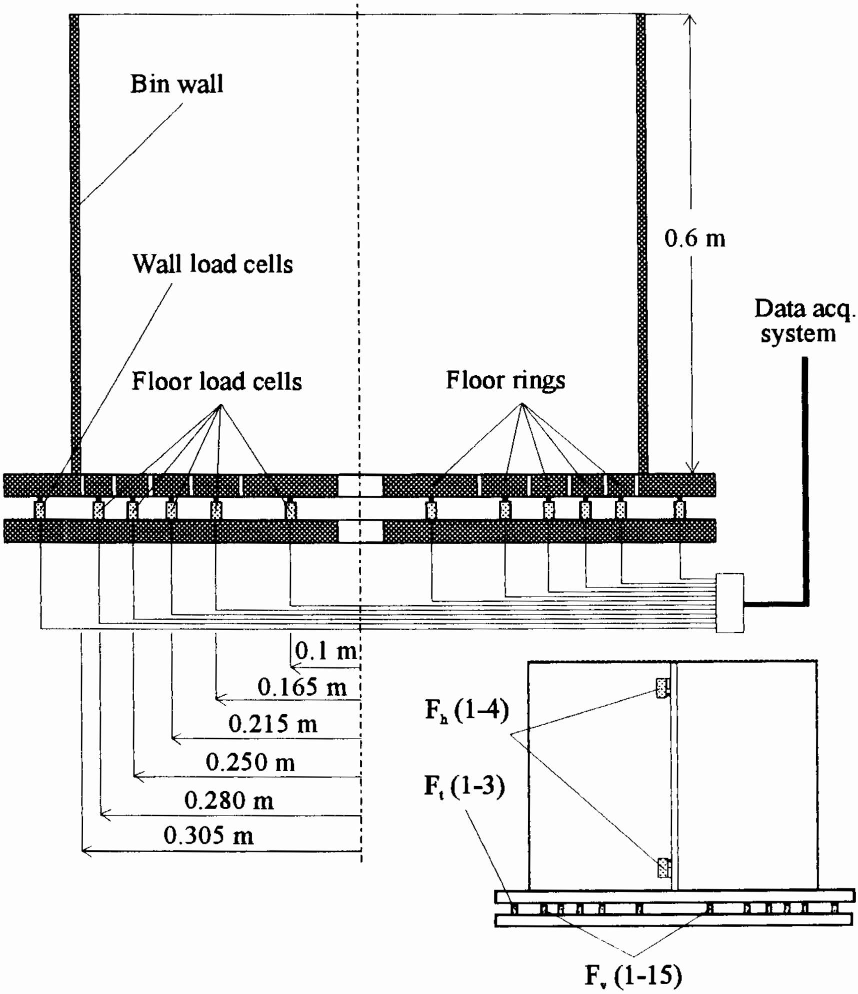

Fig. 1. Schematic diagram of pressure measuring system.

EQUIPMENT AND PROCEDURE

The test apparatus shown schematically in Fig. 1 was constructed in two semicircular halves cut along the axis. The two semicircular halves were connected with four load cells installed in pairs on the two connection lines, restoring the cylindrical shape of the wall. The bin wall, constructed of galvanized steel 3 mm thick, was 0.6 m in diameter and 0.6 m high. The flat bottom consisted of five concentric rings of equal area to measure radial variation in vertical pressure $\sigma_v(r)$. Each ring, and the wall, was supported independently on three load cells spaced at an angular distance of 120° apart. The cells were connected to a data acquisition system and loads were measured with an accuracy of ±0.5 N. The average vertical pressure on the bin bottom $\overline{\sigma}_v$, the average vertical wall stress $\overline{\sigma}_t$, and the average lateral wall pressure $\overline{\sigma}_n$ were calculated as follows [5]:

$$\overline{\sigma}_v = \frac{\sum_{i=1}^{i=15} F_{vi}}{\pi r^2}\ ;\ \overline{\sigma}_t = \frac{\sum_{i=1}^{i=3} F_{ti}}{2\pi\, rH}\ ;\ \overline{\sigma}_n = \frac{\sum_{i=1}^{i=4} F_{ni}}{2rH} \quad (1)$$

where F_{vi} - indications of the 15 load cells supporting the bottom rings, F_{ti} - indications of the 3 load cells supporting the wall, F_{ni} - indications of the 4 load cells connecting the wall halves, H - height of the bin, r - radius of the bin.

An average tangential stress on the cylindrical surfaces separating granular medium into five concentric sections located over bottom rings (Fig. 2) can be determined from static equilibrium equation. The average tangential stress τ_1 on the central cylindrical surface can be determined from equilibrium equation for the central section of the slice of granular medium:

$$\tau_1 = \frac{\rho g V - (F_{v1} + F_{v2} + F_{v3})}{2\pi r_1 H} \qquad (2)$$

where ρ - bulk density (assumed to be constant along the bin radius for very gentle filling procedure), $F_{v1,v2,v3}$ - measured values of load for three load cells supporting the central cylinder, g - acceleration of gravity, r_1- radius of the central cylinder, V - volume of considered layer of material.

The average tangential stress τ_2 (see Fig. 2) can be determined from equilibrium equation for the slice of granular medium located over two central adjoining rings of the bottom, etc.

The three methods of bin filling used in the experiments: central, circumferential and

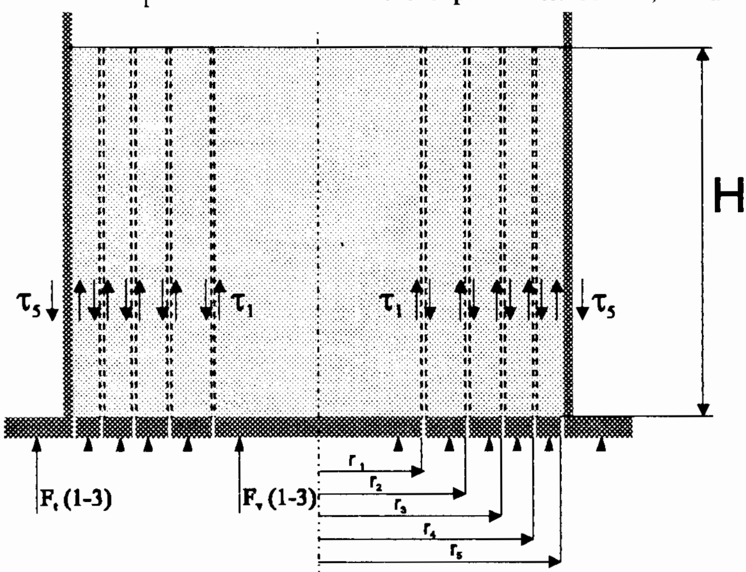

Fig. 2. Imaginary cross-section of a cylindrical layer of granular material.

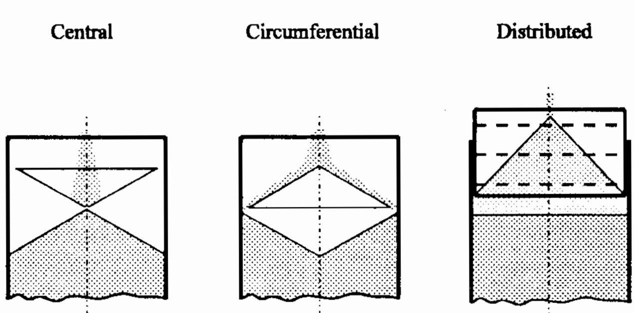

Fig. 3. Schematic diagrams of filling methods.

sprinkle (distributed), are shown schematically in Fig. 3. For the central and circumferential filling methods the cone shaped filling device was used to direct seeds to the centre or to the wall of the bin. As a result, seeds formed a regular conical sloping surface, and bulk density was independent on falling height. The sprinkle filling method did not form a sloping surface. Rapeseed with moisture content of 7 % and bulk density of 660 kg/m^3 was used for all tests. Six replications were performed for each variant of the experiment.

RESULTS AND DISCUSSION

Experiments confirmed earlier reports of researchers, that the sprinkle filling method significantly increases bulk density compared to stream filling methods [1,4,6]. For sprinkle filling the bulk density was found to be 713 ±3 kg/m^3, while for circumferential filling 675 ±3 kg/m^3, and for central filling 693 ±3 kg/m^3. The lateral to vertical pressure ratio was determined according to the procedure proposed by Molenda and Horabik [5] and was found to be highest in the case of central filling (0.48 ±0.01) and the lowest in the case of sprinkle filling (0.41 ±0.01). For circumferential filling the pressure ratio was equal to 0.45 ±0.01.

The filling method significantly (α=0.05) influenced the radial distribution of vertical pressure on the bottom of the bin. Pressure distributions for the three filling methods are presented in Fig. 4. Sprinkle filling produced the highest mean vertical pressure on the bottom. Circumferential filling resulted in the highest vertical pressure at the centre of the bin, while the highest pressure for central filling was near the bin wall. Sprinkle filling resulted in a very uneven pressure distribution. The distribution of vertical pressure reflects a random structure of contact points in the granular material, therefore to give a clear interpretation of the pressure, it is necessary to provide an accurate description of the paths of stress transmission throughout the granular material. Tangential stress distributions, calculated using Eq. (2), are presented in Fig. 5. Circumferential filling resulted in the lowest tangential stress, while central filling produced the highest tangential stress. Different course of tangential stress with radius obtained for three filling methods can be helpful in verifying hypotheses concerning the location of regions inside Janssen's slice, where yield condition is fully developed [2].

Different pressure distributions for circumferential and central filling indicate the influence of anisotropy of granular material. Anisotropy of granular material results from the preferred orientation of non-spherical particles, or concentration of normal directions in contact points. Molenda and Horabik [5] have found that the preferred orientation of non-spherical wheat grains in a model bin, obtained during filling procedure, results in nonuniform pressure distribution. This study indicates that in the case of almost spherical rapeseeds a similar effect results from concentration of normal directions in contact points. Results of triaxial compression and direct shearing tests of rapeseed, performed by Szot *et al.* [7], indicated that the angle of internal friction increased with an increase in the angle between the preferred orientation of normal direction in contact points and the slip plane (Fig. 6).

In the case of central filling, the preferred orientation of normal directions in contact points follows the generatrix of the natural repose cone with the vertex directed upward, while in the case of circumferential filling, with the vertex directed downward. The angle between the preferred orientation of normal directions and the slip plane is higher for the circumferential filling than for the central one, as indicated in Fig. 7. Therefore, the angle of internal friction will be higher for circumferential filling than for the central one. A higher angle of internal friction results in lower lateral pressure for circumferential filling than for the central one. Preferred orientation of contact points along to generatrix of the downward directed cone (circumferential filling) passes the majority of intergranular

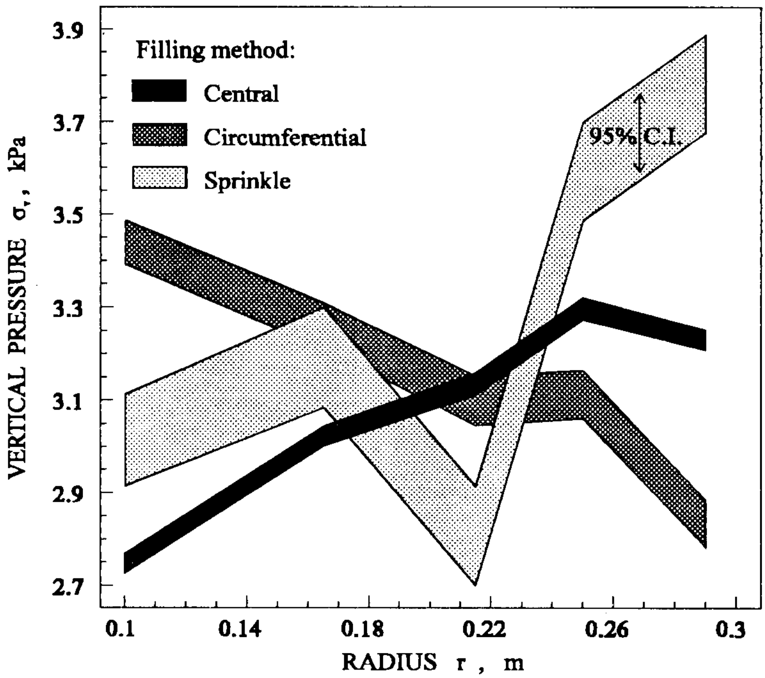

Fig. 4. Radial distribution of vertical pressure of rapeseed on the bin bottom for three filling methods.

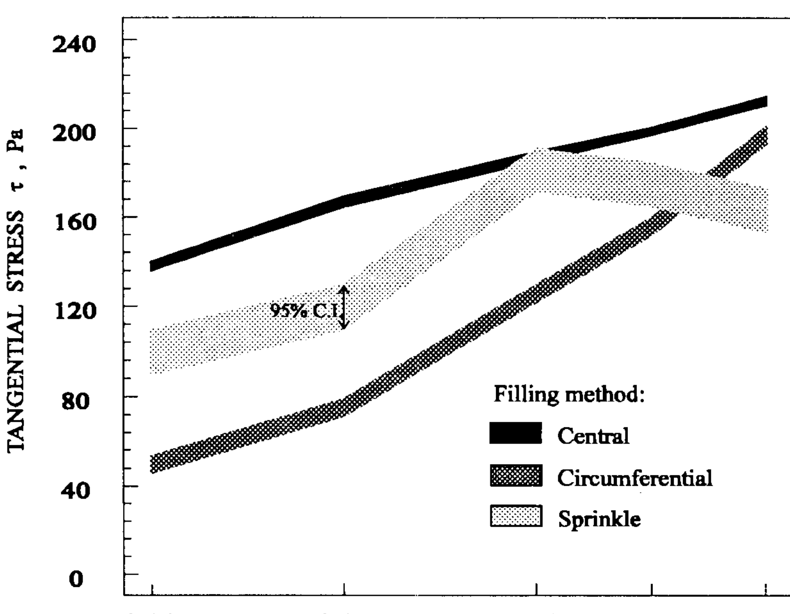

Fig. 5. Radial distribution of tangential stress on imaginary cylindrical cross-sections of rapeseed layer for three filling methods.

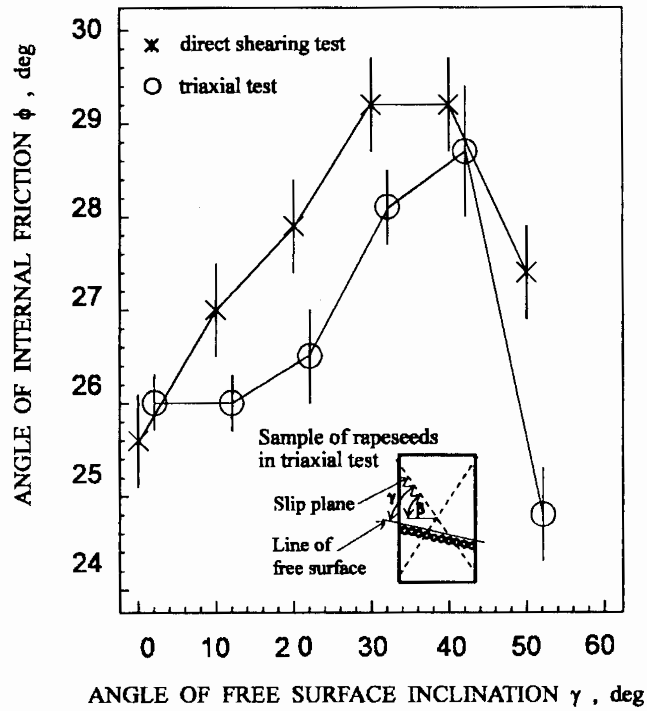

Fig. 6. Angle of internal friction of rapeseed sample measured in triaxial compression and direct shearing tests as affected by the angle (Szot *et al.* [7]).

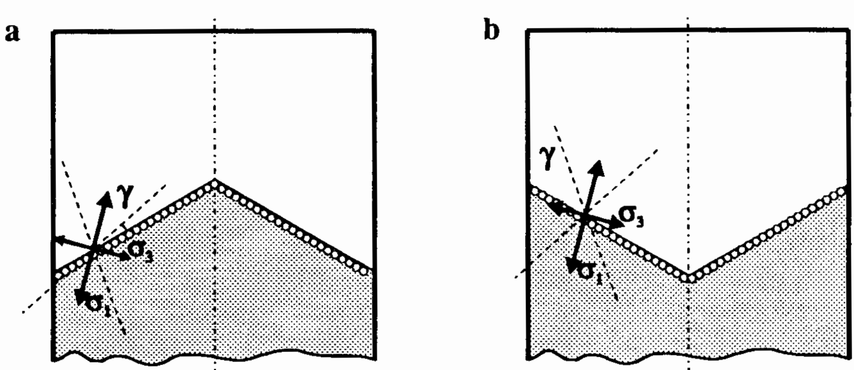

Fig. 7. Angle γ for central (a) and circumferential (b) filling.

forces to the centre of the bottom, and results in a more stable structure than preferred orientation of contact points along to the upward directed cone (central filling).

CONCLUSIONS

1. The filling method significantly influenced the radial distribution of vertical pressure on the bin bottom. Different pressure distributions resulted from both different bulk density and different orientation of contact points. From a practical point of view, the advantages of circumferential filling as compared to central filling are: lower pressure ratio, maximum of vertical pressure at the bottom centre, the lowest tangential stress in vertical direction.
2. In the case of a full scale bin the filling method can influence both bulk density, and

the spatial arrangement of seeds. When the kinetic energy of falling particles changes bulk density and the natural repose cone creates preferred orientation of contact points, the pressure distribution depends on bulk density distribution and spatial arrangement of particles.

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WPŁYW METODY NAPEŁNIANIA NA ROZKŁAD NAPORU NASION RZEPAKU NA ŚCIANĘ I DNO SILOSU

Sposób napełniania istotnie wpływa na właściwości mechaniczne zgromadzonego w silosie ośrodka sypkiego. Różne metody napełniania wytwarzają różną gęstość ośrodka oraz różną strukturę przestrzennego ułożenia granul. Zarówno gęstość ośrodka jak i rodzaj powstałej struktury wpływa istotnie na stan naprężenia w ośrodku sypkim, a tym samym na rozkład obciążenia konstrukcji zbiornika. Prezentowana praca omawia wpływ różnych sposobów napełniania cylindrycznego zbiornika na rozkład wzdłuż promienia pionowego naporu na płaskie dno oraz na wartość ilorazu naporu poziomego do pionowego. Stwierdzono, że najkorzystniejszy rozkład naporu powstaje w przypadku napełniania wzdłuż obwodu ściany zbiornika. Napełnianie obwodowe wytwarza strukturę ośrodka przenoszącą największe naprężenia normalne w kierunku pionowym w obszarze osi symetrii zbiornika.

S ł o w a k l u c z o w e: anizotropia, rozkład naporu, rzepak, silos.