Experimental method for determination of the pressure distribution in granular solids

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ABSTRACT: This paper presents two methods of determination of pressure distribution in rape seeds. The study utilized hydraulic pressure sensors with active rubber face and stress state transducer with six duralumin face sensors. This project utilized methodology well known from soil mechanics for determination stress in plant granular material. The hydraulic pressure sensors has been design to measure normal pressure in granular material. The stress transducer has been designed to measure pressure in six different directions, which orientation enable to calculate the stress state from the pressure measurements. The project enclose to design calibrations procedure. Calibration of each of sensors of stress transducer was performed both under air pressure and inside the bedding of rapeseeds. The preliminary tests of both pressure sensors developed for the direct in-bulk measurement within granular material allowed to determinations pressure distribution in granular materials. Experiments were performed inside bedding of rapeseeds of 6% moisture content.

Keywords: pressure; granular material; hydraulic pressure sensors; state stress transducer

Storage, handling and processing of grain constitute a considerable part of technology in food industry. Better understanding of the mechanical behaviour of granular materials is of fundamental importance in the design and operation of facilities for storage and processing of granular materials. Mechanical behaviour of granular plant materials under conditions of processing depends on the pressure level in bedding. Pressure exerted on the bedding may generate stress in the material, which exceeds the crushing strength of grain. Theoretical and experimental methods of estimation are used to predict pressure level and pressure distribution in granular materials. Experimental determination of pressure distribution may be performed in a model silo or in practical conditions of silo operation. ATEWOLOGUN and RISKOWSKI (1991) determined stress ratio *k* for soybeans by four different methods. The four methods were: measuring mean vertical and horizontal pressure in model silo, measuring vertical and hoop strains in the bin walls with six, two-element rosette gages, measuring horizontal and shear loads at the bin wall with three ring loads cells fixed in different heights on the model silo wall and the last method by IMT (In Mass Transducers) measured vertical and horizontal stresses within the grain mass. LAW et al. (1993) measured horizontal to vertical pressure ratio of wheat and barley in a circular bin by measuring apparatus with three pressure sensors fixed at Cartesian coordinate systems.

Reported project used the load cells, pressure transducers and measuring system to determine forces exerted by grain on the structural elements and pressures inside grain bulk. A method and construction of transducers used in this project to determinate pressure distribution in plant granular material were adapted from soil mechanic (PYTKA, KONSTANKIEWICZ 1998; PYTKA et al. 2000).

MATERIAL AND METHODS

This study utilized 0.61 m high and diameter model silo to determine the mean horizontal pressure and mean shear stress on the wall, as well as vertical pressure distribution in grain bulk.

The cylindrical silo wall consisted of two semicircular halves cut along the axis and connected with four load cells installed in pairs on the two connection lines. Top and bottom plates consisted both of five concentric

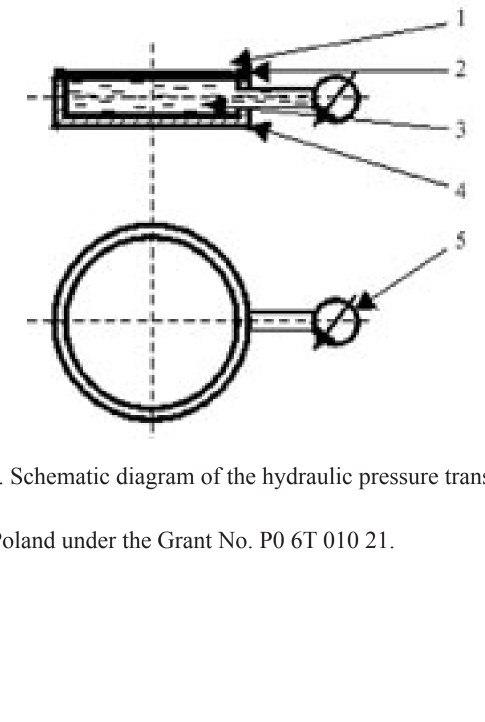

Fig. 1. Schematic diagram of the hydraulic pressure transducer

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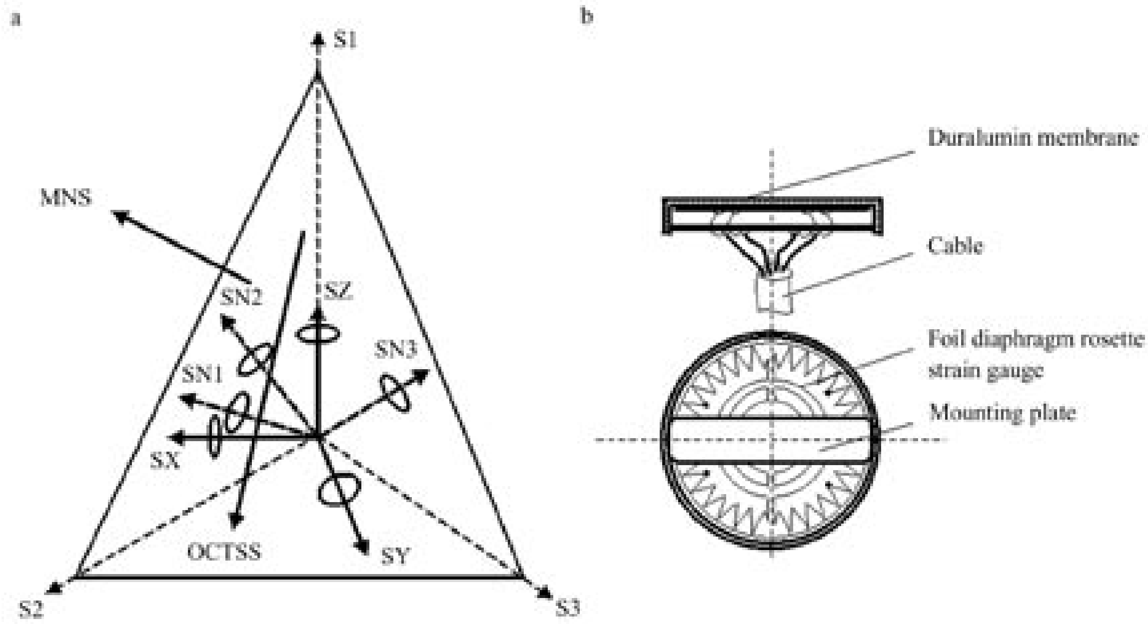

Fig. 2. Schematic diagram: a – stress state in granular material and coordinate systems of measuring head, b – duralumin pressure sensor

rings, each ring was supported by three load cells. The measuring set-up allowed for loading and unloading the bedding of granular material (HORABIK, RUSINEK 2000).

The hydraulic pressure sensors allowed to determine normal pressure in bulk. Hydraulic pressure sensor consisted of: pressure transducer (5), metal carcass (4) (bowl shape) covered with active rubber face (2) with a stiff cover plate (1) attached and was filled with silicon oil (3). Diameter of deformable rubber membrane was 56 mm while the diameter of single grain was about 2 mm. This difference in dimensions allowed to treat the load from individual granules transmitted to the membrane as an uniform stress.

The stress transducer was machined of duralumin in a shape of a quarter of hemisphere. This transducers contained of six pressure sensors. The membrane of each pressure sensor was 30 mm in diameter. Sensing element was a foil diaphragm rosette strain gauge TFm-25/350, which was fixed by glue to membrane according special procedure. The membrane of sensors were made of duralumin PA 7. These pressure sensors were mounted flush on surface of the transducer. The orientation of these surface was such that the stress state could be calculated from the pressure measurements. Stress state transducer allowed for estimation of principal stresses inside the examined region of the bedding as well as to estimate mean shear stress and mean normal stress at the octahedral plane (BAILEY et al. 1988).

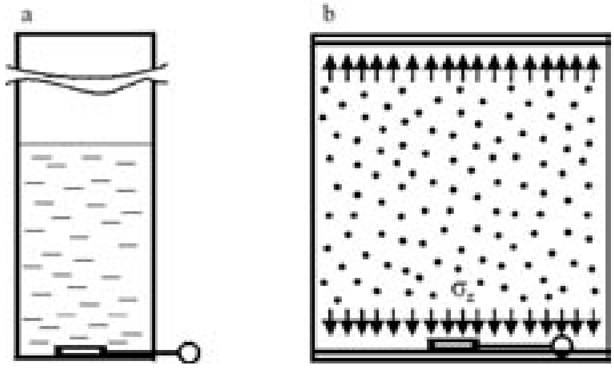

Fig. 3. Calibration of pressure transducer: a – under hydrostatic pressure, b – inside the bedding of rape seeds

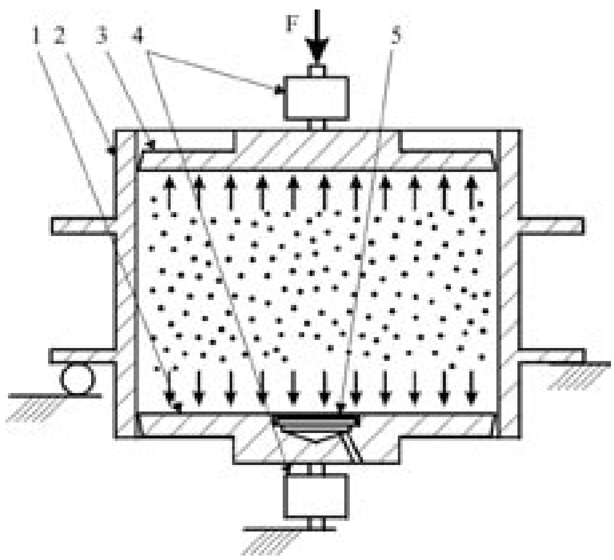

Fig. 4. Uniaxial compression tester for calibration of pressure transducers inside bedding of granular material

Calibration and measuring procedure

Calibration of the hydraulic pressure sensors was performed both under hydrostatic pressure and inside the bedding of rape seeds (for range of 0–25 kPa). Calibra-

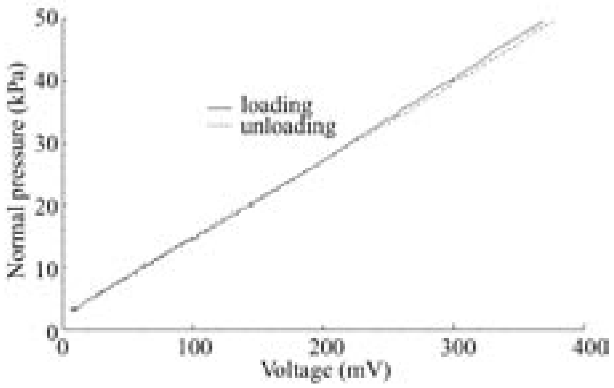

Fig. 5. Typical plot of the normal pressure σ_z versus the voltage signal relationship during loading and unloading of the sample of seeds (rape seeds of 6% of moisture content w.b.)

tion under hydrostatic pressure was performed in 2.5 m high pipe (sensors were located on the bottom), which was filled with liquid. Calibration inside the bedding of rapeseeds was performed in model silo. Each of sensors was located on the bottom of experimental set.

The experiment allowed to determine both normal pressure on the bottom and sensing element of transducer and calibration constant for rape seed.

Calibration of each of sensors of stress transducer was performed both under air pressure and inside the bedding of rapeseeds (NICHOLS et al. 1987). The calibration in air was performed by placing the sensor in an empty triaxial chamber, in which pressure was monitored by means of piezoelectric manometer.

The uniaxial compression tester was used for calibration of each of transducer inside the bedding of rapeseeds. The test chamber was 210 mm in diameter and 100 mm high. An experimental set for the calibrations consisted of cylindrical wall (2), bottom (1) and top plate (3) of the chamber transmitted the vertical load through the load cells (4). The sensors were located at vertical axes of uniaxial compression tester in bottom plate (5). The experimental set allowed to determine both normal pressure on sensor and bottom (HORABIK, MOLENDA 2000).

The calibrations tests for hydraulic and duralumin pressure sensors allowed for the determination of mean parameters of transducers: measuring range, linearity error (hysteresis loop) and calibration constant for rape seeds.

The sample was poured into the model silo through centrally located spout, without vibration or other compacting actions. The pressure sensors were located along the radius of the silo at the half of the silo height. Next the sample was loaded and unloaded in range of 0–12 kPa.

RESULTS

The sensors developed for the direct in-bulk measurement within granular material functioned well and provided reliable data for rape seed.

Calibration of each of transducers should be performed both in hydrostatic pressure of air and inside the bedding of granular material. Diameter of active membrane was 56 mm (hydraulic pressure sensor) and 27 mm (duralumin membrane sensor) while the diameter of single grain was about 2 mm. This difference in dimensions allowed to treat the load from individual granules transmitted to the membrane as an uniform stress.

The lateral to vertical pressure ratio k is one of the most important mechanical parameter commonly used to calculate the loads exerted by grain on storage structures. Distributions of lateral to vertical pressures in the model silo were determined for cycles of loading which simulated conditions of storage in a silo ($k1$, $k2$, $k3$…). Vertical pressure decreased along the radius with an increase in the distance from the wall while horizontal pressure increased simultaneously. Mean horizontal to vertical pressure ratio k (0.45) determined in large volume was close to that obtained for local pressure ratio at the wall (0.44), while local k at the centre of the model silo was found to be distinctly lower and ranged from 0.33 to 0.38.

CONCLUSIONS

After filling the silo pressure ratio $k1$ along the radius were lower than the pressure at next cycles of loading

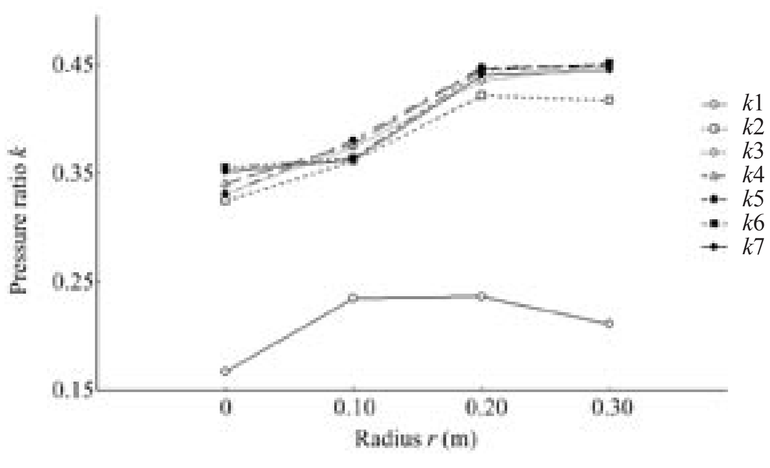

Fig. 6. Pressure ratio k along the radius of model silo determined for cycles of loading

($k2$, $k3$, $k4$…). With the vertical pressure increase, the friction force and the cohesion between grain increased and influenced for pressure ratio. The lateral to vertical pressure ratio determined at the wall of silo for cycles of loading generally depends on the coefficient of wall friction. When the wall friction increases vertical pressure at the wall decreases, as a result the pressure ratio increases.

The values of local pressure horizontal to vertical ratio k for rape seed were found at the wall and at the centre of the silo 0.44 and 0.35 respectively and were significantly lower than the range of 0.50–0.53 recommended by the Polish Standard (PN-89/B-03262, 1989) for filling and storing.

Values of local pressure ratio at the wall of silo were near to the determined values according to standard Eurocode 1 (0.46) in uniaxial compression test.

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Experimentální metoda stanovení rozložení tlaku v zrnitých materiálech

ABSTRAKT: Příspěvek prezentuje dvě metody zjišťování rozložení tlaku v řepkovém zrnu. Používaly se hydraulické snímače tlaků s aktivním pryžovým povrchem a detektor stavu tlaku se šesti duralovými snímači povrchu. Tento projekt používal metodu dobře známou z mechaniky půd pro zjišťování tlaku v rostlinných zrnitých materiálech. Hydraulické snímače tlaků jsou konstruovány za účelem měření normálních tlaků v zrnitých materiálech. Detektor tlaku byl zkonstruován k měření tlaku v šesti různých směrech, jejichž orientace umožňuje vypočítat stav tlaku z těchto měření. Je navržena konstrukce kalibračního postupu. Kalibrace každého ze senzorů tlakového detektoru byla stanovena na povrchu i uvnitř vrstvy řepkového zrna. Předběžné testy obou tlakových senzorů vyvinutých pro přímé měření v objemu zrnitých materiálů umožnily určit přímo rozložení tlaků v těchto materiálech. Experimenty byly provedeny uvnitř vrstvy semene řepky o vlhkosti 6 %.

Klíčová slova: tlak; zrnitý materiál; senzory hydraulického tlaku; stav detektoru tlaku

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