Influence of moisture content on pressure ratio of rape seeds

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ABSTRACT: The pressure ratio of rape seeds was determined for four levels of moisture content in a model silo. The silo was 0.6 m in diameter and 0.6 m high. Ratio of horizontal to vertical pressure and distributions of local horizontal to vertical pressure along the radius of the floor in the model silo were determined for cycles of loading and unloading simulated conditions observed in a silo (in a range of 0–13 kPa). The sample was poured into the model silo through centrally located spout, without vibration or other compacting actions. The pressure ratio rape seeds generally decreased with an increase in moisture content. Experimental results were compared with simplified approximation recommended by the Eurocode 1 (2003) and theoretical values obtained for active and passive stress case.

Keywords: pressure ratio; granular material; rape seed; model silo

The horizontal to vertical pressure ratio k is one of the three most important parameters required for the calculation of stresses that granular materials exert on the wall and floor of a silo, introduced by JANSSEN (1895). The author assumed that the vertical pressure was uniform in a horizontal section of the silo and that ratio k was constant everywhere within the material.

Two states of stress are commonly associated with the pressure ratio in a deep silo: the active state for filling and storage and the passive state for discharge mode (MOYSEY 1979). The pressure ratio k depends not only on stress state, but also on type of grain, moisture content, bedding structure of grain formed during the filling process, angle of internal friction (ŁUKASZUK, HORABIK 2002) and coefficient of friction on the wall. Experimental determination of pressure distribution in a bulk of grain may be performed in a model silo or in practical conditions of silo operation.

ATEWOLOGUN and RISKOWSKI (1991) used four different experimental methods for determination of soybeans pressure. Static stresses were measured in a 0.91 m diameter and 2.74 m high model smooth galvanized steel silo. The results of this study indicated that the pressure ratio k decreased with grain depth and that the highest values of k occured between the silo center and wall.

LOHNES (1993) determined pressure ratio k in the triaxial test apparatus for cereal grains and several levels of moisture content during loading and unloading. Experimental values of pressure ratios were compared to the values estimated form RANKINE (1857), HARTMANN and JAKY'S (1948) theories. The Rankine equation results were below the measured values, Hartmann were higher and Jaky's showed reasonable agreement.

WILMS (1991) compared and evaluated values of loads calculated from silos codes and standards. General criteria included the most important physical parameters of bedding such as: wall friction, cohesion, stress state. Question of non-uniform pressure associated with eccentric discharge was also considered.

HORABIK and RUSINEK (2002) used uniaxial compression tester for determination of pressure ratio of cereal grains for five levels of moisture contents. Experiments were performed according to the Eurocode 1 recommendations. The tester was 210 mm in diameter and 100 mm high. The specimen was loaded to the reference vertical stress of 100 kPa using a universal loading frame by the top cover plate at the constant displacement rate of 0.35 mm/min. Mean lateral to vertical pressure ratio was found dependent on procedure of the sample deposition. The pressure ratio of cereal grain generally decreased with an increase in moisture content.

MATERIALS AND METHODS

A model silo 0.6 m high and 0.6 m in diameter was constructed and instrumented to measure mean pressure ratio k, mean tangent stress on the wall σ_t, as well as distribution of vertical pressure σ_z along the radius of the silo (Fig. 1). 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. The silo wall constructed of galvanized steel was 3 mm thick. Top and bottom plates, both consisting of five concentric rings of equal area were used to measure radial variation in vertical pressure. Each ring was supported by three load cells and separated by an angular distance of 120°. The cells were connected to a data acquisition system and loads were measured with an accuracy of ±0.5 N. The measuring set-up allowed for loading and unloading the bedding of granular material (HORABIK, RUSINEK Part II 2000).

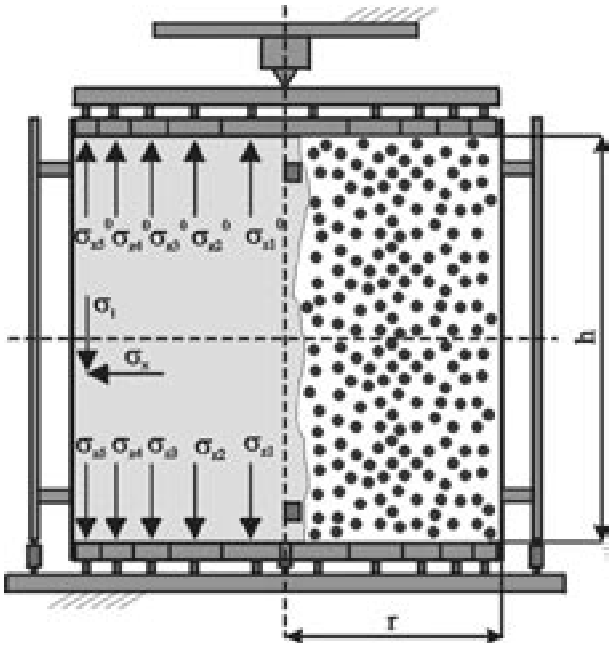

Fig. 1. Model silo

The average value of the stress ratio, *k*, was calculated utilizing a numerical solution of Janssen's equation for the mean vertical pressure on the bottom of the container:

$$\sigma_z = \frac{\rho g r}{2k\mu} + (\sigma_z^{o} - \frac{\rho g r}{2k\mu})\, e^{\frac{-2k\mu}{r} h} \qquad (1)$$

where: ρ – bulk density,
g – acceleration of gravity,
r – radius,
μ – coefficient of wall friction,
h – height of deposit.

The experiments were performed for four levels of moisture content (6, 9, 12 and 15%) for rape seeds variety Lirajet. Each variant of the experiment was performed in three replications.

RESULTS

Mean values of the ratio of horizontal to vertical pressure were determined for cycles of loading/unloading which simulated conditions observed in practice in a silo (passive and active case).

Pressure ratio during the first loading, the first unloading and the second loading of the sample of seeds is shown in Fig. 2. During first loading values of pressure ratio *k* for all levels of moisture content were stable and corresponded to phase of active stress state. During unloading values of pressure ratio increased and corresponded to the passive stress state. During loading, deposit of granular material generated stresses at horizontal and vertical directions, while unloading freed energy of resilience only at vertical direction, while the release of energy in horizontal direction was limited by the wall. During second loading the values of pressure ratio decreased below the unloading line and finally they corresponded to values from the first loading. Thus the test results formed hysteresis loop as a result of elasto-plastic properties of rape seeds.

Within increase in the moisture content of seeds, the frictional force, the angle of internal friction and the cohesion between seeds increased. As a result stress in vertical direction was higher then this in horizontal. Consequently, the lateral to vertical pressure ratio should decrease with the moisture content increase. In the tests with increasing moisture content the pressure ratio for every experimental point (as an example first step of loading, Fig. 2) decreased. Similar relationship between the pressure ratios and the moisture content of cereal grains were observed by HORABIK and MOLENDA (2000).

Comparison of the experimental and theoretical values of the pressure ratio is shown in Fig. 3. The values of pressure ratio for the tested seeds and all the levels of moisture content during loading were located near the lower limit of theoretical values obtained for yielding at the wall in the active stress case (dark gray). During un-

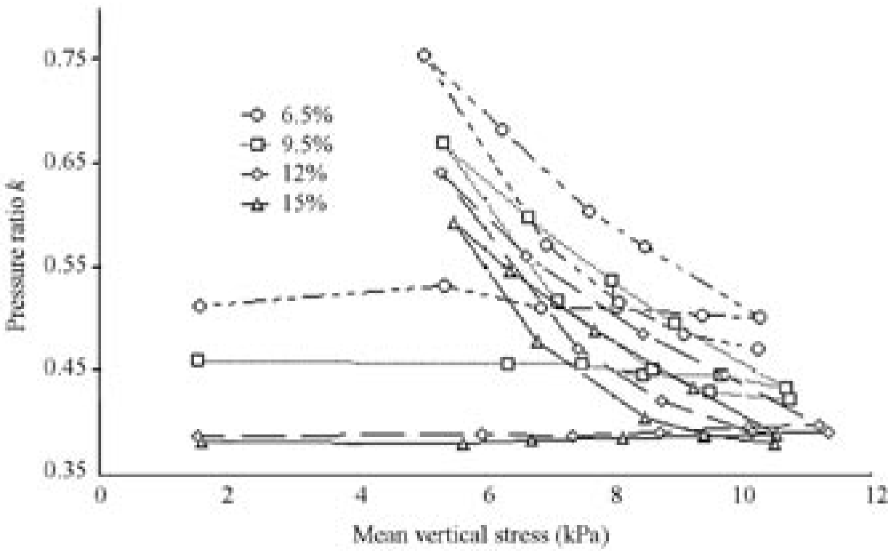

Fig. 2. Mean values of pressures ratios in the loading/unloading cycles for four levels of moisture content

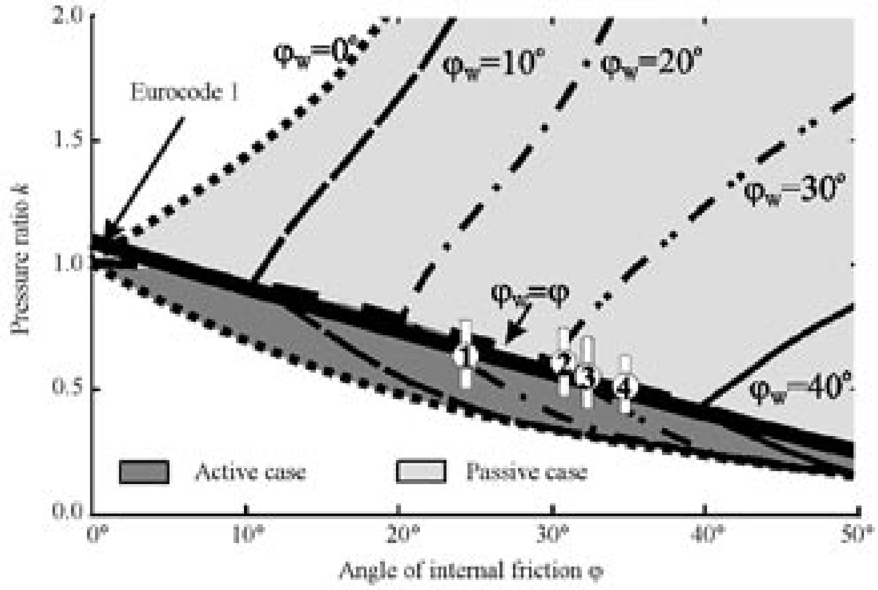

Fig. 3. Pressure ratio as the function of the angle of internal friction and the angle of wall friction for yielding at the wall (HORABIK, RUSINEK Part I 2000); ▬ the pressure ratio according to Eurocode 1; 1(6.5%), 2 (9.5%), 3 (12%), 4 (15%) – mean values of pressure ratio for cycles of loading/unloading for four levels of moisture content of rape seeds

loading the values moved to the passive case area (light gray). Values of pressure ratio obtained from Eurocode 1 recommendation are located in the center of the area obtained in the cycles of loading – unloading of rape seeds.

Local values of the pressure ratio were found to be the highest at the wall and the lowest at the silo center for both the cycles of loading/unloading for all levels of moisture content. Vertical pressure decreased with an increase in the distance from the wall while horizontal pressure increased. This confirms the opinion that coefficient of wall friction influences on values of pressure at vertical axis and as a result the pressure ratio. With the moisture content increased, the friction forces on the wall decreased. This was the reason of the strong increase of the values of the local pressure ratio at the wall for the moisture content 6.5%.

CONCLUSIONS

1. After filling the silo and during first loading pressure ratio *k* is stable. Deposit of rape seeds simultaneously and similarly generates stresses in vertical and horizontal directions. This action corresponding to the theoretical active case and in practice the operation of filling the silo. Unloading phase of the cycle

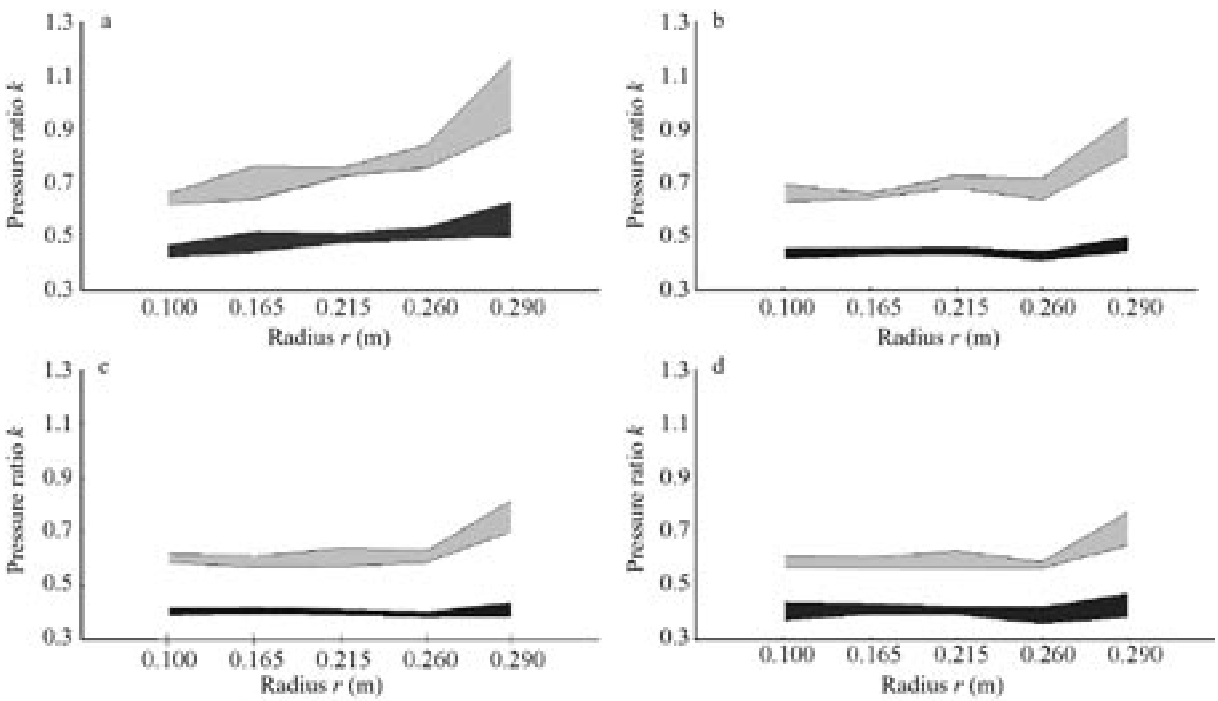

Fig. 4. Variation of the pressure ratio k of rape seeds along the radius of model silo determined for cycles of loading (dark grey) and unloading (light grey) for four levels of moisture content: a) 6.5%, b) 9.5%, c) 12%, d) 15%

corresponding to the theoretical passive case and in practice to discharge of the silo. Unloading of deposit results in an release of elastic energy mainly in vertical direction, while the release of energy in horizontal direction is restricted by the wall. As a result pressure ratio increases and is similar to the theoretical passive case.

2. The friction force and the cohesion between seeds increase with increasing moisture content. As a result the pressure ratio decreases.
3. The lowest pressure ratio is in the center of the silo and the highest is close to the wall. For each variant of the test the ratio of horizontal to vertical pressure in loading part is lower than in unloading part of each cycles.

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Vliv vlhkosti na koeficient bočního tlaku u semen řepky

ABSTRAKT: Koeficient bočního tlaku byl určován pro čtyři vlhkosti semen řepky skladované v modelovém silu o průměru 0,6 m a výšce 0,6 m. Poměr horizontálního a vertikálního tlaku a lokální rozložení obou zmíněných tlaků podél poloměru sila na jeho dně byly stanoveny pro cykly zatěžování a odtěžování simulující poměry v silu (v rozmezí 0–13 kPa). Koeficient bočního tlaku zrnitých materiálů rostlinného původu obecně klesá s jejich rostoucí vlhkostí. Experimentální výsledky byly srovnány prostřednictvím zjednodušené aproximace doporučené v Eurocode 1 (2003), a tak byly získány teoretické hodnoty pro případy s aktivním a pasivním napětím. Modelové silo bylo plněno vzorky centrální hubicí bez jakýchkoliv vibrací a jiných zhutňujících vlivů.

Klíčová slova: koeficient bočního tlaku; zrnitý (partikulární) materiál; semena řepky; modelové silo

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