

UNIAXIAL COMPRESSION OF RAPESEED USING APPARATUS WITH CUBOID CHAMBER

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Abstract. A uniaxial compression apparatus was constructed, having a cubical test chamber of adjustable width. The bottom of the chamber and one of its walls were both supported on three load cells to permit determination of vertical and horizontal pressures. Tests were performed with rapeseed to validate the apparatus, to determine minimum specimen width, and to determine horizontal to vertical pressure ratio. Specimens 120 mm high (initially) and 120 mm long that had adjustable widths of 8, 14, 21, 27, 33, 39 and 44 mm were tested. Results showed that testing with specimens of width smaller than 10 seed diameters gave unstable values of pressure ratio. Results of tests with specimens wider than 10 seed mean geometric diameters gave values of pressure ratio consistent with those obtained earlier in cylindrical uniaxial compression apparatus.

Keywords: granular material, minimum specimen dimension, pressure ratio, rapeseed, uniaxial compression, stress transmission

INTRODUCTION

Cereal grains and oilseeds are a major food source. Storage, handling and processing of grain constitute a considerable part of operations 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. The lateral to vertical pressure ratio, bulk density and friction coefficient are the three most important mechanical parameters commonly used to calculate the loads exerted by grain on storage structures (Drescher 1991). The most popular method of experimental determination of the lateral to vertical pressure ratio is the uniaxial compression test (Kwade *et al.* 1994, Horabik and Rusinek 2002). The test is usually conducted in cylindrical apparatus that, assuming homogeneity of the material, adequately reflects conditions of

axial-symmetric state of stress. For mathematical description of material behaviour in such a state the cylindrical system of coordinates is convenient.

In recent decades in examinations of behaviour of granular material under mechanical load numerical simulations are widely used complementary to laboratory testing. Usually the model of the real system involves an imaginary sector of the material of a cuboid shape. To describe asymmetric loading conditions and orientations of non-spherical particles the Cartesian system of coordinates is more feasible. Such conditions are frequently adopted by designers of software for numerical simulations of mechanical phenomena, and such is the case of the discrete element method (DEM). Thus, to validate DEM simulations in cuboid geometry conducted in IA PAS a modified uniaxial compression apparatus was constructed and examined.

The purposes of the reported project were as follows: a) to validate the applicability of the uniaxial compression apparatus with cuboid test chamber for determination of pressure ratio of granular material, and b) to determine the minimum specimen width assuring reliable test results. The results of present determination of pressure ratio have been compared with earlier obtained results of testing with cylindrical apparatus (Horabik and Rusinek 2002).

METHOD AND MATERIAL

The vertical and horizontal pressures in uniaxial compression apparatus were estimated using measured floor and wall loads exerted by a bulk of rapeseed. The device is different from most of the conventional testers (e.g. recommended by Eurocode 1, 2003) in that the specimen has rectangular cross-section. This test simulates conditions in cuboid imaginary section of the material considered in common mechanical analyses.

A schematic of the uniaxial compression apparatus used in the reported project is shown in Figure 1. The elements of the apparatus were machined of 6 mm thick steel and galvanized. Two walls of the apparatus, parallel to the plane of the figure located at a distance of 120 mm, were attached to the solid support plate. The floor of the apparatus was supported on three load cells (S1, S2 and S3) to measure vertical loads. Two other adjustable walls of the apparatus, perpendicular to the plane of the figure, were located 1 mm above the floor to avoid load transmission onto the floor. The construction of the supports of this pair of walls allowed for adjustment of the distance between them from 0 to 100 mm. Guides assured that the walls remained parallel when moved, while bolts were used to fix in position the two walls after adjustment. One of the walls (right in Figure 1) was supported on three load cells (S4, S5 and S6) to measure normal wall load used for estimation of horizontal pressure. The apparatus was placed on the table of a testing machine under its crosshead. During the test, the material was filled to the top of the test

chamber and levelled. The top plate of prescribed width (one of: 8, 14, 21, 27, 33, 39 or 44 mm) was placed on the free surface of the material and the movement of the crosshead of the universal test machine was started. The vertical force acting on the plate was measured. A displacement speed of 0.35 mm min^{-1} was used in all experiments. Three replications were made for each measurement that proved to be very close. For the purpose of this article (i.e. general evaluation of the new apparatus) results of one replication will be used. Winter rapeseed of Licosmos variety with moisture content of 6 % (w.b.) and uncompacted bulk density of 645 kg m^{-3} was used in the experiments. The mass of 1000 seeds was 3.47 g and geometric mean diameter was 1.8 mm.

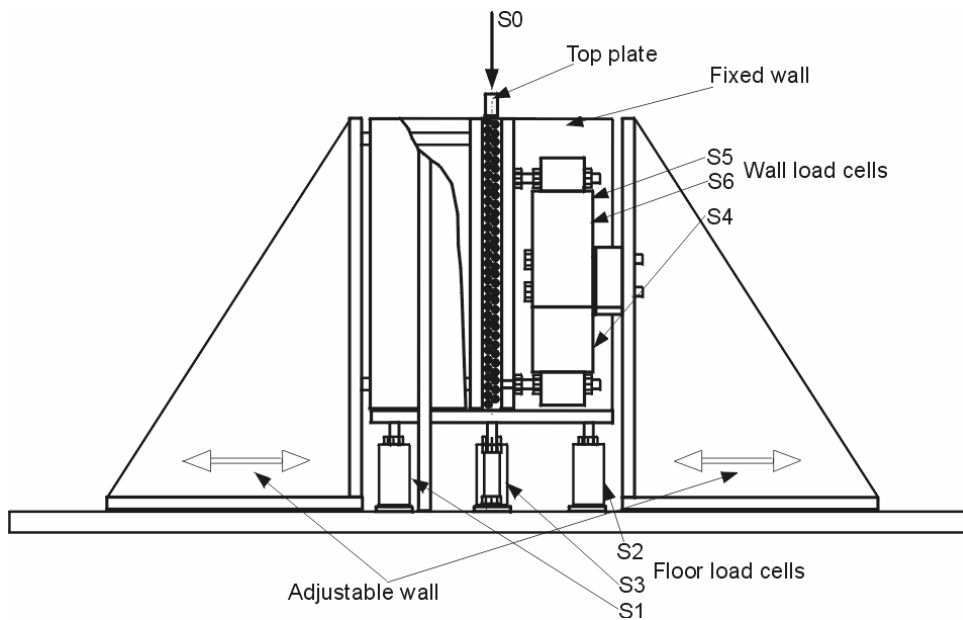


Fig. 1. The uniaxial compression apparatus

RESULTS

Force-displacement characteristics

Figure 2 illustrates relationships of measured forces: vertical S_0 – acting on the top cover 0.12 m long and 0.044 m wide, S_1 , S_2 , S_3 acting on the floor load cells, and horizontal normal to the wall S_4 , S_5 , S_6 . Maximum force acting on the top cover was found to be 530 N which corresponds to vertical pressure of approximately 100 kPa. The specimen achieved this state at relative deformation

$\Delta L/L$ of approximately 0.035. Forces S1 and S2 recorded by a pair of floor load cells mounted in line recorded maximum forces of 87 N and 81 N, respectively, and the third floor load cell recorded force S3 of 156 N. Such a result points out to fairly uniform load distribution on the floor of the test chamber. The force S4 recorded by the lower and single wall load cell was 206 N, while the forces S5 and S6 recorded by the pair of upper wall load cells mounted in line were 143 N and 133 N, respectively. Thus, the distribution of horizontal wall load along the wall height was found fairly uneven, with higher pressure in the upper region of the wall.

During the initial phase of unloading to $\Delta L/L$ of approximately 0.027, floor loads S1, S2 and S3 as well as wall load S4 followed relatively close the loading path, while the cover load S0 and upper wall loads S5 and S6 decreased much faster. This effect was caused by the action of wall friction that disturbed the relaxation of load.

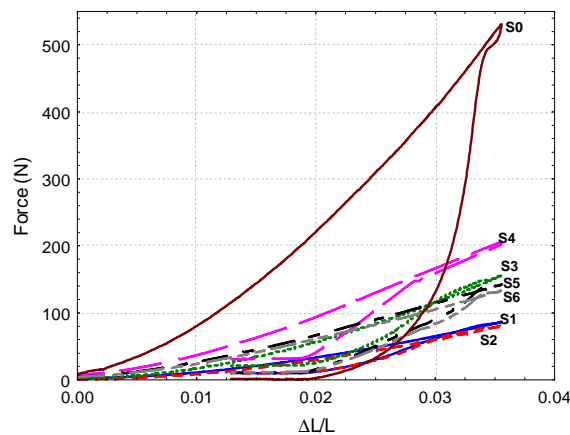


Fig. 2. Relationships of measured forces: vertical S0 – acting on the top cover 0.12 m long and 0.044 m wide, S1, S2, S3 acting on the floor load cells, and horizontal normal to the wall S4, S5, S6

Response of wall loads to change in specimen width

Figure 3 shows relationships of wall loads S4, S5, S6 versus relative displacement $\Delta L/L$ for specimens of widths: a) 8 mm, b) 21 mm and c) 44 mm. In the case of the narrowest specimen (see Fig. 3 a) the loading curves of the three load cells follow a fairly close path and reach maximum of approximately 90 N. During unloading forces recorded by load cells S5 and S6 decrease to approximately 20 N at $\Delta L/L$ of 0.025, while the force recorded by the load cell S4 presents an unexpected behaviour. It increased with a decrease in deformation to 0.03 and then decreased with decrease in deformation and stabilized after reaching $\Delta L/L$ of approximately 0.025. In the case of specimen 21 mm wide (see Fig. 3b), during loading

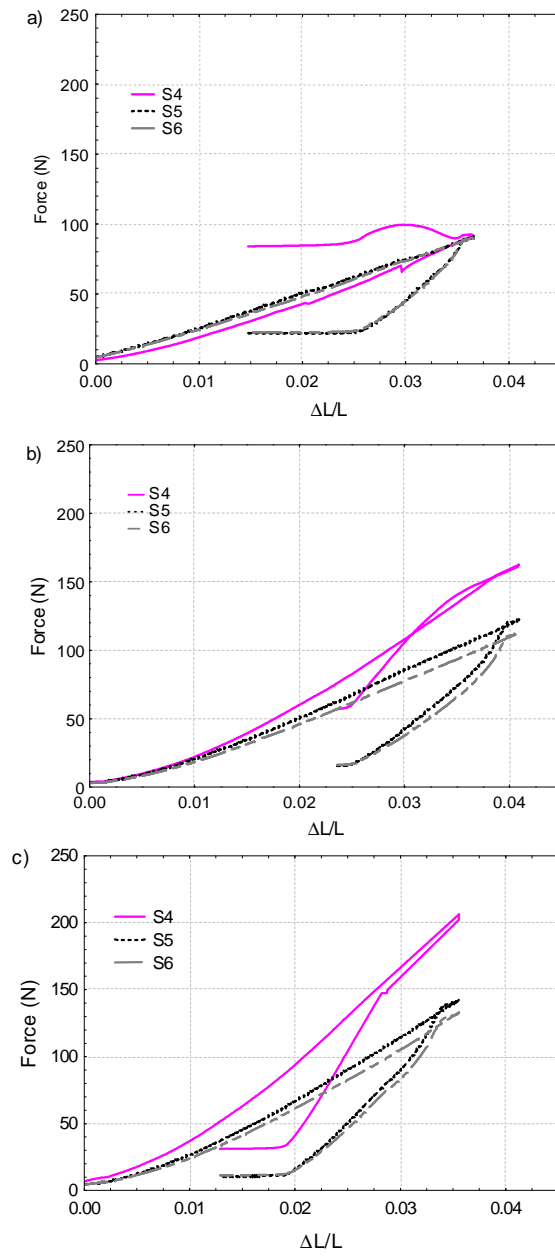


Fig. 3. Relationships of wall loads S4, S5, S6 versus relative displacement $\Delta L/L$ for specimens of widths: a) 8 mm, b) 21 mm and c) 44 mm

force S4 was higher than S5 and S6 that were fairly close. Maxima of S4, S5 and S6 at the end of loading were of approximately 161, 123 and 113 N, respectively. This result is as theoretically expected, maximum recorded by the single cell supporting the wall was higher than those recorded by the two cells mounted in line. The force-displacement relationships in the case of the specimen 44 mm wide (see Fig. 3c) reached maxima of 206, 142 and 133 N. During the first phase of unloading characteristics showed typical linear-elastic behaviour as described by Sawicki (1994) followed by non-linear phase, and finally wall loads remained locked at 34 N (S4) and approximately 11 N (S5 and S6).

Pressure ratio

Characteristics of pressure ratio k versus relative displacement $\Delta L/L$ are shown in Figure 4 for specimens of widths of: a) 8 mm, b) 21 mm and c) 44 mm.

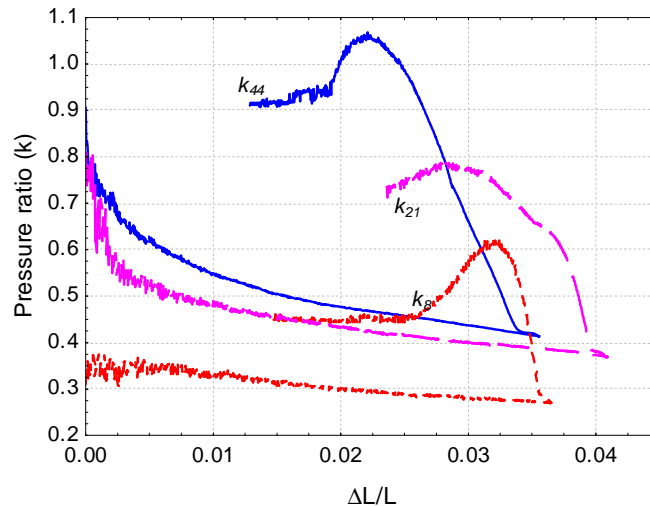


Fig. 4. Relationships of wall loads S4, S5, S6 versus relative displacement $\Delta L/L$ for specimens of widths: a) 8 mm, b) 21 mm and c) 44 mm

Obtained curves $k(\Delta L/L)$ in the cases of specimens 8 and 14 mm wide were located distinctly lower than the remaining curves that for loading phase of the cycle were fairly close and at the end of filling reached approximately 0.4. That value was in reasonable agreement with Horabik and Rusinek (2002) earlier testing with rapeseeds, as well as with results for wheat reported by Law *et al.* (1993) or by Kwade *et al.* (1994). Decrease in load resulted in a sharp increase in pressure ratio up to maximum value that is higher for wider specimens, reaching 0.5 in the case of the specimen 21 mm wide and 1.05 in the case of the 44 mm specimen. This

is again typical behaviour of the material and design codes (e.g. Eurocode 1, 2003) recommend using higher discharge wall loads than filling wall loads. Compression of grains of wheat placed in 5.75 m high silo with diameter of 1.83 m has shown similar effect (Molenda *et al.* 2007). Pressure ratio for filling was approximately 0.4, while that for discharge was found to be approximately 0.7.

Pressure ratio compared with results from cylindrical apparatus

Figure 5 shows comparison of present results for the specimen 44 mm wide with earlier determination of lateral pressure ratio k of rapeseeds by Horabik and Rusinek (2002). The earlier tests were performed in a cylindrical uniaxial tester 210 mm in diameter, holding specimen 100 mm high. Similarly to the reported project, the specimen was loaded to the reference vertical stress of 100 kPa at a constant displacement rate of 0.35 mm min^{-1} . The pressure ratio k versus vertical pressure characteristics for loading-unloading cycle show fairly good qualitative agreement. The curve obtained in the cylindrical apparatus $k_{cyl}(p)$ ran slightly higher than the curve $k_{cub}(p)$ during loading cycle, which resulted in k_{cyl} of 0.37 and k_{cub} of 0.41 at vertical stress p of 100 kPa. During unloading, after reaching p of 80 kPa $k_{cyl}(p)$ surpassed $k_{cub}(p)$ and ran above it reaching a maximum of 1.1, while the maximum of $k_{cub}(p)$ was 1.0. These differences in the courses of pressure ratio versus pressure characteristics most probably may be attributed to differences in shape of the apparatus and differences in properties of construction materials used.

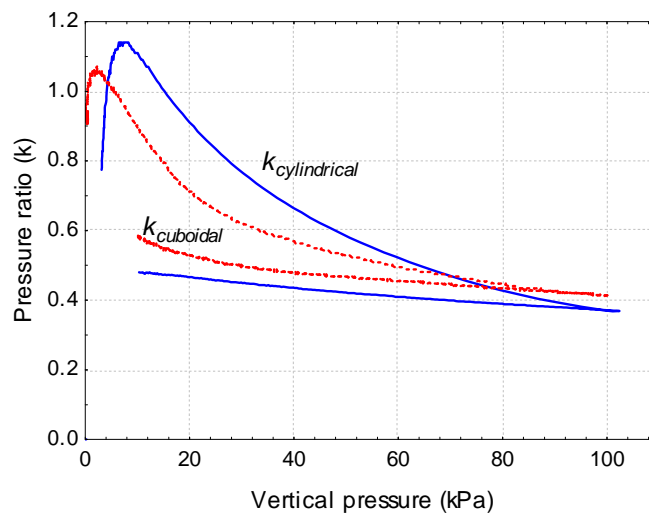


Fig. 5. Pressure ratio for the specimen 44 mm wide compared with earlier results by Horabik and Rusinek (2002)

CONCLUSIONS

1. The cuboid uniaxial apparatus was found to be an efficient tool for testing rapeseeds: free flowing granular material of spheroid particles. For specimens of thickness lower than 21 mm characteristics of wall loads versus relative displacement showed some irregularities as compared to those obtained in established standard procedures. With wider specimens, i.e. specimens of thickness higher than 11 particle diameters, the courses of the characteristics were found in good agreement with those obtained in standard apparatus.

2. Results of determination of pressure ratio k during loading–unloading cycles were found in very good qualitative agreement with those obtained in a standard cylindrical apparatus provided that the thickness of the specimen was not lower than 21 mm. Pressure ratio decreased with increase in load and at maximum pressure of 100 kPa k_{cyl} of 0.37 and k_{cub} of 0.41 were found. During unloading $k_{cyl}(p)$ surpassed $k_{cub}(p)$ and ran above it reaching maximum of 1.14 while maximum of $k_{cub}(p)$ was 1.06.

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BADANIA JEDNOOSIOWEGO ŚCISKANIA NASION RZEPAKU
W APARACIE O PROSTOPADŁOŚCIENNEJ KOMORZE

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Streszczenie. Zbudowano aparat jednoosiowego ściskania o prostopadłościenną komorę pomiarową o nastawnej szerokości. Oparcie dna komory i jednej ze ścian na przetwornikach siły pozwalało wyznaczyć napory pionowy i poziomy. W badaniach jednoosiowego ściskania próbek rzepaku określono minimalną niezbędną szerokość próbki oraz wyznaczano iloraz naporu poziomego i pionowego k . Badano próbki o wysokości początkowej 120 mm, długości 120 mm oraz zmiennej szerokości 8, 14, 21, 27, 33, 39 i 44 mm. Testy na próbkach o szerokości mniejszej niż 10 średnich wymiarów ziaren dawały niestabilne wartości ilorazu naporu. Testy z próbkami o większej szerokości dawały wyniki stabilne i zgodne z wynikami wcześniej wykonanych badań w aparacie jednoosiowego ściskania wyposażonego w standardową komorę cylindryczną.

Słowa kluczowe: materiał ziarnisty, minimalny wymiar próbki, iloraz naporu, rzepak, test jednoosiowego ściskania, przenoszenie naprężeń