Wall Friction Angle of Grain Material With Respect to Dominant Particle Orientation

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ABSTRACT

When calculating the lateral pressure on the retaining wall, and generally, where there is contact between soil and the structure, it is necessary to know angle of soil friction on construction. This paper deals with experimental research of the friction angle of the grain materials on rigid wall, with different dominant orientations of the grains relative to the wall. Twelve series of direct shear experiments were performed with the dominant orientation of the particles of grain materials 0° and 90° with respect to the wall. Specific fill in technology method was proposed. The results showed that the difference in the angle of wall friction relative to the orientation of the grain is less than 5%. In other words, we can neglect it, and in calculations with grain materials, can use the angle of wall friction as a constant irrespective of the orientation of the layers to the retaining wall.

KEYWORDS: Angle of wall friction, Anisotropy, Direct shear, Experimental research, Particulate matter, Particle orientation

INTRODUCTION

When calculating the interaction forces of structure and soil, in addition to the strength characteristics of soil, it is also necessary to determine the friction angle of the backfill on the wall of structure. Wall friction angle is necessary for solving such classical problems of geotechnics as calculation of lateral pressures on retaining walls, pressure on silo walls, friction of the wall on the ground, etc. Many scientists have already proved that the way of making backfill affects the strength properties of the backfill. For example in work of Molenda et al. [7] was conducted interesting experimental study of shear strength parameters of wheat depending on the technology of backfilling of grains. As a result internal friction angles at different orientations in grain filling differed by 16%, and the character of the shear test curve was different.

This question was also considered by many scientists such as J. Nielsen [11], M. Molenda et al. [8, 9], G.K. Klein [5], Yun-si [17], A.V. Shkola [13], A. Aniskin [1], Zheng[18] and others. They have repeatedly confirmed influence of filling methods on the shear strength characteristics and pressures in silo.

Wide and detailed overview of literature on experimental and theoretical research on shear strength anisotropy of natural and artificial soils is given in works of Shkola [13] and Voitenko [16]. Based on the analysis of literature [13] it was concluded that the substantial anisotropic properties is inherent to artificial massifs formed by hydraulic dredging or dumping under certain conditions and peculiarities of construction technologies and preparing of the massifs.

Different ways of backfilling dictate different angles of particles to walls of the structure. Therefore, the following logical question arises: Does the orientation of particles or layers of backfilling affect angle of friction against the wall?

MATERIALS AND METHODS

Materials

Two bulk media - long-grain rice and flat particles of the mussel shell were investigated. Grain of rice is anisotropic in geometry, on average the grain length is four times the thickness. Grains are white in color, with elongated form similar to ellipsoid, their medium size 2mm x 2mm x 8mm. The composition of the medium is close to homogeneous (Fig. 1a).

Flat particles of mussels shells (Fig. 1b), was sifted by a sieve with a square cell measuring 7 mm before investigating. All mussels originate from the delta of the Krka River, near the seaport of Sibenik in Croatia.

a) b)

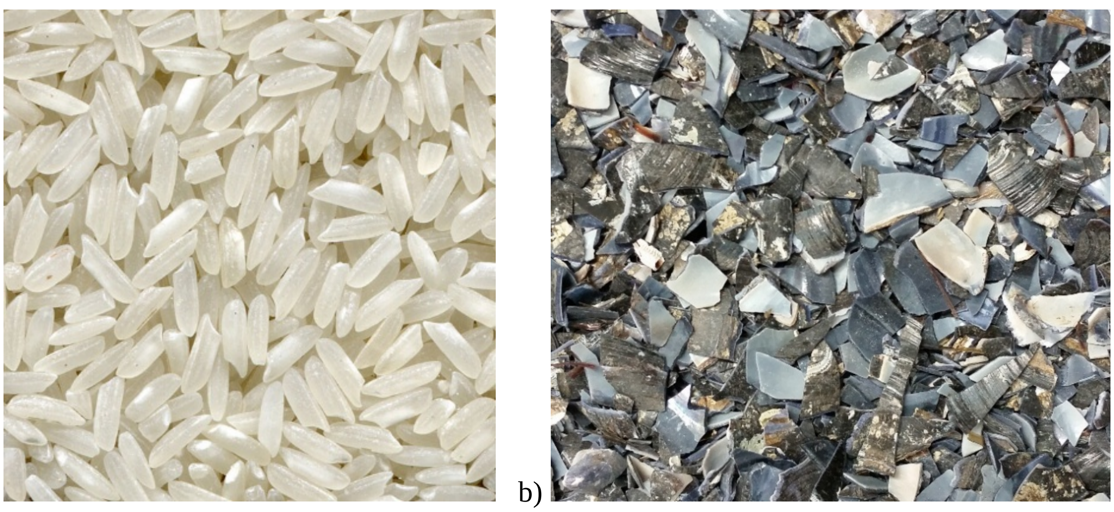

Figure 1: General view of the materials a) Rice, b) particles of the broken shells

Elongated particles of anisotropic geometry, with their orientation, cause anisotropy (texture) by different orientations in space [13]. Using such flat particles, it is possible to obtain needed prevailing angle of orientation of the grains (Fig. 2), with different technology of filling. The filling technology in this case means order of filling operations by which desired angle orientation (β) of material particles in the formed massif is achieved. In the literature, this angle is also called the angle of bedding orientation [15]. Reference plane to which angle β is usually measured is horizontal.

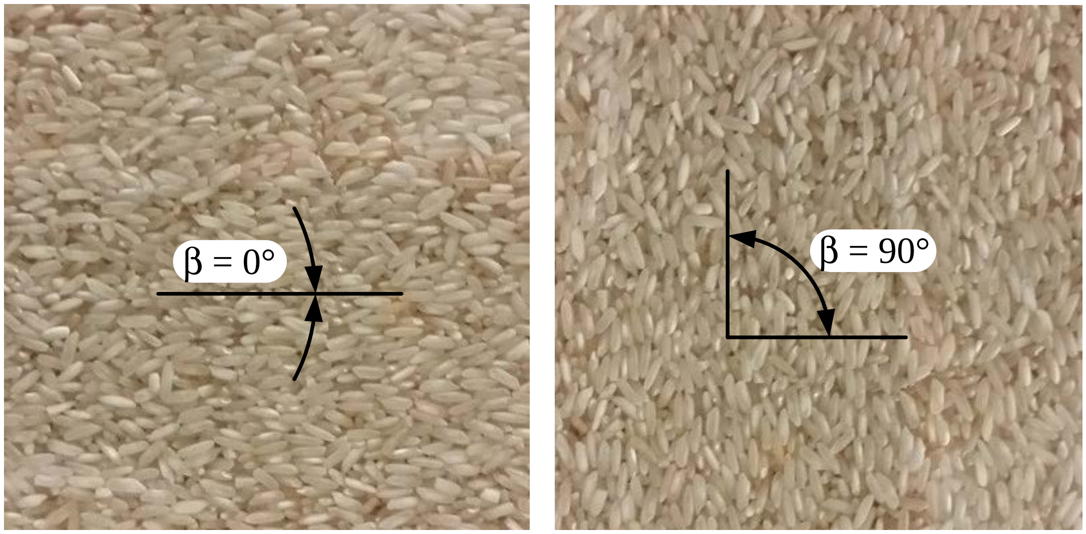

Figure 2: Prevail angle of orientation of rice grains to the horizontal β

Measuring of unit weight and particle size distribution were measured in accordance with the Croatian standards HRN U.B1.016 and HRN U.B1.018. respectively. The obtained data are presented in Table 1. It is very important to note that rice grains is organic matter, which in its composition contains water with an average of about 13%. Grains of rice were tested in a dry state.

Table 1: Basic physical characteristics

Property	Standard	Value (Rice)	Value (Shells)
Unit weight	HRN U.B1.016	γ = 8,85 кН/м^3	γ = 11,58 кН/м^3
Particle unit weight	HRN U.B1.014	γ_s = 13,72 кН/м^3	γ_s = 26,78 кН/м^3
Moisture	HRN U.B1.012	w = 13,69 %.	w = 0 %.

For the particle-size distribution used Apparatus Model 15-D0403 manufactured by Controls S.r.l., Italy. In accordance with the standard, the sieving process lasted 10 minutes. The granulometric curves are shown in Fig. 3.

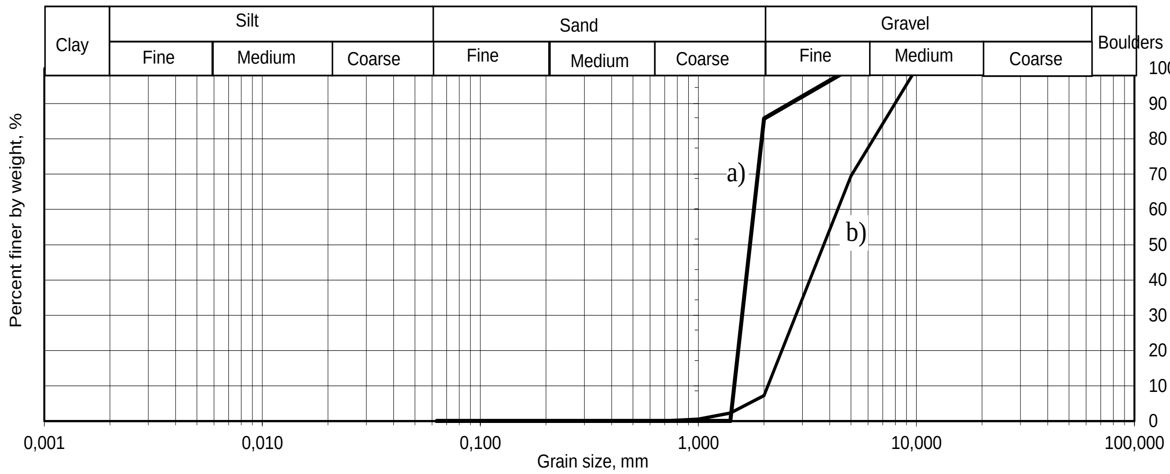

Figure 3: Particle-size distribution a) Rice b) Shells

The effective diameters (D10, D30 and D60), uniformity coefficient (CU) and coefficient of graduation (CC) were obtained from the particle-size distribution [4]. The results are shown in Table 2.

Table 2: Characteristics of the particle-size distribution

	Rice	Shell
D_{10}	1,60	2,10
D_{30}	1,70	2,80
D_{60}	1,80	4,40
C_U	1,13	2,10
C_C	1,00	0,85

The resulting uniformity coefficient for rice indicates a high degree of homogeneity of the medium. Uniformity coefficient near 1 indicates indicates the homogeneity of the medium, granulometric curve in this case is steep

Methodology of experimental research

Determination of the wall friction angle was carried out on a direct shear apparatus manufactured by "Premur" ltd. (Fig. 4). The device works on principle of constant shear velosity. The shear cell is driven by an electric motor, other side of cell rests on a dynamometer with a measuring limit of 3 kN.

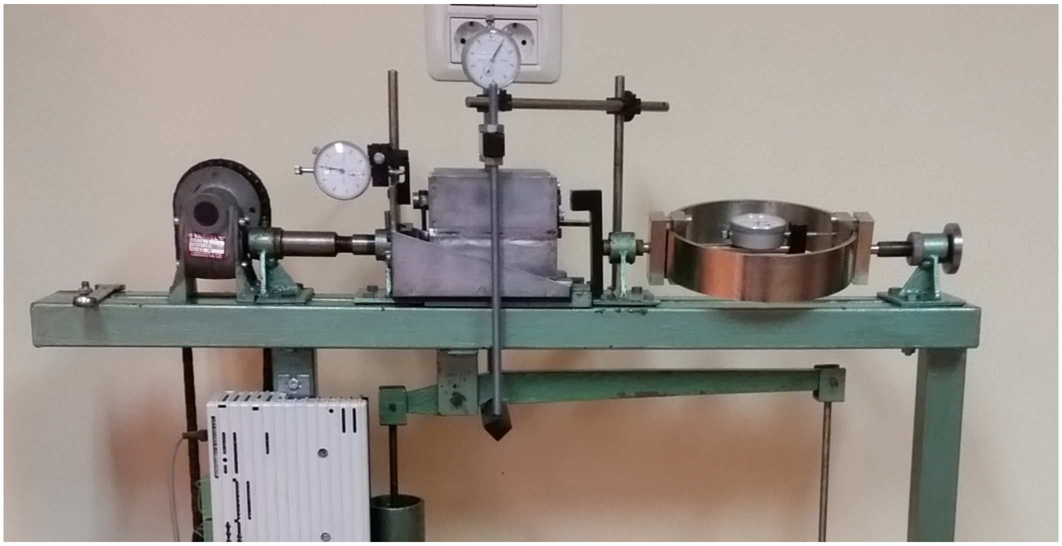

Figure 4: Direct shear apparatus

For purpose of experiment the direct shear equipment was adapted so that the upper casing was placed on the steel support, wich was same as wall material (Fig. 5).

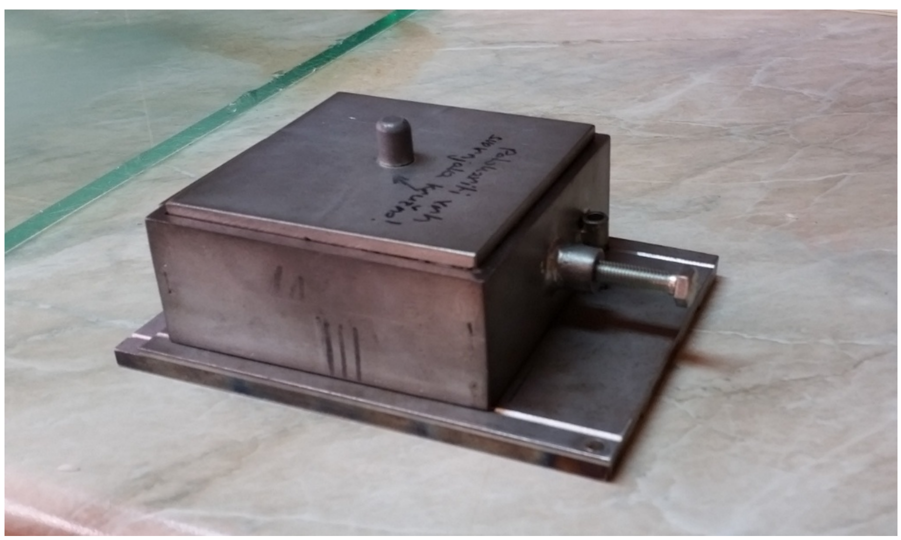

Figure 5: Adaptation of direct shear cell for measuring friction angle on steel

During the experiment, the horizontal force, horizontal and vertical movements was measured by dial idicator with a 0.01 mm graduation.

Direct shears were carried out in accordance with the British standard BS 1377; Part 7; clause 4 [2]. All materials were tested in a dry state. Unit weight was measured for each sample. All the experiments were carried out in strictly controlled laboratory conditions with a daily measurement of temperature and humidity of the air. The humidity in the laboratory fluctuated between 35% and 45%, and the temperature was 21° C to 28° C.

The angle of particle orientation (rice and shells) to the plane of shear $\beta = 0°$ and 90° (Figure 6). was achieved by specially developed filling in technology into the shear cell (Fig. 7). It is known that for rice and other bulk materials with a similar particle geometry, when pour on a horizontal surface, most grains lie horizontally on longer side, i.e. take a state of more stable equilibrium [12]. Using this property, the filling in was always carried out from above, when the position of the shear cell changes (Fig. 7b). After filling the cell up to the top, it was returned to the vertical, initial position, (Fig. 7a).

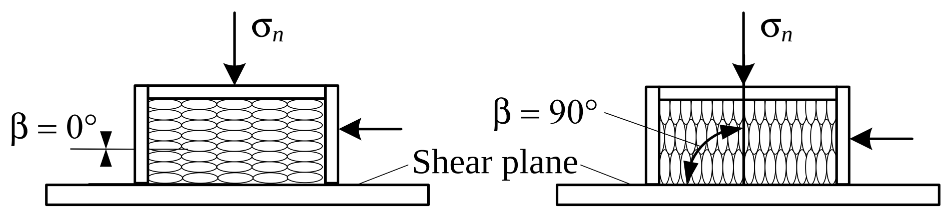

Figure 6: Layout of the model material in the direct shear cell at angles β = 0° and 90°

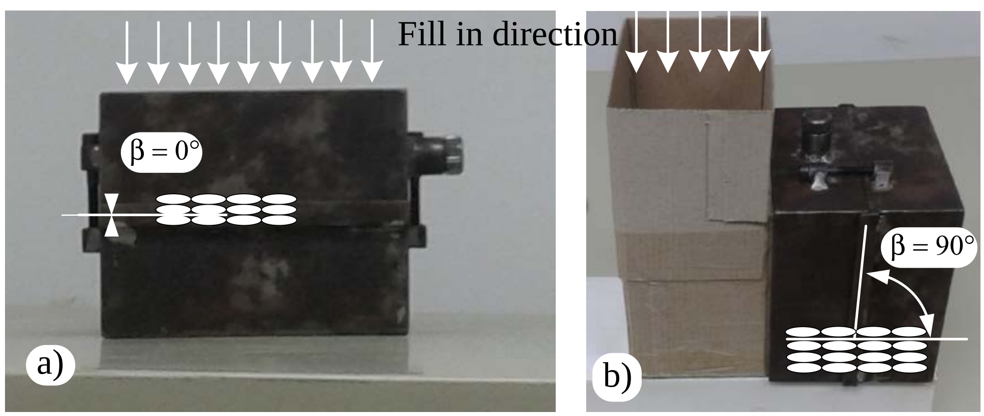

Figure 7: Achieving of the required filling angles β, a) 0°, b) 90°

Direct shears were carried out at a constant speed of 0.2 mm/min. Tangential stresses were calculated by deformations of the dynamometer which was measured during the shear. Vertical stresses used in the test was σ = 10 kN/m^2, 20 kN/m^2 and 40 kN/m^2.

Thus, testing of flat particles of selected granular matter made it possible to evaluate the effect of particle orientation angle to the wall plane on wall friction angle δ. Test results can be of interest to scientists who design silos for grain storage.

To determine wall friction angle, first of all, shearing stresses were calculated by the formula (1). Then a standard shear plot was constructed in the coordinate system where abscise is displacement x and ordinate tangential stress τ.

$$\tau = \frac{F_T}{A} = \frac{x_K \cdot K}{110(110 - x + x_K)} \qquad (1)$$

Where are: x_K is deformation of the dynamometer ring, K is the stiffness coefficient of the dynamometer ring, x –cell displacement.

RESULTS AND DISCUSSION

Experimental data statistically processed in Microsoft Excel are shown graphically for rice in Fig. 8 and 9, and for shells in Fig. 10 and 11.

The direct shear curves of the rice have a irregular, “jumpy” character, which was not observed during testing of shells. The nature of the curve can be explained by more complex shearing process of rice, in which, in addition to friction along the surface, the particles can rotate, roll over each other and break. Such a character of the curves during shear tests of the grain medium was obtained earlier in the works of the authors [3, 10], and it was concluded that the nature of the curve depends on the shearing speed, and as the test speed increases, the “jumps” decreases.

Data processing for rice was carried out by the technique mentioned in the paper [6], in which peak value of tangential stress was determined by curve of average tangential stress values. As a result, three peak values of τ were obtained for each vertical stress σ (Figures 8 and 9 b).

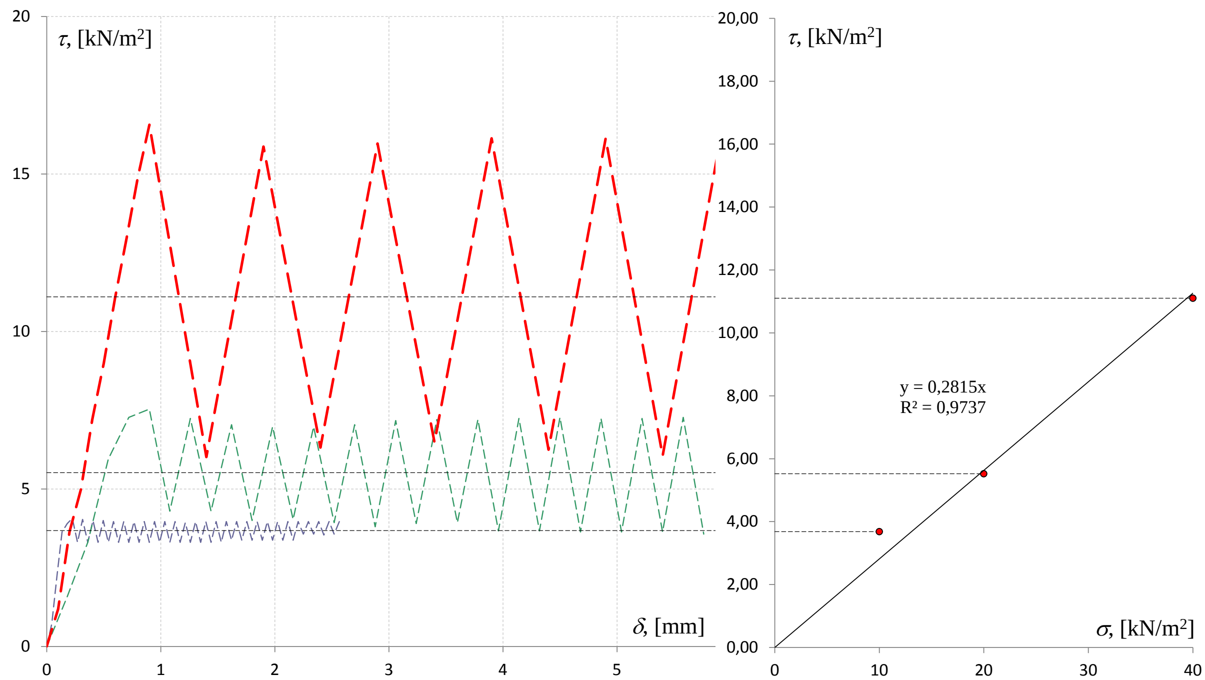

Figure 8: Analysis of rice friction data on steel for $\beta = 0°$

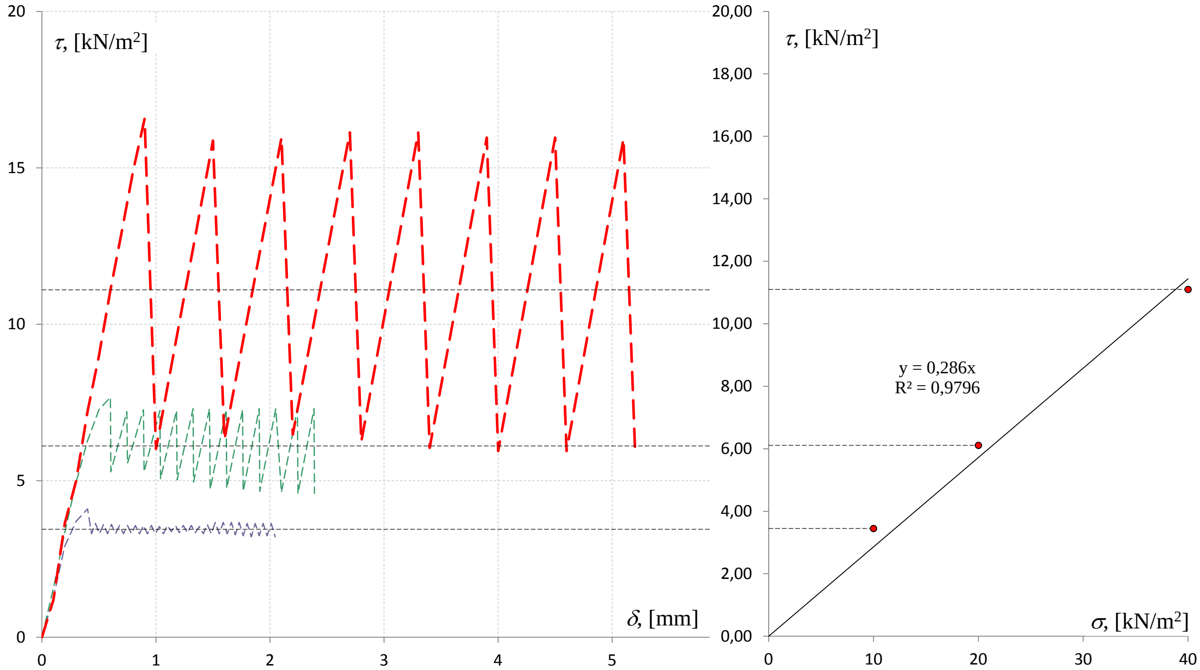

Figure 9: Analysis of rice friction data on steel for β = 90°

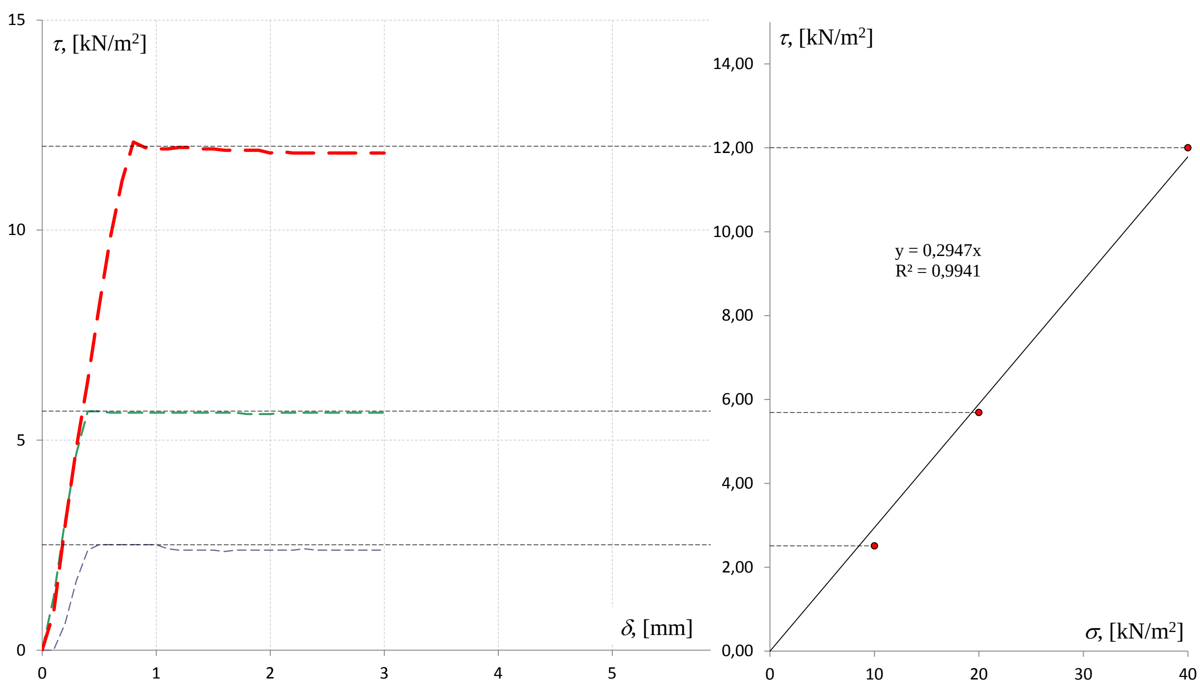

Figure 10: Analysis of shells friction data on steel for β = 0°

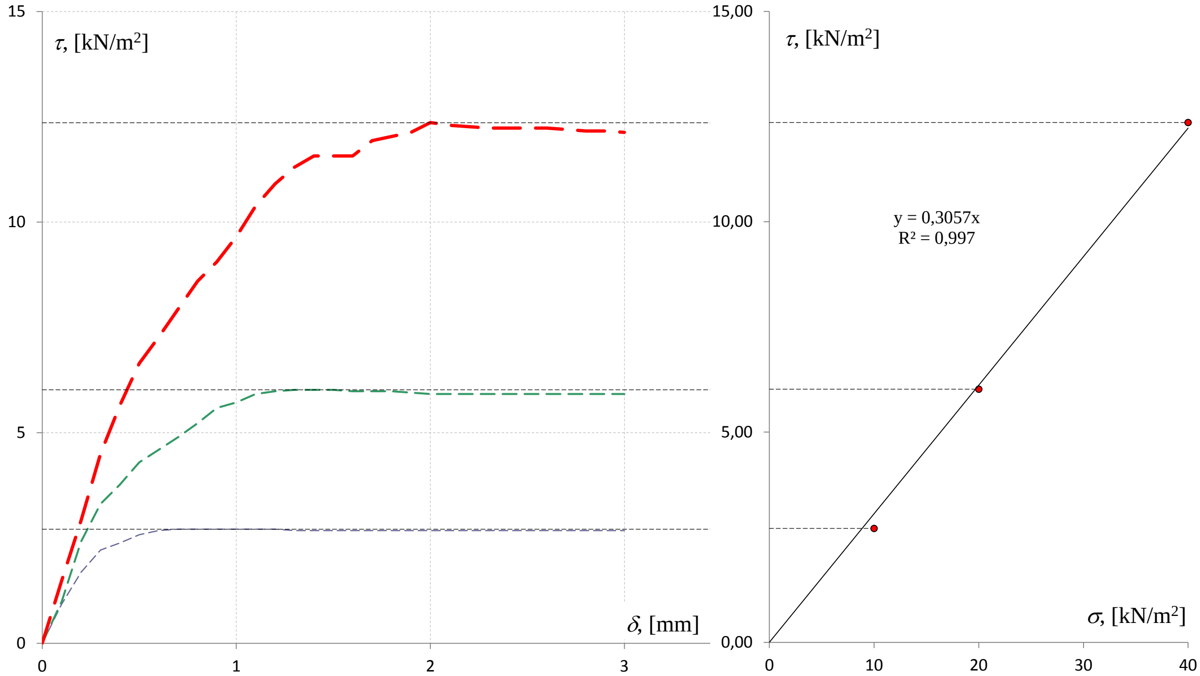

Figure 11: Analysis of shells friction data on steel for β = 90°

Summarized data on the friction angles are given in Table 3.

Table 3: Angle of friction on steel under various bedding orientation

Angle of particle orientation, β	0°	90°
Rice	15.72	15.96
Shells	16.42	16.99

The data obtained for the friction angles of rice on steel at angles of the prevailing particles orientation to the horizontal of 0 ° and 90° differ only by 1.5%, and for shells 3.5%. It is possible that in process of friction elongated particles of bulk particles against the wall, the grains almost did not engage stell plate as in the case of a shear failure inside the medium [1], hence the rotation of the grains over the metal was insignificant.

In work of Shkola [14], on the basis of calculations and analyzes of the majority of standard practical problems of soil mechanic is recommended to take anisotropic properties into account when changing the strength characteristics of soils along the directions of the angle of internal friction of at least 5% and the cohesion of at least 10%. Thus, it can be concluded that anisotropy of the wall friction of bulk particles on the steel wall is insignificant and can be neglected in practical calculations.

CONCLUSIONS

(1) The technology of filling in the direct shear cell with a different particle orientation is proposed.

(2) The friction angles of rice and flat shells on a steel wall at angle of orientation angles of 0° and 90° was measured.

(3) The angle of friction against the wall (δ) with respect to orientation angle of particles to horizontal direction β, in cases 0° and 90°, differs insignificantly, for rice 1.5%, and for the shells 3.5%, this difference in practical calculations can be neglected.

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