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THE STAND FOR LABORATORY TESTS OF LOOSE MATERIALS

1. INTRODUCTION

Loose materials used in proppants and bedding layer have several properties which distinguish them from other types of materials for e.g.: bulk density, grain size, angle of repose, friction coefficient of the internal and external, moisture and hardness. These materials exhibit distinct build from other types of commonly known materials transported by conveyors.

Knowledge of material properties is necessary for selection of proppants, bedding layer and also the proper the selection of construction the conveyors [2, 3].

2. DETERMINATION OF PROPERTIES OF SOLIDS BY EUROCODE-1

Norm EN 1991-4:2006 *Eurocode-1: Actions on structures – Part 4: Silos and tanks* is a European norm, which sets out the conditions for testing properties of bulk materials in terms of their impact on structures [7].

In paragraph 9 of *Eurocode-1* are given guidelines for carrying out direct shear tests of bulk material. The norm contains a procedure for conducting the study and interpretation of results [7].

The following are the requirements of Eurocode-1 for carrying out direct shear tests:

Set parameters:

- the angle of internal friction φ (Fig. 1),
- the coefficient of external friction μ_1 (Fig. 2).

Apparatus: cylindrical vessel (the cell) (Fig. 1).

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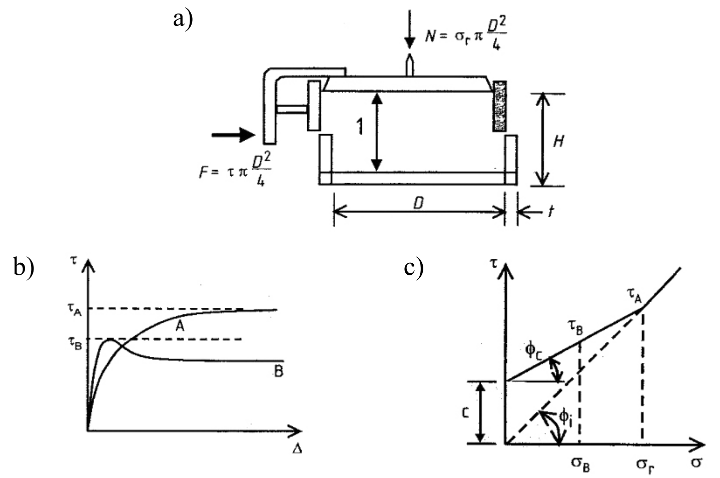

Fig. 1. Method for determining the angle of internal friction φ [7]: a) the shear cell; b) typical shear-displacement curves; c) typical relationships shear stress-normal force

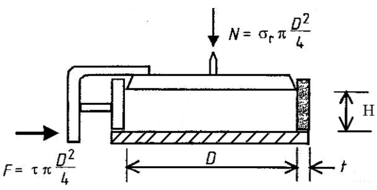

Fig. 2. Determining the coefficient of external friction μ_1 [7]

Cell diameter *D* should be 20 times greater than the maximum diameter of the particles of the material and not less than 40 times the average diameter of particles. The height *H* should be between 0.3 and 0.4 of the diameter *D*.

Procedure:

The test speed 0.04 mm/s.

Relative shift of both parts of the cell, with which to record the parameters is $\Delta = 0.06D$ [7].

The first attempt should be carried out under normal load *N* force to get a relationship with shear F_A. The second test should be conducted under the initial force *N* normal load until a shearing force as in the first case. Then attempt to stop and release the load. The second part should carried out under a load equal to half the normal load $N_B \approx N/2$ until a shearing force F_B.

The forces of aggravating the sample are shown in Table 1.

Table 1

Load values while trying to direct shear [7]

Test	Value of pre-load	Load value in test	Maximum tangential force
1	N	N	F_A
2	N	$N_B \approx N/2$	F_B

Interpretation of results:

Internal friction angle φ is calculated by the formula:

$$\varphi = \arctan(FA / N) \tag{1}$$

The coefficient of external friction μ is calculated by the formula:

$$\mu = \frac{F}{N} \tag{2}$$

where:

F – friction force,

N – normal force aggravating sample [7].

Relative offset table, followed by saving the measurement results according to the recommendations for standard cell ∅70 mm is Δ ≈ 5 mm for cell ∅110 mm Δ ≈ 7 mm. It was also the burden of five samples of materials which will be: N = 9 N, 10 N, 14 N, 18 N and 20 N.

2.1. The stand to carry out direct shear tests

Shear apparatus is used for determining the angle of internal friction of granular materials and the procedure for the measurement according to Jenike created in 1964. Angle of internal friction depends on the properties of individual grains of loose material and the structure of bulk [6].

General structure of the stand

The stand consists of a special splint, on which is positioned movable table. To them, by screws, is mounted measuring vessel. The splint is secured to a rigid frame made from aluminum profiles. The frame is attached to the gear motor, whose output is converted into rotary motion by means of screws in the sliding motion of the table. The load measuring vessel is carried by the lever to which is attached weight. The measurement of force controlled by the dynamometer is installed on the adjustable frame allows for the adjustment of the height of the dynamometer to the measurement vessel. The overall appearance of the stand, with the dimensions described in Figure 3.

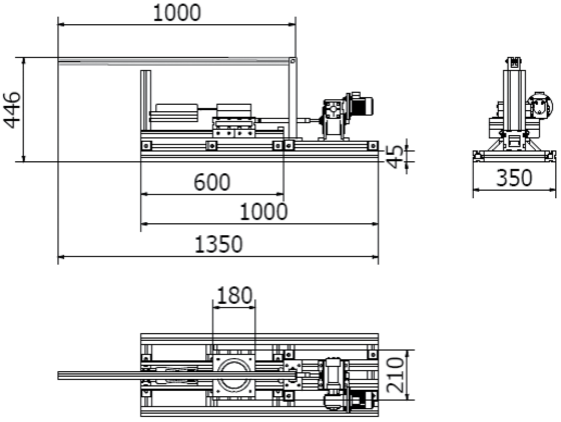

Fig. 3. Ready stand to carry out direct shear test

Parameters built station are summarized in Table 2.

Table 2

Basic parameters of the stand of the direct shear test

Engine		Gear motor		Table		Dynamometer
rotational speed [1/min]	frequency [Hz]	shift	output rotation speed	feed screw pitch [mm]	feed speed [mm/min]	the measured force [N]
1350	50	1:1200	1.12	1.5 / 2	1.68 / 2.24	0–50
1560	60		1.3		1.95 / 2.6	

Designed for the laboratory direct shear test allows for the testing of granular materials with different grain size, to evaluate the coefficient of internal friction and external friction of construction materials by holding them to the table instead of the bottom of the measuring vessel. The parameters of testing on the position are selected strictly in accordance with the norm requirements [7]. This provides values of the parameters characterizing the bulk material are useful in the design of conveyors to transport a particular type of material.

3. LABORATORY TESTS OF PROPERTIES OF SELECTED LOOSE MATERIALS FOR TEST THE STAND

3.1. The course of experimental tests

Experimental tests have assumed the measurements for determining the various properties of bulk materials [6].

For the study, there were used representative material transported various conveyors: politroksan, iron oxide, coal contaminated with sand and copper ore.

Table 3

The plan of the laboratory tests
conducted during the determination of properties of selected loose materials

Material	The measured values		
	angle of internal friction φ [°]	coefficient of external friction on steel μ_1 [°]	coefficient of external friction on conveyor belt μ_2 [°]
Politroksan Copper ore Iron oxide	5 tests 9 N, 10 N, 14 N, 18 N, 20 N Cell ∅70	5 tests 9 N, 10 N, 14 N, 18 N, 20 N Cell ∅70	5 tests 9 N, 10 N, 14 N, 18 N, 20 N Cell ∅70
Coal contaminated with sand	5 tests 9 N, 10 N, 14 N, 18 N, 20 N Cell ∅110	5 tests 9 N, 10 N, 14 N, 18 N, 20 N Cell ∅110	5 tests 9 N, 10 N, 14 N, 18 N, 20 N Cell ∅110

During the laboratory measurements on the stand there were carried out:

- internal friction angle φ for selected materials, by making measurements on a laboratory stand;
- the coefficient of external friction on steel μ_1 and μ_2 after the conveyor belt for carrying out measurements of selected materials.

The study plan is presented in Table 3, comparing the measured magnitude and manner of testing.

3.2. Results of the tests

In the study, there were done measurements for the prepared samples of materials. This was followed by measuring the angle of internal friction and external friction coefficient of steel and conveyor belt.

When performing physical measurements may have two types of errors: systematic and random, which takes into account when drawing up the results [5]. After the analysis obtained during the direct shear test results, plots designated for future materials with different loads. Then, on the basis of the results were compared with the values of the angle of internal friction and the coefficient of friction on steel and the conveyor belt in literature [6].

Angle of internal friction φ

For the final phase of the shear tests, when followed by stabilization of the shear force has been stretched out the average value of the force F. Since the value of the subtracted value of the force of friction for an empty cell. Then, by the formula:

$$\varphi = \mathrm{arctg}\frac{\mathrm{F}}{N} \tag{3}$$

was calculated the value of the angle of internal friction.

Before the test materials was carried out shear test for an empty cell, in order to obtain values of resistance movement of the vessel. After calculating the average value of force *F* with the measurement made, the value of resistance to motion an empty cell. This value is then subtracted from each measurement obtained [8].

The coefficient of external friction on steel μ_1 and on conveyor belt μ_2

As for measuring the angle of internal friction, for the last stage of the shear tests, pulled out as the average value of the force *F*. Since this value was subtracted accordingly the force of friction for an empty cell in the steel and the conveyor belt.

The results of all completed during the laboratory measurements are summarized in Table 4.

Comparison of results obtained with the values reported in the literature [6] is presented in Table 5.

Table 4

Results of the laboratory tests

Material	Angle of internal friction φ [°]	Coefficient of external friction on steel μ_1	Coefficient of external friction on conveyor belt μ_2
Politroksan	35.26	0.449	0.388
Brown coal dust	36.57	0.536	0.428
Iron oxide	37.84	0.757	0.636
Coal contaminated with sand	47.77	0.658	0.599
Copper ore	44.71	0.517	0.413

Table 5

Comparison of results obtained in tests with the values reported in the literature [6]

Material	Angle of internal friction φ [°]		Coefficient of external friction on steel μ_1		Coefficient of external friction on conveyor belt μ_2
	test	literature	test	literature	test
Politroksan	35.26	–	0.449	–	0.388
Brown coal dust	36.57	35	0.536	0.577	0.428
Iron oxide	37.84	40	0.757	0.781–1.191	0.636
Coal contaminated with sand	47.77	45–48	0.658	0.7	0.599
Copper ore	44.71	45.5	0.516	0.577–1.0	0.413

4. CONCLUSIONS AND INTENSIONS

An analysis of the literature related issues with the methods of determining selected properties of bulk materials. There were designed and built the stand to carry out direct shear tests according to Eurocode-1 norm. The results allowed the development to determine the values of the angles of internal friction, the coefficients of external friction on steel and on conveyor belt.

The studies led to the following conclusions:

1. The laboratory stand designed and built for the purpose of carrying out these tests allows you to perform tests in accordance with the norm recommendations, which allows to obtain reliable results.

2. Built stand has parameters allow testing for the majority of material transported conveyors.
3. The tested materials have a lower coefficient of friction for the outer belt than for steel.
4. Based on the comparison of results from the literature can be concluded that the properties of materials depend largely on the state in which the material is given time, it is necessary to determining the parameters for specific conditions [6].

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