# Static and kinetic friction of rapeseed

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**Abstract**: The present paper examines the static and kinetic coefficient of friction of rapeseed. The project utilized two methods of determination of coefficient of friction of rapeseed: according Eurocode 1 (kinetic) in direct shear test and (static) in model silo. Samples of rapeseed in a range of moisture content from 6 to 15% w.b. were used and the tests were performed for galvanized steel, stainless steel and concrete B 30. Coefficient of friction for both steel types approached stable value for all levels of moisture content w.b. in a range from 0.11 to 0.18, for concrete B 30 it was found in a range from 0.25 to 0.43. The coefficient of static friction found in model silo decreased with an increase in vertical pressure from 0.3 to 0.2 for first loading, while in subsequent loading cycles decreased from 0.2 to 0.1.

**Keywords**: rapeseed; static friction; kinetic friction; galvanized steel; stainless steel; concrete B 30

Coefficient of friction, bulk density and pressure ratio are the important mechanical parameters commonly used to calculate loads exerted by grain on storage structures. The coefficient of friction depends on the type of grain, bulk density and strongly on the roughness of the wall surface. Grain moisture content is also considered one of the main reasons for variability of the coefficient of friction (Mohsenin 1978). Numerous researchers reported that coefficient of friction on various sliding surfaces was dependent on normal pressure (Thompson & Ross 1983). Molenda *et al.* (2000) measured force of friction between granular materials and corrugated steel surfaces using a modified direct shear tester. The tester was slightly different from most conventional devices in that the tested material (steel) was pulled to create a shear plane as it was moved within stagnant pressurized granular material. Tests were performed at three different normal pressures of 6.9, 27.6 and 48 kPa for four speeds 0.05, 0.5, 5 and 50 mm/min for red winter wheat on corrugated steel and smooth galvanized steel. Friction forces were measured using a tilting table test method, too. These authors found that the values of the coefficient of friction strongly depended on the measuring method. Widely scattered results were usually observed while measuring friction forces in a range of normal pressure below 25 kPa.

According Eurocode 1 tests to determine the wall friction coefficient (kinetic) for calculation of loads should be determined at a particle packing density and at stress level corresponding to conditions in the stored solid in the silo (Eurocode 1 2003). Horabik and Rusinek (2000) measured coefficient of friction of cereals grains (barley, wheat, oat and rye) against galvanized steel, stainless steel and concrete following procedure recommended by the Eurocode 1 in the Jenike shear cell and using tilting table. The authors concluded that the coefficient of friction depended strongly on roughness of wall material and surface properties of grain (Laskowski *et al.* 2005; Molenda & Horabik 2005).

The objective of the reported project was to determine coefficients of friction of rapeseeds against typical silo wall materials and to compare results with cited above.

## MATERIALS AND METHODS

Rapeseeds of varieties Licosmos and Lirajet having moisture content in a range from 6 to 15% w.b. were used for testing (Ohlson & Appelqvist 1972). The coefficients of friction were determined according to Eurocode 1 (2003) for galvanized steel, stainless steel and for B 30 (kinetic friction) and in model silo for loading/unloading cycles (static friction). A schematic diagram of the direct shear test apparatus applied is shown in Figure 1. The test apparatus was a cylindrical shear cell of the diameter of 0.21 m and 0.08 m high. The sample of seeds was poured into the cell, without vibration or other compacting forces and covered with the top plate. Normal reference stress $\sigma_n$ was applied and

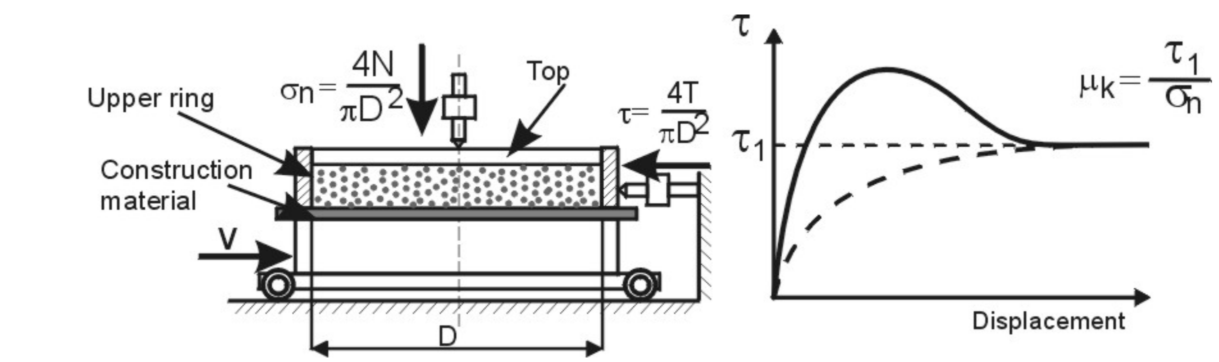


Figure 1. Schematic drawing of the direct shear tester for measuring the coefficient of friction of granular material on steel and concrete surface

the top plate was rotated backwards and forwards three times through an angle of 10 degrees to consolidate the sample. The normal reference stress in a range from 20 to 60 kPa was applied. Shearing of sample was carried out at a constant rate of approximately 0.04 mm/s. The coefficient of wall friction $\mu_k$ was determined as a ratio of value of shear stress τ to the applied normal vertical stress $\sigma_n$ (see Figure1).

The stainless steel model silo 0.6 m high and 0.6 m in diameter was constructed and instrumented to measure mean horizontal stress $\sigma_x$, mean tangent stress on the wall $\sigma_t$, as well as distribution of vertical pressure $\sigma_z$ along the radius of the silo (Figure 2). 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 was constructed of galvanized steel 3 mm thick. Top and bottom plates, both consisted 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 2000). The average value of the static coefficient of wall friction $\mu_s$, was calculated as tangential to horizontal stress ratio (Figure 2). Rapeseeds of Lirajet variety at four levels of moisture content (6, 9, 12 and 15% w.b.) were used for testing. Each variant of the experiment was performed in three replications. Normal pressure in a range from 20 to 60 kPa was applied in direct shear tests, while in a model silo tests pressure ranged from 2 to 6 kPa. The results obtained using direct shear test and model silo were compared.

## RESULTS AND DISCUSSION

The typical curves of the measured stress τ versus relative displacement $\Delta L/D$ obtained in direct shear apparatus are shown in Figure 3. Three distinct parts may be observed in the experimental curve; first (A–B) – was nearly vertical and corresponds to hardening of material by grain reorientation under shearing strain with an increase in a number of contact points between particles and steel; second (vicinity of point B)

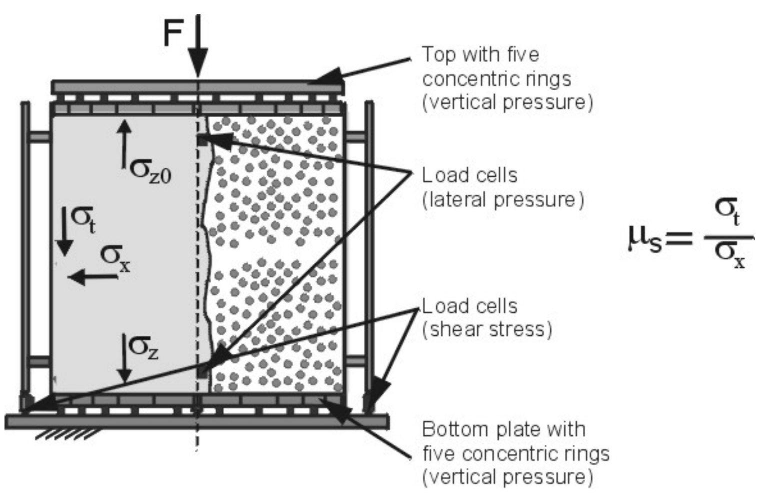


Figure 2. Schematic diagram of the stainless steel model silo 0.6 m high and 0.6 m in diameter

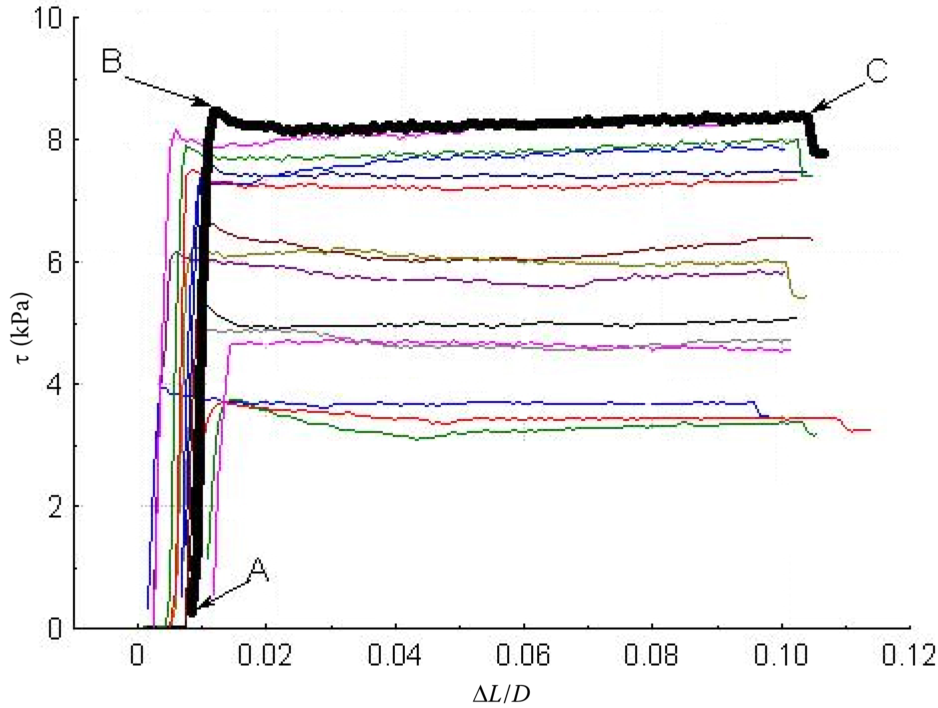


Figure 3. Typical shear stress τ versus relative displacement $\Delta L/D$ relationships for rapeseed variety Lirajet sliding against stainless steel in direct shear apparatus

– approaching maximum of static friction stress; and third (B–C) – nearly horizontal curve reflecting kinetic friction. The static friction was generally higher than the kinetic friction.

Coefficients of friction determined for stainless steel and galvanized steel reached stable value in a range from 0.13 to 0.16 for all levels of moisture content (see Figure 4). The values of coefficient of friction obtained for concrete B 30 were found in a range from 0.35 to 0.43, increasing with an increase in moisture content.

Thompson and Ross (1983) applied normal pressure in a range from 7 to 172 kPa. These authors observed a decrease in the coefficient of friction with an increase in normal pressure. Tests were performed for wheat against steel. A similar tendency was observed in our testing for both steel types in a pressure range from 20 to 60 kPa (Figure 5). Coefficient of friction of rapeseeds against concrete B 30 was found nearly stable in a range of applied pressure, having value of approximately 0.35.

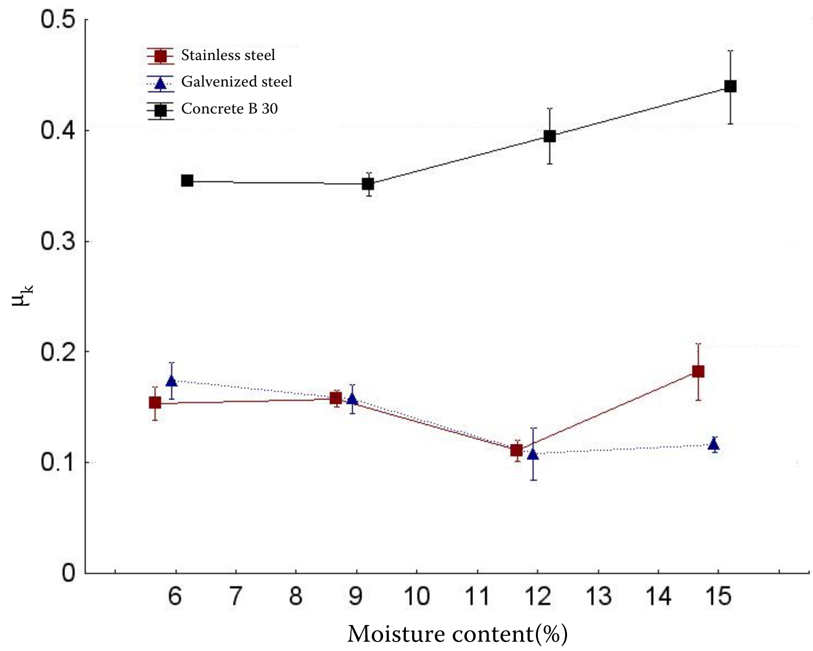


Figure 4. Kinetic coefficients of friction $\mu_s$ determined in shear test for rapeseed variety Licosmos of four levels of moisture content w.b.

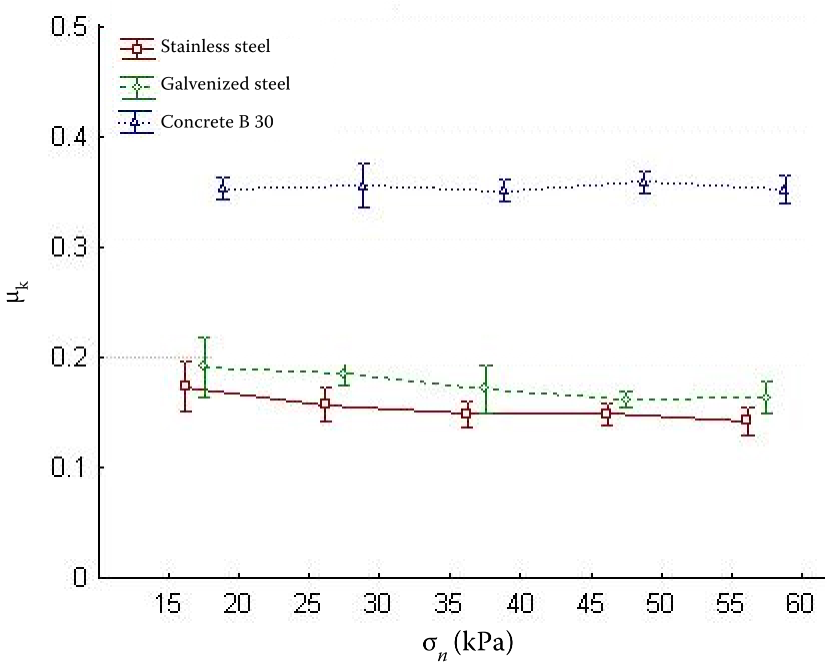


Figure 5. Kinetic coefficient of friction $\mu_k$ determined in shear test for rapeseed variety Licosmos of five levels of normal pressure

As shown in Figure 6 static coefficient of friction $\mu_s$ found in model silo tests followed approximately level course of 0.2 during the first loading cycle, and for unloading decreased to approximately 0.08. During unloading tangent component of wall stress decreased or even changed its direction leading to decrease in coefficient of friction. For subsequent cycles of loading/unloading values of coefficient of friction followed hysteresis loops slightly lower than the first $\mu_s(\sigma_h)$ path. The loops formed as a result of combination of reversible deformations of seeds and rearrangements of packing structure with new frictional bonds forming during loading-unloading cycles. In Figure 5 $\mu_s(\sigma_h)$ relationships for higher levels of seeds moisture content are shown as well. Increase in moisture content resulted in an increase in initial coefficient of friction (up to approximately 0.25) the most probably due to increase in seed-to-seed coefficients of friction. With an increase in moisture content the minimum value of $\mu_s$ observed at the end of unloading distinctly decreased reaching the lowest of all observed value of 0.02 for moisture content of 15% w.b. This effect is probably a result of decrease in modulus of elasticity of seeds

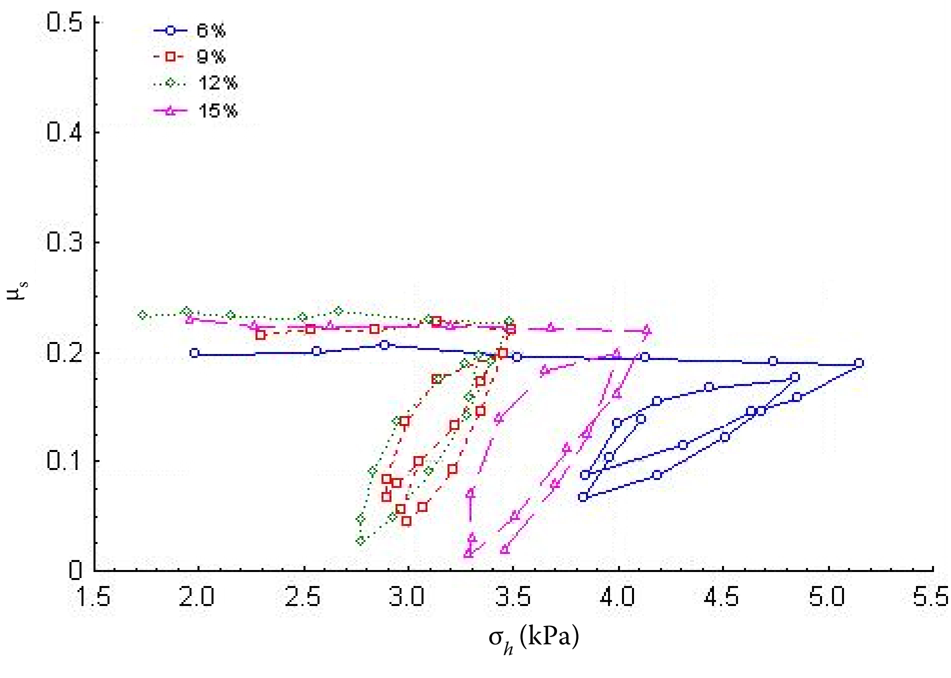


Figure 6. Static coefficient of friction $\mu_s$ determined in model silo for rapeseed variety Lirajet of four levels of moisture content w.b.

that allowed for larger deformation of seeds and relatively stronger rebound of wall tangent stress during unloading.

**Comparison of direct shear and model silo tests**

Direct shear and model silo test were performed with rapeseed on stainless steel. Maximum of normal pressure applied in model silo test was approximately ten times lower than that in direct shear test. Static coefficients of wall friction obtained in model silo ranged from 0.2 to 0.02 depending on degree of mobilization of friction forces. Values of the kinetic coefficient of friction of approximately 0.16 obtained in direct shear test were in reasonable agreement with the model silo values in the case of the load increase phase of loading/unloading cycle.

## CONCLUSIONS

In direct shear tests, under normal pressure up to 60 kPa, mean values of coefficients of kinetic friction $\mu_k$ of rapeseeds of moisture content from 6 to 15% w.b. against stainless and galvanized steel were found in a range from 0.11 to 0.18, without clear tendency of variation.

Coefficients of friction against concrete increased consequently with an increase in moisture content from 0.35 to 0.44. With an increase in normal load up to 60 kPa coefficients of friction of dry rapeseed against galvanized or stainless steel slightly decreased, respectively while $\mu_k$ remained approximately equal to 0.35 in the case of concrete.

Testing in model silo of stainless steel walls under load cycling to 5 kPa has shown strong dependence of coefficient of friction $\mu_s$ on the state of stress. During initial increase in load only small variations in the coefficient of friction were observed (around value of 0.19 in the case of 6% w.b.). Decrease in load resulted in distinct decrease of coefficient of friction (to 0.08 for dry seeds). This wide variation in $\mu_s$ may be attributed to variation in wall tangent (frictional) stress corresponding to compaction – expansion of material under cycling normal pressure. Range of variability of $\mu_s$ was found larger in the case of wetter seeds.

Coefficient of friction on stainless steel measured in model silo during load increase was found in reasonable agreement with that obtained in direct shear test.

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Received for publication September 26, 2006
Accepted after corrections October 17, 2006



**Abstrakt**

Rusinek R., Molenda M. (2007)**: Statické a kinetické tření řepkových semen.** Res. Agr. Eng., **53**: 14–19.

Práce se zabývá výzkumem koeficientu statického a kinetického tření řepkových semen. Projekt použil dvě metody zjišťování koeficientu tření řepkových semen: podle Eurokódu 1 přímou smykovou zkouškou (u kinetického tření) a testem v modelovém silu (u statického tření). Byly použity vzorky řepkového semena o vlhkosti v rozmezí 6 až 15 % hmotnostního základu na povrchu pozinkované ocele, nerezové ocele a betonu B 30. Koeficient tření pro oba druhy ocele se blížil stálé hodnotě při všech úrovních vlhkosti v rozmezí od 0,11 do 0,18. Pro beton B 30 byly zjištěny koeficienty v rozmezí 0,25–0,43. Koeficient statického tření, zjišťovaný v modelovém silu klesal s růstem vertikálního tlaku z 0,3 na 0,2 při prvním plnění, zatímco v dalších cyklech plnění klesl z 0,2 na 0,1.

**Klíčová slova**: řepkové semeno; statické tření; kinetické tření; pozinkovaná ocel; nerezová ocel; beton B 30

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