INVESTIGATION OF FRICTION COEFFICIENT BETWEEN VEHICLE BODY AND SOIL

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Abstract

If a vehicle leaves the on-road, and enters the terrain, its movement is determined by the physical and mechanical laws of terrain-vehicle interaction. The problem with the run-off-road accidents is that the effect of the soil physical properties are not known clearly, so that in many cases only approximate results can be provided by the accident analysts. The objects of the project were to create a soil-database, and determine the friction coefficient between the vehicle body and the terrain surface.

Keywords

terramechanics, accident, friction coefficient

Introduction

The travel resistance of a vehicle running on to terrain after collision is determined by the rolling resistance, bulldozing resistance, slope resistance, air resistance, slowing effect of engine brake or vehicle brake, if the vehicle spins around its vertical axis then resistance due to vehicle spin and if the vehicle turned over then frictional resistance of vehicle body (Kiss, 2009). The problem with the road-leaving accidents is that the effect of the soil physical properties are not known sufficiently, so that in many cases only approximate results can be provided by the accident analysts (Pillinger and Kiss, 2011).

Complex field measurement series were performed by the colleagues of Department of Automotive Technology of Szent István University. The purpose of the project was to determine the friction coefficient between the soil and the vehicle body in case of overturn.

Examination of friction coefficient

To determine the coefficients of friction, pulling tests were performed, and soil parameters were also measured by in situ and laboratory devices. Friction between the soil and vehicle body, traction force, speed, and different soil conditions (cone index, moisture content, physical properties) were examined during the experiment. The test vehicle was a UAZ-469B type off-road vehicle, and a John Deere 6600 was used as puller (Fig. 1-2.). A special converted forklift was used to turn over the test vehicle to its body side. A purpose-designed drawbar mechanism was used for the pulling tests (Fig. 3.). The measurements were carried out on different soil conditions: concrete, grassy field, stubble-field, disc-tilled field and cultivator-tilled filed at a speed of 5-10-15 km/h.

Figure 1. UAZ set up for measurement.

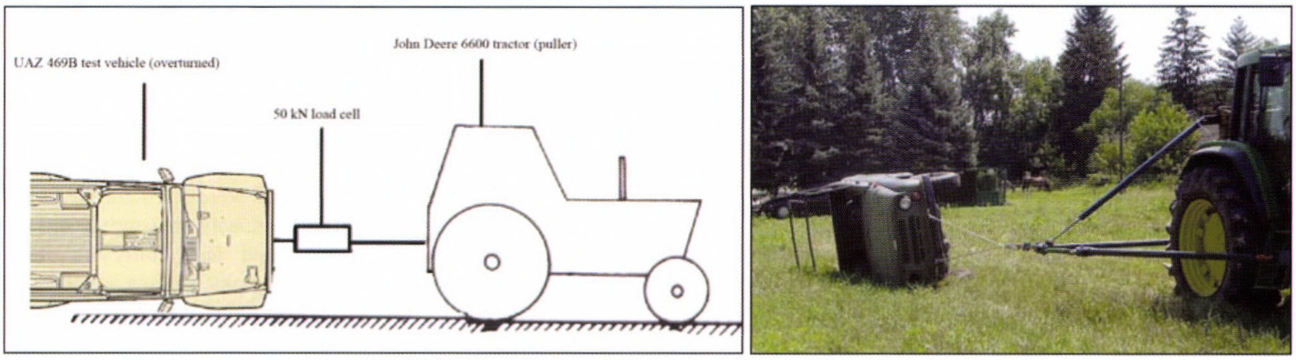

Figure 2. Set up of the field measurement.

Measurement devices

The following equipments were used at the measurements: purpose-designed drawbar mechanism and converted forklift (Fig. 3.), 50 kN load cell (Fig. 4.), measurement battery, Spider-8 data collection and measurement computer (GDS Instruments, Hampshire, United Kingdom), Eijkelkamp Penetrologger (Fig. 4.) (Eijkelkamp, Giesbeek, The Netherlands), PCE-SMM-1 field soil moisture meter (PCE Instruments, Southampton, United Kingdom), soil sampling cylinders (Fig. 4.), wheel load weighers to measure vehicle weight.

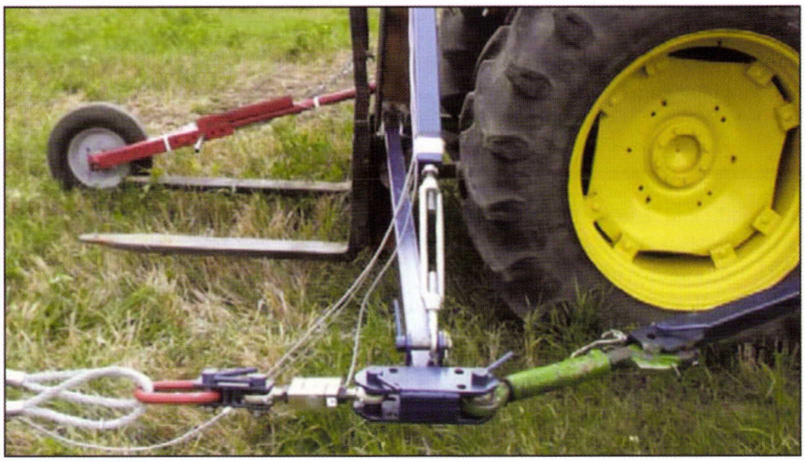

Figure 3. Purpose-designed drawbar mechanism with a converted forklift.

Figure 4. Eijkelkamp Penetrologger, soil sampling cylinders, load cell.

Results

Table 1. shows the physical characteristics of the test field. The measurements were performed with the help of staff of the Institute of Soil Science of Szent István University.

Table 1. Physical properties of the test field.

Field condition:		Stubble-field	Disc-tilled	Cultivator-tilled
Soil type:		Loamy sand		
Moisture content (% dry basis)	[%]	15.8	11.5	10.8
Pore volume	[%]	36	38	42
Dry bulk density	[g/cm³]	1.61	1.65	1.52
Vegetation:	-	Stubble+weeds	A few weeds	No plants

Table 1. Physical properties of the test field.

$$F_t = \mu \cdot m \cdot g \cdot \cos\alpha \pm m \cdot g \cdot \sin\alpha \quad [\mathrm{kN}] \tag{1}$$

$$\mu = \frac{F_t \cdot \cos\alpha}{m \cdot g} \mp \mathrm{tg}\alpha \quad [-] \tag{2}$$

Where: F_t – traction force; m – mass of test vehicle; g – gravitational acceleration; μ - friction coefficient; α – slope angle.

The pulled vehicle's weight was measured by wheel load weighers. The measured mass was 1310 kg. The pulling force was measured in the tests. The speeds were 5, 10 and 15 km/h, and each test was performed on a previously undisturbed surface of grassy field, stubble, disc-tilled and cultivated land. Measurements were carried out on concrete surface as well.

The friction coefficients were determined at each surface type. Table 2. gives the values of the coefficients. The field coverage is an important factor during the investigation. The concrete was dry and without dirt. The grassy field was covered by 5-10 cm high vegetation, mainly grass. The stubble field was covered by 15-25 cm high weeds and harvested corn stalks. On disc-tilled field only rare weeds were recognized and the cultivator-tilled field was without vegetation. Table 2 gives the cone index (CI) values at a depth of 5 and 10 cm as well, characterizing the soil's load-bearing capacity. The measurements were performed for all soil conditions, taking the soil moisture content into account. The average slope angle, that was taken into consideration during the evaluation, on the test field was $\alpha = 1.1°$. The slope angle on concrete was $\alpha = 0°$.

Table 2. Results of examination of friction coefficients.

Field condition	**Traction speed (v) [km/h]**	**Traction Force (F_t) [kN]**	**Friction Coefficient (μ) [-]**	**Cone Index (CI_5) [MPa]**	**Cone Index (CI_{10}) [MPa]**	**Comment**
Concrete	5	6.6	0.518	80	80	Dry, without dirt
	10	5.4	0.424			
	15	5.2	0.405			
Grassy field	5	7.8	0.591	2.146	2.345	5-10 cm high vegetation
	10	8.1	0.607			
	15	8.2	0.621			
Stubble-field	5	12.2	0.932	0.809	1.185	15-25 cm high vegetation
	10	-	-			
	15	-	-			
Disc-tilled field	5	12.4	0.946	0.427	1.498	Rare vegetation
	10	13.1	0.993			
	15	-	-			
Cultivator-tilled field	5	14.1	1.081	0.034	0.048	No vegetation
	10	16.1	1.227			
	15	-	-			

Conclusions

In case of two rigid bodies, the magnitude of friction force is commensurable to the normal force; its direction is parallel to the contact surface. In this situation the friction coefficient depends on the quality of the contact surface. If a rigid body gets in contact with a deformable surface, further factors affect the value of friction coefficient. Table 1. shows that on terrain the value of friction coefficients increased as traction speed increased as well, and the looser the soil structure became, the greater the value of friction coefficients. It can be seen on concrete that the value of friction coefficients decreased as speed increased. It is due to the multiple repeated pulling tests where the vehicle body side and the protruding parts were deformed and dulled, thus the value of friction coefficients decreased. It can be concluded from the researches that on terrain the coefficient of friction depends on more parameters. Their effects are different, field measurements are required to determine the significance of each factors, which are the following in order of importance:

Normal force: The greater the normal force (vehicle mass), the greater the soil deformation and the probability of bulldozing-effect.

Surface quality: The smoother the vehicle's and soil's surface, the smaller the friction coefficient. The vegetation can redound the bulldozing-effect.

Material of deformable surface: It is expressed by the cone index (CI) that describes the load bearing capacity of the soil. This is a measurable soil parameter. It depends on the moister content and the physical-mechanical properties of the soil

Area of contact surface: The contact area between the vehicle body and soil affects the soil deformation and increases the possibility of bulldozing formation.

Geometry of surface: The protruding parts of vehicle body increase the value of friction coefficient and these can cause bulldozing.

Speed: The higher the vehicle's speed on terrain, the greater the extent of bulldozing.

During the analysis of an off-road accident, the auxiliary tables and values, which can be found in technical literature, are not enough to determine the most important parameters. In situ field measurements are required after an accident in order to recognize the real factors that affected the accident.

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