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IN-PLACE DETERMINATION OF TOPSOIL SHEAR PROPERTIES FOR OFF-ROAD VEHICLE TRAFFIC

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Abstract: The study of the off-road vehicle traffic consists in estimating the drawbar pull of a vehicle on a given soil and can be calculated by means of such models as that of Janosi–Hanamoto which depends on the soil mechanic parameters, i.e., the angle of friction and cohesion. These parameters result generally from shearing tests. The annular shearing test is often used to estimate the soil shearing in mobility studies. Other shearing test is the translation shearing test which consists in the translation, at a constant speed, of a loaded plate with a smooth interface or with grousers. This article aims to present the validation of the translation shearing test for the study of the shearing of the granular surface soils and the method allowing us to link this operational test with the efforts measured during full-scale tests. An experimental device was developed to perform superficial translation shearing tests of a loaded plate at slow speed or fast speed to obtain the shearing forces.

1. INTRODUCTION

The movement of a vehicle on a soil induces two types of opposite forces. Under off-road conditions, the running gear, composed of tracks or wheels, sinks down into the surface soil and encounters obstacles which cause a resistance to the movement. At the same time, it provides a tractive effort making it possible for the vehicle to advance. This effort results from the transmission of the engine torque to the soil. The study of these resisting and driving forces is necessary to model the movement of a vehicle.

Within an investigation of a global mechanical device for mine clearance, full-scale tests were carried out on various soils to identify the mechanisms influencing the movement of a vehicle and to validate the models developed. In order to reproduce and to study the two principal mechanisms, a prototype experimental device was developed allowing sinkage tests and translation shearing tests (BENOIT [1], BENOIT et al. [3], GOTTELAND and BENOIT [4]). This can be effective to model the tractive effort of a vehicle, provided that the phenomena brought into play are well understood.

This article reports the validation of the translation shearing test for the study of granular top soil shearing. The experimental study presents: the prototype device allowing the translation shearing tests and the granular soil testing. The results are given and the phenomena are modelled to understand the soil's failure mechanism.

2. EXPERIMENTAL METHODS AND SOIL TESTED

2.1. EXPERIMENTAL DEVICE

In order to reproduce the mechanisms associated with soil shearing by the running gear, a prototype experimental device was developed (Upadhyaya et al. [2], Benoit [1]) providing a shearing test by the translation of a plate (see figure 1).

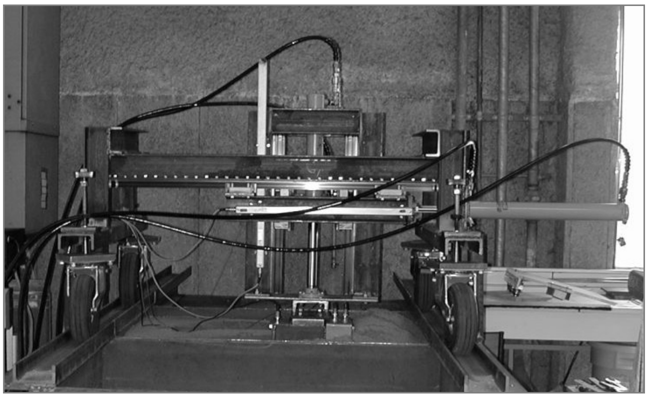

Fig. 1. Translation shearing test with the prototype experimental device

This test is carried out with the translation on approximately 400 mm, at a slow constant speed (~23 mm.min^{-1}) or fast (~840 mm.min^{-1}), with an instrumented shear head (see figure 2) loaded vertically. Five parameters are measured simultaneously: the horizontal displacement j, the vertical displacement (sinkage) z, the vertical load N, the total horizontal force T_{total}, the bulldozing force T_{bull}. The shearing force T is calculated as the difference between the total horizontal force and the bulldozing force ($T = T_{\text{total}} - T_{\text{bull}}$). Horizontal and vertical displacements are measured. The shear plate (340 mm length (L), 240 mm width (l)) can have a smooth interface to represent the soil–steel friction, a bin interface to confine the soil inside and to reproduce a soil–soil friction, and an interface with grousers to study their influence.

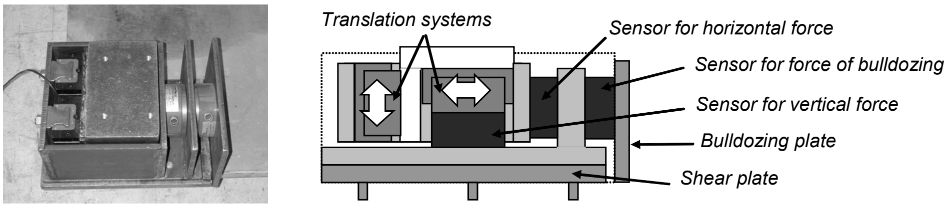

Fig. 2. Instrumented shear head

2.2. THE SOIL TESTED AND EXPERIMENTAL PROTOCOLS

The translation shearing tests were carried out on 0/5-mm sand. Extracted underwater, it has less than 0.3% fine particles (<80 mm) and 85% of particles smaller than 2 mm. Its low content of fine particles makes it insensitive to water. The primarily siliceous grains are angular. The French GTR classification [5] of this sand is D1 with a friction angle close to 33° and a cohesion close to zero (<1 kPa). The behaviour of this sand can be considered as purely frictional. In the translation shearing tests presented, the device is fixed on a 1 m^{-3} bin (0.8 m height, 1 m width, 1.3 m length). The sand set-up is defined by a protocol so that the bulk density can be reproduced. The average bulk unit weight obtained is 16.3 $kN.m^{-3}$. The water content was also controlled by four samples per layer that were dried and weighed (see the table).

Table

Properties of D1 sand

D1 sand	Properties	Mean value	Variability
Mechanical characteristics (triaxial tests, direct shearing tests)	Friction angle Cohesion *c*	33° <1 kPa	6% –
(translation shearing tests)	Water content *w* Bulk unit weight	1.2% 16.3 $kN.m^{-3}$	6% 5%

2.3. EXPERIMENTAL RESULTS

Two phenomena were studied: the relationship between the normal load *N* and the shearing force *T* as well as the sinkage of the instrumented shear head induced by the shearing of the D1 sand. Twenty-four translation shearing tests were carried out on

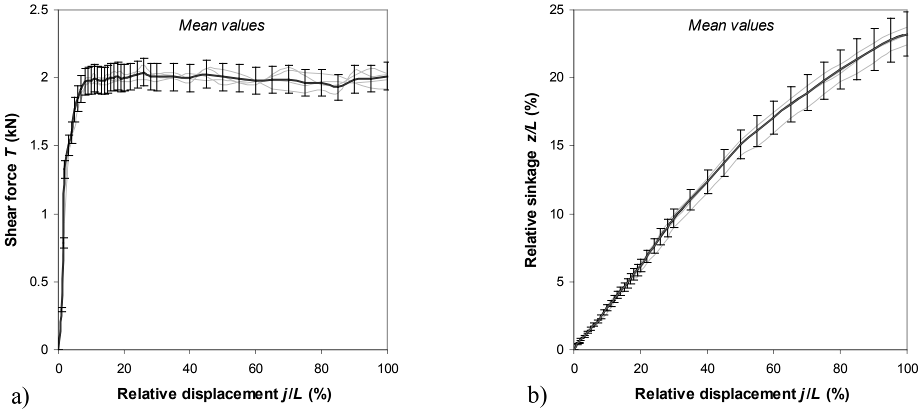

Fig. 3. Translation shearing test (normal stress of 50 kPa, slow speed of 23 $mm.min^{-1}$): (a) mean values (j/L, T) curve, (b) mean values (j/L, z/L) curve

sand, four per modality. The shear plate used was the alveolate plate to reproduce a soil–soil friction necessary for determining the mechanical parameters of the sand. The normal loads N tested were 4.1 kN, 8.2 kN and 12.3 kN (the normal stress of 50, 100 and 150 kPa, respectively). The force–displacement curves and the sinkage–displacement curves showed good reproducibility, confirming the relevance of the protocol's set-up (figure 3).

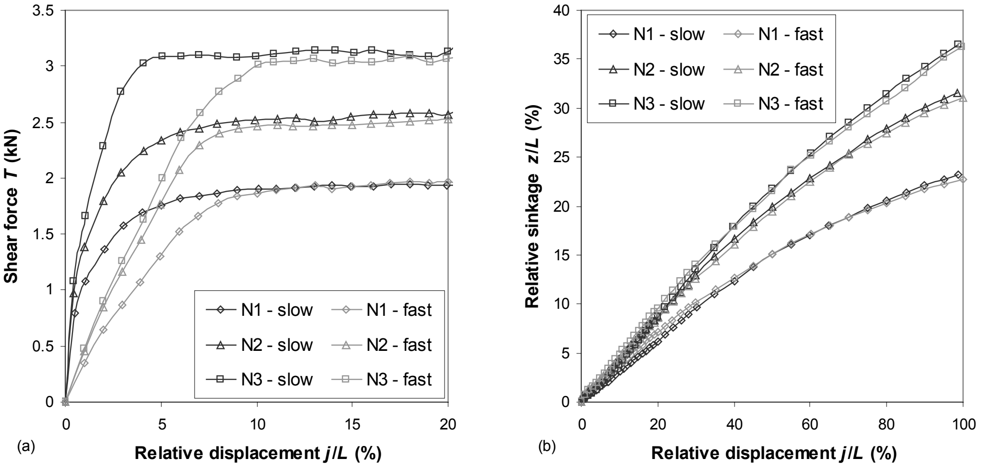

Fig. 4. Influence of the translation speed ($N1$ = 50 kPa, $N2$ = 100 kPa, $N3$ = 150 kPa): (a) mean values (j/L, T) curves, (b) mean values (j/L, z/L) curves

The same shapes of the average curves were found for the other normal loads and translation speeds (figure 4). The change of the translation speed influenced the initial slope of the curves (j/L, T) (figure 4).

3. MODELLING AND CALCULATION OF SOIL PARAMETERS

3.1. EQUATIONS OF THE PROBLEM

The failure mechanism can analytically be approached by geometry with two rigid blocks (figure 5). This method, where the blocks are widespread for stability calculations, is kinematically acceptable according to JANOSI et al. [6].

Using the identified geometry, the force balance can be inserted into an equation to carry out an ultimate equilibrium calculation, i.e., by assuming that the limit of soil resistance is reached along the lines. Solving the problem leads to the system of two equations in two unknown factors. The force balance provides a relationship between the forces *N* and *T* on the plate, the soil parameters and the geometrical parameters.

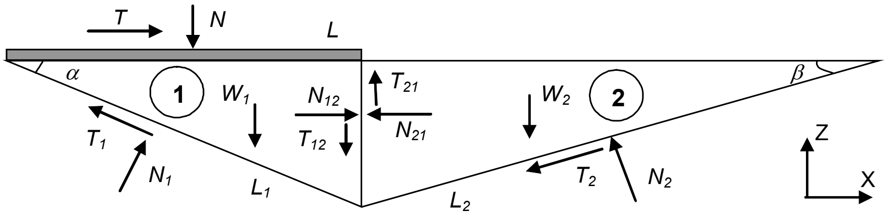

Fig. 5. Failure mechanism with two rigid blocks

3.2. PARAMETRIC STUDY

In order to evaluate the influence of each parameter being compared to the others, a parametric study was carried out. Some parameters were fixed (the friction angle of 33°, the null cohesion *c*, the bulk unit weight of 16.3 $kN.m^{-3}$). The plate length *L* was 340 mm. Then the horizontal force *T* depended only on the angles α and β and on the normal load *N* equal to 4.1, 8.2 or 12.3 kN. Since the experimental observations confirmed that the values of the two angles α and β were close to each other, the assumption $\alpha = \beta$ was made. The calculated forces *T* were compared with the experimental data (figure 6). In D1 sand and for the normal loads $N = 4.1$ kN, $N = 8.2$ kN and 12.3 kN, the value of the calculated force *T* was respectively equal to 1.9 kN, 2.5 kN and 3.1 kN for the angles $\alpha = 11°$, 18° and 22°. The angle α between the failure line and the horizontal line increased with the normal load *N* applied to the shear plate.

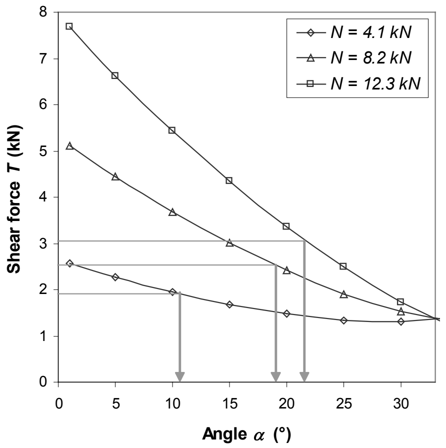

Fig. 6. Determination of the angle α for different normal loads *N*

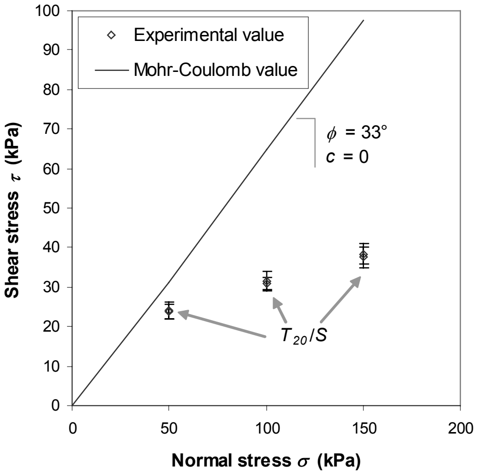

Fig. 7. Experimental results and the Coulomb straight line in the Mohr plan

The sinkage induced by soil shearing was observed in all experimental tests. Two combined mechanisms caused this phenomenon. The first is a variation of the stress distribution below the plate, involving a modification of the bulk unit weight of the soil. The second mechanism is the sinkage of the plate, depending on the failure line induced by its load. In the shearing tests carried out on D1 sand, the sinkage induced by the horizontal displacement was quasi-linear. In experiments, the shear plate followed a slip surface with an angle that can be evaluated with the measured sinkage ($\tan\alpha = z/L$). The results of the calculations of the angle α for various normal loads N highlight their similarity with the experimental data of the sinkage induced by shearing. The experimental values of the relative sinkage z/L for a normal load N of 4.1 kN, 8.2 kN and 12.3 kN were equal to 23%, 31% and 36%, respectively (figure 7).

3.3. CALCULATION OF THE SOIL PARAMETERS

One of the advantages of shearing tests is that they provide the parameters of soil mechanics, and in particular the friction angle and the cohesion c used in the Mohr–Coulomb yield criterion. The determination of the maximum shear stress on the failure surface is required of calculating these parameters. In this type of test, the shearing force T divided by the plate surface S does not correspond to the maximum shear stress. The T_m/S values show a linear behaviour, but they are not superimposed with the Coulomb straight line corresponding to the values of the D1 sand, $\phi = 33°$ and $c = 0$ (figure 7). The analysis of the failure mechanism provides a Mohr–Coulomb behaviour by locating the failure lines and therefore specifying the value of the maximum shear stress. With the angle α and the parameters T, N, bulk unit weight, β, L, and c described previously, the friction angle of granular topsoil can be calculated using equilibrium calculation.

4. CONCLUSION

A prototype experimental device allows laboratory and in-situ shearing tests by the translation of a plate at slow or fast speed, representative of traditional soil mechanics tests and the real kinetics of the slip under a vehicle's running gear, respectively. The tests presented were performed in the laboratory on clean sand. The protocol to set up the soil allows a good reproducibility of the tests. The main results are: 1. The shear–displacement curves had no peak state so that the Janosi–Hanamoto approach [6] could be used. 2. The tests showed a significant sinkage. 3. The increase in the translation speed induced a decrease in the initial slope of the curve. 4. The critical state force was not modified by the speed (i.e., cohesion and friction angle were not affected by the translation speed). In the first approximation, an analytical approach of this mechanism relating the geometry of the slip line to the mechanical parameters of the granular soil is used. This approach is based on the method of calculating the ultimate equilibrium for two rigid blocks.

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