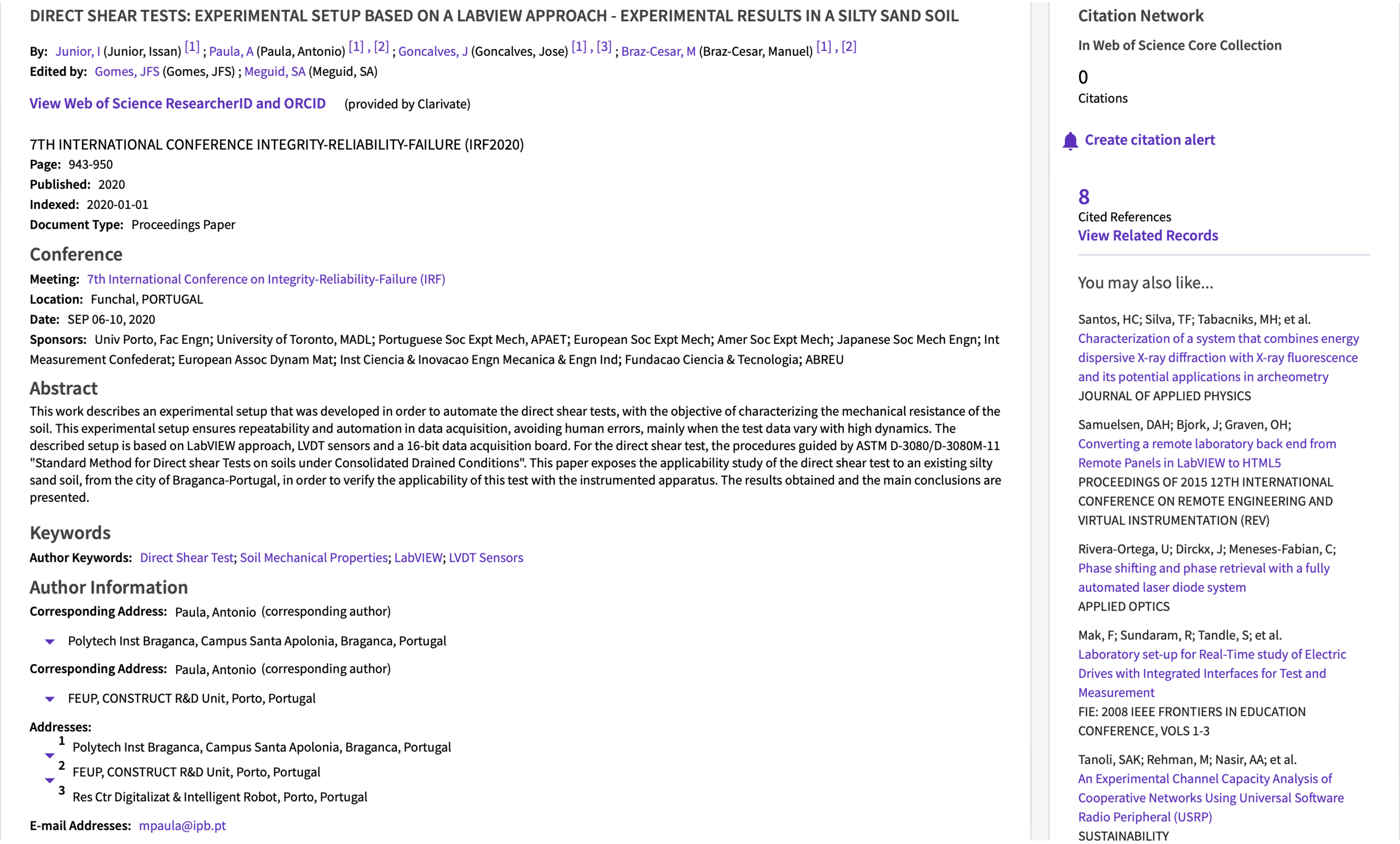

DIRECT SHEAR TESTS: EXPERIMENTAL SETUP BASED ON A LABVIEW APPROACH - EXPERIMENTAL RESULTS IN A SILTY SAND SOIL

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Abstract

This work describes an experimental setup that was developed in order to automate the direct shear tests, with the objective of characterizing the mechanical resistance of the soil. This experimental setup ensures repeatability and automation in data acquisition, avoiding human errors, mainly when the test data vary with high dynamics. The described setup is based on LabVIEW approach, LVDT sensors and a 16-bit data acquisition board. For the direct shear test, the procedures guided by ASTM D-3080/D-3080M-11 "Standard Method for Direct shear Tests on soils under Consolidated Drained Conditions". This paper exposes the applicability study of the direct shear test to an existing silty sand soil, from the city of Braganca-Portugal, in order to verify the applicability of this test with the instrumented apparatus. The results obtained and the main conclusions are presented.

Keywords

Author Keywords: Direct Shear Test; Soil Mechanical Properties; LabVIEW; LVDT Sensors

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DIRECT SHEAR TESTS: EXPERIMENTAL SETUP BASED ON A LABVIEW APPROACH - EXPERIMENTAL RESULTS IN A SILTY SAND SOIL

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ABSTRACT

This work describes an experimental setup that was developed in order to automate the direct shear tests, with the objective of characterizing the mechanical resistance of the soil. This experimental setup ensures repeatability and automation in data acquisition, avoiding human errors, mainly when the test data vary with high dynamics. The described setup is based on LabVIEW approach, LVDT sensors and a 16-bit data acquisition board. For the direct shear test, the procedures guided by ASTM D-3080/D-3080M-11 "Standard Method for Direct shear Tests on soils under Consolidated Drained Conditions". This paper exposes the applicability study of the direct shear test to an existing silty sand soil, from the city of Bragança-Portugal, in order to verify the applicability of this test with the instrumented apparatus. The results obtained and the main conclusions are presented.

Keywords: Direct Shear Test, Soil Mechanical Properties, LabVIEW, LVDT Sensors.

INTRODUCTION

In this work is described an experimental setup, existing in the Geotechnical Laboratory of the Polytechnic Institute of Bragança, developed to automate the direct shear tests. This experimental setup assures repeatability and automation in data acquisition testing, avoiding human errors. These errors occur mainly when the test data change with high dynamics, being difficult for humans, who use an analog sensor with a screen to record the correct values.

The system developed for test data acquisition and recording, is based on LVDT (Linear Variable Differential Transformer) sensors, a data acquisition board, LabVIEW PC application software and specific dedicated hardware.

For the direct shear test it was used an apparatus, covered in ASTM D-3080 / D3080M-11 [1], "Standard Method for Direct Shear Tests on Soils under Consolidated Drained Conditions". The direct shear device is used to determine the failure envelopes of the soil, and is not suitable for the determination of stress-strain properties of these soils. In many engineering problems, such as foundation designs, retaining walls, slab bridges, pipes, sheet piling, the value of the internal friction angle and cohesion of the soil involved is necessary for the design, and direct shear testing is used to predict these mechanical parameters quickly. Based on the analysis of the acquired data, a laboratory report is produced, covering the laboratory procedures to determine these values for the soils.The direct shear test as we know it [1] was perfected by several individuals during the first half of the twentieth century [2].

DIRECT SHEAR TEST

The direct shear test, which is represented in Figure 1, is the oldest and most usual method of soil characterization with respect to its resistance to the shear action, and is based directly on the Mohr-Coulomb criteria. The test is made by applying a horizontal translation with constant speed to the lower half of the shear box, while the upper is kept fixed at the expense of a reaction, T, whose value is measured at each instant by means of a dynamometer ring [6], which allows obtaining the peak and residual resistance, which is given when the ground cannot resist any increase in horizontal load, which occurs gradually from the plane, developing from the edge to the centre of the specimen.

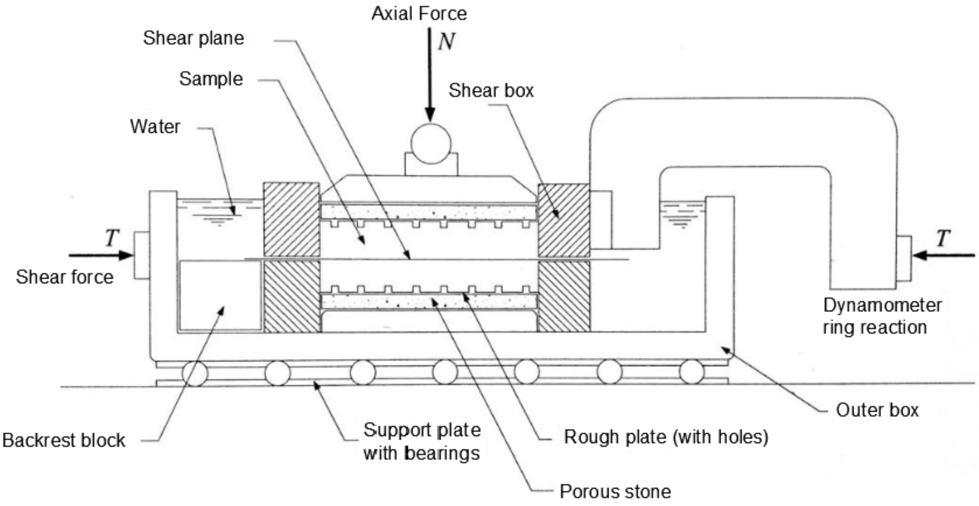

Fig. 1 - Schematic representation of a direct shear apparatus [6]

In this type of test, the main actions applied are the normal plane and shear stresses, the first being previously defined before the test and applied to the upper part of the specimen by means of a static system of weights and lever, and the second action is variable, because the tangential stresses are gradually increased as the displacement occurs until rupture occurs in accordance with the horizontal shear plane already defined. At the end of the test it is possible to obtain the reading of the horizontal deformations (whose maximum amplitude depends on the displacement capacity of the equipment) and vertical deformations, in addition to the shear force applied, which is later divided by the corrected area of the sample and graphically plotted versus the relative displacements, as shown in Figure 2, where the maximum shear stresses can be obtained.

This procedure permits to find the necessary parameters to satisfy the Coulomb equation, such as cohesion and angle of friction, under a normal stress and requested by that maximum shear stress. These values are obtained from the graphical relationship between normal and tangential stresses from a minimum of three specimens [1], where the inclination of the line formed between the points permits to obtain the angle of internal friction (ø) and the intersection with the ordinate permits to obtain the value of the cohesion of the soil, as seen in Figure 3.

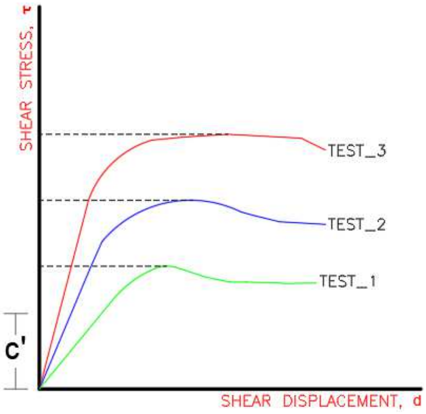

Fig. 2 - Graphic "Shear Stress vs Shear Shear Displacement" for 3 direct shear tests

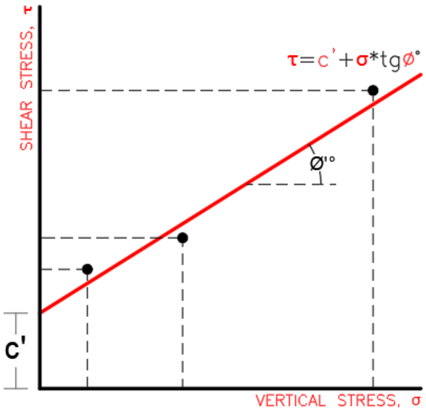

Fig. 3 - Morh-Coulomb Diagram (Effective Vertical Stress)

However, direct shear tests are analysis in terms of vertical effective stresses, as they do not permit the measurement of neutral pressures and do not assure control of the drainage of the specimen, which may be especially useful for draining forces of sandy soils, but difficulties arise in the interpretation of results, especially in clay soils [6]. The test has also the inconveniences of forcing the shear along a specific plane, instead of allowing the soil to break through the weaker zone, and produces non-uniform deformations in the specimen, what can produce wrong results [3].

DATA ACQUISITION SYSTEM

The system developed for data acquisition and recording for direct shear test in a given soil is based on LVDT (Linear Variable Differential Transformer) sensors, a data acquisition board and a LabVIEW PC software application [3]. The dynamics of the proposed system is the replacement of the old mechanisms for obtaining the results, which use analog sensors and the results are noted manually.

The sensors instrumented with the direct shear device can be seen in Figure 4, where it can be observed that a dynamometer ring [4][5] was used for force measurement. The Figure 5 illustrates the main interface of the LabVIEW software, developed for the shear test, which provides a user-friendly interface for the end user.

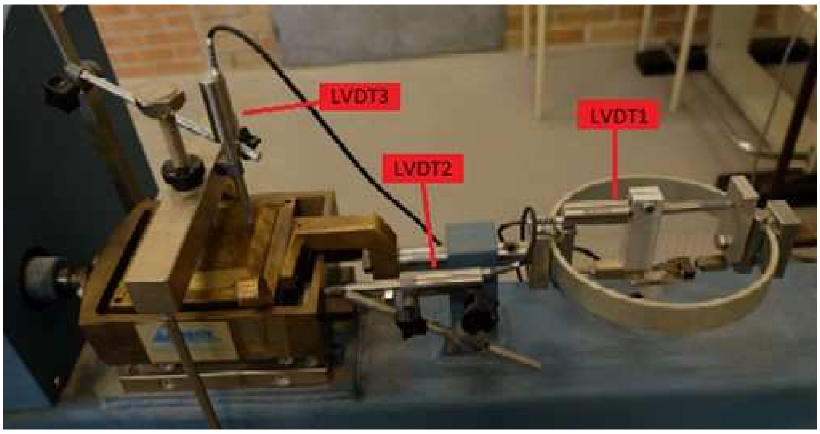

Fig. 4 - Instrumentation for direct shear apparatus.

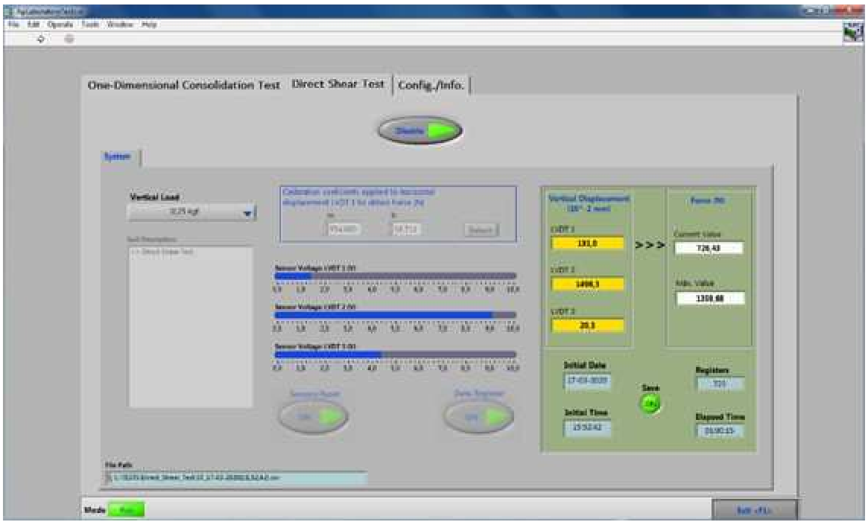

Fig. 5 - User Interface in Direct Shear Test.

The LVDT sensors used for the test incorporate a signal conditioning that is necessary to obtain an output directly proportional to the linear displacement, which is powered by direct current and has an input range of ±5 mm. Its characteristic was obtained experimentally, being powered by a voltage of ±5 V. The sensitivity of the sensor is almost 600 mV/mm, with an output voltage of ±3.5 V and an input current of 12mA. For the data acquisition board, the NI PCI-6202, which is a generic multifunctional board, was used, and has PCI bus characteristics, 8 differential analog inputs, 16 single end analog inputs, 16-bit analog-digital converter, 250 kS/s sampling rate and 24 digital I/O [3]

When using the equipment for the test, we can demonstrate in Figure 4, the 3 sensors used, which sequentially numbered are able to perform the measurement of the dynamometer ring deformation to obtain the shear force (LVTD1), the horizontal displacement of the lower box (LVDT2) and finally the vertical displacement of the upper rigid plate (place of application of the normal force P), with the LVDT3. Getting the previously referred data, it is possible to construct the graph as a function of the tangential stress and relative displacement as shown in Figure 2, in order to determine the mechanical parameters of the soil.

The interval of time for the data measurement, the vertical load used and the description of the soil can be selected by the user in the LabVIEW interface before the start of the test in the tab of "CONFIG./INFO.", the first option allows to select time intervals between 1.5,10,15,20 and 30 seconds, while the loads can be between 0.25 and 256 kg. In the main screen of the software it is possible to see the measurement of the values in each LVDT in the 10^{-2} mm scale, as well as the options to start or stop the sensor register at any time. At the end of the test, the data (with 5000 Hz sampling rate) obtained during the test are read out and then presented via CSV file (comma separated value file) in the Excel Software, with a name already set automatically.

METHODOLOGY

The work consisted in the physical and mechanical characterization of the soil in the laboratory, analyzing its main properties and shear strength, and in so testing the new automated test equipment. The work consisted in collecting specimens from a soil located in the region of Bragança-Portugal, proceeding with physical characterization tests, such as: Identity Test, Proctor, Moisture Content and Specific Weight, having the values presented in Table 1.

Table 1 - Soil physical characterization

SOIL PHYSICAL CHARACTERIZATION	
Density- γ [kN/m³]	16,5
Particle Density - G_s	2,06
Water Content "in situ"- w [%]	35,10
Maximum Dry Unit Weight [kN/m³]	13,93
Optimum Water Content- W_{otm} [%]	26,50
Liquid Limit -LL	47,9
Plastic Limit - PL	43,1
Plasticity Index - PI	5

With regard to the mechanical characterization tests of the soil, in order to analyses its shear strength, reconstituted soil specimens with physical properties similar to natural (keeping the initial density and moisture content "in-situ") were tested in direct shear equipment. For this purpose, the specimens were subjected to vertical loads of 75, 150 and 300 kPa and were tested at loading speeds of 0.25, 1 and 2 mm/min (millimeter/minute).

Subsequently, the test results were automatically obtained using the data acquisition instrumentation coupled with the test equipment, by recording all the values, in order to proceed with the data processing and demonstrate the results

RESULTS OF A REAL TEST FOR A SILTY SAND SOIL

It is important to highlight that in the present work, the determination of the peak soil resistance was the main focus, which was based on the criteria determined in the test standard ASTM D-3080/D-3080M-11 [1]. The tests were performed at normal stresses of 75, 150 and 300 kPa and with speeds of 0.25, 1 and 2 mm/min, obtaining a maximum relative displacement of 15 mm during the tests. In tests of this nature, working with direct shear equipment, dispersion of the results is expected because the tests were not performed under controlled drainage conditions [7]. Therefore, if necessary, the test was performed with at least 3 specimens for each speed, testing each one on a normal stress value.

The results obtained during the tests include a total sample of 9 tests, each on a given axial load and loading speed. These same specimens were reconstituted in order to assure the same natural properties of the soil, such as specific weight, moisture content, void index and degree of saturation of the sample, and in order to assure the uniformity between them, taking into consideration the limits of acceptable deviations.

In the analysis of results, the first parameter necessary to characterize the shear strength of the soil is to obtain the maximum values of tangential stress through the graphs shown in Figures 7, 8 and 9. These models also allow the characterization of soil compactness as low density, since the higher the compactness of the soil, the more the resistant capacity presents peaks for shear strength with a later drop to the point where the residual resistance is maintained, being different from what can be seen in the graphs.

From the data obtained, it can be observed that in general terms, the loading speed doesn't have a significant influence on the resistant capacity of the soil, since the shear strength parameter analyzed doesn't present great magnitudes of difference on the same axial load, the last one being a preponderant factor in the cohesion and friction angle parameters, presented in Table 2. These analyses are in accordance with the findings made by other authors [7] [8], who worked with a larger sample of results.

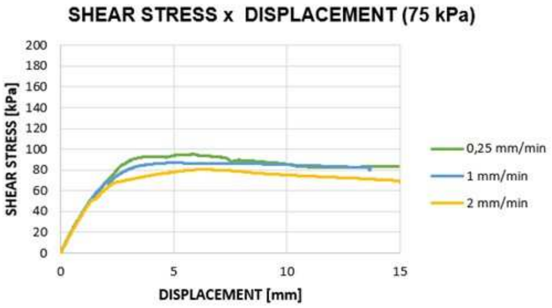

Fig. 7 - “Shear Stress vs Shear Displacement" curves for 3 direct shear tests submitted to a vertical load of 75 kPa and variations in displacement velocity [0.25, 1 and 2 mm/min]

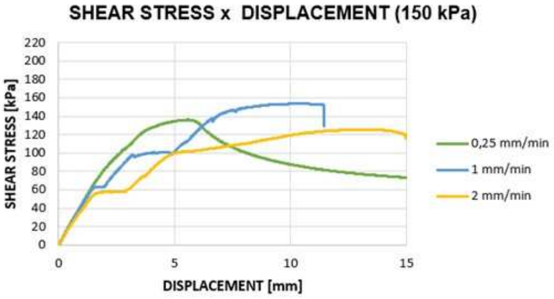

Fig. 8 - “Shear Stress vs Shear Displacement" curves for 3 direct shear tests submitted to a vertical load of 150 kPa and variations in displacement velocity [0.25, 1 and 2 mm/min]

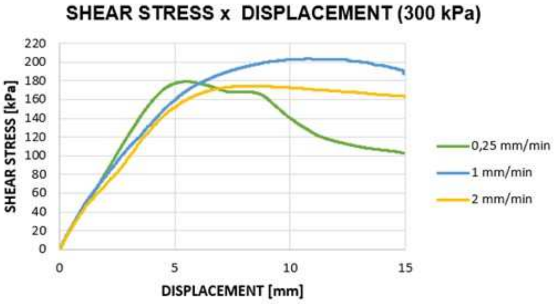

Fig. 9 - “Shear Stress vs Shear Displacement" curves for 3 direct shear tests submitted to a vertical load of 300 kPa and variations in displacement velocity [0.25, 1 and 2 mm/min]

In addition, can analyze in the graphs, that according to the increase in normal stress, it will be more difficult for the particles of the soils to reallocate one over the other, reducing the possibility of resisting the "interlocking" of these same particles, becoming progressively less evident the peak of resistance. It is important to highlight a possible failure in the tests performed on velocity of 0.25 mm/min over the stresses of 150 and 300 kPa, as they contrast with the other results.

The Mohr-Coulomb diagram of the soil tested is shown in Figure 10, whose values of the cohesion and friction angle parameters for each test speed can be verified in Table 2, which have been obtained using the straight-line equation, representing the Coulomb equation.

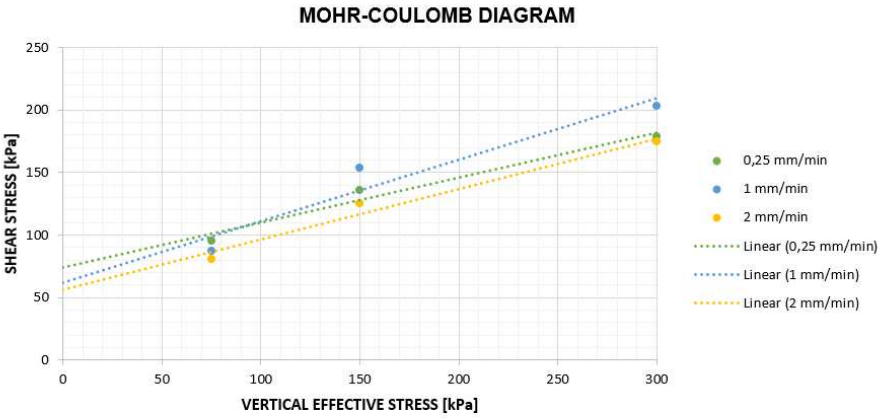

Fig. 10 - Mohr-Coulomb diagram for 9 tests with variations of vertical load and displacement speed

Table 2 - Values of the Cohesion Parameters and Friction Angle for different speeds

SPEED	c'	ø'
[mm]	[kPa]	[°]
0,25	73,675	19,82
1	62,005	26,16
2	55,935	22,04

The vertical displacements are important for the analysis of the soil behavior during the test and demonstrate consolidation characteristics of the specimens. The analysis of the relationship between vertical and horizontal displacements allows to characterize the soil in terms of expansibility or compressibility during the test, where the tendency of expansion in denser soils and compression in soils with less compaction is verified. In the analysis of the graphs in Figures 11, 12 and 13, we can verify that the variation in velocity and the increase in normal stresses influence the variation in volume of the specimen.

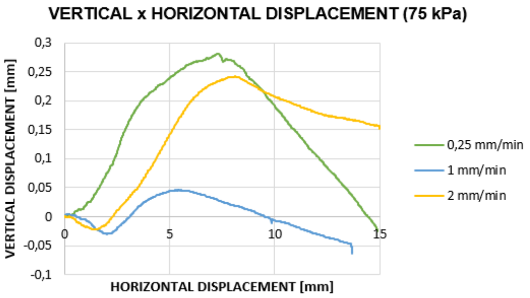

Fig. 11 - “Vertical Displacement vs. Horizontal Displacement" curves for Direct Shear tests submitted to a vertical load of 75 kPa and 3 variations of displacement speed

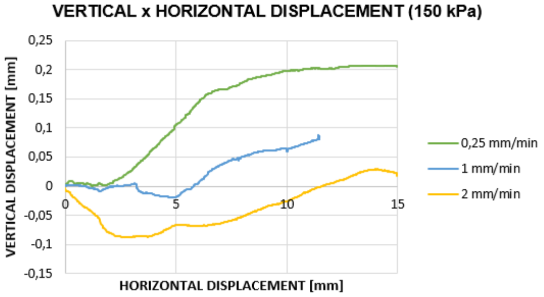

Fig. 12 - “Vertical Displacement vs. Horizontal Displacement" curves for Direct Shear tests submitted to a vertical load of 150 kPa and 3 variations of displacement speed

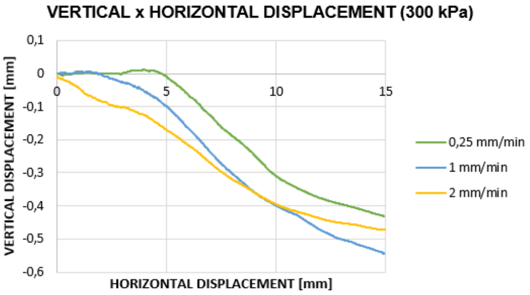

Fig. 13 - “Vertical Displacement vs. Horizontal Displacement" curves for Direct Shear tests submitted to a vertical load of 300 kPa and 3 variations of displacement speed

It can be seen that for specimens with lower normal stresses and higher loading velocities (less time to reallocate) they tend to compact first, becoming denser, and later expand. Unlike specimens under higher axial loads, as in Figure 12, which under higher stresses tend to present a higher compressibility.

CONCLUSIONS

The studies about the influence of the loading speed in a silty sand soil with low compactness and on several normal stress ranges, it can be concluded that this speed doesn't have a significant pattern in the result of the soil resistance parameters. However, a high applicability of the data acquisition system can be verified in this type of test, since it allows to correctly obtain, per second, an immense range of values, assuring a greater reliability in the results and obtaining other fundamental characteristics in the soils, such as their consolidation behavior during the test through vertical displacements.

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