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EVALUATION OF SHEAR STRENGTH PARAMETERS OF GRAVEL SOILS WITH DIFFERENT SHAPE AND RELATIVE DENSITY

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ABSTRACT: This article presents the results of large-scale direct shear tests in laboratory, to evaluate the parameters of shear strength of remodeled gravel soils at different degree of compaction, with a direct shear equipment built in the Soil Mechanics Laboratory of the Universidad Nacional de San Antonio Abad del Cusco, Perú. The cylindrical shear box with 30 cm diameter and 25 cm high, allows testing gravel soils with maximum size particles of 38.1 mm (1.5"). The four samples of gravel soils evaluated correspond to four quarries of the Cusco region, classified according to the Unified Soil Classification System as: GP (M-1), GM (M-2), GW (M-3) and GW (M-4). The tests were developed considering an incremental sequence of normal load to each sample of 49.0, 98.1 and 196.1 kPa. According to the results, for the four samples tested, the apparent cohesion was obtained in a range of 19.61 to 64.72 kPa and the internal friction angle in a range of 35.2° to 52.4°, for the states of relative density very loose, medium and very dense. These results allow us to conclude that the factors that affect the shear strength of the material are the density and the relative density of the remolded gravel samples, as well as the fragility at break and the rounded or angular shape of the soil particles.

Keywords: Large scale direct shear tests, Gravel soils, Internal friction angle, Apparent cohesion

1. INTRODUCTION

In the Andean mountain region, where the city of Cusco is located, there is a significant presence of coarse materials deposits, which according to their size vary from gravels to cobbles. Due to the excellent mechanical properties of coarse grained soils, an adequate evaluation of their mechanical properties allows important optimizations in geotechnical designs. However, for the evaluation of the properties of these soils, it is generally difficult to execute large scale direct shear tests in laboratory, due to the scarcity of equipment to evaluate this type of soils. This problem motivated the design and construction of a large scale direct shear equipment in the Materials and Soil Mechanics Laboratory of the Faculty of Civil Engineering of the Universidad Nacional de San Antonio Abad del Cusco (Fig. 1, Fig. 2), whose cutting box has 30 cm in diameter and 25 cm in height, allowing to evaluate the parameters of shear strength of remolded gravel soils with a maximum size of 38.1 mm (1.5") for different relative densities states [3].

The results obtained, using this equipment, correspond to the evaluation of four soil samples from different quarries, analyzing the variation of their strength parameters of the remolded specimens with relative densities of very loose, medium and very dense [5].

2. METHODOLOGY

For the design of the shear box was considered the evaluation of gravelly soils with a maximum particle diameter of 38.1 mm (1.5"), and in order to prevent the size of the shear box influence the results of shear strength of the remolded specimens [4], guaranteeing the thickness of the specimen greater than six times the maximum diameter of the particles [1], the shear box of the large scale direct shear equipment was constructed with an inner diameter of 30 cm and a height of 25 cm (built with metal plates of 1/4" thick). The shear box was split horizontally in halves to allow the relative displacement without friction of the lower half over the upper half, applying the horizontal shear force by means of a hydraulic jack, establishing a strain controlled test, with a shear speed of 2 mm/min.

The maximum normal stress for which the equipment was designed is 196.1 kPa, transmitting the maximum normal force of 13.86 kN on the specimen cross sectional area of 706.86 cm^2. To maintain the accuracy, in the order of ± 1%, of the normal force applied during the execution of the test, allowing to evaluate the effect of the positive or negative dilatancy that will occur in the specimen, a lever arm with 160 cm of length was implemented, whose length was designed to allow that the loads to be used are not high (weights of 392.3 N, 196.1 N, 98.1 N, 49.0 N, 29.4 N, 19.6 N, 14.7 N and 9.8 N) and to be capable to transmit the load without deformations of the lever arm indicated.

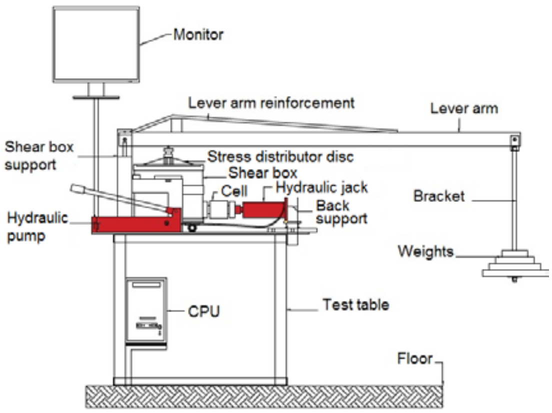

Fig.1 General scheme of the large scale direct shear equipment designed and built to evaluate gravelly soils.

Fig.2 Picture of the large scale direct shear equipment.

Regarding to the system of measurement of the shear force, an analog load cell of 196.13 kN of capacity was considered, which allowed the data recording with an accuracy of 1% of the shear force at the failure [1]. For the measurement of the horizontal and vertical displacements, it was planned to use LVDTs but these had the limitation of their maximum length less than the total displacement of the shear box, so it was decided to use 0.01 mm precision digital vernier calipers, with an adaptation by means of output cables for data recording automatically and synchronized with the data log of the load cell.

The gravelly soils evaluated correspond to the following representative soil samples: M-1 from the Tipón quarry (Fig. 3a), M-2 from the Larapa quarry (Fig. 3b); M-3 from the Huambutio quarry (Fig. 3c) and M-4 from the Collana quarry (Fig. 3d).

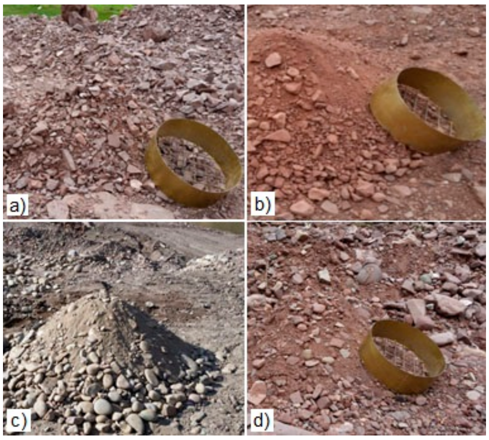

Fig.3 a) Soil sample M-1, b) Soil sample M-2, c) Soil sample M-3, d) Soil sample M-4.

3. RESULTS

Table 1 shows the results of particle shape, index properties, particle size distribution coefficients and classification of soil samples according to the Unified Soil Classification System (USCS).

Table 1 Characteristics and physical properties of the gravelly soil samples.

Description	M-1	M-2	M-3	M-4
Quarry	Tipón	Larapa	Huambutio	Collana
Particle shape	Angular	Sub-angular	Rounded	Sub-rounded
$D_{máx}$ (mm)	38.1	38.1	38.1	38.1
Fines (%)	4.5	13.22	4.8	3.6
Sand (%)	14.6	33.13	27	32.9
Gravel (%)	80.9	53.65	68.20	63.50
C_u	40.74	-	76.67	57.22
C_c	8.75	-	2.65	2.06
w (%)	0.42	2.36	0.30	0.55
LL (%)	NP	20.1	NP	NP
LP (%)	NP	16.8	NP	NP
IP	NP	3.3	NP	NP
USCS	GP	GM	GW	GW

For the particle size analysis test [2], samples with a maximum particle diameter of 38.1 mm (1.5") were considered. In Fig. 4, the particle size distribution curves of samples M-1, M-2, M-3 and M-4 are shown.

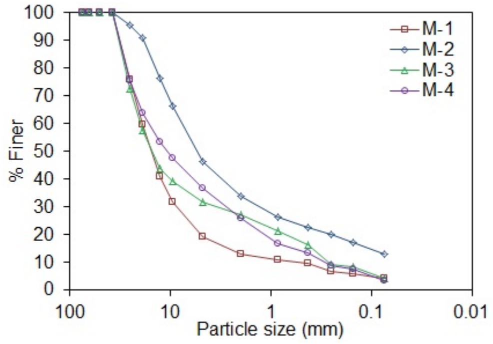

Fig.4 General scheme of the large scale direct shear equipment designed and built to evaluate gravelly soils.

To evaluate the variation of the shear strength parameters of the remolded specimens, with natural water content, considering very loose, medium and very dense relative densities, the minimum and maximum densities of the evaluated soil samples were previously determined [7].

For the evaluation of the shear strength parameters of the evaluated specimens, normal stress of 49.0 kPa, 98.1 kPa and 196.1 kPa were considered. In Table 2, the variation of the shear strength parameters c' and ø', obtained for the relative densities evaluated with the large scale direct shear equipment is shown.

Table 2 Variation of the shear strength parameters for the specimens tested with very loose, medium and very dense relative density states.

Soil sample	Relative density	ρ_d (kN/m^3)	c' (kPa)	ϕ' (°)
M-1	Very loose	15.69	34.32	36.3
	Medium	16.77	40.21	41.9
	Very dense	18.73	64.72	48.6
M-2	Very loose	18.34	19.61	35.2
	Medium	19.42	35.30	39.5
	Very dense	21.57	40.13	42.4
M-3	Very loose	19.32	36.28	41.6
	Medium	20.79	44.13	44.8
	Very dense	22.56	59.82	50.5
M-4	Very loose	18.63	37.27	42.7
	Medium	19.61	36.28	47.1
	Very dense	21.38	54.92	52.4

Note: should be placed under the table leaving no space in-between; 10-pt font; and left- and right-justified.

The specimens remolded with the soil sample M-1, for the states of very loose, medium and very dense relative density, presents increases of the apparent cohesion of 5.89 kPa for the densification of the very loose to medium state and of 24.51 kPa from the medium to very dense state. Whereas the internal friction angle presents an increase of 5.6 ° for the densification of the very loose to medium state and of 6.7 ° from the medium to very dense state.

In the case of the soil sample M-2, increases in apparent cohesion of 15.69 kPa are observed with the densification of the very loose to medium state and of 8.83 kPa from the medium to very dense state. The internal friction angle presents an increase of 4.3° for the densification of the very loose to medium state and of 2.9 ° from the medium to very dense state.

For the soil sample M-3, increases in the apparent cohesion of 7.85 kPa are observed with densification of the loose to medium state and 15.69 kPa from the medium to very dense state. The internal friction angle presents an increase of 3.2° with densification of the very loose to medium state and of 5.7 ° from the medium to very dense state.

In the case of soil sample M-4, there is a decrease of the apparent cohesion of -0.99 kPa with the densification of the very loose to medium state and an increase of 18.64 kPa from the medium to very dense state. The internal friction angle presents an increase of 4.4° with the densification of the very loose to medium state and of 5.3 ° from the medium to very dense state.

The values of internal friction angle for all the soil samples are in a range of 35.2° to 52.4°, considering the relative density states of very loose, medium and very dense. The highest value of the internal friction angle corresponds to the soil sample M-4 classified as GW, attributing this value mainly to its adequate particle size distribution.

The soil sample M-1 with angular particle shape, classified as GP, shows the greatest increase in the internal friction angle (+ 12.3°), due to the densification of the relative density state and the particle shape. While the increments are smaller for the soil samples M-3, with rounded particle shape, and soil samples M-4, with a subrounded particle shape, both classified as GW, showing that the increase of the internal friction angle is less for rounded and subrounded particles shapes [6].

The apparent cohesion of the soil samples of the different quarries is in the range of 19.61 to 64.72 kPa. The increase in this value is mainly attributed to the state of relative density of the remolded specimen, as well as the rolling, sliding, rearrangement and breakage of the particles during the test. These factors allow interpreting the non-linearity of the failure envelope, which will not necessarily pass through the origin of coordinates [8]. The influence of the natural water content in the increase of the apparent cohesion is minimal, because the resistance to the intense shear forces is mainly established between the granular particles of the soil.

In the graphs of shear stress as a function of the horizontal strain of each of the specimens tested with different states of relative density (Fig. 5, Fig. 6, Fig. 7 and Fig. 8) it is observed that the slope of the initial tangent of the curves increases as a function of the very loose, medium and very dense relative density states respectively. The graphs also show the presence of some sections in zigzag form, due to the process of granular material breakage for the case of specimens tested with a very dense relative density or the rearrangement, sliding and rolling of the particles for specimens tested with relative density very loose. In addition, the results for soils with very dense relative density show well-defined shear stress peaks, while the loose samples show increasing curves. In general for specimens with very dense relative density, the shear stress is reached in a horizontal strain margin between 4%-5%, for specimens with medium relative density in a range between 8%-9% and for specimens with very loose relative density in a margin between 10% -11%.

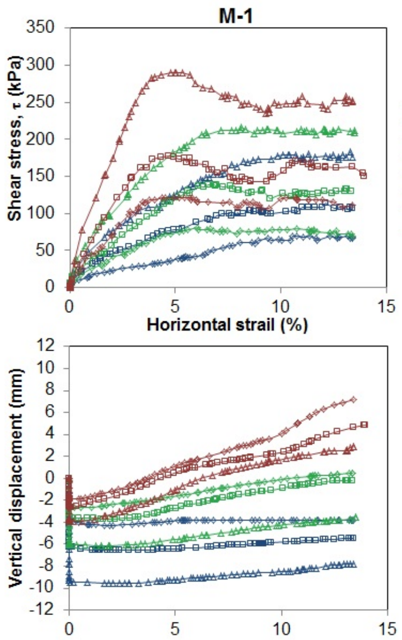

Fig.5 Graphs of shear stress and vertical displacement vs. horizontal strain for remolded specimens of the soil sample M-1, with relative density states: (a) very loose, (b) medium, (c) very dense.

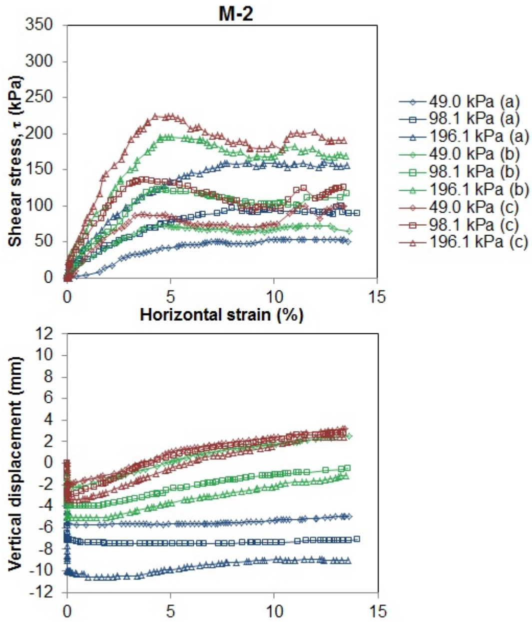

Fig.6 Graphs of shear stress and vertical displacement vs. horizontal strain for remolded specimens of the soil sample M-2, with relative density states: (a) very loose, (b) medium, (c) very dense.

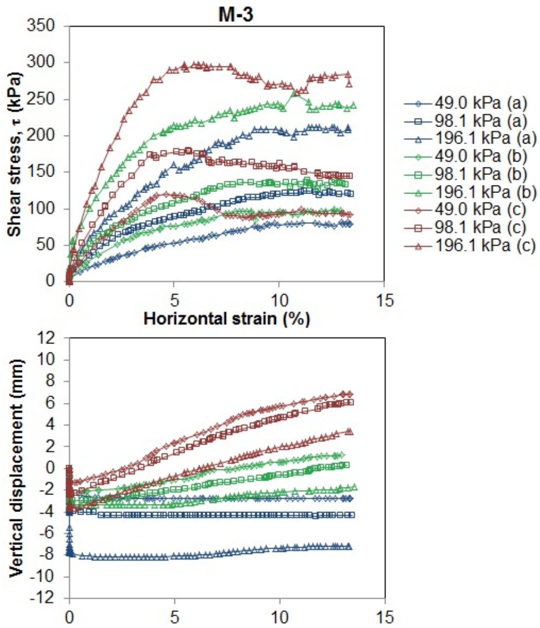

Fig.7 Graphs of shear stress and vertical displacement vs. horizontal strain for remolded specimens of the soil sample M-3, with relative density states: (a) very loose, (b) medium, (c) very dense.

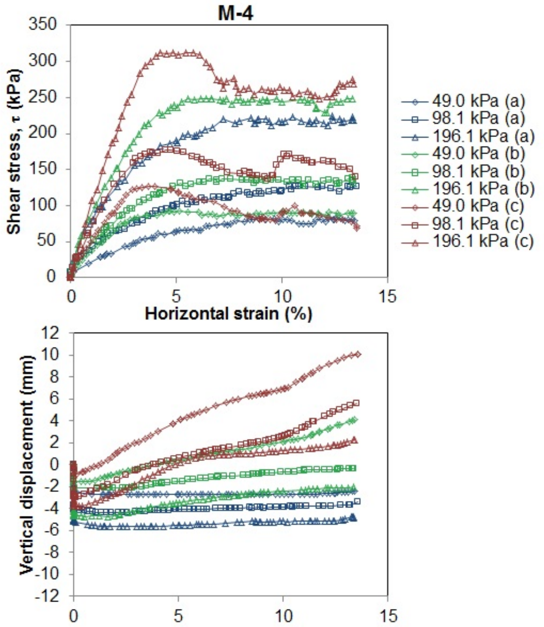

Fig.8 Graphs of shear stress and vertical displacement vs. horizontal strain for remolded specimens of the soil sample M-4, with relative density states: (a) very loose, (b) medium, (c) very dense.

Regarding the results of volumetric variation, in the graphs of vertical displacement as a function of the horizontal strain for each of the specimens tested with different states of relative density (Figs. 5-8), it is observed that the vertical displacement in the initial stretch presents compression, being greater for the state of very loose relative density, however the variation of the vertical displacement during the test is minimal, while in the specimens with very dense relative density the initial vertical displacement is lower but its increase during the test is greater, presenting expansion; this fact is attributed to the dilation process either positive or negative. The Figs. 9-12 shows the failure envelopes of the direct shear tests for the soil samples M-1, M-2, M-3 and M-4, each one remolded for relative density states of very loose, medium and very dense, with sequences of consecutive normal stress of 49.0, 98.1 and 196.1 kPa. Also it is observed that as the relative density of the remolded specimen increases, the shear strength of the soil also increases.

4. CONCLUSIONS

The large scale direct shear equipment designed and built in the laboratory of the Universidad Nacional de San Antonio Abad del Cusco allows to evaluate the shear strength parameters of gravelly soils with maximum particle size of 38.1 mm (1.5").

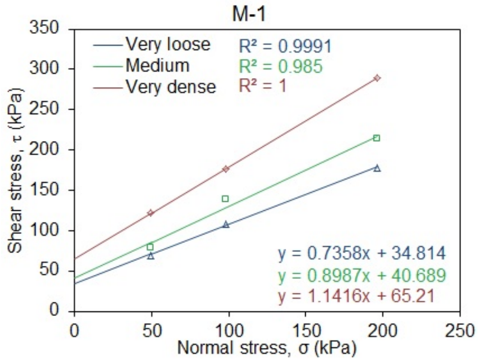

Fig.9 Failure envelopes for soil sample M-1.

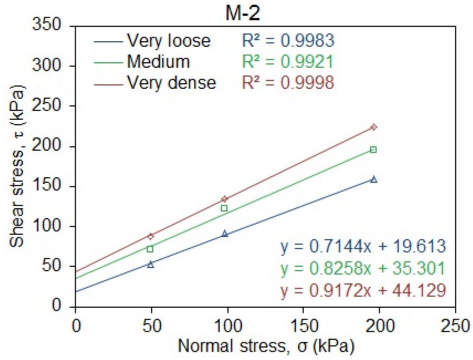

Fig.10 Failure envelopes for soil sample M-2.

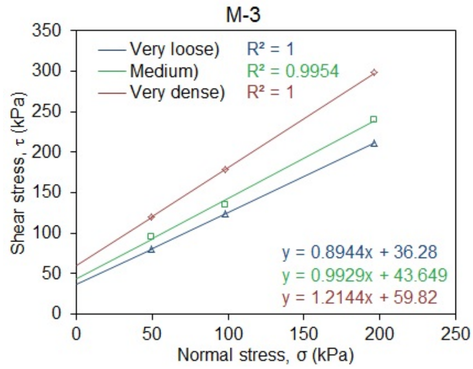

Fig.11 Failure envelopes for soil sample M-3.

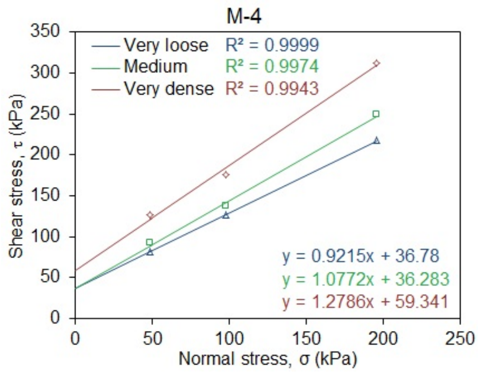

Fig.12 Failure envelopes for soil sample M-4.

For the present research project the direct shear tests were carried out with four samples using remolded specimens with very loose, medium and very dense relative density states. From the results obtained, the apparent cohesion varies in a range of 19.61 to 64.72 kPa and the internal friction angle in a range of 35.2° to 52.4°. It is observed that the angle of friction increases according to the greater state of relative density of the soil, shape of the particles, particle size distribution and breakage of the particles during the test. Likewise, the increase in apparent cohesion is verified as the value of the internal friction angle increases.

The graphs of shear stress as a function of horizontal strain show that for remolded specimens with very dense relative density state, sharply defined shear peaks occur, while for the very loose state of remolded specimens there are increasing curves. In general, for very dense state of remolded specimens the maximum shear stress is reached approximately for a horizontal strain of 4%, while for specimens of medium state for 8% and for very loose state for 10.5%.

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