N.P. López-Acosta et al. (Eds.)

doi:10.3233/STAL190025

Study of the Characteristics of Anisotropy in the Hydro-Mechanical Behaviour in Clayey Silt

Octavio CÁRDENAS[a,1], Jaime González[a], José DOMINGUEZ[a] y Juan ALMANZA[a]
[a] *Autonomous University of Coahuila*

Abstract. The study of anisotropic behavior of soils has been widely addressed in various investigations. Results of the analysis of the mechanical behavior of soils have shown a different response depending on the anisotropy inherent in the formation of the direction of the stress application. The existence of specific laboratory apparatus for the evaluation of anisotropy such as the true triaxial or hollow cylinder have allowed significant advances in the development of models to predict the behavior of soils. In this research the anisotropy of clayey silt soils of the City of Torreón Coahuila it is evaluated, and its hydro-mechanical behavior is studied using conventional triaxial equipment and oedometer device in undisturbed samples varying the direction of soil extraction (0 °, 45 ° and 90 °). Preliminary results show differences in the stress-strain response of soils depending on the direction of application of stresses.

Keywords. Anisotropy, triaxial test, oedometer.

1. Introduction

Anisotropy in soils is a phenomenon that has two components according to the definition stated by Casagrande and Carrillo in 1944 [1]: an inherent anisotropy and an induced anisotropy. The first of them is considered a characteristic of the material and independent of the conditions of the applied stress, while the second developed from the direction in which efforts are applied.

It has also been recognized that the inherent anisotropy of the soil mass depends on several factors such as: the shape and size of the grains, the variations in the distribution of the grains during the soil formation process, and in the case from cohesive soils, the stresses that occur during sedimentation are probably the determining factors of anisotropy, [2]. The induced anisotropy develops as soon as external loads on the soil mass are applied.

In the present paper, the term anisotropy will refer to the combination of both components of the anisotropy, the inherent and the induced ones. For the study of anisotropy, increasingly sophisticated laboratory equipment has been developed that allows the study of this phenomenon based on the stress application mechanisms they use. Investigations developed in the true triaxial equipment by Hoyos [3], [4] and

[1] Octavio Enrique Cárdenas Díaz, Facultad de Ingeniería Civil, Universidad Autónoma de Coahuila. Carretera Torreón-Matamoros Km. 7.5, Ejido el Águila. Torreón, Coahuila. México. Email. ecardenas@uadec.edu.mx

Matsuoka [5] or in the hollow cylinder equipment by Nishimura [6], Toyota [7], to mention just a few, have allowed evaluating the response of the soils to loading in function of the anisotropy.

However, these devices are expensive, and it is difficult for most laboratories in Mexico to have them. Particularly in this work, more conventional equipment such as triaxial and oedometer test are used to analyze the influence of anisotropy on the hydro-mechanical response of sandy silt soils depending on the direction in which the stresses are applied.

2. Experimental Programme

2.1. Sample extraction and characterization.

Open-pit wells (PCA) were conducted as part of this site investigation program in the urban areas "La Unión" (UN) and "La Concha" (CN), both are part of the municipality of the City of Torreón in the State of Coahuila located north of the Mexican Republic. These study areas are zones of population growth and it is in this sense the importance of testing and characterizing the soils.

Six samples were taken from each of the zones to be studied by doing excavations through to 6 inches diameter and 12 inches long tube sections. The penetration was carried out at the bottom of each PCA and the extracted samples were covered with wax at the edges to avoid the loss of their properties both in the transfer to the Geotechnical laboratory and during the time they were stored in the humid chamber. Likewise, disturbed and undisturbed samples were taken during the excavation index tests and the initial characterization of the soils. Granulometry test and Atterberg limits were determined and the results are shown below. The grain sizes are presented in Figure 1, and the soils were classified according to the Unified Soil Classification System (SUCS), as presented in Table 1.

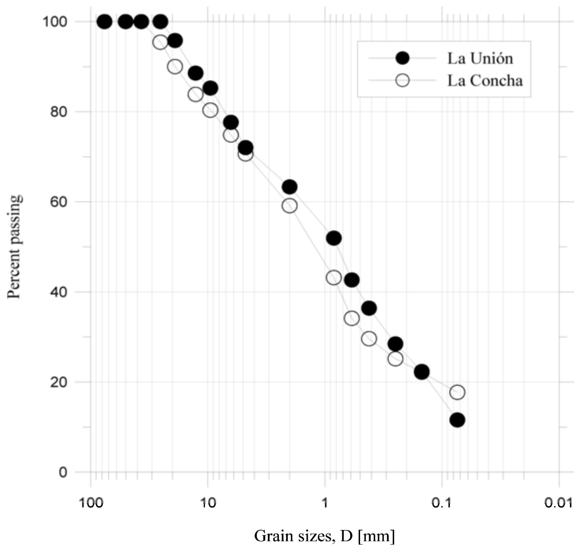


Figure 1. Grain sizes distribution curve for (UN) and (CN) soils.

Table 1. Soils properties and classification

Soil	ω [%]	ω_{LL} [%]	PI [%]	SUCS
La Unión	13.5	56	39	SC
La Concha	13.2	38	17	SC

2.2. Oedometer test

For the elaboration of the samples that were tested in the oedometer, cuts were made with values of α = 0 °, 90 ° and 45 ° (vertical, horizontal and with 45 ° of inclination, Figure 2) of the specimens extracted from the PCA. An oedometer ring with 50 mm in diameter and 20 mm in height was introduced in order to ensure that equal in situ conditions were maintained. A scheme of the cuts is presented in Figure 2. The procedure for specimen preparation has been carried out in other investigations such as those presented by Attom and Al-Akhras, (2008) [8]. The same process was used to obtain triaxial tests specimens.

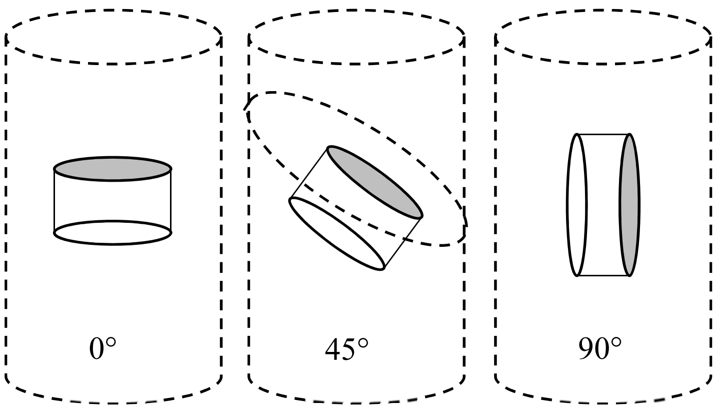
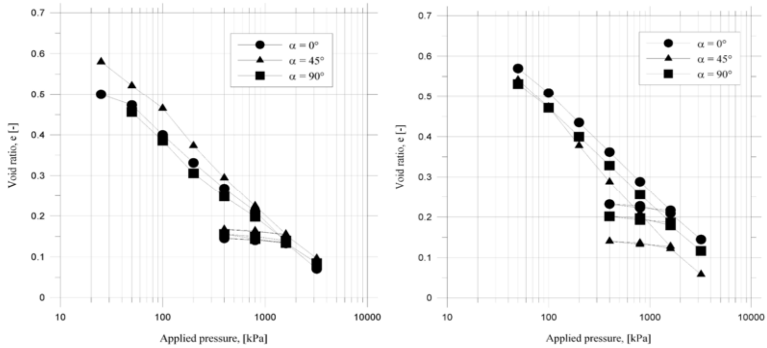


Figure 2. Odometer´s sample cutting.

Loading steps (50,100,200,400, 800 and 1600 kPa) were carried out, continued by an unloading step (1600, 800 and 400 kPa), to finish with a reloading (400, 800, 1600 and 3200 kPa). This procedure was used to guarantee a wide degree of deformation under loading. The entire test was performed under saturated conditions, taking care always that the temperature gradients did not affect the test conditions.

The *e-versus log*σ graphs shown in Figure 3 represent the deformation trajectories followed during the tests on both soil types. The three directions trajectories (α = 0 °, 45 ° and 90 °) are presented in the same graph in order to observe the degree of anisotropy and its effect on hydro-mechanical behavior.

In the same way, the trajectories of the two types of soil studied are presented in the Figure 3, in order to allow a better comparison between both conditions. The analysis of the results is presented in detail in later sections, as well as the conclusions.



[a] [b]

Figure 3. The oedometer test results. [a] La Unión; [b] La Concha.

Some parameters determined from the oedometer tests are also presented in Table 2 in order to evaluate the degree of anisotropy.

Table 2. Soil parameters determined from the oedometer tests.

Soil	α	Pre-consolidation pressure, p'_o [kPa]	Compression Index Cc	Swell Index Cs	Oedometer modulus, *Em* [kPa]
La Unión	0°	60	0.199	0.015	3592
	45°	100	0.247	0.024	5602
	90°	65	0.182	0.018	3188
La Concha	0°	50	0.245	0.025	6322
	45°	100	0.280	0.021	7299
	90°	70	0.239	0.025	6322

2.3. Triaxial Test

The samples were prepared for the triaxial test following the same procedure described in the previous section. In this case, a cylindrical extractor mold of 3.5 cm in diameter and 7 cm in height was used. The specimens were collected in the same directions (α) as in the case of the oedometer tests, Figure 2.

The triaxial test were carried out in a piece of conventional equipment. The tests were carried out in the consolidated undrained (*CU*) conditions, in order to get the data faster. Two confining pressures (σ_3) of 200 and 400 kPa for the consolidation phase were used. The rupture stage was carried out in undrained conditions monitoring the increase in pore pressures, (u).

Six trials were developed combining of the α angle and the confining pressure to assess the influence of the anisotropy on the hydro-mechanical behavior of the soils. The obtained results are shown in Figures 4 and 5 where the stress versus strain graphs for both studied soils are presented. In addition, Figures 6 and 7 show the stress trajectories in *p-q* Lambe's plane for both soils. The equations to determine the parameters of the plane are presented below.

$$p_L = \frac{\sigma_1 + \sigma_3}{2} \tag{1}$$

$$q_L = \frac{\sigma_1 - \sigma_3}{2} \tag{2}$$

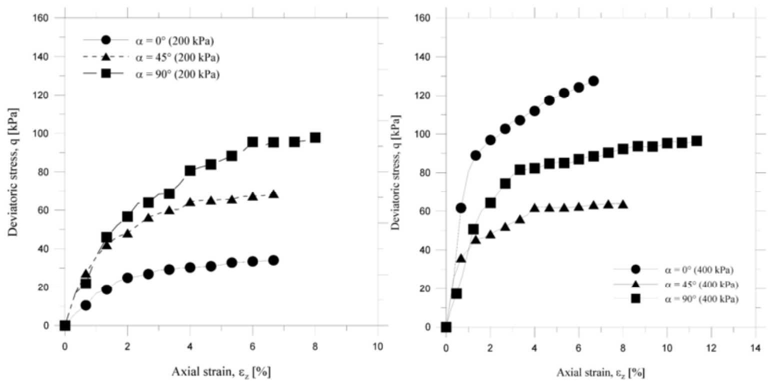


Figure 4. Deviatory stress versus axial strain curves for different confining pressure for (UN) soil.

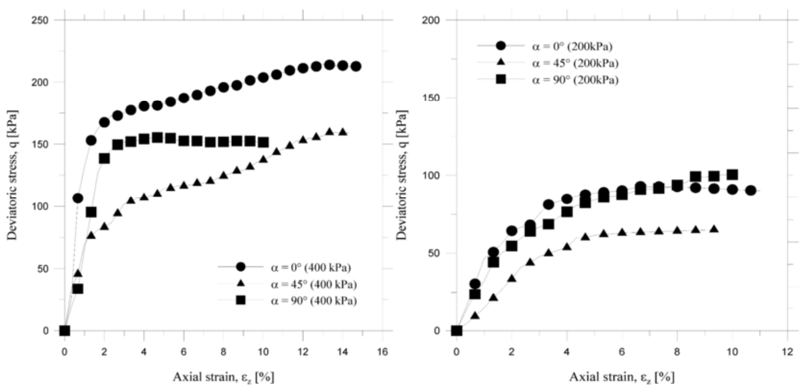


Figure 5. Deviatory stress versus axial strain curves for different confining pressure for (CN) soil.

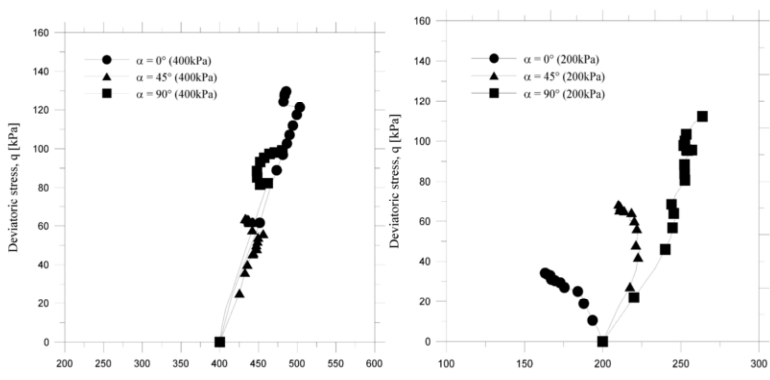


Figure 6. Stress paths for UN soils for 200 and 400 kPa confining pressure.

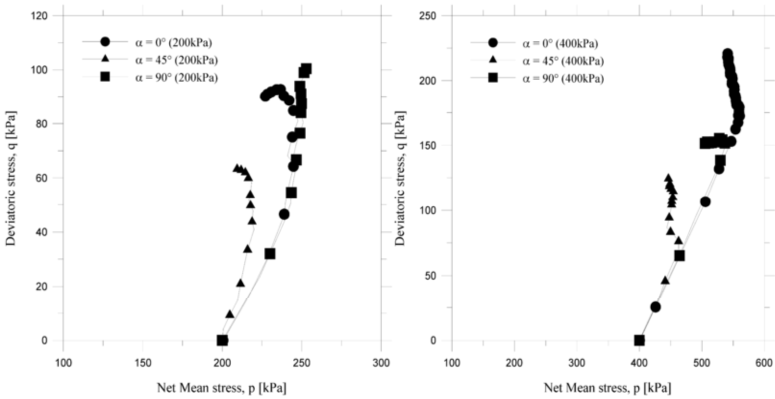


Figure 7. Stress paths for CN soils for 200 and 400 kPa confining pressure.

3. Results

3.1. Oedometer test

The results of the oedometer tests of both La Unión (UN) and La Concha (CN) soils show little anisotropy, as can be observed in the consolidation curves of Figure 3. The stress paths for the directions of $\alpha = 0$ ° and 90 ° (vertical and horizontal direction) follow practically the same trajectory, both in the loading and in the unloading sections. The difference was observed in the α = 45 ° direction, where in the case of the La Concha (CN) soil tests the slope of the virgin section (*Cc*) is greater than for the 0 ° and 90 ° directions, so that there is a greater volume change in this case.

In this sense, it can be said that the anisotropy of the "Union" soil is practically null for the 0 ° and 90 ° directions and only a difference appears in the initial section of the loading stage. This phenomenon is associated with a higher initial pore index in the case of the direction of $\alpha = 45$ °.

Therefore, the anisotropy in the case of oedometer tests is a small and not significant influence on the soil deformation response was observed.

3.2. Triaxial Test

3.2.1. La Unión

Regarding the triaxial tests carried out in the studied soils, a significant anisotropy is observed in the hydro-mechanical response under strain stresses. In the graphs presented in Figure 4, corresponding to the trajectories ε_z-*versus* q of the soil, a considerable difference is observed in terms of the maximum resistance for $p' = 200$ kPa. The trajectory for α = 90 ° (horizontal) has a greater resistance than for $\alpha = 0$ ° (vertical) and for $\alpha = 45$ ° an intermediate resistance.

On the other hand, in the tests with $p' = 400$ kPa the maximum resistance is presented for the direction of $\alpha = 0$ ° and the least for the direction of $\alpha = 45$ °, the direction of α = 90 ° presents an intermediate resistance. The foregoing demonstrates an important anisotropy in terms of the resistance depending on the direction (α) of application of the deviatoric stress.

The same mentioned characteristics can be seen in Figure 6. It shows the trajectories *p-q* in the Lambe´s plane for the effective stress. The paths followed for the tests of p'= 400 kPa show the same slope throughout its development until failure. The difference is observed in the maximum reached resistance, as it was already mentioned in the previous paragraph.

3.2.2. La Concha

For a confining pressure of p' =200 kPa, the graphs in ε_z *versus* q in Figure 5 show equal trajectories for α =0° and 90°, suggesting isotropic behavior. Reaching equal maximum resistance for these directions and a lower resistance for α =45°.

On the other hand, the results for p'= 400 kPa show that the three directions have different resistances. Reaching a maximum resistance for α = 0 ° and the lowest resistance for α = 45 °. Which indicates a clear anisotropic behavior, this condition can be an acquired anisotropy due to the increase in the initial confining tension.

The same can be observed in the graphs of Figure 7, in which it is observed that the maximum cutting resistance is reached for values close to 100 kPa for α = 0 ° and 90 °, practically following the same path, while for α = 45 ° the resistance reached is lower in the tests for p'= 200 kPa.

The trajectories observed in the three tests follow the same direction but reached lower maximum resistances for the tests of p'= 400 kPa.

4. Conclusion

The laboratory tests were carried out with the aim of observing the characteristics of anisotropy and its influence on the hydro-mechanical response of sandy clay soils of two areas in the City of Torreón. The Union and La Concha. The test was carried out in a piece of conventional triaxial equipment and an oedometer device. During the analysis of the results, it was observed that there is a difference in the degree of deformation and resistance depending on the inclination with which the load is applied (α = 0 °, 45 ° and 90 °). The soil from the Union is the one with the highest degree of anisotropy.

Natural and Inherent components of the anisotropy could be observed in the soils studied. Both components were observed in the oedometer tests, and only the inherent anisotropy was observed in the triaxial tests, varying the confining pressure.

Acknowledgements

The authors thank the Faculty of Civil Engineering of the Autonomous University of Coahuila for the facilities provided in the use of materials and equipment from the Geotechnics laboratory.

References

[1] Casagrande, A. and Carrillo, H., Shear failure on anisotropic material, *Proc. Boston. Soc. Of Civil Eng.* **31-2** (1944), 74-87

[2] Minh, N.A., An investigation of anisotropic stress-strength characteristics of an Eocene clay, *PhD. Thesis, Department of Civil and Environmental Engineering, Imperial College London,* (2006).
[3] Hoyos, L. R., Experimental and computational modelling of unsaturated soils under true triaxial stress state, *PhD. Thesis, Georgia Institute of Technology. GA,* (1998).
[4] Hoyos, L.R., Pérez-Ruiz, D.D. and Puppala, A. J. Constitutive modelling of unsaturated soil behavior using a refined suction-controlled true triaxial cell: Preliminary observations, *Proc. of the fifth international conference on unsaturated soils* ***1*** (2011). 671-676
[5] Matsuoka, H., Sun, D.A., Kogane, A., Fukusawa, N. and Ichihara, W. Stress-strain behavior of unsaturated soil in true triaxial test, *Canadian Geotechnical Journal* ***39*** (2002), 608-619.
[6] Nishimura, S. Laboratory study on anisotropy of natural London Clay, *PhD. Thesis, Department of Civil and Environmental Engineering, Imperial College London,* (2005).
[7] Toyota, H., Nakamura, K. and Sramoon, W. failure criterion of unsaturated soil considering tensile stress under three-dimensional stress conditions, *Soils and Foundations* ***44(5)*** (2004), 1-14.
[8] M. F. Attom and N. M. Al-Akhras, Investigating anisotropy in shear strength of clayey soils, *Geotechnical Engineering* ***161*** (2008), 269-273