# Behavior of Asunción's cemented sands

## Comportement des sables cimentés de Asunción

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ABSTRACT
The imperious need to determine the geotechnical properties of the cemented sands of the city of Asunción and to obtain a knowledge closer to reality of the behavior of these soils under load at its natural state, as well as the determination of the characteristics and factors that influence their behavior, leads to the need of performing in-situ load tests. New equipments were designed and built and procedures were established both for the performance of load tests as well as for the extraction of samples. A great deal of information was obtained and used to establish correlations between the values of in-situ strength and deformation of the cemented sands of Asunción in their natural condition and the results of the tests obtained in the laboratory.

RÉSUMÉ
Le besoin impérieux de déterminer les propriétés géotechniques des sables cimentés de la ville d'Asuncion et d'obtenir une connaissance plus proche de la réalité concernant le comportement de ces sols sous la charge de leur état naturel ainsi que la détermination des caractéristiques et des facteurs qui influencent ce comportement, mènent au besoin d'effectuer des essais de charge in-situ. A cette fin, de nouveaux équipements ont été conçus et construits et des procédures ont été établies tant pour la réalisation des essais de charge comme pour l'extraction de témoins. Grâce à ceux-ci ont été obtenues de nombreuses informations utilisées par la suite pour établir des corrélations entre les valeurs de la résistance et la déformation in-situ des sables cimentés d'Asuncion dans leur état naturel et les résultats des essais obtenus en laboratoire.

Keywords : cemented sands, load tests

## 1 INTRODUCTION

Cemented sands are considered a transition material between soil and rock and exhibit characteristics that are common to both of them, as well as their own characteristics. The available knowledge on physical and mechanical properties of Asunción's cemented sands derives mostly from laboratory tests on samples extracted from soil exploration pits and from the interpretation of the small penetrations obtained beyond SPT refusal values (N > 50) using the same equipment and energy from the SPT test, obtained for an arbitrary number of blows. These tests are important because they give an insight into the heterogeneity of the tested material, but they do not give results that represent the actual conditions under which these cemented soils are encountered at its natural state, as well as the factors that modify and influence their behavior under load.

Figure 1. Equipment designed for in-situ load tests.

The difficulty of the study of these cemented sands is that, since it is a heterogeneous and transition material, there are no standardized test methods to determine their geomechanical properties.

For the purposes of study of these soils in this current work, a load test equipment was designed for the performance of in situ load tests, as well as equipments for the recovery of slightly disturbed core samples using an electric portable drilling rig and a small specially designed core sampler used with compressed air as a drilling fluid for not changing the water content of the sample for subsequent tests at the laboratory. In-situ load tests were performed with this equipment to obtain a great deal of information that was later on used to establish correlations between in-situ ultimate strength and deformation values of Asunción's cemented sands and laboratory test results. In addition, this equipment was used to determine the stress-deformation characteristics of Asunción's cemented sands through the performance of in-situ load tests, as well as to determine the factors and index properties that influence the behavior of these soils in their natural condition under load.

## 2 EQUIPMENTS USED FOR IN-SITU LOAD TESTS

The new equipment consists of a metallic tank of 2.50m length x 1.60m wide x 2.00m height, thus totalizing a volume of 8.00m$^3$ and 720 kg of tare. The tank is externally surrounded by a metallic structure that acts as a guide for its vertical displacement once the load has been applied, as well as for its transport. Figure 1 shows a picture of this equipment.

The operating principle of this equipment for the application of load to the soil is based on pouring water inside the tank, which can displace freely along the vertical axis inside the metallic structure

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that acts as a guide as the soil starts to deform. The transmission of load to the soil is accomplished by leaning the tank on a solid metallic transmission rod. This solid rod has a screw thread in its lower end to extend the load transmission rod (in an eventual test at a greater depth) and to fit the small metallic footings of different diameters, which finally make contact with the soil and transmit the load to it. Footings of 4.4cm, 7.5cm, 10cm and one of 15cm were used to cover a wide range of pressures. A transparent and graded hose which goes from a small hole located at the bottom of the tank to the upper end of one of the side walls was placed in order to measure the water level inside the tank. The maximum load that can be applied with this equipment is 8,729Kg, which corresponds to 8,000 kg from the water that was poured inside the tank and 720 kg from the tank's tare.

The measurements of deformations were performed using a micrometer with a precision of 0,001", which is connected to the load transmission rod through a metallic bar. As the tank moves down due to the soil deformation, the micrometer's spindle begins pressing a transversal metallic bar specially provided for this purpose and starts measuring deformations.

## 3 IN-SITU LOAD TESTS

Fourteen field load tests were performed with the equipment on a site located in the city of Asunción, where in certain parts of the terrain, cemented sands were outcropping or at shallow depths beneath the surface. Seven tests were performed with a 4.4cm diameter footing, one test with a 7.5cm diameter footing, two tests with a 10cm diameter footing and one test with a 15cm diameter footing. In addition, three more tests were performed with a 4.4cm diameter footing in which a confinement equivalent to a 1m depth of the same soil was simulated. To simulate this confinement, iron discs with flat faces and circular holes at the center of them were used (to allow the insertion through these holes of the transmission rod and footing). Thus, a test performed at a depth of 1m is simulated, with the difference that the test is carried out at the surface level. In this way it is also ensured that the only difference between the test at the surface level and at 1m depth of soil simulated confinement is exclusively the confinement and not other factors such as void ratio, density, cementation, water content, etc. The selection of the footing's sizes was based on two factors, the first one is to cover a wide range of pressures, and the second one is to determine if there is any influence over the soil's behavior due to the scaling factor.

## 4 LABORATORY TESTS

The purpose of performing diverse laboratory tests with the samples recovered from the field was to obtain the different properties and characteristics of the tested material and to compare and correlate these results with those obtained with the field tests. Sieving tests and hydrometry tests were performed on this material, classifying these cemented sands as silty sands (SM). Comparing this material with other soil samples recovered in other site investigations in the city of Asunción (Bosio, 1997), it can be concluded that they properly represent the cemented sands of Asunción.

In addition, different index properties were determined from the field-extracted samples, such as dry density, porosity, void iratio, water content and saturation. Unconfined compression tests were performed with the samples extracted from the field test location. The unconfined compression tests were performed according to ASTM D 2166 – 79. The samples were tested at their natural water content, and thus obtaining curves of stress-strain for different values of water content as seen in Figure 2.

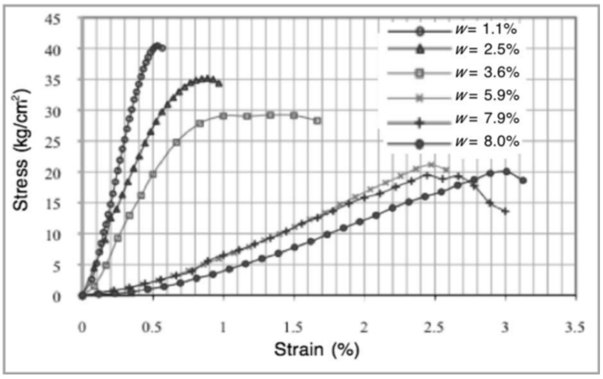


Figure 2. Laboratory stress-strain curves.

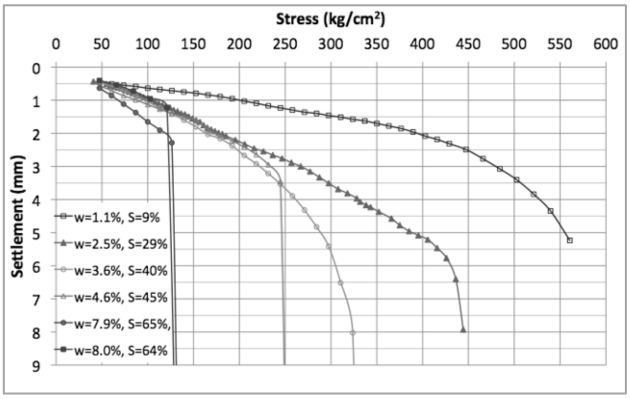


Figure 3. In-situ stress-settlement curves.

## 5 ANALYSIS OF RESULTS

### 5.1 *Influence of water content*

While performing the in-situ tests, a wide range of intermediate and ultimate resistance and deformation values of tested cemented sands were observed. The *stress-settlement* characteristic curves were obtained for a wide range of water content. Observing the *stress-settlement* curves of all tests plotted in the same chart, as seen on Figure 3, it can be observed the influence and the importance that water content has regarding the strength and deformation of these soils.

Ultimate soil resistance values were obtained at the field, which vary from 120Kg/cm$^2$ for a water content of 8.0% and a saturation of 64% to 500Kg/cm$^2$ for a water content of 1.1% and a saturation of 9%. These values were compared to the characteristics and properties of the samples recovered on the field test site and determined in the laboratory. There is a clear correlation between the soil's water content and the ultimate resistance and deformation of these cemented sands, which can be seen in Figure 4, where the ultimate resistance values of tested cemented sands for different water contents fit perfectly to a curve, showing a clear tendency of decrease in soil's ultimate resistance for greater water content values. It is of importance to mention that the relation between the degree of saturation, water content and the ultimate resistance of cemented soils has already been appreciated by other authors in laboratory tests (Bosio, 1997) (Dobereiner, 1987). However, it has never been possible before to determine a correlation between water content and ultimate resistance of cemented sands obtained through the performance of in-situ load tests.

During the unconfined compression tests performed at the laboratory, the same behavior due to the influence of the water content was observed, as Figure 2 shows.

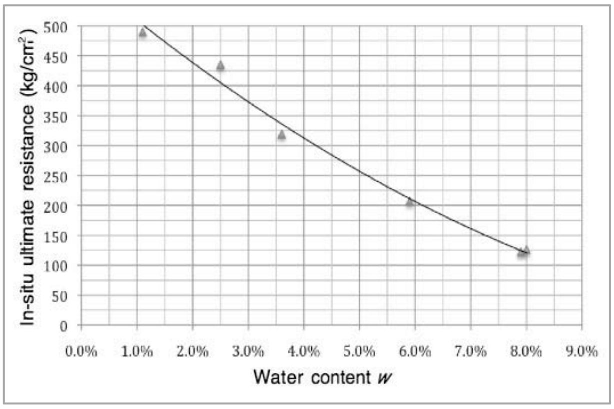


Figure 4. Water content vs. in-situ ultimate resistance.

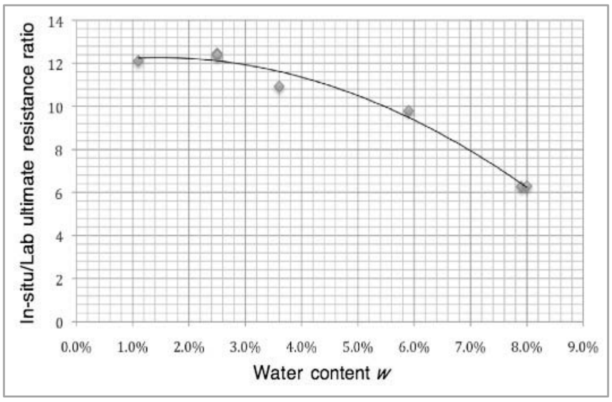


Figure 5. Correlation between in-situ and lab ultimate resistance.

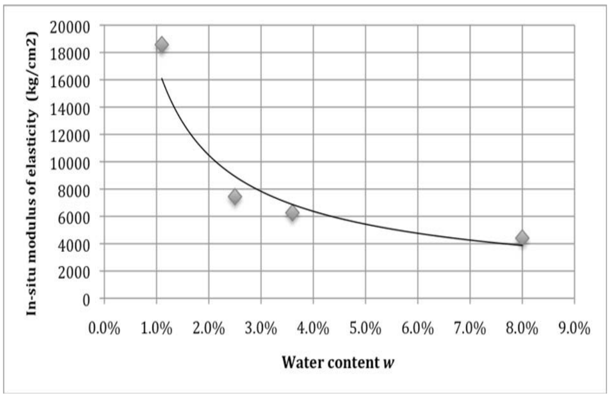


Figure 6. In-situ modulus of elasticity vs. water content.

Ultimate resistance values were compared for both in-situ and laboratory tests for different water content values, attempting to determine a correlation between these values, and thus, to be able to estimate the ultimate soil resistance at the field, knowing the laboratory ultimate soil resistance value and water content. A very good correlation was obtained between the ratio of the in-situ and laboratory ultimate soil resistance values and the water content, as seen in Figure 5.

## 5.2 *Elasticity modulus*

The difficulty in the obtainment of the elasticity modulus for in-situ tests lies in that there is no depth limit determined in the soil in which to establish deformations that occur during load tests. Since the pressure bulb reaches values that are still significant at depths of 1.5 to 2.0 times the diameter of the load footings, being this last value adopted with more frequency, it was adopted that deformations take place within a depth that is

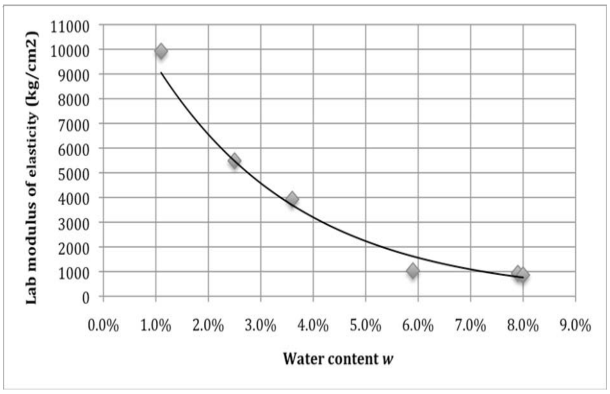


Figure 7. Lab modulus of elasticity vs. water content.

equivalent to twice the diameter of the footing used for the test. Above this value, stresses and therefore deformations are negligible.

The method used to obtain the elasticity modulus was to draw a tangent to the *stress-deformation curve* at a point equivalent to 50% of the soil's ultimate resistance**.** It was possible to observe a tendency for the elasticity modulus to decrease as the water content increases, as can be observed in Figure 6. This means that the greater the water content is, the greater the deformations are, and that beyond 8% of water content, the decrease in modulus is reduced significantly.

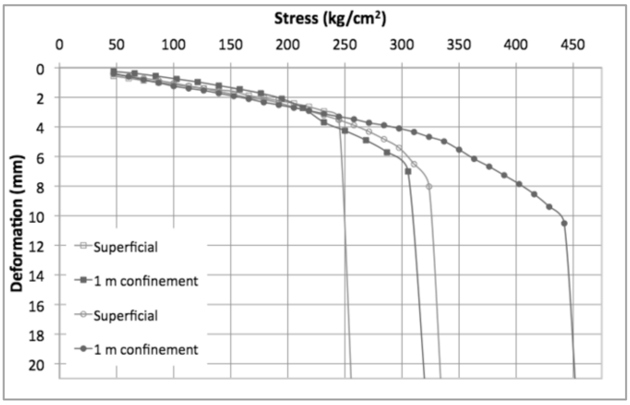


Figure 8. Influence of the confinement.

Regarding the unconfined compression tests at the laboratory, the attained correlation between the elasticity modulus and the water content percentage was very good, showing a remarkable adjustment of the curve to the obtained values of the elasticity modulus for the different water content percentages, as seen in Figure 7.

## 5.3 *Influence of the confinement*

In-situ tests at surface level simulating a confinement equivalent to a depth of 1m of the same soil were performed at the work site using iron discs as surcharge, as previously mentioned. These tests results were compared to other in-situ tests performed at surface level without the iron discs but with similar water content percentages in order to determine the influence of the confinement regarding resistance and deformation.

Stress-deformation curves obtained at the field tests with and without this simulated confinement can be observed in Figure 8, clearly noticing the greater ultimate resistance values obtained at the tests corresponding to a 1m of soil simulated confinement. The color pairs in this figure are equivalent to tests with similar water content values.

### 5.4 *Influence of the scaling factor*

In-situ tests were performed with load footings of different diameters in order to determine whether the scaling factor exerts any influence on the ultimate soil resistance and deformation values of these cemented sands. These tests were performed under similar conditions of water content, thus to discard to a great extent the influence of water content on the ultimate resistance and deformation values of these soils.

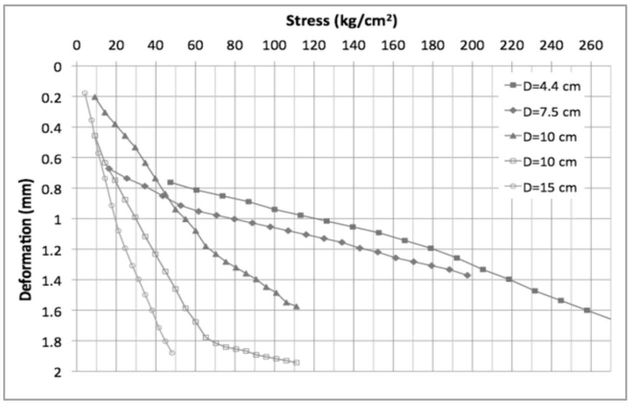


Figure 9. Influence of the scaling factor

Figure 9 shows the curves for the above-mentioned tests. Tests with 4.4, 7.5, 10 and 15cm diameter footings are compared. These curves indicate that up to a pressure level of around 65 kg/cm$^2$, there is a greater deformation of the soil for a determined level of pressure. This greater initial deformation may be due to the relocation of the sand grains, which takes place at the beginning of the loading phase (Dobereiner, 1987). It can also be noted that these initial deformations are greater as the diameter of the footings increases. This might be so because at the work site the soil's water content increases with the soil's depth, and since the pressure bulb tends to reach a greater depth in the soil as the footing diameter increases, there is a greater deformation of deeper soil layers.

Once a certain level of stress has been attained, being in these soils approximately 65 kg/cm$^2$, an increase of the resistance of these soils is observed and is reflected by an abrupt change of slope, being the slopes of the curves similar for different sizes of footings used. This increase of resistance may possibly be due to the end of relocation of the sand grains, and the predominance of the resistance caused by the interlocking of the sand grains and friction.

## 6 CONCLUSIONS

The performed field tests have been satisfactory in collecting important information about the behavior under load of the cemented sands at its natural state. This obtained information has permitted a better comprehension of the real behavior of these cemented soils and the factors that influence their behavior under load.

The analysis of the results of this work has allowed to reach certain conclusions regarding the soil under study:

- There is no single value of ultimate resistance for the cemented sands of a specific site. There is a clear connection between the water content and the ultimate resistance and deformation values of these cemented sands, being this the main factor influencing the behavior of these soils. There is a clear tendency to decrease the ultimate resistance as well as to increase the deformation of the soil for greater water content percentages.
- There is a clear increase in the ultimate resistance of this cemented sands due to the increase of the confinement. For the same confinement, the increase in the soil ultimate resistance for different tests at different levels of water content remains approximately constant.
- As the diameter of the load footing increases, greater soil deformations can be observed in the initial portion of the stress-deformation curve. Afterwards, there is an increase of the soil's resistance, reflected in the correspondent graph by a change of slopes, being these slopes similar for the different tests with load footings of different sizes.
- The equipment which was designed for the load tests results appropriate for this type of geological formation, being able to obtain excellent results in the performed field tests. The soil sampling equipments designed for the extraction of undisturbed samples are adequate for these soils.
- While performing this work, procedures to be followed were established for the performance of field tests in cemented sands with the designed equipment.

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