*Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering*
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*doi:10.3233/978-1-61499-656-9-735*

# Evaluation of the collapsibility of a sandy soil by in situ collapse tests

## Évaluation du collapsibility d'un sol arénacé par les essais in situ d'effondrement

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ABSTRACT
This paper presents some results of a research project aiming at understanding the behavior of collapsible soils in order to improve settlement prediction in foundation design. Two series of in situ tests were performed: one using circular load plate (0.80m of diameter - Group 1 test) and another using an equipment called "Expansocollapsometer" with a circular load plate (0.10m of diameter - Group 2 tests). The objective of the Group 1 test was to function as a benchmark in order to evaluated procedures of collapse settlements predictions. The Group 2 tests were performed with the objective of obtaining collapse strains to be used in the collapse settlements predictions. The settlement prediction using the Expansocollapsometer data was 18% higher than the collapse settlement measured, showing that this equipment has a good potential for projects in areas of collapsible soils, aside the fact that it is simpler, faster and more economic than the traditional undisturbed sampling / oedometer tests.

RÉSUMÉ
Cet article présent les donnés d'un projet de recherche visant à comprendre le comportement de sols collapsibles pour s'appliquer dans les prévisions des tassements des fondations. Deux séries d'essais de chantier ont été réalisées : une série exécutée à l'aide d'un plat circulair de charge (diamètre de 0.80m - essai de la série 1) et une autre série exécutée à l'aide d'un équipement appelé Expansocollapsometer qui utilise le plat de charge (diamètre de 0.10m - essais de la série 2). L'objectif de l'essai de la série 1 a été de fonctionner comme repère aux procédures d'évaluation des tassements d'effondrement. L'objectif des essais de la série 2 a été l'obtention des déformations d'effondrement à employer dans les prédictions de tassements d'effondrement. Les résultats des prévisions des tassements avec l'Expansocollapsemeter ont été 18% plus hauts que ceux mesurés. Il est montré que l'équipement est adéquat pour les projets dans des régions des sols collapsibles, vue que la procédure est plus simple e rapide e moins coûteuse que les essais oédomètriques sur des échantillons non remaniés.

## 1 INTRODUCTION

The development of arid and semi-arid regions has led engineers to deal with soil whose geotechnical behavior is not easily dealt with the principles of the traditional soil mechanics. In this context collapsible soils are distinguished. They are unsaturated soils that suffer considerable reduction of volume after loaded and submitted to an eventual process of wetting. The consequence of the collapse in the foundations is differential settlements that may compromise the functioning or even the stability of the structure.

In Brazil, examples of damages of buildings involving collapsible soil have been registered in almost all national territory. In Pernambuco State the subject started to have importance after to construction of the Itaparica dam. With the necessity of displacement of cities located near to the river San Francisco for other areas not yet occupied, there were damages in several newly constructed buildings, resulting in an expensive work of recovery.

Some collapsible soils present problems of sampling, due to its structure, making it difficult to obtain reliable results from laboratory tests to be used in the predictions of settlements. This has led some researchers to consider procedures using field tests (for example Ferreira and Lacerda, 1995; Houston et al., 1995; Mahmoud et al., 1995; Lacerda et al., 1996; Coutinho et al., 2004 and Souza Neto, 2004).

This paper discusses the use of field tests in the identification and predictions of settlements of foundations in collapsible soils. This paper is part of a research project involving the Geotechnical Groups of the Federal University of Pernambuco and the Federal University of Rio de Janeiro, aiming at the understanding of the behavior of collapsible soils for the design of foundations. Campaigns involving laboratory and field tests were carried through in a collapsible soil of Pernambuco State. The emphasis will be given to the in situ collapse tests.

## 2 CHARACTERISTICS OF THE EXPERIMENTAL FIELD

The studied area (Fig. 1) is located in a region of semi-arid climate in Petrolândia City, State of Pernambuco, northeastern of Brazil. Reports of problems in some buildings are very common in this city mainly due to collapse of the soil foundation. The experimental site is an Agricultural School that presents damages (cracks) due to the collapse resulting in the loss and reconstruction of some buildings.

The relief observed in the region is predominantly flat. A gentle declivity of about 5% is observed in the Agricultural School wich turned out to be sufficient to concentrate part of pluvial waters in the direction of the buildings.

Petrolândia City is part of the basin of Jatobá, where there are sedimentary deposits dating back to the Paleozoic. A superficial mantle of elluvial soil of the Tacaratu Formation is seen in this location, which is characterized by sediments of coarse and medium sand particles, forming occasional, ill- sorted conglomerates (Ferreira and Lacerda, 1995).

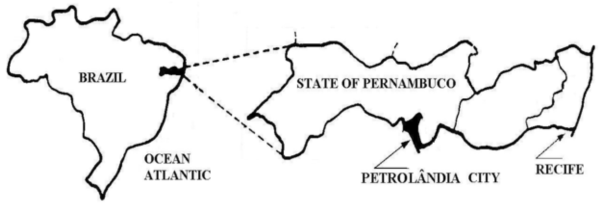


Figure 1. Location of experimental field.

A comprehensive field investigation was carried out in the experimental site by: soil sampling; moisture content profiles; suction profile; field hydraulic conductivity test (Guelph permeameter); bore-hole investigation – SPT-T; in situ collapse test and Ménard pressuremeter test. More information is presented in Coutinho et al. (2004) and Souza Neto (2004).

The bore-holes (SPT-T) were performed in the dry and wet seasons, according to Brazilian Standard NBR 6484/2001, with a penetration test every 0.5m along the depth and complementing the traditional SPT with torque measurements according to Décout and Quaresma Filho (1994).

Figure 2 presents typical results. The soil is composed of a loose to medium dense fine silty sand with no plasticity as far as 1.5 m depth and low plasticity (3 < PI % < 5) in the range of 1.5 to 3.0 m. In the depths of 2.5 to 3.0 m, the soil is in a dense to very dense condiction. This soil presents a permeability varying between $10^{-4}$ and $10^{-5}$ m/s.

The water content in the dry season (Fig.2) varies between 1 and 4%, resulting in a degree of saturation of 5 to 39%. For these values of water content, the suction varies between 10 and 20 MPa. In the rainy season, the water content was always greater than in the dry season, showing that all the soil profile was subjected to the wetting process.

In Brazil, some porous collapsible soils in southerm and central-west regions have been characterized for showing low values in blows numbers (in general N<5), with small variations in the results when the test is carried out in the dry or wetting season. Suctions in these regions are low (< 50 kPa) what may account for the small variations with the seasons.

In the northeastern region of Brazil the high value of the suction in dry season (10 to 20 MPa) may influence significanttly the results of the SPT tests. The results of Fig.2 reflect clearly this aspect, where blowcounts from SPT tests in in dry season in the collapsible layer (9 < N < 20) were about 100% greater than those obtained in the wetting season (4 < N < 13).

Décout and Quaresma Filho (1994) consider collapsible the soil displaying T/N ration between 2 and 3. This criterion is based on the results of a particular formation (porous soil of São Paulo). This criterion has been questioned when utilized for other formations. The principal criticism is the fact that the torque test to be pefermed in desestructured soil whose collapsible structure was destroyed. The results of the Fig.2 are a good example for this limitation, where the values of the T/N ratio were not in accordance with Dècourt and Quaresma Filho's criterion.

## 3 IN SITU COLLAPSE TESTS

The in situ collapse tests were performed during the dry season. Basically it consists of a plate load test where the soil is loaded and soaked after stabilization of the settlement at a selected stress (soaking stress). The settlements due to soaking (collapse settlements) were measured until stabilization. New loading could be added to obtain the rupture stress.

Two groups of tests (Group 1 and Group 2) were performed. The objective of the Group 1 tests was to serve as benchmarks to evaluate procedures of collapse settlement predictions. The Group 2 tests were performed with the objective of obtaining collapse strain to be used in the collapse settlements predictions.

### 3.1 *Group 1 Test*

The round steel plate used is rigid with a diameter of 0.8 m. The soaking stress was 100 kPa. It was installed in pits with 0.5 m in depth and 0.9 m in diameter. The bottom of the pit was leveled and covered with about 15 mm of a clean sand layer in order to make the water infiltration uniform. The same procedure was used by Reznik (1992) and Conciani et al. (1998). Electronic sensors were installed in 4 positions below the plate (to observe the progress of the wetting front). The wetting front depth was identified by a resonant sound from an electronic alarm system.

The wetting process was performed by keeping a layer of water into the pit. To keep a constant water head, a rate of 0.11 l/s was added. It was observed that the wetting front reached at least 2.0 m in depth below the plate, covering the region affected by the stress bulb.

### 3.2 *Group 2 Tests*

Ferreira and Lacerda (1995) presented an equipment for performing in situ collapse tests, which was called "Expansocollapsometer" (ECT). The tests are performed in depth inside an open auger bore-hole using a rigid circular plate of small diameter (100mm).

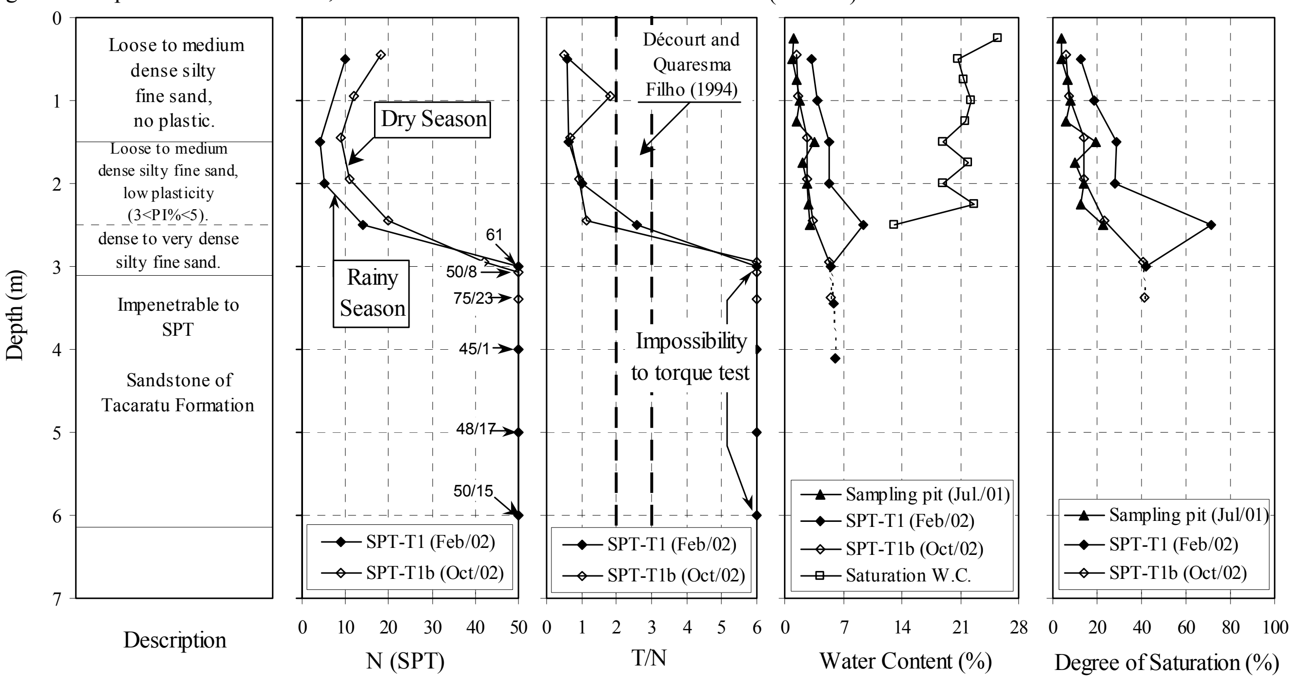


Figure 2. Typical results of a complete bore-hole SPT-T with water content profile and degree of saturation

Mahmoud et al (1995) presented a similar proposal. In this study, the Group 2 tests were performed utilizing an improved version of this equipment as presented by Souza Neto (2004).

The equipment (Fig.3) is composed of a fixed base formed by a supporting tripod (1) with adjustable shoes (2), which assist in the leveling. The loads are obtained through piling up weights calibrated previously (3), on a platform (4) connected to a steel pipe (5). The platform possesses a central axle (6) to facilitate the centralization of the load. The verticality of the steel pipe is kept through two sets of adjustable rollers (upper and lower) (7). The loading is transmitted to the soil through a circular rigid plate (8) connected in the lower extremity of the steel pipe. The plate has small holes to allow the wetting of the soil beneath the plate. The water reaches the soil under the plate by means of a water line (9) connecting the plate to a reservoir with a controlled flow tap and measurement of the volume of water. For this purpose the graduated reservoir of the Guelph permeameter was used. The measurement of the displacements is made through strain gages (10), which are fixed to a magnetic base (11) and supported on the upper extremity of the steel pipe.

The tests were performed in the depths of 0.5, 1.0 and 1.5m, within the limits of the stress bulb of the Group 1 test (0.5 to 1.6m). The general procedure consisted: 1) opening of the bore-hole using an auger and leveling of the base of the bore-hole; 2) assembly and leveling of the equipment; 3) application the loads and displacements measurements; 4) soaking of the soil beneath the plate; 5) estimate of the depth of the wetting front.

For the leveling of the base of the bore-hole an auger with a special plane surface was used. The soaking stresses were 15, 30, 60 and 100 kPa. The soaking of the soil was performed under a rate flow about 0.25 ml/s. The estimate of the depth of the wetting front was performed on the basis of the moisture content of the soil under plate after the tests. It was observed after the tests that the significant variations of moisture content occurred until a depth about 120mm beneath the plate, nearly the half of the stress bulb (200mm). More information about the procedure can be obtained in Souza Neto (2004).

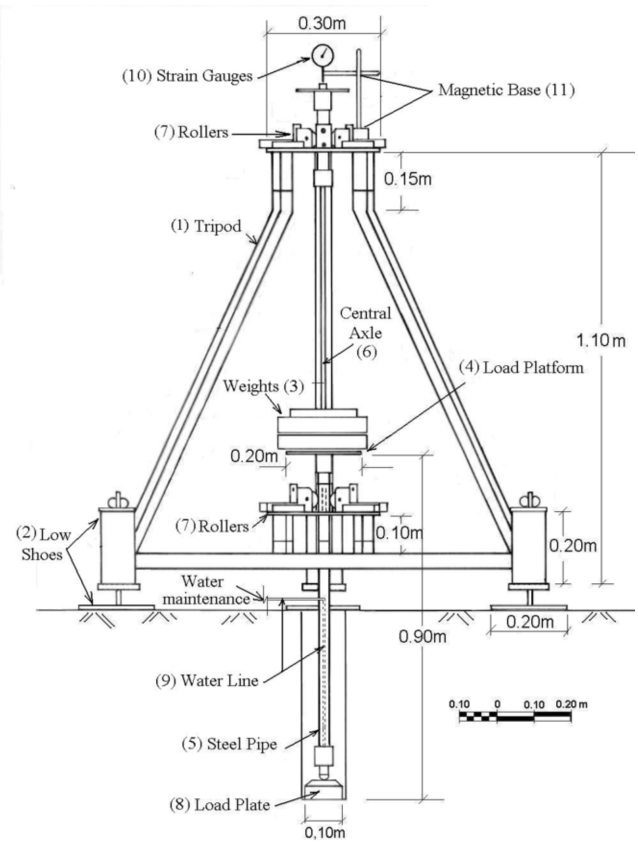


Figure 3. Equipment Expansocollapsometer (ECT) utilized by Souza Neto (2004) to in situ collapse test.

## 4 TESTS RESULTS

### 4.1 *Group 1 Test*

Figure 4 presents the results of the plate load tests. The settlements before wetting (natural water content) were 1.24mm. After wetting the collapse settlements measured were 45.0mm.

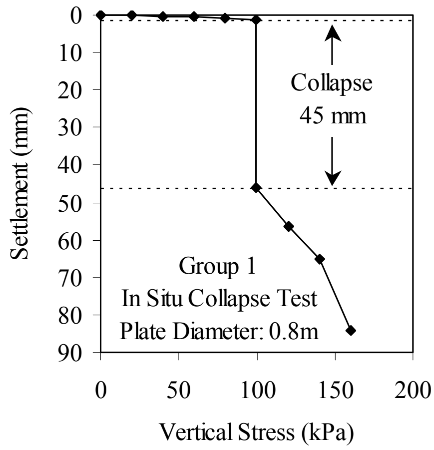


Figure 4. Results of the in situ colapse test – Group 1

Fig.5 present the variations of the collapse settlements, volume of water and the depth of the wetting front with time. The advance of the wetting front was evaluated empirically through the adjustment of the experimental data to a power function, in accordance to Houston et al. (1995).

Most of the collapse settlements (43.5mm) occurred for a time around 100min, consuming about 600 liters of water (Fig.5a). In this exact time the wetting front reached a depth about 0.90 m

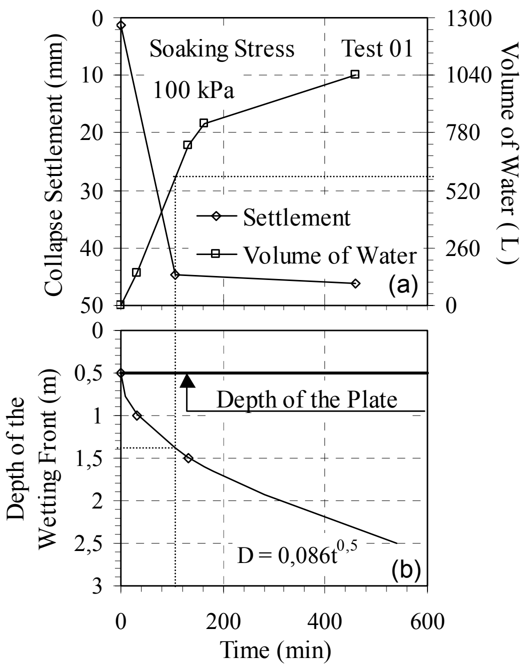


Figure 5. Variation of the collapse settlements, volume of the water and depth of wetting front with the time – Group 1 test.

beneath the plate (Fig.5b). The additional volume of water (about 700 liters) did not result in significant collapse. These results suggest that most of the collapse settlements will occur in the superior half of the stress bulb, although the wetting front reached the entire stress bulb (1.6m under the plate).

### 4.2 *Group 2 tests*

Figure 6 presents typical results of in situ collapse tests performed with the ECT. The collapse settlements increase with the soaking vertical stress, as expected.

In some tests effort was performed to wet the depth of the stress bulb, pouring an additional volume of water after collapse settlement stabilization. Fig.7 presents the variation of the collapse settlement and volume of water with the time. The behavior was similar to that observed in the Group 1 test (Fig.5).

The total volume of the water used up the end of the test was about 4 liters (Fig.7). Only about half of the total volume of water contributed effectively with the collapse. In other test performed with lower soaking stress it was observed that the volume of water until the stabilization of collapse settlements was lower. This suggests that the thickness of the soil layer involved in the collapse process, adopted in this study, was half of the stress bulb.

## 5 COLLAPSE SETTLEMENT PREDICTION

From the results of the tests performed using the ECT (Group 2), a tentative was make to predict the collapse settlement

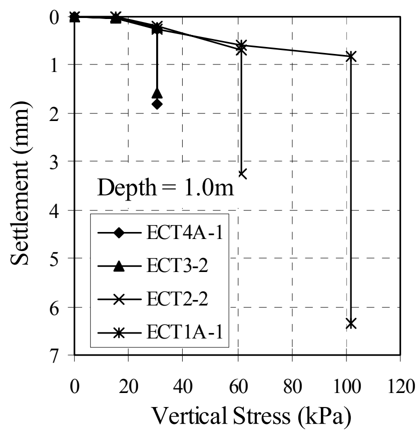


Figure 6. Typical result of the in situ collapse test – Group 2 tests

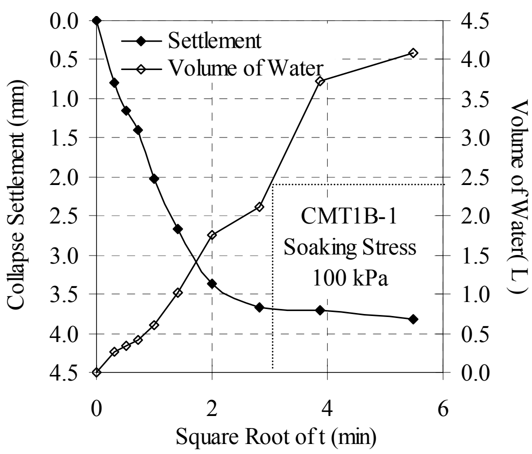


Figure 7. Variation of the collapse settlement and volume of the water with the time – Group 2 tests.

obtained from Group 1 test. The settlement prediction was made analytically. Initially the stress bulb of the Group 1 tests was divided in three layers with thicknesses of about 0.50m and calculated the total stress ($\sigma_{vo} + \Delta\sigma_v$) in the center of the each layer. The stress parcel due to the loading was calculated on the basis of the equations of the theory of elasticity for a rigid circular plate. The estimates of the collapse settlements were performed multiplying the collapse strain by the thickness of each layer.

The collapse strains were calculated dividing of the collapse settlements ($s_c$) for the thickness ($t_w$) soil layer involved in the collapse process. In this case, $t_w$ was determined empirically considering the thickness of the soil involved for the stress bulb and submitted to the wetting. Considering the previous discussion, it was adopted $t_w$=100mm, corresponding to half of the stress bulb.

The collapse settlement predicted according to this procedure (53mm) was of the order of 18% higher than the collapse settlement measured (45mm). This result can be considered to be situated in the error range generally obtained by other design methods.

Complementary studies involving numerical modeling associated to more results of in situ tests will allow better evaluation of the in situ collapse behavior and, consequently, a more rational interpretation of the in situ collapse tests.

## 6 CONCLUSION

The in situ collapse tests using Expansocollapsometer showed to be a simple and economic way for project in collapsible soil, despite the uncertainties involved in the calculation of the collapse strains, specifically in the determination of the $t_w$.

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