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# Measure of the pore water pressure during expansion tests - physical and numerical approach

## Mesure de la pression interstitielle lors de l'essai d'expansion – approche physique et numérique

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**ABSTRACT:** The knowledge of the evolution of the pore water pressure around the pressuremeter probe during an expansion test can allow us to better control the drainage conditions of the expansion test. This paper presents the calibration chamber developed by JEANLUTZ SA. In this chamber, dissipation tests of pore water pressure observed during the pressuremeter test can be followed. The chamber includes sensors of the total and pore pressure installed in the soil close to the probe. Thus, the variation of the pore pressure tests could be registered in differents points around the probe in real time. Moreover, a mini-sensor installed in contact with the probe allows us to analyse the variation of the pore pressure in the walls of the boreholes.Two prototypes were created in order to take the water pressure with the pressuremeter during in situ tests. At the end, the first results performed with this experimental tool in comparison with numerical and analytical mode are presented.

**RÉSUMÉ:** La connaissance de l'évolution du champ de la pression interstitielle autour de la sonde pressiométrique lors d'un essai d'expansion peut permettre de mieux maitriser les conditions de drainage lors de l'essai. Ce papier présente une chambre d'étalonnage développée par JEANLUTZ SA. Des essais de dissipation de la pression interstitielle pendant l'essai pressiométrique peuvent être réalisés. La cuve comporte un ensemble de capteurs de pression interstitielle et totale installés dans le massif du sol à proximité de la sonde. Ainsi, la variation de la pression interstitielle a pu être suivie dans différents points autour du pressiomètre en temps réel. De plus, un mini capteur installé en contact avec la sonde permet d'analyser la variation de la pression sur les parois du forage. Deux prototypes ont été montés pour mésurer la pression interstitielle avec le pressiomètre in the in situ tests. A la fin, les premiers résultats effectués avec l'appareil experimental en comparaison avec le mode numérique et analytique sont presentés.
**Keywords:** Pore pressure, Pressuremeter, calibration chamber, cyclic tests, monotonous tests

# 1 INTRODUCTION

The idea of the pore water measurement during the pressuremeter test is based on the Terzaghi‘s principle.

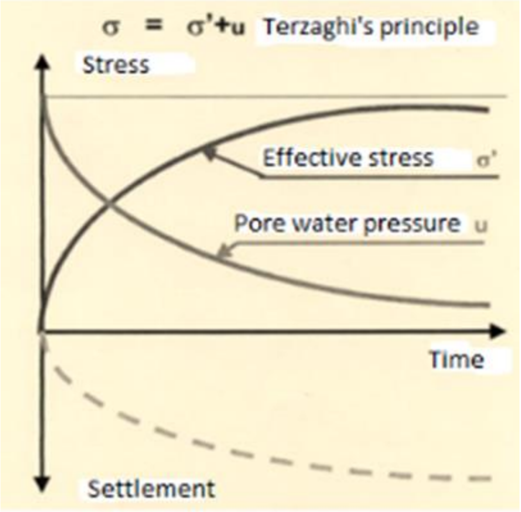


*Figure 1: Terzaghi's principle*

The normal pressuremeter test allows us to measure only the total pressure applied to the soil and does not give us any element about the water pore pressure developed during the test. The main purpose of this study was a minimal modification of the existing material in order to do this measurement practical and functional.

At the same time, a waterproof calibration chamber was built in the headquarters of JEANLUTZ Ltd in order to test the developed material and define the rheological model of each type of soil (rate of dissipation and evolution of the effective stresses).

# 2 DESCRIPTION OF THE PROTOTYPES

Two mini-sensors with their electronic board are inserted in the body of the slotted tube. The sensors are positioned diametrically opposite on the slats of the slotted tube passing the wires inside the top fitting. A sealing paste is used throughout the groove to waterproof the entire electronics. A screwed metal plate is placed over the groove to mechanically protect the measuring system and fix the porous stone.

*Figure 2: Electronic board inserted in the slotted tube*

The electronic boards are connected with 2 wires that pass through the groove made in the slotted tube and end on the M6P module which gives us the variation of the electrical signal in 4-20mA. Then, the values of the interstitial pressure are read in real time on the Dialog device with the other values of the water and air pressure. We can see a representative diagram of the operation of the whole equipment in the next figure.

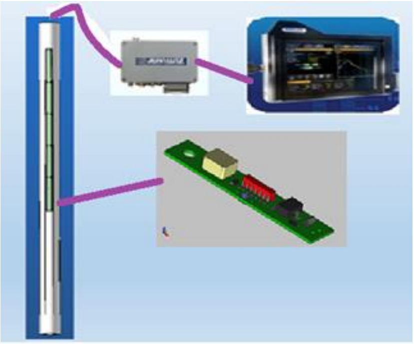

*Figure 3: Set of equipment for measurement and reading of the pore water pressure*

A second prototype was created without the slottet tube by putting the sensor directly in the flexible rubber. In this way we can avoid the big inertia of the slotte tube. This prototype will be tested in the near future.


Figure 4: Sensor integrated in the flexible rubber

## 2.1 Electronics of the prototype

The sensor chosen has a measuring range of 12 bars. The calibration was done for a maximum pressure of 10 bars (between 0-10 bars). The circuit gives a 4-20mA signal conditionned by the M6P module (JEANLUTZ SA trademark). Then the Dialog PC industrial touchpad, with the correct calibration and zeroing, displays the value in bars. All the electronic boards have been calibrated in such a way that the 10 bars correspond to the saturation of the sensor (20mA).

## 2.2 First in situ results

The first real test in situ conditions was performed in the dike of Saint Malo where the height of water varies during the day because of the low and high tide.

The basement of the dike consists in a permeable silty sand as we can deduce from the variation of the pore water pressure during the pressuremeter test (figure 5).

The other tests in different depths have more or less the same variation of the pressure (pore water and total pressure).

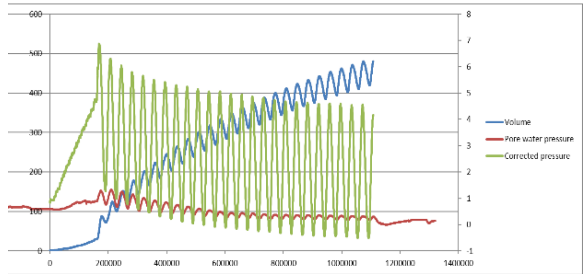

Figure 5: Cyclic tests with measurement of pore water pressure

# CALIBRATION CHAMBER

## 3.1 Design

A sealed tank is built in the headquarters of JEANLUTZ SA which allows us to have an experimental approach of the pressuremeter test with measure of the pore water pressure (Dupla et al., 1991) in addition to its numerical and analytical simulation.

Water pore pressure and total pressure sensors are placed inside the soil sample. In this way, we can have the variation of the total and water pore pressure in real time during the pressuremeter test. We are interested in the dissipation of the water pore pressure according to the distance of every sensor from the probe. This will be a key information for the fitting of a rheological model for numerical application.

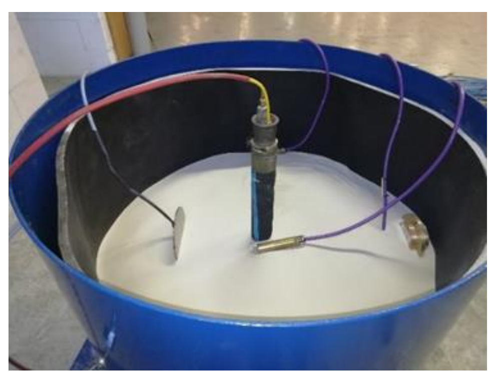
Figure 6: Preparation of the experience and setting up of the sensors

For the application of the lateral and vertical forces to the sample, two airbags of the vertical force and one airbag of the lateral force are used to simulate the in situ conditions of the sample.

These airbags can be inflated to 10 bars and in this way they can transmit the generated pressure to the sample.

*Figure 7: Airbags for the simulation of the lateral and vertical forces*

The height of the chamber is 72cm and the diameter is 90cm. There is an axisymmetry in the chamber around the axis of the probe which is fixed in the center of the tank with brass nipples.

A grain auger screw elevator with an adjustable flow is used for the sample deposition. Furthermore, a system of suction with a vacuum pump is being deployed when the tank is being filled with carbonic gas before the water filling.

*Figure 8: Prepared sample for the experience before the placement of the lid*

In this way, we can achieve a high level of saturation filling the voids between the soil grains with water and dissolving the air trapped with the carbonic gas.

*Figure 9: Grain auger screw elevator used for the sample deposition*

### 3.2 *Sample reconstitution*

The tests are carried out with the probe fixed in the center of the tank with nipples and the wires of the sensors with cable glands under his base and its lid.

The sensors placed in the tank are either of total pressure or pore water pressure. In total, 4 sensors of total pressure and 4 of pore water pressure are installed in different positions inside the calibration chamber. More precisely the sensors are installed close to each aribag in order to measure the real pressure transmitted to the sample. Furthermore, one sensor of the pore water pressure is placed next to the probe to simulate the sensor placed in the prototype for the in situ measurements.

The deposition of the soil is done by pluviation using the sieves no.6 (3.36 mm) and no.8 (2.38 mm).

For every experience a first calibration in a small container is carried out in order to define the deposition intensity and the falling height. In reality, other factors like shutter porosity, shutter-hole pattern, vertical stress on shutter falling distance, distance between diffuser sieves, diffuser sieve opening and the number of diffuser sieves can have an impact in the density of the sample. However, according to the bibliography and the studies already performed about the pluviation of samples in the laboratory, the principal factors are the deposition intensity and in a lower level the falling height-distance between the sieves and the sample (Nader et al., 1987). In this way, we vary only these two factors to reach the desirable density.

# 3 NUMERICAL AND ANALYTICAL SIMULATION

## 4.1 *Analytical model*

In a first approach, we used analytical models to simulate the pressuremeter test. Isotropic rheological models were used to simulate some specific pressuremeter tests. The simulation is carried out taking into account the models of Mohr Coulomb (Dano et al., 2002), Tresca and modified Cam Clay (Mestat et Riou, 2002) according to the type of soil. These models are the most used in the existing bibliography and allow us to describe the soil behaviour with a sufficient accuracy.

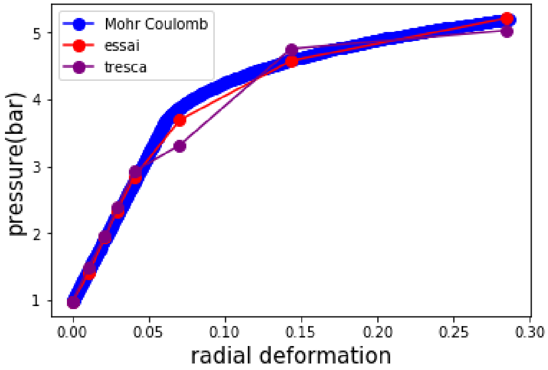


*Figure 10: Analytical simulation of a real in situ test with Mohr Coulomb and Tresca models (Python software)*

## 4.2 *Numerical model*

A numerical model is developed using the finite elements software Cesar-LCPC. The probe is placed in the center of the model in accordance with its placement in the calibration chamber. The soil is considered as an elastoplastic material with a density between 1300 and 1600 kg/m3, a Young modulus around 150 MPa and a Poisson ratio of 0.33. For the plastic phase of the soil material, the cohesion c of the soil was taken equal to 5 kPa, the friction angle between 25 and 35 degrees and the dilatancy angle was negligible.

Concerning the boundary limits, the four sides of our model were considered embedded. The lateral and vertical forces were applied inside the borders of the model as we can see in the next figure. In this way, the thickness of the airbags was taken into account.

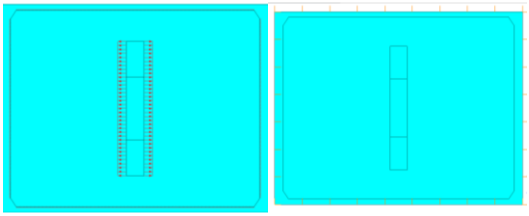

*Figure 11: Loadings and boundary limits of the numerical model*

Regarding the modelisation of the probe an elastic material was used with the rubber properties. The material density is 900kg/m$^3$, the elastic modulus around 10 MPa and the poisson ratio 0.5 (incompressible material). However, the loads are applied only in the soil material and in this way only the soil deformation and stress is examined.

A quasi static model was used to describe the different levels of the applied pressure. In each level of pressure a combination of boundary conditions in term of pressure (airbags) and probe pressure was imposed in the numerical model. Figure 12 shows the displacement of the soil for an applied pressure of 4 MPa and a uniform external vertical and lateral pressure of 0.3MPa.

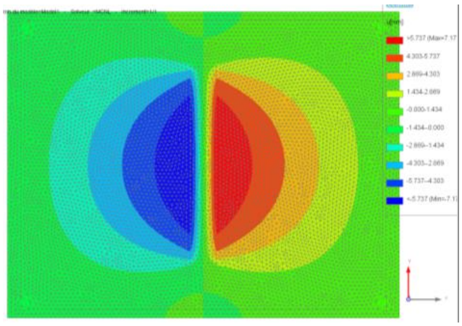

*Figure 12:Displacement of the soil in the numerical model with Mohr Coulomb law in Cesar LCPC*

These results deduced from the model of the calibration chamber show that the stress field around the probe even for high pressure values is well reproduced by the model.

High pressure has to be applied to reach plasticity in the soil sample.

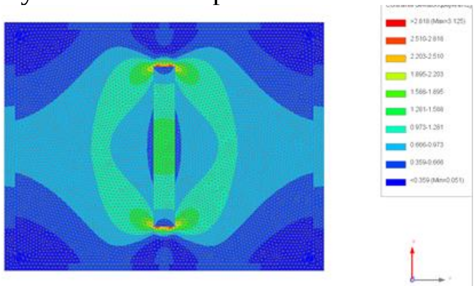

*Figure 13:Deviatoric stress in the numerical model*

4.3 Experimental model

For our first tests of calibration chamber validation, we used a very low flow of deposition intensity of the order of 0.07gr/cm2/s. The falling height used is 55cm (distance between the bottom of the last siever and the sample). The reached density is 1.62 t/m3 or 15,89 kN/m3. As wee can see in the technical note of Hostun sand (Flavigny et al., 1990) it corresponds to a soil density close to the γmax=15.99 kN/m3 which correspond to a very low deposition intensity. So a 90% of relative density has been used in these first experiment.

*Figure 14: Pluviation of the sand sample in the calibration chamber*

The measurements are recorded in real time by Dialog touchpad using the same system developed for the prototype (see paragraph 2). In this way, we can control the evolution of the experience and detect possible dysfunctions.

The pressuremeter tests in the calibration chamber were performed primarily in a dry sand. It was a kind of control of the calibration chamber performance and quality of the soil sample. However, as it was described previously, the chamber is designed waterproof to a pressure level of 10 bars. These tests are to be realised in the near future.

Concerning these preliminary dry tests, a first phase of lateral and vertical stress increase of the soil was performed. The values of the 4 total pressure sensors were recorded. Table 1 presents the program of this preliminary test as it was performed using the automatic Prevo CPV apparatus (JEANLUTZ SA trademark).

Table 1

| Step number | Pressure setting | Lateral stress | Pressure setting | Vertical stress |
|---|---|---|---|---|
| 1 | 0 | -0,1 | 1 | 0,9 |
| 2 | 0 | -0,1 | 2 | 1,9 |
| 3 | 0 | -0,1 | 3 | 2,9 |
| 4 | 0 | -0,1 | 4 | 3,9 |
| 5 | 0 | 0 | 5 | 5 |

| | | | | |
|---|---|---|---|---|
| 6 | 0 | 0 | 6 | 6 |
| 7 | 1 | 1 | 2 | 2,3 |
| 8 | 2 | 1,9 | 2 | 2,3 |
| 9 | 3 | 2,9 | 2 | 2,3 |
| 10 | 4 | 3,9 | 2 | 2,3 |
| 11 | 5 | 4,9 | 2 | 2,3 |
| 12 | 6 | 5,8 | 2 | 2,3 |

The small differences of the real pressure values are due to the high volume of the airbags and the difficulty to control small pressure variations.

*Figure 15: System of pressurization of the probe and the airbags in the same time*

During this pressurization of the airbags the time for each step was 15 min in order to have a stabilization of the stress in the sample. The pressure given by the 4 total pressure sensors appears in table 2.

Table 2

| Step number | Center of the probe (bars) | 20 cm from the probe center (bars) | top boundary limit (bars) | lower boundary limit (bars) |
|---|---|---|---|---|
| 1 | 0.4 | 0.2 | 0.6 | 0 |
| 2 | 0.7 | 0.3 | 1.4 | 0.9 |
| 3 | 1.1 | 0.5 | 2.4 | 1.8 |
| 4 | 1.5 | 0.7 | 3.4 | 2.9 |
| 5 | 2.1 | 0.9 | 4.4 | 4.1 |
| 6 | 2.7 | 1.1 | 5.5 | 5.2 |
| 7 | 2.1 | 1.3 | 4.7 | 4.1 |
| 8 | 2.3 | 2.4 | 1.9 | 1.8 |
| 9 | 3.5 | 3.7 | 2.2 | 2.00 |
| 10 | 4.5 | 5.3 | 2.5 | 2.1 |
| 11 | 5.6 | 6.9 | 2.7 | 2.20 |
| 12 | 6.5 | 8.3 | 3 | 2.3 |

In the previous table we can observe that the sand pressure varies according to the distance from the applied boundary pressures (airbags in this case) and it is not uniform inside the sample (pressure bulb for uniform loads theory). The differences in the vertical stress of the up and down boundary limit is due to the way of the sensors' placement in the sample ( distance from the center, direction of the sensitive sensor area).

Moreover, a first cyclic pressuremeter test of low deformation and pressure was realised after this pressurization of the airbags. The lateral and vertical stress was kept constant at 3 bars.

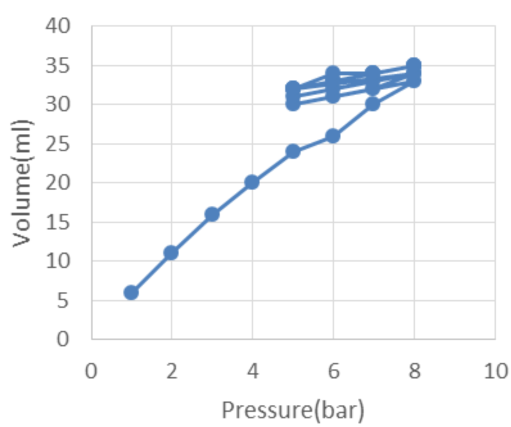


*Figure 16: Pressure volume curve*

In this validation test, we can see that the probe is correctly preconfined (very low volume for the level of the applied pressure) with the prior application of the lateral and vertical pressure. This is also due to the used method for the placement of the soil sample. The probe is primarily fixed in the center of the chamber and the soil is pluviated around it. This result is in accordance with the numerical simulation which predicts a 25% of probe deformation (radial expansion) for a 40 bar pressure.

The transmission of the probe pressure to the soil sample is low. Figure 17 presents the variation of the soil pressure in the chamber in combination with the applied pressure in the probe.

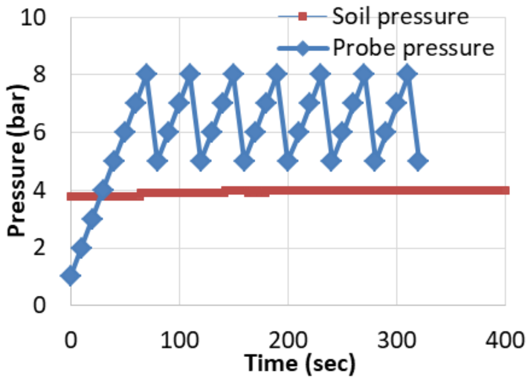


*Figure 17: Reaction of the soil sample to the pressuremeter test*

This phenomenon is explained by the high diameter of the calibration chamber in comparison with the probe (ratio 15).

## 4 CONCLUSION

The results presented in this paper show the ability of the developed systems to have in situ measurements of the pore water pressure during the pressuremeter test. In the other hand, the calibration chamber can give us accurate results of the pore water dissipation during the pressuremeter test in drained or undrained conditions. The post processing of these results will give us very valuable information about the liquefaction and the cyclic mobility of the different examined types of soil.

Finally, a combination with the analytical and numerical analysis will allow to propose some rheological models specifying the different parameters appeared in these equations. In this way, we can have a global description of the pressuremeter test with measure of the pore water pressure experimentally, numerically and analytically.

The soil used in the first experiment is a Hostun sand (France) which can be considered to have a marked drained behaviour. Other types of soil will be used in future experiments with differents properties like green clay, silt etc.

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