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# Comparison of the measurement of swelling pressure through different tests

## Comparaison de la mesure de la pression de gonflement avec différents essais

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**ABSTRACT:** The determination of the soil swelling pressure is a major topic for geotechnical structures such as foundations and retaining walls. It is commonly observed that different values of swelling pressure can be measured for the same soil sample, through different testing methods. The swelling pressure does not appear to be an intrinsic property of the swelling soil, but is rather the result of the imposed stress paths. This paper presents the first results of a comparative study carried out on clays from the Paris Basin and also on reference clayey materials such as an illite and a bentonite. Oedometer tests were carried out following different procedures (constant volume, in parallel and Huder-Amberg), then compared.

**RÉSUMÉ:**

La mesure de la pression de gonflement des sols revêt une grande importance pour les structures de génie civil comme les fondations et les parois. On observe souvent que pour un même échantillon de sol, plusieurs pressions de gonflement peuvent être obtenues par des méthodes d'essais différentes. La pression de gonflement ne semble pas être une propriété fondamentale du sol gonflant, mais plutôt le résultat de chemins de contraintes extérieures imposées. Cette communication présente les résultats d'une étude comparative menée sur les argiles de la région parisienne (vertes et plastiques) mais aussi sur des matériaux de référence comme une illite et une bentonite. Des essais œdométriques à volume constant et en parallèle ainsi qu'Huder-Amberg ont été menés et sont comparés.

**Keywords:** clays, swelling pressure, laboratory testing, soil-structure interaction

## 1 INTRODUCTION

The soil swelling phenomenon is related to variations of the water content of some clayey soils in the sub-surface layers, that can swell when put in contact with water.

Under temperate climates, clayey soils are often close to saturation and their swelling potential is relatively limited. However, if the stresses in place come to decrease, during the realization of an excavation, the opening of a tunnel or of a diaphragm wall panel for example, this swelling phenomenon can occur, causing damages or even the ruin of the structures.

Some clays have extraordinary swelling potential, up to four times as water changes their interfoliar spacing (spacing between clay sheets). The water molecules slip between the layers of clay and cause swelling. These clays are called "sensitive" or "swelling" clays and belong to the smectite family. This family has much larger swelling potential than other clay species.

This phenomenon occurs in natural or compacted clayey soils, marls, clayey rocks and anhydrite rocks during periods of heavy rainfall after periods of drought (Serratrice, 1996 and 2007), breakage of sewers or adduction pipes, or after completion of an excavation, but also when carrying out drilling and digging panels and tunnels for example.

These generally non-uniform deformations can cause cracking of individual houses, light structures or even some old buildings. The pressure exerted by this phenomenon can also generate significant solicitations in the geotechnical structures, which it is necessary to take into account in the design. Understanding the swelling of so-called "sensitive" clays is therefore an essential step to solve soil-structure interaction problems.

Therefore, as the swelling pressure does not appear to be an intrinsic property of the swelling soil, but is rather the result of the imposed stress paths, it is important to better apprehend the swelling phenomenon as well as to achieve reliable means of measuring the swelling pressure and the amplitude of deformations caused by this phenomenon for any given soil.given its nature and state. This paper presents the results of multiple swelling tests carried out to determine the swelling pressure of soils, and confronts and discuss the results.

# 2 CLAYS, TESTING PROTOCOLS AND ANALYSES METHODS

## *2.1 Soils*

To carry out this study, four clays were tested: three natural clays taken from Ile de France construction sites and representative of "sensitive" clays of the Paris Basin on the one hand, and one reconstituted soil (Arvel clay), resulting from a mixture of illite and bentonite, on the other hand. Table 1 shows the main properties of these soils.

*Table 1. Properties of the four clays*

| Clay | wi (%) | wL (%) | PI | C80 (%) | C2 (%) | OCR |
|---|---|---|---|---|---|---|
| Green | 30.7 | 61 | 33.5 | 100 | 55 | 1.25 |
| Black | 32 | 87.1 | 57.4 | 98.6 | 88.1 | 1.02 |
| Plastic | 24.5 | 110.2 | 71.3 | 97.6 | 80.9 | 1.24 |
| Arvel | 42.5 | 105 | 63.7 | 100 | 72 | 1 |

where PI is the Plastic Index and C80 and C2 are the percentages (in mass) of particles passing through the 80 µm and 2 µm sieves respectively.

For this study, the Green clay was sampled at 13 meter in depth, the Black clay at 45 meter in depth and the Plastic clay at 50 meter in depth.

The overconsolidation ratios of these three clays were estimated using the chart proposed by Bjerrum (1973) linking the plasticity index to the cu / σ‘p ratio as well as the equation (1) proposed by Skempton :

$$c_u = (0.11 + 0.0037 * \mathrm{PI}) * \sigma'_{v0} \qquad (1)$$

Where $c_u$ is the undrained cohesion, PI the plasticity index, and $\sigma'_{v0}$ the in situ vertical effective stress.

The Arvel clay was created from a mixture of illite and bentonite (50/50 % ratio in mass) and statically compacted: this allowed for a very good reproductibility of the specimens.

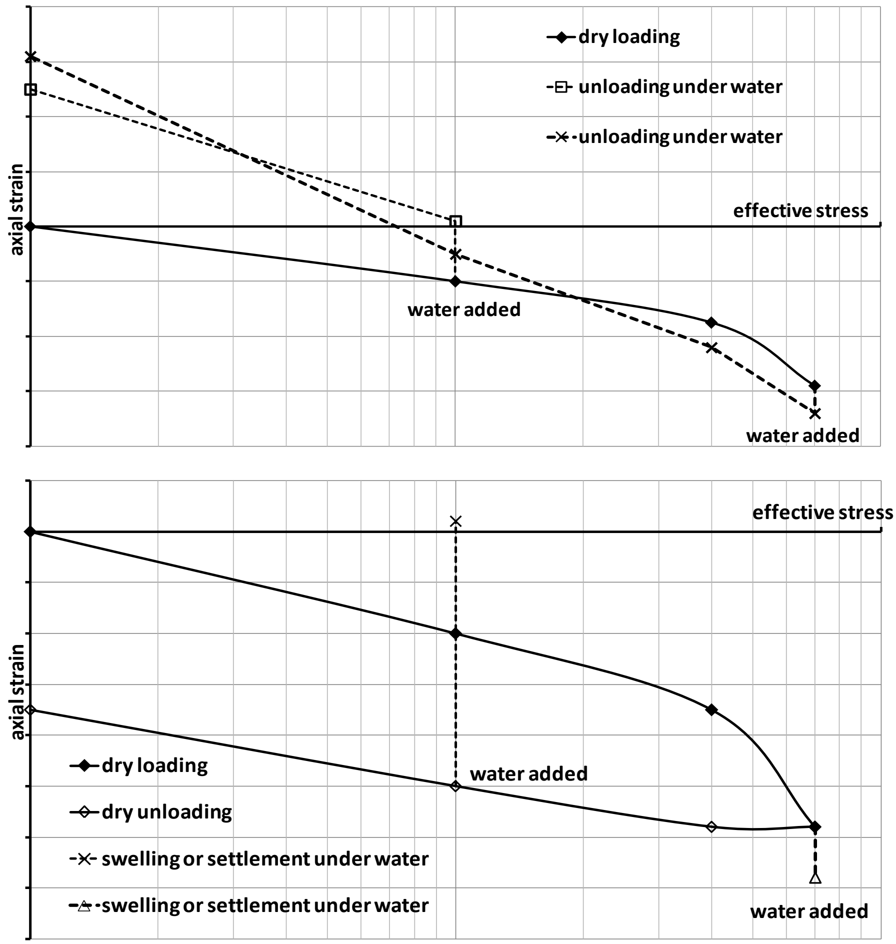


*Figure 1: examples of stress paths for two specimens for swelling tests in parallel without (left) or with (right) pre-loading cycle*

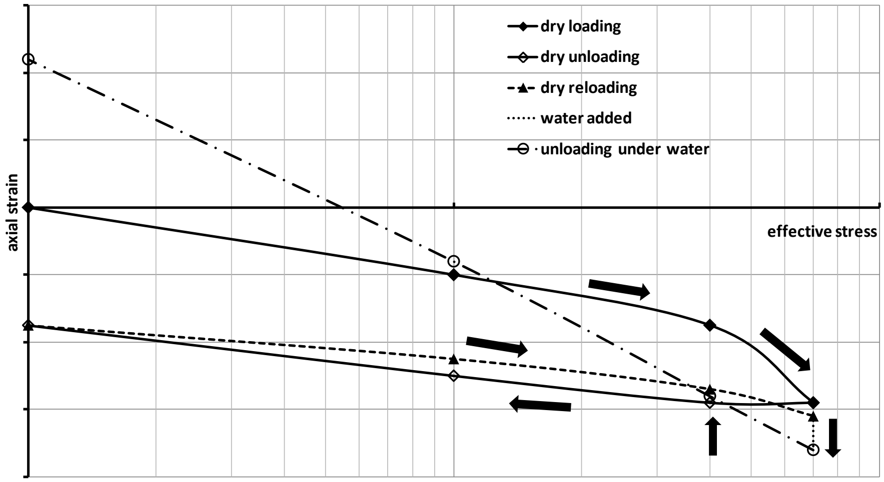


*Figure 2: Complete stress path of a Huder-Amberg test, with the different loading stages*

## *2.2 Testing protocols*

Four types of swelling tests were performed in this study, using an oedometer apparatus.

The first test is the swelling test in parallel (noted // in the following tables) (with or without pre-loading cycle), which consists in loading several specimens (typically four) at different stresses, then adding water and measuring the axial deformation as a function of time. In the case of a test with a pre-loading cycle, the specimens are first submitted to maximum axial stress and then unloaded to the stress at which the addition of water will be performed. At the end of the swelling stage, the specimens can be unloaded in successive stages, until a quasi-zero axial stress is reached. Tests without cycles were carried out following the standard XP P94-091 (AFNOR, 1995).

Figure 1 shows examples of stress paths for swelling tests in parallel, without and with pre-loading.

The second test is the constant volume swelling test, which consists in putting a specimen in water and then increasing the axial stress so as to maintain a constant volume. When the swelling pressure is exceeded, an additional increment of stress causes a settlement.

The Huder-Amberg swelling test (Huder and Amberg, 1970) consists in submitting an unique specimen to a cycle of loading-unloading-reloading in steps, in dry conditions, up to a maximum stress, then to submerge it in water under this stress, and then to unload it in successive steps, constantly measuring the variation of axial deformation. Figure 2 shows a complete Huder-Amberg test.

The different tests carried out on the four clays to determine the swelling potential as well as the swelling pressure are listed in Table 2.

*Table 2. Tests realised on the different clays*

| **Tests** | Green | Black | Plastic | Arvel |
|---|---|---|---|---|
| // without cycle | | | | X |
| // with cycle | X | X | X | X |
| Constant Volume | X | | | X |
| Huder-Amberg | X | X | X | X |

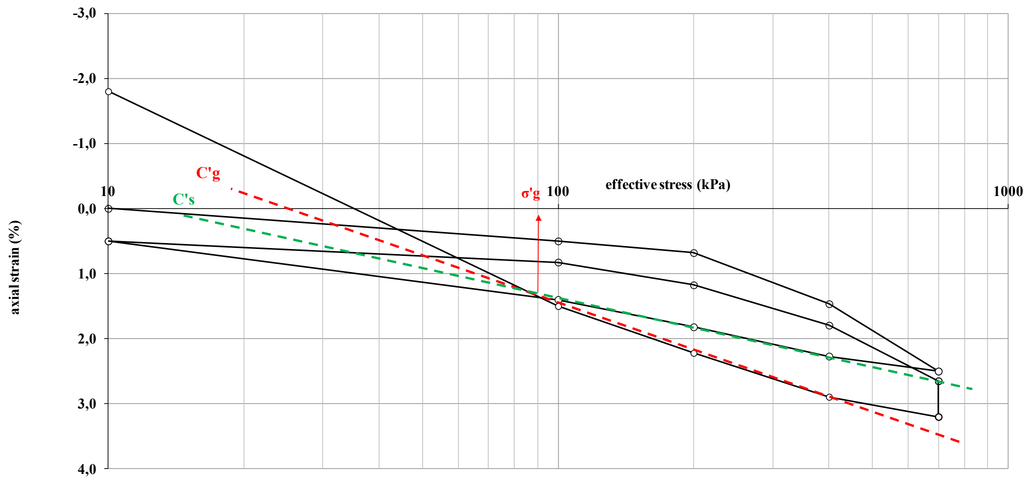


*Figure 3: Stress – strain relation for a Huder-Amberg test carried out on Arvel clay.*

### 2.3 Analyses methods

While the analysis of a swelling test in parallel is pretty much straightforward, it is necessary to introduce some derivated parameters to be able to discuss a Huder-Amberg test results.

The coefficient C's is the swelling coefficient and is represented by the swelling of the first unloading stage (in dry conditions). It is expressed in absolute value.

The coefficient C'g is the unloading coefficent and is represented by the swelling of the second unloading stage (with water). It is expressed in absolute value.

The swelling pressure σ'g is determined as the intersection of the lines C's and C'g, as shown on Figure 3.

Also, taking into account that performing a swelling test in parallel (with cycle) is essentially similar to performing a Huder-Amberg test, albeit with four specimens and without a second loading stage in dry conditions, it is therefore possible to analyze the combined results of these tests as a Huder-Amberg test, by determining again the various coefficients. Then it is possible to compare these results to those of the 'true' Huder-Amberg test.

## 3 RESULTS AND DISCUSSIONS

### 3.1 Arvel clay

The results of the two swelling tests in parallel carried out on Arvel clay and which are shown in Figure 4 give a swelling pressure equal to 400 kPa. Furthermore, as the results of both these tests are quite similar, it can be implied on a first approach, all other things being equal, that the loading history does not affect the results of the test.

Reconstructing a whole Huder-Amberg test with the results of the test in parallel (with cycle) as explained in paragraph 2.3 allows to determine another swelling pressure (Figure 5a). The measured value for σ'g is still 400 kPa.

Doing the same exercice for the test in parallel (without cycle) again allows for a comparison of the results and an assessment of the impact of the loading history (Figure 5b,c and d).

As the value of the C'g coefficient does not change with the loading history, and therefore the value of σ'g does not change too, it seems that slight changes in the loading history do not impact the value of the swelling pressure.

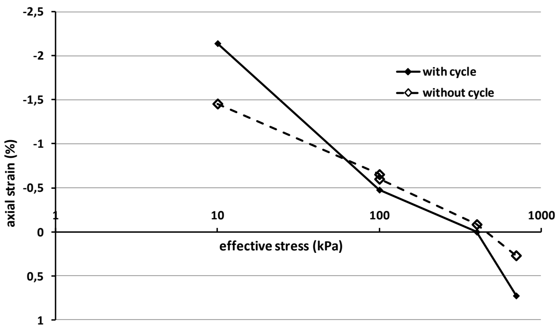


*Figure 4: Results of the two tests in parallel carried out on Arvel clay.*

However, the swelling pressure of the Arvel clay and determined with a Huder-Amberg test is equal to 90 kPa (see Figure 3). Therefore, the loading history in this case must have an impact on the value of the swelling pressure, or the state of the clay prior to testing. Another reason for this difference in results could also be the duration of the tests: the time spent by the samples during tests in parallel (even with cycle) is shorter than that of samples submitted to a Huder-Amberg test. Therefore, the state of the sample may change due to this increasing time spent in “dry“ conditions.

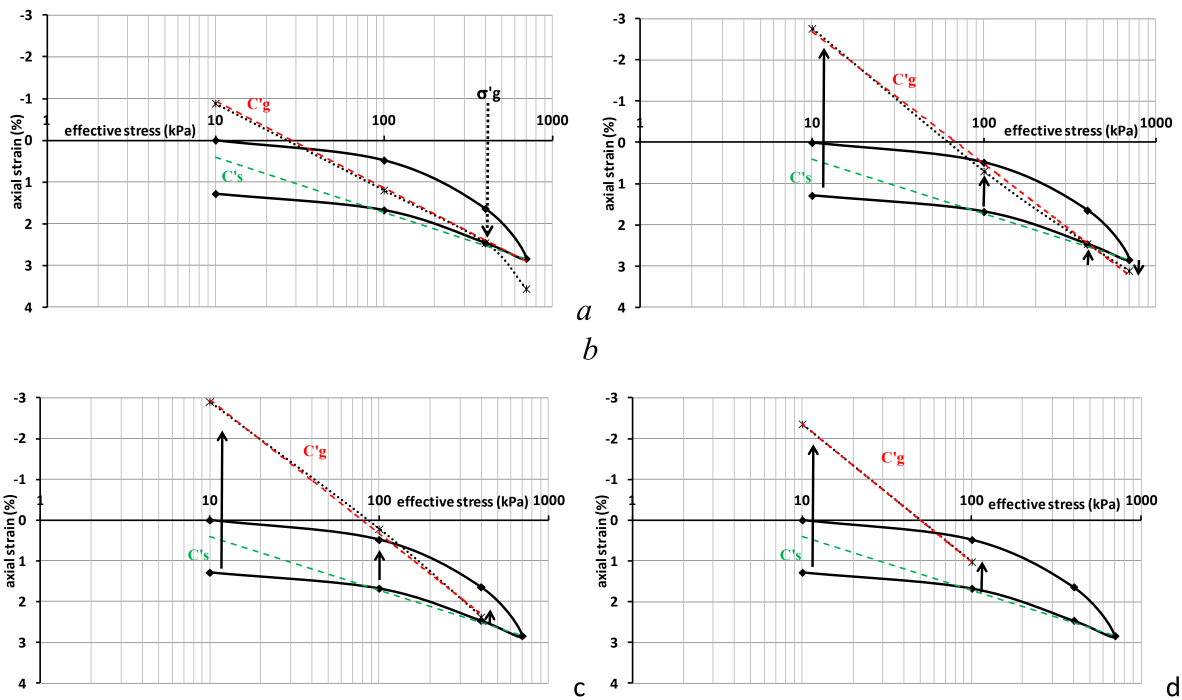


*Figure 5: Stress – strain relation for tests in parallel (with cycle (a) or without cycle (b,c and d) analysed as Huder-Amberg tests and carried out on Arvel clay.*

### 3.2 Tests on other clays

Similar tests were carried out on the other clays, allowing for a comparison of the impact of the testing procedure on the determination of σ‘g.

Table 3 sums up all the results, including the ones achieved on the Arvel clay.

It can be seen that the results obtained with the Black clay show the same difference than the ones obtained on the Arvel clay: swelling pressure measured by mean of a Huder-Amberg test is around 45 kPa, while it is equal to 600 kPa when determined by mean of a test in parallel (with cycle).

However, for the Green and Plastic clays, results are in the same range for both procedures.

Looking back at Table 1, it is not possible to establish a clear relation linking the swelling pressure to the identification parameters of the samples.

Therefore, it seems possible that the OCR has an impact on the validity of the use of the Huder-Amberg test to determine the swelling pressure of a soil, given that the Green and Plastic clays are overconsolidated and that the Black and Arvel clays are normally consolidated (cf. Table 1).

However, this observation necessitates to be looked at more in details, as only two overconsolidated soils and two normally consolidated soils where tested in this study.

*Table 3. Tests results for all clays*

| *Clay* | *Test* | *C's* | *C'g* | *σ'g (kPa)* |
|---|---|---|---|---|
| Green | Huder-Amber | 2.18 | 4.83 | 100 |
| | // with cycle | 2.01 | 5.18 | 150 |
| Black | Huder-Amber | 1.56 | 3.25 | 45 |
| | // with cycle | 0.91 | 2.51 | 600 |
| Plastic | Huder-Amber | 2.26 | 8.50 | 1250 |
| | // with cycle | 1.22 | 10.46 | 900 |
| Arvel | Huder-Amber | 1.45 | 2.32 | 90 |
| | // with cycle | 1.31 | 2.10 | 400 |
| | // without cycle | 1.31 | 2.37 | 400 |
| | constant volume | | | 400 |

### 3.3 Dispersion of the swelling pressure and swelling coefficient values

In parallel to this study, ten other Green clay samples were tested by mean of a test in parallel (without cycle), in order to assess the dispersion of the values of the swelling pressure. Figure 6 shows the relation between the depth at which the clay specimens were sampled and the measured swelling pressure.

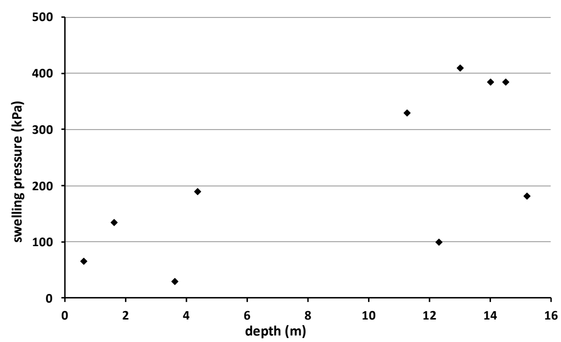


*Figure 6: depth – σ‘g relation for the Green clay.*

It can be observed that the swelling pressure increase as the sampling depth increases, which seems logical: shallow layers of sensitive soils, due to their position, are more prone to have already swollen. Therefore, for soils of the same nature, loading history should have an impact on the results of swelling test.

However, the different values of C‘g collected thanks to these tests do not appear to be linked to the initial water content, sampling depth, or dry density, parameters that are linked to the initial state of the soil. The values are ranging between 2 and 6, with two groups distinctly appearing (Figure 7). Hence, the value of C‘g coefficient does not appear to be linked to the state and the swelling pressure of the soil.

However, a remaining unknown factor would be the cinetic of swelling, this phenomenon being time-dependant.

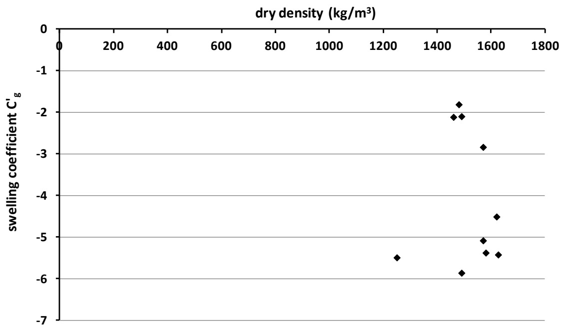


*Figure 7: C'g – dry density relation for the Green clay.*

# 4 CONCLUSIONS

This communication compares different testing procedures aiming to assess the swelling pressure of sensitive soils.

After a brief description of the different testing procedures, results are analyzed.

It was found that :

- For overconsolidated soils, Huder-Amberg tests and test in parallel (with or without) give similar results in terms of swelling pressure;
- For normally consolidated soils, however, results differs much more;
- This difference could be explained by a combination of the loading history and the duration of the initial loading-unloading-loading stages (for the Huder-Amberg test), causing succion in the specimen and changing its apparent homogeneity;
- All things equal otherwise, swelling pressure seems to be dependant to the depth at which the specimens were sampled;
- The swelling coefficient C'g does not appear to be directly linked to the properties of the soil, nor to the testing procedure.

The study will now try to confirm these first results by carrying out a systematic parametric study on soils of different natures and states on one part, and will focus on the remaining unknown factors, emphasizing the importance of the steps prior to the addition of water as well as the initial state of the clays, on the other part.

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