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Mechanical behavior of Ypresian plastic clays

Comportement mécanique des argiles plastiques de l'Yprésien

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ABSTRACT: Ypresian plastic clays are formations with a complex behavior, particularly due to their anisotropy and their swelling properties, which can make it difficult to interpret the results observed during laboratory or in situ tests campaigns. It is therefore sometimes necessary to use different methods to better understand their mechanical behavior. This communication presents the results of tests carried out in laboratories as part of several projects in the Paris region on Ypresian Clay formation. The soils studied come from deep core drillings taken between 20 and 70 m deep during various geotechnical investigation campaigns. The tests include both static and dynamic tests, making it possible to observe the mechanical behavior evolution of the material according to the stress path used. The different results were achieved using the cyclic triaxial, the resonant column, the shear wave propagation measurements from the Bender Elements, the stress paths and K_0 measurements at the triaxial. An analysis of the decrease in the shear modulus is then carried out, which will feed a rheological model and calibrate it according to the confining pressure.

RÉSUMÉ: Les argiles plastiques de l'Yprésien sont des formations au comportement complexe du fait, notamment, de leur anisotropie et de leur caractère gonflant qui peuvent rendre difficile l'interprétation des résultats obtenus lors de campagnes d'essais en laboratoire ou in situ. Il est donc parfois nécessaire d'avoir recours à différentes méthodes pour mieux comprendre leur comportement mécanique. Cette communication présente les résultats d'essais réalisés en laboratoire dans le cadre de plusieurs projets de la région parisienne sur les formations de l'Yprésien argileux. Les sols étudiés sont issus de sondages carottés profonds prélevés entre 20 et 70 m de profondeur lors de différentes campagnes de reconnaissance géotechnique. Les essais regroupent à la fois des essais statiques et dynamiques qui permettent d'observer le comportement mécanique du matériau en fonction de la sollicitation utilisée. Les différents types d'essais ont été réalisés à partir du triaxial cyclique, de la colonne résonante, des mesures de propagation des ondes de cisaillement aux Bender Elements, des chemins de contraintes et des mesures de K_0 au triaxial. Une analyse de la diminution du module de cisaillement est ensuite réalisée, ce qui permettra d'alimenter un modèle rhéologique et de le calibrer en fonction de la pression de confinement.

Keywords: Ypresian clay; shear modulus; laboratory tests.

1 INTRODUCTION

In urban environnements, modern practices of building construction or large structures can lead to new problems of interaction between soils and structures, particularly when using more fragile materials that can tolerate less strains.

The structures are mainly designed from methods incorporating mechanical characteristics defined by a single type of test and therefore only one mode of loading. However, depending on the actual stress path in the soil, the stiffness observed during the tests may not be realistic. Indeed, depending on the soils properties, the type of structure and its location, applied loads can be different and induce different mechanical responses. In order to identify the most representative test for in situ stresses, it is necessary to compare different methods for evaluating the mechanical parameters of materials. The improvement of the design of the structures through a better evaluation of the response of the soils to low-intensity loads is therefore an important issue.

Since several years, a database of tests carried out on Ypresian plastic clays, concerning Grand Paris Express worksites and other construction projects in the Parisian region, has been collected.

After a brief presentation of the geological context and the location of the sites studied, this communication will present the results of tests that have provided an overall view of the mechanical behavior of these plastic clays. These tests include controlled deformation and stress path triaxial tests, tests to define the earth pressure coefficient at rest K_0, resonant column tests, cyclic triaxial tests and wave propagation velocity measurements with Bender

Elements. We carried out nine monotonic triaxial tests under drained conditions (three specimens each) and 27 under undrained conditions, 15 cyclic undrained tests, 15 resonant column tests, 12 bender element tests, 23 triaxial tests following a specific stress path (drained and undrained), and five tests under K_0 condition.

The results which are presented in the following paragraphs will enable us to define a modulus degradation curve and different mechanical parameters. Then these parameters will be implemented in a finite elements numerical model which will be able to reliably represent the mechanical behavior of the soil nearby a structure.

2 GEOLOGICAL CONTEXT

Plastic clays are part of an impermeable geological formation of fluvio-lacustrine origin identified at the base of the Ypresian (Lower Eocene), called the Sparnacian, which also includes the upper sands, false glaises and Auteuil sands (Filliat et al., 1981).

This formation is framed by Campanian flint chalk (Upper Cretaceous) and Lutetian coarse limestone (Middle Eocene). The plastic clays or "argiles bariolées" are very compact and composed of clays sometimes marbled with various colors ranging from red to gray, bluish, black or yellowish (figure 1). They vary in thickness from 8 to 12 m depending on their location.

Figure 1. Plastic clay samples (Paris15e).

Their main characteristics are their high plasticity (plasticity index over 50) and their sensitivity to water, which gives them a swelling behavior that requires certain precautions to be taken, particularly when sampling them and carrying out experimental studies in the laboratory.

3 LOCATION OF STUDY SITES

The sites studied are part of the Grand Paris Express project, which involves the construction of several metro lines and stations in the Paris region (figure 2). The plastic clays that are the subject of this article are located on line 15 west at La Défense and line 14 south at Paris 13e.

Two other sites are also being studied, related to other construction projects in Paris 15e and Paris 12e.

Soil samples were taken at depths ranging from 20 m to 70 m, depending on location.

4 EXPERIMENTAL ANALYSIS

Various tests were carried out in the laboratory: the drained monotonic triaxial, the cyclic undrained triaxial, the resonant column, measurement of shear wave propagation velocity at the Bender Elements, stress paths in drained and undrained conditions and measurements of the earth pressure coefficient at rest K_0 at the triaxial.

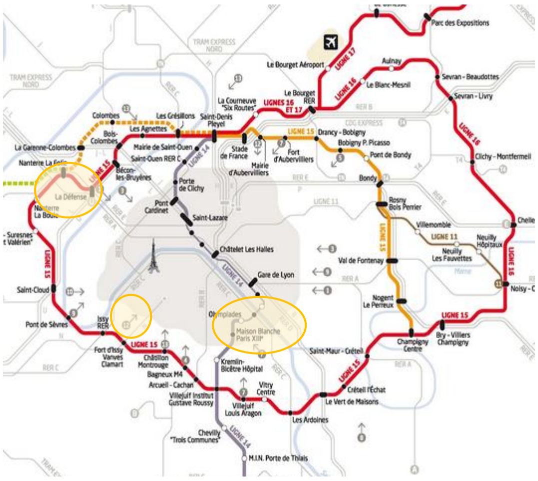

Figure 2. Location of sites studied in Paris region (source www.societedugrandparis.fr).

4.1 Consolidation and swelling of specimens

Assembly, saturation, measurement of Skempton B coefficient and consolidation were carried out in the same way for all specimens except those in the K_0 test, where a cell pressure corresponding to the vertical stress in place was applied with taps closed, in order to limit swelling due to water absorption before the saturation phase. A value of 800 kPa of back pressure was applied.

Consolidation phases were stopped once constant back volume had been achieved. Consolidation times varied from several hours to several days. Tests were then carried out with confining pressures ranging from 200 to 920 kPa, depending on the depth of the samples.

4.2 Triaxial drained and undrained tests

Drained consolidated tests were used to obtain mechanical parameters such as long term cohesion, angle of internal friction and Poisson's ratio with the variation in specimen volume. The results give an average of 20 kPa for effective cohesion, 15° for the effective internal friction angle, and 0.45 for Poisson's ratio.

4.3 Cyclic triaxial tests

Cyclic tests were carried out with force control and global strain measurement. A loading program was established with 9 loading phases ranging from 2 to 500 kPa, each consisting of 5 cycles starting from a minimum effective axial stress equal to the consolidation stress plus 10 kPa. Some results are shown in figure 3.

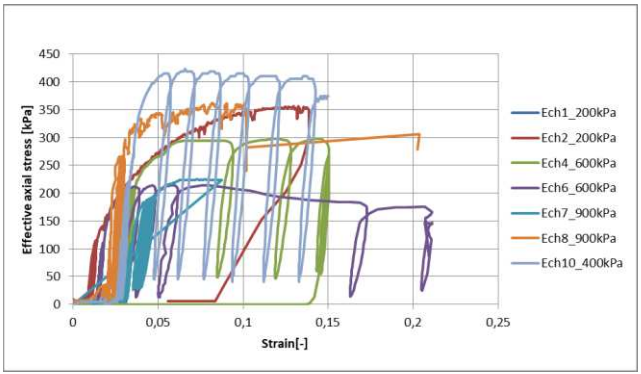

Figure 3. Example of cyclic tests at different confinement.

4.4 Resonant column tests

Resonant column tests were carried out at various confining pressures ranging from 200 to 920 kPa. Shear modulus results were obtained at strain values between 10^{-3} and 10^{-6}. A shear modulus degradation curve was established from the various tests (figure 4).

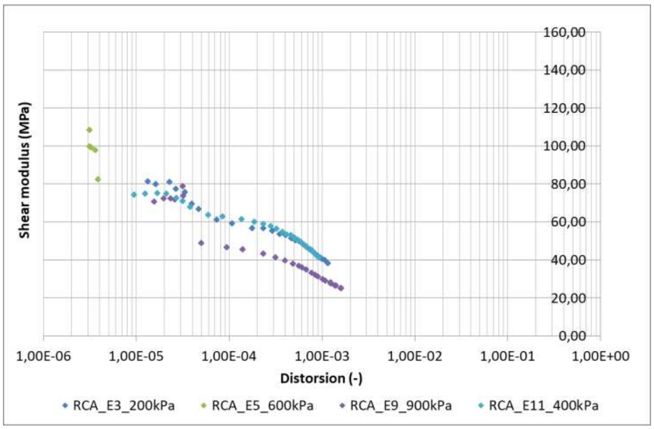

Figure 4. Shear modulus degradation curve for four samples.

4.5 Shear wave propagation tests

Shear wave propagation tests were carried out using a set of Bender Elements at confining pressures ranging from 0 to 900 kPa. Measurements at 0 kPa correspond to the stage before saturation just after installation in the cell. The figure 5 shows an example of a wave propagation test result.

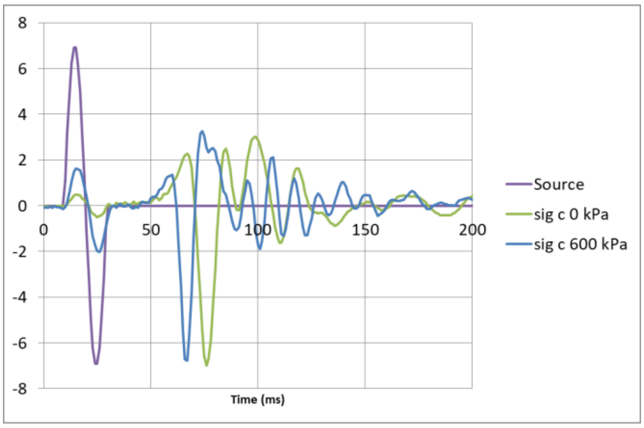

Figure 5. A specimen test results with the Bender Elements.

4.6 Stress paths

Specimens were tested along deviatoric paths according to mean stress p and deviator q in drained and undrained conditions. Two types of path were used for stress path testing. The first one describe the path tests in line with simulations and the life of the structure. The different stages are defined below:

1: geostatic stress state
2: existing loads (loading)
3: unloading/reloading cycle
4: simulation of earthworks (excavation)
5: end of project stresses
6: creep (long term condition)

The second type of stress path test has the same four stages as the first type but the deconfinement is realized until failure.

The curves shown in figure 6 represent the degradation curves of secant modulus observed during these tests.

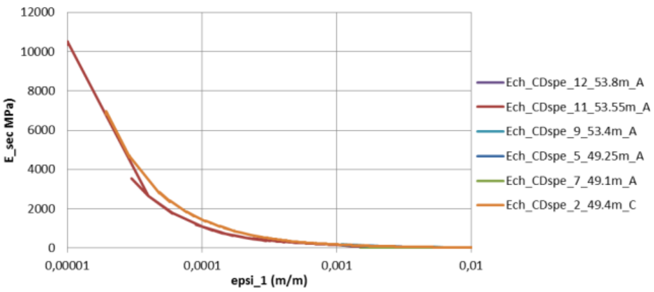

Figure 6. Secant modulus degradation curve for different stress path tests.

4.7 K_0 tests

The earth pressure coefficient at rest K_0 has been extrapolated directly from laboratory tests by imposing a condition of no radial displacement of the specimen. The cell pressure is increased and the axial force is controlled to limit diameter variation.

The figure 7 shows four tests. The K_0 value is close to 1 for three specimens. Another specimen, for which swelling was observed at saturation, shows a higher K_0 value, which then decreases to 1 as it approaches in-place stress.

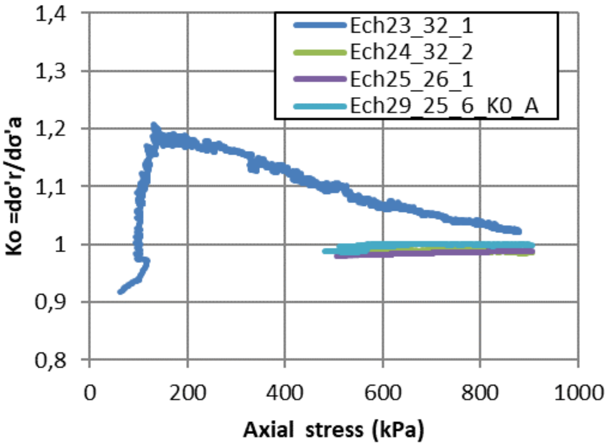

Figure 7. Results of four K_0 tests.

5 RESULTS SYNTHESIS

The different laboratory tests carried out eneabled us to obtain a degradation of the shear modulus, normalized with the G_0 modulus at very low strains, as a function of distortion for each site studied.

The figure 8 shows results of Bender Elements, resonant column and cyclic triaxial tests carried out for the site located in Paris 15^e. It shows a marked decrease in shear modulus for strains of between 0.001% and 0.1%.

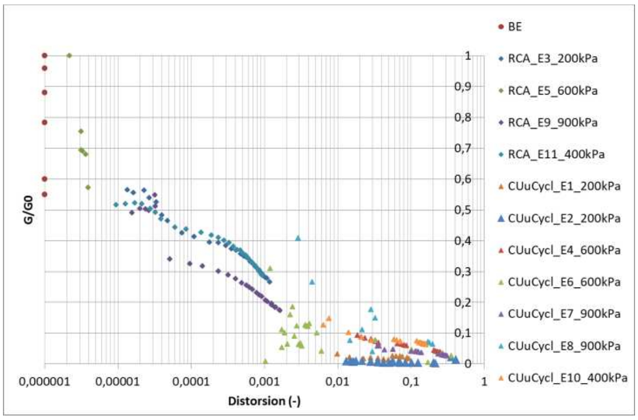

Figure 8. Shear modulus degradation curve on the site Paris 15^e.

The modulus degradation curve will be used to feed a rheological model and calibrate it as a function of confining pressure.

6 CONCLUSION

The tests presented here are used to determine the parameters of a model specifically developed to improve the representation of displacements in finite element simulations of the behavior of specific structures in the Grand Paris station projects, in particular vertical displacements around the structures. At present, it is difficult to know which models are really suitable for modeling structures. The simplest models sometimes provide vertical ground displacements that do not necessarily reflect ground movements observed in reality. It is therefore important to be able to propose a model that aims to take better account of ground behavior on unloading stress paths. The parameters obtained from these tests will then be used to feed a rheological model and calibrate it as a function of confining pressure.

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