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Experimental study on strength and deformation properties of treated clay soils under triaxial and oedometric conditions

Étude experimentale de la résistance et de la déformabilité de deux sols argileux traités au ciment sous triaxiale et œdométrique conditions

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ABSTRACT: This paper presents an experimental study to evaluate the influence of adding 5% of cement, by dry mass of soil, on the strength and deformability of two different clays. Oedometer tests were performed on specimens of two different clayey soils, low plasticity Portugal clay and high plasticity Pljevlja clay, compacted according to standard Proctor test. Adding cement to the specimens resulted in reduction of instantaneous and time-dependent deformations under oedometric conditions. The increase in the preconsolidation stress, as determined by the oedometer test, along with the foregoing, indicates that adding cement has the similar effect as to pre-consolidate the clay. Conventional triaxial compression tests (CU) were performed on specimens of Portugal clay. The results of these tests showed that, with added cement, the compressive strength and secant Young's modulus E50 increases. Results of the CU tests indicated also that, once the cement is added, the soil behaviour changes from plastic to brittle plastic along with the pore pressure dropping during the shear stage.

RÉSUMÉ: Cet article présente une étude expérimentale pour évaluer l'influence de l'addition de 5% de ciment, par poids sec de sol, sur la résistance et la déformabilité de deux argiles différentes. Des éssais œdométriques ont été effectués sur des échantillons des deux sols argileux différents, l'argile du Portugal à faible plasticité et l'argile de Pljevlja à haute plasticité, compactés avec le même poids volumique sec déterminé par les éssais Proctor. L'ajout de ciment aux échantillons a entraîné une réduction des déformations instantanées et dépendantes du temps dans des conditions œdométriques. L'augmentation de la contrainte de préconsolidation, telle que déterminée par le test œdométrique, ainsi que ce qui précède, indique que l'ajout de ciment a le même effet que la pré-consolidation de l'argile. Des essais de compression triaxiale (CU) conventionnels ont été réalisés sur des échantillons d'argile du Portugal. Les résultats de ces éssais ont montré qu'avec l'ajout de ciment, la résistance à la compression et le module d'Young sécant E50 augmentent. Les résultats des tests CU ont également indiqué qu'une fois le ciment ajouté, le comportement du sol passe de plastique à plastique cassant et la pression interstitielle diminnue pendant l'étape de cisaillement.

Keywords: Cement-stabilized soil; clay soil; triaxial compression test; oedometer.

1 INTRODUCTION

Numerous reviews of soil stabilization using cement (Jawad, 2023) emphasize the efficiency of this old soil improvement method. Most of the researchers are focused on the strength parameters of the cemented soil, with fewer researchers oriented to the deformation properties (Rios et al, 2019). Moreover, in the field of improved soil strength, the unconfined compressive strength (UCS) has received much attention in comparison to the triaxial shear behaviour of cement improved soil (Azneb et al, 2021;Rios et al, 2019), due to the simplicity of determining this parameter. This paper presents an experimental study to evaluate the influence of the amount of cement on the strength and deformability of two different clayey soils.

2 EXPERIMENTAL INVESTIGATION

For the purpose of testing the characteristics of the cement-stabilized clay soil, the laboratory testing was performed including oedometer tests and conventional triaxial compression tests.

2.1 Materials

A sample of a clay soil was obtained along the local road in the place Capuchos of the Almada County, south of Lisbon, Portugal (Miocene "Xabregas blue clays"), hereinafter referred to as the Portugal clay. The samples of the Miocene lacustrine clay, referred as the Pljevlja clay were collected from the construction site of the transformer station 400/220/110Kv Pljevlja 2, K.O. Ilino Brdo Municipality of Pljevlja in Montenegro (Figure 1). The basic physical properties of these two soils are summarized in Table 1. X-ray diffraction (XRD) was performed on Portugal clay. According to XRD, Portugal clay is mainly composed of quartz (52.9%), albite (18.3%), muscovite (10.8%), microcline (10.3%), calcite (3.0%), donbasite (3.2%).

Figure 1. Sampling locations of of the tested clays.

Table 1. Tested soil physical properties.

Soil	Portugal clay	Pljevlja clay
Unit weight (kN/m^3)	19.5	20.7
Liquid limit (%)	39	62
Plasticity limit (%)	25	24
Plasticity index (%)	14	38
D_{50} (mm)	0.20	0.0035
Unified Soil Classification	CL	CH
Optimal moisture content OMC (%)	13.5	-

The cement used for the purposes of this work was PC 35M (V-L) 32,5R, which represents a Portland-composite cement containing 64-79% clinker and 21-35% mixed silica fume and fly ash and lime. The water used was from public water system (potable water).

2.2 Specimen preparation and test procedure

Conventional triaxial tests were performed at the geotechnical laboratory of the Department of Civil Engineering, NOVA University of Lisbon. The testing involved the consolidated undrained triaxial tests (CU) on specimens of Portugal clay compacted at energy level of the standard Proctor's. Six specimens were tested, out of which three cemented-soil specimens with 5% of added cement. Oedometric tests were performed at the geotechnical laboratory of the Faculty of Civil Engineering, University of Montenegro in Podgorica. One non-cemented and one cemented specimens (5% of added cement) per each clay type were tested. A review of the specimens properties before testing is given in Table 2.

Table 2. Review specimen's properties before testing.

Soil	Test	w(%)	γ_d (kN/m^3)
Portugal clay	Triaxial	12.6	18.7
	Oedometer	13.5	16.1
Pljevlja clay	Oedometer	13.5	16.5

2.2.1 Oedometer test

Cement in quantity of 5% of the total dry weight was added to the clay, after which water was added. For specimens of both clays, a water content of 13.5% was achieved. The specimens for the oedometer test were compacted in oedometer cell by a 2.5 kg hammer dropped from the height of 30.5 cm, with 6 blows per one layer. This way, the compaction energy of 572 kJ/m^3, similar to the one specified by Standard Proctor test (624 kJ/m^3), was achieved. Immediately upon preparation, the non-cemented specimen was placed in the oedometer cell and then subjected to testing. Two cemented-soil specimens were cured for 7 days. The initial load applied was 100 kPa, with each subsequent load increment doubling the previous value, i.e. 200, 400 and 800 kPa respectively. Each loading step lasted for 24 hours and exceptionally for 48 hours.

2.2.2 Triaxial compression test

Cement in quantity of 5% of the total dry weight was added to clay that was in a relatively loose condition with the moisture content varying around 0.79%.

Upon achieving the moisture content, on dry side of optimal, of 12.6% (OMC – 0.9%), the specimens were compacted. The two-part cylindrical mould was used. Specimen diameter was D = 70 mm and the specimen height was H = 140 mm. The soil was compacted in four layers of 3.5 cm in thickness, using the 2.5 kg hammer dropped from the height of 30.5 cm.

This way, the equivalent compaction energy of 566 kJ/m^3 was achieved. The specimens were kept in plastic bags for 8 days to preserve moisture content of the specimen to the highest extent possible. Triaxial automated system (GDS Instruments) was used for the purposes of conducting CU test. The test was performed in three phases - saturation, consolidation and shear under undrained conditions with pore pressure readings. The specimen was sheared at rate of 0.05 mm/min.

3 RESULTS AND DISCUSSION

3.1 Oedometer test

Comparative diagrams of the total settlement to time and vertical load σ_z to vertical strain ε_z for the two clay specimens are shown in Figure 2 and Figure 3, respectively. Adding cement to soil specimens results in reduction of vertical settlement and vertical strains ε_z in vertical load σ_z range from 100 to 800 kPa, for specimens cured for 7 days.

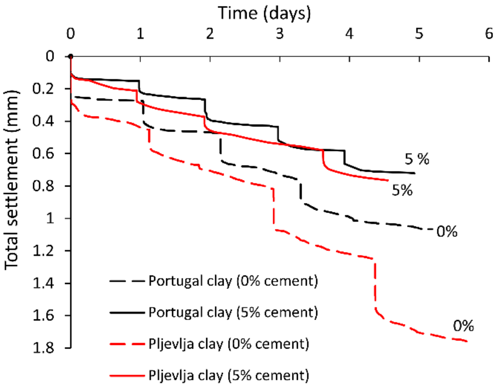

Figure 2. Comparative diagram of total settlement in relation to time for the clay specimens.

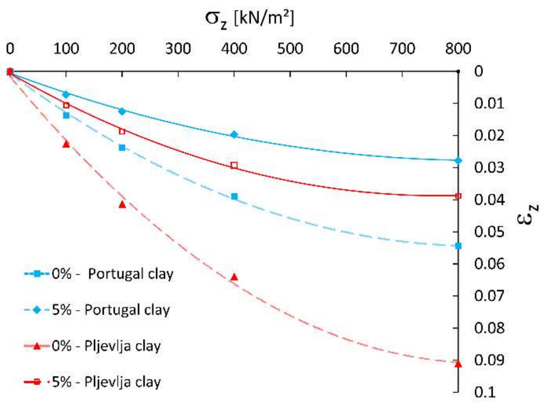

Figure 3. Comparative σz–εz diagram for the two clays.

Adding of cement affects the reduction in the instantaneous and time-dependent deformations (primary consolidation and/or creep), i.e. increases in the oedometric modulus E_{oed}. Calculated values of E_{oed} for cemented specimens are from 2.1 to 2.8 times higher compared to untreated specimens. The increase in the E_{oed}, can be partly attributed to the hardening, i.e. hydration of cement over the course of time.

The pre-consolidation stress can be defined by means of the Casagrande's method (1936), provided that the values of void ratio are known. For the cement-treated specimen of Portugal clay with the 5% added cement, the pre-consolidation stress p‘ is approximately 300 kPa, which is by 2.3 times higher than the p‘ for the same clay without added cement (p‘=130 kPa). The obtained result is compliant with the conclusion reached by Tugba (2015), indicating that the pre-consolidation stress changes with adding of cement, meaning, that increases with the percentage of cement.

3.2 Triaxial test

Figure 4 presents the deviator stress relation with axial strain of the non-cemented and cement-treated clay specimens of Portugal clay. The diagram indicates that for each value of the consolidation pressure of 100, 200 and 400 kPa, the maximum deviator stress of the cement-treated specimens is approximately 1.5 times higher than the deviator stress of the non-cemented specimens. It is also characteristic that at all levels of the all-around stress of 100, 200 and 400 kPa the cement-treated specimens underwent brittle failure at relatively low values of axial strain of about 5-7%. The non-cemented specimens underwent ductile failure, while in case of the cement-treated specimens a failure plane (shear bands) can be easily observed (Figure 4).

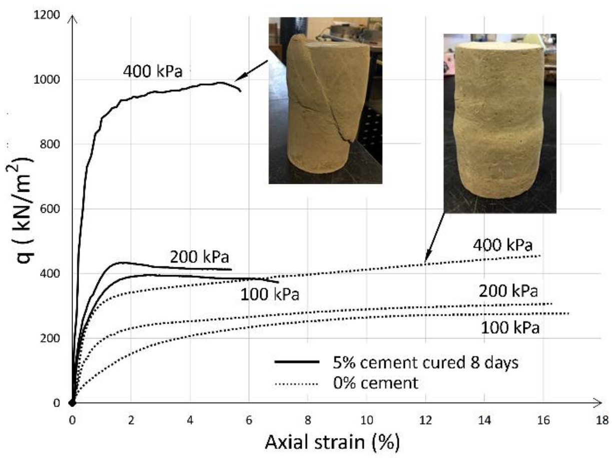

Figure 4. Diagram of ratio between the axial strain and deviator stress.

The effective stress paths for all specimens are illustrated in Figure 5. Reducing pore pressures during shearing of the non-cemented clay specimens (negative pore pressures for σ_c'=100 kPa) suggests that the tested Portugal clay has the properties of the overconsolidated clay.

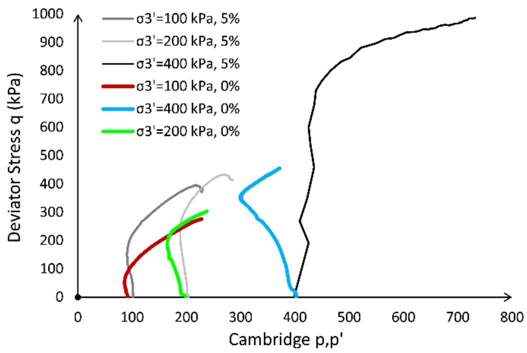

Figure 5. Effective stress paths for all specimens.

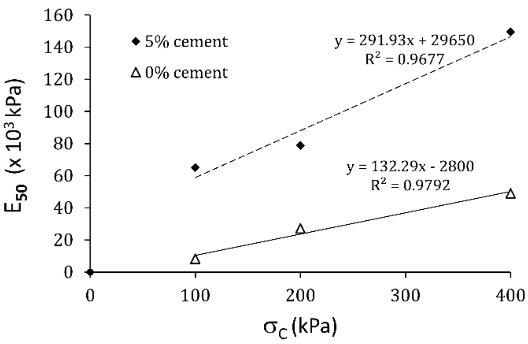

Figure 6. Diagram of the Young's modulus of elasticity E_{50} and lateral stress σ'c.

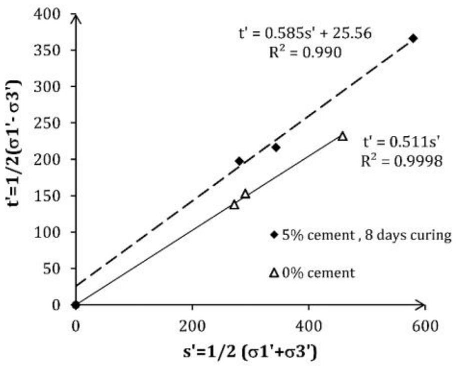

Figure 7. Mohr-Coulomb failure envelope for effective stresses for cement-treated and non-cemented specimen.

Secant elastic moduli of clay E_{50} have been obtained as a value of ratio of 50% of total deviator stress to the corresponding axial strain. E_{50} of the cement-treated specimens 3 to 7 times higher compared to the results of the non-cemented specimens under a lateral stress range from 100 to 400 kPa (Figure 6). Figure 7 shows Mohr-Coulomb failure envelopes for the cement-treated and non-cemented test specimens. It can be observed from the diagram, that for the non-cemented specimen the effective cohesion c' is 0 kPa as expected, and the angle of internal friction ø' is 30.7°. These values for the cement-treated specimen are cohesion c'=25.5 kPa and ø'=35.8°. Observed cohesion intercept indicates existence of true cohesion which results from chemical bonds between particles.

4 CONCLUSIONS

According to the results of oedometer test, adding of cement by 5% affects the reduction in the deformations of both clay specimens. Calculated values of E_{oed} for cemented specimens are from 2.1 to 2.8 times higher compared to untreated specimens. Results of CU triaxial tests on specimens of Portugal clay indicate an increase in value of the cohesion from zero value to 25.5 kPa, angle of internal friction from 30.7° to 35.8° and elastic moduli E_{50} by 3 to 7 times, compared to relevant values of parameters of nontreated soil. For Portugal clay, the increase in the preconsolidation stress by 2.3 times compared to the non-cemented clay and transition from ductile to brittle failure mode indicates that adding cement has the similar effect as the overconsolidation of the clay. Bearing in mind the limited scope of experimental testing, the verification of the above conclusions is foreseen through the directions of further research that may include other percentages of cement and longer times of curing, conducting similar tests at higher compaction energy (Modified Proctor test) conducting in-situ tests on the selected trial location of the cement-stabilized soil.

REFERENCES

Azneb, A.S., Banerjee, S., Robinson, R.G. (2021). Shear Strength of Cement-Treated Marine Clay under Triaxial and Plane Strain Conditions, In: *Proc. Inst. Civ. Eng. Ground Improv Vol.174*, pp.143–156. DOI:10.1680/jgrim.18.00090.

Casagrande, A. (1936). The Determination of the Pre-Consolidation Load and Its Practical Significance, In: *Proceedings of the 1st International Conference on Soil Mechanics*, Harvard, Vol. 3.

Jawad,I.T.,Taha,M.R.,(2023) Portland Cement Treated Soil: Evaluation and Conflict Results, *Civil Engineering and Architecture*, 11(2), pp.560-568. DOI:10.13189/cea.2023.110203.

Tugba, E., (2015) Influence of Cement Treatment on Unconfined Compressive Strength and Compressibility of Lean Clay with Medium Plasticity, *Arabian Journal for Science and Engineering*,40(3),pp.763—772. DOI:10.1007/s13369-015-1579-z.

Rios, S. et al. (2019) Mechanical and durability properties of a soil stabilised with an alkali-activated cement, *European Journal of Environmental and Civil Engineering*, 23(2), pp.245–267. DOI: 10.1080/19648189.2016.1275987.