Laboratory Equipment for the Determination of Soils Compressibility Characteristics

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ABSTRACT: The laboratory equipment used for the determination of soils compressibility characteristics is composed of two loading systems for soil samples, directly into the sampler, of large diameter, in which it has been extruded. This equipment simulates a compressibility test with plate in a borehole. The primary loading system allows the sample loading and consolidation to pre-consolidation pressure (σp`), in order to bring the specimen to a strain state as similar as possible to in situ state. The secondary loading system enables, after a preliminary drill and disposal at the base of the ”borehole” of a sample, the execution of several loading stages and measurement of corresponding settlements, similar with a test with plate in borehole. Based on the obtained results and the compressibility-settlement and compression-porosity curves are being determined the soil compressibility parameters.

Keywords: soils compressibility; soils testing; laboratory equipment; mechanical parameters; samples disturbance;

1. Introduction

The equipment necessary for the investigation and determination of soils physical and mechanical characteristics [3, 5, 6, 10, 11, 12] should reproduce, as faithful as possible, the in situ soils behaviour, simulating the stress transmitted by constructions foundations loads.

In short, soil behaviour to mechanical actions, is also reflected by the values of parameters (E, E_{oed}, m_v, c_c, c_r, etc) which characterize their compressibility [12, 13, 15, 16].

Currently, the laboratory equipment used to estimate the values of above mentioned parameters, based on pressure – settlement/pressure – porosity curves (Fig. 1 a and b) are affected by certain errors ($\Delta e \neq 0$) due to, mainly, disturbance of soil samples on the path: drilling – transport – storage – specimen assay – testing.

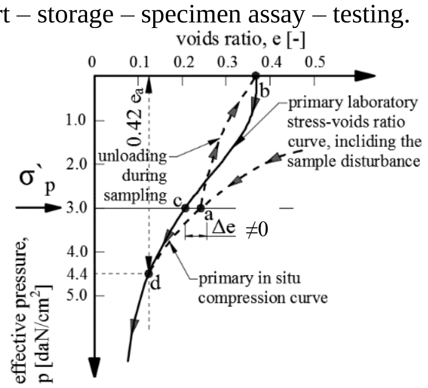


Figure 1.a. Path of in situ/laboratory compressibility – porosity curves for a normally consolidated soil, highlighting the effect of samples disturbance $\Delta e \neq 0$

Determination of parameters based on in situ testing [6, 12, 13] would represent, to a greater extent, the real behaviour of the foundation soil under tests/loads.

The usually high costs, as well as the addiction to meteorological conditions for some of these tests, regularly plate load tests, presiometric, dynamometric tests etc., doesn't recommend them for regular constructions.

In order to eliminate these shortcomings, characteristic to in situ testing, it was designed and created [4, 9, 14] an original laboratory equipment, (Consolidometru), Fig. 2, which would combine plate load testing methodology [11] with oedometric testing, in order to reduce the effect of path steps (drilling – transport – storage –testing) on final results. The laboratory equipment – Consolidometru – built with this purpose is presented schematically in Fig. 2.

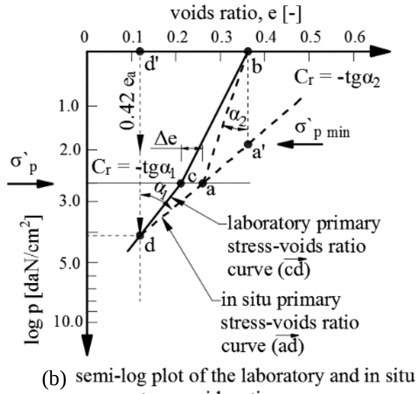


Figure 1.b. Path of compressibility – porosity curves in situ/ laboratory for a normally consolidated soil, underlying the samples disturbance effect $\Delta e \neq 0$

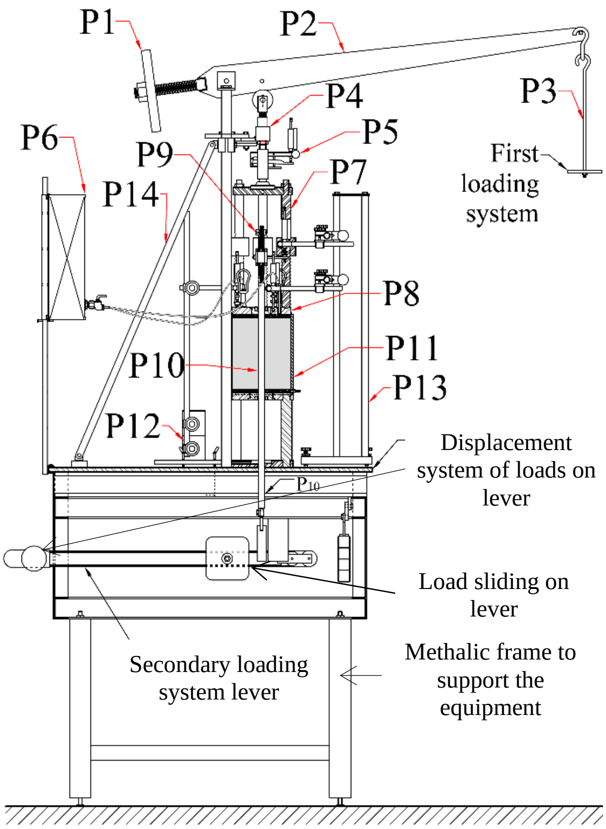


Figure 2. Lateral view of Consolidometru with details, sections and indication of main component pieces.

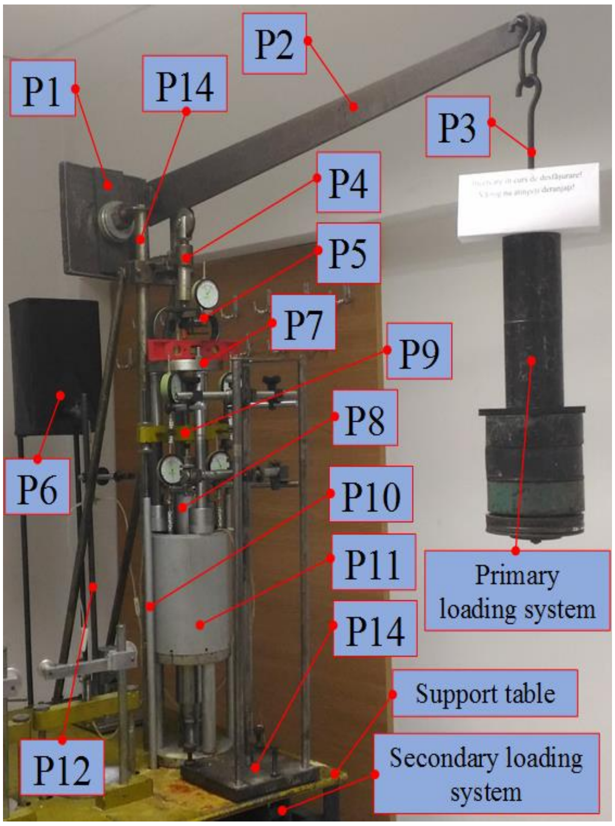


Figure 3. Photo of the original conception equipment Consolidometru, and component pieces.

The Consolidometru allows the performance for three types of tests [4, 9, 15, 16]:

- Current use test, plate load test in ”borehole” [11, 13] with potential assay and testing on oedometric samples [12], titled ”Testing Type I – TI”;
- Non-invasive plate load test, on reshuffled samples (Testing type II – TII) aimed for the study of compressibility;
- Non-invasive triaxial type test [10], on reshuffled samples (Testing type III – TIII) aimed, also, for the study of soils compressibility.

In the present article is presented, in detail, the laboratory equipment (Consolidometru) and plate load test in ”borehole”, with specimen assay (Testing Type I).

2. Equipment presentation and work environment

The Consolidometru, as laboratory equipment, Fig. 2 and Fig. 3, is composed, mainly [4, 9, 14], of two driving and loading systems of the soil sample, placed inside a metallic cylinder/sampler.

The main loading system (P1-P4), Fig. 2; Fig. 4, exerts, by a multiplication lever (P1; P2; P3) and pieces (P4; P7), a vertical force, measured with a dynamometric ring (P5), which acts on a cylindrical plate (P8.12), provided with a central plug, positioned above a soil sample, situated in a sampler (P11) and loaded using a tripod (P7), Fig. 5.

Main loading system, (Fig. 4) with component pieces previously detailed, provides the loading of the soil sample found in the cylinder/sampler (P11) (Fig. 8.a) with a pressure (p_v). This equals the pre-consolidation pressure ($\sigma`_p \cong \gamma \cdot z$) [1, 7, 8] corresponding to the depth of the layer from which it has been extracted, (Fig. 1) creating a tension and deformation state in the sample, similar to in situ state.

The pre-consolidation pressure (Fig. 1) ($p_v \cong \sigma`_p$) [1, 7, 8] is obtained using weights/loads positioned on the piece (P3) (Fig. 4) which exerts, by piece (P4), Fig. 2 and Fig. 3, respectively by the dynamometric ring (P5), a force P $= \sigma`_p \cdot A$ (A – sampler transversal section aria). This force is taken over by the tripod (P7), Fig. 6, and transmitted, by its three foots, in share of (P/3), to the loading plate (P8.12), Fig. 5 and Fig. 7, resulting, in the end, a reinforced soil sample (Fig. 13), positioned in the metallic cylinder/sampler (P11), Fig. 8.a. At the end of sample reinforcement, any potential settlement is blocked by unfastening the three retainers (P7.4), Fig. 5, until they are suspended on the upper edge of the sampler (P11), Fig. 12.

The secondary loading system (Fig. 2) with component pieces, presented in Fig. 5, is provided with a force multiplier lever, installed on a metallic frame and insures, by an ensemble of pieces (Fig. 7; Fig. 10) the extraction of specimen/”borehole” execution and plate load test. In figures 8 a, b, c, d are presented, schematically, the steps of testing type (TI) for a reconsolidated soil sample, from the sampler located in Consolidometru, for its testing in steps and measurement of settlements for laying out compressibility – settlement curve (C-T) necessary to calculate the parameters which define soils compressibility.

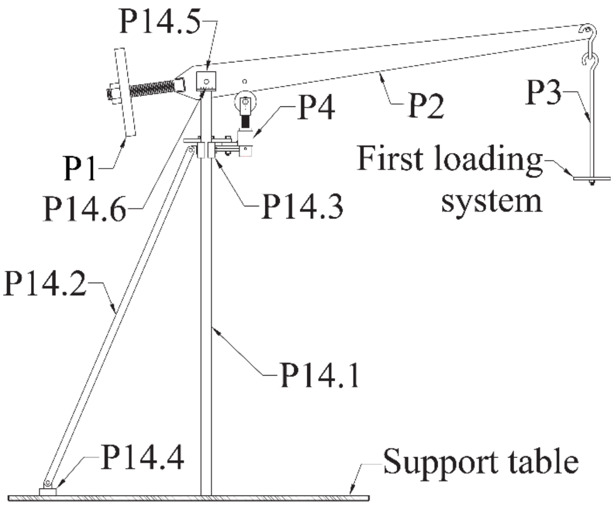


Figure 4. Lateral view of pieces ensemble (P1 – P4 and P14) component of main loading system.

Pieces presented in Figure 4 are components of the main loading system, used to reconsolidate the sample from the metallic cylinder/ sampler (P11) until reaching the value of in situ pre-consolidation pressure.

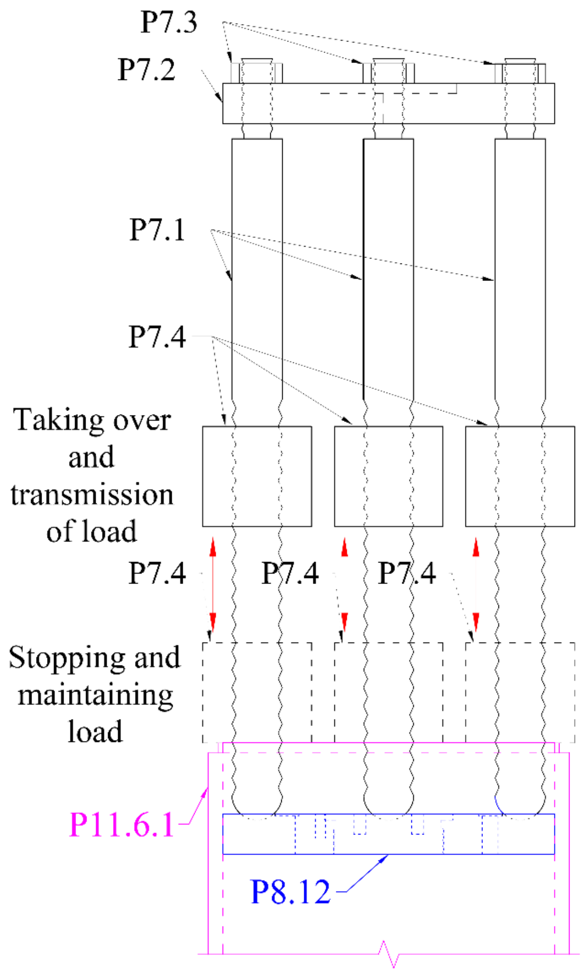


Figure 5. Lateral view of P7 piece.

In figure 5 is presented the tripod which transmits the loads to the sample situated in the metallic cylinder/sampler, component part of the main loading system, until sample reconsolidation under the pre-consolidation in situ pressure. Pieces P 7.4, by their suspension on the edge of the metallic cylinder (P11) block the settlements without modifying the initial load (Fig. 12).

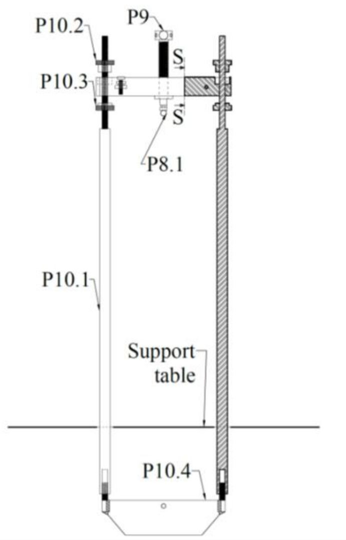


Figure 6. Front view of the collar (P10), with component pieces (P10.1-P10.4).

The collar in figure 6 is a component part of the secondary loading system and is used to perform the stamp extraction, "borehole" realisation (Fig. 8.c) and exertion, in steps, of pressures on the plate positioned at the base of the "borehole" (Fig. 8d).

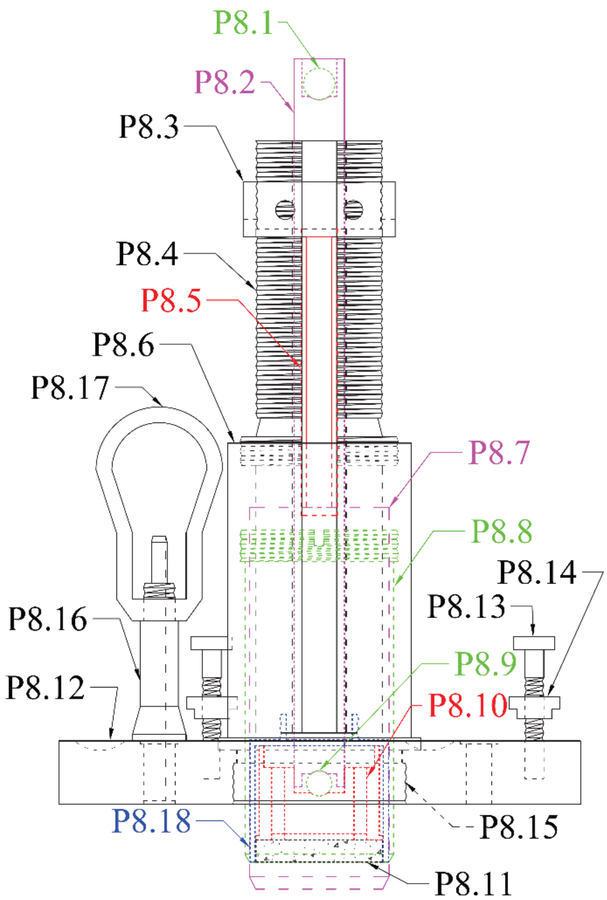
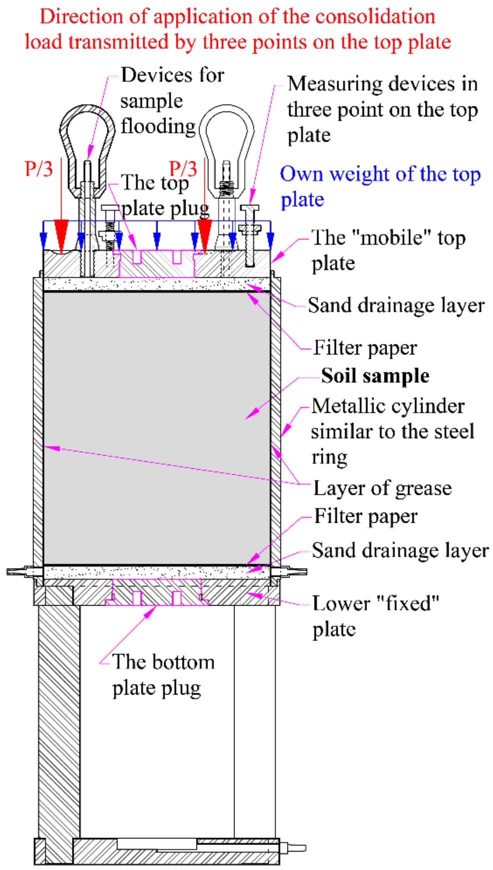


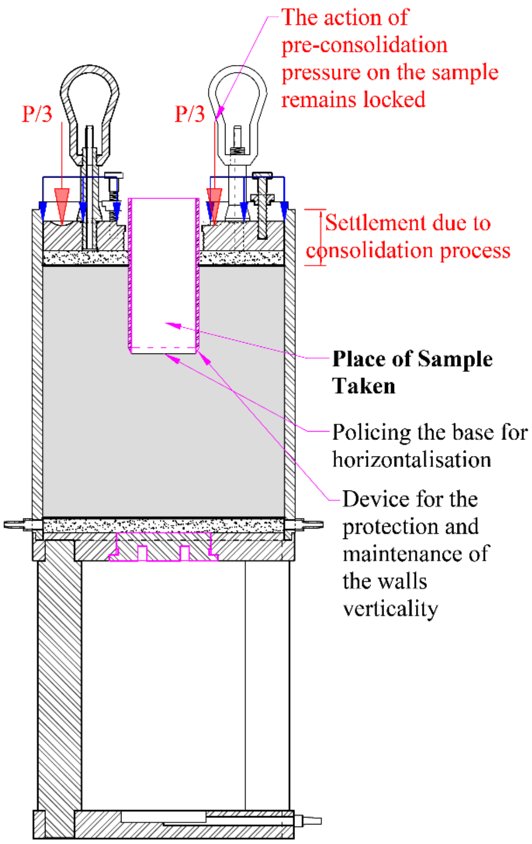
Figure 7. View of non-porous plate (P8.12) of exertion the reconsolidation pressure on the soil sample, situated in the metallic cylinder/sampler and pieces ensemble (P8)

The pieces ensemble (P 8.1 – P8.18) represents the main component of the Consolidometru. This ensemble is used to introduce, by pressing, the stamp in the sample situated in the sampler, (Fig. 8.b) and to performe the plate load test (Fig. 8.d) using the collar of the secondary loading system (Fig. 6).



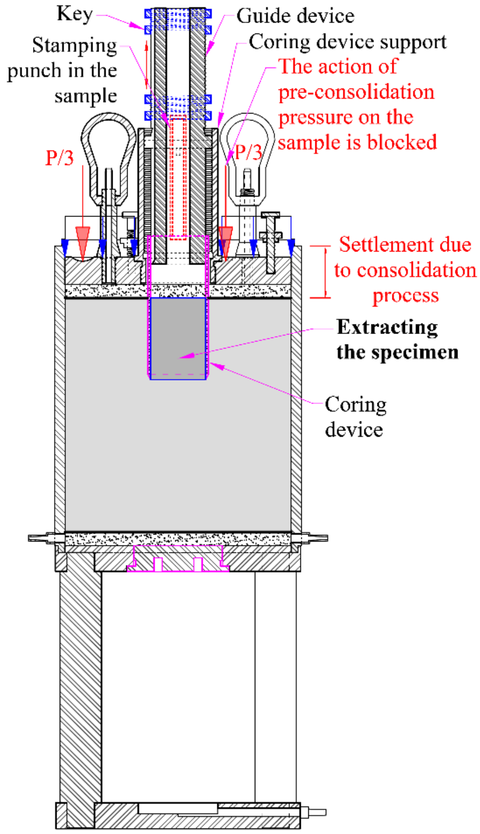
(a) Section through the Consolidometer Cylinder in the consolidation stage (T1.a)

Figure 8.a. Soil sample from the sampler/cylinder under consolidation loadings (P/3+P/3+P/3)



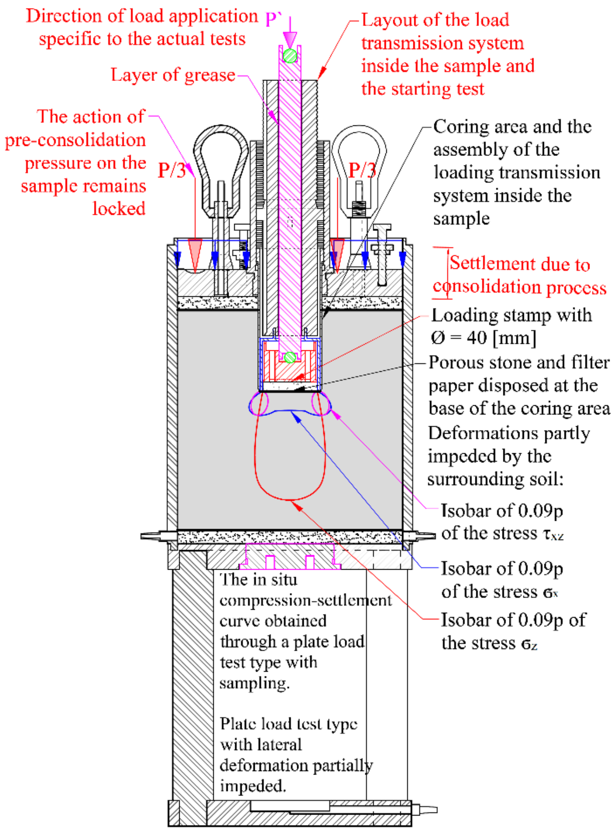
(c) Section through the Consolidometer Cylinder at the polishing stage after the extraction of the specimen (T1.c)

Figure 8. c. Preparing the borehole base for laying out the plate and loading device (P8).



(b) Section through the Consolidometer Cylinder at the sample extraction stage (T1.b)

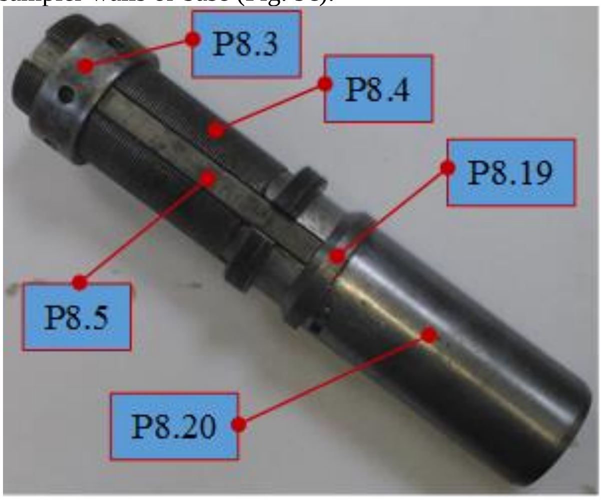
Figure 8.b.. P8 device assembled on the loading plate P8.12 following the displacement by compression of the coring device.



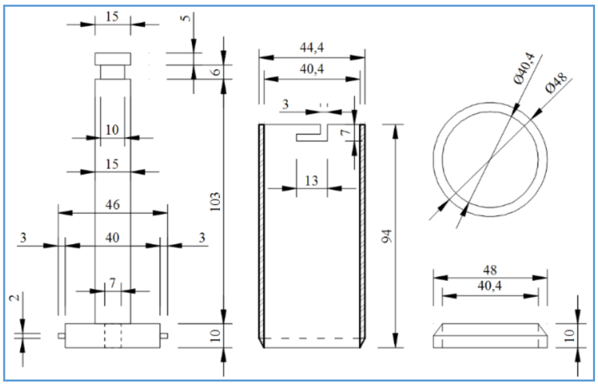
(d) Section through the Consolidometer Cylinder at the stage of the actual test (T1.d)

Figure 8. d. Testing in steps of the plate load test and isobars emphasizing.

After soil sample reconsolidation, situated in the metalic cilinder/sampler, is unfastened the metallic plug from the central area of the loading plate (Fig. 8.a) and is assembled by threading in the loading plate (P8.12) the pieces ensemble (P8), Fig. 7; Fig. 8b. Follows the introduction in the soil sample, by pressing, using a proper device, Fig. 9.a, of a stamp (P8.20), respectively port stamp (P11.3.2), Fig. 9b, and its extraction using the piece P8.21, resulting a ”borehole”, Fig. 8c, ”protected” by the port stamp P11.3.2. The borehole depth, Fig. 9b, and the sampler cylinder height and diameter must be chosen so that the isobars (σ_z, σ_y, δ_{zy}) don’t touch the sampler walls or base (Fig. 9c).



a) Stamp and port stamp (P8.20, P11.3.2) on the pressing ensamble of specimen and guide (P8)



b) Stamp (P8.20) inside port stamp (P20) with their pressing devise (P8.19) in the sample by displacement (P8.5) as a result of piese threading P8.3.

c) Stamp P20 (ϕ 30 mm; h=60 mm) with piece P21 for extraction from sample using P8.1 and P9 from the collar P10, Fig. 5

Figure 9. Pieces ensemble for the mechanism introducing into the sample of port stamp and stamp, respectively, for soil specimen extraction from the sample

Following the stamp extraction, removal of P8 (Fig. 7) and realisation of the ”borehole”, Fig. 8.c, is being polished the borehole base using the device in figure 10 [4]

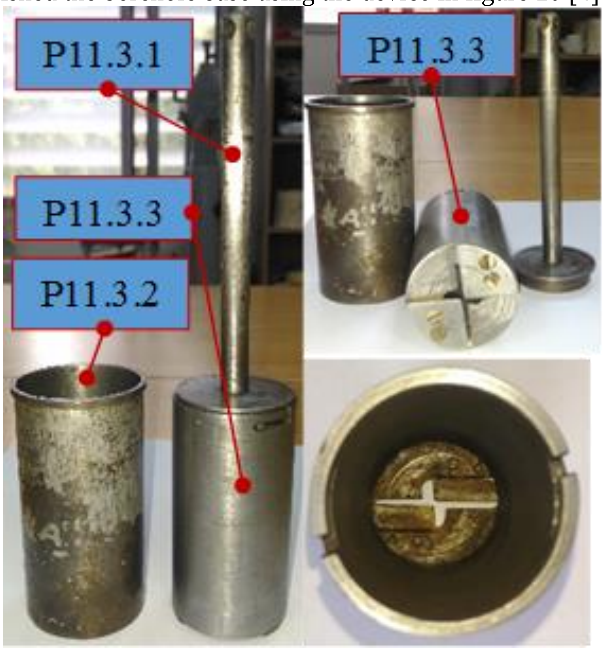


Figure 10. Device for “borehole” base polish and component pieces (P11.3.1, P11.3.2; P11.3.3)

After polishing the ”borehole” base and laying a thin layer of sand, over which is positioned a filter paper, is lowered the loading plate (P8.9, P8.10) which has fixed, to the inferior part, a circular porous plate (P8.11), Fig. 11, followed by rethreading the loading device from Fig. 7 and Fig. 8.d.

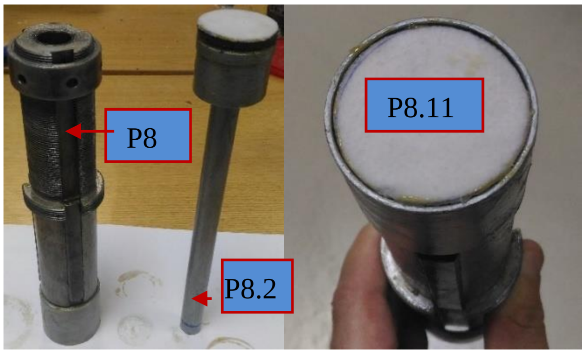


Figure 11.a Loading plate (P8.10) with porous stone (P8.11), guiding device (P8) and loading stern (P8.2)

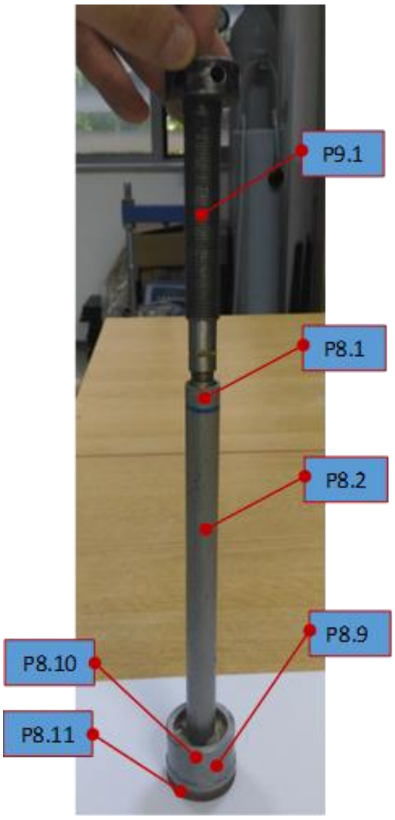


Figure 11.b P8 and P9 loading chain for plate loading with Ø = 40 mm. (P8.1 – sphere for loading centring; P8.2 – stern for loading transmission to the plate; P8.9 – sphere for loading alignment; P8.10 – loading plate; P8.11 – porous stone; P9.1 – threaded stern for transmission of load to the plate from secondary loading system)

The loaded plate, with a diameter of 40 mm, is positioned at the borehole base (Fig. 8d). The loading is performed using the collar from (Fig. 5) by pieces P8.1; P9; respectively P10, Fig. 11. b, connected by P10.4 to the secondary loading system (Fig. 2) composed, in short, of sliding weight on a metallic lever. The traverse which unites the straps P10, Fig. 5, is mounted through the free space in between the tripod feet, (Fig. 12) so that the sample from the sampler cylinder stays loaded with the pre-consolidation pressure ($\sigma_p^{'}$). The small plate/loading plate (Ø 40 mm) can be activated by secondary loading system.

The entire ensemble which constitutes the soil testing equipment to compression, including the cylinder/sampler with the two loading systems, main and secondary, is mounted on a metallic table supported on a metallic frame (Fig. 2 and Fig. 3).

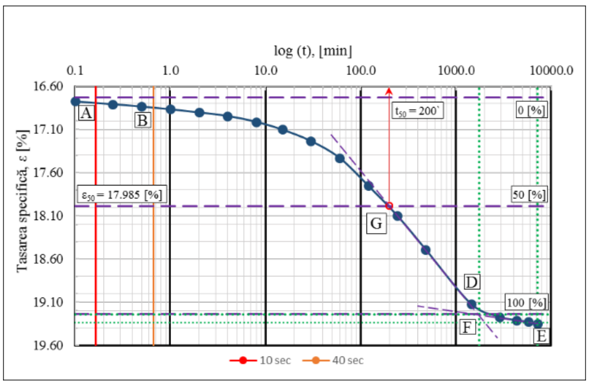


Figure 13.a. Compresibility – consolidation curve under pre-consolidation pressure $\sigma_p^{'}$= 150 kPa for sample T I A1

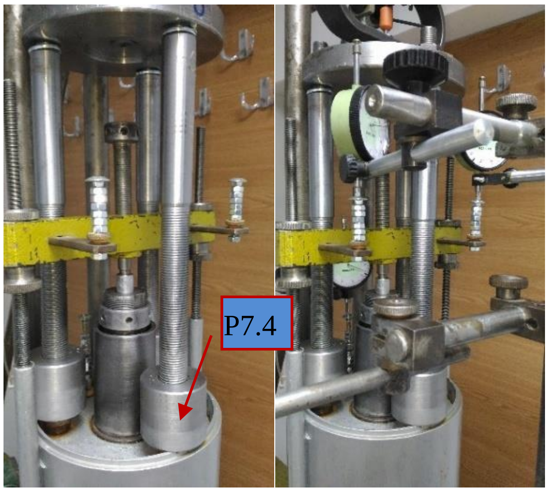


Figure 12. Settlement obstruction using P7.4 (Fig. 6) and disposal of plate pieces in the sample from the sampler, connection of secondary loading collar and putting in place the micro comparators mounted on P13 (Fig. 3)

3. Execution of a Type I (T1) Test in Consolidometru

In order to test the Consolidometru functioning, have been used samples (TI A1/TI A2) from kaolinite clay (clay 80%, dust 20%) brought to flow limit (W_L=58,70%, W_P=37,50% and W_s=25,51%) with which was filled the metallic cylinder/sampler (P11.6.1) with the interior diameter of 165 mm and height of 230 mm (Fig. 9a), on a height of 200 mm. Previously, to the cylinder base, has been laid a sand layer of 10 mm, for drainage, over which was placed a filter paper, similar to the sample superior part (Fig. 8a).

In order to prevent the humidity loss during the test, the sample is connected to a water tank (P.6). The cylinder is provided, along the inferior sand layer, with holes for water drainage.

Above the upper part of the sample, equipped in this way, have been placed the loading plate (P8.12), three micro comparators/electric transmitters for settlements reading/registering, positioned on stand (P13), the tripod (P7), the dynamometric ring (P5) to read the vertical force (P), for each loading/consolidation step of soil sample from the cylinder/sampler (12,5 kPa; 25 kPa; 50 kPa; 100 kPa and $\sigma_p^{'}$ = 150 kPa corresponding to a sample extraction depth of approx. 8 m).

Compresibility – consolidation curves for the final step $\sigma_p^{'}$ = 150 kPa are presented in Fig. 13 a. and b.

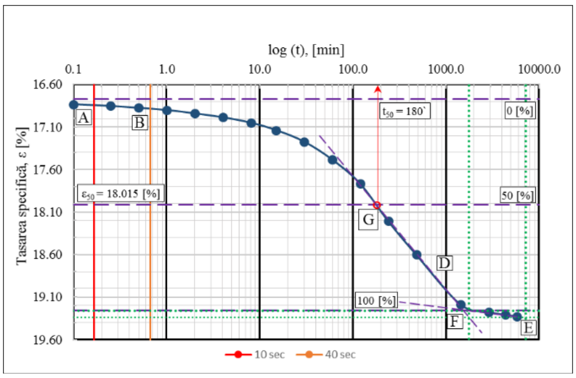


Figure 13.b. Compresibility – consolidation curve under pre-consolidation pressure σp'= 150 kPa for sample T I A2

After the consolidation in steps of the two samples of kaolinite clay to the pressure σ_p'=150kPa (Fig. 8a) it's moved to a new phase of plate load test.

In order to do this, are performed the following preparatory steps:

- Is blocked any potential settlement by the descent of stoppers (P7.4) mounted on the tripod foots (P7.1), Fig. 5; Fig. 12;
- Is unfastened the central plug from plate P8.12 and is thread the device for specimen extraction (P8), Fig. 8.b and ”borehole” execution (Fig. 8c), by extracting the stamp which contains the specimen (Ø = 40 mm, h=60 mm) unfastening (P8);
- Is prepared the ”borehole” base for testing, as previously presented, and is introduced the loading plate, equipped with porous stone, followed by the P8 device rethreading, equiped with the loading stern (P8.1; P8.2) Fig. 11.b;
- Through the tripod feet Fig. 5; Fig. 12 is fixed the collar of secondary loading system and mounted micro comparators/transmitters for reading the plate settlements on stand P13;
- The plate is loaded until the settlements stabilisation under each loading step (25 kPa; 50 kPa; 75 kPa; 100 kPa; 125 kPa; 150 kPa; 175 kPa; 200 kPa; 225 kPa; 300 kPa; 325 kPa; 350 kPa; 375 kPa; 400 kPa; 425 kPa) and then are unloaded in double pressure step;

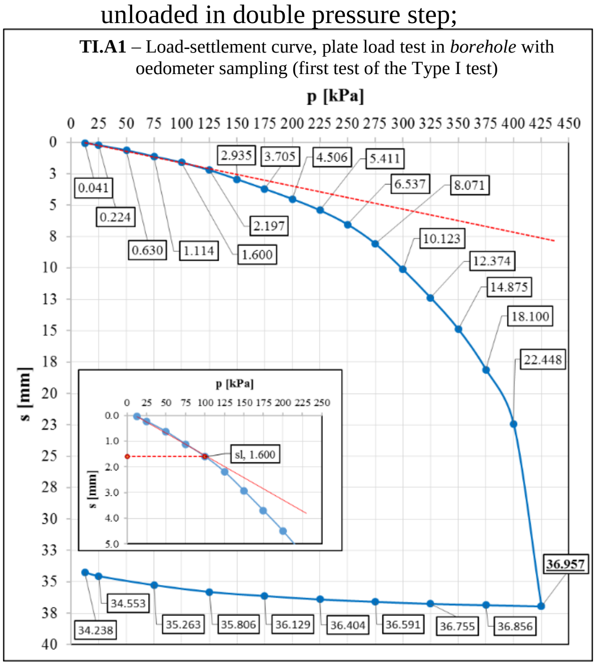


Figure 14. a. Stress – deformation curve (p-s) for the first test Type I, on sample TI A1.

- Based on read/registered settlements are plotted the compression – settlement/stress - deformation curves for the two tested samples TI A1, TI A2 (Fig. 14 a. si b.).

After plotting the two curves for the samples (TI A1 and TI A2) have been calculated the characteristics of mechanical parameters to the plate load test in borehole [2, 11, 13], which characterises the compressibility of soil from cylinder/sampler subjected to the action of pre-consolidation pressure σ_p' = 150 kPa and of pressures transmitted by the loading plate (Ø = 40 mm in a ”borehole” of 60 mm).

Table 1 contains the values of linear deformation modulus/Young elasticity modulus (E'); plate load test settlement (E_{PLT}) as well as the reaction coefficient (Ks) calculated [3] based on the two curves.

Table 1. Mechanical parameters characteristics to plate load test determined on stress – deformation curves established in consolidometru.

Param.	Formula	Sample TI.A1	Sample TI.A2
p_t	Directly on the chart (*STAS 8942/3,1990)	100 [kPa]	100 [kPa]
E	$E=\frac{\omega\cdot p_l\cdot d}{s_l}\cdot(1-\upsilon^2)$ (*STAS 8942/3,1990)	1663.72 [kPa]	1602.62 [kPa]
E_{PLT}	$E=\frac{\Delta p}{\Delta s}\cdot\frac{\pi\cdot b}{4}\cdot(1-\upsilon^2)$ (*SR EN, 1997-2:2007)	1654.03 [kPa]	1593.29 [kPa]
E	$E=\frac{1.5\cdot Q_{appl}\cdot D/2\cdot(1-\upsilon^2)}{\delta}$ (*ASTM D 1194,1994)	1579.48 [kPa]	1521.48 [kPa]
K_s	$K_s=\frac{p}{s}$ (Winkler, 1967)	62500 [kN/m^3]	60205 [kN/m^3]
K_s	$K_s=\frac{E}{C_f\cdot R\cdot(1-\upsilon^2)}$ (Caquot, A., Kerisel, J.)	62898 [kN/m^3]	60588 [kN/m^3]

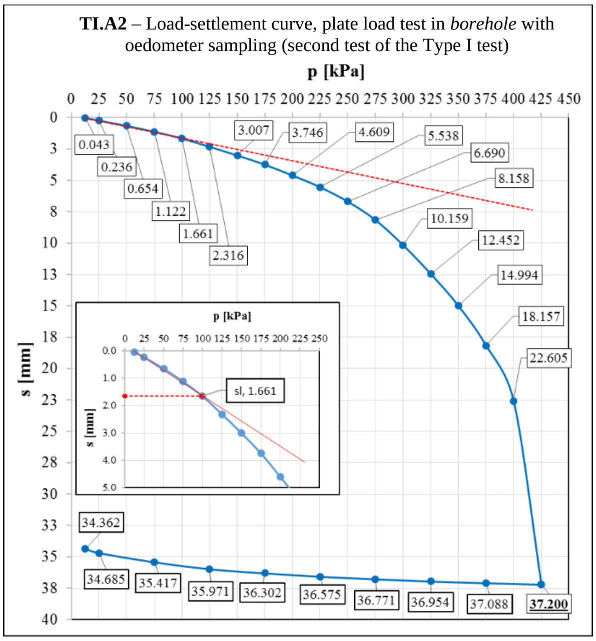


Figure 14.b. Stress – deformation curve (p-s) for the second test Type I, on sample TI A2.

4. Conclusions

For the calculation of constructions foundations settlements are necessary tests on soil specimens in laboratory (oedometer or triaxial tests) or in situ (plate load tests in boreholes, presiometer, dilatometer etc.) in order to determine the oedometric deformations modulus (E_{oed}, m_v, c_c, c_r etc.) or linear/elasticity deformation (E).

The results of laboratory tests on small specimens (∅ 70 mm; h=20 mm – oedometer; ∅ 38 mm; h=76,20 mm – triaxial) are affected by several errors due to samples disturbance but also by the limitations of tests types (lateral – detained deformation – in the case of oedometer or the stress state axial symmetric inconsistent with in situ state – triaxial).

In situ compressibility test with plate in borehole can offer the most credible results for the values of elasticity modulus (E) or for the reaction coefficient (K_s).

The difficulties in the realisation of this type of tests for soils from each layer from the foundation soil, as well as the high costs, make that plate load tests to be used, regularly, for constructions of high importance.

As a result, was designed and implemented an original laboratory equipment – Consolidometru - which would simulate, as much as possible, the plate load test in situ. Practically, the soil sample extracted from a certain depth in a borehole, in samplers is reloaded in laboratory to pre-consolidation pressure (σ_p') using a main loading system.

Using a characteristic equipment, presented in the paper, is performed in the reconsolidated sample from the sampler a ”borehole” with the diameter of ∅40 mm and depth of 60 mm. To its base is placed a metallic plate provided with a porous disk, used to perform the loading in steps of the sample from the sampler, using a secondary testing system, similar with plate load test in borehole. On the compression-settlement curve, obtained in this manner, with the lateral displacement partially blocked (by the soil around and not completely blocked as in oedometer) is determined the elasticity modulus, eliminating, partially, the errors from oedometric or triaxial tests.

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