Some comments on the oedometric relaxation test

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Abstract

Hydraulic fracturing occurs on the condition that the tensile strength of the particle contacts is equal to the absolute value of the negative effective stress. The measurement of the tensile strength of the particle contact is not easy. This paper discusses the Multistage Oedometric Relaxation Test (MRT). Analysis of test results shows that MRT can be a candidate test for the aforementioned measurement.

Keywords: soil mechanics, oedometer, relaxation

1. Introduction

The oedometric relaxation test is a type of one dimensional oedometric compression test. The test is generally used for the determination of the compression curve, the coefficient of consolidation and the permeability. In the oedometric relaxation test (ORT) (1 to 8) the pore water pressure and the total stress are measured under a constant displacement load. But ORT has not been applied in a multistage form. Therefore, the objective of this study was to perform multistage oedometric relaxation tests (MRT) on various soils, compare the test results with the multistage oedometric compression test (MCT) data, discuss and validate a model and a method of evaluation. As a by-product of the study, a specific use of the test was found which is presented after a short summary of modeling and laboratory testing.

2. Modelling

A joined model was suggested for the evaluation of a stage of the relaxation test. The model consists of a linear coupled consolidation part-model and, an empirical relaxation part-model. Only the consolidation part-model is considered which has two initial conditions with zero solution (the uniform non-zero function and the identically zero function). It follows that the load imposition cannot be instantaneous and, the initial condition has to be identified.

The effective stress σ' depends on the final total stress, the difference between the pore water pressure u and its mean for a given time t:

$$\sigma(t) = \frac{E_{oed}\, v_0}{H} + u_{mean}(t) - u(t, y) \tag{1}$$

where the final total stress (and the mean effective stress, being the volume is constant) and

$$\sigma_\infty = \frac{E_{oed}\,v_0}{H} \tag{2}$$

depends on the displacement boundary condition v_0 and on the constitutive law which is dependent on the load history. The total stress σ:

$$\sigma(t) = \frac{E_{oed}\,v_0}{H} + u_{mean}(t) \tag{3}$$

The effective stress is maximal at the sample top (y=0, where σ' decreases with time t), minimal at the sample bottom (y=H, where σ' increases with time t) of the single-drained sample as the pore water pressure u dissipates for a given time t (Fig 1). The effective stress values can be shifted by the partial unloading when the pore water pressure is unchanged for plastic clays but the compression curve point changes, which may cause negative effective stress at the sample bottom, as it is shown in the following Section (see Fig 2).

Table 1. Physical parameters of plastic soils (Szeged city, Szolnok city and a bentonite)

Soil	0	1	2	3	4	5	6	7	8
I_P [%]	10	17	22,8	29,9	31,7	37	37,8	41	62,8
w_L [%]	32,4	41,7	57,9	63	56,1	64,1	63,6	72	118,7
OCR	1,05	1,05	1,05	1,05	1,05	3,6	1,05	1,05	4,35

3. Laboratory testing

For the test the single-drained Geonor type swelling pressure apparatus h-200A was used. In the short multistage oedometric test procedure the load imposition is fast but not instantenous. The stages are generally 10 - 20 minutes long (i.e. being interrupted before the t_{99} dissipation time) except the last one being longer than the t_{99} dissipation time.

The load imposition was made with a constant mechanical power gear, resulting in a a strain rate of 0.002 to 0.08 %/s, which was larger than the upper validity limit of the Leroueil's 7 time dependent constitutive relation (0.001 %/s).

This procedure is similar to the CRS tests, except the larger loading rate and the stages which allow the determination of the relaxation soil properties as well. More than 30 soils of various plasticity were tested with the quick MRT and standard MCT procedure. The major part of the samples was saturated intact clay. A silt and some sands were also tested (Table 1). The results are shown in Figures 2 to 4.

4. Results

4.1 Measured data

According to the results, at the start of the stages, after a time delay, a fast immediate stress drop occurred. During this stress drop partial unloading took place since the control was too slow. The displacement loading became non-monotonic, a temporary reversal occurred. Then, in the actual relaxation stage, in the so called 'time dependent relaxation period', the stresses and displacement were measured for model fitting or evaluation.

In detail, in the case of fast load imposition the time delay this is just a few seconds and is frequently overlooked. In our case the value of the measured time delay – within 1 sec for intact clays - was in accordance with the prediction of the existing empirical equation. The nearly instantaneous dissipation at the start of the relaxation tests ('immediate stress drop') can primarily be related to a property of the solution of the consolidation model. As a consequence of the non-trivial zero solution at the usual Terzagi's uniform initial condition, the dissipation becomes extremely fast due to the near uniform initial condition (4). During time dependent relaxation, the effective stress at the impermeable boundary depends on the soil type (it increases/decreases in low/large plasticity soils at the start of the stage).

4.2 Model fitting

According to Figure 5, the data measured during time dependent relaxation, and simulated data showed good agreement.

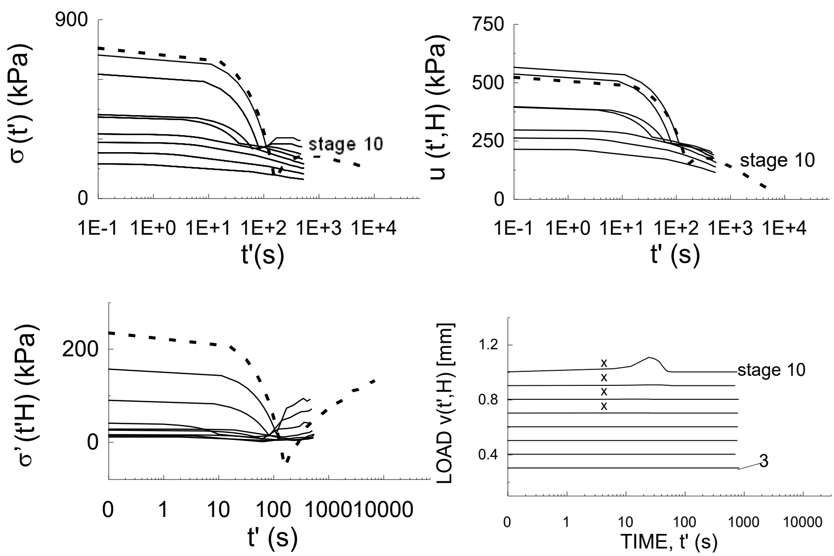

Figure 1. Measured MRT data for soil 4. In the case the last stage a large partial unloading was caused intentionally inducing local negative effective stress. (a) Total stress. (b) Pore water pressure.(c) Effective stress. (d) Displacement. (Note the initial fast stress drop, the partial unloading is indicated by x)

5. Partial unloading and compression curve

The control system of the Geonor type swelling pressure apparatus h-200A is working through load reversal which may have special effects for soils. If total stress drop occurs at the start of the test this may cause partial unloading. If the side friction is large then the load reversal may have a significant effect.

The partial unloading during the stress drop had a very slight impact in the case of intact, plastic clays, the MRT and MCT compression curves agree possibly due to the fact that the bonds were cohesive with some tensile strength. For sample 4, last stage (Figs 2) the large partial unloading was intentional and negative effective stresses were recorded at the sample bottom. There was no hydraulic fracturing since the soil had some tensile strengh. The effect of the partial unloading was more pronounced for small plasticity soils (e.g., soils 0 and 1, Fig 4) where the MRT compression curve deviated from the usual compression curve considerably.

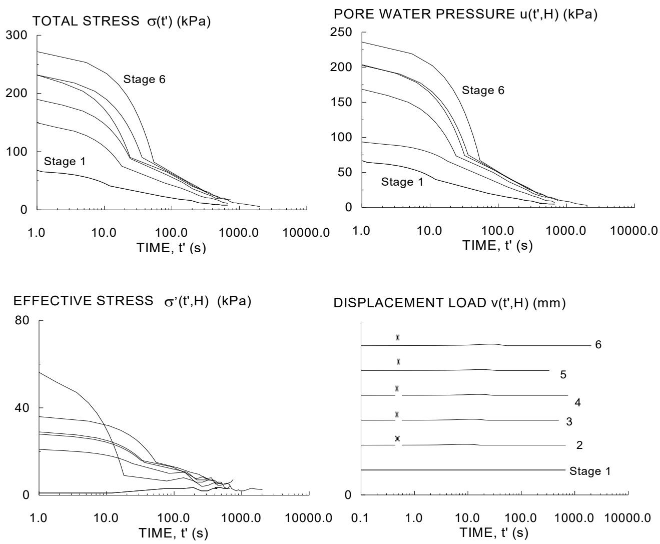

Figure 2. Measured MRT data for soil 0. (a) Total stress. (b) Pore water pressure. (c) Effective stress. (d) Displacement. (The partial unloading is indicated by x)

6. Discussion

In the model of the oedometric relaxation test the final total stress under the given displacement load is not unique, depends on the load history. The transient component of the total stress is equal to the mean pore water pressure. In the oedometric relaxation tests reported here the control system caused a slight partial unloading on most of the saturated clay samples at the start of the stage which did not influence the MRT compression curve for intact plastic clays and caused an increasing deviation from the usual compression curve for clays with I_p<20%. This can probably partly be explained by a micromechanical model (8 Luding, 2012) anice the contact force –displacement curve has a varying secant modulus for cohesive particles, and, a tiny load cycle may be fully reversible. When a large partial unloading was intentionally caused during the MRT then this did not influence the pore water pressure, but reduced the total and effective stress

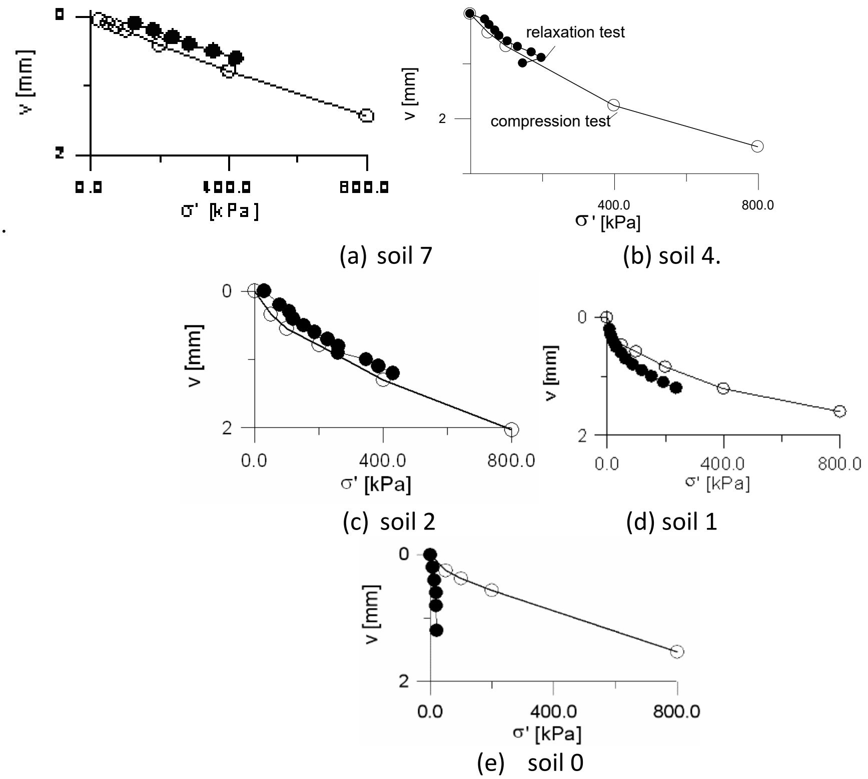

Figure 3. The measured short MRT compression curves (full circles) and standard MCT

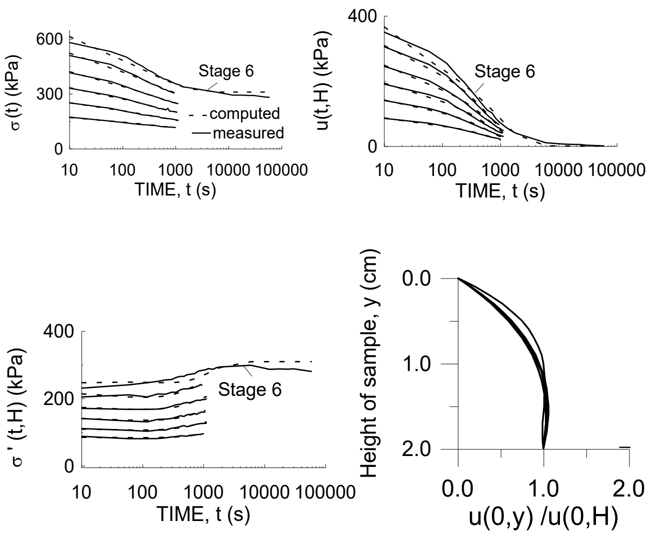

Figure 4. MRT, simulated (model ECRT) and measured stresses, sample 6 (a) Total stress. (b) Pore water pressure. (c) Effective stress. (d) Identified initial condition.

7. Conclusion

The dynamic-static transition may cause a slight partial unloading in the test load and the MRT compression curve point can be changed. In case of soft, plastic soils with some tensile strength the change is reversible (in accordance to [8]). In case of less plastic soils it is increasingly irreversible, the compression curve point is drifted away on the unloading curve. For some soils with more frictional or breaking bonds the difference is larger. The size of the deviation may indicate the nature of the bonds and some special engineering geological features, like salinity of the soils, the test have not been completely been discovered from this aspect.

In extreme case, hydraulic fracturing may occur in the sample, or even negative effective stress can be induced locally at the bottom of the sample either by applying an intentional, large partial unloading in the displacement load (or by increasing the pore water pressure here). This follows from the facts that the total stress (1) can be decreased even to zero by partial unloading but (2) the pore water pressure is practically unchanged at the bottom since the soil can not be drained so fast, (3) as a result, the difference may become highly negative.

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