Laboratory creep and relaxation after partial unloading

Les procès secondaires après un déchargement partiel

E. Imre
Budapest University of Technology and Economics, Budapest, Hungary
Szent István University, Budapest, Hungary

B. Móczár, J. Farkas
Budapest University of Technology and Economics, Budapest, Hungary

ABSTRACT

The “secondary processes” such as creep and relaxation (being related to constant stress or constant displacement boundary conditions) are generally observed after monotonously increasing loading. The processes are described by some empirical laws which are frequently linear with log time. The processes are hardly known for non-monotonous previous loading. In a starting research both experimental (triaxial and oedometric tests on peat) and theoretical works are made in the topic. The first results of the experimental study are presented in this paper. These indicate that (i) the creep stops after partial unloading, (ii) there is an experimental evidence for the restart of creep after partial unloading, the creep continues after a definite time interval of pause.

RÉSUMÉ

Les procès secondaires – comme fluage, relaxation (relié á contraint constant ou déformation constante) sont en général analysés après un chargement augmenté monotone. Les procès sont décrits par quelques lois empiriques, très souvent linéaires, en temps logarithmiques. Les procès sont peu connus pour chargements précédents.

En connexion avec une recherche justement commencée également expérimentale (essais triaxiaux, essais oedométriques) que théorique son exécutés dans ce sujet. Les premiers résultats des essais sont présentés. Ils nous prouvent, que (i) le fluage est stoppé pendant un déchargement partiel et (ii) qu’une évidence existe pour le nouveau recommencement de fluage.

Keywords : creep, partial unloading, peat, primary consolidation, relaxation

1 INTRODUCTION

We know very few about the “secondary processes” such as creep and relaxation after partial unloading. In the starting research some drained multistage oedometric compression tests and undrained triaxial creep tests with partial unloading were made on peat to study these phenomena.

The results - presented in this paper - indicate that the creep temporarily stops then restarts after a pause. The pause time is dependent on the size of the unloading and can be predicted with the same empirical creep equation which is used after increasing loading. This result is in agreement with the results of Lacerda (1977) concerning relaxation after partial unloading.

2 METHODS

2.1 *Laboratory tests*

Four different - highly compressible - peats were used with organics content of 60-90%, water content of 300-600%, and void ratio of 3,9-7,0.

Nine peat samples were tested by multistage oedometric compression tests. During this test the sample is placed into a rigid ring, the total stress is controlled, the displacement is measured on the upper surface of the sample. The pore water of the sample can flow in and out.

A typical applied load regime can be seen in Figure 1(a). The stages were short and the long term compression curve was predicted on the basis of the parameters of the Bjerrum model.

Four peat samples were tested by undrained triaxial creep tests. In this test the radial and the vertical total stresses of the cylindrical sample are controlled and the pore water pressure is measured, the system is closed. Two creep tests with and without partial unloading were made, respectively.

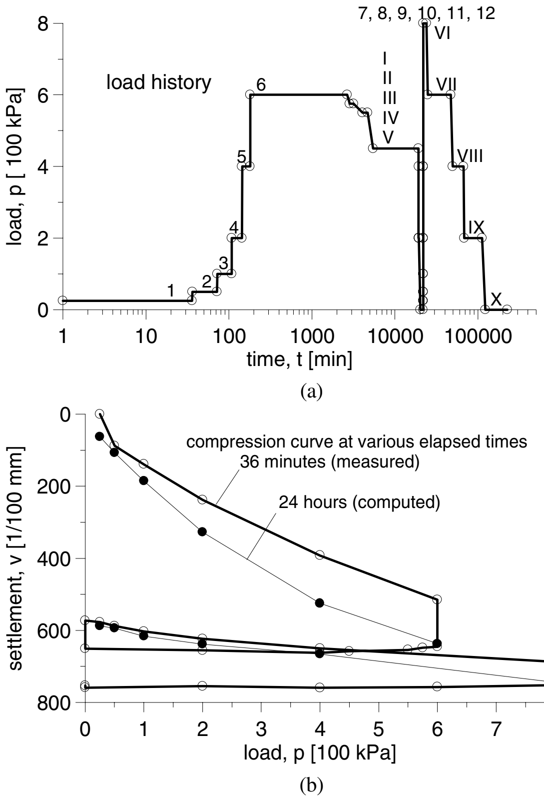

Figure 1. Multistage oedometric compression test, Sample 2. (a) Loading scheme. (b) Compression curve. Notation: 1, 2 …: increasing load beforehand, I, II… decreasing load beforehand.

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-742

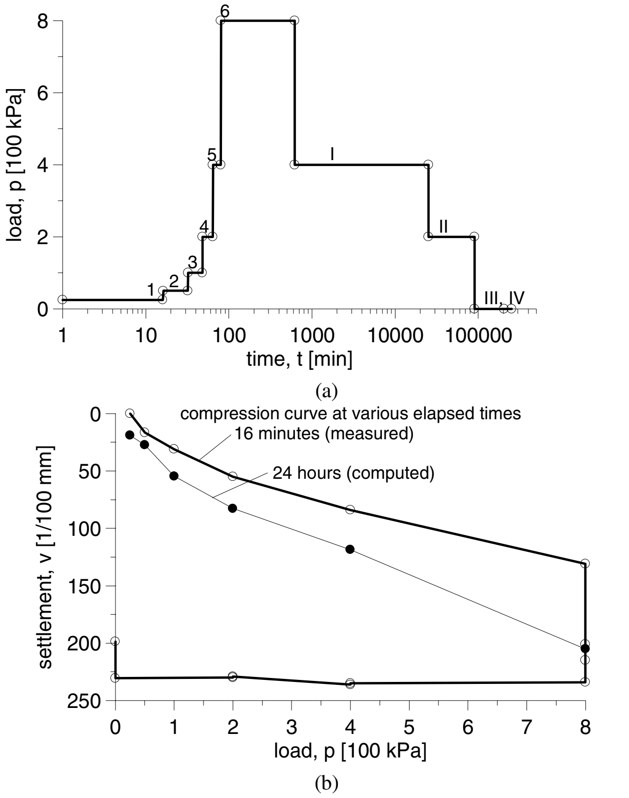

Figure 2. Multistage oedometric compression test, Sample 9. (a) Loading scheme. (b) Compression curve. Notation: 1, 2 …: increasing load beforehand, I, II… decreasing load beforehand.

2.2 *Modelling of the stages*

The Bjerrum's model was used for the evaluation of the measured. The sample top displacement:

$$v(t) = v_1(t) + v_2(t) \tag{1}$$

$$v_1(c_v, t) = v_\infty f(c_v, t) \tag{2}$$

$$v_2(t) = C_\alpha \frac{2H}{1+e_0} \log \frac{t+t_0}{t_0} \tag{3}$$

where v_1 is primary consolidation settlement, f is solution of the Terzaghi's model depending on the coefficient of consolidation c_v, time t, v_2 is creep settlement, C_α is coefficient of creep, t_0 is a time parameter, H is sample height, e_0 is initial void ratio.

3 RESULTS

3.1 *Stages of the oedometric tests after monotonically increasing loading*

The Bjerrum model was fitted on the measured data using the method described in Imre et al (2001). The result of the inverse problem solution is shown in the Appendix on the example of Sample 2. The identified coefficient of creep [C_α] was realistic. Only lower bound was given for the coefficient of primary consolidation in many cases.

Using the results, the model response was simulated, the compression curves were predicted (Figs 1 to 3). The measured and the simulated data for the stages (Fig 3) were not in good agreement in every case. The simulated primary consolidation was generally unrealistically fast indicating that the Terzaghi model may not be acceptable.

3.2 *Stages after non-monotonic unloading*

3.2.1 *Stages after partial unloading*

According to the results (Fig 4), at first rebound takes place in a time dependent manner. Then the creep restarts. The larger is the rebound displacement the greater is the pause time.

3.2.2 *Stages immediately after a load increase*

It can be expected on the basis of the foregoing results that if partial unloading occurs and there is load increase immediately before the stage then during the stage the creep can be in stopped state or can be in restarted state. The results of the parameter identification are in agreement with this expectation.

The identified coefficient of creep [C_α] was very small immediately after the partial unloading then – after a definite time – its value became realistic (Table A-2). In accordance with this, the full and open symbols are far from each-other in the virgin curve, coincide first in the rebound curve then the distance is larger again (Fig 1 (b)).

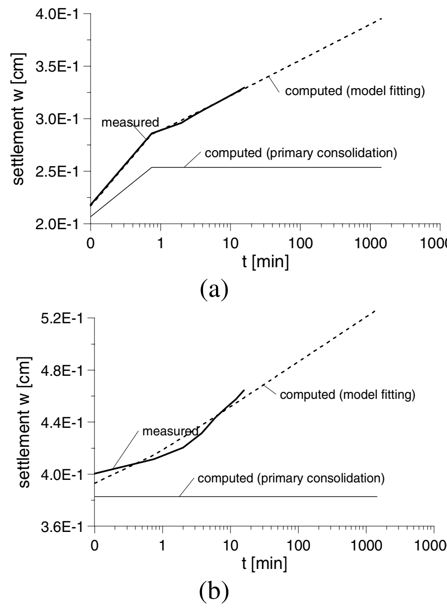

Figure 3. Simulated model response for stages after increasing load during the MCT of Sample 3,. (a) Stage 3. (b) Stage 4.

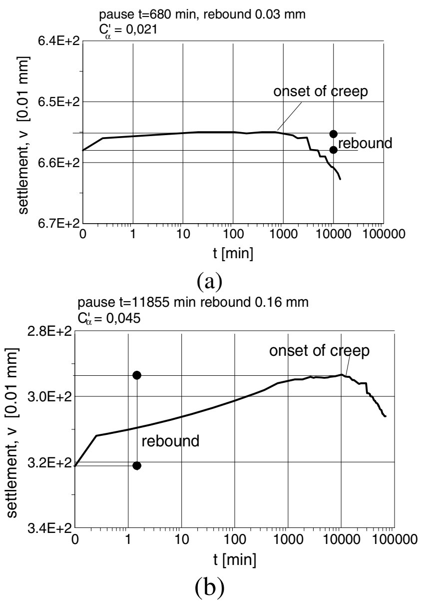

Figure 4. The time variation of the displacement in a stage after partial unloading. (a) Sample 2, stage III, (b) sample 3, stage I.

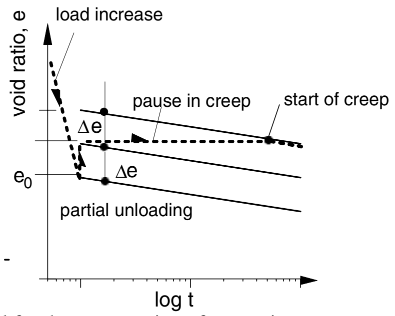

Figure 5. Model for the computation of pause time

Table 1. Measured rebound and computed creep settlement Δv [mm]

Sample, stage	measured	Computed using t_{pause} [min]		
		10	100	1000
sample 2, III	0,03	0,04	0,02	0,01
sample 2, VI	0,03	0,09	0,06	0,03
sample 3, II	0,16	0,14	0,09	0,05
sample 4, I	0,04	0,06	0,04	0,01
sample 4, III	0,09	0,35	0,25	0,16
sample 6, III	0,03	0,13	0,06	0,02
sample 7, I	0,05	0,12	0,06	0,02
sample 7, II	0,1	0,14	0,10	0,05

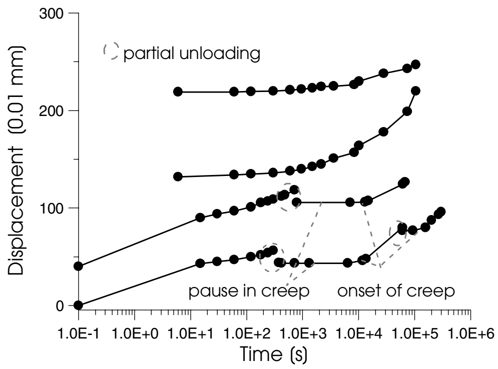

Figure 6. Triaxial tests on peat (upper 2 tests - creep tests after monotonous loading, lower 2 tests: creep tests after partial unloading).

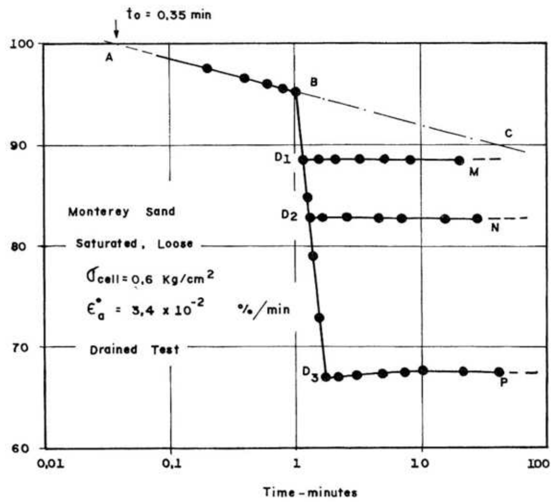

Figure 7. Triaxial relaxation tests on sand (Lacerda 1977)

3.3 *Prediction of the pause for oedometer test*

It is assumed that after a rebound displacement Δv (or void ratio increase of Δe) the pause time is equal to the time necessary for the development of the same sized creep settlement (Fig 5).

To verify this model, the creep settlement was computed with the creep equation using the following parameters. The measured pause times t_{pause} was used for t, the measured slope of the creep settlement-log time plot C'_α was included and 3 different values were applied for the time parameter t_0. According to the results, the measured rebound and the computed creep settlements were in good agreement (Table 1).

It follows that the pause time t_{pause} can be computed such that the creep equation is solved for t assuming that v_2 is equal to the rebound Δv:

$$\Delta v - C'_\alpha \quad \log \frac{t_{pause} + t_0}{t_0} = 0 \tag{4}$$

where C'_α is the slope of the creep settlement-log time plot.

3.4 *Triaxial creep test after partial unloading*

The first results of the undrained triaxial creep tests on peat are shown in Figure 6 where two pairs of samples are shown, with and without partial unloading. The shift between the measured time-displacement curves can be attributed to inhomogenity of the samples.

According to the results, the rebound in terms of the displacement is immediate and the creep continues after a definite time interval of pause. The time of pause is depending on the size of the unloading in terms of the displacement: the larger the rebound the greater is the pause.

Similarly to the case of the oedometer test, the pause seems to be predictable on the basis of the time- displacement relation valid after increasing loading.

4 DISCUSSION

4.1 *Relaxation tests after partial unloading*

According to the results of the triaxial relaxation tests of Lacerda (1977), the relaxation (total stress decrease) stops if the relaxation test is made after partial unloading (Fig 7). Lacerda assumes that relaxation continues after a definite pause which is related to the size of the partial unloading. No experimental evidence was achieved for this hypothesis, some indirect proofs were found in a model validation study (Imre, 1994).

4.2 *Physics*

The physical explanation of the relaxation and creep can be related to material dislocations moving under the effect of the displacement or stress load, respectively (Tasnádi, 1985). An interesting feature is the size effect.

It can vaguely be assumed that - due to partial unloading - the movement of the dislocations temporarily stop and after a rearrangement restart if the load is not completely ceases. Further research is suggested (Ván –Imre, 2003).

4.3 *Multistage compression tests*

The conventional multistage compression test can be used for the determination of the compression curve and the primary and secondary consolidation indices.

Several faster procedures have been elaborated. These “continuous” tests need more complicated equipment and the evaluation is based on simpler models (e.g. the effect of creep is generally neglected).

In this work the fast multistage compression testing was applied with short stages. The Bjerrum model was used to compute the 24 h displacements so that the long term compression curves could be plotted.

This was possible since the primary consolidation was generally very fast and the identified model parameters were generally reliable. (In the case of peats the modelling of great strains, the organics degradation, the double porosity could be necessary, see e.g. Yong et al, 1995).

4.4 *Rebound*

The rebound displacement is immediate in the triaxial creep tests and is time dependent in the oedometer test. The time dependency in the latter case can possibly be attributed to the facts that oedometer test is drained and the wall friction on the confined sample is time dependent.

5 SUMMARY, CONCLUSION

The results of the multistage oedometric compression tests and the undrained triaxial creep tests can be summarized as follows.

According to the results of the oedometric compression tests, the creep stops after partial unloading and restarts after a pause. The usual empirical creep model – valid after monotonic loading - can successfully be used to predict the order of magnitude of the pause time on the basis of the rebound displacement and the coefficient of creep.

The results of the undrained triaxial creep are similar. The creep stops after partial unloading then continues after a pause. The pause time is estimable on the basis of the creep relation valid after monotonically increasing loading.

These results are in agreement with the hypotheses of Lacerda (1977) stating that the relaxation restarts after a time period being related to the size of the unloading. For normal soils the time of pause was long and the onset of relaxation was not observed. Peats show the same rheological features as normal soils but in a "more pronounced" manner. In this study on creep after partial unloading not only the pause of creep but also the onset of creep was experienced.

ACKNOWLEDGEMENTS

The help of István Groma and the support of the Fund Jedlik Ányos NKFP B1 2006 08 is greatly acknowledged.

REFERENCES

Bjerrum, L.; Simmons, N.; Torblaa, A. 1958. The Effect of time on the shear strength of a soft marine clay. *Publication No. 33. Norwegian Geotechnical Institute, Oslo.*

Imre, E., Aradai, L., Vértes, K. Menyhárt, P., Telekes, G. (2001): Multistage compression test – in a shorter way. Proc. of the XV. ICSMGE, Istanbul, 2001, August. I. 127-131.

Terzaghi, K. 1923. Die Berechnung der Durchlassigkeitsziffer des Tones aus dem Verlauf der hydrodynamicshen Spannungsercsheinungen, *Sitzber. Akad. Wiss. Wien*, Abt.IIa, Vol. 123.

Imre, E. (1994). Model validation for the oedometric relaxation test. *Proc. of the 13th Inter. Conf. on Soil Mech. and Found. Eng. New Delhi, India, 1123-1126.*

Lacerda, W. A. (1977). Stress Relaxation after Partial Unloading. *Proc. of the 9th Inter. Conf. on Soil Mech. and Found. Eng. Tokyo*, Vol.1. pp.117-179.

Press, W.H.; Flannery, B.P.; Teukolsky, S.A.; Wetterling, W.T. 1986: Numerical Recipes. Cambridge Univ. Press, Cambridge

Tasnádi, P.(1985). Mikromechanisms of creep. Fiz. Folyóirat 646-479.

Ván, P; Imre, E.(2003) Dynamics and failure of soils – beyond rheology. *Soil Rock America 2003, Proc. of the 12th Panamerican CSMGE and 39th US Rock Mech. Symp.* Vol. 1. p.1219-1224.

Yong, R.N.; Lechowicz, Z.; Wolski, W. (1995). Consolidation of organic subsoil in terms of large strains. Proc. of 8-th Baltic Geotechnical Conference, 261-267.

APPENDIX

The solution of the inverse problem is considered as reliable if it is unique and the confidence interval of the parameters does not exceed the range of the parameters. The solution is unique if the global minimum of the merit function is not degenerated.

The uniqueness was tested by representing some sections of the merit function constructed from real data and from simulated data as well. The standard deviation of the parameters was determined with the conventional procedure using the linearised model (Press et al 1986).

The error of the three identified parameters was as follows (Tables 1, 2). The standard deviation was generally less than about 10% for the primary consolidation settlement, 20% for the coefficient of creep. Only lower bound was given for the coefficient of primary consolidation in many cases, the minimal section concerning c_v was generally quasi-degenerated (see Fig A-1, stage 12).

Table A-1 Sample 2, identified parameters and fitting error *F*. Notation: **, *** mean stages after non-monotonic load steps, either without creep or with creep (i.e. the creep is stopped, restarted), respectively; * means lower bound.

Stage	c [cm^2/s]	v_∞ [cm]	C_α [-]	F [%]
01	0,02	0,04	0,01	12,21
02	0,10	0,03	0,01	4,34
03	3,00	0,03	0,04	1,13
04	0,10	0,07	0,06	3,05
05	0,30	0,09	0,10	0,43
06	3,00*	0,03	0,10	2,30
07**	0,10	0,00	0,01	8,74
08**	3,00*	0,01	0,01	0,52
09**	3,00*	0,01	0,01	0,42
10**	0,10	0,02	0,01	2,81
11**	3,00*	0,02	0,01	1,28
12***	3,00*	0,01	0,05	4,74
mean :	1,09	0,05	0,06	3,91

Table A-2 Sample 2, standard deviation of the identified parameters. Notation are the same as for Table A-1.

Stage	SD(c)/c [-]	SD(v_∞)/v_∞ [-]	SD (C_α)/C_α [-]	F [%]
01	1,46	0,17	0,83	12,21
02	0,71	0,06	0,27	4,34
03	10<	0,02	0,03	1,13
04	0,67	0,06	0,10	3,05
05	0,66	0,01	0,01	0,43
06	10<	0,16	0,05	2,30
07**	3,64	0,36	0,17	8,74
08**	10<	0,01	0,02	0,52
09**	10<	0,01	0,01	0,42
10**	0,42	0,04	0,13	2,81
11**	10<	0,02	0,05	1,28
12***	10<	0,34	0,09	4,74
mean	0,87*	0,08	0,21	3,91

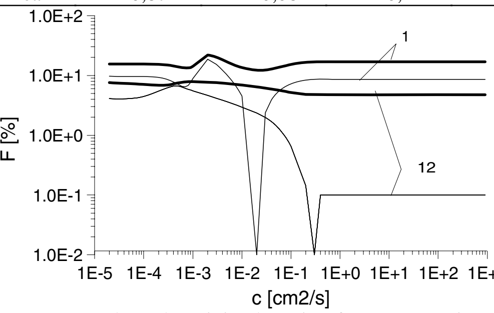

Figure A-1 Sample 2, the minimal section for c_v concerning stage 1 and 12. (Legend: thick line: real data, thin line: simulated data).