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Two deformation mechanisms with granular soils

Deux mécanismes de déformation des sols granulaires

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ABSTRACT
Creep of granular clay is studied by one-step loading up to 1000 kPa in oedometers. Dry and loose specimens were used. Two phases of creep were found. The first one, up to 10^4 min., represents a regular secondary compression of semilogarithmic nature and is ascribed to the transformation of inborn fabric (produced by the specimen preparation) into the compression fabric. The other one is formed by a periodic variation of the s-creep and g-creep. S-creep is produced by the diffusion of the oedometric compression from the loaded plate downwards, g-creep results from the nonhomogeneity of the specimen. Granular clay is supposed to model waste clayey (double-porosity) material of open coal mines. Complexity of the creep process even in uniaxial compression points to the difficulty of numerically modelling of problematic soils.

RÉSUMÉ
La fluage de l'argile granulaire était étudiée dans un oedomètre sous la charge jusque 1000 kPa. Deux phases étaient observée. La première jusque 10^4 min. est la consolidation secondaire régulière produite par la transformation de la structure original à la structure compressive par le chargement. La deuxième est formée par la variation périodique de la s-fluage et g-fluage. S-fluage résulte de la diffusion de déformation de haut en basse de l'oedomètre, g-fluage est la conséquence de nonhomogénéité de échantillon. L'argile granulaire est le modèle des matériaux (de double porosité) de déchet des carrières du lignite. La complexité de fluage seule sous le chargement uniaxial prouve la difficulté de modéllement numérique des sols problematiques.

1 INTRODUCTION

Soil deformation is realized by different mechanisms. They depend on the type of soil and on such effects like the stress level, density, water content etc. The most common is the particle rearrangement, their aligment (eg. compression fabric with structural units perpendicular to the stress direction) etc. At higher stress levels, bonding rupture occurs and particle crushing takes place. The author of the present contribution has chosen a granular clay (dry clay crushed and sieved to the max 7 mm grain size) as a model material to study the creep behaviour of the so called double-porosity soil (Feda, 2003a). In addition to the rich structural modes, it has a practical significance (waste material of the open coal mining – Feda, 1998).

2 LABORATORY EXPERIMENTS

Tests were carried out with dry granulated (grains < 7 mm) Neogene clay, loose (total porosity about 70 %), with the plasticity index of about 45 %. In an oedometer (Fig. 1) with the diameter 100 mm and specimen's height 19 mm, the load was applied in one step from 50 to 1000 kPa and creep deformation measured which is expected to be irregular (Feda, 2003b).

Fig. 2 depicts the creep curves measured (some tests were repeated and show good reproducibility, Fig. 3). Two phases of creep were found. The first one (up to about 10^4 min.) is the ordinary secondary consolidation (linear deformation-log time dependence) with the C_α parameter 0.062 %. This is the common (standard) logarithmic (primary) creep (Boltzmann law) and expresses the gradual accomodation of the inborn structure (the structure of the unloaded specimen) to the load (development of the compression fabric). In some cases (test III, IV) secondary consolidation reaches beyond t = 10^4 min. The creep behaviour thus bears a stochastic nature.

Fig. 3 depicts the immediate (t ≈ 0) compression curve (compression index C_c = 0.025). The ratio C_a / C_c = 0.025 and is situated within the common limits for clays.

For t > 10^4 min. some creep curves are enlarged (Figs. 4, 5). They show a nonstandard behaviour, being generally a combination of s-curves (s-creep) and g-curves (garlandlike creep).

3 NON-STANDARD CREEP

S-creep can be interpreted as a diffusion process. Compression of the oedometer specimen spreads from the loaded (upper) plate downwards. The process is well know in different forms, in soil mechanics eg. as the primary (hydrodynamic) consolidation of water saturated clay. Fig. 6 shows a simple form of this process in case of the tested granular clay loaded by 1000 kPa. Solving the diffusion equation (partial differential equation of the second order of parabolic type) one gets an s-shaped relation as depicted in Fig. 6.

Such an ideal process cannot be fully developed unless the specimen is homogeneous. Fig. 7 depicts the degeneration of the diffusion in case of a nonhomogeneous specimen (upper half of the specimen was dry, the lower one wet). The creep curve takes the form, called by the author "garlandlike". The creep curves in Figs. 4 and 5 are the combinations of the two basic forms of creep curves. In Fig. 8 the effect of nonhomogeneity is explained. Upper loose layer (1) increases the compression (2) to the final value (1 + 2) and, in the same time, deforms the s-creep.

It can physically be illustrated by Fig. 9. a-c-f-e-g-h indicates the variable density of the specimen (upper part denser than the lower one). S-curve 2 is deduced for the density a-b-g-h, s-curve 1 for additional density b-c-f-e. Contrary to Fig. 8 the upper layer is denser and the additional compression should, therefore, be substracted (final compression is smaller).

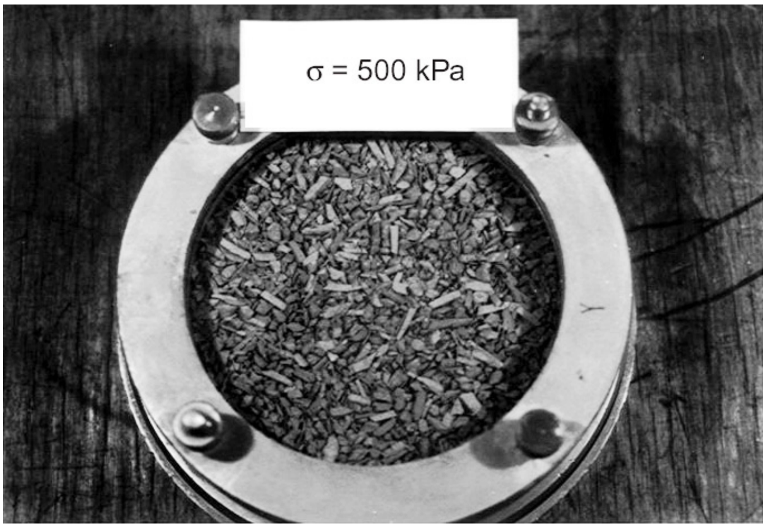

Figure 1. Oedometer ring after the test with 500 kPa

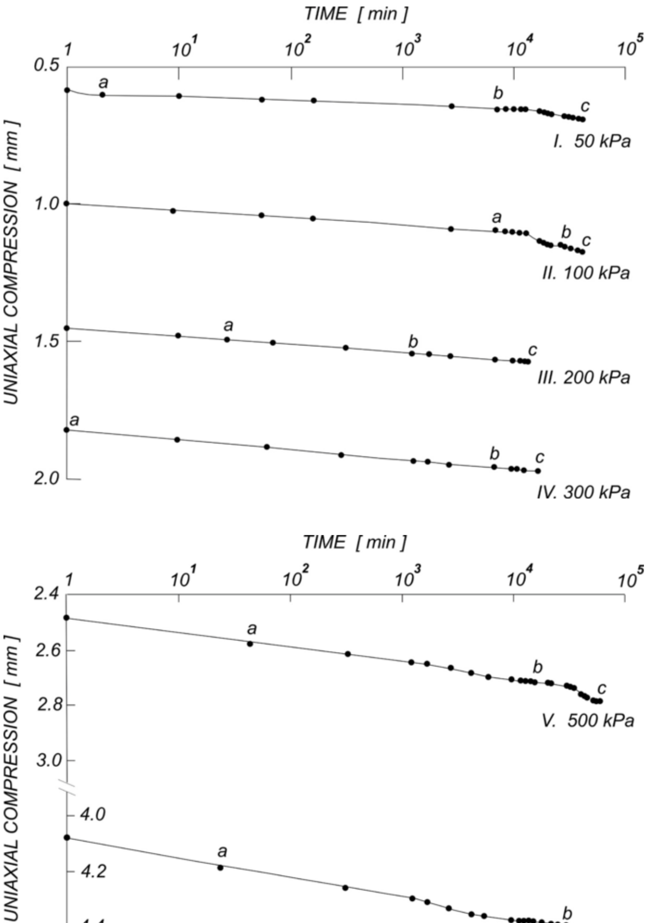

Figure 2. Oedometer creep curves of dry granulated loose Neogene clay at different stress levels

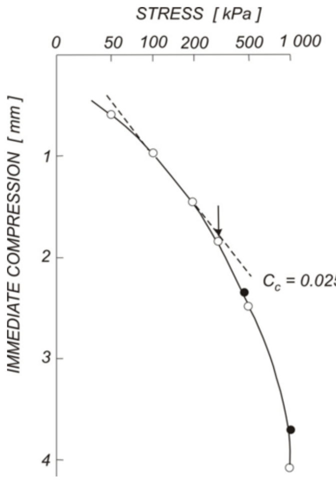

Figure 3. Immediate compression curve of granulated clay. Full circles – repeated tests.

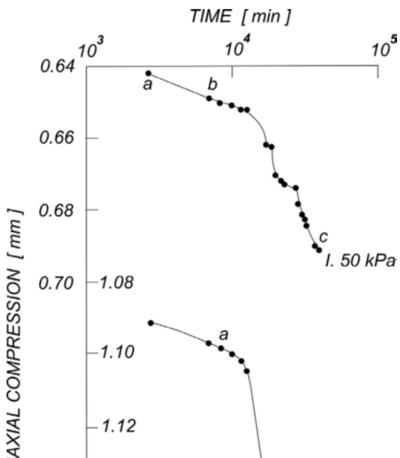

Figure 4. Tests I, II – enlarged for t > 10^3 min

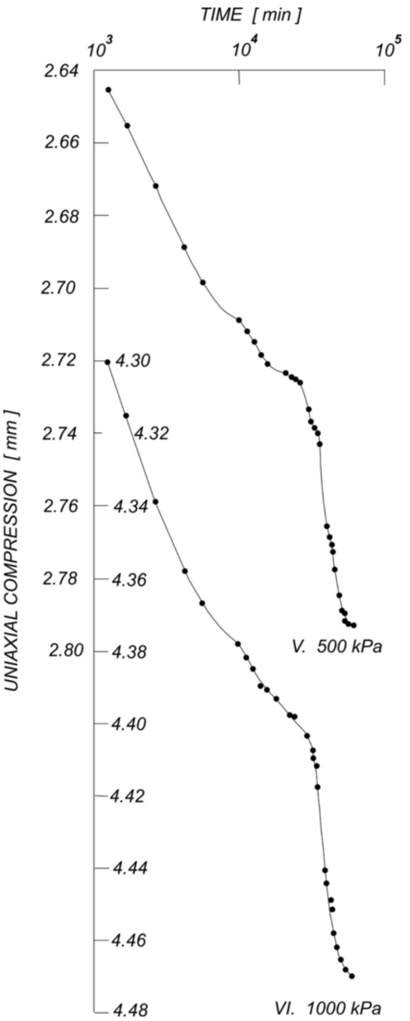

Figure 5. Tests V, VI – enlarged for t > 10^3 min

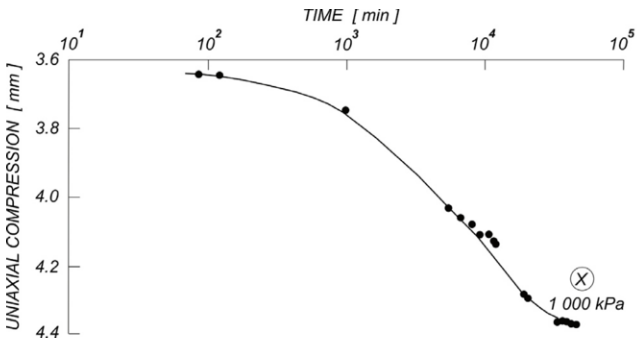

Figure 6. Repeated test VI (σ = 1000 kPa) – perfect diffusion

If the nonhomogeneity of the material is due to the density, then materials with small extent of porosities (the difference of maximum and minimum porosities) are well suited to model the diffusion effects (for the clay tested, the range of porosity was about 1.5%, contrary to sands where it may surpass 10-15 % – Feda, 2004).

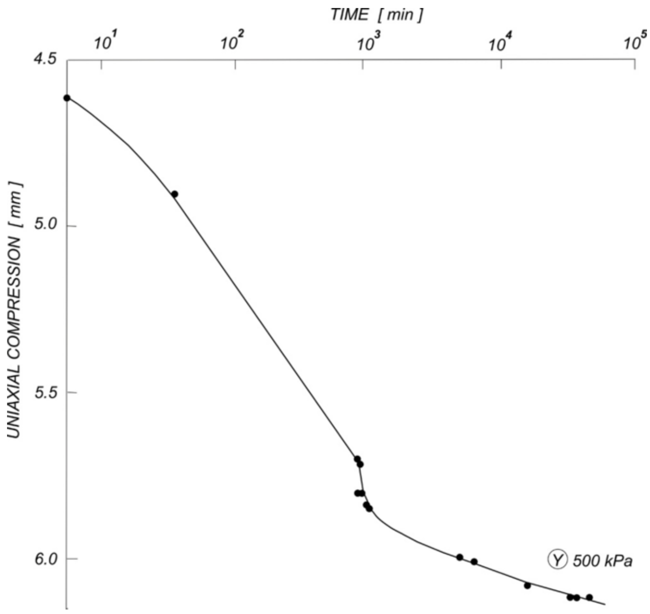

Figure 7. Garlandlike creep with two-layered specimen
(upper layer – dry granulated clay, lower layer – wet granulated clay) – perfect garland

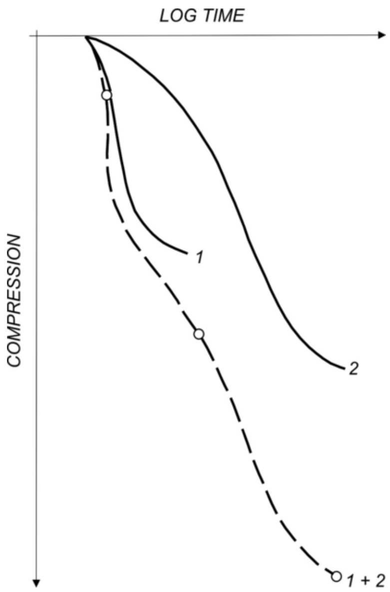

Figure 7. Conception of summing the diffusion curves (1, 2)

4 GRANULOMETRY

Fig. 10 presents the dependence of the various granulometric groups on the stress level. Contrary to the common picture, the quantity of very small grains may increase with stress level due to the aggregation of the particles (Figs. 11, 12). As shown by repeated tests, the extent of grains at high stress level is rather variable. The process of aggregation (and crushing?) is clearly even with (more or less) identical specimens of stochastic nature.

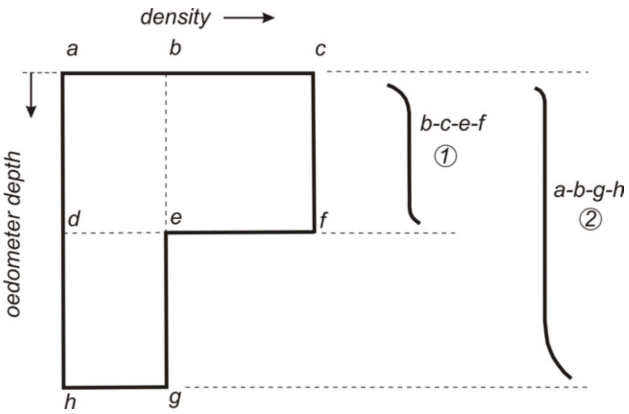

Figure 9. Illustration of the nonhomogeneity effect in Fig. 8 due to the variable density of the specimen

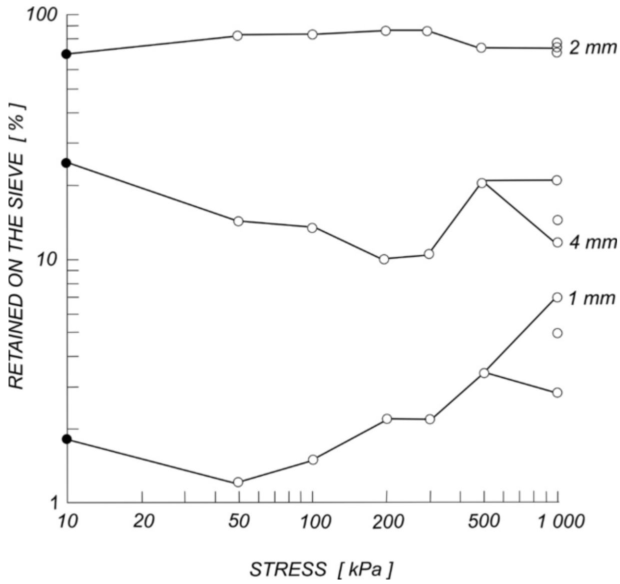

Figure 10. Clayey grains fractions on sieves 1, 2 and 4 mm

5 CONCLUSIONS

With nonstandard soils, like fragmentary clay, soils with crushable grains and other problematic materials strange behaviour is sometimes met. Then numerical modelling is rather difficult. Such materials should be carefully studied and the common routine approach avoided.

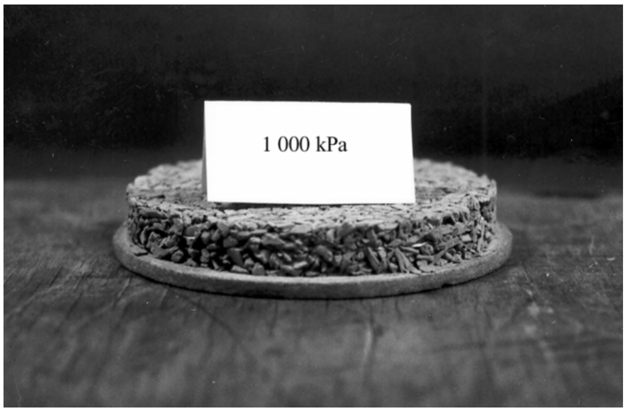

Figure 11. Lateral view of the specimen of granulated clay after being loaded by 1000 kPa

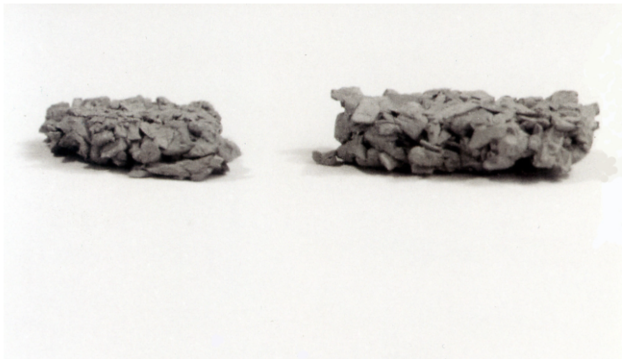

Figure 12. Aggregates of clayey grains after the application of the load 1000 kPa

ACKNOWLEDGMENT

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