NEWSLETTER

CREEP OF GEOMATERIALS

ISSUE OF JANUARY '14.
EDITOR: PROF. GUSTAV GRIMSTAD

FROM THE EDITOR

Prof. Gustav Grimstad, NTNU

Welcome to the first newsletter of the CREEP project. CREEP is an industry-academia partnerships and pathways (IAPP) project funded from the 7th framework program (FP7/2007-2013) of the EC under grant agreement PIAG-GA-2011-286397. The research topic of this Marie Curie action is creep behavior of geomaterials and its incorporation in geotechnical design; the project aims at establishing a consensus in creep modelling. Slow time-dependent movements caused by creep of natural geomaterials affect the performance of infrastructure and cause high maintenance and repair costs, and the partial closures of infrastructure networks during the repair work have significant economic and social impact. Although the phenomenon of creep is well-known for being a major design issue, there is currently no accepted consensus on the best way to model creep. Reliable calculation tools are either missing or - due to their scientific nature - out of reach for the engineer in charge. If as a consequence creep is underestimated in design, structures will possibly be damaged so that they will not reach their design life.

The goal of the CREEP project is to: *supply the industry with the tools and knowledge needed in creep analysis.*

In this 1st Newsletter of the project you will find some of the work that has been going on in the project so far and plans for the future in the project.

CREEP IS A TIME DEPENDENT PROCESS IN WHICH MATERIALS ACCUMULATE STRAINS (DEFORMATIONS) UNDER THE INFLUENCE OF CONSTANT (EFFECTIVE) STRESSES.

THE 4TH CREBS WORKSHOP

Dr. Evert den Haan, Deltares

The 4th CREBS workshop was held in Delft 8th and 9th of January 2014. It was the 2nd workshop of the EU project of CREEP OF GEO-MATERIALS. The main focus of the workshop was on creep in Clays, Peats, and Frozen soils.

CREBS workshop	Place	Date
CREBS-I	Oslo	Jan 2006
CREBS-II	Pisa	Sep 2007
CREBS-III	Gothenburg	Jun 2009
CREBS-IV	Delft	Jan 2014

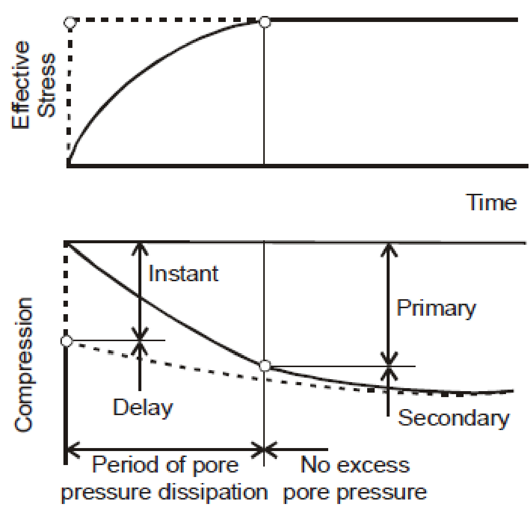
CREBS has helped the understanding of creep behaviour of soft soils forward immensely. The End of Primary controversy (the question whether the strain at the end of primary consolidation is independent of layer thickness), was taken into study as a result of discussions at CREBS I. CREBS II provided strong impulses to develop advanced computer models of behaviour, combining anisotropy, destructuration and time effects. A Case Prediction exercise started after CREBS II and was presented at CREBS III.

Keverling Buisman was the pioneer of soil mechanics in Holland. He is best known for his log(t) compression 'law' - secondary compression if you like, and he was aware that that word was being used in the USA. But he preferred the word 'secular' in the sense of a period spanning approximately a human lifetime. And he used the word 'direct' in the sense of instant compression. This is the famous equation from his 1936 paper to the 1st ICSMFE:

$$z_t = \alpha_p + \alpha_s \log_{10} t$$

The p signifies the direct influence of effective stress, and p was the symbol for effective stress at that time. So he used the terms direct and secular, not primary and secondary. The Americans continued along the primary and secondary path and got stuck in the end of primary (EOP) hypothesis. The choice of terminology may have influenced thinking. What is only a consecutive separation, primary followed by secondary, mutated in this thinking into constitutive separation (hypothesis A), while direct and secular is much closer to the isotache principle (hypothesis B).

A lot of Keverling Buisman's work was rediscovered much later, e.g. Bjerrum in 1967 later reintroduced the terms direct and secular as 'instant' and 'delayed', but the meaning is precisely the same.



However, Šuklje already had the isotache principle worked out in 1957, but it took decades more before it became common knowledge. Eventually the isotache principle has become accepted.

The next major breakthrough was to combine Modified Cam-clay with the isotache principle, which led to the Soft Soil Creep model (SSC). Prof. Kutter and Prof. Vermeer take credit for that development. From then on, theoretical developments have accelerated, although at the last CREBS III, Vermeer stated that the recent models (EVP-SClay1S (developed by Prof. Karstunen et al.) and its variations e.g. n-SAC (Prof. Grimstad et al.) were not yet sufficiently developed to be included in Plaxis. 4½ years later the situation is the same.

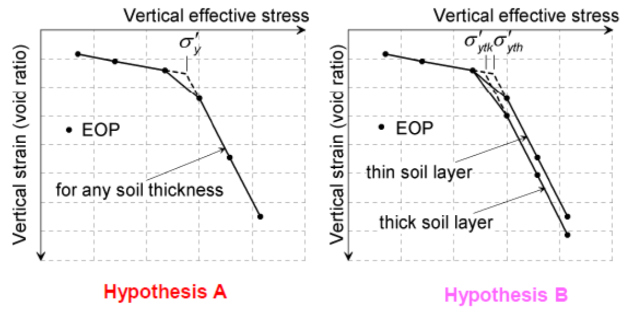
PERHAPS IT IS JUST A GIVEN FACT THAT SOIL BEHAVIOUR AND ITS NUMERICAL MODELLING IS COMPLICATED.

RATE DEPENDENT "PRE- CONSOLIDATION STRESS"

Dr. Samson A. Degago, NPRA (SVV)

Two hypotheses namely A and B, formally proposed by Ladd et al. (1977), were used as a basis for discussion as how to extrapolate creep from short time observation in laboratory to long term predictions in field. This discussion was re-started by NGI in 2006 at the CREBS I. In 2007, this study was initiated and carried out at NTNU, NGI and Chalmers with additional funding from ICG (International Center for Geohazards). Principle sketch of the two creep hypotheses for varying soil layer thicknesses is shown:

WILL A SOIL ELEMENT AT THE DRAINAGE FACE REALLY 'WAIT' FOR THE EOP STATE OF THE BOTTOM SUB-LAYER TO START ITS SECONDARY CONSOLIDATION?! (JOSTAD, CREBS I)



Several EOP laboratory tests considered in this study demonstrated the validity of hypothesis B. In fact, this study disclosed that the empirical data that were previously used to wrongly substantiate hypothesis A actually imply hypothesis B. EOP strain-effective stress relationship is not unique but it depends on consolidation time. This implies that local compressibility of a soil element is governed by its current effective stress-strain-strain rate rather than what is happening elsewhere in the soil layer. This means that a soil element will creep also during primary consolidation.

The two hypotheses could give significant practical differences when predicting in-situ settlements. However, on several occasions, the advocates of the two hypotheses have independently presented acceptable predictions. Constitutive models for hypothesis A i.e. ILLICON and hypothesis B i.e. SSC are considered for Väsby test fill with the elasto-plastic SS model used as a reference. Both ILLICON and SS, while disregarding creep, gives overall acceptable predictions. However, this should not imply that the clay does not undergo creep. The acceptable predictions are mainly due to two factors: disregarding effect of large deformations (disregarded load reduction due to the buoyancy forces) and most importantly use of soil data from 'disturbed' samples.

Generally OCR values used in ILLICON and SS analysis were low and are believed to be affected by sample disturbance. For instance, in Väsby test fill, EOP OCR for low quality sample and high quality sample is 1.31 or 1.82, respectively. When soil data are interpreted from tests on disturbed samples creep effects is already 'incorporated'. In such cases rate-independent elasto-plastic model could give then acceptable settlement predictions but relatively low excess pore pressure responses.

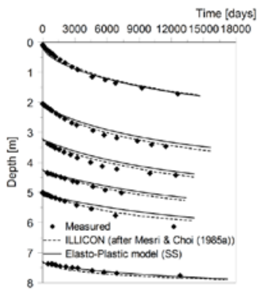


Fig.: Settlement history predictions (ILLICON vs. SS)

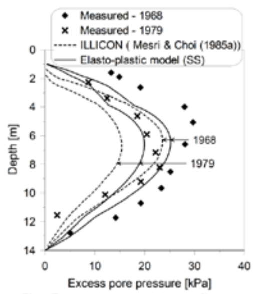


Fig.: Excess pore pressure profile predictions (ILLICON vs. SS)

When soil data are interpreted from disturbed soil samples, an isotache model, on the other hand, would significantly overestimate settlement and could give unrealistically large excess pore pressure responses. However, when soil data are interpreted from tests on high quality samples and used for settlement analysis a rate-independent elasto-plastic model (SS) significantly underestimates settlement and excess pore pressure responses while an isotache model (SSC) would yield excellent prediction of settlements and excess pore pressure.

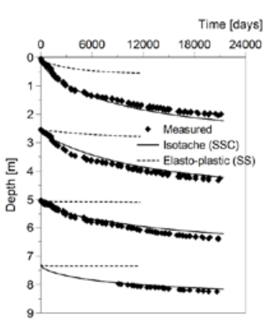


Fig.: Settlement history predictions (SSC vs. SS)

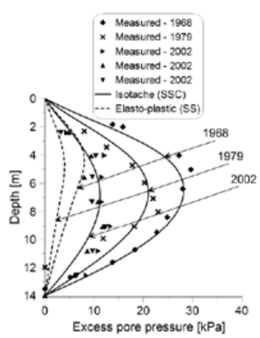


Fig.: Excess pore pressure profile predictions (SSC vs. SS)

Awareness regarding the significance of selecting appropriate p'c (or OCR) in settlement analysis needs to be stressed by the profession. Creep models based on isotache principle (hypothesis B) are well suited to predict settlements of saturated soft clays when the input data are deduced from laboratory tests of 'good' quality samples.

THE PRECONSOLIDATION STRESS, P'C, (OR OCR) AS WELL AS EOP STRAIN ARE RATE DEPENDENT

Future developments related to the compressibility of natural clays should be focused on enhancing models that are based on the isotache framework or similar.

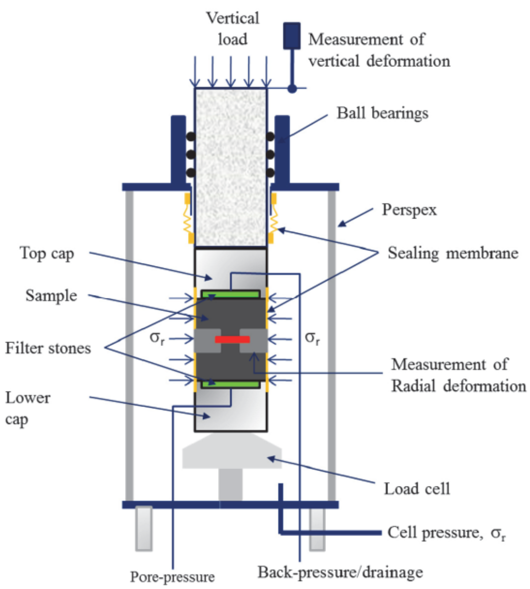
MODELLING RATE DEPENDENCY OF GOTHENBURG CLAY

Dr. Mats Olsson, Chalmers

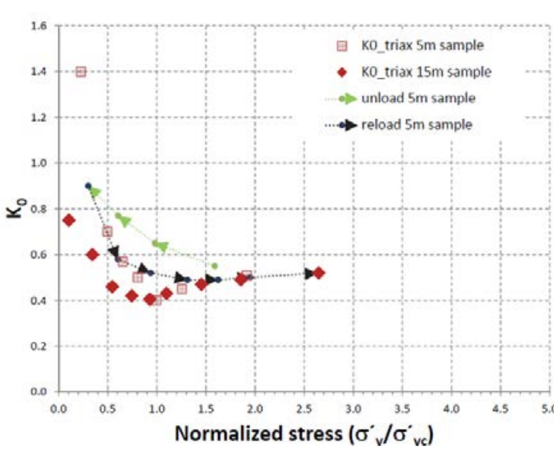
One of the most important steps in constitutive modelling of clay is Modified Cam-clay by Roscoe & Burland back in 1968. However, Cam-clay incorporates neither anisotropy of the clay nor its creep. Later on constitutive models developed to include either *anisotropy* e.g. SCLAY1-S by Wheeler et al. 1999 and Karstunen et al. 2005; or *creep* e.g. Isotropic Soft Soil Creep (SSC) (standard model in Plaxis); or *both anisotropy and creep* e.g. n-SAC, Creep-SCLAY1S and recently Modified Anisotropic Creep Model with structure model (MAC-s).

Advanced constitutive models such as MAC-s demand more parameters e.g. K_0-value for normal consolidation compression (K_0^{nc}). In general, strength parameters may obtain by triaxial tests, deformation parameters by oedometer tests (IL/CRS), and creep parameters by IL test. However K_0^{nc} may not be obtained by conventional triaxial or oedometer tests. New K_0-triaxial cell at Chalmers University was developed to address this issue. Important features of the device are: measuring K_0 value as a function of stress and strain, Incremental loading, deformation gauge control and zero radial deformation.

New K_0-triaxial cell at Chalmers University:



One of the important results which can be obtained from K_0-triaxial cell is K_0 versus normalized stress. For Gothenburg Clay, the evaluated K_0^{nc} is in a range of 0.50-0.55 as shown. Gathering more data on K_0^{nc} values for different types of soft soils could be advantageous.

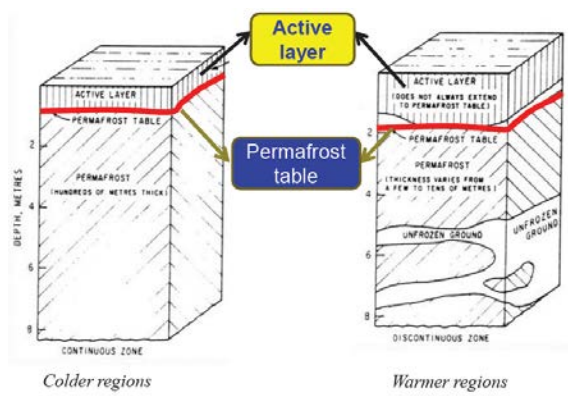


CREEP IN FROZEN SOILS

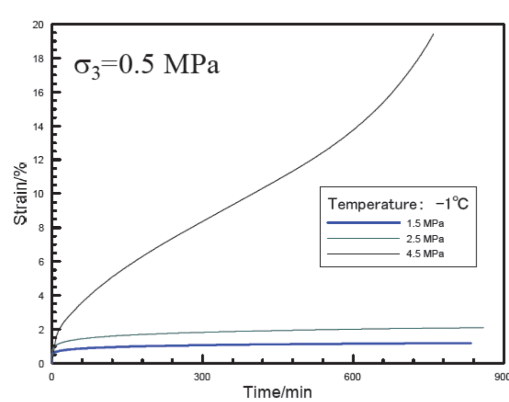
Prof. Qi Jilin, CAREERI

Frozen soils can be found in several regions around the globe. e.g. northern part of Scandinavia, Canada, Russia, etc. Permafrost can be categorized in colder or warmer regions. On the top of permafrost there is active layer, which its depth is in the range from tens cm to several meters, as depicted below from Andersland and Ladanvi (1999).

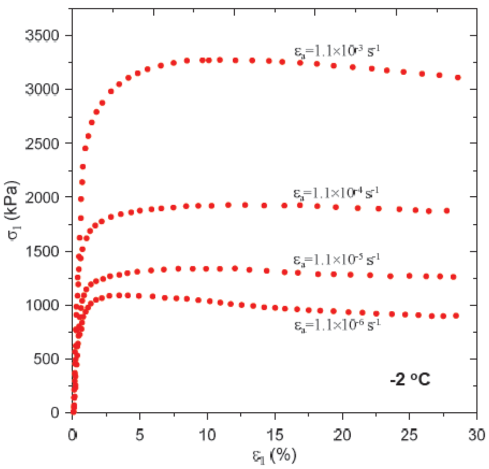
GENERAL FEATURES IN STRESS-STRAIN-TIME CURVES FOR FROZEN SOIL ARE SIMILAR TO THAT OF UNFROZEN SOILS



Typical triaxial creep test on frozen sand can be seen in the following figure.

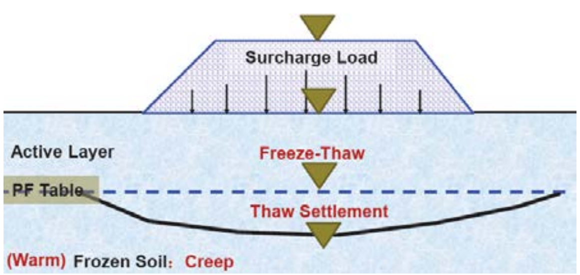


Stress-strain relationships in uniaxial compression tests at different loading rates indicate rate dependency of frozen soils.

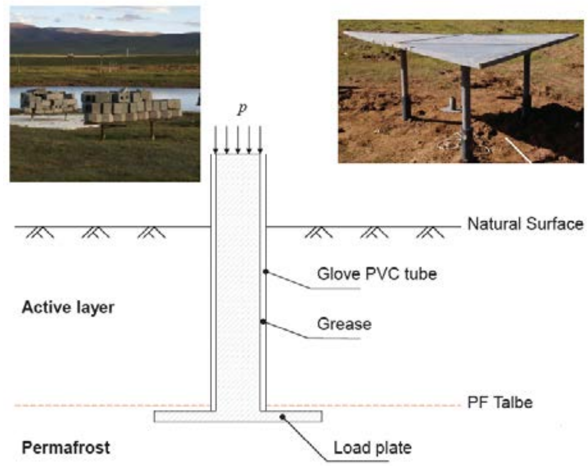


Similar to the soft soils, permafrost exhibits temperature dependent behavior-the lower temperature, the higher strain rates. In addition, frozen soil is dependent on the water content and water solute. Total water content is counted as ice together with unfrozen part. The higher solute content, the larger axial strain under a certain stress level.

To calculate the settlement of road embankment on warm frozen soils as depicted below, different layers with different physical and mechanical processes can be distinguished: freeze-thaw in active layer, thaw settlement, , and creep of (warm) frozen soil.



Usually Constitutive model for frozen soil e.g. visco-hypoplastic model by Guofang Xu, Wei Wu borrow theories from unfrozen soils. Long-term field load test is performed to study of the permafrost behavior and verification of models e.g. Beiluhe field station. Conclusion was that warm frozen soil is closer to unfrozen soil and its creep was successfully observed in-situ.



CREEP IN PEAT

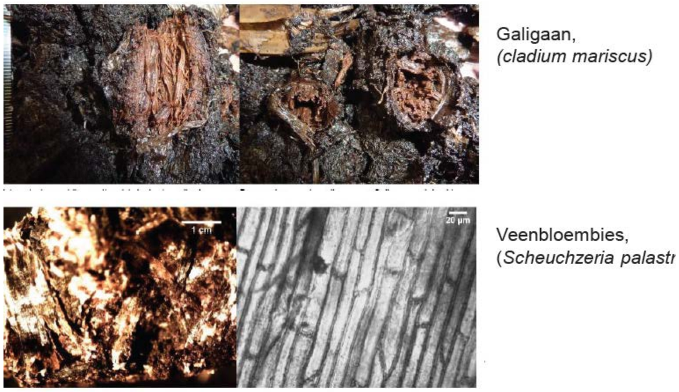
Dr. Cor Zwanenburg, Deltares

Soils with organic content higher than 30% are termed highly organic soils or peats. Probably the best known classification system for peats is *von Post scale* which is based on categorization of botanical degree of decomposition. According to this scale, peat is classified as being completely undecomposed (H1) to completely decomposed (H10).

Uitdam field test (2011-2013) conducted to optimize dike reinforcement. Biological background of peat in the area is mainly sedge/reed. Von Post classification

> TYPICAL PEAT CHARACTERISTICS, LIKE LOW DENSITY AND LOW STIFFNESS MAKES NUMERICAL ANALYSIS DIFFICULT. THIS HOLDS ESPECIALLY FOR NON PRE-LOADED PEAT WHEN INITIAL CONDITIONS LEAD TO RELATIVELY LARGE OCR.

is H2/H3 meaning that peat is undecomposed (H2) or very slightly decomposed (H3). Plant remains are identifiable and no amorphous material is present.



6 field tests were performed near the location of the dam. Test no. 6 carried out by: 1. Pre-loading of 10 concrete slabs to q = 33 kN/m² (construction period 56 days); 2. Consolidation and creep for 160 days; 3. Starting application of failure load by adding 10 extra concrete slabs; 4. Placement of containers; 5. Application of failure load by filling the containers.

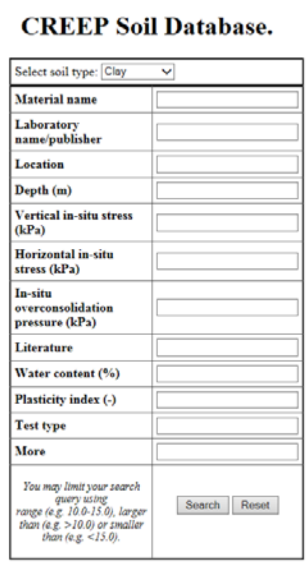
Horizontal and vertical deformations were simulated relatively good using Plaxis SSC model with parameters calibrated from laboratory tests such as K_0-CRS, CIUC and DSS whereas failure was not well captured.

CREEP DATABASE AND BENCHMARK CASES

Associate Prof. Jelke Dijkstra, Chalmers & Prof. Gustav Grimstad, NTNU

Within the CREEP project we decided to collect all available data on existing field tests with a special focus on sites with sufficient experimental data available for the use of model calibration (laboratory tests) and validation (instrumented field test). The project has also in the two first years conducted own laboratory tests, that can be used for model calibration

Database is to be found at:
http://www.ntnu.edu/creep



As opposed to failure tests not many tests sites are designed to study serviceability limit state, SLS, (long-term deformations). Creep tests require a significant amount of time and successful sites on clay are already in service for 20 years or longer. Typically these are national test sites or owned by other governmental bodies. Instrumentation of such test sites is of great importance. Usually pore pressure (u), vertical displacement (v), and horizontal displacement (h) are measured. The quality of recorded data is assessed as very good (++), good (+), fair (0), poor (-), and very poor (--). After comparison the sites are grouped within the following categories: Class 1 (high quality field test), Class 2 (sufficient field test quality), and Class 3 (insufficient field test quality). Selected test cases can be seen from the table. Selected cases in Class 1 are to be considered as benchmark cases. That will be used in this project for model validation (on clay).

Site	Soil	u	v	h	class
Antoniny	peat	0	+	0	3
Booneschans	peat	0	+	+	3
Boston Blue	clay	0	+	0	3
Bothkennar	clay	+	+	+	1
Gloucester	clay	0	+	0	3
Haarajoki	clay	0	+	0	2
Murro	clay	+	+	+	1
Nödinge, Stora Viken and Surte	clay	-	0	-	3
Onsøy	clay	+	+	+	1
Perniö	clay	+	++	+	2

UPCOMING EVENTS

CREEP training courses are offered by the consortium as an add-on to NTNU's PhD course Soil Modelling (BA8304) which is taught biannually. The theme of the first CREEP training course in 2012 was Advanced Constitutive Modelling of Creep in soft soils. The second course in 2014 will deal with Modelling of Creep in Various Geomaterials. The 3rd CREEP workshop will be held at NGI. For more information please visit us at:

http://www.ntnu.edu/creep