NGM 2016 Reykjavik
Proceedings of the 17th Nordic Geotechnical Meeting
Challenges in Nordic Geotechnic 25th – 28th of May

Swell pressure and yield stresses in Danish, highly overconsolidated, Palaeogene clays of extreme plasticity

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ABSTRACT

Oedometer tests with highly overconsolidated clays of extreme plasticity often detect two yield stresses at very different stress levels. In the tests, the clay specimens yield first time when exposed to a rather low stress, which is only slightly - but significantly - higher than both the in situ stress and the swell pressure. The second time, the specimens yield at a much higher stress level, which can only be identified, if the specimens are exposed to stress levels beyond the typical range for conventional oedometer testing equipment. It is the widespread opinion that the geological preloading causes the high yield stress, whereas a profound physical explanation to the low yield stress has not yet been found.

The paper starts from the oedometer apparatus, which is subject to shortcomings and sources of error, such as non-control of the radial stresses and friction stresses between specimen and load cell, as well as non-control of the full range of creep processes. The paper provides consistent models on how these shortcomings and errors affect the performance curve of the test. Based on this, a physical explanation not solely to the low yield stress has been derived, but also to phenomena as swell pressure and hysteresis with its yield points that can be observed in connection with unloading and reloading processes. As expected, the performance curve of the test suffers from this, and there is potential risk for misinterpreting the stiffness parameters of the clays, unless being able to sort out, what is governed by the soil properties and what shall be referred to the test procedures and the test apparatus itself.

Keywords: Oedometer, Yield, Swell, Friction, Creep, Palaeogene clays

1 INTRODUCTION

Oedometer tests with highly overconsolidated clays of extreme plasticity exhibit some striking features and divergences, when compared with oedometer tests with more widespread clays of lower plasticity.

First and foremost, the clays exhibit swell potential. This is reflected in an oedometer test, where the clay specimen is being soaked, before being exposed to an axial load which is even distinctly larger than the vertical effective in situ stress.

Further, two yield stresses are often being identified at very different stress levels. A yield stress is defined as a point, which separates elastic from plastic behavior, but this condition is not necessarily fulfilled in both cases.

The low yield occurs, when the specimen is exposed to a stress, which is slightly, but significantly, higher than both the vertical effective in situ stress and the swell pressure.

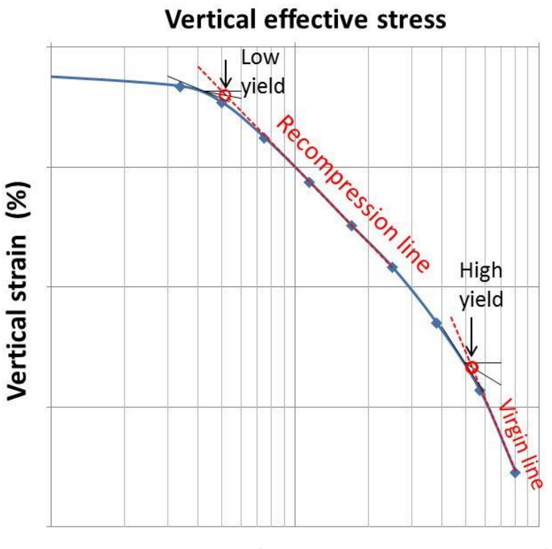

Figure 1 Example of a stress-strain curve for highly overconsolidated Palaeogene clay of extreme plasticity showing low yield and high yield.

The high yield occurs at a much higher stress, which can only be identified, if the specimens are being exposed to stresses beyond the typical range for conventional oedometer test equipment.

The low yield stress often can be detected from Casagrande's (Casagrande, A., 1936), Janbu's (Janbu, N., 1969) and Becker's (Becker, D.E., 1987) methods, but not from Akai's (Akai, K., 1960) method. The high yield stress is best detected from Akai's method, but often also the other methods are applicable.

There has not yet been found a physical explanation to the low yield stress, whereas it is widely held that the high yield stress shall be referred to the geological preloading.

Those two yield stresses separate the stress-strain curve into an initial part, representing the adaptation of the specimen to the load cell, a recompression curve, representing compression in overconsolidated state, and a virgin curve, representing normally consolidated state. A full understanding of those striking features is a prerequisite of interpreting and deriving swell pressure, stiffness parameters and yield stresses from the testing; i.e. whether the results refer to soil characteristics, or whether they are a consequence of shortcomings of conventional oedometer test equipment:

- The radial stresses in the specimen can neither be controlled nor measured in the conventional oedometer test apparatus.
- The stress-strain curves are subject to interference from frictional stresses between the specimen and the load cell.
- The creep processes affect the specimen in a way different from the in situ conditions.

These shortcomings of the oedometer test have an effect on all the phases of the test, viz. loading, unloading and reloading, as can be seen by examples in the following chapters. The changes of stress conditions throughout the whole process have been analyzed, from in situ conditions to sample recovery, to trimming of specimen and to the loadings, unloadings and reloadings during the testing. This gives rise to the understanding, what is de facto the outcome of an oedometer test.

To simplify and clarify the analyses it is a precondition that sample disturbance from the drilling work, from handling of samples and from trimming of specimens can be neglected.

2 DANISH PALAEOGENE CLAYS

Danish Palaeogene clays are high-colloidal clays of extremely high plasticity, and practically free of sand and larger particles. The index properties are summarized in Table 1.

The clays are deposited in Palaeogene oceans, and they are now heavily preconsolidated by the weight of the many glaciers and the weight of younger layers now eroded away during the Quaternary period.

Table 1 Index properties of Palaeogene Clays.

Property	**Range**
Natural water content	25-70 %
Liquid Limit	80-350%
Plasticity Index	50-290 %
Unit weight	17-19 kN/m^3
$CaCO_3$	0-60 %

The samples extracted are frequently fissured and show slickensides with shining surfaces in the fractures. Such features shall be referred to slips and failures caused by ice dynamics and/or release of ice pressure.

Usually, the clays are saturated due to the wet Danish climate, the relatively high lying ground water and the capillary rise of the clay. In the following the clay samples are considered being completely saturated, when installed into the oedometer apparatus.

3 THE RATIO BETWEEN HORIZONTAL AND VERTICAL STRESSES IN SITU

Throughout the geological periods the highly overconsolidated Palaeogene clays have undergone parts of the stress history illustrated in Figure 2.

The stress path OA represents the virgin loading (compression) as it occurs during the sedimentation – i.e. compression in the normally consolidated state. The vertical

stresses are larger than the horizontal stresses, so that the coefficient of earth pressure at rest $K_0 = K_{0,NC} < 1.0$ during this virgin loading.
During unloading (ABC) the vertical stresses reduce faster than the horizontal stresses, implying that the horizontal stresses become larger than the vertical stress at a certain unloading stress, so that $K_0 = K_{0,OC} > 1.0$. If unloading continues further, the stress path may reach the failure stress path, and then follow that path for the continued unloading.

During reloading (CDA), the original ratio between horizontal and vertical stresses will gradually restore. The coefficient of earth pressure at rest reduces again to a value below 1.0.

Thus, for highly overconsolidated clays K_0 decreases when the vertical load increases, whereas K_0 increases when the vertical load decreases (Mayne, P. W., 1982).

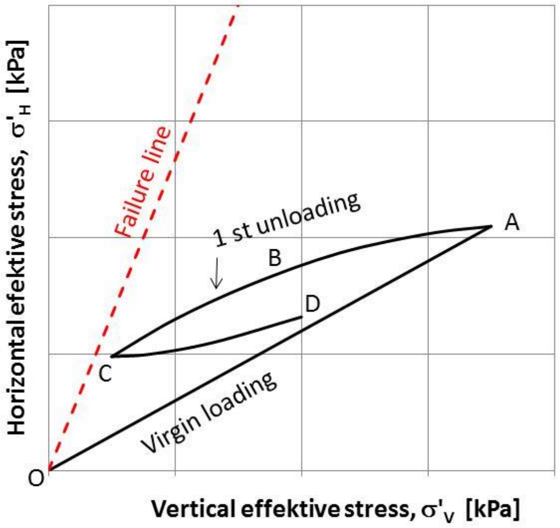

Figure 2 The ratio between the horizontal and the vertical stresses under virgin loading, unloading and reloading

For the Palaeogene clays, the geological preloading typically ranges some 4,000-6,000 kPa. For the near surface deposits the pertaining overconsolidation ratios, *OCR*, are excessive, so there is no doubt that the failure line in Figure 2 has been reached during the geological unloading, and further that this is the case for the layers to tens of meters below surface. Consequently, for the uppermost highly overconsolidated Palaeogene clays the mutual connection between *OCR* and K_0 has been broken.

4 STRESS CONDITIONS AND SWELL PRESSURE

When carrying out oedometer tests with Danish, highly overconsolidated Palaeogene clays of extreme plasticity it is observed that the specimens often exhibit swell during the minor load steps. This is due to a procedure, where the specimen is being soaked at an axial load in the oedometer test, which is too small to resist the swell pressure in the specimen.

The presence of a swell pressure is a term of an imbalance of the total water potential, defined as the potential energy per unit volume. Such imbalance occurs, when the total water potential changes in situ or if the in situ conditions are not correctly regenerated in the oedometer cell. For saturated soil, the total water potential is the sum of the pressure potential and the osmotic potential.

In this paper it is a precondition that the salinity of the pore water in the specimen equals the salinity of the water used for soaking the specimen in the apparatus, so that the osmotic potential can be neglected.

4.1 The sample under in situ conditions

Under in situ conditions the effective vertical stress is well-known. For the uppermost tens of meters it represents the minor principal stress, as often $K_0 > 1.0$, and thus the horizontal stresses represent the major principal stresses. However, these major stresses are often unknown.

4.2 The sample after recovery

When extracting and trimming a high plasticity Palaeogene clay sample to a specimen for testing, the partial vacuum pore pressure keeps the soil structure together as a monolithic specimen. Thus, the negligible compressibility of the pore water compared to the one of the soil skeleton ensures that both the void ratio (the volume) of the specimen and the effective mean stress of the specimen remain unchanged, compared to the in situ conditions.

The total water potential of the specimen after trimming is equal to the partial vacuum pore pressure that arises during extraction of the sample.

In this specific phase the ratio between the horizontal and the vertical stresses is equal to unit, $K = 1.0$, despite the size of $K_{0,insitu}$. Even though the volume and the mean stress become unchanged compared to the in situ conditions, the change of K implies that the shape of the specimen will change. However, most likely this is a matter of secondary importance as to affecting the result.

4.3 The specimen in the oedometer cell

The void ratio and the mean stress remain unchanged, when installing the specimen in the oedometer apparatus. This is valid until the specimen is being loaded or being soaked (without loading), after which the void ratio and the mean stresses change.

The swell pressure is the same in all directions. This has been demonstrated experimentally in a constant volume test, where the swell pressure is measured in specimens, extracted in pairs from one and the same level, in both horizontal and vertical direction. As seen from Figure 3, the measured swell pressure is broadly identical in both directions.

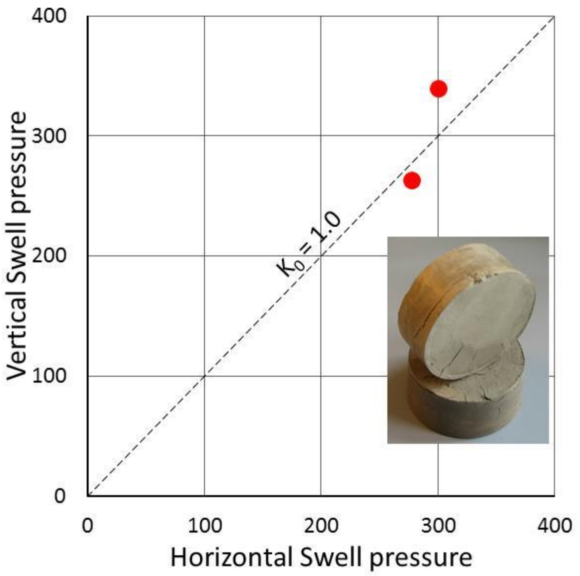

Figure 3 Measured swell pressure in specimens extracted from horizontal and vertical direction, respectively (Okkels, N. 2012).

In constant volume tests the ratio between the horizontal and vertical stresses is at unit, $K_0 = 1.0$. This is also the case, when the specimen is being soaked, under the precondition that the void ratio (the volume) is kept unchanged compared to the in situ conditions.

By keeping the void ratio (the volume) constant and unchanged until and during measuring the swell pressure, this implies that the mean stress in situ is identical with the swell pressure. This further implies that $K_{0,in\ situ}$ can be assessed from the swell pressure, σ_{swell} and the vertical effective in situ stress,$\sigma'_{v,in\ situ}$:

$$K_{0,insitu} = \frac{1}{2}\left(3\,\frac{\sigma_{swell}}{\sigma'_{v,insitu}} - 1\right) \qquad (1)$$

5 MEASURING SWELL PRESSURE

It is of the utmost importance to measure the swell pressure at the same void ratio (volume) as is the case in situ; i.e. the measuring shall be a true constant volume test. Otherwise, the swell pressure – or rather the mean stress of the specimen – will change.

In a constant volume test, the vertical stress inside the specimen is known, as no frictional forces between specimen and load cell are present. At the same time, the horizontal stresses are known as well ($K_0 = 1.0$). The swell pressure in such a test can only be determined with an approximation, by continuously adjusting the vertical stress so that the vertical deformation maintains at mini-mum; cf. Figure 4a.

5.1 Dubious procedures for determining swell pressure

Some recognized procedures to determine the swell pressure are based on test phases with distinct deformations and thereby with effects from a changed K_0 as well as effects from side friction. Consequently, the mean stress will change. The virtual stress conditions are therefore unknown, and in reality it is not possible to derive a swell pressure that reliably represents the in situ swell pressure.

In the *Free Swell-Consolidation test method*, ref. ASTM D4546 2003 Method C, the specimen is allowed to freely swell for an exposed small load (point 0 to 1 in Figure 4b). The swell pressure is then determined as the further exposed load that brings the specimen back to its initial void ratio (point 2 in Figure 4b).

In the *Loading-Wetting test method*, ref. ASTM D4546 2008 Method A, a number of specimens (1 – 4 in Figure 4c) are loaded under dry conditions to predetermined stress levels, after which they are being soaked and allowed to swell or consolidate for the respective stresses. The swell pressure is then determined as the stress, where these tests indicate that no strain will occur; cf. Figure 4c.

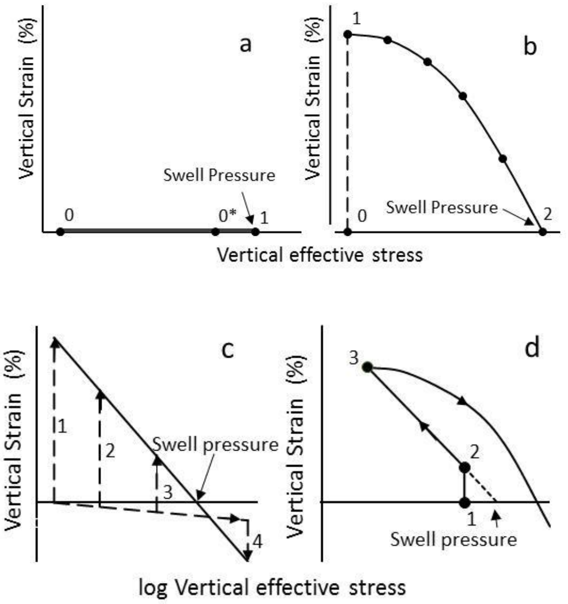

Figure 4 Determination of swell pressure. (a) Constant volume method, (b) Free Swell-Consolidation method, (c) Loading-Wetting method and (d) AASHTO Code method.

In the *AASHTO Code test method (AASHTO Standard T258-81)* the specimen is exposed to a vertical load equal to the in situ stress under dry conditions (point 1 in Figure 4d). After adding water to the specimen, it is allowed to swell for this constant in situ stress (point 2). Then the specimen is being stepwise unloaded (point 3). The swell pressure is determined as the resection of the unloading line to the 0-line.

5.2 *Adjusted procedures to Constant volume tests*

In practice, it is an inevitable consequence to allow for a certain deformation during the initiation of a swell test. This is due to the fact that the adaptation of the specimen to the load cell and the filters together with the potential sample disturbance gives rise to volume changes, i.e. an initial compression to restore the in situ void ratio.

In the *CEN ISO/TS 17892-5:2004* test method the following pragmatic description has been chosen. The specimen is quickly loaded under dry conditions to an estimated swell pressure (point 0 to 0* in Figure 4a), where the measuring is set to zero. Then the specimen is soaked, and the vertical stress is adjusted to hinder development of strains in excess of ±0,01mm. The swell pressure is equal to the applied stress that stabilizes accordingly. However, it cannot be excluded that the result is influenced by friction forces and change of K_0, due to deformations during initiation of the test.

6 CREEP AND CREEP PRESSURE

According to Degago S.A. (2013) the existence of creep during primary consolidation is evident. Consequently, the stress-strain curve (<u>E</u>nd <u>O</u>f <u>P</u>rimary consolidation, EOP) depends on the rate of loading; the higher rate, the farther the stress-strain curve will move to the right; cf. figure 5.

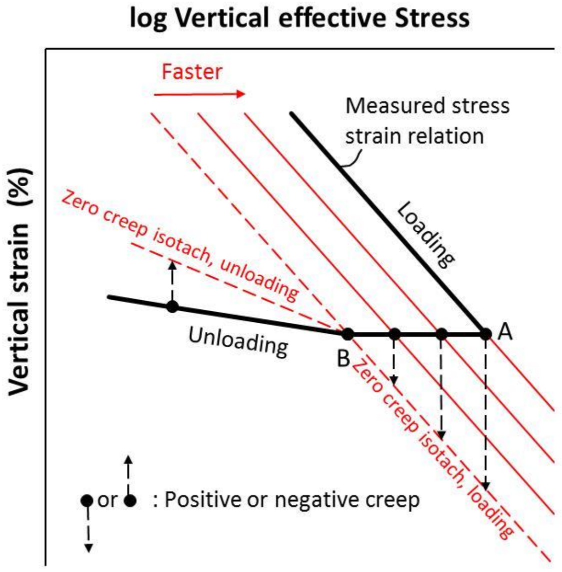

Figure 5 Illustration of stress-strain relations and creep. Unloading from A to B is performed so creep exactly is avoided (after Kawabes S., 2013).

Also the shape of the stress-strain curve is affected, when loading shifts to unloading. Immediately after such a shift the creep acts in opposite direction to the change of load (point A in Figure 5), (Kawabes S., 2013).

Not until the change of load reaches a certain size, the unloading path will intersect the zero creep isotach (point B in Figure 5), and then the creep will act in the same direction as the unloading. A creep isotach is defined as a line of equal creep strain, and the pertaining stress change necessary to reach the zero creep isotach is interpreted as a negative creep pressure.

Conversely, when unloading is shifted to loading the stresses shall be increased, if upwards creep shall be hindered. The pertaining excess stress required for totally hindering upwards creep, and thereby ensure constant volume during this stage of test, is interpreted as a positive creep pressure.

In conclusion, creep pressure at the individual load steps changes by time as creep strains develop. Creep affects the initial part of the unloading as well as the reloading paths. Therefore, the deformation parameters shall be derived with due consideration to the creep, alternatively, creep shall be incorporated in the constitutive model.

7 SIDE FRICTION

During oedometer testing shear forces develop along the cylindrical surface of the specimen, due to the relative movements of the specimen against the inflexible oedometer ring.

Therefore, during loading the specimen in reality is loaded by a vertical stress less than the applied stress, whereas during unloading the vertical stress is larger than the applied vertical stress; cf. Taylor, D.W. (1942) and Olson, R.E. (1986).

Side friction between specimen and steel surface is not present during the initial part of the test. It will not generate, till the in situ volume of the specimen changes after change of loading. The induced vertical strains in the specimen will generate shear strains, and in doing so also shear stresses will generate in the boundary surface between the specimen and the steel ring.

The side friction will generate rapidly during loading beyond the swell pressure, cf. Figure 7. When loading is shifted to unloading, the side friction will gradually decrease to zero and eventually be regenerated in the opposite direction. This process will repeat, when the unloading is shifted to loading, etc.

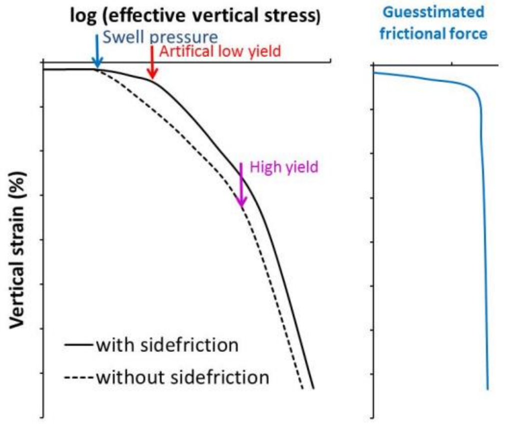

Figure 7 Illustration of the effects of side friction. The test result without friction is constructed by subtracting the guesstimated frictional force from the applied load. The generation of side friction changes the position of the yield points.

In the oedometer test, the stress-strain curve is conventionally drawn with the applied load, i.e. without any correction for side friction. This means that the generation of side friction will create an artificial yield point on the stress-strain curve as shown in Figure 7. This yield point indicates the stress, where the main part of side friction is generated during the loading. The same occurs, when the side friction turns around and regenerates during unloading and reloading. In all cases, the generation of side friction makes the specimen stiffer than it really is.

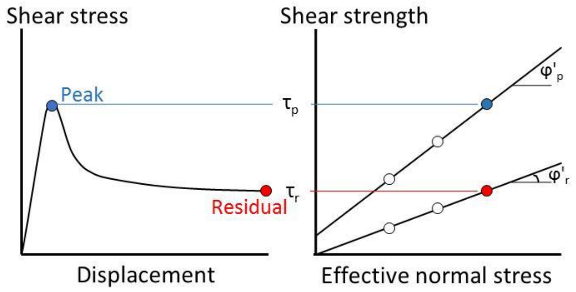

Figure 8 Shear strength tests with Palaeogene clays.

Unfortunately, it is normally not possible to compute the side friction. Partly, it depends on the radial stresses from the oedometer steel ring, which cannot be measured in conventional oedometers. Partly, it depends on the lack of knowledge to the shear stress-strain relationship in the lubricated interface between the specimen and the steel ring at the actual stress levels, cf. Figure 8.

However, we do know the displacements in the interface. In case of a fixed ring, the displacement decreases approximately linearly from a maximum value at the top of the ring, equal to the measured displacement, to zero at the bottom of the ring. In case of a floating ring, the displacement decreases approximately linearly from half of the maximum value at both ends of the ring to zero at the middle of the ring; cf. Figure 9.

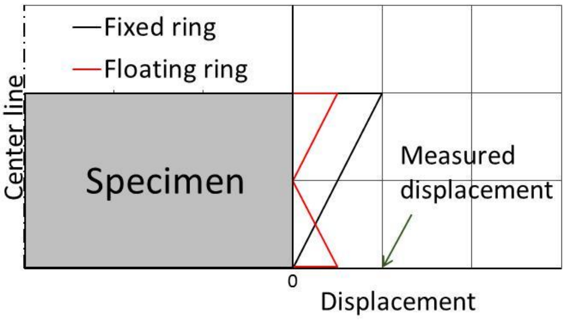

Figure 9. Simplified variation of soil-ring displacements in a fixed and floating ring oedometer

Following Figure 8 the shear stress-displacement relationship depends on the effective normal stress on the failure envelope.

The side friction can be separated into a static contribution, where no failure occurs in the interface between specimen and steel ring (pre peak friction), so that the specimen sticks to the steel ring, and a kinematic contribution, where failure appears (post peak friction) in the interface. Due to the softening behavior of the Palaeogene clay the static contribution is larger than the kinematic contribution.

Both types of friction will normally contribute to the side friction, as the displacements vary along the surface of the ring. Further, the two contributions depend on the size of displacements, where the static contribution is directly proportional to the size, whereas the kinematic contribution converges to a constant residual value.

For the Palaeogene clay with its distinct softening behavior, it cannot be concluded in beforehand, whether the side friction is the lesser in a floating ring or in a fixed ring. Most probably, this depends on the actual distribution between static and kinematic friction, and likely, the distribution will change with the increase of loading.

8 PERFORMANCE CURVE AT PRIMARY LOADING

A typical stress-strain curve for high plasticity Palaeogene clay exposed to loading is shown in Figure 10a and 10b. The strain refers to end of primary consolidation.

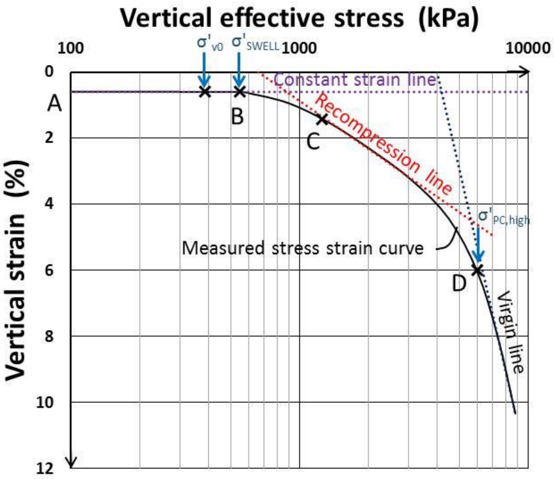

Figure 10a Logarithmic stress-strain curve, loading.

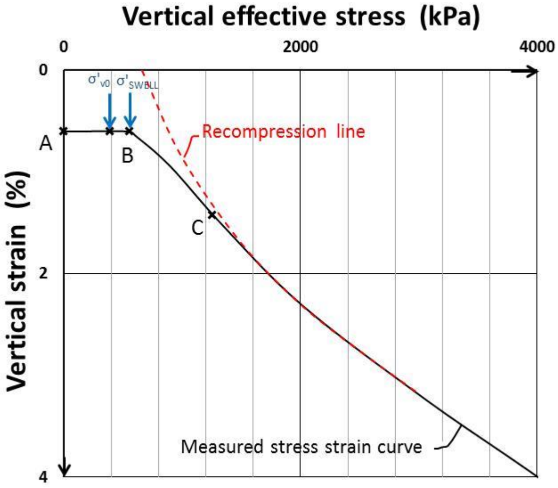

Figure 10b Arithmetic stress-strain curve, loading.

During the initial part of the primary loading, the swell pressure has been measured at constant volume (point A to B). Constant volume ensures that no frictional forces act on the sides of the specimen (the strain is zero), that the relation between the horizontal and vertical stresses is known ($K = 1.0$), and further that the swell pressure can be measured being equal to the vertical stress being exposed to the specimen to maintain constant volume (no strain). Thus, knowing the effective vertical stress in situ, the earth pressure at rest in situ, $K_{0,insitu}$, can be computed from equation (1).

The curvature A-B is a sort of regeneration phase, where the effective mean stress in situ is regenerated in the oedometer specimen at the in situ void ratio.

The change at point B from the regeneration phase to the virtual compression phase appears as a distinct break. This point B might be interpreted as a yield point; however, as the virtual compression starts at point B, such an interpretation is meaningless.

The curvature B to C is a transition part from the initial constant volume part to the recompression part of the curve.

In this transition phase, where the loading is increased, the vertical strains will develop, and at the same time, side friction generates in the reverse direction of the loading. Thus, the vertical stress will be less than the applied stress, and the specimen, therefore, looks stiffer than it de facto is for small stress increases in excess of swell pressure.

Without friction the recompression curve in Figure 10a and 10b would start from the swell pressure (point B), however, the effect from side friction will move the curve to the right by inserting a somewhat stiffer transition curve, point B to C; cf. Figure 7.

The curvature B – C causes that a yield point appears in this inserted transition curve, cf. Figure 1, which can be detected by the recognized methods as stated in chapter 1. From C to D the loading increases, and K decreases further. At point D the side friction is still acting upwards. The vertical stress in the specimen, therefore, is still larger than the applied stress.

At point D the stress-strain curve goes from a bending curvature to a straight curve, as it passes a yield point. At the same time, the creep index increases to a maximum value, typically around 1 %/lcs for the Palaeogene clays. This yield point represents the geological preconsolidation; cf. the high yield stress in Figure 1.

After point D the stress-strain curve enters the virgin curve, and K is reduced to its minimum value, $K_{0,NC}$.

It is the overall evaluation that the shortcomings of the oedometer test apparatus influence especially the initial part of the stress-strain curve (point A to C in figure 10).

The influence upon the performance curve, obviously, will make the derivation of reliable deformation characteristic subject to uncertainties.

9 HYSTERESIS IN RELATION TO UNLOADING AND RELOADING

Figure 11 shows a typical unloading-reloading path for Palaeogene clay of extreme plasticity, compared with the same path cleaned for stresses related to side friction. The strains refer to end of primary consolidation.

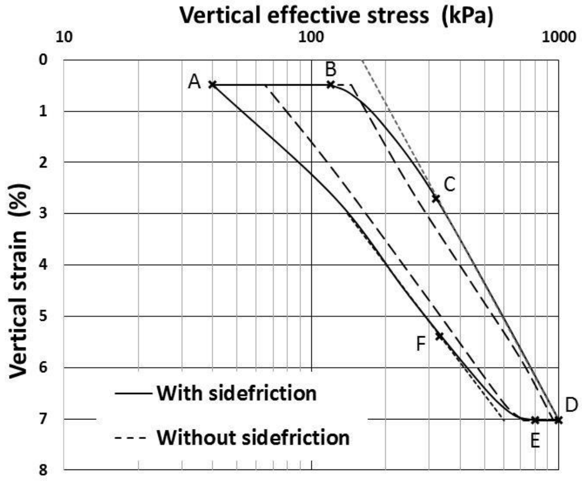

Figure 11 Hysteresis in relation to unloading and reloading with and without sidefriction.

The unloading starts from point D, where the fully soaked specimen after stepwise loading has reached end of primary consolidation. At this stage the stresses from side friction acting on the specimen are pointing upwards, so that the true vertical effective stress in the specimen is less than the applied stress.

From point D to E the test from pedagogical reasons is being carried out, so that downwards directed creep is just hindered by reducing the applied load appropriately. During this phase the vertical strain is unchanged (constant volume), and so the side friction must be unchanged as well.

The true vertical stress in the specimen, thus, is still less than the applied stress in point E.

From point E to F the loading is being reduced. Concurrently with the change of loading the side friction will eventually and gradually change from directed upwards at point E to directed downwards at point F. The true vertical stress in the specimen now has become larger than the applied vertical stress.

The curvilinear part between point E and F might be interpreted as a yield point with a yield stress that can be determined from a Casagrande construction. However, as this yield point is caused by creep and friction stresses, it has only a marginal effect upon the conventional deformation characteristics of the clay.

The loading is being further reduced from point F to A, and concurrently with this the ratio between horizontal and vertical stresses, *K*, increases. After end of primary consolidation at point A the side friction on the specimen is still directed downwards, and its numerical value is somewhat larger than at point F. This is due to the fact that the vertical effective stresses reduce faster than the *K* increases. The true vertical stress in the specimen is still larger than the applied load. From point B to C the loading is being increased, and the side friction gradually decreases and changes direction so that it is directed upwards at point C. The true vertical stress in the specimen now is less than the applied load.

The curvilinear part between point B and C is similar to E-F and the part from C-D are similar to F-A.

10 CONCLUSIONS

The Danish Palaeogene clays are highly overconsolidated clays of extreme plasticity. For these clays in general, this implies that the horizontal in situ stresses are in excess of the vertical ones, and thereby that the earth pressure at rest $K_0 > 1.0$. However, for the near-surface layers the conventional connection between the overconsolidation ratio, *OCR* and K_0 has been broken due to passive failure, emerging during the unloading from the very high geological preconsolidation stresses.

This paper has analysed shortcomings and sources of error of conventional oedometer tests, caused by non-control of the radial stresses and friction stresses generated in the specimen from the contact to the oedometer load cell, as well as non-control of the full range of creep.

The analysis starts from the premise that a laboratory specimen of high plasticity Palaeogene clay preserves the effective in situ mean stresses and the in situ void ratio during the whole process from sampling to trimming for testing. This premise has been made, so that the analysis can focus directly upon the shortcomings and sources of error of the oedometer test equipment, without being blurred by potential effects from sample disturbance.

The analysis draws attention to the following items, the ones of which might affect the results of oedometer tests:

(i) Swell pressure shall be measured at the same void ratio (volume) as is the case in situ; i.e. the measuring shall be a true constant volume test. Otherwise, the swell pressure, or rather the mean stress of the specimen, will change and friction stresses evolve in the specimen.

(ii) Creep affects the shape of the stress-strain curve, especially when loading shifts to unloading and vice versa. Immediately after such a shift, the creep acts contrary to the change in load. This affects the initial parts of the unloading and reloading paths to an extent that these parts of the performance curve are not representative of the true stress-strain relation.

(iii) Shear forces develop along the cylindrical surface of the specimen, as vertical strains generate friction against the oedometer ring. Therefore during loading, the specimen in reality is loaded by a vertical stress less than the applied stress, whereas during unloading the vertical stress is larger than the applied vertical stress. This again affects the initial part of the unloading and reloading paths to an extent that these parts of the performance curve are not representative of the true stress-strain relation.

(iv) The mobilization of shear forces along the cylindrical surface of the specimen generates an artificial low yield point on the stress-strain curve, when the stress-strain curve conventionally is drawn with the applied load and without correction for side friction.

(v) Many of the current methods for deriving yield stresses are solely based on the curvature of the stress-strain curve, and without due consideration, whether the curvature solely is defined from characteristics of the soil, or whether the shortcomings of the oedometer apparatus affect on the curvature to a conclusive degree. Thus, when the curvature is affected from side friction and creep an artificial yield point will appear on the performance curve. Such an artificial yield point is a fine example of a spurious relationship, as no causality with a genuine yield point is detected.

(vi) Hysteresis during unloading and reloading are much more profound for high plasticity Palaeogene clays compared with more widespread clays of lower plasticity. This is due to the fact that the loops of high plasticity clays are affected from side friction and creep pressure.

It is the overall conclusion that the stiffness parameters derived from an oedometer test shall take due consideration to the shortcomings and sources of error of the oedometer test apparatus, as the performance curves are affected from side friction and creep pressure.

In this respect, the stiffness parameters should be derived from an extrapolation of the lesser affected parts of the unloading and reloading paths, often being the parts that lies after the artificial yield points provoked by side friction.

The extrapolation shall extend those lesser affected parts of the performance curve to include also the specific stresses relevant for the project, and the stiffness parameters hereafter shall be derived from the extrapolated curves.

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