TESTS AND FORMULAS CONCERNING SECONDARY CONSOLIDATION

EXPERIENCES ET FORMULAS CONCERNANT LA CONSOLIDATION SECONDAIRE

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SYNOPSIS. An extensive series of Oedometer tests with a remoulded glacial lake clay was carried out in order to study the secondary consolidation. The effects of sample height, temperature, stress history, final load, load increment ratio and duration of previous steps were investigated. As a result, a comparatively simple empirical formula is proposed, which seems to describe all observed features of the secondary consolidation quite well. Some tests were also made with a normally consolidated intact clay, for which the same type of formula was found to apply. On the basis of this formula, a calculation method for secondary settlements of structures is proposed, and for a bridge in Denmark the secondary settlement is calculated and compared with actual measurements.

INTRODUCTION

Secondary consolidation is the name commonly used for compressions or settlements, which continue to develop after the practical disappearence of all excess pore pressures.

That secondary settlements may be as important as the primary ones, and that they can go on for many years, has f.inst. been proved in the case of the Aggersund Bridge in Denmark (Bjerrum, Jønson and Ostenfeld 1957). In a semi-logarithmic plot the time curve has been a perfectly straight line for at least 12 years.

Also in Oedometer tests, secondary consolidation has been proved to go on for at least 4 years (Cox 1936). Here, the time curve was slightly downwards concave.

Since the physical mechanisms and causes of secondary consolidation are not yet known, it is not apriori certain that secondary settlements of structures can be calculated on the basis of laboratory tests. Of course, the best way to investigate this problem is to compare observed secondary settlements with rational calculations.

Such calculations cannot be made in any reliable way, however, until we have a mathematical formula for the process of secondary consolidation, describing its dependence on the different loading steps and their duration, as well as on other pertinent parameters (void ratio, temperature etc.). Then we can, by means of suitable laboratory tests, determine the constants in this equation, and afterwards apply it to the conditions in situ.

The main purpose of the present paper is to propose such a formula. It has been developed so as to give reasonable agreement with at least one extensive series of consolidation tests, in which the effects of final stress, stress increment ratio, number of loading steps, duration of previous step etc. were investigated separately.

The main part of the described tests were carried out by Ses Inan at the DGI from 1966-68. The empirical formulas were developed by J. Brinch Hansen, whereas the detailed comparison between formulas and test results were made jointly.

OEDOMETER TESTS

This paper deals exclusively with one-dimensional compression of clay, as investigated in the Oedometer test. All tests were made in the new „inelastic" Oedometers of the DGI, in which both lateral yield and ring friction are minimized.

The tests were primarily made with a remoulded clay, both in order to get sufficiently reproducible results, and also because samples for comparative tests could be made practically identical.

The investigation was only concerned with primary loading (each loading higher than the previous one), not unloading and reloading.

It has been found practical to plot the time curves in a composite $\sqrt{t}$ - log t diagram (Brinch Hansen 1961). Fig. 1 shows such a diagram, in which the length of the $\sqrt{t}$ - part must be about 0.87 times (= 2 log e) the length of a decade in the log t - part in order to get a smooth time curve across the boundary line.

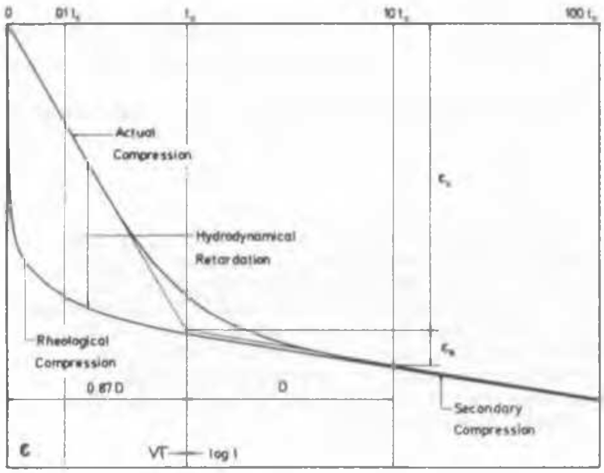

Fig. 1 : Oedometer time curves.

In such a diagram a normal time curve (for $\Delta p/p > 0.3$) will consist of two straight lines, connected by a transition curve. The time scale should be adjusted so that the two straight lines will intersect approximately on the boundary line. The intersecting point defines the „consolidation time" t_c ($\sim T = \pi/4$) and the „primary compression" ε_c, whereas the „secondary compression" ε_s is the increase per time decade after dissipation of pore water pressures.

In the opinion of the authors, the secondary compression represents the real, rheological behaviour of the clay under the given conditions (stress, temperature, vibrations etc.). If the voids were empty, we would probably get a time curve as the one marked „rheological compression", but since it takes time to expel pore water from the voids, we get actually a „hydrodynamical retardation" of the compressions(see Fig. 1).

SOIL

Soil samples have been taken from a brick factory pit near Nivaa, which is about 30 km north of Copenhagen. The samples were taken 4-5 m below ground surface, where the average field vane strength was about 8 t/m^2.

The soil is a late glacial lake clay, containing 46 % clay fraction, 54 % silt and 0.1 % sand. The natural water content was 23 %, the liquid limit 46 % and the plastic limit 19 % (all average values).

The remoulded samples were prepared by first crumbling the clay and then mixing it with water. The mixture was put into a rubber tube and stored there for about 10 days. Each day it was kneaded in the tube for some time.

PRELIMINARY TESTS

Parallel tests were made with identical samples and loading procedures in order to investigate the reproducibility of the tests. This proved to be quite good, although a small amount of accidental scattering occurred.

Further parallel tests were made with different heights of the samples, from 13 to 46 mm, whereas the diameter was always 60 mm. The purpose was to investigate a possible effect of ring friction, and whether the secondary compression should be a function of sample height. The tests showed only small and non-systematic variations with the sample height, however. The consolidation times were, of course, longer for the higher samples.

Finally, parallel tests were made in two Oedometers at a constant temperature of 23°C. and in two others at 36°C. The observed variations, both of total and of secondary compression, were small and non-systematic. In fact, the greatest deviation was found between two tests at the same temperature. However, the consolidation time was about 30 % longer at the lower temperature, as should be expected.

NUMBER AND SIZE OF LOADING STEPS

Two identical samples were subjected to two different loading procedures (Fig. 2). One sample was loaded in one step from 100 to 130 t/m^2, whereas the other sample was loaded in 3 steps (100-110-120-130 t/m^2).

The result was that both total compression and secondary compression (indicated by the final inclination of the time curve) were nearly the same, independent of the number and size of the loading steps.

Conclusion: The void ratio e_n depends mainly on the final load p_n.

There is, however, a second order effect indicating a slight decrease of the total compression with the number of loading steps - or with the total time spent in the Oedometer. This effect may be due to ring friction.

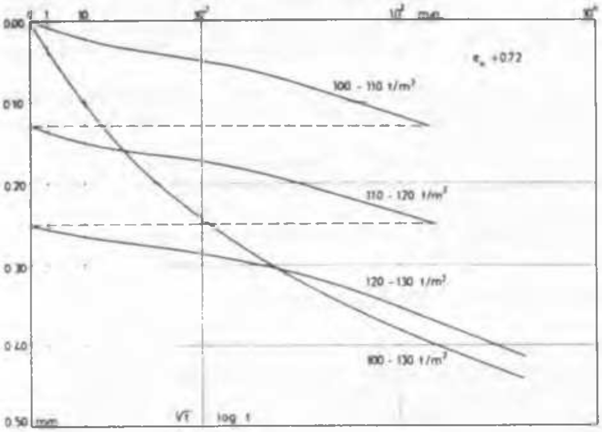

Fig. 2 : Different number and size of loading steps.

VOID RATIO - LOAD FUNCTION

In order to study the relation between load and void ratio we must consider loading steps of equal duration t_o (here chosen equal to 24 hours = 1440 min.). At the end of an arbitrary step n we measure a void ratio e_n, corresponding to the load p_n.

For a typical test, fig. 3 shows the usual semi-logarithmic plot of e against p. The curve is seen to be quite straight between 1.5 and 40 t/m², but it is curved at both ends.

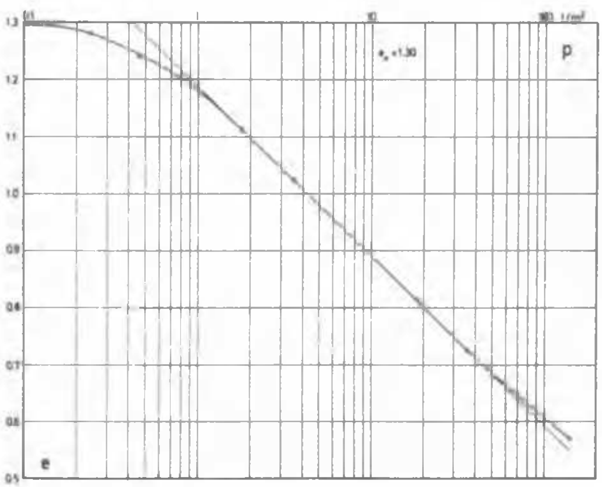

Fig. 3 : e-p-curve in semi-logarithmic plot.

However, as already pointed out by Terzaghi, the curvature for low loads can be eliminated by plotting e against p + p_o, where p_o is a constant load. And the curvature for high loads can apparently be eliminated by using a double-logarithmic diagram.

Such a plot is shown in fig. 4, the upper curve representing the same test as in fig. 3. With p_o = 1.1 t/m² a straight line is seen to approximate the test results for the whole stress interval quite well. Accordingly, the void ratio - load relationship can be expressed as :

$$e_n = e_o \left[1 + \frac{p_n}{p_o} \right]^{-a} \qquad (1)$$

The power a is found as the inclination of the straight line. Since, in fig. 4, a vertical decade is equal to 4 times a horizontal decade, the inclination should be divided by 4, giving here a = 0.167.

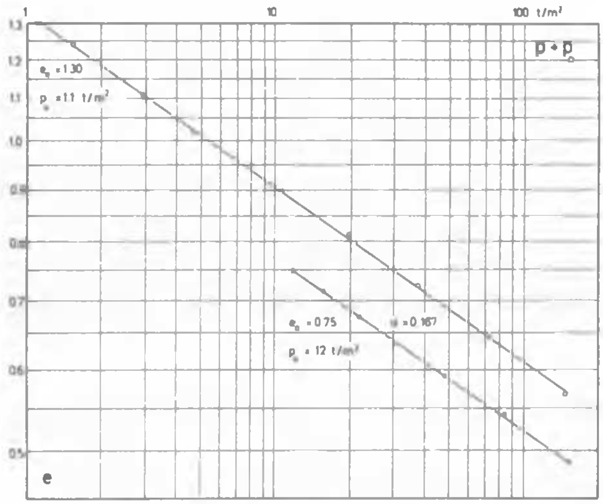

Fig. 4 : e-($p+p_o$)-curves in double-logarithmic plot.

In fig. 4, the lower curve represents the results of another test, this time with a much lower initial void ratio e_o. With p_o = 12 t/m² a straight line is obtained, and with the same inclination, i.e. the same value of a.

If the best possible straight line is determined for each test separately, it is usually found that the power a increases slightly with e_o. However, it is a quite good approximation to assume a constant a and determine p_o accordingly, as in fig. 4.

p_o is evidently a function of e_o, and the values found in 9 different tests are plotted in fig. 5. The results can be approximated by a straight line, corresponding to the formula :

$$p_o = 4\ e_o^{-4}\ \text{t/m}^2 \qquad (2)$$

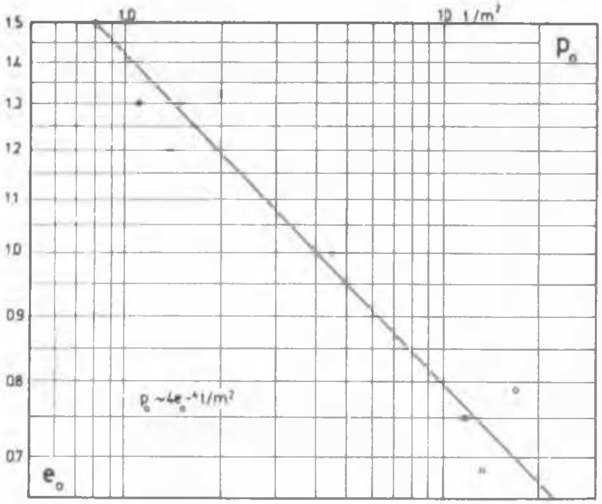

Fig. 5 : Relation between p_o and e_o.

DURATION OF PREVIOUS STEP

Two identical samples were subjected to the same loads, but with different durations in a certain step (Fig. 6). Both samples were loaded from 50 to 100 t/m^2, but in one case for 1500 min. and in the other for 6000 min. After this, they were both loaded to 110 t/m^2.

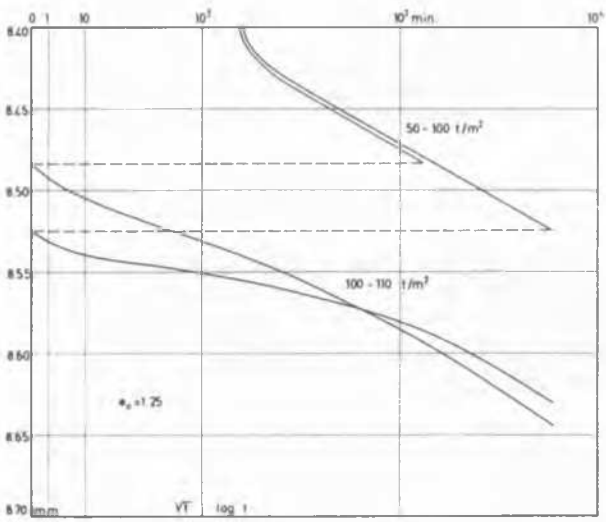

Fig. 6 : Different durations of previous step.

The result was that both the total compression and th secondary compression(indicated by the final inclination of the time curve) were nearly the same, independent of the duration of the previous step. In other words: what was gained in the previous step was lost in the following, and vice versa.

Conclusion: The void ratio e_n depends mainly on the duration Δt_n of the load p_n.

There is, however, a second order effect indicating a slight decrease of the total compression with the total time spent in the Oedometer. This effect may be due to ring friction.

LARGE LOAD INCREMENT RATIOS

For load increment ratios $\Delta p/p > 0.3$ it is usually found that the secondary part of the time curve (for $\Delta t > 10\ t_c$) is very nearly a straight line in a semi-logarithmic plot. Since e varies very little during secondary consolidation, a straight line will also be obtained in a double-logarithmic plot.

Fig. 7 shows an example with $\Delta p/p = 1.0$. In order to see the deviations from the straight line, the lower part of the diagram has been magnified 10 times in relation to the upper part. The duration of the considered loading step was 4 weeks.

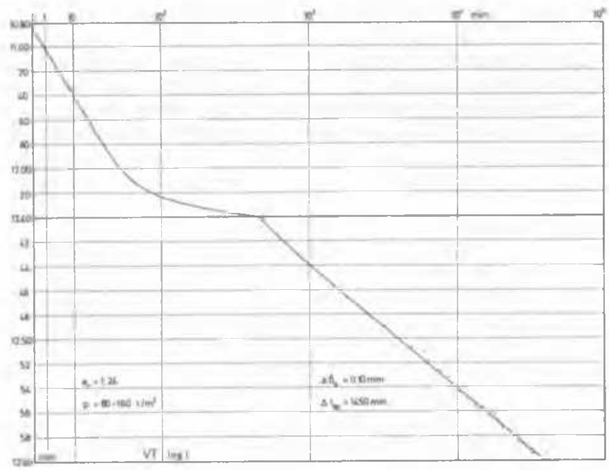

Fig. 7 : Time curve for large load increment ratio.

For the considered large load increment ratios we propose the relation :

$$e_n = e_o \left[1 + \frac{p_n}{p_o} \left[\frac{\Delta t_n}{t_o} \right]^c \right]^{-a} \qquad (3)$$

where Δt_n is the duration of the step with load p_n. For t_o is chosen the constant value of 24 hours = 1440 min.

Since we usually find $c < 0.05$ and $a < 0.3$, equation (3) will give a very nearly straight secondary time curve in both semi- and double-logarithmic plots.

As compared with the usually employed relationships involving log p and log Δt, equation (3) has the theoretical advantage of giving a finite compression (to $e = 0$) for both $p = \infty$ and $\Delta t = \infty$. Moreover, it gives $e = e_o$ for both $p = 0$ and $\Delta t = 0$ but is, of course, not intended to be used for such small values of Δt.

SMALL LOAD INCREMENT RATIOS

For load increment ratios $\Delta p/p < 0.2$ a different shape of the time curve is usually found, involving an inflexion point if plotted in the $\sqrt{t}$ - log t diagram.

Fig. 8 shows a typical example with $\Delta p/p = 0.07$. The duration of the considered loading step was 9 weeks. It will be seen that also here the time curve eventually becomes straight, but only after a much longer time ($\Delta t > 100\ t_c$).

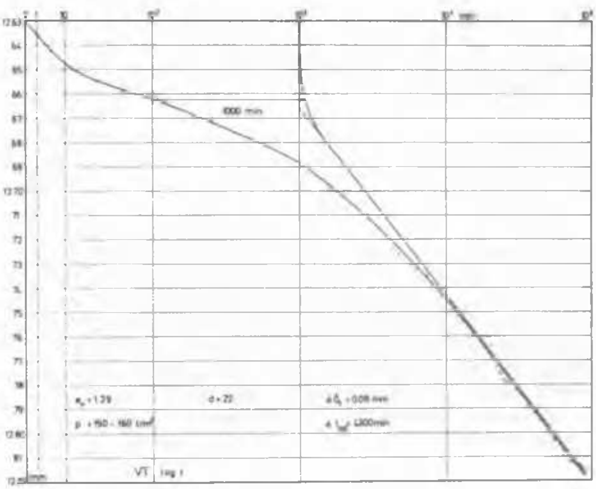

Fig. 8 : Time curve for small load increment ratio.

However, by adding a certain constant time t_n^o to the actual times Δt_n, it is possible to transform the time curve to a straight line for the usual duration of the secondary compression ($\Delta t > 10\ t_c$). In fig. 8 the best value of t_n^o is found by trial to be 1000 min.

This means that, for a small load increment ratio, we can write :

$$e_n = e_o \left[1 + \frac{p_n}{p_o} \left[\frac{\Delta t_n + t_n^o}{t_o} \right]^c \right]^{-a} \qquad (4)$$

Of course, we can also use this formula for large load increment ratios, if t_n^o is given sufficiently small values.

For one case, namely zero load increment (after previous loading steps with large load increments), it is easy to indicate the value of t_n^o, because then the last two steps (with identical loads $p_{n-1} = p_n$) can also be considered as one step with a total duration of $\Delta t_{n-1} + \Delta t_n$. Consequently we have in this case $t_n^o = \Delta t_{n-1}$ (the duration of the previous loading step).

A simple formula, which gives the correct result both for zero and for large load increments, is :

$$t_n^o = \left[\frac{p_{n-1}}{p_n} \right]^d \Delta t_{n-1} \qquad (5)$$

Since we usually find $d = 20 - 30$, t_n^o will become very small for large load increment ratios, as required.

For further investigation of the validity of formula (5), tests were made on identical samples with different load increments in the last step. Fig. 9 shows the time curves for 3 such tests, all with $p_{n-1} = 150\ t/m^2$, but with $\Delta p = 5$, 15 and 30 t/m^2 respectively. By adding $t_n^o = 30$, 300 and 1300 min. respectively in the 3 cases, the indicated 3 straight lines were obtained. By insertion in formula (5) we find in all 3 cases the same $d = 24$.

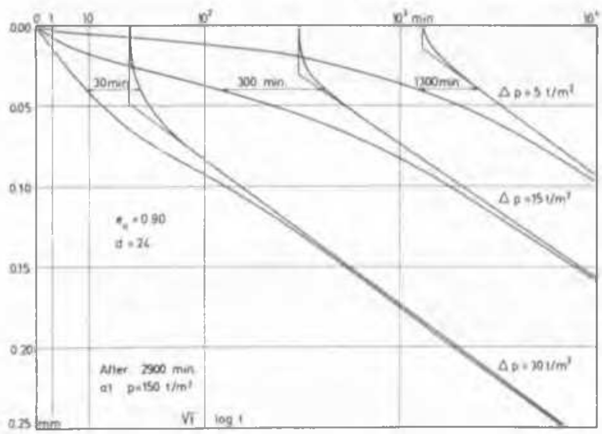

Fig. 9 : Different load increments.

Tests were also made with the same small load increment in the last step, but with different durations of the previous step. Fig. 10 shows the time curves for 2 such tests (in fact the same as in fig. 6). Both tests have $p_{n-1} = 100\ t/m^2$ and $p_n = 110\ t/m^2$, but Δt_{n-1} was 1500 and

6000 min. respectively. Straight lines are obtained with t_n^o = 150 and 600 min. respectively, t_n^o being proportional with Δt_{n-1} as required by formula (5). In both cases we find d = 25.

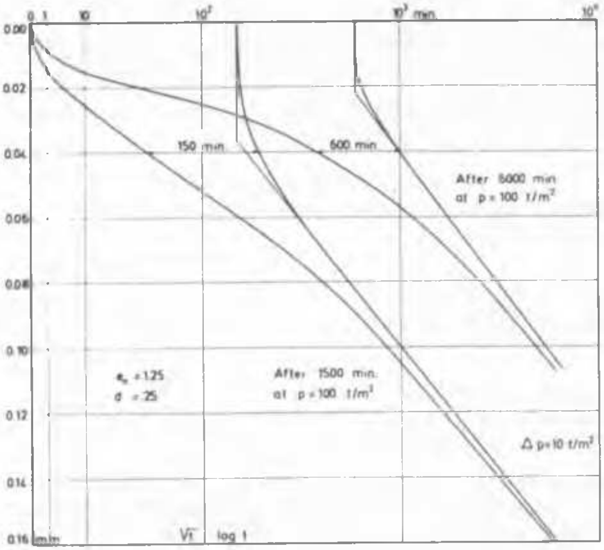

Fig. 10 : Different durations of previous step.

THE COMPLETE EQUATION

Since we can have small load increment ratios in more than one step, and since all previous loading steps give, in principle, a contribution to any later time curve, we must actually extend formula (5) to the following :

$$t_n^o = \sum_{i=1}^{i=n-1} \left[\frac{p_i}{p_n}\right]^d \Delta t_i \tag{6}$$

which should be used in combination with (4). The final result can be written in one equation :

$$e_n = e_o \left[1 + \frac{p_n}{p_o}\left[\sum_{i=1}^{i=n}\left[\frac{p_i}{p_n}\right]^d \cdot \frac{\Delta t_i}{t_o}\right]^c\right]^{-a} \tag{7}$$

This equation may be said to imply a „superposition" of the different loading steps, but it is a superposition of loading times, not of load increments. In the senior author's previous paper on secondary consolidation (Brinch Hansen 1961) it was assumed, that a simple superposition could be made of the time effects of all individual load increments. This assumption is now seen to be unwarranted and, consequently, the conclusions in the above-mentioned paper are not correct.

Equation (7) describes with good approximation the observed shapes of secondary time curves, both for small and large load increment ratios. Consequently, the distinction made by some other authors between „Type I", „Type II" and „Type III" curves is really quite arbitrary and unnecessary.

By differentiation of (4) with regard to log Δt_n we can find the secondary compression per time decade :

$$\varepsilon_s = \frac{2.3\ a\ c\ e_n}{1 + e_o} \cdot \frac{1 - (e_n/e_o)^{1/a}}{1 + t_n^o/\Delta t_n} \tag{8}$$

or, using for e_n the approximate value (1) :

$$\varepsilon_s = \frac{2.3\ a\ c\ e_o\ (1 + p_n/p_o)^{-a}}{(1 + e_o)(1 + p_o/p_n)(1 + t_n^o/\Delta t_n)} \tag{9}$$

For a large load increment ratio, e.g. $\Delta p/p$ = 1.0, the time t_n^o becomes insignificantly small compared with measured values of Δt_n. If the load p_n is also large compared to p_o, we get the simple approximate expression :

$$\varepsilon_s \approx \frac{2.3\ a\ c\ e_n}{1 + e_o} \tag{10}$$

This equation shows that ε_s is not only independent of the load increment ratio, but depends also rather little on the actual load and does, in fact, decrease slightly with this load, except for small loads, where equation (8) indicates an increase with further load. Several investigators have reported experimental results in agreement with this.

If p is a continuous function of t, the void ratio at the time t_n will, of course, be :

$$e_n = e_o\left[1 + \frac{p(t_n)}{p_o}\left[\int_o^{t_n}\left[\frac{p(t)}{p(t_n)}\right]^d \cdot \frac{dt}{t_o}\right]^c\right]^{-a} \tag{11}$$

DETERMINATION OF CONSTANTS

As already described, p_o and a can be determined by plotting p + p_o against e in a double-logarithmic diagram. e should for each loading step be the value obtained after a time $\Delta t = t_o$ = 1440 min, and it should be corrected for initial compressions (bedding effects), if any.

If p_o is already known, either from an empirical formula such as (2), or by other means (see later), we can find a from (1) :

$$a = \frac{\log (e_o/e_n)}{\log (1+ p_n/p_o)} \qquad (12)$$

Inversely, if a should be known, we can find p_o from :

$$p_o = p_n : \left[(e_o/e_n)^{1/a} - 1\right] \qquad (13)$$

In order to get a reliable determination of the constant c, we should preferably use a loading step with a load increment ratio around 1.0, a rather great load p_n and a rather long duration ($\Delta t_n > 100\ t_c$). An example is shown in fig. 7. If the secondary curve is straight, we can measure the compression ε_s per time decade and then find c from (10) :

$$c = \frac{(1 + e_o)\ \varepsilon_s}{2.3\ a\ e_n} \qquad (14)$$

If more accuracy is required, we must use (9) or (8) instead.

The last constant d can only be determined by means of a loading step with a load increment ratio around 0.1, and a rather long duration ($\Delta t_n > 200\ t_c$). The previous loading step should have a load increment ratio around 1.0. An example is shown in fig. 8. By trial we find the constant t_n^o which, when added to the observed times, gives the longest possible straight line. If the duration of the previous loading step was Δt_{n-1}, we can find d from (5) :

$$d = \frac{\log (\Delta t_{n-1}/t_n^o)}{\log (p_n/p_{n-1})} \qquad (15)$$

Evaluating our tests with the remoulded glacial lake clay in the way described, we have found the following average values of the 3 constants :

$a = 0.16 \qquad c = 0.022 \qquad d = 24$

Apart from the already mentioned slight dependency of a on e_o, we have not been able to establish any systematic variations with e_o. The values from different tests show, of course, some scattering, but it is quite a good approximation to assume a, c and d to be real constants for the clay investigated (standard deviation ± 15 %).

INFLUENCE OF PRIMARY CONSOLIDATION

Until now we have tacitly assumed that each load increment Δp becomes effective instantly, i.e. already for $\Delta t = 0$. Actually, the effective load increment increases from zero to full value during primary consolidation. However, since we have so far only considered values of $\Delta t > 10\ t_c$, the error has been insignificant. But for values of Δt between t_c and $10\ t_c$ a correction must be made.

During primary consolidation the effective stress varies, not only with time, but also with distance from draining boundaries. However, for simplicity we consider here an average effective stress, which varies only with time. Moreover, we assume the following variation during the consolidation time t_{ci} :

$$p_i(t) = p_{i-1} + (p_i - p_{i-1}) \sqrt{t/t_{ci}} \qquad (16)$$

We define now an „equivalent" time t_{ei} by the condition that a constant effective load p_i, acting for a time t_{ei}, should have the same effect as the varying effective load during the consolidation time t_{ci}. This gives, by means of (11) :

$$\int_0^{t_{ci}} \left[p_{i-1}+(p_i-p_{i-1})\sqrt{t/t_{ci}}\right]^d dt = p_i^d t_{ei} \qquad (17)$$

The integration is easy, but the resulting expression a little complicated. Since (16) represents an approximation anyway, the following simplified result may be sufficiently accurate :

$$t_{ei} = t_{ci} : \left[1 + \frac{d}{2}\ (1 - p_{i-1}/p_i)\right] \qquad (18)$$

This formula is actually correct in both the limits $p_{i-1} = 0$ and $p_{i-1} = p_i$.

We can now use the general formula (7), when we insert, instead of Δt_i, the „effective" time $\Delta t_i - t_{ci} + t_{ei}$.

Especially, the void ratio e_{cn} at the end of primary consolidation in step n can be found from (7) by inserting for Δt_n the effective time t_{en}. The primary compression in this step is then :

$$\varepsilon_c = \frac{e_{n-1} - e_{cn}}{1 + e_o} \qquad (19)$$

if the compression is related to the original height of the sample or layer (corresponding to void ratio e_o).

NORMALLY CONSOLIDATED INTACT CLAY

A similar, but less extensive series of Oedometer tests has been carried out with intact samples of the normally consolidated clay found under the earlier mentioned Aggersund Bridge.

It was found that, also in this case, the general formula (7) gave a quite accurate description of the test results. The average values of the constants were for this clay :

$a = 0.22 \qquad c = 0.040 \qquad d = 20$

The constant load p_o was generally found to be approximately 1.5 times the effective vertical overburden pressure in situ (see later).

Since the expansion of a normally consolidated clay is usually rather small, we can assume as an approximation, that the void ratio e_o measured on the intact sample is the same as found in situ under the effective overburden pressure p_b before construction.

Equation (7) describes the compression of an intact sample in the Oedometer and gives, correctly, $e_n = e_o$ for $p_n = 0$. The equation describing the compression in situ should, for $p_n = p_b$ and the given geological history, also give $e_n = e_o$. Moreover, for great pressures the two equations should give practically the same final void ratio.

These conditions can be satisfied if we, for the compression in situ, omit the unity sign in (7) and simply write :

$$e_n = e_o \left[\frac{p_n}{p_o} \left[\sum_{i=1}^{i=n} \left[\frac{p_i}{p_n} \right]^d \cdot \frac{\Delta t_i}{t_o} \right]^c \right]^{-a} \qquad (20)$$

where t_o is chosen arbitrarily equal to 24 hours, whereas e_o is the void ratio in situ before construction.

For the determination of p_o we must consider the geological history of the deposit. If the clay at the considered depth has been loaded by increasing effective loads p_1, p_2 etc. up to p_b, for corresponding lengths of time Δt_1, Δt_2 etc. to Δt_b, we must, in order to make (20) give $e_n = e_o$ for $p_n = p_b$, assume :

$$p_o = p_b \left[\sum_{i=1}^{i=b} \left[\frac{p_i}{p_b} \right]^d \cdot \frac{\Delta t_i}{t_o} \right]^c \qquad (21)$$

This p_o might appropriately be called the „effective preconsolidation pressure". Due to the secondary consolidation it exceeds the overburden pressure p_b, in the investigated case with about 50 %.

Using formula (6) we can write equation (20) simpler :

$$e_n = e_o \left[\frac{p_n}{p_o} \left[\frac{\Delta t_n + t_n^o}{t_o} \right]^c \right]^{-a} \qquad (22)$$

By differentiation with regard to log Δt_n we find the secondary compression per time decade :

$$\varepsilon_s = \frac{2.3\ a\ c\ e_n}{(1 + e_o)(1 + t_n^o/\Delta t_n)} \qquad (23)$$

By using for e_n the value given by (20), but neglecting the time effect herein, we find approximately :

$$\varepsilon_s \sim \frac{2.3\ a\ c\ e_o (p_o/p_n)^a}{(1 + e_o)(1 + t_n^o/\Delta t_n)} \qquad (24)$$

CALCULATION OF SETTLEMENTS

First we must determine e_o, and then the constants a, c and d as previously described. If the geological history is known, we can calculate p_o by means of (21) otherwise we must find it from the Oedometer tests as described.

The soil under the foundation is now divided into a number of horizontal layers as usual in a settlement calculation. The compression of each layer should be calculated separately, and added later. The vertical loads p_b before and p_a after construction are calculated for the middle of each layer.

For each layer the time t_{ca} necessary for about 90 % primary consolidation is calculated (or estimated), and the corresponding equivalent time t_{ea} calculated from (18).

Next, t_a^o is calculated from (6). It should, in principle, include all previous loading steps, also the geological ones. However, for not too small load increments in the last step the previous steps will have a negligible effect. On the other hand, they may give a significant contribution for small load increments, and in the limiting case of no load increment they give the only contribution to the secondary compression.

We calculate now e_{ca} from (22), inserting for Δt_n the time t_{ea}. The total primary compression is then :

$$\varepsilon_c = \frac{e_o - e_{ca}}{1 + e_o} \tag{25}$$

Up to the consolidation time t_c the primary compression can be assumed equal to $\varepsilon_c \sqrt{t/t_c}$.

Finally we can, for any later time Δt_a, calculate the secondary compression ε_s per time decade from (23) or (24), inserting for Δt_n the effective time $\Delta t_a - t_{ca} + t_{ea}$.

COMPARISON WITH MEASURED SETTLEMENTS

For the Aggersund Bridge, ε_s was calculated from (23), using the values of a, c and d found by Oedometer tests. The calculated secondary settlement of the abutment was 20 cm per time decade.

The corresponding measured value was 35 cm, but it should be noticed that the calculation, being based upon Oedometer tests, cannot take any regard to the actual lateral yield under the abutment. In view of this, the agreement may be considered satisfactory. At least, the calculated value is of the right order of magnitude, and the deviation between measured and calculated values goes in the right direction.

CONCLUSIONS

1) By means of an extensive series of Oedometer tests with a remoulded clay it has been shown, that a comparatively simple empirical formula as (7) can describe satisfactorily all main features of the secondary consolidation observed in the tests.

2) The same type of formula seems to be valid for Oedometer tests with a normally consolidated intact clay.

3) The formula (7) for Oedometer tests can be modified to a form (20), describing the secondary consolidation in nature under structures, provided that lateral yield is negligible.

4) A method for calculating secondary settlements of structures is indicated, and is shown to give fair agreement with measured secondary settlements of a bridge abutment in Denmark.

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