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LATERAL STRESS AND PRECONSOLIDATION PRESSURE MEASURED BY LABORATORY TESTS

MESURE DES CONTRAINTES LATERALES ET LA PRESSION DE PRECONSOLIDATION AVEC UN OEDOMETRE SPECIAL

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SYNOPSIS: The relationship between vertical and horizontal in situ stresses in natural soils is of interest both in advanced soil modelling and as a soil characterization. A vertical stress increase introduces an increase in horizontal stress. But the relation between these stress changes is dependant on type of soil and preconsolidation pressure. The characteristic behaviour of different clays during increasing vertical load has been investigated by the use of a split ring oedometer, where lateral stress is measured.

The test results are interpreted by stress field theory and stress path diagrams. The stress ratios $\sigma_h'/\sigma_v'$and $\Delta\sigma_h/\Delta\sigma_v'$, are both constant and equal to K_0' when $\sigma_v' > \sigma_c'$. Statistics over K_0' versus in situ water content seems promising. For stresses below preconsolidation, the K'-values and the stress-path behaviour is radically different, and thus lead to new ways for determination of σ_c'.

INTRODUCTION

Both laboratory and in situ methods are generally used to evaluate the horizontal stress condition in soils. The tests in this investigation are carried out in a split ring oedometer. The equipment was described by Senneset (1989).

Several clays from the Trondheim region have been investigated, from stiff overconsolidated to a soft normally consolidated clay. Quick clays are also included. The results from a normally and an overconsolidated clay are presented in detail in this paper.

The sampling technique lead to nearly undisturbed soil samples. But unloading takes place, with a corresponding swelling of the soil. In the triaxial test an approximate in situ stress situation is reintroduced to the soil sample by reconsolidation. By performing an oedotriaxial test (Janbu 1973) we may get information about the coefficient at rest for the soil. In the split ring test we may also reintroduce the in situ stress of the sample.

The oedometer ring is split in three parts made to fit a given sample diameter. The ring is adjusted to the sample while contact pressure is measured. This contact pressure may then be given a magnitude corresponding to an estimated in situ horizontal stress. Simultaneously the in situ overburden pressure is applied as a vertical stress. On the other hand, if the influence on compressibility of a controlled lateral deformation is wanted, a gap between the ring and the sample may be introduced. The sample is one-way drained with porepressure measured at the base. Tests may be performed with incremental loading, continuous loading with constant rate of strain, or continuous loading with constant relation between vertical pressure and developed pore pressure (Janbu, Tokheim and Senneset 1981).

The test results from two marine clays are presented in this paper, the Glava clay which is a stiff overconsolidated clay, and the Eberg clay which is a soft, nearly normally consolidated clay.

SOIL DATA

For direct comparison of test data, the oedometer and the triaxial tests are generally made on specimens from the same sampling tube (piston sampler, tube diameter 54 mm, length 80 cm). Some index properties and soil parameters are summarized in the table below.

Table 1 Some average geotechnical data

Data		Eberg	Glava
Sample depth,	m	6.0-6.8	8.0-8.8
Water content	%	63	33
Liquid limit	%	45	35
% clay < 2 μ		61	43
Undrained shear strength	(kPa)	15	40-50
Effective overburden pressure	(kPa)	55	95
Preconsolidation pressure	(kPa)	70	~300
Modulus number		18	21
Friction	($\tan\phi$)	0.52	0.50
Attraction (triax)	(kPa)	10	15-20

TEST RESULTS

The test results shown in Figs. 1 and 2 were obtained in a split ring oedometer with continuous loading, at a constant rate of strain of 2% per hour.

The influence of applied initial contact pressure was investigated. It was varied from zero, both vertical and horizontal, via approximate in situ stresses, to a significant pressure of 70-90 kPa for the overconsolidated clay. The influence of these variations in the lower stress range is significant, but the values of K' above the preconsolidation stresses are nearly constant.

The initial contact pressures in horizontal and vertical direction for the tests described were less than the in situ stresses:

Eberg clay : σ_{hi} = 1.1 kPa, σ_{vi} = 1.4 kPa
Glava clay : σ_{hi} = 12 kPa, σ_{vi} = 10 kPa

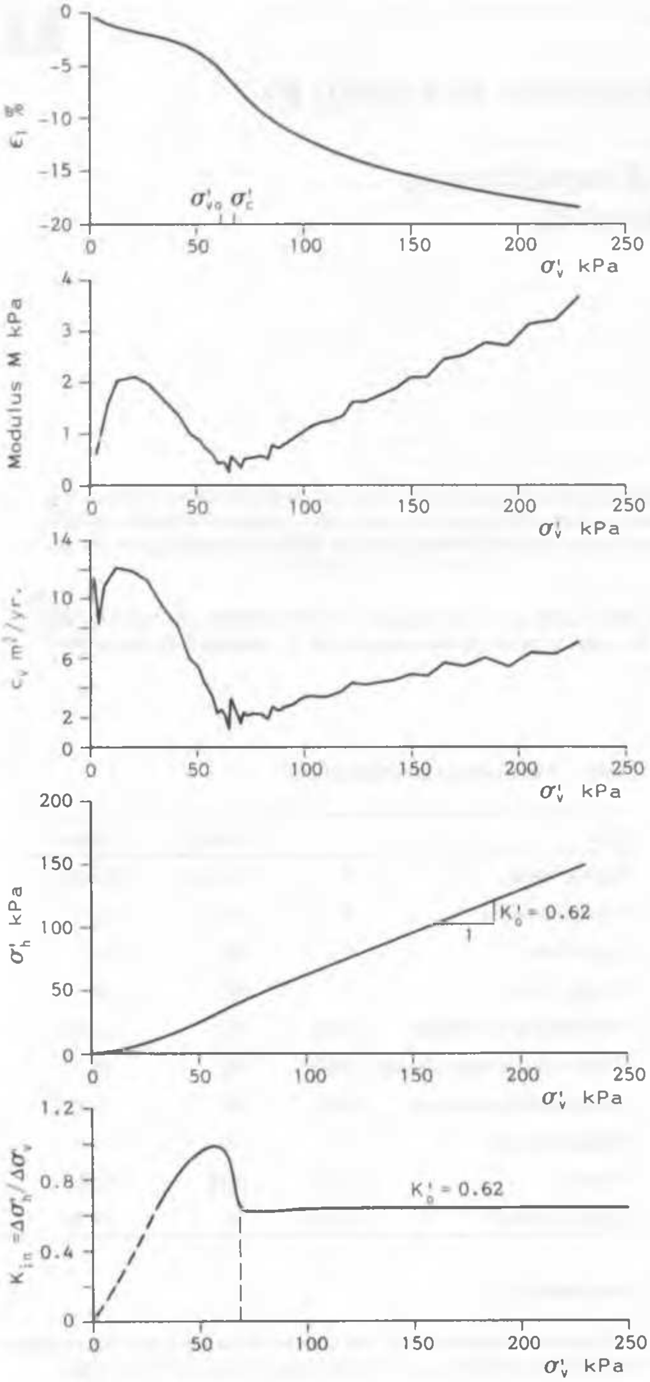

Fig.1. Eberg clay, test results

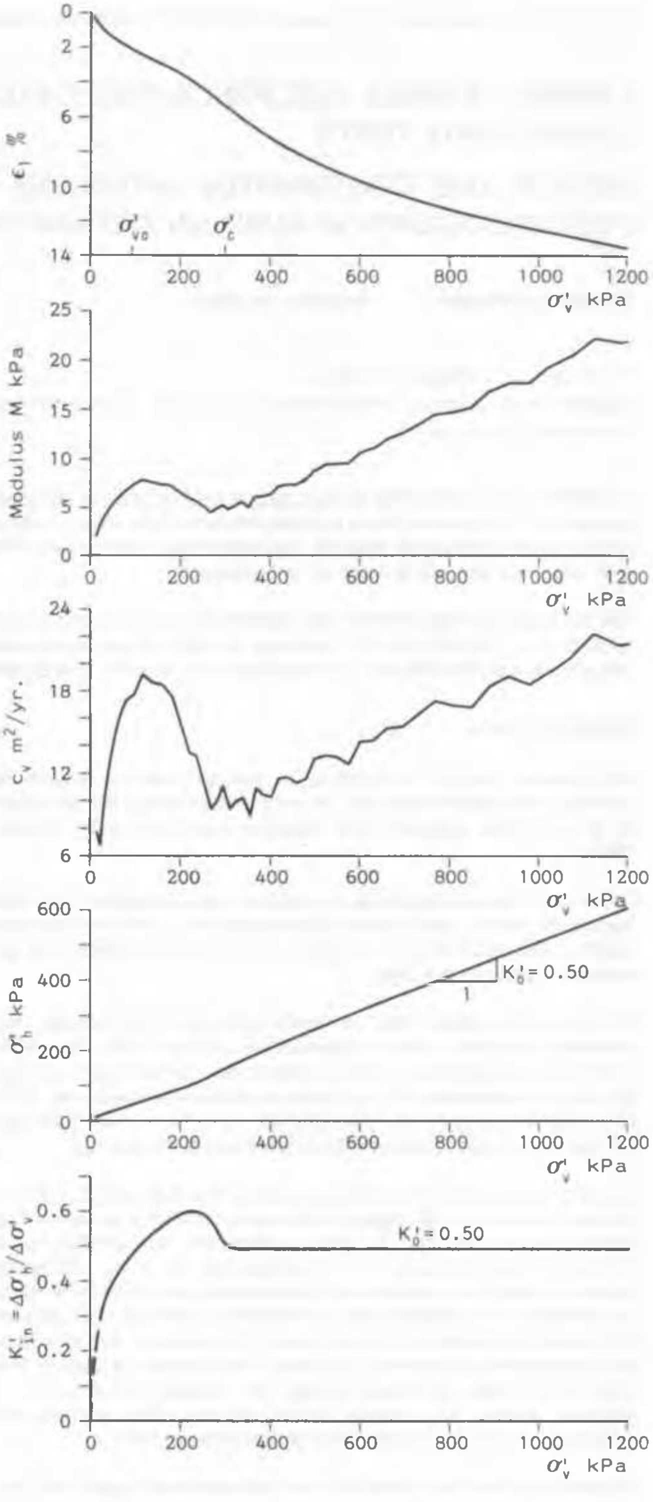

Fig.2. Glava clay, test results

The arithmetic diagrams in Fig.1 and 2 are (from the top down):

- **stress-strain: σ_v' - ε_v**
- **modulus-stress: M - σ_v'**
- **coeff.of consolidation: c_v - σ_v'**
- **horizontal-vertical stress: σ_h' - σ_v'**
- **incremental stress ratio: K_{in}' - σ_v'**

It is readily seen that all 5 diagrams show appreciable changes around, σ_c', leading to σ_c' = 300 kPa and σ_c' = 70 kPa for the Glava and the Eberg clay, respectively.

INTERPRETATION OF STRESS RATIOS

The diagrams of σ_h' versus σ_v' in Figs. 1 and 2 show clearly that the stress ratios $K' = \sigma_h'/\sigma_v'$ remain fairly constant when $\sigma_v' > \sigma_c'$. For smaller stresses, however, the stress ratios varies, and a closer look is therefore desireable.

From the effective stress field theory, Janbu (1985), it is known that

$$\sigma_3' + a = K'(\sigma_1' + a) \qquad (1)$$

where a = attraction (c = a·tanϕ) and K' = 1/N, when $N = \tan^2(45+1/2\ \rho)$ and tanρ = mobilized friction.

Differentiation of Eq.(1) gives

$$K_{in}' = \frac{\Delta\sigma_3'}{\Delta\sigma_1'} \qquad (2)$$

when a = constant (or a = 0) provided K'_{in} is independent of stress level. For larger variable stress levels, where a/σ' = small, one will often find $K' = K'_{in}$ = constant. In the test interpretations it is assumed that $\sigma_3' = \sigma_h'$ and $\sigma_1' = \sigma_v'$ for simplicity. The deviations are probably small.

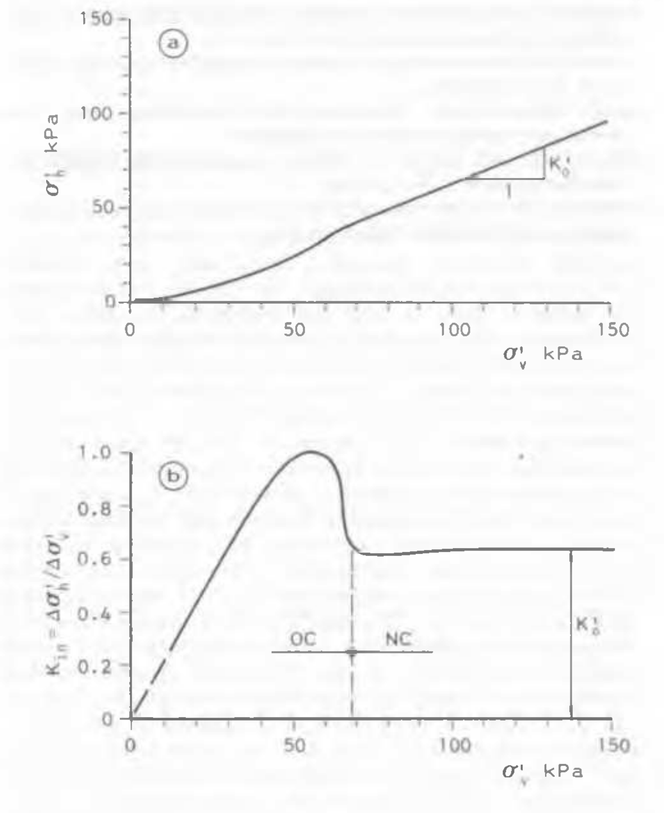

Fig.3. Measured stresses, and calculated incremental ratio, K_{in}'

The example in Fig.3a shows that K_0' = constant = 0.62 for $\sigma_v' > \sigma_c' \simeq 65$ kPa. However, for lower stresses K_{in}' varies substantially. Fig.3b shows that K_{in} increases gradually from nearly zero to a maximum of roughly 1.0, and then drops dramatically around σ_c', and thereafter approaches a constant value. Hence, $K'_{in} = K' = K_0' = 0.62$. The a-value for this soft clay sample is probably small, (a = 5-10 kPa).

The incremental stress ratios K'_{in} are plotted versus $\sigma_v' \equiv \sigma_1'$ in Figs. 1 and 2 for both the Glava and the Eberg clays, see lower diagrams.

In both cases $K' = K_{in}' = K_0'$ for $\sigma' > \sigma_c'$, resulting in:

Glava: $K_0' = 0.50$, $\sigma_c' \sim 300$ kPa, w = 33%
Eberg: $K_0' = 0.62$, $\sigma_c' \sim 65\text{-}70$ kPa, w = 63%

For $\sigma' < \sigma_c'$ the variation in K_{in}' is substantial. For the Glava Clay K_{in}' increases from fairly small values to a maximum of 0.65 and then drops to about 0.50 around σ_c'.

For the Eberg clay K'_{in} increases from about zero to a maximum of roughly 1.0 and then drops sharply to about 0.62 at σ_c'. This is very typical for sensitive NC-clays, as opposed to the slower decrease of K_{in}' around σ_c' for low-sensitive OC-clays, like Glava. The plots of K'_{in} versus σ_v' is yet another way of determining σ_c'.

STRESS PATH INTERPRETATIONS

A comprehensive effective stress-path study of oedometer tests (where $\sigma_h' = \sigma_3'$ is measured) was performed by Janbu (1981). When applying the same theory to the Brooker and Ireland (1965) results, some very important information emerged about the sample behaviour prior to and after preconsolidation. A small part of the theory will be used here for the Glava and the Eberg clay.

From the effective stress field theory, Eq.(1), it follows that

$$\tau_{max} = \frac{1}{2}(\sigma_1' - \sigma_3') = S(\sigma_3' + a) \qquad (3)$$

where S = (N-1)/2, or N = 1 + 2S = 1/K'. The stress path diagram we use is $(\sigma_1' - \sigma_3')/2$ versus σ_3'. When this path is linear the intercept at $\tau = 0$ determines a, and tanρ and K_0' are found from the slope value, S_0.

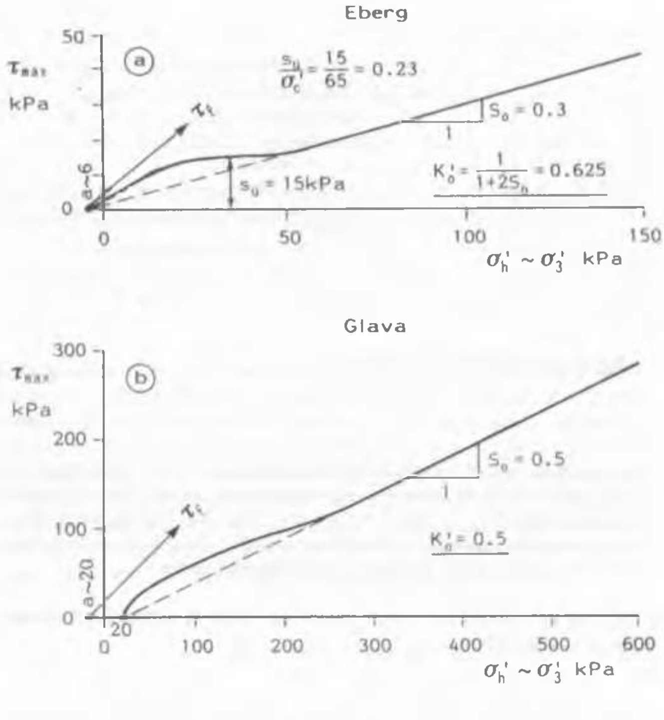

Fig.4. Stress path diagram

The σ_h' versus σ_v' curves in Figs.1 and 2 are converted into stress paths in Figs.4a and 4b. In both stress paths the triaxial, effective strength $\tau_f = (\sigma' + a)\tan\phi$ is plotted for small stress levels.

For the Glava clay the effective stress path for the oedometer test lies far away from the τ_f-line. Hence, even for the first part of the loading the clay is far from failure or critical yielding. The path starts at $\sigma_h' \sim a \sim 20$ kPa for $\tau = 0$. Then it curves upwards, like oedo-triaxial tests, and gradually approaches a constant $S_0 = 0.5$, or $K_0' \approx 0{,}5$, for $\sigma_h' \gtrsim 200$ kPa.

For the Eberg clay, the first loading, up to $\sigma_h' = 15$ kPa, is closer to an "effective stress failure path" corresponding to a = 5-10 kPa and $\tan\phi \sim 0.50$. For $\sigma_h' = 25$ to 45 kPa it is seen that τ_{max} = constant = $s_u = 15$ kPa. This is truly an "s_u-state", since $\Delta\sigma_1' = \Delta\sigma_3'$ or $\Delta\tau = 0$ for increasing effective stress from $\sigma_1' = 55$ to 75 kPa. This means that around $\sigma_c' = 65$ kPa 10 kPa, the value of $K'_{in} = 1.0$, and $\tau_{max} = s_u = 15$ kPa. The observation of $s_u = 15$ kPa leads to $s_u/\sigma_c' = 0.23$, or $s_u/(\sigma_c' + a) = 0.20$ if a = 10 kpa, and $\sigma_c' = 65$ kPa.

For $\sigma' > \sigma_c' = 65$ kPa it is seen that $S_0 \sim 0.3$ which leads to $K_0' = 0.625$, as before. The stress path interpretation of split-ring tests may now become standard at our institution.

STATISTICS OF K_0'VERSUS WATER CONTENT

The detailed interpretations shown above, lead to dependable values of K_0' for $\sigma' \geq \sigma_c'$. Several such test results for NC- and OC-clays and clayey silts are already available. Tentative statistics indicate a fairly close relationship between in situ water content w and K_0' for $\sigma' \geq \sigma_c'$, as shown in Fig.5.

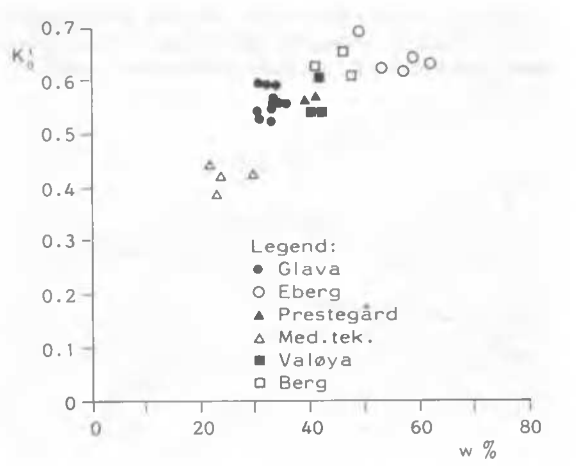

Fig.5. Statistics of K_0' versus w%

The lowest K_0' of 0.37 was found for a silt with w = 23%. The average K_0' = 0.41 for the four silt samples with an average w = 24%. The 11 tests on Glava clay lead to $K_0' = 0.55$ 0.05 for w = 34% 4%. For the Eberg clay 4 tests gave an average $K_0' = 0.63$, for w = 60% 5%. One single test gave $K_0' = 0.68$, which is the maximum value observed so far.

Fig.5 contains 7 other test results, which are scattered within the 3 average data set covered above.

SUMMARY

In a split ring oedometer test the pore pressure, the horizontal and the vertical stresses and stress changes, and vertical strains, are measured continuously, both in CRS-tests and constant u/σ-tests. Step loading can also be applied.

This paper focuses on lateral stresses and stress changes during the tests. In particular, it is found that both the stress ratio $K' = \sigma_h'/\sigma_v'$ and the incremental ratio $K_{in}' = \Delta\sigma_h'/\Delta\sigma_v'$ approaches a constant value equal to K_0' when $\sigma_v' > \sigma_c'$. Since the behaviour below σ_c' is very different, the preconsolidation pressure is also determined by the K_{in}' versus σ_v' curve.

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