Investigation of Pseudo-Overconsolidation of Soils

Investigation de Pseudo-Surconsolidation des Sols

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SYNOPSIS The paper outlines the writer's concept about the formation of the state of pseudo-overconsolidation in soil deposits. The procedure and the results of laboratory K_o-tests with undisturbed specimens of collapsible loess-soils are discribed. It has been found out that the K_o-relationship of the first loading can be used for unique determination of the natural consolidation state of the soil specimen. This is of particular interest in respect to the state of pseudo-overconsolidation.

THE PROBLEM

In the present paper the term Natural Consolidation State (NCoS) of the soil in a deposit means the consolidation state caused only by natural factors. It has been suggested that the soil deposit under consideration has horizontal upper and lower boundaries and is considerable in its lateral extent. This means that the horizontal (σ'_h) and the vertical (σ'_v) effective stresses are principal stresses and the mode of deformation is onedimensional compression. As it is well known the strain conditions in such a deposit could be modelled by an oedometer test in the laboratory.

Through the change of the overburden pressure due to different geological processes (sedimentation, consolidation, erosion) two main types of NCoS could form in a soil deposit: normal consolidation and (geological) overconsolidation. They are identified through the specific value of the overconsolidation ratio p_c/p_o (p_c-maximum effective overburden pressure for a certain depth of the deposit; p_o-correspondent present overburden pressure). For the above-mentioned two types of NCoS $p_c/p_o \geq 1$ correspondingly.

It is known at present (e.g. Burland, 1971) that a value for $p_c/p_o>1$ could be found also with soils, which have never been a subject of unloading, i.e. they are not geologically overconsolidated (GeOC) soils. In those cases the overconsolidation effect is a result of secondary consolidation or of development of interparticle bonds, the corresponding soils being known as quasi-overconsolidated (QuOC) soils and pseudo-overconsolidated (PsOC) soils. In this latter category most thoroughly studied are the highly sensitive clays of East Canada and Scandinavia and also collapsible loess soils.

The writer's opinion (Hamamdshiev, 1980) is that the QuOC and GeOC soils are similar on micro-scale i.e. structurally, both being distinguished by the dense arrangement of their structural units. They differ on macro-scale as expressed through the values of the coefficient of the earth pressure at rest $K_o=\sigma'_h/\sigma'_v$. While for QuOC soils $K_o^{nc}<K_o<1$ (K_o^{nc} is the constant K_o-value valid for the state of normal consolidation), it is known that for heavily GeOC soils the K_o-values can exceed unity and tend to reach the coefficient of the passive earth pressure K_p.

Quite different are the PsOC soils with their pronounced open structure and a trend to collapse or liquifaction (depending on the value of S_r) after some critical stress level has been exceeded. In the writer's concept meta-stable equilibrium state could arise in the deposit, caused by the development of rigid bonds in the inter-particle contacts. They strengthen the soil and, independently of its low density, reduce its compressibility which manifests itself as pseudo-overconsolidation. Besides through weakening of the bonds (e.g.through saturation or leaching) the meta-stable state may also be overcome through their mechanical disturbence, caused by the increasing overburden pressure. Since with soils the shear stresses are of primary importance as a cause for failures, it could be expected that a K_o-profile decreasing with the depth is characteristic for deposits of PsOC soils. A failure of the bonds would come into effect at a depth where K_o becomes equal to the coefficient of active earth pressure K_a, i.e. through a failure of an active mode. The hypothesized profile of K_o for a deposit of PsOC soil is shown in Fig. 1-a. Here the decrease of K_o begins below the depth of penetration of the atmospheric agents' influence. For the sake of comparison the profiles of K_o for a QuOC (Fig.1-b) and for a GeOC (Fig.1-c) deposit have also been presented.

It follows from the above told that for identification of the NCoS of a soil deposit a knowledge of its "in situ" K_o-profile would be necessary. The estimation of such a profile for a deposit of PsOC soils would be also the most reliable proof of the hypothesis of decreasing of K_o with depth. By now intensive work is being done in this area but the results of direct meas-

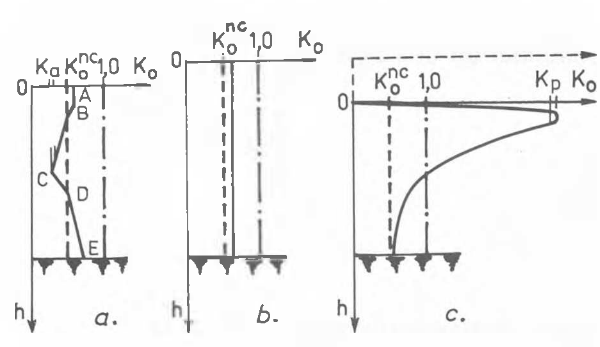

Fig.1 K_o-profiles for PsOC, QuOC and GeOC soils

urements of σ_h in deposits of PsOC clays could not be considered as satisfying so far. Nevertheless it is worth mentioning that field measurements in deposits of Scandinavian clays (Bjerrum, Andersen, 1972) have resulted in profiles of this kind.

The PsOC soils could not be differentiated by means of the p_c/p_o-value and sometimes this is a source of ambiguity which could have disagreeable consequences. The main subject of the investigation, described in the present paper, has been the study of a possibility for such a differentiation by means of the oedometer test completed by measuring the horizontal stresses (K_o-test).

EXPERIMENTAL INVESTIGATION

There are practically no results of laboratory K_o-tests with undisterbed specimens of PsOC soils published. In the K_o-tests of Bjerrum, Andersen (1972) which paralleld their field tests, a measurment of σ_h' was done only after reaching p_c. Because of this the K_o-values obtained do not reflect the specific structural features of the tested soils. A single complete laboratory K_o-relationship from the first loading of an undisturbed specimen of collapsible loess was encountered in Kane (1973). As expected, it has been found out that the relationship has a specific character. So the idea has been suggested to use this relationship for identification of the state of pseudo-overconsolidation.

It has been mentioned before that the collapsible loesses are typical representatives of pseudo-overconsolidated soils. Here it can be added that they show a considerable similarity to some highly sensitive clays as regards grading and the character of the rigid inter-particle bonds. In order to obtain additional information about their laboratory K_o-relationship, the writer performed K_o-tests with undisturbed specimens trimmed from block samples of two loess soils. Some typical index properties are shown in Table I. The tests were performed on a triaxial apparatus maintaining a zero lateral strain while increasing the vertical loading. The latter was controlled by the device described by Bishop, Henkel (1957). After a complete unloading the specimens were loaded for a second, and, in some cases, for a third time. The tests were strain controlled. They were performed at drained conditions without measuring the negative pore pressure of

TABLE I

Typical index properties of the tested soils

Origin	Depth	ρ	w	ρ_s	w_L	w_P
-	m	g/cm^3	%	g/cm^3	%	%
Russe	7,0	1,62	7,5	2,74	25,2	21,1
B.Lom	3,0	1,54	14,0	2,74	34,2	18,6

the unsaturated specimens. However, according to the special investigation of Kane (1973), at values of S_r<0,85-0,90 no changes of the negative pore pressure have been observed while increasing the loading. This means that the K_o-relationship in total and effective stresses will be parallel and their slope ΔK_o for corresponding. points-equal ($K_o = \sigma_h/\sigma_v = \sigma'_h/\sigma'_v$). In the tests reported the final values of S_r for the soils investigated were correspondingly 0,28 and 0,49. This makes it possible to compare the K_o-relationships obtained with such presented in effective stresses.

Fig.2 shows the representative result of a test with a specimen from Russe. The three consecutive loadings are presented by the compression curves in Fig.2-a and by the K_o-relationships in Fig.2-b. Of greatest interest is the K_o-relationship of the first loading. As can be seen, it consists of three linear sections characterized by different values of ΔK_o (differential value of K_o). The prolongation of the last section passes practically through the origin of the co-ordinates. This is a reason to consider that for this section $\Delta K_o = K_o^{nc}$, which is supported also by the fact that for this section K_o=0,50. This value lies between those of K_o^{nc} obtained by means of the original and the simplified Jaky's formula with a value for $\varphi'=28^o$, typical for the soil under consideration. On its part the high value of ΔK_o, characteristic of the second section, seems to be due to the intensive failing of the structural bonds. Keeping this in mind, it could be claimed that the state of the soil within the limits of the last section of the laboratory K_o-relationship corresponds to line DE of the field relationship from Fig.1-a and that of the before last-to line CD. However there is only one section in the laboratory relationship for the lines AB and BC. This fact could be explained by the disturbance of the natural stress state of the specimen after it has been removed out of the deposit. As a result during the first laboratory loading the effect of pseudo-overconsolidation combines with those of the overburden pressure and, for specimens from shallow depths, of the atmospheric agents. That is why the writer considers his earlier suggestion (Hamamdshiev, 1980) to use the first two sections of the laboratory K_o-relationship for identification of pseudo-overconsolidated soils as inappropriate. This can be done using the values of ΔK_o for the "last" and the "before last" sections of the first loading K_o-relationship. As can be seen on Fig.2-b their ratio is $\Delta K_{o,1}/\Delta K_{o,b1}$<1. On the other hand it is known (e.g. Bellotti et al., 1975)that for geologically, and presumably also for quasi-overconsolidated undisturbed soil specimens the laboratory K_o-relationship consists of two sections. If they are also named "last" and "before last"

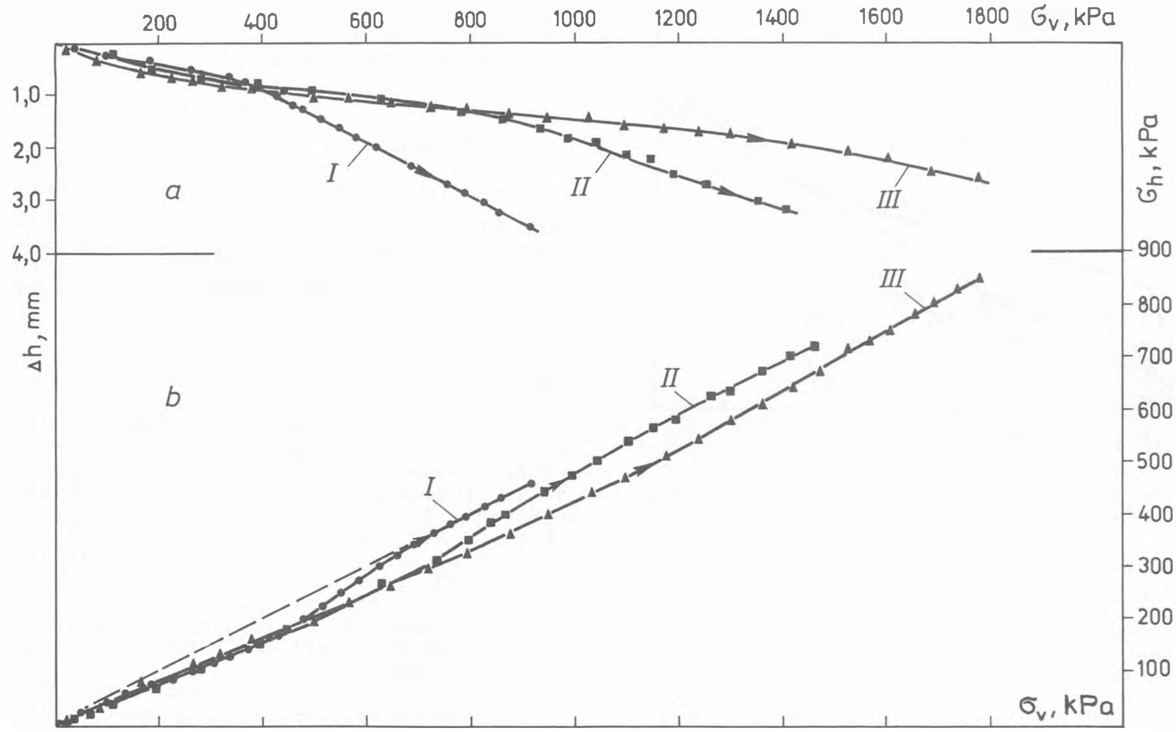

Fig.2 Laboratory compression- and K_o-relationships for a loess soil specimen

the corresponding values of K_o are such that $\Delta K_{o,1}/\Delta K_{o,b1}>1$. Hence this ratio can be used as a criterion for a unique differentiation of pseudo-overconsolidation from the other types of NCoS. Since the latter, in its turn, can be differentiated by means of the ratio p_c/p_o, it is clear that a possibility arises for the complete differentiation of natural consolidation states by means of laboratory K_o-tests.

In this respect the results of K_o-tests with Keuper marl reported by Chandler (1967) deserve special interest. At first he suggests a hypothetical K_o-relationship for a first loading of an undisturbed specimen of a presumably geologically overconsolidated soil (Chandler, Fig.1). However, the expected confluence with the K_o^{nc}-line had not been observed for the real test relationship and moreover the p_c-values obtained had been too low. That is why Chandler concluds that the marl under consideration had lost its "memory" during its geological history. As a result, at the time of testing, instead of a real overconsolidation it manifests only a pseudo-overconsolidation. It should be noted that initially the marl samples were isotropically consolidated with a stress of about 7 kPa. This is so little that it could be neglected considering the test K_o-relationship as bi-sectional. This is already an evidence that the specimen tested is of really overconsolidated soil, a conclusion coinciding with the geological one. Returning once more to Fig.2-b, III one can see that for the third loading i.e. for fully disturbed initial structure, the K_o-relationship is really bi-sectional with a smooth transition between the two sections.

On the other hand the hypothetical K_o-relationship of Chandler is quite similar to the first loading relationship I from Fig.2-b, i.e.to a relationship valid for a pseudo-overconsolidated soil. In this way the application of the approach, suggested here by the writer, shows unambiguously that the soil investigated by Chandler was not pseudo-overconsolidated. To answer the question about the origin of its overconsolidation, K_o-tests with several specimens removed from a same level but consolidated under different values of $K_o^{nc}<\Delta K_o<K_p$ and $\sigma_v'=p_o$ have to be performed. The aim of this procedure is the "by trial" restauration of the real natural stress state for the level, resp. of the additional overconsolidation effect caused by the increased latteral stresses. The test relationship whose last section confluences with the K_o^{nc}-line (Fig.3, GeOC or QuOC) will be indicative for the natural stress state saught, and hence for the corresponding NCoS. It will also reproduce the actual further change of those states under vertical loading tending to and exceeding p_c. Therefore the described procedure could also be used for estimation of p_c. The last section of the K_o-relationship for GeOC or QuOC specimens consolidated under K_o-values higher or lower than the actual ones will lie above or beneath of the K_o^{nc}-line (virgin line) and parallel to it. As an example the test-line of Chandler is shown on Fig.3 (Ch. test).In contrast to the other types of soils the K_o-relationship for a pseudo-overconsolidated specimen will always confluence in its last section with the K_o^{nc}-line. This is true independently of the K_o-value of the preliminary consolidation (Fig.3, PsOC) and even without such one (Fig.2-b, I and

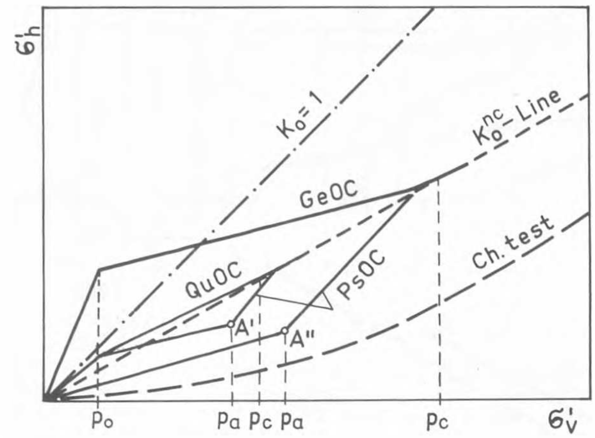

Fig.3 Identification of NCoS of soils by the laboratory K_o-relationships

II). It follows that for identification of NCoS by the ΔK_o-ratio always the section with $\Delta K_o = K_o^{nc}$ has to be counted as the "last". The particular behaviour of pseudo-overconsolidated specimens could be explained by the radical structural changes accompanying the failure of the rigid structural bonds at loading equal to p_c. As a result the material of the specimen loses its "memory" and for the first time gets into a state of normal consolidation. On the other hand a specimen of say geologically overconsolidated soil does not undergo a substantial structural change even at a loading exceeding p_c. In this case in order to bring the specimen back to the state of normal consolidation first its "memory" has to be destroyed through restoration of its natural stress state. Then, with increasing of the vertical loading, K_o^{nc} will be reached through the reduction of K_o. On the contrary, for pseudo-overconsolidated specimens the reduction of K_o will be to K_a (Fig.3, A' and A'') after which it will increase to K_o^{nc}. All this supports the hypothesis of a K_o-profile decreasing with the depth of the deposit in such soils.

The validity of these findings has to be checked through testing a broader variety of soils with different NCoS. In any case they will be valid only for soils without macro-scale deffects (e. g. fissures) for which the laboratory specimens could be considered representative.

CONCLUSIONS

1. The specific configuration of the laboratory K_o-relationship obtained at the first loading of undisturbed specimens of collapsible loess soils shows that the state of pseudo-overconsolidation is a fully definite state. It can be uniquely identified through a laboratory K_o-tests which can also provide the value of p_c resp.of p_c/p_o. In this way a possibility for a comparatively easy and cheap identification of all natural consolidation states arises.

2. The laboratory results obtained support the hypothesis about a decreasing with the depth, tending to K_a, K_o-profiles in deposits of pseudo-overconsolidated soils.

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