Effects of sampling on artificially reconstructed cohesive soils

Effets de l'échantillonnage sur des sols cohésifs obtenus artificiellement

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SYNOPSIS The disturbance due to sampling and specimen preparation related to the oedometric parameters is analyzed in the paper. The experimental study considered artificially reconstructed soil mixtures of various plasticity which have undergone preconsolidation. The comparisons and analysis refer to stresses in the normally consolidated field.

1. INTRODUCTION

The term disturbance, when applied to soil behaviour, often refers to the physical modifications induced on soil structure by operations of sampling and specimen preparation, and thus influences the results of mechanical tests in various ways.

As reported by Broms (1980), disturbance may affect the quality of geotechnical parameters following this sequence: (1) modulus of elasticity and shear modulus; (2) preconsolidation pressure; (3) compressibility; (4) shear strength; (5) permeability; (6) water content, void ratio and unit weight of soil; (7) liquid and plastic limits; (8) grain-size distribution.

With reference to geotechnical design, many researchers have examined this problem with the aim of quantifying the "true values" of compressibility and shear strength parameters. These last aspects are presented in the well-known papers of Schmertmann (1955), Ladd & Lambe (1963), Skempton & Sowa (1963), and Noorany & Seed (1965).

These and other authors quantify the degree of disturbance by taking a "virgin condition" as a point of reference:

- Schmertmann (1955) considers the compressibility of soil and defines the degree of disturbance as a ratio $\Delta e/\Delta e$ max, where Δe is the difference between the in situ void ratio and that of a soil sample at the pressure of preconsolidation, and Δe max is the difference between the in situ void ratio and that of a thoroughly remoulded soil.
- Ladd & Lambe (1963), Noorany & Seed (1965) and Okumura (1971) consider disturbance as relations between the residual effective stress of a taken sample and that of a perfect one.
- Berre & Bjerrum (1973) and Bromham (1971) consider the volume variation of a taken sample compared with the in situ soil as a measure of disturbance.
- Hvorslev (1949) quantified disturbance by comparing undrained shear strength and stress-strain curves of taken and undisturbed samples; the same parameters were used by Raymond et al. (1971).

All the quoted researchers deal with in situ conditions reconstructed from experimental data deduced from natural soils.

In this paper, the effects of disturbance are referred to remoulded soils prepared in the laboratory. This procedure was adopted in order to obtain homogeneous materials undergoing the tensional variations which characterize sampling operations. Similar techniques were adopted by Skempton & Sowa (1965) and Atkinson & Kubba (1981).

With reference to reconstructed soil, these authors examine virgin and perfect sampling conditions compared to a condition in which disturbance was due to sampling and specimen preparation.

Following this last comparison technique, this paper examines disturbance effects on compressibility and consolidation parameters.

2. PROBLEMS INVESTIGATED

This paper analyses and quantifies the effects of mechanical disturbance induced by operations of sampling and specimen preparation on soil undergoing laboratory consolidation tests.

The materials examined were consolidated from slurries at various vertical effective stresses in order to simulate a natural sedimentation process.

The disturbance investigated is referred to a procedure in which a thin-wall piston sampler was used to take samples. The study considers experimental determinations obtained in the laboratory from artificial soil slurries. This procedure was adopted in order to analyse reproducible and homogeneous materials.

The scatter of the following oedometric parameters was compared with virgin situations:

- C_c, compression index;
- m_v, coefficient of volume change;
- C_v, coefficient of consolidation;
- C_α, rate of secondary consolidation.

3. SOILS AND LABORATORY METHODS

The following soils were used in this research:

- a natural kaolin (K) from Cornwall (United Kingdom);
- a bentonite (B) from the region of Venice (Italy).

Pure kaolin or a mixture of the above soils were prepared starting from dry materials; their plasticity index and grain-size distribution curves are shown in Fig. 1. The plasticity index ranges from 18 to 70% with the kaolin percentage decreasing from 100 to 60%.

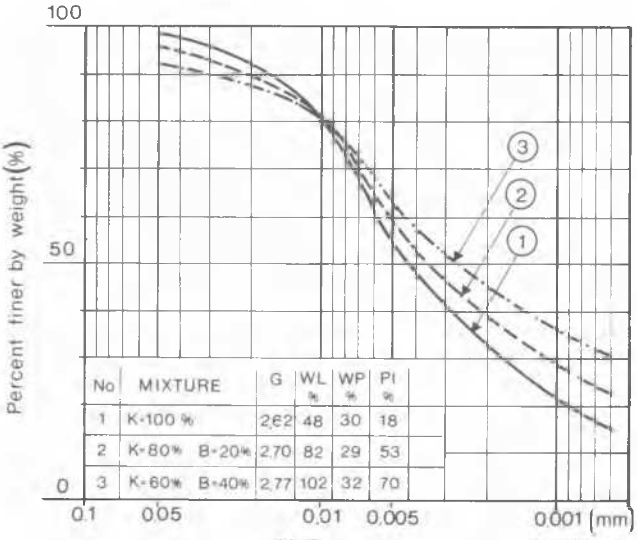


Fig. 1 - Gradings and Atterberg limits of the test mixtures.

Table 1

Mixture no.	Percentage by weight		Preconsolidation pressure σ'_p (kPa)
1	K = 100		200 - 500 - 2000
2	K = 80	B = 20	200 - 1000
3	K = 60	B = 40	200 - 1000

K = kaolin; B = bentonite

Slurries of the above soils, with a water content close to the liquid limit, homogenized with an electromechanical mixer, were consolidated in a Rowe consolidometer (diameter = 250 mm) with preconsolidation pressure σ'_p ranging from 200 to 2000 kPa as shown in Table I.

Sampling was carried out by mechanical apparatus capable of driving a thin-wall stainless steel sampler inside the Rowe cell. Sampler penetration velocity was 0.002 m/s.

The distinctive geometrical features of the sampler were as follows: diameter = 8 cm; length = 15 cm; ratio length/diameter of cutting toe = 2; thickness of wall = 2 mm.

Cylindrical specimens were prepared from the taken samples (diameter 5.0 cm; height = 2.0 cm).

For comparison, soil specimens defined as "virgin" were tested in oedometric cells starting from slurries (i.e., σ'_p = 0.0 kPa) at liquid limit water content. The load increment ratio of the compression tests ranged from 0.6 to 1.0.

A set of five tests was used in order to analyse the behaviour of the virgin compression parameters.

When a noticeable scatter was observed, the range of values of the parameters is shown in the figures, otherwise a single broken line represents the virgin situations.

Tests performed on taken samples considered a set of three determinations for each mixture and for each preconsolidation pressure.

4. ANALYSIS OF TEST RESULTS

Typical oedometric compression curves are shown in Fig. 2a. They refer to a "virgin compression" and a preconsolidated sample taken from the Rowe cell. Δe is the difference in void ratio between the above curves.

Curves Δe vs. σ' (vertical effective stress) are shown in Fig. 2b in a semi-logarithmic plane; they are related to the examined soil preconsolidated at various vertical stresses.

The value of Δe for stresses above the preconsolidation pressure may be taken as a measure for soil disturbance due to the stages of sampling, specimen preparation and reloading.

Fig. 2b shows that the difference in void ratio also increases with preconsolidation pressure for values which exceed it, although it tends to decrease at high vertical stress values.

Since Δe is proportional to strains, it affects the determination of compressibility parameters C_c and m_v as well as the stress history of the soil specimens.

4.1 Compression index

The slope of the straight portion of the e, logσ' curves is compression index C_c.

Fig. 3 shows the values of C_c for the soil mixture examined. The average values of C_c of the virgin samples are shown by a broken line; a

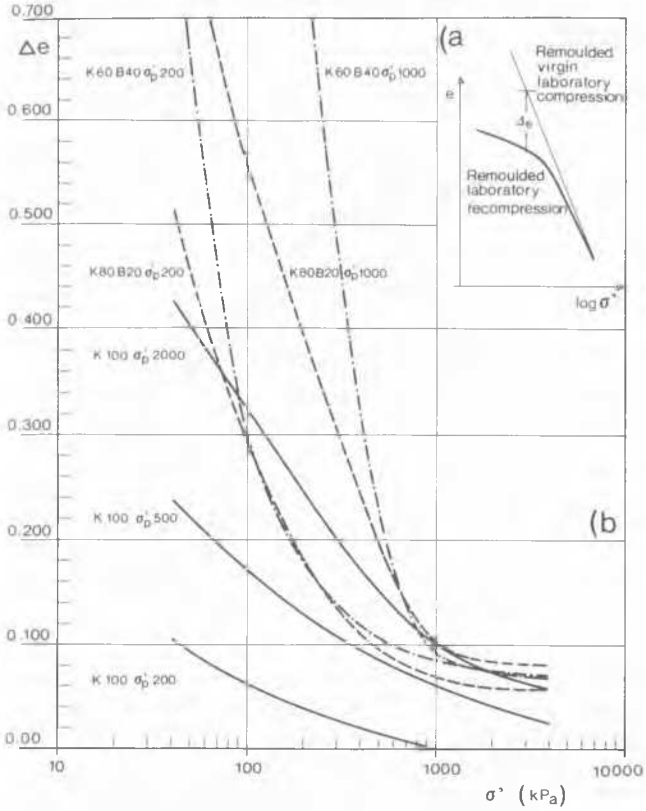


Fig. 2 a,b - Void radio difference between virgin and preconsolidated samples correlations with effective vertical pressure.

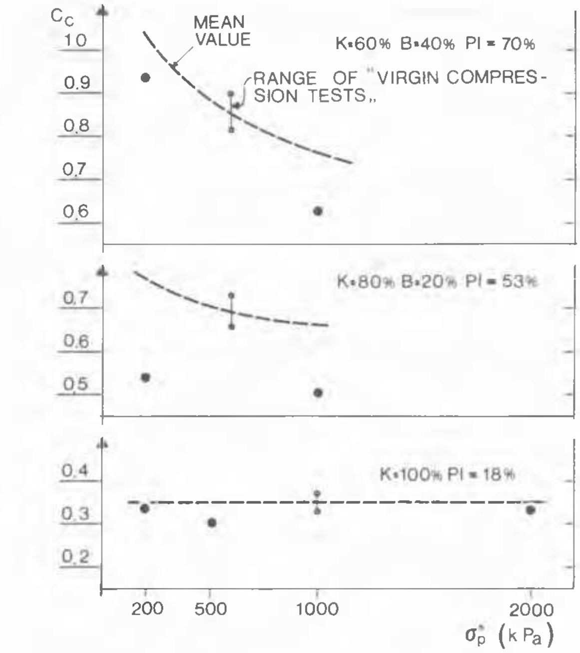


Fig. 3 - Compression index as a function of effective vertical pressure.

range of experimental values is also shown. The values of C_c of the taken samples are shown by black dots and are reported as a function of σ'_p.

The soil mixtures with PI = 53 and 70% exhibit virgin compression curves in the plane e vs. log σ', which is slightly concave; it follows that C_c is considered as a function of σ' as reported in Fig. 3b and c.

The compression index of the preconsolidated samples was evaluated in the final portion of the compression curves which reached pressures higher than 4 σ'_p.

It may be observed that the compression indexes of the preconsolidated samples have smaller values than those of the virgin samples. The magnitude of this scatter does not seem to be connected either to plasticity index or to consolidation pressure.

4.2 Coefficient of volume change

The trend of the coefficient of volume change vs. vertical effective pressure is shown in Fig. 4a, b and c for the various examined soils.

The parameters calculated from virgin consolidated and taken preconsolidated samples are connected by broken and full lines respectively; the preconsolidation pressure is also indicated for the latter samples.

The specimens with lower plasticity (PI = 18%) show almost linear and parallel trends (in the bilogarithmic plane) of the parameter considered.

The scatter between the values of the virgin consolidated and taken preconsolidated specimens increases with preconsolidation pressure.

The plastic soil mixtures (PI = 53 and 70%) show substantial overlapping of m_v for vertical effective pressure values greater than σ'_p. These mixtures show a well-defined knee related to the preconsolidation pressure.

4.3 Consolidation coefficient

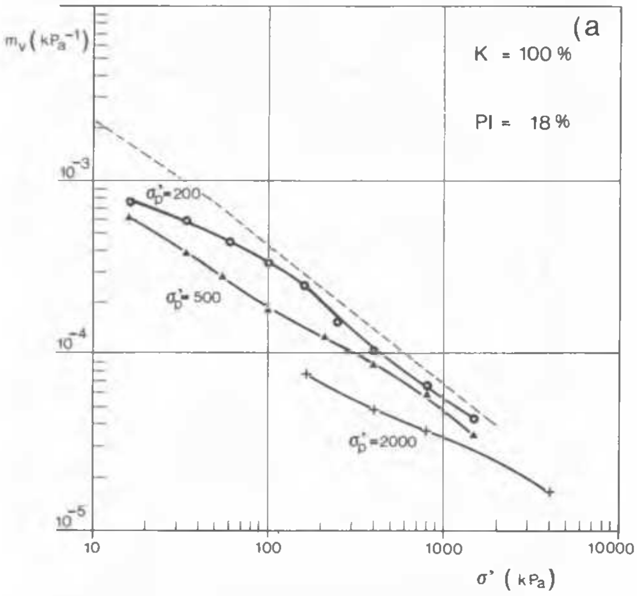
Consolidation coefficients, computed by the square root of time method, are shown in Fig. 5a, b and c, as a function of σ'.

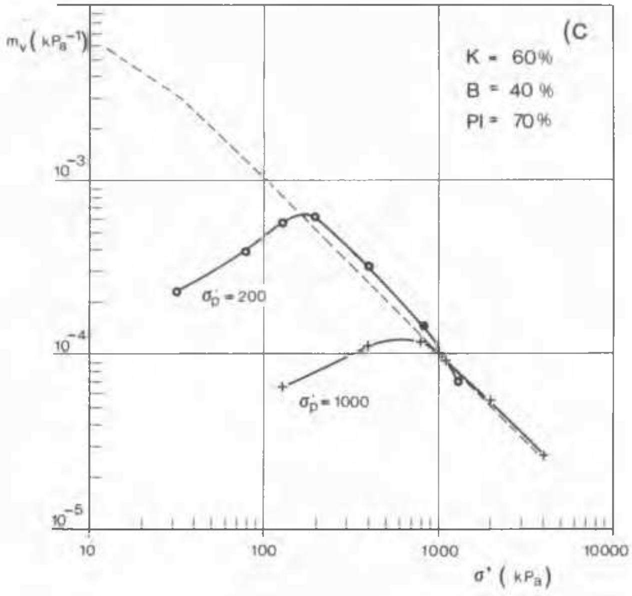
The virgin consolidated specimens exhibit C_v increasing linearly with log σ'.

A similar linear trend is shown by the K100 mixture (i.e., PI = 18%). In this case, for constant vertical effective pressure, C_v values increase with the preconsolidation pressure of the taken sample (Fig. 5a) and no variation of slope is shown as a consequence of previous consolidation.

On the other hand, a well-defined variation of the slope of the trend C_v vs. log σ' is shown by the more plastic mixtures (i.e., PI = 53 and 70%) (Fig. 5b,c).

The last two mixtures have similar trends: C_v values rapidly decrease to stresses which





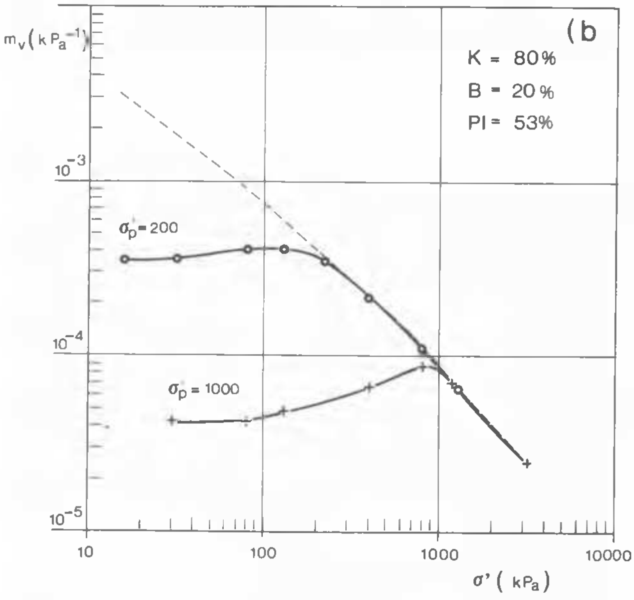


Fig. 4 a,b,c - Coefficient of volume change as a function of effective vertical pressure.

slightly exceed preconsolidation pressure, and then show a moderate linear rise following the pattern of the virgin consolidated samples.

4.4 Rate of secondary consolidation

This was defined as the slope of the final portion of the change of volume per unit volume-time curve in a semi-logarithmic plot:

$$C_\alpha = \Delta e / [(1+eo) \;.\; \Delta \log t] .$$

For this last parameter too, different trends may be noted for the K100 soil and the two more plastic mixtures which show similar qualitative behaviours. Fig. 6a, b and c shows the C_α values vs. effective stress in a semi-logarithmic space where the well-known dependence of the parameter on the plasticity of the examined soil mixture may be observed.

The virgin consolidation of the specimen of lower plasticity gives C_α values substantially constant with vertical stresses, while there is a noticeable decrease in C_α over a wide range of stresses for the two more plastic mixtures, followed by a slight increase.

The behaviour of the taken preconsolidated samples shows an increase of the examined parameters up to stress values which may exceed the preconsolidation pressure; for higher stresses, they show almost constant values.

This trend is more evident for the highly plastic soils and less so for the slightly plastic ones, where graphic errors in the determinations are of the same order as variations of the same parameter.

In the normally consolidated region of each taken specimen, the effect of disturbance gives an underestimation of C_α for the less plastic clay and an overestimation for the more plastic mixtures. In all cases, it may be noted that the C_α values of the taken specimens, for σ' greater than σ'_p, tend to be constant and independent of the preconsolidation pressure.

5. CONCLUSIONS

The disturbance caused to the reconstructed soils examined here by sampling and specimen preparation induces variations in the mechanical parameters of the soils themselves.

The research revealed the importance of soil plasticity on degree of disturbance of the examined soil mixtures.

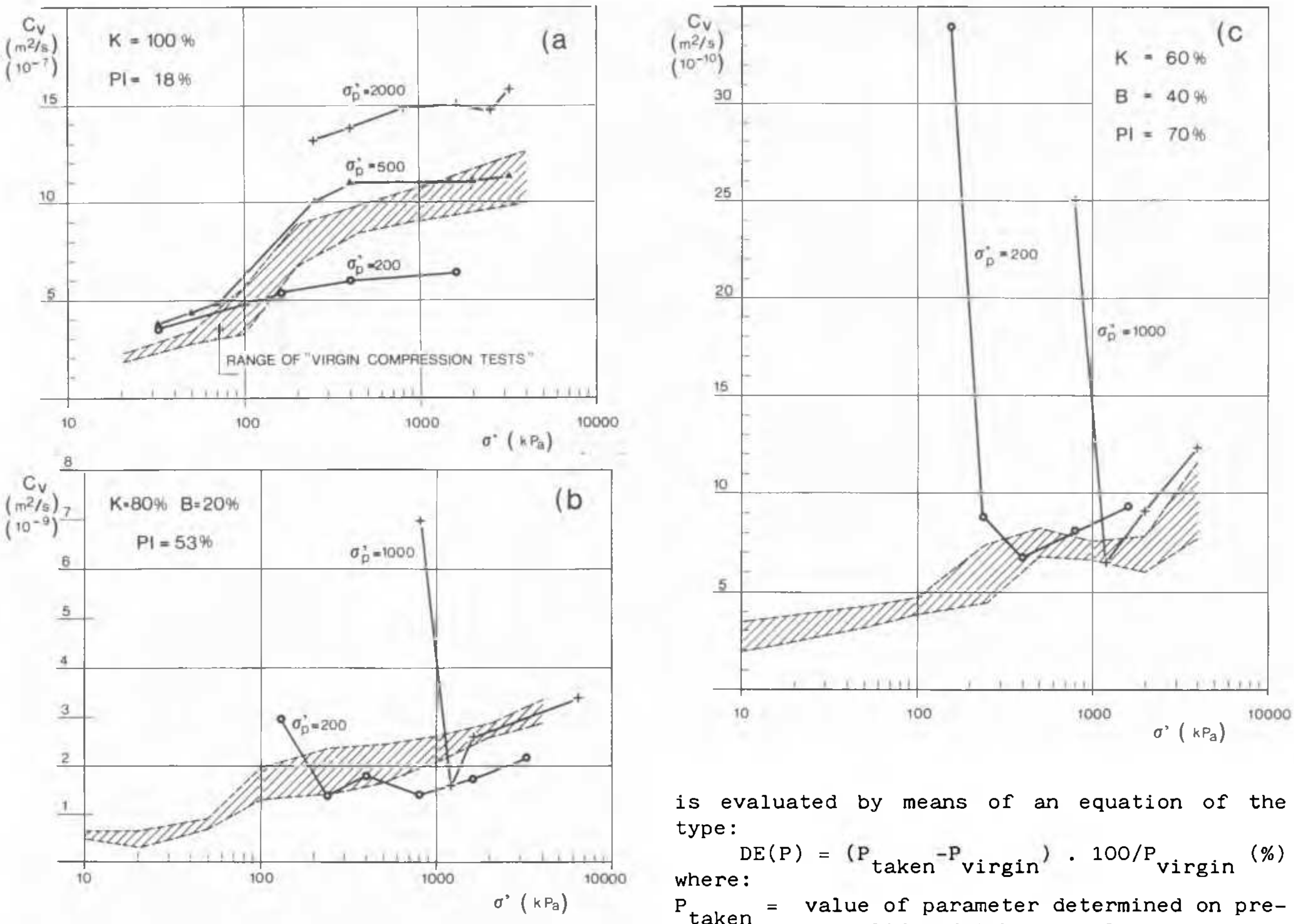


Fig. 5 a,b,c - Consolidation coefficient as a function of effective vertical pressure.

Except for the compression index, the behaviour of all the considered parameters is related to soil plasticity.

As a matter of fact, we show that the trends of the less plastic taken specimens is roughly parallel to those of virgin oedometric compression, both in the overconsolidated and in the normally consolidated stages.

The values of the parameters depend on the preconsolidation pressure of the taken specimens. On the other hand, the two more plastic mixtures exhibit a behaviour which shows a significant change at stress levels approaching preconsolidation pressure. It follows that the lower the plasticity, the greater the disturbance.

In order to give a rough estimation of such disturbance, a pragmatic method of quantification was used, that is, a direct comparison between the parameters of the reconsolidated taken and virgin consolidated specimens. Such comparison takes place for vertical pressures greater than the preconsolidation pressure (i.e., in the normally consolidated region).

The disturbance effect on each parameter DE(P) is evaluated by means of an equation of the type:

$$DE(P) = (P_{taken} - P_{virgin}) \cdot 100/P_{virgin} \quad (\%)$$

where:

P_{taken} = value of parameter determined on preconsolidated taken sample;

P_{virgin} = value of parameter defined by virgin compression test.

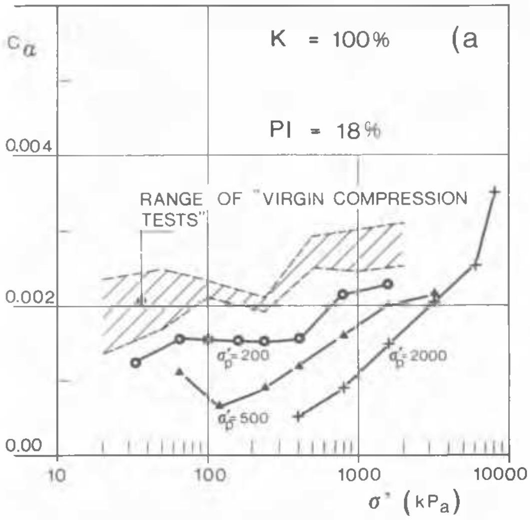
It follows that DE(P) = 0% means a coincidence between the determinations; lower or higher values cause underestimation or overestimation of the parameter examined.

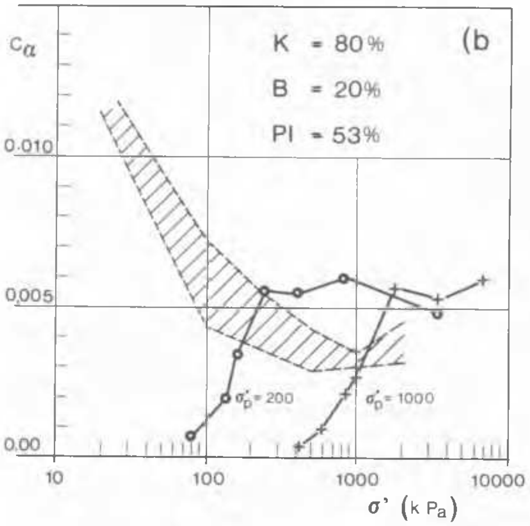
Referring to the data plotted in Fig. 3, we obtain $DE(C_c) = -(5:30)\%$; the parameter is always slightly underestimated. Dependence on plasticity or preconsolidation pressure was not observed.

$DE(m_v)$ ranges from -30 to 10%; the lowest values refer to the least plastic soil mixture.

The rate of secondary consolidation seems to be influenced by vertical pressure for stresses higher than the preconsolidation pressure. In this case, while the least plastic soil gives $DE(C_\alpha) = -(20:50)\%$, plastic soils (i.e., PI = 53 and 70%)) overestimate C_α and give $DE(C_\alpha) = (20\text{-}120)\%$.

The coefficient of consolidation values are comparable for the two more plastic mixtures and for σ' greater than 2 σ'_p, while the less plastic soil is affected by the preconsolidation pressure; $DE(C_v)$ is negative for σ'_p = 200 kPa and positive for σ'_p = 2000 kPa (-30-+40%). Of course, when comparing the above data, the calculation methods related to the parameters





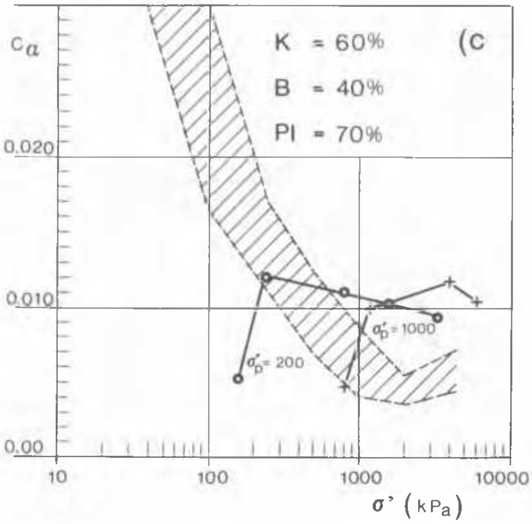


Fig. 6 a,b,c - Rate of secondary compression as a function of effective vertical pressure.

themselves must be borne in mind. Some parameters (e.g., m_v, c_v) are evaluated directly from the experimental values; others (e.g., C_v and $C\alpha$) require graphic constructions for interpretation.

Finally, the value of preconsolidation pressure $\sigma'p$ is not always identifiable through analysis of the trends of the parameters as a function of σ' (or of the logarithm of σ').

We noted that this datum may be deduced only for the more plastic specimens, with scatters of the order of 10-30%.

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