Reflections on the Consolidation Test

Réflections sur l'Essai de Consolidation

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SYNOPSIS A research on the stress-strain behaviour of soils during consolidation tests, developed to refine the state of knowledge about void ratio versus effective stress relations, leads to an exponential expression $\varepsilon = \alpha \, . \, e^{-\beta\sigma'}$, applicable for stresses below, or something above pre-consolidation pressure. The value "α" represents the initial void ratio, and "β" defines curve's shape and consequently is related with pre-consolidation pressure, wich depends only on curve's shape.

It was concluded that axial deformations depends on both "α" and "β", and so, pre-consolidation pressure, wich depends only on "β", isn't a good subsidy for the estimation of foundation's allowable pressure. In addition, the exponential expression is a straight line in a mono-log diagram, wich makes easy the study of void ratio versus effective stress relations.

INTRODUCTION

The interpretation of consolidation tests, related with stress-strain behaviour, have been based, fundamentaly, in pre-consolidation and compression index parameters, with little or no attention to recompression index and expansion index. In this traditional approach, the void ratio versus effective stress behaviour, below pre-consolidation, have been relegated, despite being extremely important for foundation engineering purposes.

During the research reported here, condolidation tests have been studied principally in the view of strain behaviour, and in this basis, it was concluded that pre-consolidation pressure, individually, isn't interesting in the estimation of allowable pressure for a foundation.

THE SHAPE OF CONSOLIDATION CURVE

The results of consolidation tests have ussualy been represented in void ratio versus log pressure graphs, wich show a slight curvature until pre-consolidation pressure is reached, and then, a straight line for pressures above pre-consolidation. The same test, drawn in linear scale, as in figure 1, show that there is no abrupt shape's change in the vicinity of pre-consolidation and so, based in this observation, it was concluded that a sole mathematical expression could represent the curve, either for pressures below or little above pre-consolidation.

With this expression, one can calculate settlement, under unidimensional compression condition, for pressures below or a little above pre - consolidation.

THE MATHEMATICAL EXPRESSION $\varepsilon = \alpha \, . \, e^{-\beta\sigma'}$

In order to establish the mathematical expression representing the best fit for a large serie of consolidation tests, a lot of statistical analysis were developed, and the result is an exponential equation as indicated below (1).

$$\varepsilon = \alpha \, . \, e^{-\beta\sigma'} \tag{1}$$

Some examples are given in table I, where may be noted the high values of correlation coefficients.

THE "α" AND "β" PARAMETERS

The analysis of equation (1) shows that when $\sigma' = 0$, the term $e^{-\beta\sigma'} = 1$, and so $\varepsilon_o = \alpha$, wich means that "α" is the initial void ratio. In the same equation, one may note that "β" defines curve's shape, as in figure 2, where for example is assumed that $\alpha = 1$.

Once the parameters "α" and "β" where characterised, it is easy to see that pre-consolidation pressure (σ'_c) depends only on "β", wich defines curve's shape, because the determination of σ'_c, based on the traditional process proposed by Casagrande, depends only on curve's shape.

Figure 3 shows that pre-consolidation pressure (σ'_c) depends only on "β" and doesn't depends on "α".

LINEAR GRAPHIC FOR $\varepsilon = \alpha \, . \, e^{-\beta\sigma'}$

Curiosly and ironicaly equation (1) is mathematicaly a straight line in a mono-log diagram, where in the vertical scale are the logarithmics of void ratios, and in the horizontal scale are the effective pressures, wich is exactly the contrary of the habitual manner.

The transformation is:

$$\varepsilon = \alpha \cdot e^{-\beta\sigma'}$$

$$\log \varepsilon = \log(\alpha \cdot e^{-\beta\sigma'})$$

$$\log \varepsilon = \log\alpha - \beta \cdot \sigma' \cdot \log e$$

wich represents a linear equation (Y = A-BX) , where $Y = \log\varepsilon$, $A = \log\alpha$ and $B = \beta \cdot \log e$.

According with this approach, to study the relation between "ε" and "σ'", for pressures below or a little above "σ_c'", it is proposed the use of a mono-log diagram ($\log \varepsilon \times \sigma'$) where a straight line, can easily be fitted to the data, and so, the value of "β" can be determined by expression (2) as shown in figure 4.

$$\beta = 2{,}3 \cdot \frac{\log(\varepsilon_2/\varepsilon_1)}{\sigma_2' - \sigma_1'} \qquad (2)$$

STRESS x STRAIN BEHAVIOUR

What is fundamental in consolidation behaviour, is that not only "β" (the curve's shape or indirectly the pre - consolidation pressure) condition the stress x strain behaviour, but also α (the initial void ratio) plays an important rule. According with this, two soils with the same pre-consolidation pressure (same β) , can show different strain, for the same stress level, if the initial void ratios (α) are different. It evinces that pre - consolidation pressure isn't a good approach in the estimation of allowable stress for foundation engineering, since it isn't related directly with the principal condition, wich is the deformation (settlement).

Equation (3) shows how the parameters α and β influences the deformations (Δ H/H).

$$\frac{\Delta H}{H} = \frac{\Delta\varepsilon}{1+\varepsilon_o} = \frac{\varepsilon_o - \varepsilon}{1+\varepsilon_o} = \frac{\alpha - \alpha \cdot e^{-\beta\sigma'}}{1+\alpha}$$

$$\frac{\Delta H}{H} = \frac{\alpha}{1+\alpha} \cdot \left(1 - e^{-\beta\sigma'}\right) \qquad (3)$$

The larger is the initial void ratio (α) , keeping constant "β" and "σ'", the larger is the deformations (ΔH/H).

In order to understand how "α" , "β" and "σ'" influences ΔH/H, was developed figure 5 wich gives for various initial void ratios (α), the variation of ΔH/H as a function of "β" and "σ'". In this figure is easy to see that, as "β" defines "σ_c'", for a given "β", the deformation under the pressure equivalent to "σ_c'", will be large if large is the initial void ratio, and will be small if small is the initial void ratio.

CONCLUSIONS

The most important conclusion is that pre - consolidation pressure doesn't defines deformation and so cannot be used in the estimation of foundation's allowable strees.

The $\varepsilon \times \sigma'$ behaviour, below or a little above "σ_c'", is easy to be studied in diagrams $\log \varepsilon \times \sigma'$, and has a great importance in foundation engineering, where the stress applied seldom exceeds to much the value σ_c.

The aspiration in the use of consolidation tests in foundation engineering, is to look for the stress wich leads to the same deformation wich was used succesfully in a similar building constructed in a different soil.

TABLE I

LOCAL	SOIL	GRADATION			PLASTICITY		INDEX			CONSOLIDATION.				
		<0,002mm (%)	<# 200 (%)	< # 40 (%)	WL (%)	WP (%)	W (%)	γ (kN/m³)	ε *	σc' (KPa)	Cc	α	β x10³	R **
MÉXICO	Clay	—	—	—	—	—	370	—	9,50	120	7,00	10,00	224	0,94
PRINCETON	Loess	—	—	—	—	—	—	—	0,95	110	0,35	0,94	58	0,98
NOVA AVA. DAM	Basalt Saprolit	42	86	100	73	45	40	17	1,47	700	0,56	1,48	12,2	0,99
NOVA AVA. DAM	Sandy Clay	56	75	97	52	30	26	20	0,84	1000	0,25	0,87	8,6	0,99
SÃO PAULO	Sedimentary Clay	30	50	58	45	20	14	21	0,47	2150	0,18	0,45	6,3	0,95
SÃO PAULO	Sedimentary Clay	47	70	100	74	35	41	18	1,08	200	0,26	1,05	24,5	0,98
CAMBRIDGE	Clay	—	—	—	—	—	—	—	1,10	300	0,40	1,18	36,5	0,99
SÃO PAULO	Gneiss Saprolit.	4	77	85	52	26	33	17	1,17	280	0,39	1,16	28,3	0,99
UNION FALLS	Sandy Silty Clay.	—	—	—	—	—	25	—	0,88	240	0,25	0,87	34,5	0,99
MANAUS	Clay	78	88	97	86	43	26	14	1,58	60	0,42	1,59	99,6	0,99
SÃO PAULO	Sand Sediment.	1	6	18	—	—	22	18	0,75	—	—	0,73	9,8	0,94
BRASÍLIA	Silt	4	98	100	53	35	40	18	1,25	650	0,52	1,25	17,2	0,99
CURITIBA	Clay	73	98	99	99	45	37	18	1,14	1300	0,47	1,11	14,9	0,85

* ε denotes void ratio, because "e" is the neperian base

** R is the correlation coefficient.

FIGURE 1 — Consolidation test in log and linear diagram.

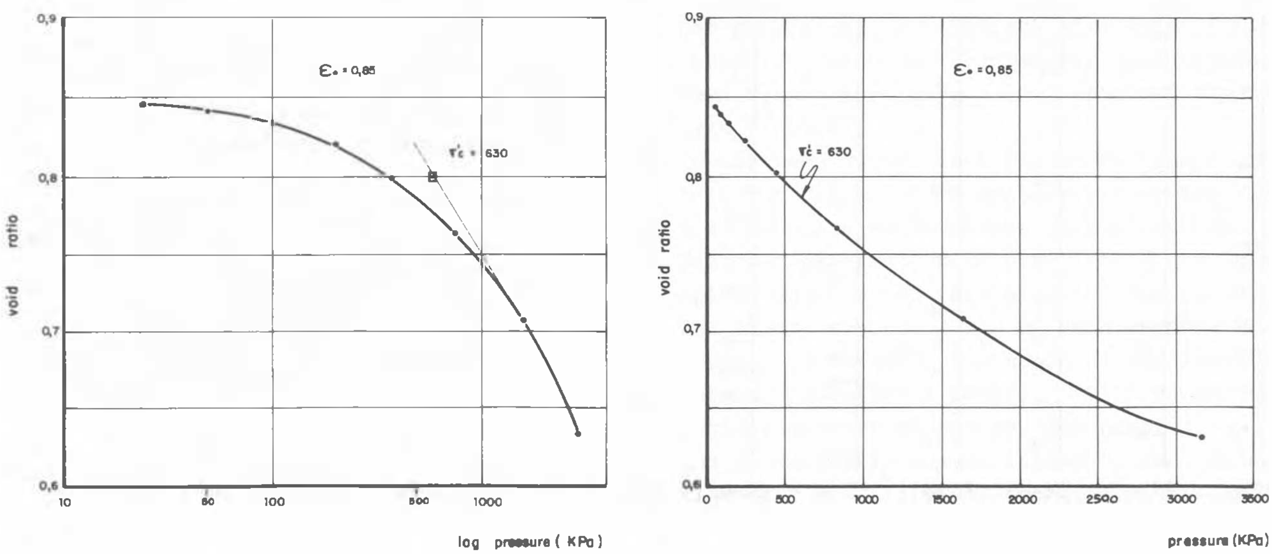

FIGURE 2 — Relations between ε and σ' for different β, with α = 1,0

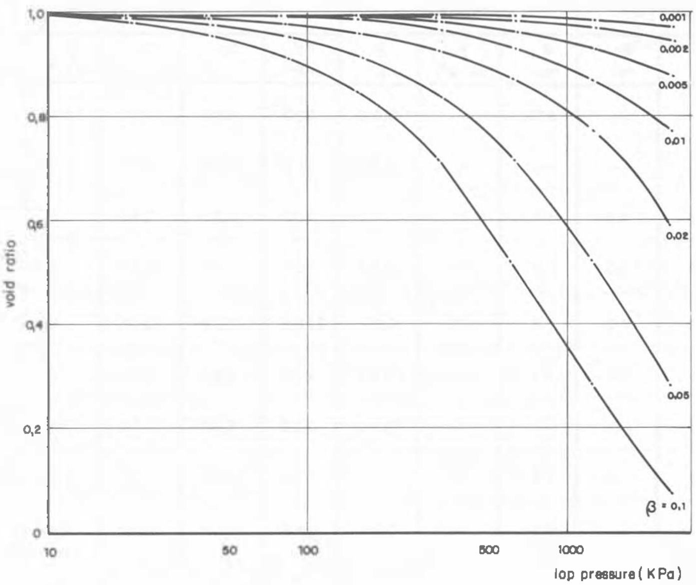

FIGURE 3 — Relation between β and σ'_c

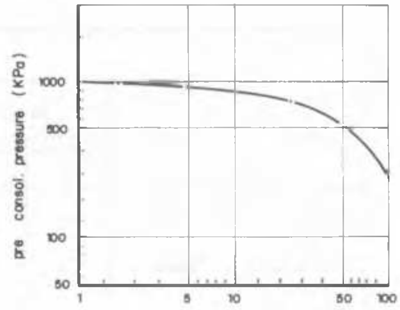

FIGURE 4 — Linear graphic for $\varepsilon = \alpha \cdot e^{-\beta \sigma'}$

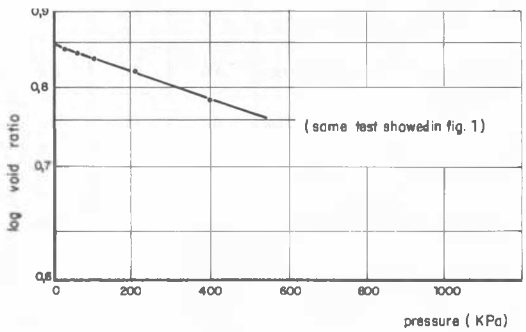

FIGURE 5 — Deformations ΔH/H for varius α, β and σ'