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DISCUSSION

Hydraulic conductivity of a recent estuarine silty clay at Bothkennar

S. LEROUEIL, P. LERAT, D. W. HIGHT and J. J. M. POWELL (1992).
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The Paper contains good experimental data which help understanding of the hydraulic behaviour of soils and in obtaining the best parameters to characterize a given soil. I would like to present a general equation, given by the principle of natural proportionality, which can be applied to experimental permeabilities measured in the laboratory (Figs 6 and 9).

The natural equation provided by the principle of natural proportionality reads (Juarez-Badillo, 1983, 1992)

$$\frac{k}{k_1} = \left(\frac{V}{V_1}\right)^{\kappa} = \left(\frac{1+e}{1+e_1}\right)^{\kappa} \tag{3}$$

where k is the permeability, V is the total volume, e is the nominal void ratio in terms of the initial volume of solids, κ is a constant parameter—the coefficient of permeability, characteristic of the material and (k_1, e_1) is a known point. The known point may be the in situ point (k_0, e_0).

When a soil is one-dimensionally compressed its permeability anisotropy increases so that

$$k_v = k_{v1}\left(\frac{1+e}{1+e_1}\right)^{\kappa_v} \tag{4}$$

$$k_h = k_{h1}\left(\frac{1+e}{1+e_1}\right)^{\kappa_h} \tag{5}$$

$$r_k = \frac{k_{h1}}{k_{v1}}\left(\frac{1+e}{1+e_1}\right)^{-(\kappa_v-\kappa_h)} \tag{6}$$

Equations (4)–(6) may alternatively be written as

$$k_v = k_{v0}'(1+e)^{\kappa_v} \tag{7}$$

$$k_h = k_{h0}'(1+e)^{\kappa_h} \tag{8}$$

$$r_k = \frac{k_{h0}'}{k_{v0}'}(1+e)^{-(\kappa_v-\kappa_h)} \tag{9}$$

where k_{h0}' and k_{v0}' are the permeabilities for the nominal (not the actual) void ratio $e_1 = 0$.

Equations (4)–(6) may also be written as

$$k_v = k_{ip}\left(\frac{1+e}{1+e_{ip}}\right)^{\kappa_v} \tag{10}$$

$$k_h = k_{ip}\left(\frac{1+e}{1+e_{ip}}\right)^{\kappa_h} \tag{11}$$

$$r_k = \left(\frac{1+e}{1+e_{ip}}\right)^{-(\kappa_v-\kappa_h)} \tag{12}$$

where k_{ip} is isotropic permeability for $e_1 = e_{ip}$ such that $r_k = 1$.

I believe that e_{ip}, k_{ip}, k_0', together with κ_v and $\kappa_v - \kappa_h$, may be used to characterize the permeability of soils.

By applying equations (4)–(12) to the experimental data presented in Figs 6 and 9 the results in Table 3 were obtained. The last column is the in situ value of k_0 from the equations (4)–(12); it compares well with the values of k_0 in Table 1.

From 6 m to 15 m depth, κ_v varies from 5·5 to 7·6, κ_h from 5·2 to 6·6 and $\kappa_v - \kappa_h$ from 0·5 to 1·5. Negative values of $\kappa_v - \kappa_h$ are unrealistic for a given soil sample. Values of e_{ip}, k_{ip} and r_{k0} that appear as unrepresentative of the clay deposit are written in parenthesis. When duplicated, values of k_0', κ and $\kappa_v - \kappa_h$ that appear representative are given in italics. It therefore appears that κ_v varies from 6·7 to 7·6. For the cases that are considered to be representative, the values of k_{v0}' vary from 0·26 to 0·82 × 10^{-12} m/s, e_{ip} varies from 4·3 to 5·2, k_{ip} varies from 0·91 to 3·6 × 10^{-7} m/s and the in situ permeability anisotropy r_{k0} varies from 1·8 to 3·1, i.e. the clay deposit is very uniform.

Table 3 also shows the parameters I have found (Juarez-Badillo, 1991) for other soils; additional data are given in Juarez-Badillo (1983).

An important topic for future research is the variation of all of these parameters as a function of the mineralogy, size, form, structure and activity of the solid particles and of the quality of water.

The relationship between the parameter C_k used by the Authors and κ is

$$C_k = de/d\log k = 2{\cdot}3k\, de/dk \tag{13}$$

Thus

$$\frac{1}{k}\frac{dk}{de} = \frac{2{\cdot}3}{C_k} \tag{14}$$

and, as

$$\kappa = \frac{dk/k}{de/(1+e)} = \frac{1+e}{k}\frac{dk}{de} \tag{15}$$

Table 3. Characteristics of laboratory permeability tests

Depth: m	Test	e_0	k_0': 10^{-12} m/s	κ	$\kappa_v - \kappa_h$	e_{ip}	k_{ip}: 10^{-7} m/s	r_{k_0}	k_0: 10^{-9} m/s
3	k_v oedometer	1·37	1·2	8·5	1·0	(0·25)	—	—	1·84
	k_h radial flow	1·65	1·5	7·5	—	—	—	—	2·24
6	k_v oedometer	1·97	*0·82*	*6·7*	*1·5*	5·1	1·5	2·9	1·21
	k_v triaxial (UL)	1·93	2·9	5·7	0·5	(16·7)	(380)	2·5	1·33
	k_h radial flow	1·84	12·2	5·2	—	—	—	—	2·78
9	k_v oedometer	2·20	0·25	7·0	1·0	(24)	(14,000)	(7·8)	0·86
	k_v triaxial (UL)	1·95	*0·40*	*7·5*	*1·5*	5·2	3·6	3·1	1·34
	k_h radial flow	1·74	6·2	6·0	—	—	—	—	2·62
12	k_v oedometer	1·89	*0·34*	*7·5*	*1·0*	4·3	0·91	1·8	0·97
	k_v triaxial (UL)	1·86	2·5	5·5	(−1·0)	—	—	—	0·81
	k_h radial flow	1·88	1·8	6·5	—	—	—	—	1·74
15	k_v oedometer	1·73	0·26	7·6	—	—	—	—	0·54
	k_h radial flow	1·60	*1·5*	*6·6*	*1·0*	4·8	1·6	2·2	0·82
	k_h radial flow	1·45	0·60	9·4	(−1·8)	—	—	—	2·73
Kaolin tested by Al-Tabba & Wood (1987)		k_v	11·1	5·5	2	2·4	0·093		
		k_h	128·3	3·5	—	—	—		
Mexico City clay		k_v	0·08	4·0	—	—	—		
Clay tested by Basak (1972)			—	—	4·5	—	—		
Sand statically compacted		k_v	$2·65 \times 10^{-6}$ m/s	10·4	2·4	0·815	$1·31 \times 10^{-3}$ m/s		
Chapuís *et al.* (1989)		k_h	$11·1 \times 10^{-6}$ m/s	8·0	—	—	—		

then

$$\frac{1}{k}\frac{dk}{de} = \frac{\kappa}{1+e} \tag{16}$$

Comparing equations (14) and (16) gives

$$C_k = 2·3(1+e)/\kappa \tag{17}$$

Equation (17) is very similar to the relationship between the compressibility index C_c and the coefficient of compressibility γ (Juarez-Badillo, 1975)

$$C_c = 2·3\gamma(1+e) \tag{18}$$

The values of C_k and C_c decrease when the volume decreases and both tend to zero, as they should, when the volume tends to zero ($e = -1$).

By taking $e_0 = 2$ and $\kappa_v = 7$ with $\kappa_h = 6$, for this clay in the neighbourhood of e_0, equation (17) gives

$$C_{kv} = \frac{2·3}{7}(1+2) = 0·9857 = 0·5e_0 \tag{19}$$

$$C_{kh} = \frac{2·3}{6}(1+2) = 1·15 = 0·58e_0 \tag{20}$$

Equation (19) agrees with the equation quoted by the Authors. For large compressive strains, the variation of C_k may be taken into account by equation (17), i.e. C_k is directly proportional to $1+e$.

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