DETERMINATION HORIZONTAL COSOLIDATION COEFFICIENT OF SOFT CLAY, MIDDLE HOLOCENE FORMATION, IN MEKONG RIVER DELTA, VIETNAM

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ABSTRACT: This article is represented the determination of coefficient of rate of horizontal consolidation of soil belong to amQ_2 formation distributed in Mekong delta in laboratory. Procedure for horizontal consolidation test with drainage radially inwards according to BS 1377: Part 6: 1990. This result showed that the horizotal coefficient(c_h) is always larger than the vertical coefficient (c_v) of consolidation of soil and the ratio of c_h/c_v is in the range of 1,46 to 35,68 for small pressure (before preconsolidation stress) and from 1,50 to 5,89 in normal consolidated state.

INTRODUCTION

We know the placement of an external load on a soft soil layer will induce excess pore water pressure, causing a consolidation process in which pore water is squeezed out of the soil, accompanied by a gradual increase in effective stress and a corresponding decrease in excess pore water pressure. The consolidation process will continue until the excess pore water pressure has dissipated, a process whose duration depends on the consolidation characteristics of the soil and the drainage paths. The installation of vertical band drains is to shorten the drainage paths and thereby reduce the time of consolidation (or required the time for the excess pore water pressure, induced by loading operation, to dissipate).The water flows from the soil in horizontal direction to drainage well (or vertical band drains) and dissipates through them. For most transported soil, the particle arrangement was formed such that the flow in horizontal direction is more dominant as compared to the vertical direction. Thus, under a consolidation pressure, water tends to flow faster from the soil in the horizontal direction than in the vertical direction. The particle arrangement will also influence the rate of flow as water tries to dissipate from soil under loading. General practice is to use coefficient of rate of horizontal consolidation (c_h) twice the coefficient of rate of vertical consolidation (c_v) for clay and the ratio is much higher for peat soil. Therefore, providing the ratio of horizontal consolidation coefficient and vertical consolidation coefficient is very important. In laboratory, we measured the horizontal coefficient of consolidation, c_h of soil by standard consolidation using Oedometer cell as similar to Rowe consolidation cell.

METHODOLOGY

Test equipment

Test equipment was designed as similar to Rowe consolidation cell [6,7] according to British standard BS 1377: part 6:1990 [3]. The “Rowe” consolidation cell was calibrated by Quatest 1[2]. Test equipment for horizontal consolidation includes (fig.1):

- Consolidation cell body of 62 mm internal diameter. At the center of the base is a small circular recess containing a porous ceramic for drainage water out. There is a pore pressure point is provided at distances 0,55R (R –the cell radius) from the center. At the rigid loading, there is a point to air going out. There is a air bleed valve in the rigid loading for saturated sample of soil.
- Dial gage for measuring vertical settlement (0,01mm)
- Drainge (or to saturation sample of soil).
- Pore pressure measurement include water pore pressure device.

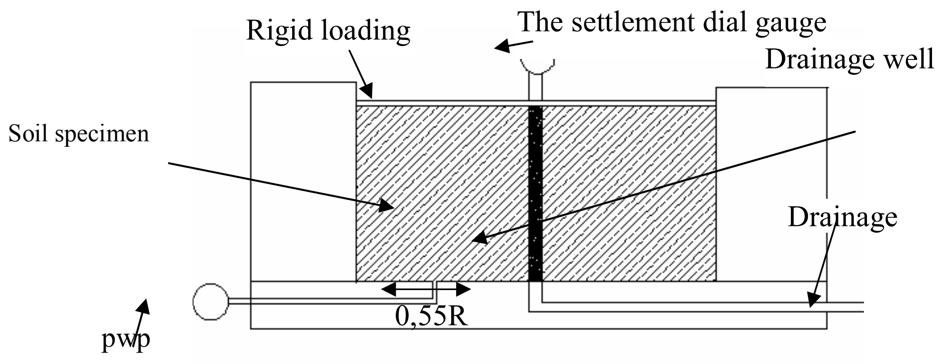

Figure 1 The "Rowe" consolidation cell for radial drainage to centre

The "Rowe" consolidation cell is placing in position on the bed of the loading apparatus of the traditional oedometer consolidation apparatus. A loading device having a rigid bed for supporting the consolidation cell. The device shall enable a vertical force to be applied in increments to the test specimen through a loading yoke. Each force increment shall be maintained constant by stress –control method while permitting increasing vertical compression of test during the consolidation test.

The advantage of "Rowe" consolidation cell:

+Drainage of the sample can be controlled, horizontal drainage to drainage well at the center axis, under rigid loading;

+Pore water pressure can be measured accurately at any time; pore pressure is measured in the base at a distance of 0.55R from the center (R is the radius of the cell).

Horizontal consolidation test procedures

Horizontal consolidation test procedures according to BS 1377:1990: Part 6 [3]. But when increment loading, using a loading device of the traditional odometer consolidation apparatus.

Evaluation of the coefficient of consolidation horizontal direction was performed on consolidation tests using "Rowe" consolidation cell with internal diameter of 62 mm and height of 20 mm. The horizontal consolidation was evaluated by horizontal drainage to drainage well center. The soil samples were subjected to loading consolidation pressures of 12.5, 25, 50,100, 200, and 400 kPa.

Sample preparation: After trimming of the sample and extruding sample into the consolidation cell body, the central drainage well is prepared. The hole diameter should normally be about 5% of sample diameter and filling the hole saturated fine sand.

Saturation: Stage connect the drainage valve on the base of the consolidation cell to the de-aerated water supply. Allow de-aerated water to enter the cell and slowly percolate upwards through the sample until it flows from the air bleed valve.

Consolidation (drainedstage): Initiate consolidation by opening the central stage drainage valve. Measure pore water pressure offset from centre.

Record the initial readings of pore pressure, the compression gauge indicator corresponding to zero time.

Open the valve of drainage and at the same instant start the timer.

Record readings of pore pressure, the compression gauge indicator at suitable intervals of time after opening the drainage valve. Intervals of 0, 1/4. 1/2, 1,2,4, 8, 15,30, 60 min; 2, 4, 24 h, are convenient for plotting on a log time base. Alternatively intervals of 0, 1/4, 1/2, 1, $2^{1/4}$, 4, 9, 16, 25, 36, 49, 64 min; $1^{1/2}$,2,4, 8, 24h are more convenient for a square –root time plot.

Close the drainge valve to terminate the load stage. Record the final readings of pore pressure, settlement gauge indicator.

Increase the diaphragm pressure to give the next vertical stress on the specimen, as described in above.

Repeat those for each value of applied stress in the desired loading sequence.

Unloading stage

After completing the consolidation stage under the maximum applied pressure record the final readings and close the valve. Unload the specimen in a sequence of decrements of diaphragm pressure.

Ploting results: as consolidation proceeds, plot the following graphs from the observed data.

Settlement (ΔH mm) against log time. This graph should be kept up to date during each stage so that the approach to 100% primary consolidation can be monitored. This graph can be used to obtain T_{50} to be calculated c_h.

Calculate void ratio at the end of each loading stage and plot the void ratio against effective pressure on a log scale. This graph could be used to obtain, c*c* and *cr*. Pre-consolidation pressure can also be obtained if possible.

Test data analysis

Barron (1948) [8,9] conducted a comprehensive of consolidation with radial inward flow by making assumption similar to Terzaghi's one –dimensional consolidation theory except that the water flow was considered to be in horizontal direction. The following assumptions are made for the analysis of horizontal consolidation of soil:

- Soil is homogeneous and isotropic
- Soil is fully saturated
- Soil deforms on the vertical direction only.
- The pore water and soil particles are incompressible
- Darcy's law is valid.
- Water only dissipates from soil in the horizontal direction via either inward or outward radial drainage and vertical is prevented.

Two types of vertical boundary conditions were considered by Barron: free vertical strain and equal vertical strain. Free vertical strain results from a uniform distribution of surface load. The assumption is that the vertical surface is constant during consolidation process and thus, that the resulting surface displacement are non-uniform. Equal vertical strain results from imposing the same vertical deformation at all points on the surface. The assumption is that the vertical surface displacement are constant throughout the drained area and thus, that the resulting vertical stress at the surface is non-uniform.

For radial consolidation test subject to free vertical strain, the governing equation in cylindrical coordinates is shown in the following equation:

$$\frac{\partial u}{\partial t} = \left(\frac{1}{r}.\frac{\partial u}{\partial r} + \frac{\partial^2 u}{\partial^2 r}\right).c_h \quad (1)$$

where, u-excess pore pressure at any point and any time;

T-time after an instantaneous increase of the total vertical stress;

R-radial distance of the considered point from the centre of the drained soil cylinder;

c_h-coefficient of consolidation for horizontal flow, $c_h = \frac{k_h m_v}{\gamma_w}$

k_h-coefficeint of permeability for horizontal flow;

γ_w-unit weight of water;

m_v-coefficeint of volume compressibility.

For equal vertical strain, which is given in the following equation:

$$u = \frac{u_0}{r_e^2.F(n)}\left[r_e^2 \log_e\left(\frac{r}{r_w}\right) - \left(\frac{r^2 - r_w^2}{2}\right)\right] \exp(\lambda) \quad (2)$$

where, u- excess pore pressure;
u_0-initial excess pore pressure;
r_e-radius of equivalent soil cylinder ($d_e/2$);
r_w –radius of drain ($d_w/2$).

$$\lambda = -\frac{8T_h}{F(n)};\ T_h = \frac{c_h t}{d_e^2};$$

n-the drain spacing ratio, $n = d_e/d_w$;

d_e-the diameter of cylinder soil around drain;

d_w-the diameter of drain

$$F(n) = \frac{n^2}{(n^2-1)}\ln(n) - \frac{(3n^2-1)}{4n^2} \quad (3)$$

In this case, the average degree of consolidation due to radial drainage becomes:

$$U_r = 1 - \exp\left[\frac{-8T_h}{F(n)}\right] \quad (4)$$

Head, 1986 [8] provided the calculation of the horizontal coefficient of consolidation, c_h, in all free vertical strain or equal vertical strain condition.

For consolidation cell which we designed, in case equal vertical strain condition, horizonal drainage to drainage well at the center axis, the horizontal coefficient of consolidation, c_h, is calculated from the following equation:

$$c_h = 0{,}102\frac{(D/2)^2}{t_{50}} \text{ (m}^2\text{/year)} \quad (5)$$

D-diameter of soil specimen cylinder, mm;

t_{50}- time to 50% degree of consolidation, minutes.

RESULT OF HORIZONTAL CONSOLIDATION TEST ON VERY SOFT SOIL OF MEKONG DELTAL

Soil identification tests are carried out in order to determine the soil's physical propertVies and to classify the soil (TCVN 1995). The tests for index properties include tests of moisture content, the soil's unit weight and specific gravity (TCVN 1995). Organic content of the soil are determined from the loss of ignition test whereby the oven dried mass of soil is further heated at a temperature of 440°C for 4 hours (BS 1377-3 or ASTM D2974)

Evaluation of the coefficient of consolidation horizontal direction was performed on consolidation tests using "Rowe" consolidation cell. The vertical consolidation was tested under two-way vertical drainage on the traditional oedometer consolidation apparatus, while the horizontal consolidation was evaluated by horizontal drainage to drainage well center. Under both conditions, the soil samples were subjected to loading consolidation pressures of 12.5, 25, 50,100, 200, and 400 kPa. The sample was placed in Kien Giang, Tien Giang and Soc Trang province. Test result shows in table 1, table 2 and fig. 2, fig. 3.

Table 1 Summary of physical soil properties of soil samples

No	Soil parameter			Unit	Sample No										
					KG1	KG2	KG3	TG1	TG2	ST1	TG12	TG13	TG16	TG17	TG18
1	Particle size distribution	sand	> 0,1	%	4,6	21,5	9,7	1,5	2,0	13,0	1,5	0,4	1,7	1,2	1,1
			0,1 – 0,05	%	10,1	8,6	4,5	29,8	31,7	32,0	6,0	8,8	5,8	3,8	3,2
		silt	0,05 - 0,01	%	14,6	18,7	25,0	18,3	20,0	12,0	10,7	10,7	12,2	15,7	12,7
			0,01-0,005	%	16,3	12,9	15,2	9,2	13,2	12,0	37,8	21,1	28,2	18,1	24,3
		clay	<0,005	%	53,3	38,3	45,6	41,1	33,2	31,0	44,0	59,0	52,1	61,2	58,7
2	Moisture content			%	65,6	98,0	82,0	69,0	75,0	56,0	56,5	79,9	76,3	86,0	78,9
3	Unit weight			g/cm^3	1,57	1,45	1,50	1,57	1,55	1,65	1,64	1,48	1,54	1,44	1,53
4	Dry unit weight			g/cm^3	0,95	0,73	0,82	0,93	0,89	1,06	1,05	0,82	0,87	0,77	0,86
5	Specific gravity			g/cm^3	2,65	2,62	2,66	2,67	2,68	2,67	2,67	2,69	2,65	2,67	2,66
6	Void ration				1,795	2,578	2,227	1,874	2,026	1,524	1,548	2,270	2,034	2,449	2,110
7	Porosity			%	64,2	72,0	69,0	65,2	67,0	60,4	60,8	69,4	67,0	71,0	67,8
8	Degree of saturation			%	96,8	99,6	97,9	98,3	99,2	98,1	97,5	94,7	99,4	93,8	99,5
9	Liquid limit			%	56,2	74,0	68,6	62,2	64,3	46,8	57,4	64,3	58,6	59,2	54,5
10	Plastic limit			%	39,1	45,1	38,0	35,0	36,4	28,8	25,2	29,6	25,5	27,5	23,0
11	Plasticity index			%	17,1	28,9	30,6	27,2	27,9	18,0	32,2	34,7	33,1	31,7	31,5
12	Liqidity index				1,55	1,83	1,44	1,25	1,38	1,51	0,97	1,45	1,53	1,85	1,77
13	Organic content			%							3,5	4,5	4,8	5,3	4,0

It can be observed from Table 3 that for a range of consolidation pressure of 12.5 kPa to 400 kPa, the *ch/cv* ratio for the soil based on Casagrande's method range from 1.46 to 35,86. It is in the range of 1,46 to 35,68 for small pressure (before preconsolidation stress) and from 1,50 to 5,89 in normal consolidated state.

The ratio of *ch*/*cv* of the soil is greater than 1 implies that more void spaces are created within the soil horizontally than vertically as the consolidation pressure is applied incrementally on the soil. Hence, excess pore water within the soil tends to dissipate faster in the horizontal direction than in the vertical direction when the soil is subjected to a consolidation pressure. The results indicate that the utilization of horizontal drain may be suitable for soil improvement to accelerate the primary consolidation process of the soil.

Table 2 Summary of the horizontal and vertical coefficients calculation

No	Sample No	The horizontal coefficient of consolidation, c_h, m^2/year						The vertical coefficient of consolidation, c_v ,m^2/year						Ratio c_h/c_v					
		Consolidation pressure, σ, kG/cm^2						Consolidation pressure, σ,kG/cm^2						Consolidation pressure, σ,kG/cm^2					
		0-0,125	0,125-0,25	0,25-0,5	0,5-1,0	1,0 -2,0	2,0-4,0	0-0,125	0,125-0,25	0,25-0,5	0,5-1,0	1,0 -2,0	2,0-4,0	0-0,125	0,125-0,25	0,25-0,5	0,5-1,0	1,0 -2,0	2,0-4,0
1	KG1	7,75	5,77	2,20	0,89	0,72	0,69	0,22	0,16	0,15	0,15	0,14	0,14	34,45	35,68	14,80	5,77	5,16	4,87
2	KG2	39,77	24,03	7,78	1,66	0,84	0,84	2,67	1,66	0,55	0,37	0,27	0,21	14,90	14,47	14,26	4,51	3,08	4,08
3	KG3	6,41	2,56	2,53	1,76	0,74	0,68	1,86	0,95	0,70	0,31	0,27	0,23	3,45	2,68	3,62	5,60	2,79	2,94
4	TG1	5,36	0,92	0,92	0,91	0,91	0,89	0,58	0,51	0,37	0,28	0,27	0,21	9,18	1,81	2,46	3,20	3,43	4,24
5	TG2	9,86	4,81	3,49	1,86	1,53	1,03	0,67	0,51	0,33	0,31	0,27	0,20	14,80	9,38	10,75	5,89	5,64	5,22
6	ST1	11,92	3,20	2,51	1,28	1,00	0,89	0,43	0,40	0,32	0,27	0,22	0,18	27,96	8,11	7,93	4,77	4,63	4,90
7	TG12	4,69	5,64	0,98	0,96	0,93	0,89	1,10	0,93	0,67	0,58	0,51	0,33	4,27	6,09	1,46	1,65	1,84	2,73
8	TG13	12,98	9,15	8,15	1,15	1,21	1,45	2,71	1,86	0,79	0,61	0,80	0,96	4,79	4,92	10,32	1,90	1,50	1,51
9	TG16	18,25	3,10	6,78	1,20	1,22	4,09	4,34	1,88	1,92	0,76	0,77	1,08	4,21	1,65	3,53	1,58	1,59	3,78
10	TG17	10,26	5,64	7,27	4,58	2,30	3,64	1,93	2,05	0,89	0,84	0,76	0,74	5,33	2,75	8,16	5,44	3,03	4,90
11	TG18	14,17	7,27	6,04	3,10	2,52	5,64	4,06	2,12	1,29	1,35	1,19	1,19	3,49	3,42	4,69	2,30	2,12	4,73
Average		12,86	6,55	4,42	1,76	1,27	1,88	1,87	1,18	0,72	0,53	0,50	0,50	11,53	8,27	7,45	3,87	3,17	3,99
Max		39,77	24,03	8,15	4,58	2,52	5,64	4,34	2,12	1,92	1,35	1,19	1,19	34,45	35,68	14,80	5,89	5,64	5,22
Min		4,69	0,92	0,92	0,89	0,72	0,68	0,22	0,16	0,15	0,15	0,14	0,14	3,45	1,65	1,46	1,58	1,50	1,51

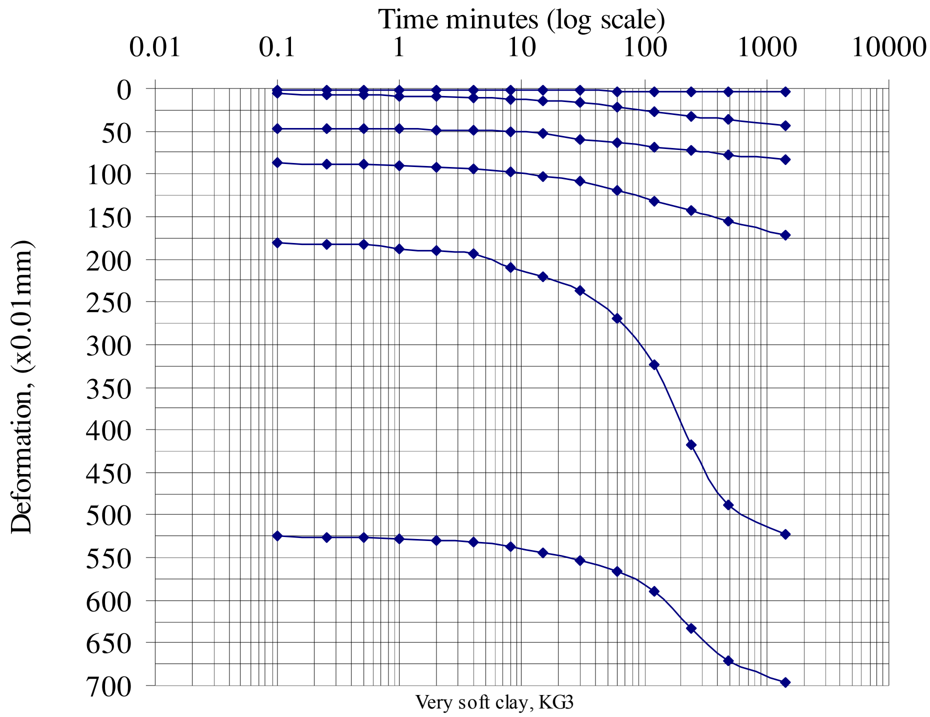

Figure 2 Deformation vs time plot for very soft clay sample KG3

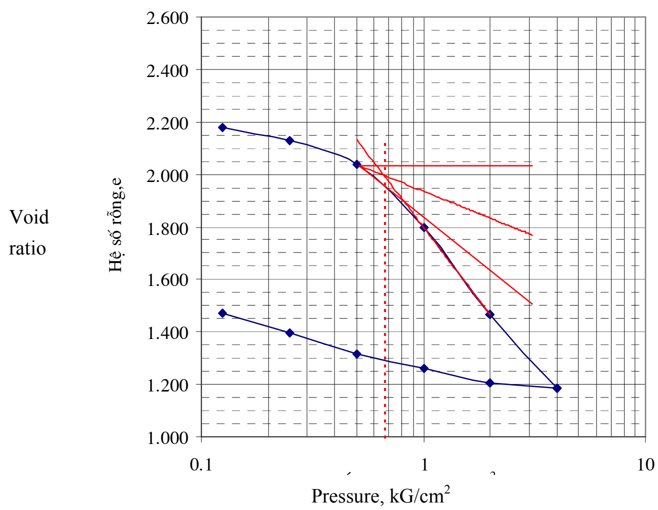

Figure 3 Void ratio vs pressure plot

CONCLUSION

The determination of coefficient of rate of horizontal consolidation of soil belong to amQ$_2$ formation distributed in Mekong delta in laboratory was showed that the horizotal coefficient (c_h) is always larger than the vertical coefficient (c_v) of consolidation of soil and the ratio of them (c_h/c_v) is in the range of 1,46 to 35,68 for small pressure (before preconsolidation stress) and from 1,50 to 5,89 in normal consolidated state.

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