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Consolidation Settlement Analysis of Cemented Clay Layer Including Effect of Curing Pressure

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Abstract**:** *In geotechnical analyses on cemented clay layers, the shear strength and compressibility parameters are generally obtained from laboratory tests on cement admixed clay specimens, cured under atmospheric pressure. In practice, after completion of operation of jet grouting technique, the improved clay layers are actually cured under confining pressure of the surrounding clays. Thus, the results from the analyses on cemented clay layers must be different from the actual behaviors in the field. In this paper, the influence of curing pressure on consolidation settlement of cemented clay was investigated. The simulations of consolidation settlement due to uniform load were performed on the cemented clay layer. The simulation results show that final settlement decreased with increasing cement content and curing pressure. The rate of settlement with time increased with increasing cement content for both curing pressures of 0 kPa and 50 kPa. The simulation results also show that the rate of settlement with time increased with increasing curing pressure for both cement contents of 1 and 2 percent.*

Keywords: *Cement admixed clay, consolidation, settlement, curing pressure*

1. Introduction

In constructions of foundation, pavement layers or other earthworks on soft clay layers, the excessive settlement and slope failure is generally encountered due to high compressibility and low shear strength of soft clay. Typically, soil stabilization by adding cement into clay is used to improve characteristics of soft clay. The jet grouting, one of popular techniques, is often chosen to improve soft clay layers [1-3].

In geotechnical analyses on cemented clay layers, the shear strength and compressibility parameters are generally obtained from laboratory tests on cement admixed clay specimens, cured under atmospheric pressure. However, after completion of operation of jet grouting technique, the improved clay layers are actually cured under confining pressure of the surrounding clays [4-6]. Uchaipichat [7] reported that with increasing curing pressure and cement content, the value of recompression index decreased while the value of compression index was approximately constant. Furthermore, the values of preconsolidation pressure and coefficient of consolidation increased with increasing curing pressure. Thus, the results from the analyses on cemented clay layers must be different from the actual behaviors in the field.

In this paper, the influence of curing pressure on consolidation settlement of cemented clay layers caused by applied uniform load was simulated. The comparison between simulation results for cement admixed clay layer with different curing pressures was also presented. The parameters used in simulations were obtained from experimental data reported by Uchaipichat [7].

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2. Consolidation Settlement of Clay Layer

Consolidation settlement of clay layer is the time-dependent settlement which occurs during consolidation process in the clay layer. During the consolidation process, the change in effective stress of clays and settlement of the layer occur simultaneously. The consolidation settlement analysis of clay layer can be performed based on the classical consolidation theory proposed by Terzaghi [8]. Using this theory, Taylor [9] presented the relationship between two dimensionless terms, namely consolidation ratio and time factor, at any point in the clay layer. However, in practice, engineers are typically interested in the average value of consolidation ratio throughout clay layer, which is defined as,

$$U_{avg}(\%) = (S_t / S_f) \times 100 \tag{1}$$

in which, U_{avg} is the average consolidation ratio, sometimes called degree of consolidation or percent of consolidation, S_t is the consolidation settlement for any elapse time, and S_f is the final consolidation settlement at the end of consolidation. The final settlement can be calculated using the parameters which are obtained from compression curve plotted between void ratio and logarithm of vertical effective stress.

In case of normally consolidated clay, the final settlement can be expressed as,

$$S_f = H_c C_c \log(\sigma'_f / \sigma'_o)/(1+e_o) \tag{2}$$

in which, H_c is the thickness of clay layer, C_c is the compression index which is the slope of compression curve in the normal consolidation range, e_o is the initial void ratio, σ'_o is the initial vertical effective stress and σ'_f is the final effective stress at the end of consolidation.

In case of overconsolidated clay, the calculation final settlement can be expressed as,

$$S_f = H_c C_r \log(\sigma'_f / \sigma'_o)/(1+e_o) \qquad \text{for} \quad \sigma'_f < p'_c \tag{3}$$

$$S_f = H_c [C_r \log(p'_c / \sigma'_o) + C_c \log(\sigma'_f / p'_c)]/(1+e_o) \qquad \text{for} \quad \sigma'_f > p'_c \tag{4}$$

in which, p'_c is the preconsolidation pressure, C_r is the recompression index.

Das [10] proposed the relationship between the time factor and the average consolidation ratio, which can be expressed as,

$$T_v = (\pi/4)(U_{avg}/100)^2 \qquad \text{for} \quad U_{avg} < 60\% \tag{5}$$

$$T_v = 1.781 - 0.933\log(100 - U_{avg}) \qquad \text{for} \quad U_{avg} > 60\% \tag{6}$$

in which, T_v is the time factor and can be expressed as,

$$T_v = c_v t / H^2 \tag{7}$$

where, c_v is the coefficient of consolidation, t is the elapse time, and H is the length of drainage path. The value of $H = H_c/2$ if there are the drainages at both top and bottom of the clay layer, and the value of $H = H_c$ if there is the drainage at either top or bottom of the clay layer.

3. Simulation of Consolidation Settlement

In this paper, the simulations of consolidation settlement due to large area of uniform load ($\Delta\sigma$) of 300 kN/m^2 were performed on the cemented clay layer with the thickness of 5 m as shown in Fig. 1. The drainages are at both top and bottom of the clay layer. The consolidation settlement were simulated using equations (1) to (7). The clay layer was divided into 10 sub-layers in calculating the final settlement. The properties of clay used in the simulations were obtained from the experimental data reported by Uchaipichat [7] as shown Table I.

The values of simulated settlement for all cases are shown in Table II. The final settlement decreased with increasing cement content and curing pressure. The simulation results of the change in average consolidation ratio and settlement with time for cemented clay layer with various cement contents are presented in Fig. 2. It can be noticed that the rate of settlement with time increased with increasing cement content for both curing pressures of 0 kPa and 50 kPa. Fig. 3 shows the comparison between simulation results for cemented clay layer with curing pressures of 0 kPa and 50 kPa. The simulation results show that the rate of settlement with time increased with increasing curing pressure for both cement contents of 1 and 2 percent.

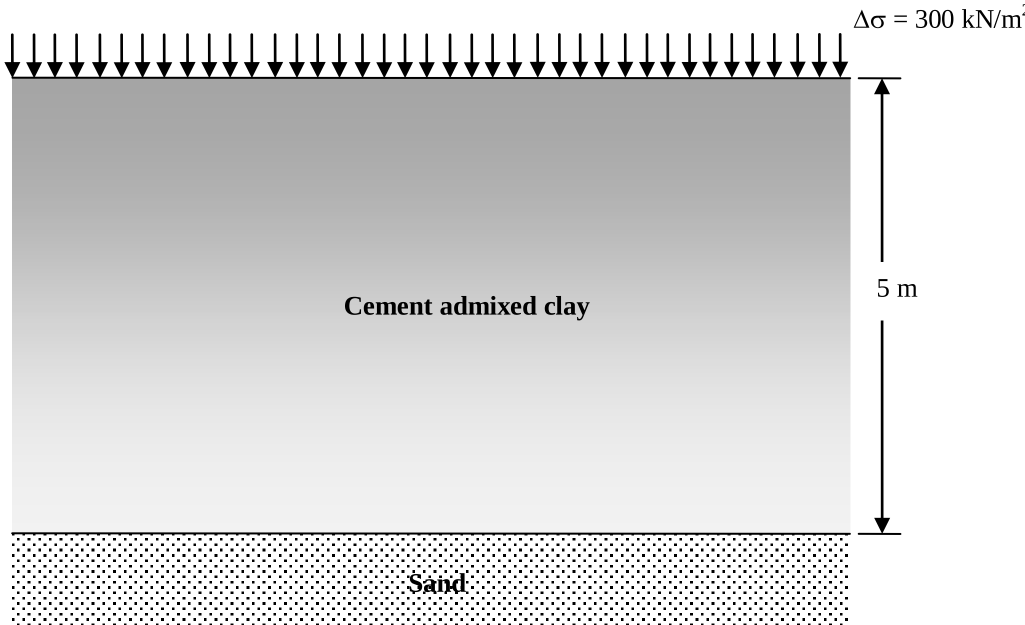

Fig. 1: Soil layer and uniform load used in simulation.

TABLE I: Parameters Used in Simulations [7]

Cement content	Curing pressure (kPa)	Initial state	e_o	Total unit weight (kN/m^3)	$c_v \times 10^{-7}$ * (m^2/s)	C_r	C_c	p'_c (kN/m^2)
0%	0	Normally Consolidated	1.191	17.51	0.618	0.040	0.15	-
1%	0	Overconsolidated	0.485	21.17	1.054	0.030	0.15	150
1%	50	Overconsolidated	0.270	23.01	2.734	0.020	0.15	500
2%	0	Overconsolidated	0.453	21.42	1.276	0.020	0.15	270
2%	50	Overconsolidated	0.261	23.19	4.718	0.015	0.15	750

* Average value for the effective stress ranging from 25 to 400 kPa

TABLE II: Final Consolidation Settlement

Cement content	Curing pressure (kPa)	Final settlement (m)
0%	0	0.458
1%	0	0.257
1%	50	0.088
2%	0	0.119
2%	50	0.066

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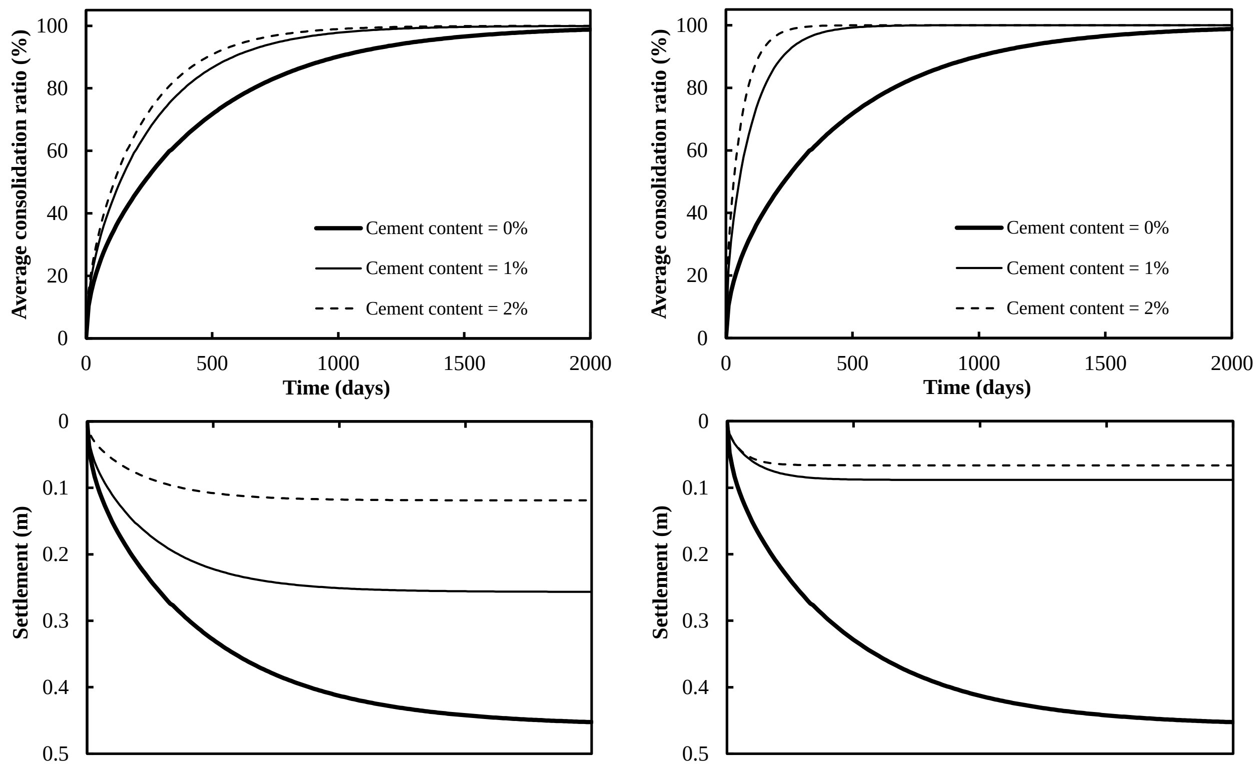
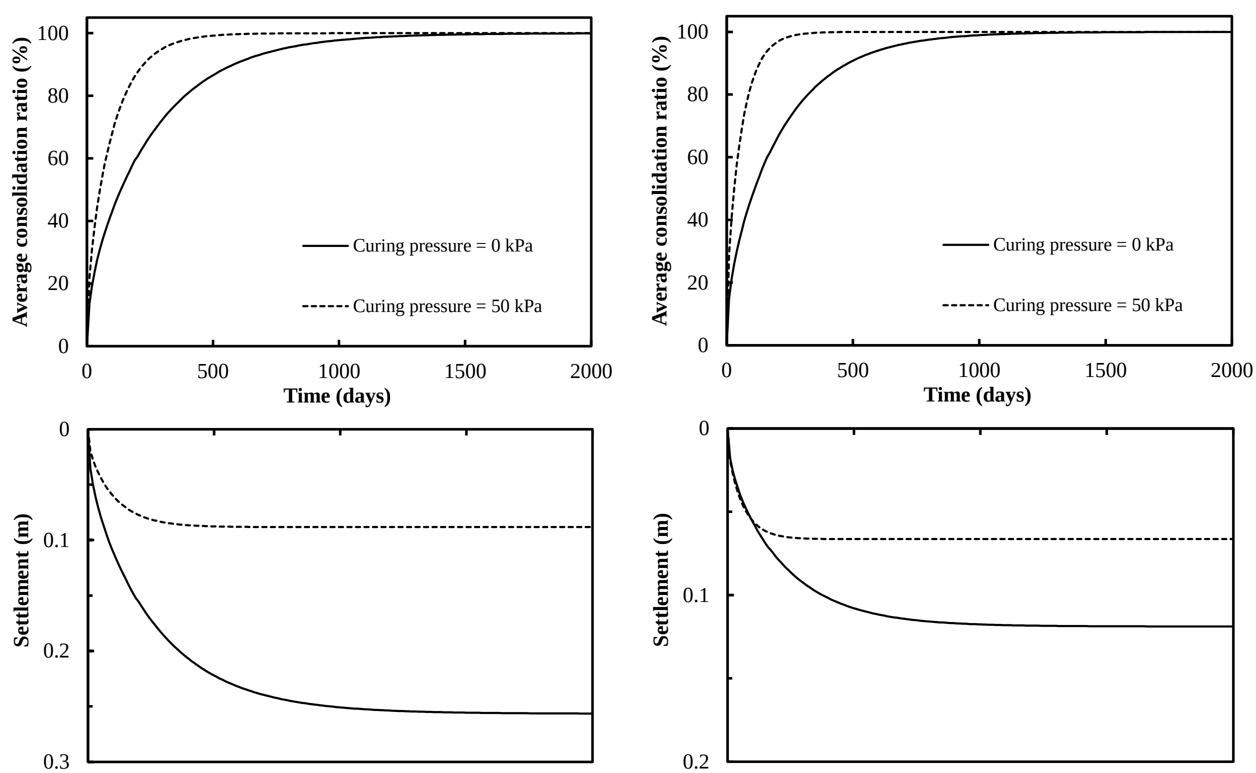


(a) Curing pressure = 0 kPa

(b) Curing pressure = 50 kPa

Fig. 2: Simulation results for cement admixed clay layer with various cement contents.



(a) Cement content = 1 %

(b) Cement content = 2%

Fig. 3: Comparison between simulation results for cement admixed clay layer with curing pressures of 0 kPa and 50 kPa.

4. Conclusions and Discussions

The simulations of consolidation settlement due to uniform load were performed on the cemented clay layer. The simulation results show that final settlement decreased with increasing cement content and curing pressure. The rate of settlement with time increased with increasing cement content for both curing pressures of 0 kPa and 50 kPa. The simulation results also show that the rate of settlement with time increased with increasing curing pressure for both cement contents of 1 and 2 percent.

From this study, engineers should be careful that, with using the parameters obtained from laboratory tests on cement admixed clay specimens which were cured under atmospheric pressure, the final settlement from the analysis is overestimated while the settlement from the analysis is slower than that in the field. Therefore, using these parameters in design and analysis can increase the construction cost due to the requirement of larger foundation and addition works to solve the excessive settlement.

5. Acknowledgements

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6. References

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