III - A194 LINEAR ln(e)-ln(p'c) RELATION OF STRUCTURED NATURAL CLAY

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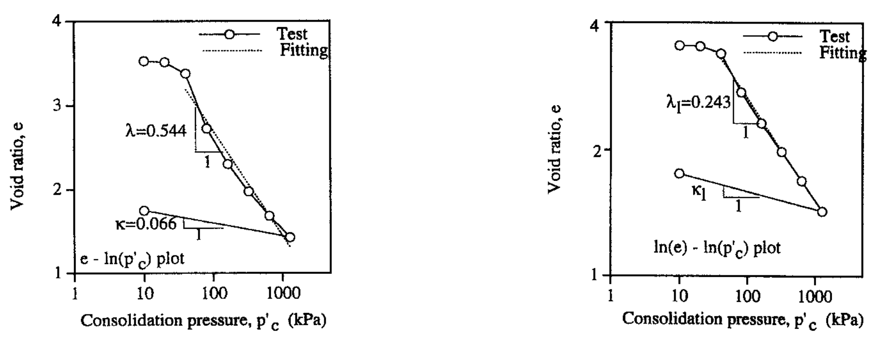
1. Introduction

For structured natural clay, the relation between void ratio (e) and consolidation pressure (p'_c) is more linear in ln(e) - ln(p'_c) plot than in e - ln(p'_c) plot. A settlement calculation equation by using linear ln(e) - ln(p'_c) relation was derived and applied to calculate the load-settlement curve of the undisturbed Ariake clay. The linear ln(e) - ln(p'_c) relation was also incorporated into the modified Cam clay model by modifying the hardening function. It is shown that with the linear ln(e) - ln(p'_c) relation, the model can represent the consolidation behavior of structured natural clay better.

2. Compression Curve of Structured Natural Clay

For remolded clay, the compression curve in e - ln(p'_c) plot is very close to a straight line, and which forms the base of conventional one-dimensional (1D) settlement calculation equation. However, the most natural clays are structured due to aging, cementation effect, etc. For these kind of clays, the compression curve is nonlinear in e - ln(p'_c) plot. This nonlinear phenomenon has been reported by several investigators[1].

It had been noticed that for the most of natural clays, the ln(e) - ln(p'_c) relation is close to linear[2]. Figs. 1 (a) and (b) show a typical laboratory consolidation test result of undisturbed Ariake clay. It can be clearly noticed that ln(e) - ln(p'_c) plot (Fig. 1 (b)) has a better linearity than e - ln(p'_c) plot (Fig. 1 (a)). Butterfield[2] proposed a compression law using a linear ln(1+e) - ln(p'_c) relation, in which the natural strain was used. In this study, for easy to computer the settlement with the linear ln(e) -ln(p'_c) relation, an equation similar to that of conventional settlement calculation was derived. Defining the slop of virgin compression line in ln(e) - ln(p'_c) plot as λ_l (Fig. 1 (b)), the vertical strain (ε_v) for 1D case is as follows:



(a) e - ln(p'_c) plot (b) ln(e) - ln(p'_c) plot

Fig. 1 A typical compression curve of undisturbed Ariake clay

$$\varepsilon_v = \frac{e_0}{1+e_0}\left[1-\left(\frac{p'_c}{p'_{c0}}\right)^{-\lambda_l}\right] \qquad (1)$$

where e_0 = initial void ratio and p_{c0} = yield stress. The Eq. (1) can be used for 1D settlement calculation. To illustrate the difference of using λ_l and λ (Fig. 1 (a)) on settlement calculation, the settlement versus load curves were calculated using the best fitted λ_l and λ values as indicated in Fig. 1. The computed results are compared with test data in Fig. 2. It can be seen that even the final settlement does not different much, using the linear ln(e) - ln(p'_c) relation yielded a much better simulation of the test data. The proposed equation is as simple as conventional one, and can be easily used in practice for structured natural clay deposit.

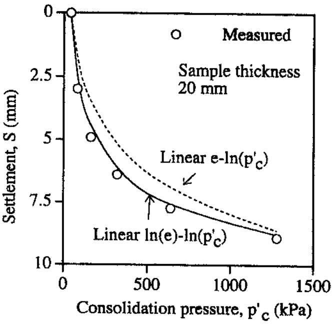


Fig. 2 Comparing the consolidation curves

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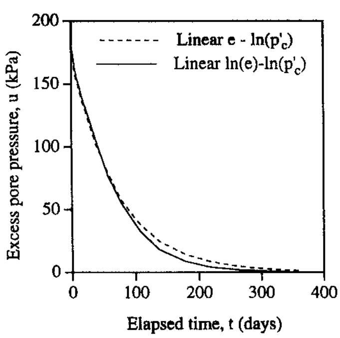
3. Incorporate Linear Ln(e)-Ln(P'$_c$) Relation into Modified Can Clay Model

The modified Cam clay model[3] is one of the widely used soil models for soft clay due to its simplicity and easy to determine the model parameters. However, the model assumes a linear e - ln(p'$_c$) relation, which does not represent the compression behavior of structured natural clay. In this study, the linear ln(e) - ln(p'$_c$) relation was incorporated into the modified Cam clay model by modifying the hardening law. The performance of the model is discussed by comparing the simulated consolidation results with those of using the linear e - ln(p'$_c$) relation.

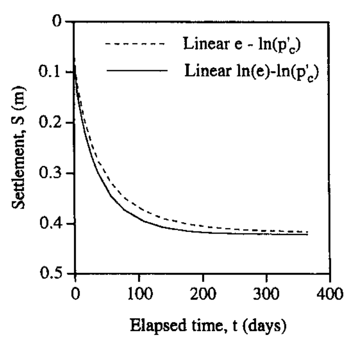
It has been derived that using a linear ln(e) - ln(p'$_c$) relation into the hardening law of modified Cam clay theory means to replace the λ by $e\lambda_1$. By this simple treatment, the compression behavior of the structured natural clay can be better modelled. Introducing the linear ln(e) - ln(p'$_c$) relation also implies that the critical state line is linear in ln(e) - ln(p'$_c$) plot. Butterfield[2] showed that although the critical state line is close to linear in e - ln(p'$_c$) plot, the linearity is slightly improved in ln(e) - ln(p'$_c$) plot.

The model was incorporated into a finite element program. 1D consolidation analyses were conducted and compared with those of using the linear e - ln(p'$_c$) relation. The discussions are made on the characteristics of the model.

Numerical 1D consolidations were conducted for a 1 m thick sample with one way drainage. The consolidation pressure was from 20 kPa to 220 kPa. The initial value of hydraulic conductivity was assumed as 10^{-8} m/sec. Since the non-linearity of the compression curve in e - ln(p'$_c$) plot (Fig. 2 (a)), in order to obtain a comparable value of final settlement, the λ value was redetermined for the stress level less than 220 kPa, which gave a value of λ=0.72. Other parameters were the same as those indicated in Fig. 1. It was assumed that the slope of failure line in q-p' (q is deviator stress and p' is mean effective stress) plot (M) is 1.2 (ϕ'=30°). Figs. 3 (a) and (b) compare the average excess pore pressure and settlement versus time curves. It can be seen that by introducing the linear ln(e) - ln(p'$_c$) relation, the initial consolidation rate was reduced and later on was increased in term of excess pore pressure variation (Fig. 3 (a)). However, for settlement, the initial settlement rate was increased and reduced later on when comparing with those of using the linear e - ln(p'$_c$) relation. There were several field cases[4] in which the settlement increased but with little excess pore pressure reduction. Although there are other influence factors on the field measured data, at least the linear ln(e) - ln(p'$_c$) relation gives an improved prediction on the consolidation behavior of the structured natural clay deposit.



(a) Time - excess pore pressure curves



(b) Time - settlement curves

Fig. 3 Simulate 1D consolidation results

4. Conclusions

For structured natural clay, the compression curve is more linear in ln(e) - ln(p'$_c$) plot than in e - ln(p'$_c$) plot. The equation of calculating the load-settlement curve using the linear ln(e) - ln(p'$_c$) relation was derived. For undisturbed Ariake clay, the linear ln(e) - ln(p'$_c$) relation simulated the test data well.

The linear ln(e) - ln(p'$_c$) relation was incorporated into the modified Cam clay model by modifying the hardening function. It has been demonstrated that using the linear ln(e) - ln(p'$_c$) relation can represent the consolidation behavior of the structured natural clay better.

5. References

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