EXPERIMENTAL INVESTIGATIONS ON THE STRESS CONCENTRATION ON LIME STABILIZED COLUMNS

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I INTRODUCTION

In the settlement analysis of soft ground improved with lime stabilized columns, the stress concentration on the stiffer lime columns is an important consideration. The load distribution is usually expressed in terms of the stress concentration factor, $n = \sigma_p/\sigma_s$, where σ_p is the stress on the lime columns and σ_s is the stress on the unstabilized soil. Recommended values of n are from 10 to 20 (DJM, 1990). This paper presents the results of laboratory model tests wherein the settlement of composite ground were investigated. From the settlement readings, stress concentration factors were back-calculated according to the equation: $S_0/S_1=1+A_p(n+1)$, where S_0 is the settlement of unimproved soil without columns and S_1 is the settlement of the composite group. Four model tests were carried out, with the improvement type either floating or end-bearing, and the applied loads were 0.2 and 0.4 kgf/cm^2. In addition, stress concentration factors based on results of oedometer and unconfined compression tests are also presented.

II EXPERIMENTAL DETAILS

Figure 1 shows a schematic diagram of the set-up for the model tests. Clay slurry (ω=150%) was first reconsolidated in a mold under a stress of 0.1 kgf/cm^2. Lime stabilized columns (5 cm diameter) were prepared, with 10% lime content and cured for 7 days, according to JSSMFE (1990). Using a thin-walled tube, holes were made in the reconstituted clay. Lime columns were then inserted into the holes (see Fig. 1), such that the area ratio, A_p=area of columns/total area=20%. The length of the lime columns was 7 cm for floating type or 14 cm for end-bearing type of improvement. Constant vertical load, supplied by a bellofram system, was applied through a rigid top plate to ensure equal settlement. The settlement of the composite ground was monitored until the readings were constant with time. The settlement of unimproved soil (without columns) was also measured under 0.2 and 0.4 kgf/cm^2 loads.

III RESULTS AND DISCUSSIONS

(A) **End-bearing type:** Figure 2 shows the settlements for the model tests. The settlements of the clay without improvement were 11 mm and 33 mm for q=0.2 and 0.4 kgf/cm^2, respectively. The settlements for the end-bearing type, which is equal to the elastic shortening of the columns, were very small (S_1<2mm). The significant reduction of settlements is a consequence of the very high stress concentration on the columns. Back-calculated stress concentration factors from the settlement readings were n=36.7 and 72.5 for loads of 0.2 and 0.4 kgf/cm^2, respectively. Note that the value of n was higher when the load was 0.4 kgf/cm^2; this is because the increase in S_0 was larger than the increase in S_1.

For equal settlement case, the stress concentration factor is usually expressed as a modular ratio: $n=M_p/M_s=\sigma_p/\sigma_s$. The DJM Manual (DJM, 1990) suggests the use of the constrained moduli from oedometer tests, i.e. $n=(m_{vs}/m_{vp})$=ratio of the oedometric moduli of the unstabilized soil (m_{vs}) and stabilized clay (m_{vp}). Figure 3 shows the results of oedometer tests conducted by Ogawa (1993). Considering the highly non-linear stress-strain behavior of soft clay, and also the range of linear behavior for stabilized soil, the oedometer tests will predict a wide range of n. For low strain levels of less than 2%, the stress concentration factor is about 16 to 22. It is also interesting to point out that the use of the moduli from unconfined compression tests, as shown in Fig. 4, gave stress concentration factors of n=15 to 25, for strain levels less than 2%. These results suggest that for end-bearing type of improvement, the stress concentration factors are much higher than the values obtained from oedometer and unconfined compression tests.

(B) **Floating type:** For floating type, the total settlements were 7 and 12 mm, for loads of 0.2 and 0.4 kgf/cm^2, respectively. This total settlement (S_1) is equal to the elastic shortening of the columns plus the settlement of the soft soil under the column group. Thus, the stress concentration to the floating lime columns is influenced by the settlement of the soft soil under the column group. The back-calculated values of stress concentration factor were n=4.5 under a load of 0.2 kgf/cm^2, and n=8.4 when the load was 0.4 kgf/cm^2. The low values of stress concentration for the floating type of improvement is due to the lower overall stiffness of a floating lime column as compared with an end-bearing lime column.

IV CONCLUSIONS

The stress concentration factor obtained from the results of oedometer and unconfined compression tests were found to agree with the recommended values of n=10 to 20. However, the results of model tests on reconsolidated soft clay improved with lime stabilized columns showed that the load distribution of composite ground is influenced considerably by the bearing mode of the improvement and also by the stress level. For end-bearing type of improvement, the stress concentration factors were much higher, with n=36.7 and 72.5 for applied loads of 0.2 and 0.4 kgf/cm^2, respectively. For floating type of improvement, the lower overall stiffness of the columns results to low values of stress concentration, with n=4.5 and 8.4 for applied loads of 0.2 and 0.4 kgf/cm^2, respectively.

REFERENCES: (1) DJM (1990). The Manual for the Dry Jet Mixing Method. Published by the Research Group on the DJM (in Japanese). (2) JSSMFE (1990). Methods and details of soil testing. (in Japanese).

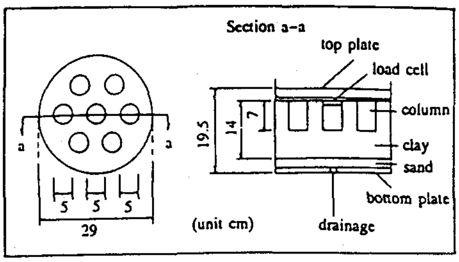

Fig.1 Details of model tests

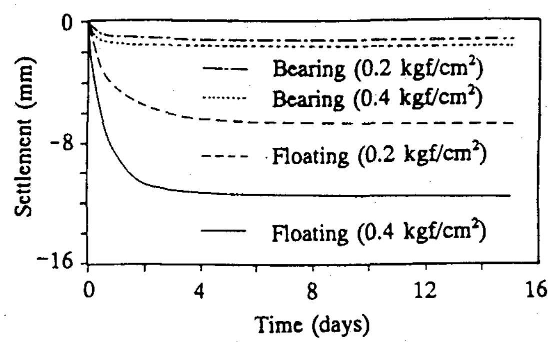

Fig. 2 Settlement data from model tests

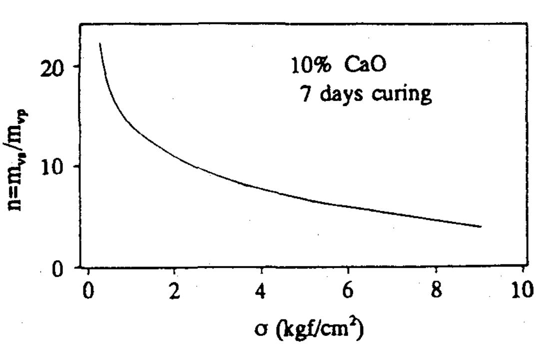

Fig. 3 Stress concentration factor from oedometer tests

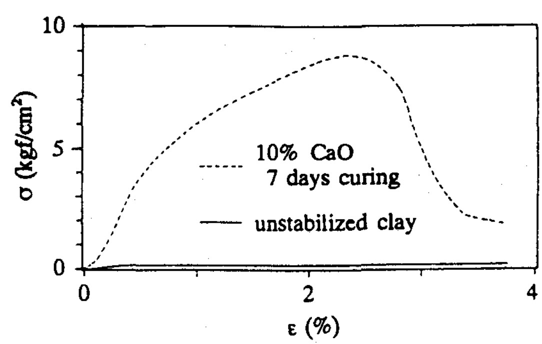

Fig. 4 Stress-strain curves from unconfined compression tests