Prediction of Negative Skin Friction on Columnar Inclusions in Soft Ground with Time

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1 INTRODUCTION

Negative skin friction or downdrag force developed along the rigid (timber/steel/concrete piles, lime/cement columns, etc.) or deformable (stone columns/granular piles, sand compaction piles, etc.) columns installed in soft ground is time dependent. A few methods are available to solve this problem due to the complexity of including the time dimension in the analysis, only the maximum skin friction is usually calculated and applied to the design by the practicing engineers. However, it is not always the case that the maximum downdrag force will develop during the life of the structure. Thus, the columns may be overdesigned if the maximum downdrag force is used. In this paper, a simple method of analysis is proposed to obtain the relationship between time and negative skin friction. Results are presented for a typical example.

2 THE PROBLEM AND THE METHOD OF SOLUTION

The considered foundation system is shown in Fig.1, in which columns are extended up to the bedrock in a homogeneous soft ground and subjected to uniform surface loading over the entire area. The foundation system is idealized into "unit cell" which consists of column and the surrounding soil zone of influence, shown in Fig.2. The magnitude of "unit cell" diameter, d_e depends on the spacing of columns and their arrangements (Balaam and Booker 1981). The mode of displacement due to the surface loading is shown in Fig.3. Since the column is siffer than the surrounding soil and as the consolidation of the clay layer proceeds, the surrounding soil moves faster than the column, and the time-dependent downdrag forces develop along the surface of column.

The idealized foundation model enjoys the condition of radial symmetry and the radial displacement component is negligible and hence can be neglected. Due to these conditions, the time-dependent solution presented by Alamgir (1996) based on the integral-differential equation proposed by Poorooshasb, Alamgir and Miura (1996) to solve this kind of time-independent problem, is employed here. The time-dependent response function of the problem can be expressed as

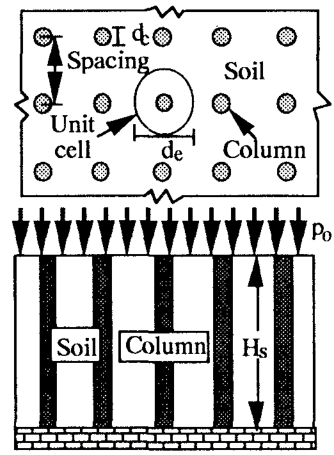

Fig.1 Problem to be analyzed.

$$\frac{\partial w(r,z)}{\partial z} + \frac{U(r,z)}{E_s(r,z)} \int_0^z \left[G(r,z)\left\{\frac{\partial^2 w(r,z)}{\partial r^2} + \frac{1}{r}\frac{\partial w(r,z)}{\partial r}\right\} + G'(r,z)\frac{\partial w(r,z)}{\partial r}\right] dz = \frac{U(r,z)p_o}{E_s(r,z)} \quad (1)$$

where G'(r,z) is the first order derivative of G(r,z) with respect to r. To solve the above equation, the evaluation of degree of consolidation, U(r,z) for t>0, is required. The "Diffusion Theory", Eq.2, which is an extension of Terzaghi's one dimensional consolidation theory is used in this analysis to determine the value of U(r,z) due to radial and vertical flow of water, as the some columnar inclusions have the free draining properties i.e. higher permeabilities than the surrounding soil.

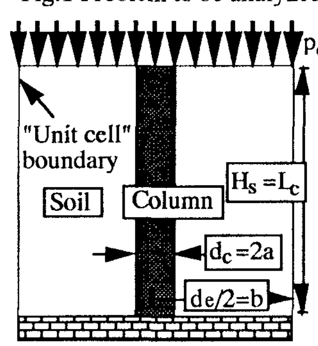

Fig. 2 "Unit cell" idealization.

$$\frac{\partial u}{\partial t} = C_v \frac{\partial^2 u}{\partial z^2} + C_h \left[\frac{\partial^2 u}{\partial^2 r} + \frac{1}{r}\frac{\partial u}{\partial r}\right] \quad (2)$$

where the symbols bear their usual meanings. The boundary conditions required to obtain a unique solution and the employed finite difference numerical scheme to solve the associated equations, are found in Alamgir (1996). As the consolidation of the clay media proceeds, the skin friction at column-soil interface, τ, at any time t>0, for no slip condition, can be obtained by Eq.3, where the superscript t stands for time level.

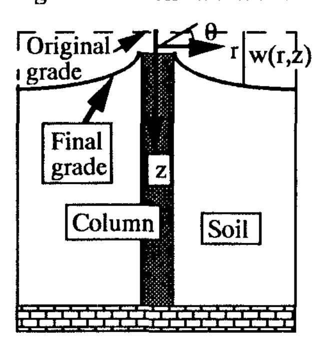

Fig.3 Mode of displacement.

$$\tau^t = G(a,z)\frac{\partial w^t(a,z)}{\partial r} \quad (3)$$

3 RESULTS AND DISCUSSIONS

A typical example of column-reinforced soft ground is considered for predictions in which the values of the parameters are $p_o/E_{so}=0.10$, $m_s/E_{so}=0.10$, $E_c/E_{so}=50$, $\nu_s=0.40$, $L_c/d_c=10$, $d_e/d_c=2.5$ to 10 and $C_h/C_v=1.0$ to 10. E_{so} is the soil modulus at the top, m_s is the rate of increase of soil modulus with depth. Time t is normalized as time factor, $T_v=[(C_h/H_s^2)*t]$.

The mobilization of skin friction with time is shown in Fig.4. The magnitude of skin friction increases as the consolidation proceeds and reaches the mximum value at the end of primary consolidation. At the early stage of loading i.e. for $T_v<0.001$, the normalized skin friction, τ/p_o, changes its sign from positive to negative, beyond a certain depth from the top of column. But after an elapsed time, $T_v>0.001$, the value of τ/p_o remains positive along the whole length of column. The variation of mobilized skin friction is more significant at smaller elapsed time i.e. $T_v<0.01$ than at later times.

The normal stresses in column, p_c, and soil, p_s, with time, are shown in Figs.5-7. Figure 5 shows that at any depth of column, p_c/p_o increases with time and reaches maximum value at the end of primary consoliadtion. At the initial stage of loading, p_c/p_o increases from unity up to a certain depth beyond which it decreases gradually to the tip of column. The changes of stress in column with time is significant in the early stages of loading than at later times. This change of stress in column is observed as expected since the skin friction changes its sign at the early stages of loading. Fig.6 shows that p_s/p_o increases as the consolidation proceeds and reaches the maximum value at the end of primary consolidation. At any time, p_s/p_o is unity at the surface and decreases gradually with depth. Beyond a certain depth p_s/p_o becomes constant. The variation of p_s/p_o with r/a, for various time levels, is shown in Fig.7. For $T_v<0.01$, p_s/p_o increases gradually with r/a up to a certain radial distance beyond which it decreases and becomes almost constant at r/a=n. For $T_v>0.002$, p_s/p_o increases with r/a and becomes almost constant at r/a=n.

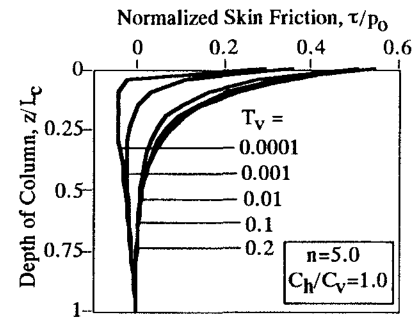

Fig.4 Skin friction with time.

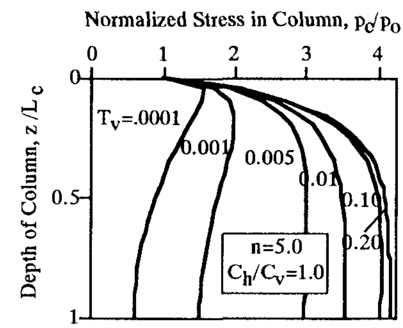

Fig.5 Stress in column with time.

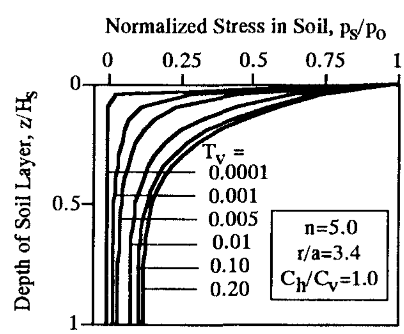

Fig.6 Stress in soil with time.

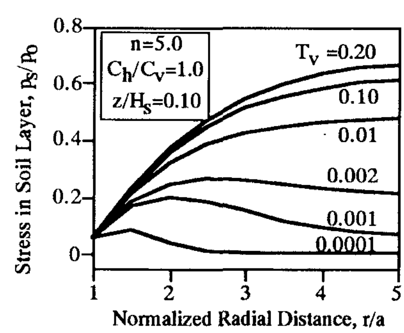

Fig.7 Stress in soil along r/a with time.

4 CONCLUSIONS

This study can be concluded as: (i) The magnitude of skin friction varies with time and appears to be function of flow parameters and the spacing of columns, (ii) The sharing of normal stresses by column and soil varies with time depending on the mobilization of skin friction, which is very significant at the early stage of loading, and (iii) The downdrag forces developed with time, not the maximum downdrag force, should be taken into account, otherwise the column may be overdesigned.

ACKNOWLEDGEMENT

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