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COMPARISON BETWEEN THEORIES FOR CONSOLIDATION BY VERTICAL DRAINS UNDER EQUAL AND FREE STRAIN CONDITIONS

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1. INTRODUCTION

All of Yoshikuni's (1974),Onoue's (1988) and Tang's(1996) theories for consolidation by non-ideal vrtical drains are rigorous. Tang's (1996) theory is based on the equal strain condition.The solutions are simple. Yoshikuni's (1974) and Onoue's (1988) theories are based on the free strain condition. The solutions are complicate. The comparison of the average consolidation degree of the whole soil layer between Yoshikuni's and Tang's theories was obtained by Tang (1996). In order to further study the difference between the solutions under equal and free strain conditions, the other comparisons between results obtained by Tang's solutions and Yoshikuni's or Onoue's solutions are presented in this paper.

2. ANALYSIS MODELLING

Fig.1 is the analysis scheme. (There is no smear zone in Yoshikuni's (1974) analysis scheme).
where: H- vertical drainage path distance of soil layer; r_w- radius of vertical drain; r_s- radius of smear zone; r_e- radius of drain influence zone; k_h- horizontal coefficient of permeability of soil; k_v- vertical coefficient of permeability of soil; k_s - horizontal coefficient of permeability of remolded soil; p_0 - uniform load; u_0-uniform initial pore pressure.

3. SOLUTIONS UNDER FREE AND EQUAL STRAINS CONDITIONS

The solutions under free strain condition were presented by Yoshikuni (1974) and Onoue (1988).
According to Tang (1996), the solutions under equal strain condition are presented as follow:

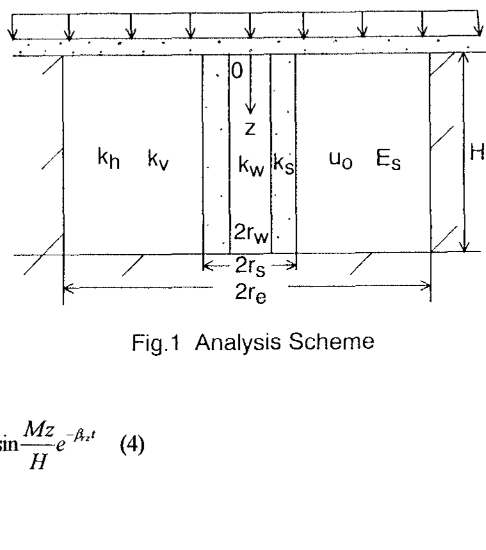

Fig.1 Analysis Scheme

The average pore pressure at any depth is:

$$\bar{u}_{rz} = u_0 \sum_{m=0}^{\infty} \frac{2}{M} \sin\frac{Mz}{H} e^{-\beta_{rz} t} \quad (1)$$

The pore pressure in vertical drains at any depth is:

$$u_w = u_0 \sum_{m=0}^{\infty} \frac{D_m}{F+D_m} \frac{2}{M} \sin\frac{Mz}{H} e^{-\beta_{rz} t} \quad (2)$$

The pore pressure at any point in smear zone is:

$$u_{rz1} = u_0 \sum_{m=0}^{\infty} \frac{1}{F+D_m}\left[\frac{k_h}{k_s}\left(\ln\frac{r}{r_w} - \frac{r^2-r_w^2}{2r_e^2}\right) + D_m\right]\frac{2}{M}\sin\frac{Mz}{H} e^{-\beta_{rz} t} \quad (3)$$

The pore pressure at any point in natural soil zone is:

$$u_{rz2} = u_0 \sum_{m=0}^{\infty} \frac{1}{F+D_m}\left[\left(\ln\frac{r}{r_s} - \frac{r^2-r_s^2}{2r_e^2}\right) + \frac{k_h}{k_s}\left(\ln s - \frac{s^2-1}{2n^2}\right) + D_m\right]\frac{2}{M}\sin\frac{Mz}{H} e^{-\beta_{rz} t} \quad (4)$$

The average degree of consolidation at any depth is:

$$U_{rz} = 1 - \frac{\bar{u}_{rz}}{u_0} = 1 - \sum_{m=0}^{\infty} \frac{2}{M} \sin\frac{Mz}{H} e^{-\beta_{rz} t} \quad (5)$$

The average degree of consolidation of the whole soil layer is:

$$\bar{U}_{rz} = 1 - \sum_{m=0}^{\infty} \frac{2}{M^2} e^{-\beta_{rz} t} \quad (6)$$

where: $F = \left(\ln\frac{n}{s} + \frac{k_h}{k_s}\ln s - \frac{3}{4}\right)\frac{n^2}{n^2-1} + \frac{s^2}{n^2-1}\left(1-\frac{k_h}{k_s}\right)\left(1-\frac{s^2}{4n^2}\right) + \frac{k_h}{k_s}\frac{1}{n^2-1}\left(1-\frac{1}{4n^2}\right)$, $n = \frac{r_e}{r_w}$, $s = \frac{r_s}{r_w}$,

$M = \frac{2m+1}{2}\pi, m = 0,1,2,\cdots$, $\beta_{rz} = \beta_r + \beta_z$, $\beta_r = \frac{E_s k_h}{\gamma_w}\frac{2}{r_e^2}\frac{1}{F+D_m}$, $\beta_z = \frac{E_s k_v}{r_w}\frac{M^2}{H^2}$, $D_m = \frac{8}{M^2}\frac{n^2-1}{n^2}G$, $G = \frac{k_h}{k_w}\left(\frac{H}{2r_w}\right)^2$

Above solutions under equal strain conditon are so simple as to easy to apply.

4. COMPARING RESULTS

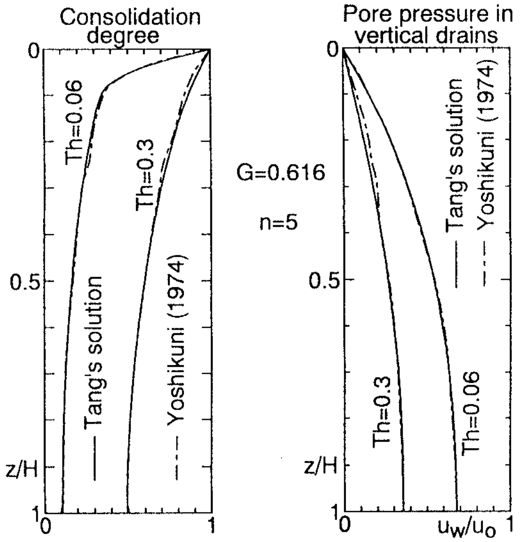

Fig.3 Average consolidation degree,and distribution of pore pressur in vertical drains at any depth

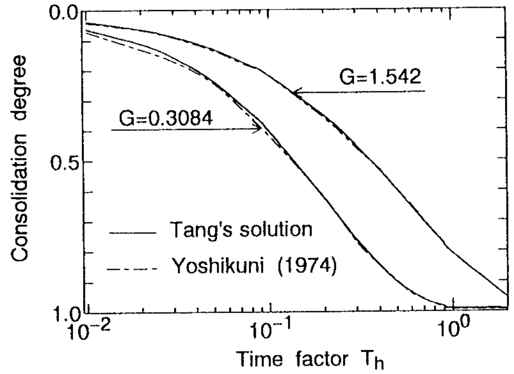

Fig.2 Average consolidation degree of soil layer

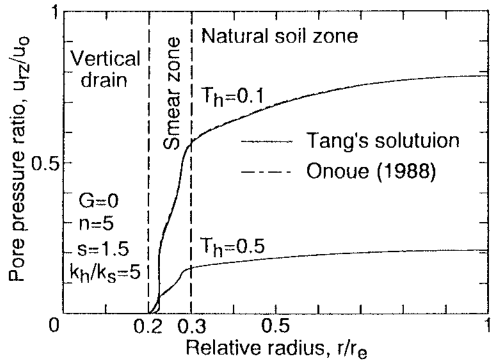

Fig.4 Distribution of pore pressure ratio with smear without well resistance

After comparing results obtained by Tang's solutions with those by Yoshikuni's or Onoue's solutions, it can be concluedd that difference between the results obtained by rigorous solutions under equal strain condition and those obtained by solutions under free strain condition is small.

5. DISCUSSION

Let us analyze simultaneous basic equations under equal and free strain conditions (in order to simplify the problem, only considering well resistance):

For equal strain condition:

$$\frac{E_s k_h}{\gamma_w}\left(\frac{1}{r}\frac{\partial u_{rz}}{\partial r}+\frac{\partial^2 u_{rz}}{\partial r^2}\right)=\frac{\partial \bar{u}_{rz}}{\partial t}-\frac{E_s k_v}{\gamma_w}\frac{\partial^2 \bar{u}_{rz}}{\partial z^2} \quad r_w \le r \le r_e \quad (7a) \qquad \frac{\partial^2 u_w}{\partial z^2}=-\frac{2}{r_w}\frac{k_h}{k_w}\left(\frac{\partial u_{rz}}{\partial r}\right)\bigg|_{r=r_w} \quad (7b)$$

For free strain condition:

$$\frac{E_s k_h}{\gamma_w}\left(\frac{1}{r}\frac{\partial u_{rz}}{\partial r}+\frac{\partial^2 u_{rz}}{\partial r^2}\right)=\frac{\partial u_{rz}}{\partial t}-\frac{E_s k_v}{\gamma_w}\frac{\partial^2 u_{rz}}{\partial z^2} \quad r_w \le r \le r_e \quad (8a) \qquad \frac{\partial^2 u_w}{\partial z^2}=-\frac{2}{r_w}\frac{k_h}{k_w}\left(\frac{\partial u_{rz}}{\partial r}\right)\bigg|_{r=r_w} \quad (8b)$$

Only difference between simultaneous equations for equal strain condition, Eq.(7a) and Eq.(7b), and simultaneous equations for free strain condition, Eq.(8a) and Eq.(8b), is that the average pore pressure of one depth of right hand side of Eq.(7a) instead of pore pressure at any point of one depth of rigth hand side of Eq.(8a). Moreover, Eq.(7b) and Eq.(8b) govern Eq.(7a) and Eq.(8a), respectively, and Eq.(7b) is the same as Eq.(8b).So,the difference between two simultaneous equations is small and partial,not whole.

6. CONCLUSION

1). Tang's (1996) solutions for consolidation by non-ideal vertical drains are easy to apply.
2). The difference of the results obtained by rigorous solutions under equal strain condition and free strain condition is small. 3). The difference between simultaneous equations for equal strain condition and for free strain condition is small and partial, not whole.

REFERENCES

1).Onoue,A.,(1988).Consolidation by vertical drains taking well resistance and smear into considering. Soils & Foundations, Vol.28(4). 2). Tang,X.W. & Onitsuka,K.,(1996). Rigorous solutions of vertical drains considering radial and vertical flow under equal strain condition. 31th Annual Conf. of the Japanese Geotechnical Society. 3).Yoshikuni, H. & Nakanodo,H.,(1974).Consolidation of soils by vertical drain wells with finite permeability, Soils & Foundations, Vol.14(2).