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Study on aging of single pile in soft soil foundation

Tiejun Chen[1] , Haiying Cao[2]

[1]Hebei Vocational & Technical College of Building Materials, Qinhuangdao Hebei 066004, China.
[2]School of Civil Engineering and Mechanics, Yanshan University, Qinhuangdao Hebei 066004, China.
chen4490@126.com

Abstract. In this paper, the single pile under load is analyzed by using the Biot consolidation equation and the modified method of the coupling of the Komala - Huang model. The consolidation of soil is simulated by Biot consolidation theory, and the whole process of the deformation of single pile is presented in the paper by means of the modified Komala - Huang model. Some useful conclusions are obtained by analyzing the variation of the pore pressure and the settlement of the soil under the action of load.

1. Introduction

It is obvious that the stress and strain of soil are affected by time, and not only the deformation of cohesive soil, but also of cohesionless sand, is not instantaneous. According to the different stress state, the deformation velocity of cohesive soil is very slow, and finally tends to stop. Others grow, eventually leading to destruction.

The deformation of piled raft foundation on soft soil foundation is a long-term settlement process under the load. It is generally considered that the deformation includes three parts: instantaneous deformation, consolidation deformation and secondary consolidation deformation. With the consolidation of soil and pore water pressure dissipation, the load is transferred to the soil skeleton. The soil skele ton under stress due to the viscous particle surface absorbed water, the rearrangement of particles and the dislocation of skeleton have time effect, the deformation of soil is related to time, so the rheological behavior of soil is considered in the settlement analysis of pile foundation, it is necessary. In particular, when the soft soil layer at the bottom of the pile is relatively soft, the rheological deformation of the soil occupies a significant proportion in the total deformation[1].

2. Visco elastic plastic constitutive model of soil

In general, the simplest model can be summarized under the premise of soft soil rheology, which is an ideal model suitable for numerical analysis of soft soil engineering. As shown in Fig.1, the model can describe the elastic deformation at the moment of loading, at the same time, it can simulate the delay phenomenon of soil deformation and the residual deformation after unloading.

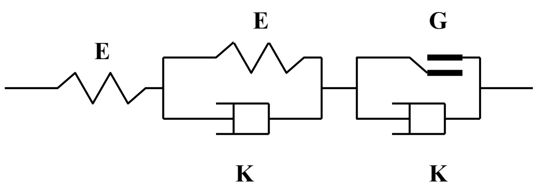


Figure.1 Komala - huang model

The total strain can be seen as consisting of three parts: $\{\varepsilon\}=\{\varepsilon_e\}+\{\varepsilon_{ve}\}+\{\varepsilon_{vp}\}$,the $\{\varepsilon_e\}$ is elastic strain; $\{\varepsilon_{ve}\}$ is viscoelastic strain; $\{\varepsilon_{vp}\}$ Is a viscoplastic strain. See $\{\varepsilon_{ve}\}$ and $\{\varepsilon_{vp}\}$ as initial strain, thus the solution of the viscoelasticity problem will be reduced to the solution of the elastic problem with initial strain.

The physical equation is:

$$\{\sigma\}=[D]\{\varepsilon_e\}=[D](\{\varepsilon\}-\{\varepsilon_{ve}\}-\{\varepsilon_{vp}\}) \tag{1}$$

The geometric equation is:

$$\{\varepsilon\}=[B]\{\delta\} \tag{2}$$

The unit node force is:

$$\{F\}=\int_v[B]^{\mathrm{T}}[D]([B]\{\delta\}-\{\varepsilon_{ve}\}-\{\varepsilon_{vp}\})\mathrm{d}V=[K](\{\delta\}-\{F_{ve}\}-\{F_{vp}\}) \tag{3}$$

$$[K]\{\delta\}=\{F\}+\{F_{ve}\}+\{F_{vp}\} \tag{4}$$

For the strain increment of the viscoplastic rheology, the following calculation method can be used:

$$\Delta\varepsilon=\varepsilon_{vp}\cdot\Delta t \tag{5}$$

$$\dot{\varepsilon}=\gamma<\Phi(F)>\frac{\partial Q}{\partial\sigma} \tag{6}$$

In the formula: $Q=Q(\sigma,\varepsilon_{vp},\kappa)$ is the plastic potential; γ is the flow parameter that controls the plastic flow rate; $\Phi(F)$ is the yield function,when $x>0$, $\Phi(F)$ is a positive monotonically increasing function; The symbol < > is a switching function,

when $x>0$, $<\Phi(x)>=\Phi(x)$;

when $x<0$, $<\Phi(x)>=0$;

Using the associated plastic flow law, then there are $Q=F$, Then the formula (6) can be transformed into:

$$\dot{\varepsilon}=\gamma<\Phi(F)>\frac{\partial Q}{\partial\sigma}=\gamma<\Phi>\alpha \tag{7}$$

Where: α is the flow vector, the specific form is as follows:

$$\alpha^{\mathrm{T}}=\frac{\partial F}{\partial\sigma}=\begin{bmatrix}\frac{\partial F}{\partial\sigma_x} & \frac{\partial F}{\partial\sigma_y} & \frac{\partial F}{\partial\sigma_z} & \frac{\partial F}{\partial\tau_{yz}} & \frac{\partial F}{\partial\tau_{zx}} & \frac{\partial F}{\partial\tau_{xyz}}\end{bmatrix}$$

The yield function F uses the Mohr-Coulomb yield criterion, which is widely used in engineering, to compensate for the shortcomings of the simple plastic slider. [2] The Mohr-Coulomb yield criterion is described in detail in many of the teaching materials that introduce the soil constitutive model[3].

3. Finite element analysis of consolidation and rheological coupling

The rheological properties of the soil is reflected by the time effect of stress - strain relationship, with the dissipation of pore water pressure, soil consolidation deformation, also produce secondary consolidation deformation, which is the main and secondary consolidation are produced at the same time. In the finite element analysis, the secondary consolidation is regarded as a posterior creep deformation.

The modified Komala - Huang model is used to reflect the visco - elastic - plasticity of the soil, and the model is combined with the consolidation theory to derive the incremental form of the Biot consolidation equation:

$$\begin{bmatrix}\boldsymbol{K} & \boldsymbol{K}'\\ \boldsymbol{K}'^{\mathrm{T}} & \tilde{\boldsymbol{K}}\end{bmatrix}\begin{Bmatrix}\Delta\delta\\ \beta\end{Bmatrix}=\begin{Bmatrix}R-R_t+R_v\\ 0\end{Bmatrix} \tag{8}$$

Where: $\boldsymbol{K}$ is the stiffness matrix; $\boldsymbol{K'}$ is the coupling matrix; $\tilde{\boldsymbol{K}}$ is the percolation matrix; $\Delta\delta$ is the displacement increment; β is the ultra-static pore pressure; R is the equivalent load of the corresponding load of the external load; R_t is the $t-\Delta t$ time Of the load corresponding to the stress balance of the part of the load; R_v is $t-\Delta t$ due to the soil viscosity corresponding to that part of the load.

According to the above principles and methods, a two - dimensional 8 - node Biot consolidation visco - elastoplastic finite element program is compiled,pile-soil contact plane unit selection Goodman unit, the program can consider plane stress, plane strain and axisymmetric problem[4][5].

4. Finite element analysis of single pile

4.1. Selection of model parameters

Single pile finite element analysis model selection pile length $l=16m$, pile diameter $d=0.6m$, pile elastic modulus $E_p=30Gpa$ soil compressive modulus $E_s=4MPa$, according to the Shanghai area statistics, soil elastic modulus and compression The relationship between the modulus is $E=(2\sim5)\ E_s$, the elastic modulus of the pile side soil is $E=8MPa$, the Poisson's ratio of soil is $\nu=0.4$, the permeability coefficient is $k_x=k_y=1\times10^{-4}$ m • d^{-1}, The calculated depth is 14 m, the total depth of the foundation is 30 m, and the calculated width is 50 m. The total load in the analysis was 250 kN, applied in 5 times, 50 kN each time.

4.2. Variation of pore water pressure at pile tip

Figure 2 is a pile at the end of the curve of pore pressure changes with time, it can be seen from the figure at the pile end Mandel effect in the early stage of consolidation, the pore pressure has not decreased, but increased gradually, reached a certain time (200 d) after the fall, which is consistent with the measured results[6].

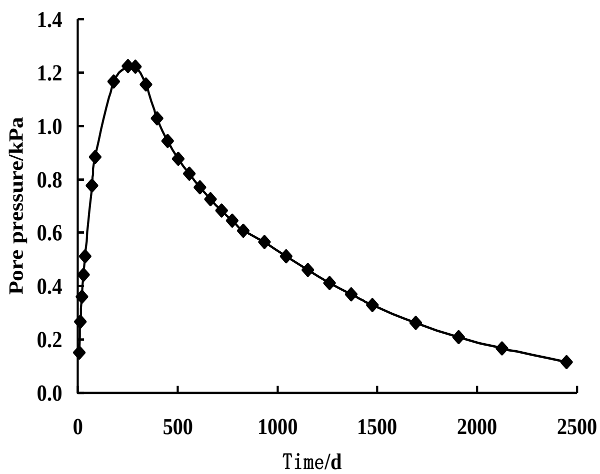


Figure. 2 Variation of pore pressure with time

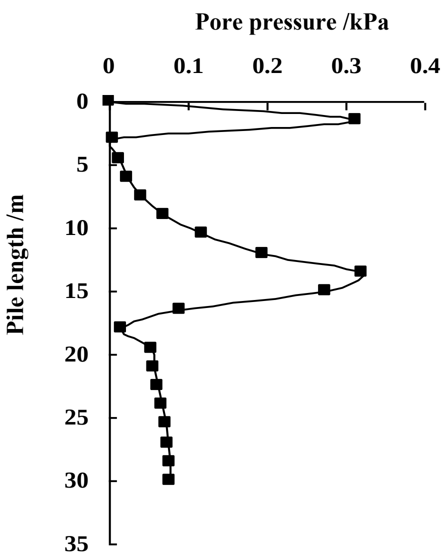


Figure. 3 distribution of pore pressure of pile side and pile tip soil when loading 50kN

Figure 3 shows the application of load 50kN, experienced 30d; Figure 4 shows the application of load 150kN, for 90d; Figure 5 shows the change of excess pore water pressure along the depth of the soil at the pile and pile ends after 150 d of the applied load of 250 kN. It can be seen from the figure that the super-static pore water pressure in the vicinity of the pile and the pile top is relatively large, and the excess pore water pressure in the soil at the pile and pile ends is small. With the increase of the load, the excess pore water pressure Change is not obvious.

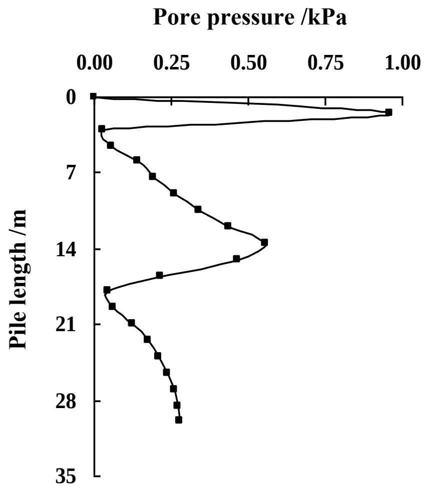


Figure. 4 distribution of pore pressure of pile side and pile tip soil when loading 150kN

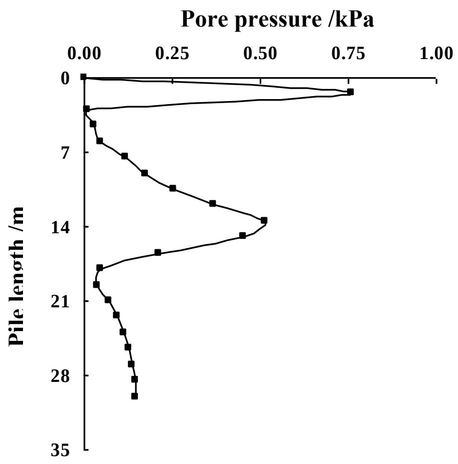


Figure. 5 distribution of pore pressure of pile side and pile tip soil when loading 250kN

4.3. Interaction between pile and soil

It can be seen from the variation curves of the stress of the pile soil contact surface element along the depth in Figure 6 that the stress of the pile soil contact surface gradually decreases with the loading time, and the phenomenon of the middle part is smaller, the pile tip and the pile end increase rapidly.

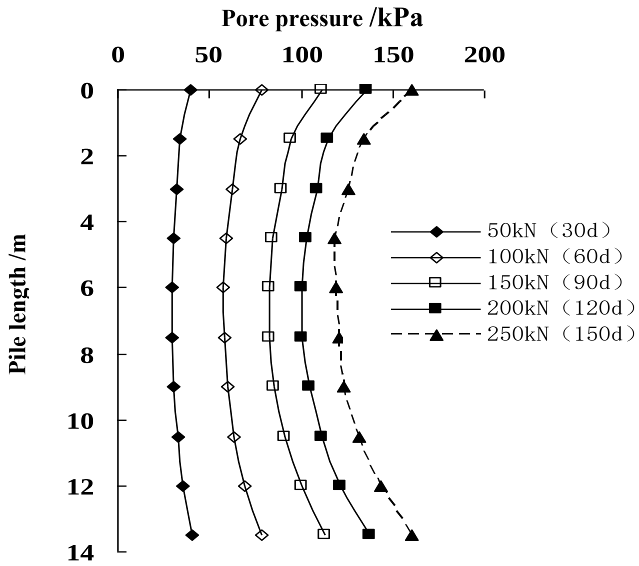
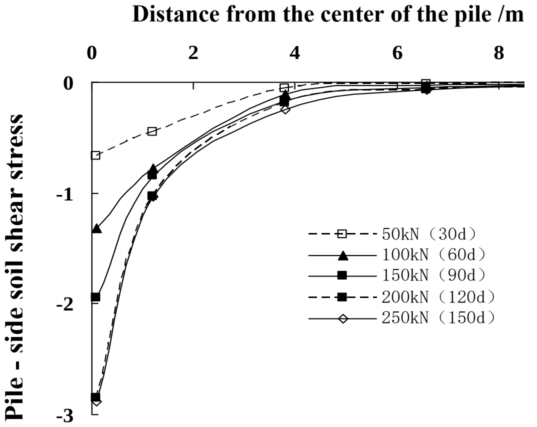


Figure.6 change of stress along the depth of pile interface

Figure 7 and figure 8 are for the changes of pile end soil shear stress along the horizontal direction and the pile end soil stress along the horizontal direction, it can be seen that the stress variation law in the two figures is more consistent. Pile soil at normal stress and shear stress are increased with the increase of pile spacing of horizontal distance decreases rapidly, more straight from the pile after 5 m curves of stress in soil is very small, can be neglected in the analysis of pile group. The influence of the stress at the pile end under load is limited, which is consistent with the conclusion obtained by Randoph et al.



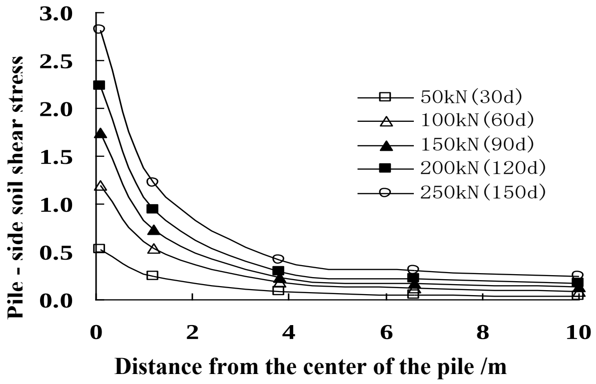


Figure. 7 Variation of τ_{zx} along the horizontal direction of soil at pile tip

Figure. 8 variation of σ_z along the horizontal direction of soil at pile tip

5. Conclusion

In this paper, the whole process of settlement and deformation of single pile under load is analyzed by the method of combining the Biot consolidation equation and the modified Komala - Huang model. Based on the simulation of the settlement process of the soil around the pile, the following conclusions can be drawn:

Under the action of load, there is a significant Mendel effect at the pore water pressure at the pile tip. At the early stage of consolidation, the pore pressure did not decrease, but gradually increased, and then began to decline after a certain period of time.

The horizontal displacement of soil caused by pile foundation settlement decreases rapidly with the increase of pile distance. Especially in the vicinity of the pile, the displacement decreases sharply, which shows that the influence of the pile on the surrounding soil displacement is limited, beyond this range, the effect is negligible.

The normal stress and shear stress in the soil at the pile tip decreases rapidly with the increase of the horizontal distance from the pile, and the curve becomes more flat after a certain distance from the pile,the stress in the soil is very small.

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