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Effect of time-dependent behavior on the pile-soil settlements

Effet du comportement dépendant du temps sur les établissements pieux-sol

Talal Awwad

Damascus University, Professor, Syria.

Emperor Alexander I St. Petersburg State Transport University, Professor, Russia.

Saint-Petersburg State University of Architecture and Civil Engineering, Professor, Russia

Salma Al Kodsi

Department of Civil Engineering, Osaka University, Japan

ABSTRACT: Prediction of long-term deformation due to secondary compression is vital in soft soils and must be considered when pile foundations are designed. Adding a surcharge load on the ground around the pile may cause a significant consolidation settlement in the clay layers next to the pile as a result of excess pore water pressure dissipation, and a relative movement between the pile and the adjacent soil takes a place. This relative movement may proceed after the end of primary consolidation as a result of secondary consolidation due to structural viscosity of the clay. In this study, the impact of time-dependent settlements due to viscosity is examined through numerical simulation using elastic-viscoplastic (EVP) soil model for a single pile. A parametric study for different surcharge and pile loading conditions is conducted by analyzing the calculation results of the soil and pile settlements during primary and secondary consolidation. Raising the applied pile load leads to maximize the difference between pile and soil settlements during primary consolidation and minimize this difference at the end of calculations.

RÉSUMÉ : La prédiction de la déformation à long terme due à la compression secondaire est vitale dans les sols meubles et doit être prise en compte lors de la conception des fondations sur pieux. L'ajout d'une charge supplémentaire sur le sol autour du pieu peut provoquer un tassement de consolidation important dans les couches d'argile à côté du pieu en raison de la dissipation excessive de la pression interstitielle de l'eau, et un mouvement relatif entre le pieu et le sol adjacent se produit. Ce mouvement relatif peut se produire après la fin de la consolidation primaire en raison de la consolidation secondaire due à la viscosité structurelle de l'argile. Dans cette étude, l'impact des tassements dépendant du temps dus à la viscosité est examiné par simulation numérique à l'aide d'un modèle de sol élastique-viscoplastique (EVP) pour un seul pieu. Une étude paramétrique des différentes conditions de surcharge et de chargement des pieux est réalisée en analysant les résultats des calculs des tassements du sol et des pieux lors de la consolidation primaire et secondaire. L'augmentation de la charge de pieu appliquée permet de maximiser la différence entre les tassements du pieu et du sol pendant la consolidation primaire et de minimiser cette différence à la fin des calculs.

KEYWORDS: Secondary compression, pile foundations, elastic-viscoplastic model.

1 INTRODUCTION

Soil creep is the main contribution to the long-term soil settlements and may cause NSF to be mobilized continuously along the pile shaft. Many researchers recognized the importance of structural viscosity in controlling many of the phenomena associated with clay consolidation. Although calculating a long-term consolidation settlement that occurs as a result of structual viscosity of a soft soil layer is an ongoing challenge due to unique theories or computational method shortage (Fatahi & Khabbaz 2013). Numbers of laboratory experiments have been carried out to study the consolidation process after Terzaghi's distinctive theory of one-dimensional consolidation of soils that explains the primary consolidation process. Settlements continue even after the complete dissipation of pore pressure (Terzaghi 1925). Creep is generally defined as the deformation under a constant effective stress (Bjerrum 1967). Several factors affect the pile-soil settlements; the thickness of the clay layer, the length of the pile, the magnitude of the surcharge load (Awwad & Kodsi 2017). The higher the applied pressure is, the earlier noticed vertical strain occurred due to secondary consolidation (Oda & Bu 2016).

This article is aimed to examine the creep influence on the pile-soil settlements by simulating a field loading test conducted for a cast in place single pile embedded in a clay deposit of Osaka Bay in Japan. Firstly, the finite element numerical model is formulated, and verified by comparing the numerical results with field test measurements. The elastic-viscoplastic (EVP) soil model defined by (Matsui & Abe 1981) is used to observe the time-dependent consolidation behavior of the main clay layer caused by the clay viscosity. A parametric study for different surcharge and pile loading conditions is conducted by analyzing the calculation results of the soil and pile settlements during primary and secondary consolidation.

2 FIELD TET PROFILE

A full-scale vertical loading test of a cast-in-place RC bored pile was carried out at downtown in Osaka city, Osaka, Japan by (Matsui 1993). The soil profile at the test site consists of both Holocene Deposits and Upper Pleistocene Deposits. The Holocene Deposits consist of loose and soft silts and clays mainly. Its thickness is about 27m. Beneath the Holocene Deposits, there is a sandy gravel layer which is Upper Pleistocene Deposits. It overlies gravel mixed sand layer and another sandy gravel layer. These three layers are very stiff. The upper sandy gravel layer was adopted as a bearing layer of the tested pile. The tested pile, cast-in-place RC pile, has 1.5m in diameter and 28.5m in length (as shown in Figure 1), and was installed with the Benito method. The vertical loading test was carried out, in accordance with the Standard of the (JGS 1972).

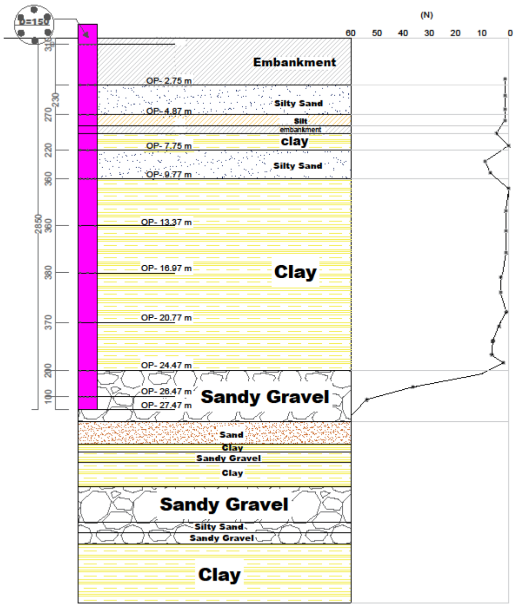

Figure 1. Field test soil profile

3 THE NUMERICAL MODEL

3.1 *Geometry and boundary conditions*

The first step of the modeling process, is to define the geometry of the domain consisting of the soil and the pile clusters. The model is axisymmetric consists of soil mass and a single pile of 28.5 m in length (Lp), and 1.5 m in diameter (D). The water table is at 0.80 m down the surface. The lateral soil boundary of the model is placed at the distance of (10D) from the axis of symmetry and restrained against horizontal movement while the vertical translation is allowable. The bottom soil boundary is at the distance of (Lp+10D) from the pile head and restricted from both horizontal and vertical movements (as shown in Figure 2).

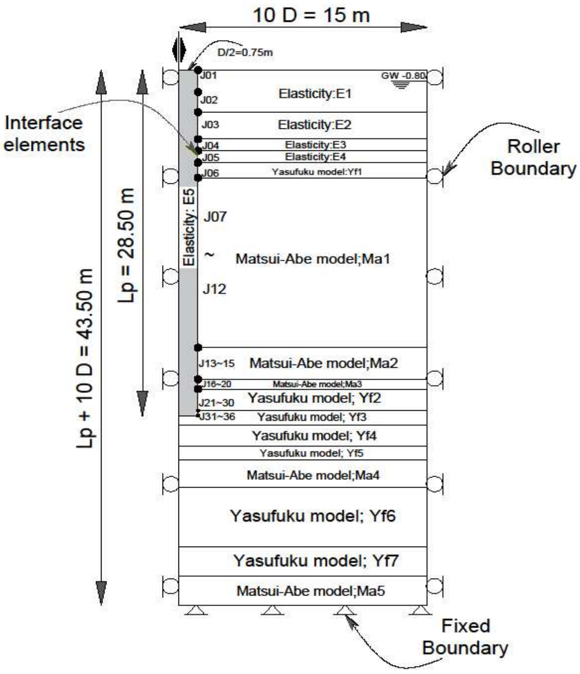

Figure 2. Analytical model and boundary conditions

3.2 *Material properties*

In order to calculate the creep settlements, elastic-viscoplastic (EVP) soil model was presented through the modified Matsui-Abe model (Abe 1984) given by the following equation:

$$f = \mu \ln \left| \frac{1}{\delta} \left[\left\{ 1 - \exp\left(-\frac{\delta \dot{v}_r^v}{\mu} t \right) \right\} \exp\left(\frac{v^p}{\mu} \right) + \delta \exp\left(-\frac{\delta \dot{v}_r^v}{\mu} t \right) \right] \right| - v^{vp} = 0 \quad (1)$$

Where μ is the coefficient of secondary consolidation, $\dot{v}_r^v$ is the reference viscous volume strain rate, δ is a material constant and v^p is the plastic volumetric strain.

3.3 *Analytical parameters*

The analytical parameters used in the numerical analysis for the elastic-viscoplastic soil model (see Table 1):

Table 1. Analytical parameters for elastic-viscoplastic soil model

Symbol	Model	Parameters
Ma1	EVP	λ=0.1024, κ=0.01240, M=1.47, μ=0.0002, υ=0.3333
Ma2	EVP	λ=0.1024, κ=0.01240, M=1.47, μ=0.0002, υ=0.3333
Ma3	EVP	λ=0.2475, κ=0.01240, M=1.41, μ=0.0002, υ=0.3333
Ma4	EVP	λ=0.4950, κ=0.02480, M=1.41, μ=0.0002, υ=0.3333
Ma5	EVP	λ=0.5800, κ=0.02430, M=1.26, μ=0.0002, υ=0.3333

4 THE ANALATICAL MODEL VALIDATION

In order to simulate the actual field test, Suehiro pile field measurements of pile tip, pile toe and axial load distribution were compared with the numerical analyzing results for EVP soil model (as shown in Figure 3, Figure 4, and Figure 5), respectively.

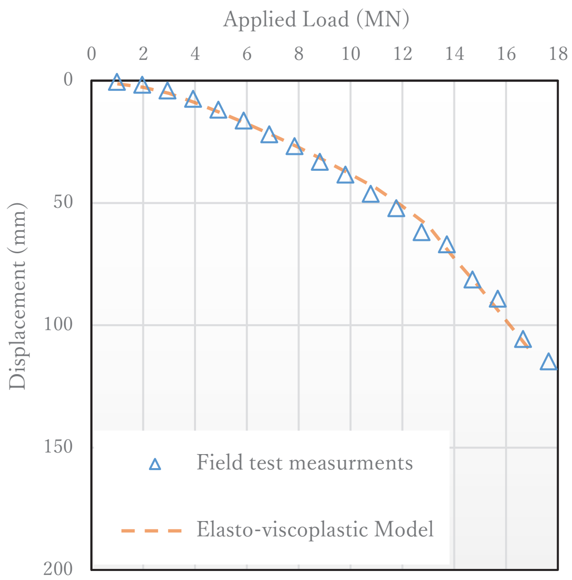

Figure 3. Pile tip settlements

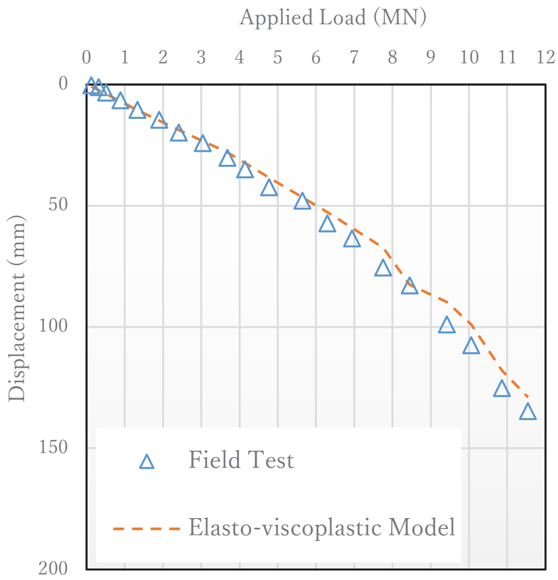

Figure 4. Pile toe settlements

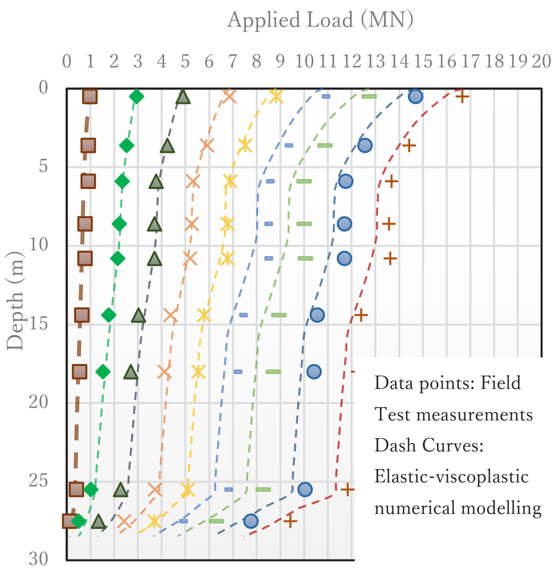

Figure 5. Pile axial load distribution

The provided field test measurements were obtained during a short term after the pile was loaded. Obtaining the field measurement result for the long-term consolidation is impossible. However, due to the current compression, it is verified that the numerical model and the employed parameter settings can simulate the axial load distributions of a single pile reasonably.

5 PARAMETRIC STUDY

The parametric study cases are summarized (see Table 2):

Table 2. Parametric study cases

Case num.	Pile load (kN)	Surcharge load (kN/m²)
1	3000	10
2	3000	20
3	6000	20
4	8000	10

The axial load and skin friction distribution were calculated at three stages; immediately after the application of the pile load, after the applying the surcharge load and at the end of calculation, respectively. The development of the axial load forces from the beginning of loading down to the end of calculation (as shown in Figure 6) for Case. 1. The difference between pile and soil settlements during primary consolidation was around 0.3 cm and raised to 1.4 cm at the end of primary consolidation (after 3.6+E05 min). However, this difference became larger at the end of the calculation (as shown in Figure 7).

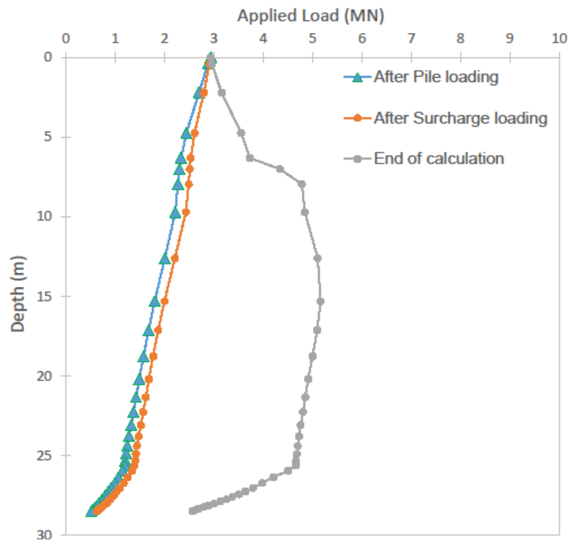

Figure 6. Pile axial load distribution - Case. 1 -

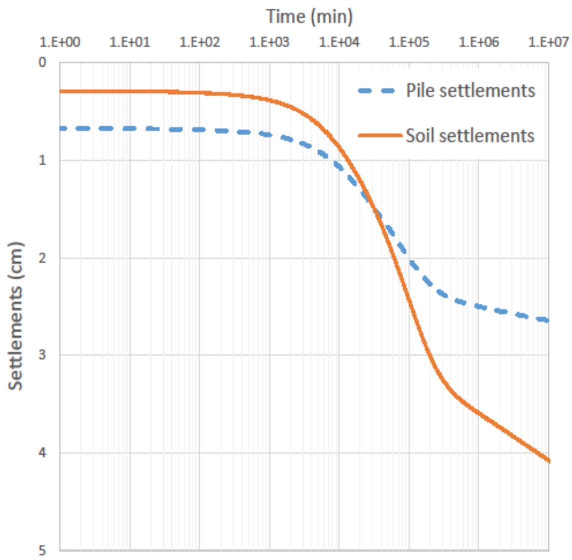

Figure 7. Pile-soil settlements – Case. 1 –

In Case. 2, the value of the surcharge load was raised without changing the applied pile load. As a result, a difference in settlements between the pile and the soil equals to around (0.2 cm) at the beginning of loading, developed to about (2.5 cm) at the end of calculations (as shown in Figure 8).

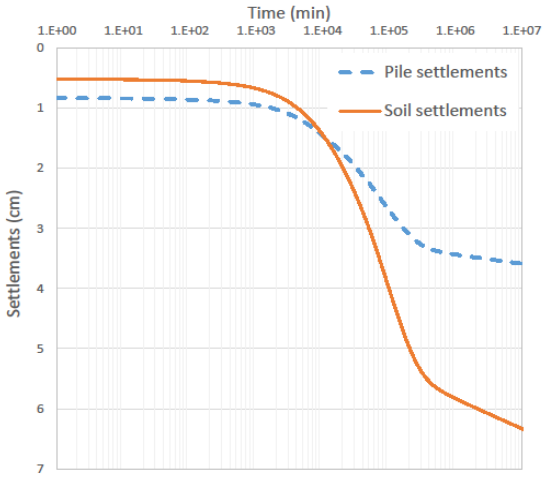

Figure 8. Pile-soil settlements – Case. 2 –

Applying a more significant pile load as in Case.3 affected the relative movement between pile and soil (as shown in Figure 9).

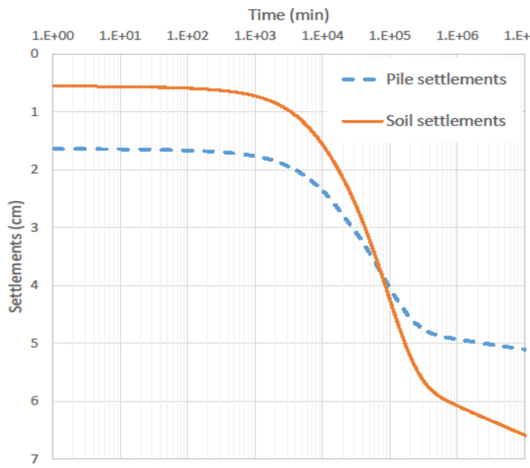

Figure 9. Pile-soil settlements – Case. 3 –

At some point, applying a large pile load as in Case. 4 caused the pile settlements to exceed the soil settlements from the beginning of loading until the end of the calculation (as shown in Figure 10)

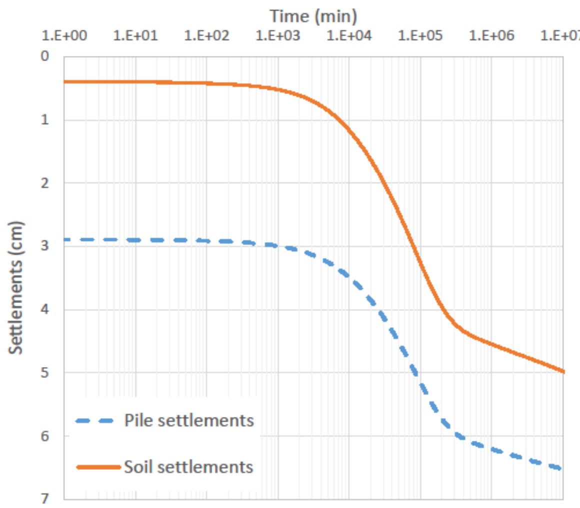

Figure 10. Pile-soil settlements – Case. 4 –

6 CONCLUSIONS

In this study, the impact of creep settlements due to viscosity and its influence on pile-soil settlements was examined through numerical simulation using elastic-viscoplastic soil model for a single pile. different pile and surcharge loading cases were discussed. It can be concluded that:

(1) Raising the applied pile load leads to maximize the difference between pile and soil settlements during primary consolidation and minimize this difference at the end of calculations.

(2) Applying a small magnitude of surcharge load results in a difference in settlements between the end of primary consolidation and the end of calculations, where the most settlements occur during secondary consolidation. On the contrary, doubling and tripling the surcharge load values, reduce this difference, where most of the settlements have occurred during primary consolidation.

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