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Simplified numerical model formulation to examine the impact of viscous parameters on pile bearing characteristics

Formulation simplifiée d'un modèle numérique pour examiner l'impact des paramètres visqueux sur les caractéristiques des pieux

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ABSTRACT: A simplified numerical model consists of two clay layers, and a single pile is performed. The purpose of the simple model is to examine the impact of changing the clay properties and the viscous parameters on the pile's bearing characteristics. The following steps are being carried out in the process of defining the numerical model; identifying: the domain geometry, boundary conditions, element types, mesh, analysis types, material properties, and loading values. The simple model consists of a pile, and two clay layers is formulated, and the impact of the coefficient of secondary consolidation, and the reference volumetric strain rate is studied. Furthermore, three different types of clay material are modeled, and the influence of soil properties on the behavior of secondary consolidation is examined. Changing the physical and mechanical properties of the soft clay layer has a significant impact on the relative movement between the pile and the soil. The soil unit weight affects the vertical stress values, which in turn changes the soil interface strength. The magnitude of the interface elements shear strength controls the pile-soil relative movements, the axial load, and the skin friction distribution.

RÉSUMÉ : Un modèle numérique simplifié se compose de deux couches d'argile et un seul tas est effectué. Le but du modèle simple est d'examiner l'impact de la modification des propriétés de l'argile et des paramètres visqueux sur les caractéristiques portantes de la pile. Les étapes suivantes sont en cours dans le processus de définition du modèle numérique identification : la géométrie du domaine, les conditions aux limites, les types d'éléments, le maillage, les types d'analyse, les propriétés des matériaux et les valeurs de chargement. Le modèle simple se compose d'un tas, et deux couches d'argile sont formulées, et l'impact du coefficient de consolidation secondaire, et le taux de déformation volumétrique de référence est étudié. En outre, trois types différents de matériaux argileux sont modélisés et l'influence des propriétés du sol sur le comportement de la consolidation secondaire est examinée. La modification des propriétés physiques et mécaniques de la couche d'argile molle a un impact significatif sur le mouvement relatif entre le tas et le sol. Le poids de l'unité de sol affecte les valeurs de contrainte verticale, ce qui modifie à son tour la force de l'interface du sol. L'ampleur de la résistance au cisaillement des éléments d'interface contrôle les mouvements relatifs pile-sol, la charge axiale et la répartition du frottement de la peau.

KEYWORDS: viscous parameters, numerical model, secondary consolidation, volumetric strain rate, skin friction.

1 INTRODUCTION

Matsui et al. (1981) gave a sophisticated technique of multi-dimensional elasto-plastic (EP) consolidation analysis due to the finite element method considering a nonlinear stress-strain relation to reflect the real mechanism of consolidation of clay. Then, the availability of the proposed analytical method of consolidation was demonstrated by showing such analytical results for a partially loaded ground model as time-dependent behaviors, especially stress path behaviors during consolidation. Oda et al. (2016) conducted a series of numerical analysis using a one-dimensional consolidation elastic-viscoplastic (EVP) consolidation finite element method to investigate long-term consolidation behavior of quasi-over consolidated clay of Kansai International airport. The aim of the study was to examine the effect of drainage path length on long-term settlements. Furthermore, the effect of drainage path length on the compression behavior of Pleistocene clay was discussed from the viewpoint of time-dependency. On one hand, the results showed the ability of numerical simulation to qualitatively reproduce the occurrence of the significant residual settlements. On the other hand, the numerical simulation results indicated to the drainage path length effect on compression curve, where compression curves in the case of drainage path length greater than 5.0m, are affected by time-dependent mechanical characteristics. In a

previous study, Salma et al. (2018) carried on a parametric study to examine the influence of the pile and surcharge load on the axial load and the negative skin friction (NSF) distribution mobilized in a pile, and to understand the bearing mechanics under various loading conditions. The results of a full-scale vertical loading test at Osaka Bay, such as the axial load distribution and the pile settlements, which is conducted for a cast-in-place RC (reinforced concrete) bored pile embedded in the clayey layers, were presented. Three soil constitutive models for clay and sandy soil were used in the analytical model. Also, the methods to determine the parameters for these models based on the laboratory and field observations were explained comprehensively. Moreover, by comparing the field test measurements with the numerical results, it was verified that the numerical models and parameter settings employed can simulate the axial load distributions of a single pile reasonably (Awwad, 2020).

To examine the influence of the clay properties and the viscous parameters on the axial load forces and the skin friction distribution, a simple model consists of a pile, and two clay layers is formulated in this paper. To study the influence of changing the viscous parameters on the axial load distribution, a simple model is developed. The following steps are being carried out in the process of defining the numerical model; identifying: the

domain geometry, boundary conditions, element types, mesh, analysis types, material properties, and loading values.

1.1 Geometry and boundary conditions

The model is axisymmetric consists of soil mass and a single pile of 8.00 m in length (L_p), and 1.00 m in diameter (D). The water table is at 0.50 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 (L_p+10D) from the pile head and restricted from both horizontal and vertical movements (as shown in Figure 1.)

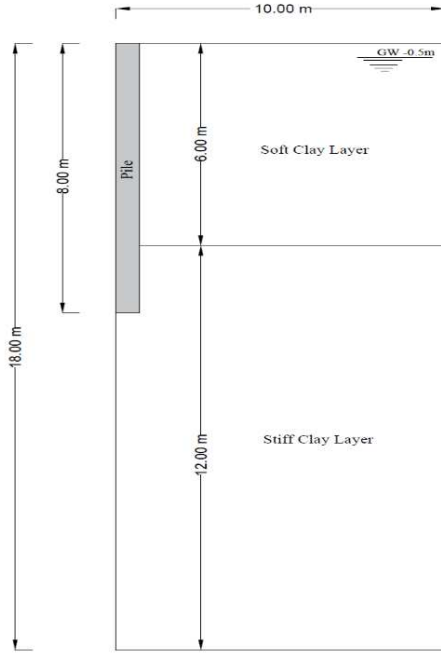


Figure 1. The simplified numerical model

1.2 Interface elements

The four-node interface element without thickness was posed by Goodman, (1968). This type of interface element is used frequently for its simple structural form, clear physical relationship and convenience. Goodman element is a four-node without thickness. The behavior of the interface elements (as shown in Figure 2.)

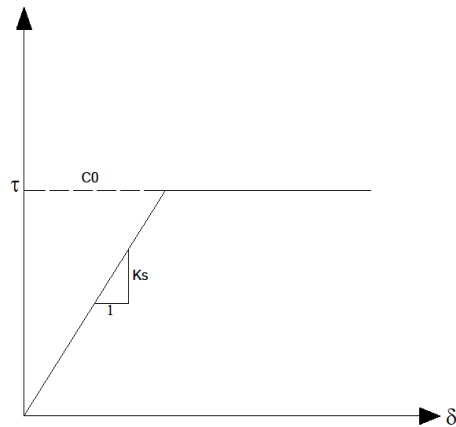


Figure 2. Interface elements behavior

1.3 Analytical mesh and the elements type

The rectangular element type is used for soil, pile, and the interface clusters. The initial data are determined in the middle of each element. The analytical model is divided into four blocks. Block (1) is represented the pile cluster and divided into 40 rectangular elements. Block (2) represents the soft clay layer, contains 54 rectangular elements. The bearing layer is divided into Block (3) and Block (4). Block (3) has 18 elements, while Block (4) divided into 140 quadrilateral elements. Finally, the interface cluster is divided into eight rectangular elements. The analytical model blocks (shown in Figure 3.).

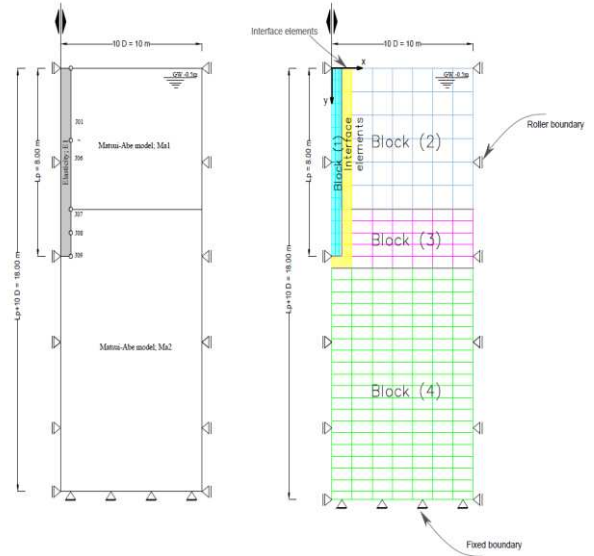


Figure 3. Analytical model blocks

1.4 Material properties

For the simplified model, the pile material is defined as an anisotropic linear elastic material where the constitutive relationship in this case can be defined by two input parameters: Young's modulus (E) and Poisson's ratio (ν).

To calculate the creep settlements, elastic-viscoplastic (EVP) soil model is presented through the modified Matsui-Abe model (see Eq. 1).

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

Where μ is the coefficient of secondary consolidation, V_r^v is the reference viscous volume strain rate, δ is a material constant and v_r^p is the plastic volumetric strain.

2 PARAMETRIC STUDY

The parametric study is conducted in order to:

- The impact of the viscous parameters on the distribution of axial loads and soil settlements.
- Examine the effect of changing the type of the clay layer

2.1 Impact of the Viscous Parameters

In this section, Osaka Bay Clay will be used to represent the soft clay layer. The parametric study will discuss changing the coefficient of secondary consolidation μ and the reference viscous volume strain rate V_r to examine the effect of the viscous parameters on the axial load distribution and pile-soil settlements.

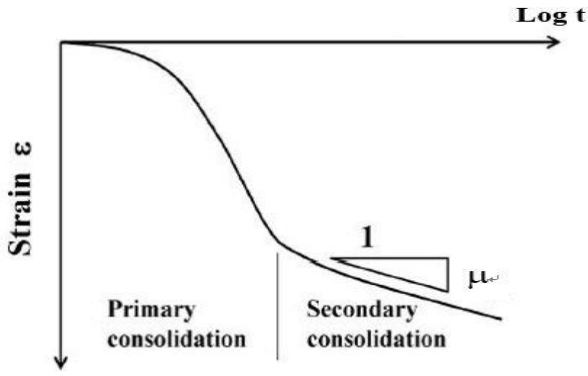


Figure 4. Consolidation curve (ϵ -log t curve)

2.1.1 Coefficient of secondary consolidation μ

After the end of primary consolidation (EOP), the incremental strain caused as a reason of secondary consolidation varies linearly with the logarithmic elapsed time (Log t) after loading for an oedometer test. The incremental strain corresponding to one cycle of logarithmic time during the secondary consolidation is denoted as μ (as shown in Figure 4.)

μ is appeared to be linearly dependent on C_c , the compression index of the soil. The μ/C_c factor explains and predicts the secondary consolidation behavior of geotechnical materials (Mersi et al., 1997). Three different values for μ summarize in (Table 1.) will be used to examine the effect of μ/C_c on the distribution of the pile axial loads and soil settlements.

Table 1. Parametric study values for μ/C_c

Case num.	μ/C_c	C_c
1	0.0001/ C_c	0.2358
2	0.0002/ C_c	0.2358
3	0.0004/ C_c	0.2358

The distribution of the pile axial load is shown in (Figure 5.). The skin friction mobilized on the pile's shaft is shown in (Figure 6.). When μ/C_c is less, the secondary consolidation effect on the negative skin friction and soil settlements would be less.

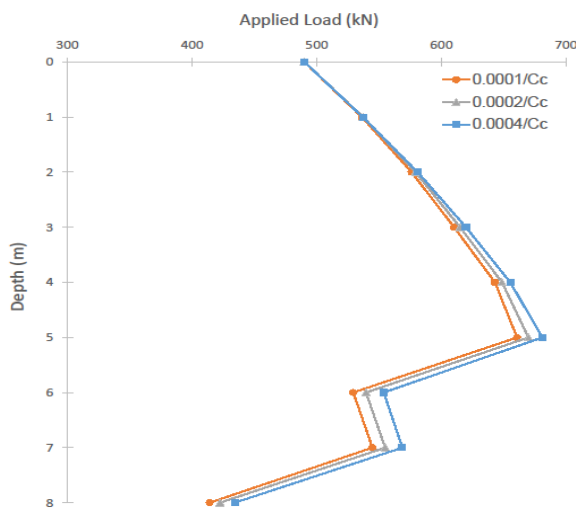


Figure 5. Pile axial loads distribution due to the changing of secondary consolidation coefficient

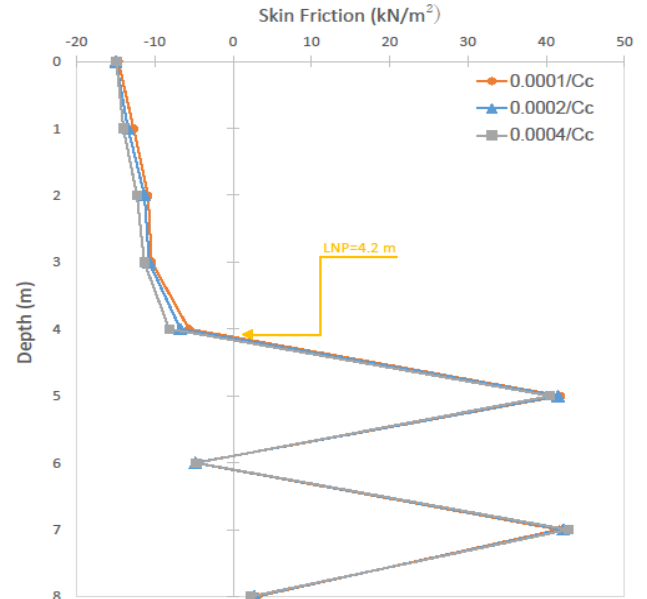


Figure 6. Skin friction distribution due to the changing of secondary consolidation coefficient

2.1.2 Reference Viscous Strain Rate $\dot{v}_r^v$

In order to explain the reference volumetric strain rate, (Figure 7) shows the parameter v^e which defined as the straight line passing through the points $(p', v) = (1 \text{ kPa}, 0)$ and (σ_{v0}', v_0) on the v -log p' curve. The value that corresponds to the effective consolidation pressure p' is denoted as $v^e(p')$. σ_{v0}' is the overburden effective stress and v_0 is the volumetric strain at $p' = \sigma_{v0}'$. C_s is the swelling index.

Table 2. Summarizes the parametric study cases for $\dot{v}_r^v$. The pile axial loads distribution, and the Negative skin friction (NSF) are increased with the $\dot{v}_r^v$ values, (as shown in Figure 8.) and (Figure 9.)

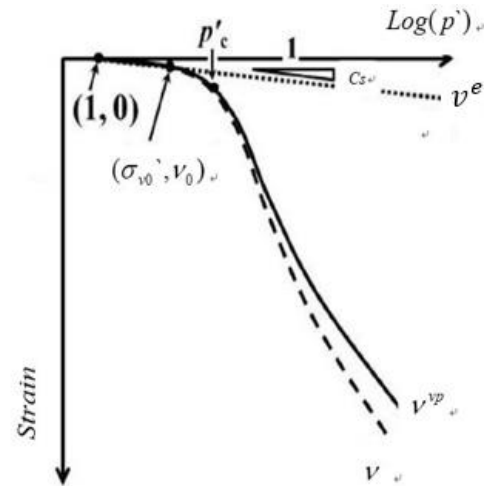


Figure 7. Compression curve (v - log p' curve)

Table 2. Parametric study values for $\dot{v}_r^v$

Case num.	$\dot{v}_r^v$ (1/min)	μ
1	5.7×10^{-7}	0.0002
2	5.7×10^{-6}	0.0002
3	5.7×10^{-5}	0.0002
4	5.7×10^{-4}	0.0002

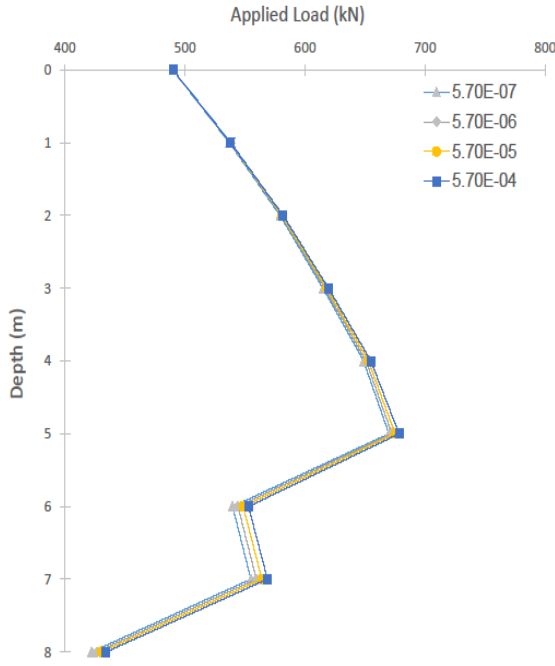


Figure 8. Pile axial load distribution due to the changing of reference viscous strain rate

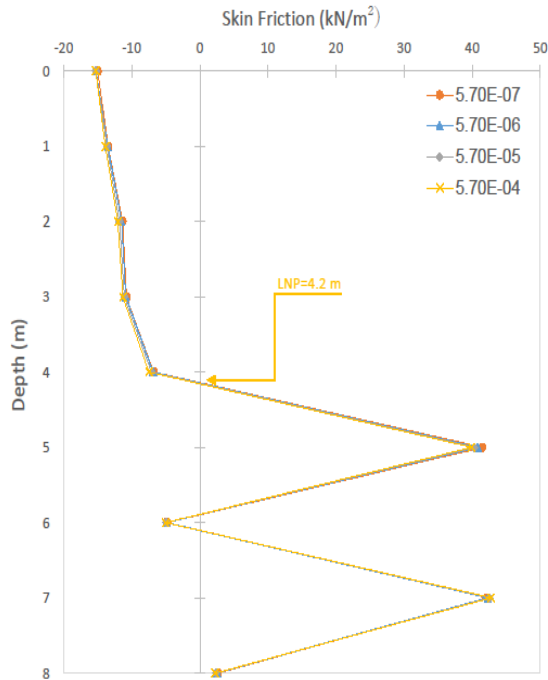


Figure 9. Skin friction distribution due to the changing of reference viscous strain rate

2.2 Impact of clay properties

In order to show the clay properties effect more clearly, three different types of clay; (Osaka Bay clay, Eastern Osaka clay, and SFBM clay) will be used. The aim of this study is to examine the effect of changing the physical and mechanical properties of clay on the secondary consolidation behavior. The properties of the soft clay and the bearing layer used in this study are summarized in (Table 3.).

Table 3. Properties of the used clay

Parameters	Osaka Bay Clay (Oda,2012)	Eastern Osaka Clay (Adachi et al., 1995)	SFBM Clay (Lacerda,1976)	Bearing Clay Layer (Oda,2012)
γ (kN/m ³)	16	16	21	18
e_0	1.75	1.8	1.3	1.12
ω	55-65%	65-72%	88-93%	42.9%
λ	0.1024	$Cc/2.303 = 0.355$	0.37	0.495
κ	0.01240	$Cs/2.303 = 0.0477$	0.054	0.0248
V	0.33333	0.30000	0.30000	0.33333
μ	0.0002	0.0327	0.053	0.0002
M	1.47	1.28	1.4	1.26
V_r^v (1/min)	5.7E-07	1E-04	1.62E-4	5.7E-07
OCR	1	2	1.8	5

When modeling using Osaka Bay Clay properties, the development of the axial load forces along the pile was clearly examined at the end of calculation. The LNP (Location of neutral plane) was at (4.2 m) from the pile head, (as shown in Figure 10). In the case of Eastern Osaka clay properties, the LNP was at (4.1 m), (as shown in Figure 11). Finally, modeling using SFBM clay properties gave the smallest magnitude of NSF where the LNP was at (1.4 m) from the pile head, (as shown in Figure 12).

The effect of the interface element strength, $\bar{C}_0$ was clearly examined when comparing the three clay types. C_0 was calculated using Eq. 2.

$$C_0 = \frac{q_{u_{soil}}}{2} \quad (2)$$

$$q_{u_{soil}} = M^* \times \sigma_v \times \exp\left(\frac{-\lambda-\kappa}{\lambda}\right)$$

The soil unit weight (γ) of SFBM Clay is the largest and as a result, the effective vertical stress (σ_v) and the interface elements strength will be larger than the other two clay types. Raising the shear strength of interface elements caused a reduction in the axial load and NSF distribution.

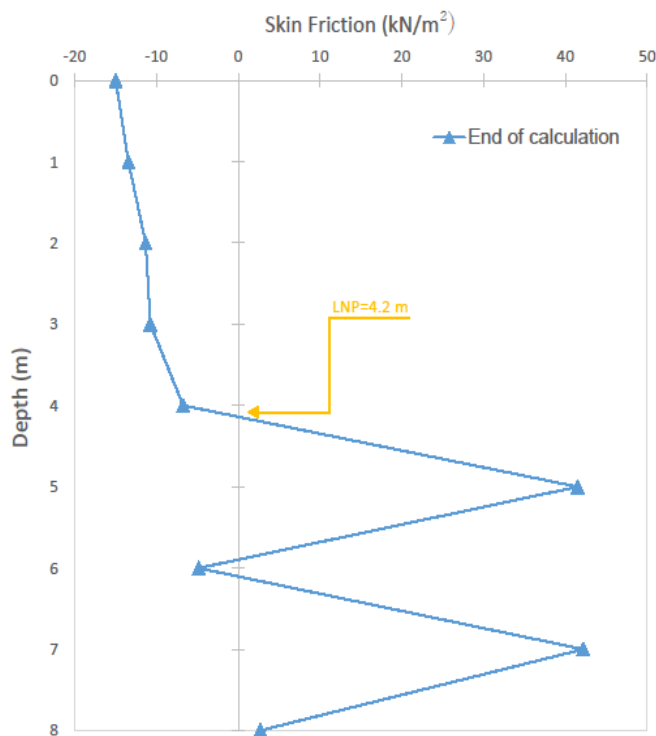


Figure 10. Skin friction distribution of Osaka Bay Clay

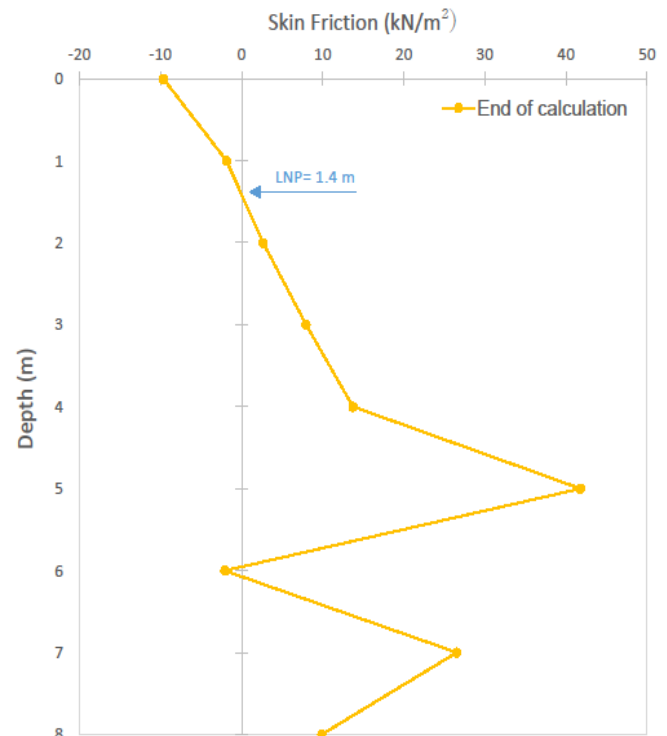


Figure 12. Skin friction distribution of SFBM Clay

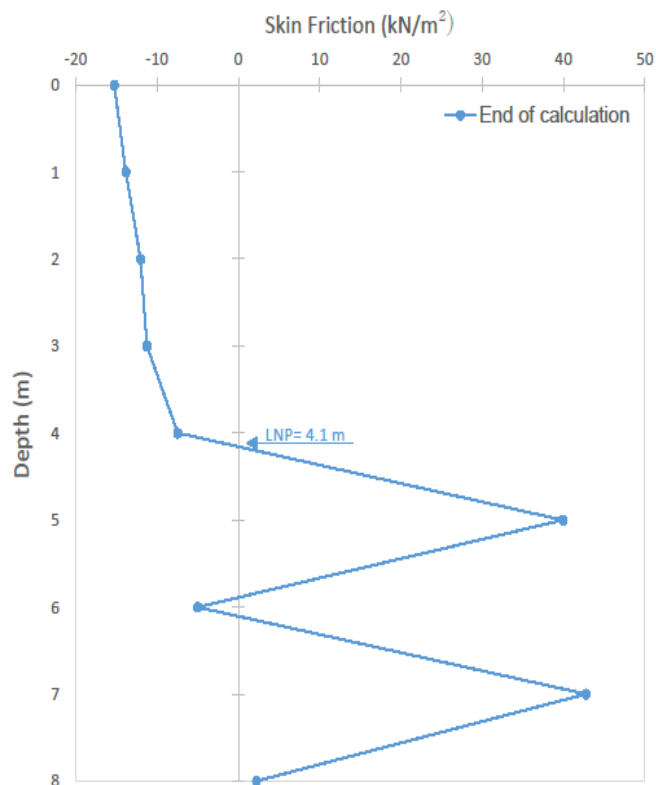


Figure 11. Skin friction distribution of Eastern Osaka Clay

3 CONCLUSIONS

A simplified numerical model consists of two clay layers, and a single pile was performed. The purpose of the simple model was to examine the impact of changing the clay properties and the viscous parameters on the pile's bearing characteristics.

The physical and mechanical properties of the clay have a significant effect on the secondary consolidation settlements. Moreover, reducing the coefficient of secondary consolidation would minimize NSF distribution. While increasing the value of the reference strain rate would raise the axial load distribution and soil settlements during secondary compression.

4 RECOMMENDATIONS FOR FUTURE WORK

The simple model was performed in order to study the influence of the physical and mechanical clay properties on the long-term settlements. However, this parametric study was limited. Conducting laboratory tests on more types of clay. Moreover, controlling the viscous strain rate to determine the most factor induce the viscous behavior, is demand.

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