# Time-dependent behavior of excavations in central Jakarta

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## ABSTRACT

This paper presents a three-dimensional (3D) numerical simulation for a large-scale deep excavation case in central Jakarta by adopting soft soil creep (SSC) model and soft soil (SS) model. The excavation case with an embankment at one side is constructed in Jakarta clay using top-down construction method. In this construction method, the diaphragm wall have been observed to deform significantly during waiting period due to soil creep. The SSC model that has capability to recognize time-dependent behavior of the soil (secondary compression) is used in this study on the excavation case in central Jakarta. Numerical results from SSC model and SS model are presented and compared with the field measurement.

**Keywords:** Soft Soil; Creep; Excavation; Central Jakarta; Clay

## 1 INTRODUCTION

Jakarta is the capital city of Indonesia which is located on the northwest coast of the island of java with 661.5 km$^2$ of total area and around 10 million of population. As the center of government and economy, infrastructure development is expanding rapidly particularly large-scale of deep excavation as the consequence of limited space in Jakarta. Mostly excavation projects in Jakarta adopted top-down construction method. This procedure generally requires considerable time to build the forms and pour the concrete slab before the next stage of excavation. Diaphragm wall have been observed to deform significantly during these waiting period. In fact, soil creep has contribute significantly to time-dependent wall displacement by adding up to 30% of the total displacement (Lin *et al*., 2002).

An excavation case with an embankment at one side is studied through numerical analysis with soft soil creep model (SSC). Soft soil creep model is adequate to model the behavior of soft soils by considering the soil creep. Parameters of SSC model was calibrated and interpreted based on both results from in situ and laboratory tests. In this study, wall deformation after completion of the slab is compared to wall deformation at 1 month after completion of the slab. This one month is considered as waiting period. The waiting period refers to no-excavation activities occurred. Figure 1 shows the relationship between the rates of maximum wall deflection ($\Delta\delta/\Delta t$) and excavation depth of this study, compared to TNEC excavation cases in Taipei. The maximum wall deflection rate is represented as the maximum wall deflection enhancement divided by waiting period. High maximum wall deflection rate at final stage is presumably due to creep effect of the soil. Consequently, this study presents a numerical analysis approach to evaluate this creep effect by adopting soft soil creep model (SSC) and using 3D finite element analysis.

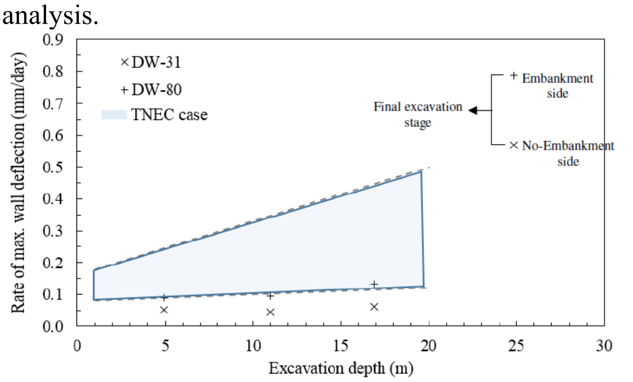



Fig. 1. Relationship between the rates of maximum wall deflection and excavation depth.

## 2 EXCAVATION CASE AND NUMERICAL MODEL

### 2.1 Details of excavation site condition

The length and width of excavation are 190 m and 21 m, respectively. The construction was performed using top-down construction method with four excavation stages, supported by four-level reinforced concrete slab with various thickness. The retaining structure of excavation adopted a diaphragm wall with

1.2 m in thick and 33.7 m in depth. A road embankment is located at one side of excavation with 60 m width and inclined from GL. +1.50 m to GL. +6.00 m. Figure 2 shows the cross section profile of excavation.

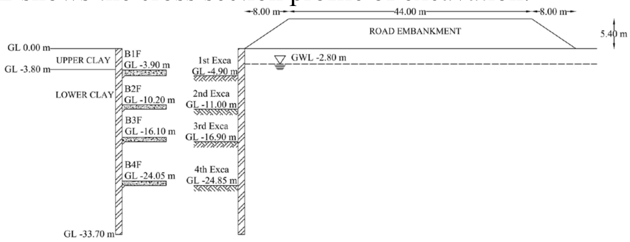



Fig. 2. Excavation profile of the excavation zone.

According to Rimbaban (1999), Jakarta is a lowland area that has five main landforms: (1) volcanic alluvial fan landforms, which are located in the southern part; (2) landforms of marine origin, which are located in the northern part adjacent to the coastline; (3) beach ridge landforms, which are located in the northwest and northeast parts; (4) swamp and mangrove-swamp landforms, which are encountered in the coastal fringe; and (5) former river channels which run perpendicular to the coastline.

Generally, Jakarta soils are comprised by quartenary and tertiary (Firmansyah & Sukamta, 2000). Quartenary deposit is structured by volcanic ash which simply divided into 3 sub layers: 3 m – 5 m thick of upper lahar that consists of silty sand; alternate silty clay, silty sand, and sandy sily; and approximately 5 m thick of lower lahar that comprises of cemented silty sand. Moreover, tertiary deposit placed around 35 m below the ground surface. This layer comprises of a very thick (more than 100 m) greenish silt with the consistency from stiff to hard. The soil properties at the excavation site is presented in Figure 3.

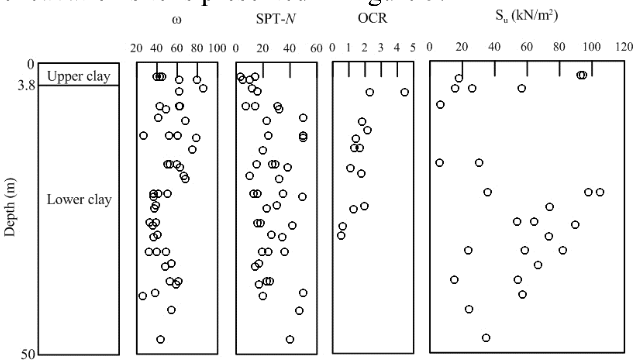



Fig. 3. Soil properties at the excavation site.

## 2.2 Numerical model

A three-dimensional (3D) finite element analysis was conducted in this research to simulate the excavation. Figure 4 shows 3D finite element model of excavation case in central Jakarta. The dimensions of the finite element model were 320 m x 340 m x 65 m. A full excavation area with a length of 190 m length was adopted to the model. Moreover, the width of excavation and road embankment are 21 m and 60 m, respectively. The boundary in x-direction was assigned to be 147 m from the diaphragm wall at no embankment side and 92 m from the end of embankment at embankment side. In y-direction was assigned to be 75 m from diaphragm wall. Additionally, the vertical boundaries were restrained from horizontal movement and the base was fixed in all directions.

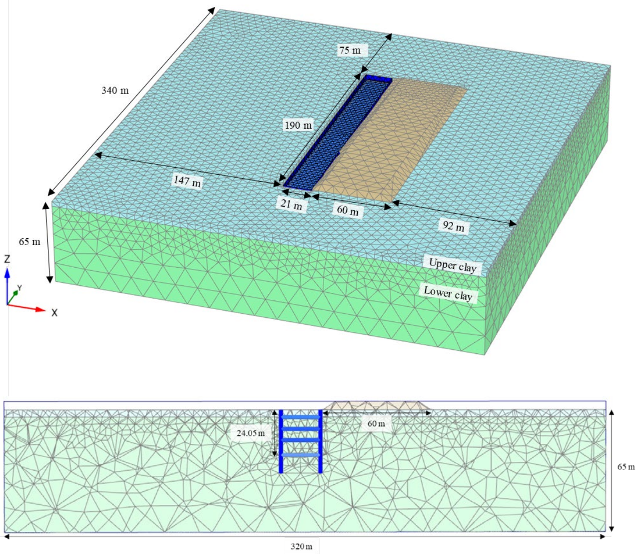



Fig. 4. 3D Finite element model of excavation case in central Jakarta.

There are 14 stages of construction in this simulation as listed in Table 1. A consolidation phase was added after installation of the slab in order to consider the creep effect of the soil at no-excavation activities or waiting period. All of the phase were designed using consolidation for the calculation type in aim to deal with time-dependent behavior of the soil.

Table 1. Stage of construction.

| Phase | Stage of construction | Time (days) |
|---|---|---|
| 0 | Initial phase | - |
| 1 | Construction of embankment | 7300 |
| 2 | Installation diaphragm wall | 150 |
| 3 | Excavate to GL. -4.90 m | 5 |
| 4 | Install B1F at GL. -3.90 m | 20 |
| 5 | Consolidation | 30 |
| 6 | Excavate to GL. -11.00 m | 14 |
| 7 | Install B2F at GL. -10.20 m | 29 |
| 8 | Consolidation | 30 |
| 9 | Excavate to GL. -16.90 m | 13 |
| 10 | Install B3F at GL. -16.10 m | 41 |
| 11 | Consolidation | 30 |
| 12 | Excavate to GL. -24.85 m | 20 |
| 13 | Install B4F at GL. 24.05 m | 56 |
| 14 | Consolidation | 30 |

For excavation structures, plate was selected to model the diaphragm wall and concrete slab. Referring to Ou (2006), the stiffness (EI) of diaphragm wall is reduced by 20-40% to consider the crack of the concrete due to large bending moment of diaphragm wall, hence reduced by 20% was adopted in the analysis. The axial stiffness of the concrete floor slab is also reduced by 20%. Table 2 list the input parameters for structural elements in numerical analysis.

Table 2. Input parameters for structural elements.

| Structure | Type | t (m) | E (Mpa) | υ |
|---|---|---|---|---|
| B1F | Plate | 0.8 | 21000 | 0.15 |
| B2F | Plate | 0.4 | 21000 | 0.15 |
| B3F | Plate | 0.4 | 21000 | 0.15 |
| B4F | Plate | 1 | 21000 | 0.15 |
| Diaphragm wall | Plate | 1.2 | 21000 | 0.15 |

### 2.3 Soft soil creep model

The soft soil creep (SSC) model is constitutive model extension from soft soil (SS) model that has capability to recognize time-dependent behavior of the soil (secondary compression). In other words, the SSC model is taking account of creep behavior of the soil under constant effective stress. The 3D states of stress and strain of this model is extended from 1D creep model for oedometer-type strain conditions by incorporating modified cam-clay and viscoplasticity. Furthermore, for the failure behavior of this model is based on Mohr-coulomb criterion (P.A. Vermeer *et al.*, 1999).

The SSC model has the same required parameters with the SS model by adding the creep parameter in the form of the modified creep index μ*, which are c', φ', ψ, λ*, κ*, and μ*. Table 3 summarized the soft soil creep model parameters.

Table 3. Soft soil creep model parameter.

| No. | Symbol | Parameter name |
|---|---|---|
| 1 | c' | Effective cohesion |
| 2 | φ' | Friction angle |
| 3 | ψ | Dilatancy angle |
| 4 | λ* | Modified compression index |
| 5 | κ* | Modified swelling index |
| 6 | μ* | Modified creep index |
| 7 | OCR | Over consolidated ratio |

### 2.4 Soil parameters

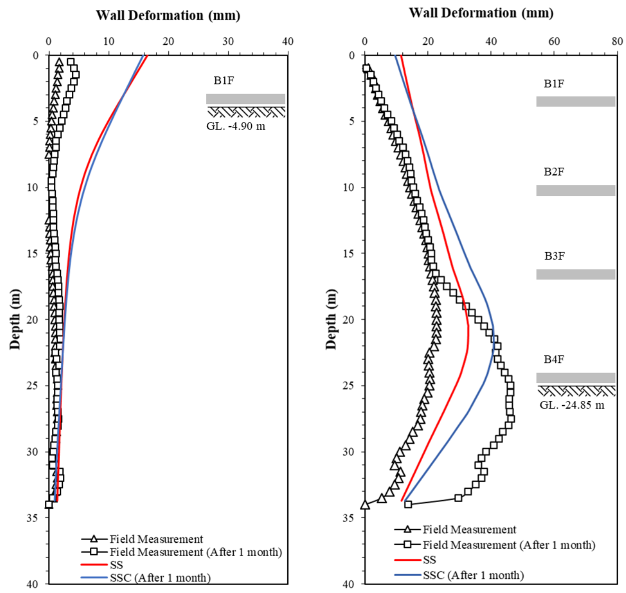
Both of SS and SSC model was simulated by applying two layers of clay, which are upper and lower Jakarta clay. Table 4 lists the input parameters of the SSC model for Jakarta clay. The stiffness parameters of the SSC model (λ*, κ*, and μ*) and OCR were obtained from oedometer tests on samples took at the excavation site. For the strength parameters were collected from isotropically-consolidated undrained triaxial (CU) tests. All of the parameters subsequently were calibrated in order to improve the performance of the input parameters. Additionally, input soil parameters for SS model is also same with SSC model as listed in Table 4. However, it did not consider the modified creep index μ*, which is the limitation of this model.

Table 4. Input parameters of the SSC model for Jakarta clay.

| No. | Symbol | Upper clay | Lower clay | Source |
|---|---|---|---|---|
| 1 | c' | 6 | 3.5 | CU test |
| 2 | φ' | 38 | 39 | CU test |
| 3 | ψ | - | 6.5 | |
| 4 | λ* | 0.1039 | 0.04647 | Oedometer test |
| 5 | κ* | 0.02772 | 0.003319 | Oedometer test |
| 6 | μ* | 0.008661 | 0.005808 | |
| 8 | OCR | 3.37 | 6.25 | Oedometer test and CU test |

## 3 ANALYSIS RESULT AND DISCUSSION

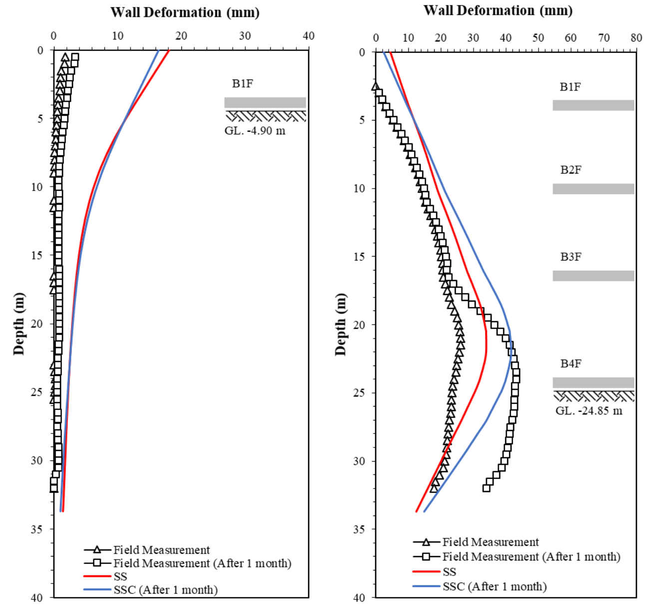
Field measurement after completion of the slab and after 1 month of completion of the slab are collected and compared with the numerical results. Simulation using SS model aims to fit with the inclinometer reading at completion of the slab (without considering the creep). The SSC model is conducted to observe the creep effect (time-dependent behavior) induced by excavation. The input parameters that used in SS model is the same with SSC model except modified creep index μ*. Figure 5 and 6 present the wall deformation (SSC and SS model) for embankment side and no embankment side, respectively.




(a) (b)

Fig. 5. Wall deformation at embankment side (SSC and SS model); (a) 1st stage of excavation and (b) Final stage of excavation

At the first stage of excavation for both of side, the results computed from SSC and SS model are larger than field measurement. It is caused by soil behavior at small strain range which is the limitation of the model. The SSC model with capability to consider small strain behavior is still needed to develop further. On the other hand, at this stage, the result from SSC either SS model is almost same. It indicates that creep has not occurred at this stage. It also has a good agreement with the field measurement that there is no significant difference between inclinometer reading at completion of the slab and after 1 month of completion of the slab. Furthermore, the creep effect starts to exhibit at the next stage of excavation and clearly seen at the final stage of excavation. At this stage, the SSC model generated larger deformation than SS model. It shows that the increments of wall deformation which caused by creep of the soil is approximately 22-25%. However, it still could not match the addition of wall deformation of the field measurement. This high increment of wall deformation at final stage might be caused by the combination of soil creep, dissipation of pore water pressure (since there was a sand layer observed on excavation site) and even the structural elements. These factors have to be studied further.




(a) (b)

Fig. 6. Wall deformation at no embankment side (SSC and SS model); (a) 1st stage of excavation and (b) Final stage of excavation

## 4 CONCLUSION

According to the finite element analysis, field measurement, and also the laboratory data, the following conclusions were drawn from the results:

1. SSC and SS model shows that soil creep (time-dependent behavior) contributes to increment of wall deformation by approximately 22-25% from total deflection. Hence, soil creep effect should be considered in top-down construction method.
2. In addition to creep effect (time-dependent behavior) of excavation, the high increment of wall deformation at final stage have to be explored further.
3. This research provides a reference for estimating the modified creep index μ* of Jakarta clay. However, further research and high quality test are highly recommended based on the result of this research.
4. SSC model with capability to consider small strain behavior has to be developed in the future.

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