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Inverse analysis to evaluate stiffness evolution in the deep excavation

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ABSTRACT

The engineering properties of the ground used in the design stages are estimated by field and laboratory investigations and are changed due to the deformation of the ground during construction. This causes the differences between the predicted results and the field measurements at the design phase. In urban environment, prediction of the ground deformation is an important factor in case of the deep excavation which requires precise ground deformation. In order to precisely estimate the ground deformation, the stiffness change of the excavation site was evaluated sing inverse analysis algorithm. The XX deep excavation site located in Incheon, Korea was selected as the application field of that algorithm. In this study, the ground deformation predicted from the design phase were compared with the field measurements of the ground and the ground properties were calculated to satisfy the field measurements. This process was performed as the excavation proceeded, and the ground properties satisfying the ground deformation in the previous phase were used to predict the ground deformation in the next excavation phase and compared with the measured values

Keywords: retaining wall; finite element analysis; ground deformation; inverse analysis

1 INTRODUCTION

The engineering properties of the ground used in the design stage are estimated by field and laboratory investigations. However, the engineering properties of the ground are changed due to the deformation of the ground during constructions, which causes the difference between the predicted results at design stage and the field measurements. In urban environment, prediction of the ground deformation is an important factor in case of the deep excavation which requires precise ground deformation. In this study, the stiffness change calculation algorithm was applied to an actual field of deep excavation to accurately estimate the stiffness change.

2 DEEP EXCAVATION SITE

2.1 Field Outline

The excavation depth of the XX deep excavation site located in Incheon is 8.45~9.55 m, soil cement wall, (S.C.W., φ550) was used for retaining wall construction, and steel pipe strut was used for retaining wall. As a result of the subsurface investigation, fill, sediment, weathered soil and weathered rock layers were found. The information of the layers is summarized in Table 1. The field view of the site and subsurface stratum are shown in Figs. 1 and 2, respectively.

Table 1. Information of the layers

Layer	Fill	Sediments	Weathered soil	Weathered rock
SPT N-value	2~14	2~6	4~50	50/10cm~2cm
Soil classification	Gravel and silt mixed sand	Silty clay	Silt mixed sand	Silt mixed sand
Total specific weight (γ_t)	1.8t/m³	1.75t/m³	1.8t/m³	1.9t/m³
Cohesion (c)	0t/m²	3.5t/m²	0t/m²	1.0t/m²

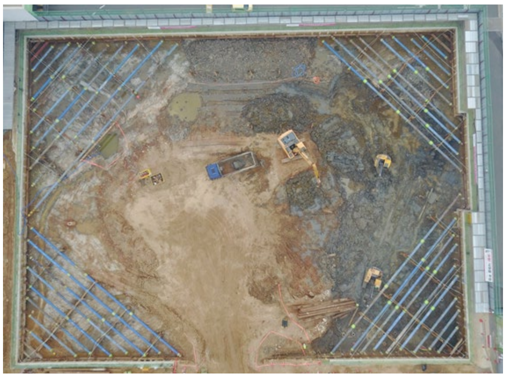

Figure 1. A field view taken with a drone

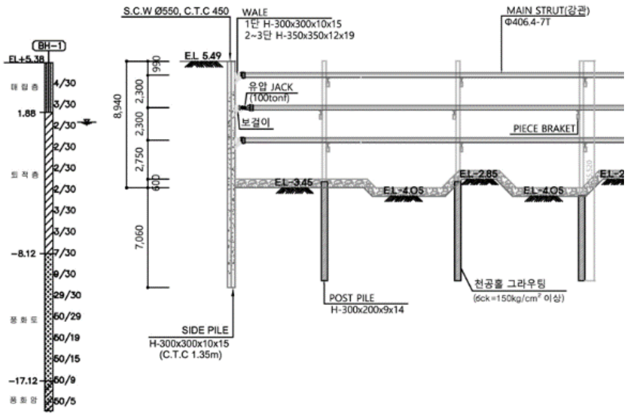

Figure 2. Outline of field stratum and retaining method

2.2 Prediction of site ground behavior

In the original design of the retaining wall, SUNEX, a program to calculate the structural stability by applying earth pressure to the wall was used; the examination of the ground deformation was carried out indirectly using Caspe(1966). In this study, the analysis was performed using PLAXIS2D 2017, a finite element analysis (FEM) program.

3 INVERSE ANALYSIS OF GROUND PROPERTIES BY EXCAVATION PHASE

3.1 Comparison of SUNEX results and Field Measurement Values

The deformation value of the excavation support wall using the original design SUNEX was compared with the measured value of the inclinometer at the site. The results of the inclinometer and SUNEX were similar until approximately 2 m excavation as shown in Fig. 3. However, as the excavation depth increased until 5 m, it was confirmed that the difference between the field measurement values and the wall deformation values using SUNEX was distinguishable.

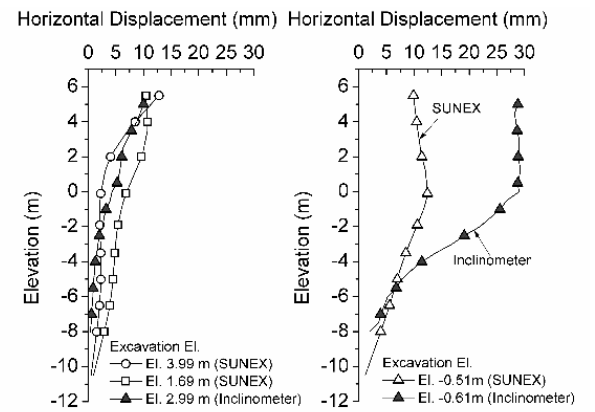

Figure 3. FEM analysis result and field measurement value comparison

3.2 Comparison of FEM results and field measurements values using design property values

The FEM analysis was performed using the original ground properties. Comparing the FEM analysis results with the field measurements, the FEM analysis results indicate that the deformation of the wall is overestimated greatly as shown in Fig. 4. It is analyzed that the ground stiffness used in the design is roughly estimated based on N values and it is estimated to be smaller than the actual ground stiffness.

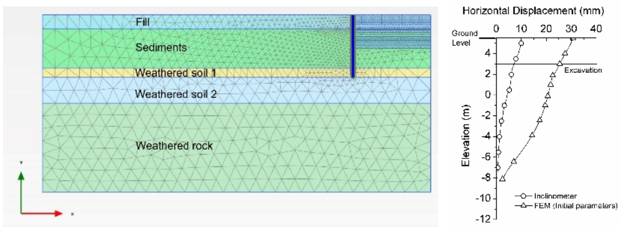

Figure 4. FEM mesh for the excavation site and comparison of FEM analysis results and measurement

3.3 Inverse Analysis

In situ measurements at excavation depth of 2.5 m were compared with the FEM analysis results, and inverse analysis was performed to estimate the ground properties satisfying the measured values. Mohr-Coulomb model was used for the simulation, and the elastic modulus values of the fill and the sediments were selected as the target properties of inverse analysis. Through inverse analysis, it was possible to evaluate the properties of the ground that satisfy the field measurements. Figure 5 shows the comparison of inverse analysis results and monitoring data. The elastic modulus of the sediments used in the original design is 10,000 kPa, but it turned out the inverse analysis resulted as 33,000 kPa. As for the sediments in the original design, the elastic modulus is 8,000 kPa, but the inverse analysis resulted as 32,000 kPa, and 11,000 kPa increased due to an increase in the depth of 1 m. It was confirmed that the ground properties used in the design were underestimated. The inverse analysis also confirmed that backside settlement of the excavation estimated from the inverse analysis is more approximate to that of the field measurements.

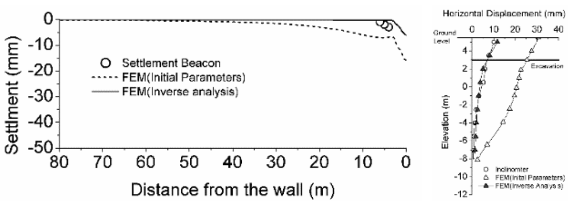

Figure 5. Comparison of analysis results and inverse analysis using field measurements and design properties

The ground property at excavation depth of 6 m was analyzed using the soil engineering property values calculated from the inverse analysis at the excavation depth of 2.5 m. As shown in Fig.6, it was found that the error between the measured value and the FEM result using the inverse analysis was remarkably reduced as compared with the simulation result using the ground property value used in designing. However, since the ground stiffness changes as the ground deformation progresses, there was still a difference between the field measurements and the analytical results. The inverse analysis was carried out again to evaluate the field measurements more precisely. As a result of additional inverse analysis, the elastic modulus of the fill slightly decreased from 33,000 kPa to 32,000 kPa, and the elastic modulus of sediments decreased from 32,000 kPa to 15,000 kPa.

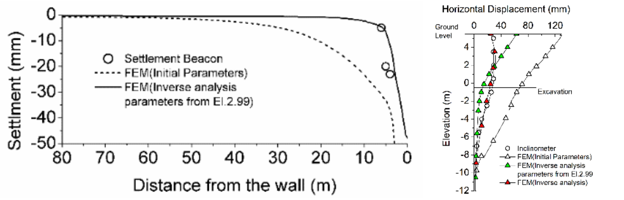

Figure 6. Analysis using inverse analysis result and field measurement value comparison, and additional inverse analysis result

Based on the ground properties derived from the additional inverse analysis, the excavation site with an excavation depth of 7 m was analyzed and it was confirmed that the analytical results were very close to the field measurements, as shown in Fig.7.

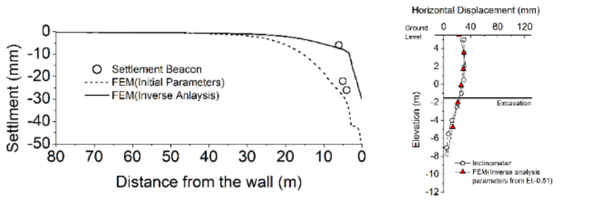

Figure 7. Comparison of field measurements and analysis results using inverse analysis results

3.4 Analysis of changes in ground properties

The soil engineering properties used in the initial design and the ground properties determined by inverse analysis are shown in Table 2. The properties used in the initial design were underestimated by a rough assessment of the ground stiffness based on N values. As the result of first inverse analysis conducted at the excavation depth of 2.5 m using the field measurements, a greater value was obtained than the soil engineering properties used in the initial design. The inverse analysis was carried out again as the excavation progressed, smaller values of soil stiffness was obtained than the properties of the ground calculated from the first inverse analysis. The soil stiffness was decreased as the excavation progressed.

Table 2. Changes in soil stiffness

Input variable	Design property(kPa)	1st Inverse analysis(kPa)	2nd Inverse analysis(kPa)
Fill	10,000	33,000	32,000
Sediments, E_{ref}	8,000	32,000	15,000
Sediments, E_{inc}	-	11,000	2,000

4 CONCLUSION

In this paper, the finite element simulation and the inverse analysis were conducted for the XX excavation site located in Incheon, Korea. Comparing the results of the numerical simulation using the soil engineering properties in the original design and measurements of the field inclinometer, it was found that the result of FEM overestimates horizontal deformation of the soil retaining wall. By conducting the inverse analysis, it was found that the soil stiffness that satisfies the field measurements is greater than that of the original design. Presumably, it results from that the stiffness used in the original design is roughly estimated from the N values obtained from the standard penetration tests.

By using the soil stiffness from the inverse analysis conducted at the previous excavation step, it was possible to significantly reduce the error between the numerical simulation at the current excavation step and the field measurements. The remaining error was able to minimize by carrying out the inverse analysis again.

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