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Field performance of a genetic algorithm in the settlement prediction of a thick soft clay deposit in the southern part of the Korean peninsula

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ABSTRACT

Long-term settlement data of a thick soft clay deposit improved by vertical drains frequently shows different field settlement behaviors from laboratory-driven predictions by conventional theories due to the variability and uncertainty of the soil properties, modeling simplifications, and types of prediction methods. This paper presents the field application of a back-analysis method based on a genetic algorithm (GA) to evaluate the performance of a new settlement prediction method compared with conventional graphical settlement prediction methods, such as the hyperbolic method and the Asaoka method. The GA back-analysis method shows better flexibility in modifying surcharging plans and adaptability to multi-layered thick soft soil deposits at the early stages of post-construction settlement. Thus, this new settlement prediction method enables geotechnical engineers to subsequently modify the heights of surcharge fills in accordance with field settlement data monitored in the interim for rapid and cost-effective construction. The comparative results show that the GA back-analysis method is capable of superior field performance in settlement predictions compared with two conventional graphical methods, within a margin of less than 200 mm in a thick soft clay deposit with multiple layers under complex loading conditions.

1. Introduction

Over the past two decades, several construction projects in Korea have been built on thick soft soil deposits to create new national infrastructure, such as container ports and a new international airport, which were built on reclaimed areas. As a cost-effective soil improvement method, embankment preloading associated with vertical drains is commonly used to accelerate the consolidation process and predict the consolidation settlement of foundation soils due to surcharge loading. Settlement prediction in a large-construction project is an important issue for rapid and cost-effective construction; however, it is frequently reported that geotechnical engineers fail to obtain accurate predictions of the long-term field settlement of soft soils even if robust calculation with advanced geotechnical technology was implemented during the design stage. Significant errors in settlement predictions during ground improvement work have been reported in many construction sites in Korea. Recent construction records in the southern part of Korea indicate that the observed settlement is generally 1.5 to 3 times greater than the settlement predicted in the design stage. It is thought that these errors in settlement prediction are mainly caused by the variability and uncertainty of the soil properties (Kim, 2008; Chung et al., 2009, 2012; Park et al., 2009).

Although the accuracy of numerical schemes and testing techniques has been significantly improved, there are still errors between the predicted and observed magnitudes of settlement. Possible reasons for these errors are the following: (1) sampling disturbances and effective stress condition during sampling, delivery, and trimming procedures; (2) a simplified analysis model, loading condition, boundary condition, and initial condition used during the design stage; (3) measurement errors caused by operators and systems; and (4) variability and uncertainty of the soil properties (Bjerrum, 1967; Jamiolkowski et al., 1985; Terzaghi et al., 1996). Graphical methods using observed settlement data are commonly employed as practical tools for interpreting field settlement data to reduce the variability and uncertainty of the consolidation parameters governing the magnitude of the consolidation settlement (Asaoka, 1978; Tan and Chew, 1996).

Soil improvement performance levels are usually evaluated by analysis of the monitored settlement data for comparison with laboratory-driven settlements determined during the design stage. The magnitude of the additional surcharge load and the surcharge period can be finally determined based on the interpretation of field settlement data. The consolidation parameters in a thick soft clay deposit with vertical drains are the main points of interest in predicting long-term consolidation settlement. The consolidation settlement of a vertical drain installed in a soft soil layer is calculated based on Barron's equation. Several

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observational methods based on settlement records are available to predict future settlement behavior, specifically the hyperbolic method and the Asaoka method. By extrapolation from observed settlement data, many uncertainties regarding the variability of the soil as well as the magnitude and distribution of loads can be overcome (Tan et al., 1991; Asaoka, 1978). These graphical methods simply predict the final settlement by means of curve fitting from observed settlement data. Therefore, observed settlement data after the removal of surcharge loads are used to predict the final settlement related to the degree of consolidation. However, these methods are not suitable for use when predicting field settlement during unloading and reloading after the removal of the surcharge load and when adjusting the height and period of the surcharging embankment (Park et al., 2009).

The BFGS (Broyden–Fletcher–Goldfarb–Shanno) method, the quasi-Newton method, and the conjugate gradient method are conventional optimization methods for consolidation-related back-analysis problems (Arai et al., 1983; Sakurai and Takeuchi, 1983; Shoji et al., 1990; Kim and Lee, 1997; Park et al., 2009). These methods are used for consolidation problems with a small number of consolidation parameters in one or two clay layers. However, the number of consolidation parameters in a multi-layered problem is typically greater than that in a single layer problem. This multi-dimensional optimization problem complicates the process of estimating consolidation parameters when attempting to predict the consolidation settlement of foundation soils accurately. Several optimization schemes generate either local or global solutions depending on the initial values of the variables used. Furthermore, as the number of the variables for the optimization process increases, the chance of a solution converging locally rather than globally increases (Renders and Flasse, 1996; Leung and Wang, 2001). Therefore, in a multi-layered soft clay deposit, it is necessary to use a robust technique that guarantees convergence to a global solution. A back-analysis method based on a genetic algorithm (GA) can be used as a parallel and global search tool that emulates natural genetic operators. GAs generally show better performance when searching for a solution than conventional optimization algorithms because GAs, which make use of an entire set of solutions spread throughout the solution space, are less affected by local optima (Holland, 1975; Goldberg, 1989; Keane, 1995). Park et al. (2009) showed that the GA back-analysis method has the advantage of robustly searching for a global solution while avoiding local solutions compared with conventional optimization schemes in a multi-dimensional consolidation problem with three consolidation layers.

In this study, the GA back-analysis method was implemented to improve the field performance of settlement prediction. The accuracy and capability of settlement prediction methods were investigated to evaluate settlement prediction performance using field settlement data from a large construction site in Busan on thick soft clay layers consisting of multiple-clay layers with a complex geological history.

2. Site description

2.1. Soil characterization

The studied site is located near the southern coastal area of the Korean peninsula. The site was mainly formed by an accumulation of a deltaic deposit near the Nakdong River. The thick deltaic deposit area was formed as a valley caused by the vertical movement of the Yangsan fault during the Cenozoic era. Various types of geo-materials have been deposited in the valley via the river flow (Kim, 2008). A representative sectional profile near the studied site is shown in Fig. 1. Sand and gravel materials were deposited in the valley first. Then, the soft soil deposit was followed by the deposition of different geo-materials affected by marine transgression and regression during the area's geological history. The sedimentary deposit can be categorized into four layers: upper clay, silty sand, lower clay, and bottom sand and gravel layers. The bottom sand and gravel layer is thick enough to hold fresh water in an aquifer. The silty sand layer in the middle is sandwiched between the upper and lower clay layers. Soft soil layers with different engineering characteristics have been deposited by the flow of the river water as well as marine transgression and regression. The soft soil layers can be categorized into two distinct silty clay layers as the upper and lower clay layers. The upper clay layer basically shows a normally consolidated state with a soft to medium consistency; however, the lower clay layer shows stiff to very stiff characteristics. The total thickness of the whole upper and lower clay layers ranges from approximately 50 m to 80 m (Chung et al., 2002, 2012; Kim, 2008).

The silty clay soils in the studied site are generally classified as CL and CH soils in accordance with the Unified Soil Classification System (USCS). Fig. 2 shows the profiles of liquid and plastic limits, water content, initial void ratio, compression index, and overconsolidation ratio of the upper and lower clay layers. There is a distinct separation around the expected border of the upper and lower clay layers in the soil profiles. The values tend to increase with depths above 25 m; however, they tend to reversely decrease below depths of 25 m. When considering this distinct difference between two groups of data in the property profiles, the clay layer can be divided into two representative layers as the upper clay layer and lower clay layer. The laboratory-driven design values of the compression index (C_c) are 0.9 for the upper clay layer and

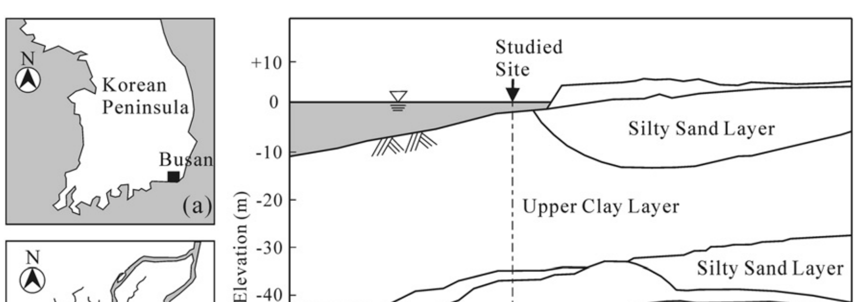

Fig. 1. Location of the studied site and sectional view of the deltaic deposits of the Nakdong River (Modified after Kim (2008)): (a) Korean peninsula, (b) location of the studied site, and (c) sectional view of soil layers of the studied site.