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Discussion on the mechanism of ground improvement method at the excavation of shallow overburden tunnel in difficult ground

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Abstract

Tunnel construction opportunities involving shallow overburdens under difficult (e.g., soft, unconsolidated) grounds have been increasing in Japan. Various auxiliary methods for excavating mountain tunnels have been developed and can satisfy stringent construction requirements. The ground improvement method, which is one of the auxiliary methods for shallow overburden tunnels, has demonstrated its ability to effectively control the amount of settlement under soft ground. However, the mechanism of the ground improvement method has not been clarified, nor has a suitable design code been established for it. Therefore, because the strength of the improved ground and the suitable length and width of the improved area have not been fully understood, an empirical design has been applied in every case. In this paper, the mechanical behavior during the excavation, including that of the stabilized ground, is evaluated through trapdoor experiments and numerical analyses. In addition, the enhancement of tunnel stability resulting from the application of the ground improvement method is discussed.

Keywords: Auxiliary method; Shallow overburden; Soft ground; Ground improvement; Settlement

Introduction

When a tunnel with a shallow overburden is excavated in a difficult (e.g., soft, unconsolidated) ground, the stability and the safety of the tunnel excavating face is of concern. Particularly in the case of soft ground, the ground that is loosened by the excavation tends to expand into the surrounding ground. In addition to the shallow overburden, the excavation also has a direct effect on the ground surface above the tunnel. Therefore, control of the loosened ground is the most important technical issue in the excavation of a tunnel located under a shallow overburden in soft ground. The cut and cover method has been widely used as the main tunneling method for excavating a shallow overburden tunnel in soft ground. Recently, use of the recently developed auxiliary method, the New Austrian Tunneling Method (NATM), has been increasing. In the construction field, when the NATM is used to excavate a shallow overburden tunnel in soft ground, an auxiliary method, such as pipe forepiling or vertical pre-reinforcement, is applied at the tunnel construction site, and stabilization of the crown and the prevention of ground surface settlement are then conducted.

Various auxiliary tunneling methods have been employed to prevent both the collapse of the tunnel excava-

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tion face and settlement at the surface and tunnel crown. When employing an auxiliary method, the workability and stability of the tunnel excavation should be explored, and a suitable auxiliary method should be chosen. Miwa and Ogasawara (2005) addressed the excavation of bullet train tunnels that crossed under a national highway with a shallow overburden. They reported that four excavation methods had been proposed and discussed and that NATM with the grouting-type pipe forepiling method was selected considering the safety, the construction term and the construction costs. As a result, the face was prevented from collapsing, and the tunnel was excavated while keeping ground surface settlement to a minimum and avoiding interference with road traffic. However, the effective mechanism of the grouting-type pipe forepiling method in this application was not discussed.

Several previous research works have discussed the advantages of stable tunnel excavation and the mechanisms of auxiliary methods. Since tunnels are often driven through soft ground containing groundwater and in locations close to various utilities and structures, Kimura, Ito, Iwata, and Fujimoto (2005) applied two methods, namely, special jet grouting for foot piles and long steel pipe fore-piling for preventing displacement, and a boring method for groundwater drainage. Oke, Valchopoulos, and Marinos (2014) analyzed literature and construction reports and discussed the effect of the umbrella arch (UA) by classifying three types of support elements: spiles, forepoles and grouted. Yoo (2002) investigated the behavior of a tunnel face reinforced by longitudinal pipes using a 3D finite element analysis. Based on the numerical results, he concluded that the face-reinforcement technique using longitudinal pipes could significantly reduce the deformation of the face and thus improve its stability. Kamata and Mashimo (2003) researched the effects of several auxiliary methods, such as face bolting, vertical pre-reinforcement bolting and forepoling, through centrifugal modeling tests on sandy ground and numerical simulation with DEM. They identified several favorable effects in terms of face stability. Taguchi et al. (2000) conducted model and full-size tests on a thin flexible pre-lining. They concluded that the pre-lining was effective for both the stability of the face and the prevention of ground surface settlement. They also proposed a quantitative estimation method for face stability. Kitagawa et al. (2009, 2010) performed trapdoor experiments and a numerical simulation to determine the effect of a reduction in settlement and the corresponding mechanism using a tunnel foot reinforcement side pile. Cui, Kishida, and Kimura (2008) performed numerical simulation of a tunnel excavation and a side pile with the aim to prevent surface settlement of the shallow overburden and the soft ground. Based on the numerical simulation, they proposed that the prevention of ground surface settlement and tunnel settlement, by the installation of a foot reinforcement side pile, affects the shear reinforcement, the load redistribution and the internal pressure. They also advised that the foot reinforcement side pile should be installed across the shear zone during tunnel excavation.

Several tunnels constructed for the Tohoku bullet train in Japan, the so-called Tohoku Shinkansen Railway, between Hachinohe and Shichinohe-Towada, were constructed under the condition of shallow overburden and soft ground. In cases without any obstacles on the ground surface, the objective ground was improved using the shallow or deep mixing stabilization method. Then, the tunnel was excavated by NATM. This approach constitutes the ground improvement method of the excavation of a shallow overburden tunnel. Fig. 1 shows the construction process associated with this method. First, the ground is excavated to the upper part of the tunnel crown. Then, cement is mixed with the natural ground around the sidewall of the tunnel using the shallow or the deep mixing stabilization method. The premixed soil is spread and compacted by rolling it over the tunnel crown area. Finally, the excavated soil is backfilled and compacted by rolling it to the ground surface. The tunnel can then be excavated using NATM. Various combinations of improved areas and levels of strength of the improved ground were implemented in the field, and the tunnels were excavated successfully. The ground improvement method was employed after considering the conditions of the overburden, the geology, the ground surface, the allowed settlement, and data from several previously reported construction projects (Kitagawa, Isogai, Okutsu, & Kawaguchi, 2004; Nonomura, Iura, Okajima, & Kishida, 2011; Saito, Ishiyama, Tano, & Haga, 2011; Tadenuma, Isogai, Konishi, Nishiyama, & Okutsu, 2003). Without disturbing any buildings and houses on the surface, this method has the advantage of pre-knowledge of the geological structure. Consequently, this method is more advantageous in terms of construction costs than other auxiliary methods, as shown in Fig. 2.

In this study, three-dimensional (3D) trapdoor experiments are conducted to simulate the progress of a tunnel excavation. In the trapdoor experiments, the

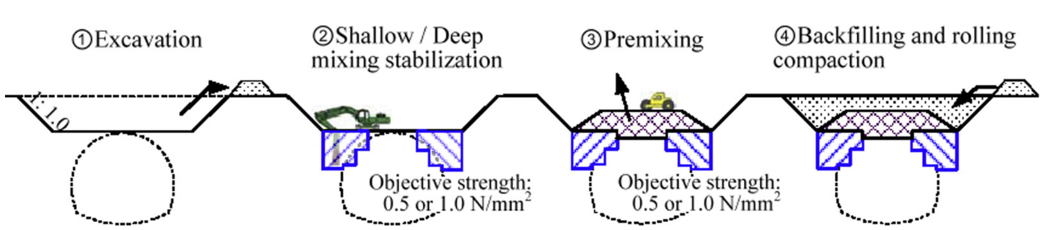

Fig. 1. Construction process of pre-ground improvement method.