Tunnelling and Underground Space Technology 50 (2015) 199–208

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

# Stability analysis of subway box structure supported by modified underpinning method

Yang-Hoo Park [a], Jin-Pal Kim [a], Kook-Hwan Cho [b,*]

[a] Doctoral course student, Dept. of Railway Construction Engineering, Graduate School of Railway, Seoul National University of Science & Technology, 232 Gongneung-ro, Nowon-gu, Seoul 139-743, Korea

[b] Associate Professor, Ph.D., P.E., Dept. of Railway Construction Engineering, Graduate School of Railway, Seoul National University of Science & Technology, 232 Gongneung-ro, Nowon-gu, Seoul 139-743, Korea

ARTICLE INFO

*Article history:*
Received 18 June 2014
Received in revised form 22 June 2015
Accepted 30 June 2015

ABSTRACT

When excavation under existing structure is planned for a new construction project, the underpinning method is one of the most applicable construction methods. This study introduces a new modified underpinning method which is applied to construct a new subway #9 line in Seoul Metropolitan in South Korea. The new subway line #9 was designed to pass underneath the existing subway line #2. Subway line #2 carries about 2 million passengers daily, which is 33% of total passengers using subway in Seoul, and is the only circulation line in Seoul. Subway trains are passing 540 times through this section in a day. By applying a new underpinning method, the subway box structure of line #2 is exposed 54 m in the air supported by bearing piles. The proposed method was carefully monitored using heavy instrumentation system during construction.

This study proposed and verified the application of the modified underpinning method, which can reduce construction period by 1.5 times and the construction cost by 1.2 times comparing with conventional method. The importance of considering construction sequence is investigated and verified by using measured load cell data. The unexpected heaving which can bring up a dangerous situation for train running stability were measured, so this study shows that the upward movement has to be analyzed in designing process. The vibration from train operation and blasting excavation was thoroughly monitored and verified that the proposed construction method can be used with safety. As the use of underground space increases, the proposed method can be a good example of underground development.



## 1. Introduction

In line with development plans in Seoul Metropolitan, the capital of South Korea, infrastructure construction has been continuously brought up a lot of issues such as efficient land use, minimizing environmental impact, harmonizing with surrounding landscape, and increasing lawsuits.

The population of Seoul is almost 10.3 million, and subway network, as shown in Fig. 1, has been continuously extended to line #9 since 1974, making total length of 316 km. About six million Passengers are using those subway lines per day.

The focused construction site in this study is on subway line #9 extension, where is to build a subway station underneath subway line #2 as shown in Fig. 2. Subway line #2 carries about 2 million passengers daily, and is the only circulation line in Seoul. 540 subway trains are passing though this section in a day.

Fig. 2(a) shows that the dimensions of the box structure of subway line #2 are as follows; the width is 10.8 m; the height is 8.2 m; the supported length is 54 m. The thickness of the soil layer above the box structure is 5.0–6.0 m. Fig. 2(b) shows that a new modified underpinning method is proposed and adopted to support the box structure of subway line #2. Fig. 2(c) shows that the new subway station is designed underneath the box structure of subway line #2, respectively.

The top of the station subway line #9 is located at the depth of 19 m from the surface.

## 2. Underpinning method

The underpinning method is usually adopted for civil work when penetrating under existing tunnels, reinforcing the foundation of existing buildings, and so on. Sato et al. (1990) introduced construction history and cases performed by underpinning method in Japan. Kordahi (2004) described advantages and disadvantages of underpinning method using grouting and micro piles from case studies. Tovey (2006) proposed a technology using concrete and underpinning to

* Corresponding author.
*E-mail address:* khcho@seoultech.ac.kr (K.-H. Cho).

http://dx.doi.org/10.1016/j.tust.2015.06.013
0886-7798/

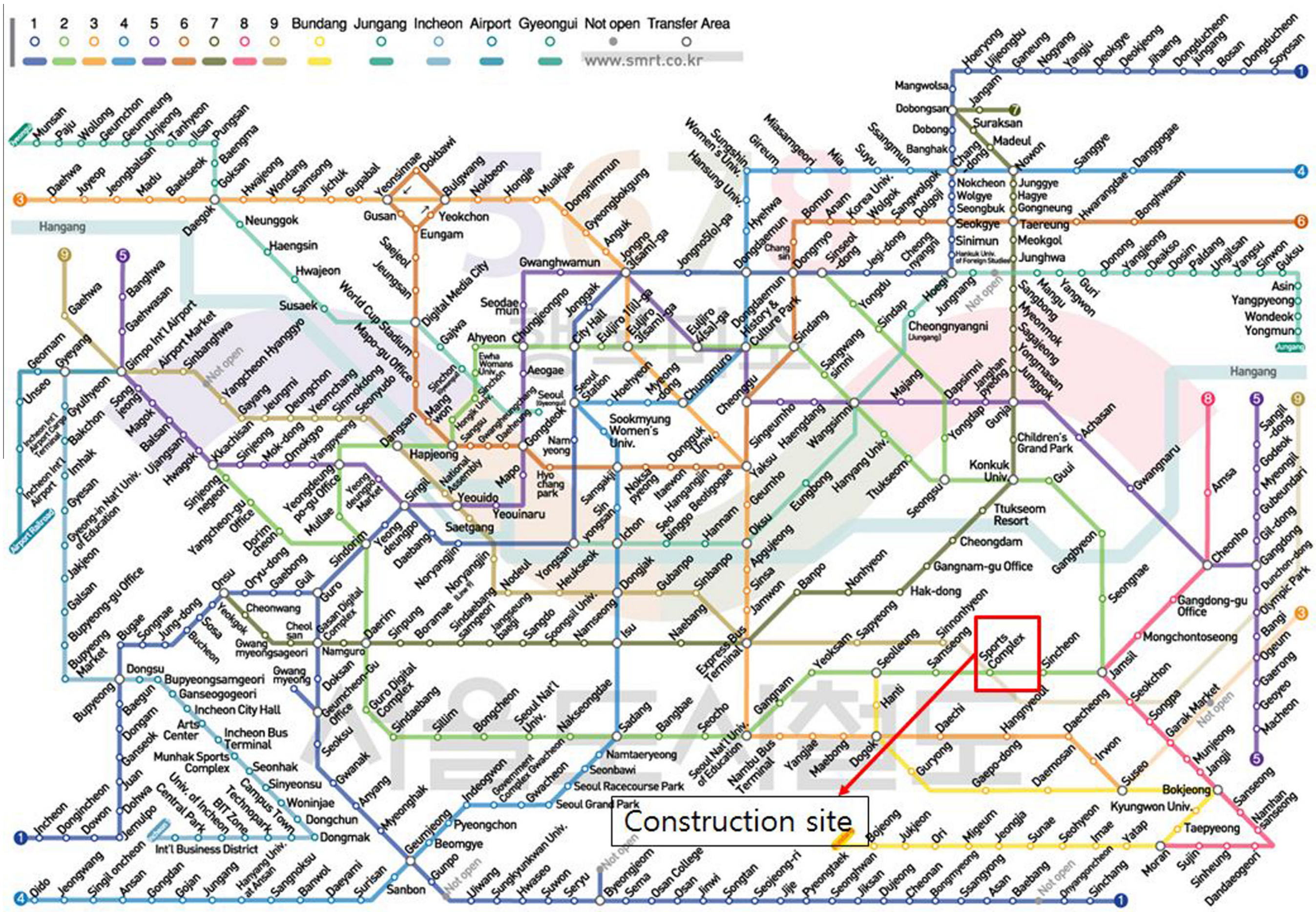


**Fig. 1.** Seoul Metropolitan subway line network.

utilize underground space due to expensive land price and high population density in London. Jia et al. (2009) conducted numerical analysis on settlement variation according to construction procedures for the case of excavating under existing building. Masuda et al. (1992) introduced the construction of the new subway line #6 under Nagoya subway station in Japan, and explained the advantage of underpinning method which was modified for the application to the site condition. Fig. 3 shows a conventional underpinning method.

A new modified underpinning method introduced in this study is designed to transfer loads from existing structure to girder, and then to piles for maximizing stability of existing structure as shown in Fig. 4. Advantages of the proposed method are as follows; Bearing piles can be placed without connecting piles during construction, which can minimize risks from pile connections; Sufficient work space under the structure can be obtained by using bearing girders; Manual excavation can be minimized, which reduces construction period and costs comparing with the conventional method.

## 3. Construction

### 3.1. Site specification

Geological conditions of the site are summarized in Table 1. The total excavation depth is about 35 m from the surface.

### 3.2. Construction sequence

Cement grouting with reinforcing steel pipes was applied to prevent seepage flow and to improve the ground strength around the project area before excavation.

Construction sequence for the modified underpinning method is presented in Fig. 5, and described as follows; (1) Casings were installed down to weathered rock layer to avoid damages on the subway box structure from pile installation procedure (Fig. 5(a)); (2) Piles were placed on the hard rock layer through installed casings (Fig. 5(a)); (3) The ground was excavated to the bottom of the box structure, and then bearing piles were cut (Fig. 5(b)); (4) The ground underneath the box structure was reinforced by grouting (Fig. 5(b)); (5) The girder support beams were installed, and then bearing girders were penetrated below the bottom of the box structure (Fig. 5(c)); (6)

Hydraulic jacks were installed on the girder support beams, and the bearing girders were pushed up tightly to the bottom of the box structure by hydraulic jacks. While jacking up, the vertical movements of the box structure were carefully monitored (Fig. 5(d)); (7) Excavation underneath the box structure was performed, and the center piles were installed (Fig. 5(d)); (8) installation of channel and bracing (Fig. 5(e)); (9) The procedures through (3) to (7) were repeated to the side of the box structure until the entire open cut area was excavated (Fig. 5(e)).

## 4. Design using numerical analysis

The full dimensions of the numerical modeling are 60 m in *X*-direction, 40 m in *Y*-direction, and 56 m in *Z*-direction. The dimensions of concrete box structure of subway #2 are 10.8 m of breadth, 8.2 m of height, 54 m of width. The top soil over the subway box structure is 5 m thickness in the model.