Technical Report

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Development of Steel Diaphragm Wall with Soil Cement

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Abstract

The steel diaphragm wall had one method, called "Steel Diaphragm Wall replete with concrete etc.", to fill concrete after stable liquid digging and built steel before. However, "Steel Diaphragm Wall with soil cement" has been developed for the application to a structure of the middle depth under the ground. Steel Diaphragm Wall with soil cement increase the cost competitiveness of steel diaphragm wall, and can make further space-saving and thin wall. Since it was used experimentally at Joban new line (Tsukuba express) Rokucho Station (the north) in 2002, it has been used many times.

1. Introduction

In September 1992, the steel diaphragm wall method was first adopted and recognized as a pilot project in the construction of a vertical shaft for a Yodo River common duct by the Kinki Regional Development Bureau of the Ministry of Construction. In those days, there was only one version of this method, which was referred to as "the steel diaphragm wall method-I (method of steel diaphragm wall filled with concrete, etc.)" (hereafter referred to as Method I). The Method I procedure includes excavation of the ground with slurry, installation of members for the steel diaphragm wall (hereafter NS-BOX), and the filling of concrete. When a conventional reinforced concrete diaphragm wall (hereafter RC diaphragm wall) is built, site-fabricated reinforced baskets are installed, and concrete is poured into the baskets. In contrast, Method I has been applied in many types of construction, such as deep shafts, subway station buildings, open-cut road tunnels, and ventilation stations due to its many advantages, including the use of the high-rigidity NS-BOX to reduce wall thickness, the use of shop-fabricated members to save space, and the use of walls for both temporary and permanent applications to reduce construction time.

However, when Method I is applied to underground structures at intermediate depths, it is sometimes outperformed with respect to cost by RC diaphragm walls. As a solution, we developed the steel diaphragm wall with soil cement (Steel Diaphragm Wall Method II), which uses a soil-mixing wall method. This approach reduces the construction period and saves on-site work yard space while further reinforcing competitive power by taking advantage of the precast method that uses NS-BOX as its core material.

In the following section, we outline the concept of the steel diaphragm wall with soil cement, its construction procedure, its reduced wall thickness, the structural type used in permanent applications, its connections with the slabs, and the water cut-off performance of the wall body. In section 3, we discuss cases in which the steel diaphragm wall with soil cement has been applied to road and railroad projects.

2. Outline of the Steel Diaphragm Wall with Soil Cement (Method II)

2.1 Outline of the method

The steel diaphragm wall with soil cement (hereinafter Method II) is characterized by construction of a soil-cement wall and installation of an NS-BOX in the soil-cement wall. As the constructed wall has uniform thickness and has excellent structural reliability, it may be used in both temporary and permanent applications. **Figure 1** shows a schematic illustration of how the wall is built using this method [1], and **Fig. 2** shows a section of a soil-cement steel diaphragm wall. [2] The NS-BOX is an H-shaped steel member with fitting type joints at both flanges. As shown in **Fig. 3**, GH-R and GH-I members, which differ in the shape of their fitting joint, are fit alternately for installation in the soil-cement wall. GH beams are used as flanges of the GH-R members and are integrally rolled products. After they are formed like H beams, the flange parts are rounded off in a rolling process to make the fitting joints. The rolling process of the GH beams is shown in **Photo 1**. [3] These fitting joints are not formed by assembly processes such as those used in welding, which is why they make structurally reliable members and are appropriate for use in the main body of the diaphragm wall.

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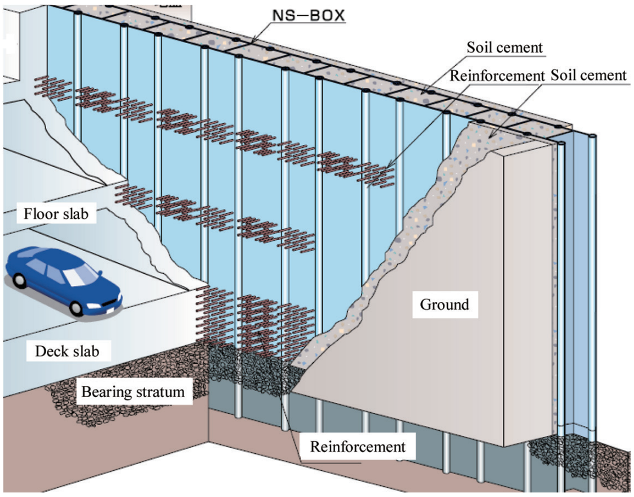

Fig. 1 Application image of a wall body [1]

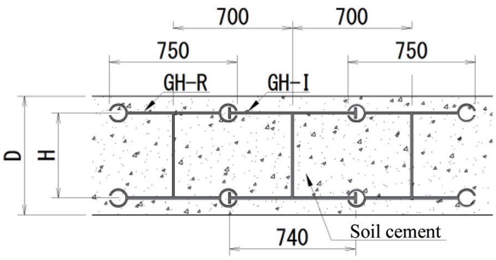

Fig. 2 Section of steel diaphragm wall with soil cement [2]

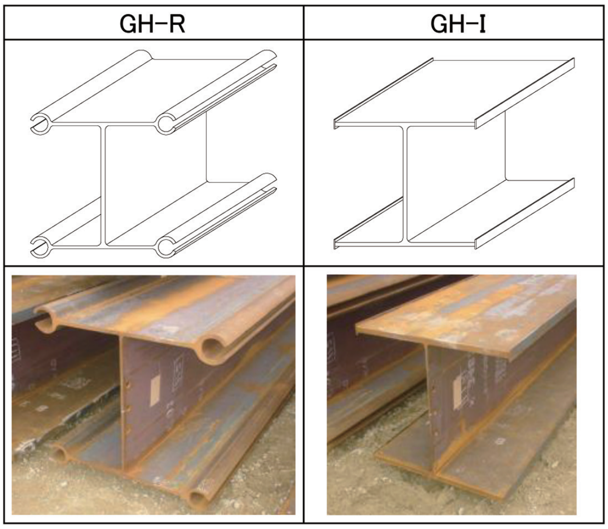

Fig. 3 NS-BOX (steel diaphragm wall with soil cement)

2.2 Construction procedure

Methods for building steel members in the soil-cement wall include soil cement pillar-lined walls such as the soil-mixing wall (SMW) method. While the SMW method simply arranges H beams as core members at a constant pitch, Method II installs NS-BOXes with fitting joints to construct a wall structure, and features precise installation of members using the joints as guides and firm linkage of members at the joints to ensure high water cut-off performance. Structures made by this method can used in both temporary and permanent applications and are highly reliable walls with excellent execution precision and water cut-off performance.

Photo 1 GH type steel [3]

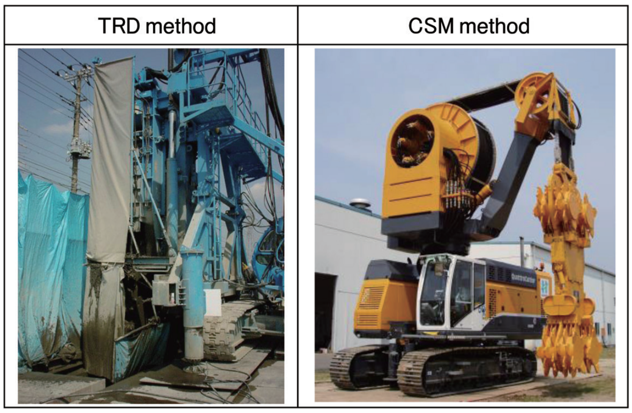

Photo 2 Construction machine of TRD method and CSM method [4]

To continuously set up these steel members, however, requires the construction of a uniformly thick soil-cement wall. The trench cutting re-mixing deep wall (TRD) and the cutter soil mixing (CSM) techniques are generally used to do this job. The TRD method involves lateral movement of a chainsaw-shaped cutter post, inserted into the ground, to excavate the soil, and mixing and agitating the in-situ soil with stabilizer to construct a wall-shaped solid body under the ground. This technique is used to construct walls with a maximum thickness of 900 mm down to a maximum depth of 60 m. The CSM method involves mixing the in-situ soil with stabilizer with a horizontal multi-axial rotary cutter, as is used in a horizontal multi-axial diaphragm wall excavator, to construct a rectangular solid body under the ground. This technique is used to construct diaphragm walls with a maximum thickness of 1 200 mm down to a maximum depth of 65 m. Both machines are shown in **Photo 2** [4], and the procedures followed in the TRD and CSM methods are shown in **Figs. 4** [1] **and 5** [1], respectively.

2.3 Reduction of wall thickness

Figure 6 shows the NS-BOX used in Method I, the technique that was developed first. In Method I, concrete is filled after excavation with the slurry and the installation of steel members. The web parts of the members have openings to allow the filling material to infiltrate the entire space. The male joints of the GH-H members are dispersed in such a way to allow the filler to surround the joints. In contrast, the soil cement diaphragm wall does not need any openings for filling or a dispersed arrangement of joints, as shown in Fig. 3, because of the installation of NS-BOXes in the soil-cement wall. This feature allows for the maximum use of steel materials and reduces the wall thickness required. **Figure 7** shows schematic repre-

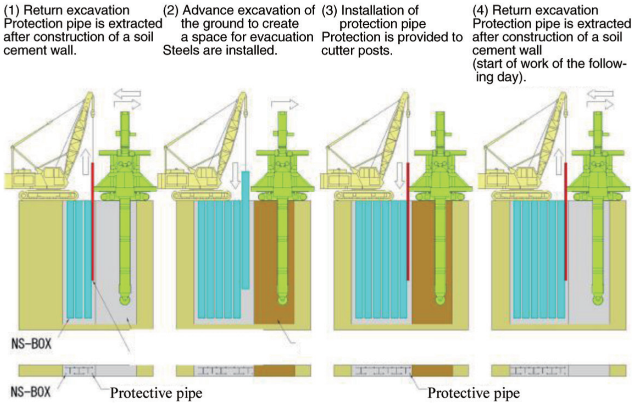

Fig. 4 Construction process of a TRD method [1)]

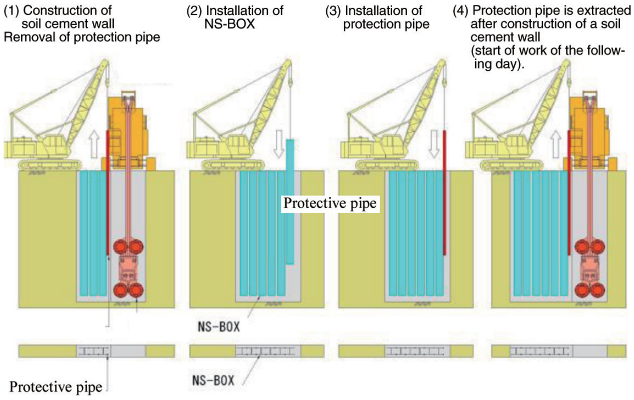

Fig. 5 Construction process of a CSM method [1)]

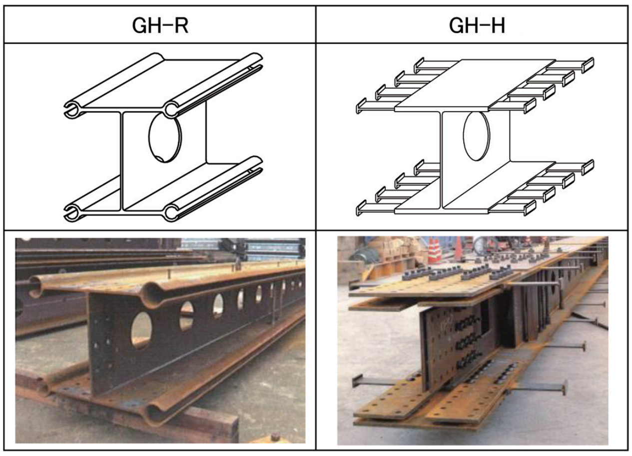

Fig. 6 NS-BOX (Method-I)

sentations of Methods I and II relative to the RC diaphragm wall method.

Method II can reduce the required wall thickness by about 30% to 40% compared to that of the typical RC diaphragm. Method II also requires less work space at the site and produces highly reliable wall bodies. Specifically, since this method brings in a shop-fabricated NS-BOXes to the site, as in the case of Method I, it requires no space for assembling reinforced baskets. It also requires less plant yard than the slurry excavation method because of its use of in-situ mixing.

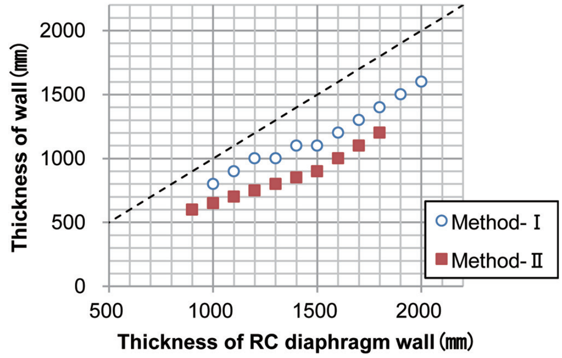

Fig. 7 Image about thickness of steel diaphragm wall to that of the RC diaphragm wall

2.4 Structural type for application to wall construction

For the body proper of a diaphragm wall, one of three structural types is selected by considering the construction conditions, load conditions, and their relative importance (see **Fig. 8** [1)]).

(1) Independent wall type: This structure resists loads using only a diaphragm wall without an additional wall inside the retaining wall (hereafter, the inner wall). This structure is used only as the main body. Since it is necessary to connect the diaphragm walls to the deck slabs, a high level of execution precision is required. Particular attention must be paid to the water cut-off performance.

(2) Superposed wall type: This structure does not transfer in-plane shear force between the diaphragm wall and the inner wall. The strength of the completed wall is ensured by the cumulative strength of the diaphragm wall and the inner wall.

(3) Integrated wall type: This structure integrates the diaphragm wall and the inner wall with, for example, studs to resist working loads by a single integrated wall.

Whichever type is selected, it is essential that a high level of execution precision is achieved to guarantee the shape, dimension, and location of the main structure as predetermined by the design. As this structure is used as the main body, durability, water cut-off performance, and earthquake-resistance are required.

For Method II, precision in producing the NS-BOXes and the installation of those boxes directly translates into the precision of the wall body. Since precision is so important, fabrication precision is generally checked in advance by the assembly inspection at the fabrication shop. To reproduce the member connection condition during assembly inspection, drift pins are driven into four corners of each splice plate, and the members are connected with high-strength bolts (see **Photo 3** [4)]).

2.5 Joints with deck slabs

To connect the soil-cement diaphragm wall to the reinforced concrete slabs, a mechanical joint may be used. Specifically, screw points (welding couplers) are welded to the flange parts of the NS-BOXes at the factory in advance. **Figure 9** show the slab connection system using mechanical joints. Use of this mechanical joint reduces the on-site workload compared with the direct joining technique and with welding of the reinforcing bars at the site. **Photo 4** shows how the welding couplers are attached and the reinforcement bars are connected.

2.6 Water cut-off performance

The soil-cement steel diaphragm wall has a high water cut-off performance as it is composed of continuously arranged NS-BOXes without filling holes and the clearances between members and in the

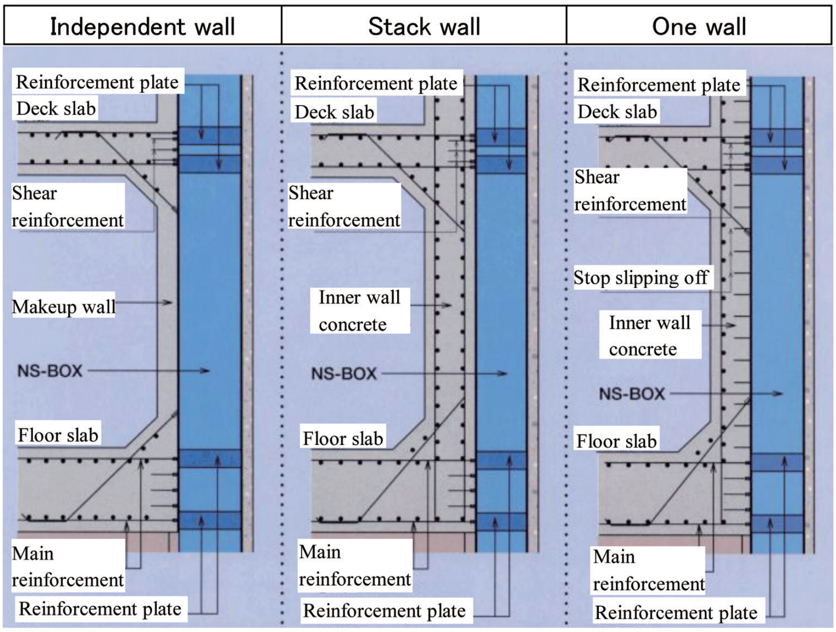

Fig. 8 Structural type [1]

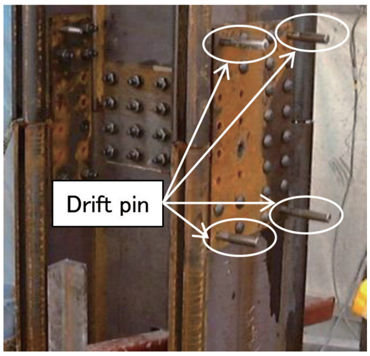

Photo 3 Drift pin driving [4]

Photo 4 Connection situation of the reinforcing bar

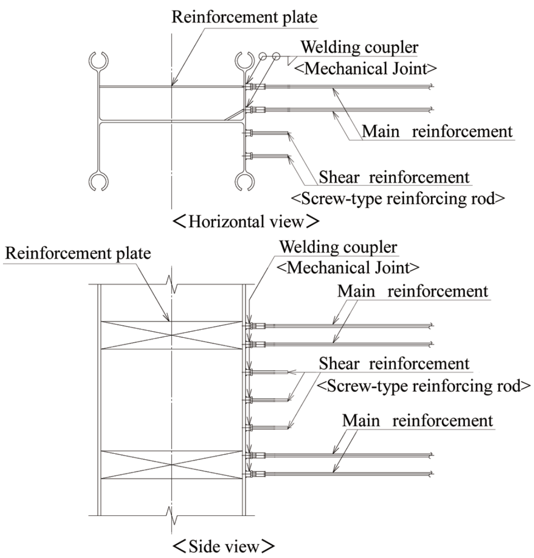

Fig. 9 Joining system with deck slab

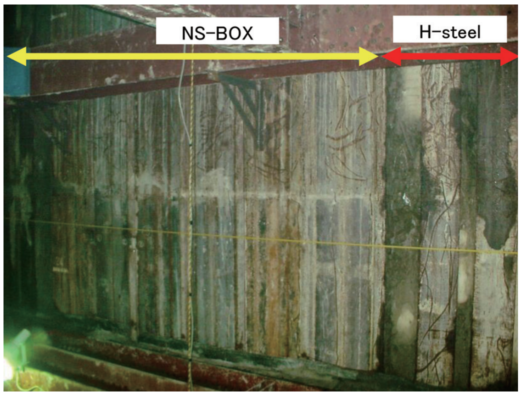

Photo 5 Situation of the wall after excavation [1]

joints are filled with soil cement. As a water leakage test, after a soil cement wall was constructed, we prepared two kinds of diaphragm wall parts, one with NS-BOXes as the core members and the other with H beams. Then we excavated the ground around those walls to check for water leakage. **Photo 5** [1] shows the wall condition after excavation. [1] We observed water leakage on the surface of the wall constructed with the H beams as the core, but no water seepage was

Photo 6 State in the joint [4)]

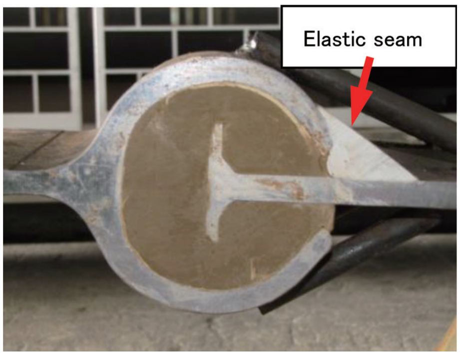

Photo 7 Joint section when applying an elasticity joint filler

Photo 8 Daytime of the construction site [5)]

Photo 9 Night construction

evident on the surface of the wall using NS-BOXes as the core, including the joint parts. **Photo 6** shows the condition of a fitting joint exposed after concrete casting [4)], which confirms the fact that soil cement filled in the joint parts.

As discussed above, the soil-cement steel diaphragm wall has good water cut-off performance, which could be further enhanced by applying elastic joint filler to the fitting joints after internal excavation. **Photo 7** shows a section of a joint coated with elastic filler.

3. Application Examples

3.1 Changes in application up to the present

Since its first application on a trial basis at a construction site at Rokucho Station (north) of the new Joban Line (Tsukuba Express) in 2000, Method II has been certified by professional organizations as a wall structure capable of serving as the main body of a structure. Originally, Method I alone was awarded the Certificate for Engineering Technology Evaluation by the Japan Institute of Countryology and Engineering. In 2002, Method II was added as a retaining wall applicable for permanent underground walls and in the same year was also registered in the New Technology Information System (NETIS) of the Ministry of Land, Infrastructure, Transport and Tourism. Method II has been applied to various projects since that time, with increasing recognition in the industry.

Method II has recently been applied to an increasing number of often large-scale road construction and railroad projects. Some of the application examples in these fields are described in the following subsection.

3.2 Application example in road projects

3.2.1 Application to construction of underground tunnel for Tokyo Ring Road II

The soil-cement steel diaphragm wall was adopted in a construction project of the Ring Road II underground tunnel (working name) (23-Ring 2 Shin-ohashi work section) by the Tokyo Metropolis. Tokyo Ring Road II is a roughly 14-km long road leading from Ariake 2-chome, Koto-ku, to Kanda-Sakumacho 1-chome, Chiyoda-ku. Road construction work is under way at a section with no existing road, and Method II was applied to part of the tunnel construction work from the Shiodome area to the Tsukiji area for its advantages of space saving, thin-wall construction, and applicability for permanent use as the main wall structure.

The work was mainly conducted at night, when the traffic volume remains relatively low, as the work section has a large traffic volume and the impact on traffic must be mitigated as much as possible. True to its stated advantages, Method II occupied a minimum work space at the site to allow for the partial use of existing roads. **Photo 8** [5)] shows the construction site in the daytime. Very heavy traffic is seen along the road running among high-rise buildings, and **Photo 9** shows the construction site in the night time.

The diaphragm walls were constructed have wall thicknesses of 700 to 800 mm at depths from 14.0 to 16.5 m from the ground level, for a total wall length of 135.83 m, and the CSM method was used to construct the walls.

3.2.2 Application to a northern trunk railroad line in Nagano

As ordered by the Nagano city government, the earth-retaining work for a northern trunk railroad line adopted the soil-cement steel diaphragm wall as an isolated permanent wall. The method was applied to the construction of a retaining wall for an approach to an

Photo 10 Construction (Nagano Northern Trunk Line) [6]

Photo 11 After NS-BOX built [6]

underpass that crosses the railway line. Its thin wall and space-saving features were effective in the construction site where work space was limited due to surrounding neighboring buildings. **Photo 10** [6] shows the work site, and **Photo 11** [6] shows the condition of the installed NS-BOX. Both photos show steel materials brought in near private housing. The wall was constructed using the TRD method to wall thicknesses from 600 to 900 mm and to underground depths from 19.5 to 25.5 m.

3.3 Application examples in railroad projects

The soil-cement steel diaphragm wall was applied to the Sotetsu and Tokyu direct route and New Yokohama station projects ordered by the Japan Railway Construction, Transport and Technology Agency. A new railroad track that serves both the Sotetsu Line and Tokyo Line trains for direct connection is planned to open in 2019. A roughly 10-km long linking section between the Hazawa Station, which serves direct connections between Sotetsu and JR, and the Hiyoshi Station of the Tokyu Toyoko Line is under construction. Construction is also planned for two new underground station buildings, the Yokohama and Tsunashima Stations.

The new Yokohama station site is located directly under Yokohama city's loop line No. 2 that has heavy traffic and runs parallel with the Shin-Yokohama Station of the Tokaido Shinkansen Line. Utilizing its advantages of space saving and thin-wall construction, the soil-cement steel diaphragm wall is under construction in the minimal work yard space to allow partial use of the existing road for public traffic. In addition, an existing shield tunnel is located under-

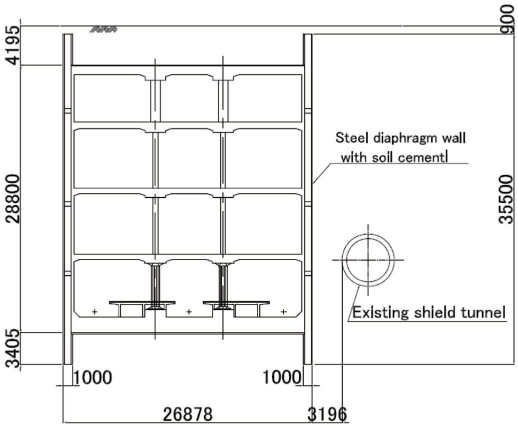

Fig. 10 Example of the cross section (Shin-Yokohama Underground Railroad Station)

Photo 12 Construction (Shin-Yokohama Underground Railroad Station)

ground, and Method II helped to minimize the impact on these existing structures with its thin-wall feature. The plan specifies that the soil-cement diaphragm wall be constructed by the CSM method to a wall thickness of 1 000 mm to depths from 35.0 to 38.5 m. As of July 2015, construction was underway. **Figure 10** shows a sample cross-section, and **Photo 12** shows the status of the work. The wall of the underground station building for the new Tsunashima station, a neighboring station, is also being constructed using Method II.

4. Conclusion

Due to its advantages of space saving and thin-wall construction, the steel diaphragm wall with soil cement is being applied to construction projects mainly in urban areas. It has recently been applied to an increasing number of road and railway projects, and more frequent use in these types of projects is expected.

Acknowledgments

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