Construction Methods Developed to Enable Work Near Tracks in Times with Train Operation

East Japan Railway Company (JR East) has been constructing and renovating railway infrastructures and station buildings continuously. Most of construction and renovation work needs to be carried out in times with no train operation for safety because those work sites are located near railway tracks. Therefore, we have been working to develop construction methods whereby safety can be secured in times with train operation to reduce cost and time of such construction work. This paper introduces the present state and achievements of non-open cut and cast-in-place piling methods that were developed and applied and have less impact on nearby railway tracks.

Keywords: Work near tracks, Non-open cut tunnel, Cast-in-place pile

1 Introduction

For railway operators, stations and tracks are important resources to provide customers with service, so we continuously carry out new construction and renovation of railway facilities to effectively use those resources. At the same time, the primary duty of a railway operator is transport, and securing transport safety is put before anything else. Based on the lessons from troubles caused to customers, JR East has set down a manual for design and construction work near tracks in times with train operation to secure safety and stability of transport, and strict restrictions are required in that manual for work near tracks in times with train operation.

As new construction and renovation of railway facilities is assumed to be done in a short time when trains are not operating, such work tends to require long periods of time and much of funds till completion.

In light of that, JR East has conducted much technical development of construction methods whereby train operation safety can be secured even at narrow work sites near commercial lines and that also enable reduction of work period and costs. Those methods are applied to work sites where work can be done in the daytime with train operation. Since work spaces of sites near commercial lines are very narrow, construction methods that can be applied to such sites are also required.

In this paper, we report on the development history and results of the under-track transverse construction method and the cast-in-place piling method among the methods developed.

2 Under-track Transverse Construction Method

2.1 Background of the Ground Cutting JES Construction Method
Many construction methods have been proposed for construction work to build roads or waterways under track (under-track transverse construction). Those include an open-cut construction method whereby construction girders are installed and frames are built and a non-open method whereby boxes are inserted under the track. JR East developed the JES (Jointed Element Structure) method whereby small box-type steel pipes (elements) are pulled forward without excavating the ground and concrete is filled in the elements connected with joints to build box culverts (Fig. 1). We have conducted almost 130 works by this method so far.

The major premise of non-open cut under-track transverse construction is to not interfere with train operation. However, in cases where the depthwise distance between the track and the elements (earth cover) is small, advancing elements could cause track deformation such as lift or settlement due to the presence of underground obstacles or insufficient ground strength. In the HEP & JES (High Speed Element Pull and Jointed Element Structure) method, the distance from the track to the top of the element is defined as earth cover thickness, and in worksites with earth cover thickness of 2.0 m or less, train speed must be lowered in the work section (slowdown) or work must be done only late at night when there is no train operation (track closure time at night) as a rule because risk of track deformation is considered high in such a worksite.

Limiting under-track transverse construction to the track closure time at night, however, causes an increase in construction cost and time due to long excavation time. Furthermore, placing an excavator under the track for a long time involves concerns about safety. We thus developed and put into practical use a ground cutting JES method that can minimize track deformation, provided that safety could be confirmed in terms of conditions such as good self-supporting ground and underground water.

Fig. 1 Overview of HEP & JES Method
2.2 Overview of the Ground Cutting JES Method

The ground cutting JES method is a new excavating method whereby the tip of the cutting edge for excavation used in non-open cut methods has a mechanism with rotating a wire to cut ground and obstacles such as boulders.

In the conventional methods, there were concerns that obstacles pushed in when propelling the elements could lift up the track, or over-excavating could cause settlement. By manually excavating within the cutting edge while cutting ground and obstacles with the ground cutting wire, such track lift and settlement can be prevented. Based on investigation of three-dimensional cylindrical sliding, we extended the roof at the tip of the cutting edge longer that with conventional methods, preventing loosening of the ground over the tip of the cutting edge.

The characteristics of this method are as follows:

1. By advancing the elements while cutting the ground and obstacles using a wire, lift and settlement of the ground can be minimized.
2. By extending the roof at the tip of the cutting edge, collapse of working face can be prevented when advancing the elements.
3. By increasing the element width over that in conventional methods, the number of elements and joints are reduced, so work cost and time can be also reduced.
4. By tapering the lower surface of the cutting end, ground settlement can be prevented when advancing the elements.

Fig. 2 shows an overview of the ground cutting JES method, and Fig. 3 shows the cutting edge immediately before being advanced.

2.3 Example of Actual Construction

The Futatsuya Underpass between Okegawa and Kitamoto on the Takasaki Line is located at the junction of the Metropolitan Inter-City Expressway and Takasaki Line. Design and construction of an under-track traverse structure was commissioned to JR East by the Ministry of Land, Infrastructure, Transport and Tourism. The structure of the underpass is a box culvert (Fig. 4) of one layer and four spans, and its large width of 49 m requires installation of many upper slab elements. Furthermore, due to the vertical alignment of the approaches before and behind the underpass, the thickness of earth cover at the junction with the Takasaki Line was just 1.4 m. Under such construction conditions, if we installed upper slab elements in the track closure time at night as is conventionally done, the long work period would be a problem. We therefore decided to apply the ground cutting JES method to this project to continue working in times with train operation, aiming to shorten construction period.

Fig. 5 shows the details of the construction. Installation of upper slab elements continued for three months from last September to late December 2012, and it took total five months including preparation time. The initial estimated plan by the usual JES method using track closure time at night only was 10 months, and accordingly, we were able to cut the construction period by half. Major construction results are as follows.

2.3.1 Work Speed

There was concern about the work period being longer for installing upper slab elements due to the limited time in which the work was allowed. From the start of the installation, we thus changed the allocated work time from track closure time at night...
to night with train operation, and finally to day and night with train operation in stages, while monitoring track deformation. As a result, the installation time per element could be reduced to a half or even a third (Table 1).

2.3.2 Cutting of Obstacles
Fig. 6 shows the obstacles that were cut by the cutting wire and removed in the excavation work. While excavating, obstacles such as boulders, wooden electric poles left underground, and concrete anchor bases for contact wire were found, but those were cut and removed without problem. Consequently, no lift, settlement, or settlement of track due to obstacles being pushed up by the cutting end or due to over-drilling occurred. The amount of track irregularity was kept to 3 to 4 mm, while the control value of that was 15 mm. We were able to confirm that this method has little impact on the track even under the construction condition of small thickness of earth cover.

3 Cast-in-Place Piling with Borehole Wall Protection (P-JET32)

3.1 Background to Development of Cast-in-Place Piling with Borehole Wall Protection
During station renovation projects in large cities, many customers use station facilities and the area around the station is often intensively used, so new piles often have to be cast in a very narrow environment.

In order to minimize the impact on track, we usually apply an auxiliary method such as chemical grouting before casting piles near tracks. However, such auxiliary methods themselves are applied near the track, so they are done in short periods of time at night when there is no train operation, increasing the work period and cost. In order to reduce work period and cost while securing safety, we developed and put into practical use cast-in-place piling with borehole wall protection where borehole protection can be placed simultaneously with drilling.

3.2 Overview of Cast-in-Place Piling with Borehole Wall Protection
Cast-in-place piling with borehole wall protection is a method of cast-in-place piling where collapse of borehole walls is prevented by connecting protective pipes while excavating into a surface embankment or loose sand layer that has high risk of borehole collapse (Fig. 7 and 8). The characteristics of this method are as follows.

(1) In this method, liner rings to protect hole walls can be installed in an area where the track is affected (approx. 10 m depth from the ground surface) at the same time as excavation is done. Installing liner rings while filling with backfill grout can drastically improve piling safety. At the lower end of the liner ring, a seal that can follow irregularities of the borehole is attached to prevent grout from leaking.

(2) Using commercially available liner rings and excavating at the design pile diameter in an area deeper than the borehole wall protection area allow cost reduction.

(3) Adopting a portal frame that takes into account overhead clearance reduces the size of the piling machine, enabling the machine to be set within a temporary fence (approx. 5 m × 8 m) on the platform.

(4) The excavating control system of the piling machine can automatically record construction data, which can be used also for quality control.

<table>
<thead>
<tr>
<th>Table 1 Work Speed</th>
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<tr>
<td>Distance excavated per day</td>
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<td>0.9 to 1.2 m</td>
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<td>Average number of work days until excavation finished</td>
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Fig. 6 Obstacle Cutting

Fig. 7 Overview of Cast-in-Place Piling with Borehole Wall Protection

Fig. 8 Full View of Machine for Cast-in-Place Piling with Borehole Wall Protection
3.3 Example of Actual Construction

JR East is carrying out a project at Chiba Station where over-track station and commercial facilities are constructed on artificial ground built immediately above five existing platforms, and the existing station building is rebuilt at the same time.

Of five piles near the track (pile diameter 3.0 m, pile length approx. 25 m), three piles were installed by cast-in-place piling with borehole wall protection (Fig. 9).

Before casting piles, we installed a temporary fence of 5.0 m at a right angle to the track × 8.0 m parallel to the track on the platform (Fig. 10), and we carried in and set an excavator within the fence using a large crane (500 t lift track crane).

Along with excavating a Ø3.4 m hole, we installed a borehole wall protecting liner ring of Ø3.2 m to the area 5.0 m from the lower end of the mouth pipe (8.5 m from the ground surface), where there is high risk of hole wall collapse. The liner was manually assembled and stacked on the ground, and then it was installed by reeling down the wire hanging from the portal frame.

In the gap between the borehole wall surface and the liner rings, we injected self-filling backfill grout (specific gravity approx. 1.13, pot life (fluid) for about 36 hours), and sealing material was attached to the lower end of the protective pipe to prevent grout from leaking.

In order to prevent damage to the borehole protecting liner from contact with the drill bit and to prevent pre-excavation, we constantly controlled the distance between the lower end of the borehole wall protecting liner and the excavating bit to 20 to 40 cm when excavating.

3.3.1 Work Speed

The assembling time of a borehole wall protecting liner was 9 minutes per ring at the shortest and 17 minutes on average, and the excavation speed was 12.5 mm/min. on average in the borehole wall protecting area (40 min. per ring). We were able to assemble borehole wall protecting liner rings without lowering drilling speed.

After completing installation of the liner rings, we reduced the diameter of the drill bit from Ø3.4 m to the design pile diameter of Ø3.0 m, and then we drilled at this diameter to the specified depth. Excavation speed was 11.6 mm/min. on average, and we excavated in the daytime and nighttime even in times with train operation. Thus, drilling to approx. 25 m depth was completed in approx. 32 hours not including work rest time.

3.3.2 Impact on Tracks

As shown in Fig. 9, we cast piles while securing 1.5 m space from the edge of the platform. As the distance from the nearest rail to the borehole wall was about 2.0 m, we installed a link-type displacement gauge at the railside and constantly measured longitudinal level and alignment of the track to observe the impact of drilling on the track. As a result, almost no track irregularity occurred, allowing us to work without affecting train operation.

![Fig. 9 Cast-in-Place Piling with Borehole Wall Protection](image)

![Fig. 10 Temporary Fence on Platform](image)

![Fig. 11 Actual Work](image)
4. Very Low Overhead Clearance Cast-in-Place Piling Machine (JET-18)

4.1 Background of Development and Overview of Very Low Overhead Clearance Cast-in Place Piling Machine

When casting piles in place on a platform, we ordinarily install a temporary fence on the platform and set a casting machine in it and cast piles. However, dimensions of existing pile drivers are large, and the temporary fence area accordingly is large too, causing customers inconvenience. We therefore developed a compact and lightweight very low overhead clearance cast-in-place piling machine that has capacity for large-diameter piling.

The characteristics of the machine are as follows:

1. The machine can excavate pile holes of a diameter of ø0.8 to 3.0 m in a work space with overhead clearance of 2.0 m and width of 4.0 m even in a narrow space under the platform or under the stairs on the platform.

2. The compact and lightweight machine exhibits ability of piling in a narrow space, enabling reduction of work period and cost thanks to labor saving in temporary construction. Also, transport machinery used when bring it to the worksite can be made compact.

3. The drive system adopted a turntable + special kelly rod system, securing workability equivalent to conventional machines.

4. The same as with in cast-in-place piling with borehole wall protection, the machine has a boring control system as a standard feature, which can be coordinated with a borehole water level control system.

Table 3 shows the specifications of the compact reverse JET-18, Fig. 12 shows its appearance, and Fig. 13 shows the drive system.

Fig. 14 shows a comparison of the cross section of the compact reverse JET-18 and that of a small-sized conventional machine. While the conventional machine has a top-drive system with its driving motor on the top, the compact reverse JET-18 adopted a rotary drive system with a turntable, reducing the machine height to less than a half of the conventional machine.

4.2 Example of Actual Construction

In the Chiba Station improvement project, we also cast a total of 47 piles (pile diameter 3.0 m, pile length 25.7 to 33.8 m) using the very low overhead clearance cast-in-place piling machine (Fig. 15), the same as with cast-in-place piling with borehole wall protection.

We installed temporary fences (Fig. 16) 3.4 m at a right angle to the track and 6.5 m parallel to the track (5.0 m × 8.0 m in some sites) on the embanked platform, and we carried in and set a drill bit, a stabilizer, and a piling machine using a large crane (500 t lift truck crane).

As a mouth pipe, we installed a ø3.2 m liner ring to a depth of 8.5 m in advance to set the drill bit and remove obstacles.

By injecting water-stopping chemical into the loose sand layer, we cast piles in daytime with train operation too (Fig. 17).

We installed a link-type displacement gauge at the railside and constantly measured longitudinal level and alignment of the track. However, almost no track irregularity occurred, allowing us to work without affecting train operation.

During excavation, we constantly monitored using a monitor...
of the excavation control system, and we carried out construction while watching penetration force, excavation speed, rotation speed, and rotation torque displayed real-time.

By comparing and checking that data and the soil boring log, we could select appropriate excavation speed and rotation speed, and we finished the work without the borehole walls collapsing. The actual excavation speed and rotation speed were around 50 mm/min. and 6 rotations/min. for the loose sand layer and around 20 mm/min. and 6 rotations/min. for the hard fine sand layer.

5 Conclusion

JR East is working on technical development of seismic reinforcement methods and also on various structures and construction methods. In this paper, we reported on the under-track traverse construction method and the cast-in-place piling method as examples of construction methods that can be used even in times with train operation, under the keyword of “near-track construction.”

If construction work near the track can be carried out at day and night, new construction and renovation of facilities can be done, contributing to improvement of service for railway passengers. On the other hand, from the perspective of train operation safety, even a slight defect in a construction method can lead to a critical threat to safety. Technical development was therefore carefully verified in terms of safety and finally put into practical use.

These construction methods have been successfully developed and applied to actual worksites, yet we still think that there is room for improvement. While improving the developed methods, we will focus on the needs of worksites from a perspective of passenger service improvement and work on new technical development.

Reference:
3) Satoshi Honda, Takashi Saito, Hirokazu Inoue, Satoshi Ozeki, “Building Large-scale Box under In-service Tracks with Ground Cutting JES: Takasaki Line between Okegawa and Kitamoto New Construction of Futatsuya Underpass”, Tunnel to Chika, Vol. 44, No. 8 (August 2013): 516