The Ueno Tokyo Line Construction project enables direct links the Utsunomiya, Takasaki, and Joban lines to the Tokaido Line. According to the new seismic design standards considering Level 2 seismic motion changed after the 1995 Hanshin-Awaji Great Earthquake, we developed a new method of reinforcing existing structures. The development of this new method was necessary for the achievement of the project. Also, under narrow and severe construction space conditions adjacent to conventional lines and just above Shinkansen lines, steel members and girders had to be installed. For steel member installation, we contrived ways to carry members and conducted various studies to secure seismic resistance and installation accuracy. For girder installation, we used a movable installing machine designed on the fail-safe concept and completed installation safely while securing the performance of seismic durability.

**Keywords:** Spiral reinforcement, Slab covering on ground surface method, Steel frame installation, Girder installation

### 1 Introduction

JR Tokyo and Ueno Stations are connected by the Yamanote and Keihin-Tohoku Lines; however, the Utsunomiya, Takasaki, and Joban Lines until recently terminated at Ueno Station, not allowing trains on these lines to run directly to Tokyo Station. The Ueno Tokyo Line Construction project had an aim of allowing trains on these lines to directly run to Tokyo Station, enabling through service between these lines and the Tokaido Line, by laying double track between Tokyo Station on the Tokaido Line and Ueno Station on the Utsunomiya, Takasaki, and Joban lines.

The completion of the Ueno Tokyo Line brought about a variety effects. Those include alleviation of congestion of the Yamanote and Keihin-Tohoku lines, particularly in the section between Ueno and Okachimachi in the commuting hours; shorter travel time from the Utsunomiya, Takasaki, and Joban lines in the direction of Tokyo Station by eliminating the need to transfer; and contribution to invigorating local economy by enhancing north-south transport network in the Greater Tokyo area.

In this paper, we will report on reinforcing technology for existing structures newly developed in this project, difficult construction of abutment and pier steel frames immediately above the Shinkansen line, and installation of PC and steel girders.

### 2 Project Overview

Fig. 1 shows an overview of the track and stations related to the Ueno Tokyo Line. In the 3.8 km construction section, approx. 0.9 km from Tokyo Station was constructed by renovating a side track for the Tokaido Line to make it main track. In the next section of approx. 1.3 km including Kanda Station, new viaducts were built and existing viaducts were renovated to construct track structures. In the approx. 1.6 km section between Akihabara and Ueno stations, existing storage tracks were renovated to make them main track. Here, we call the 1.3 km section including Kanda Station where the Ueno Tokyo Line was constructed above the Shinkansen line the "multi-level section".

### 3 New Technologies Applied to Reinforce Existing Structures

#### 3.1 Reinforcement of Existing Steel Rigid Frame Abutments and Piers

Fig. 2 shows an overview of the section where viaducts were newly built or renovated. The existing Shinkansen viaduct in the multi-level section near Kanda Station has a simple girder form, and its understructure is of a form with steel rigid frame abutments and piers. For steel member installation, we contrived ways to carry members and conducted various studies to secure seismic resistance and installation accuracy. For girder installation, we used a movable installing machine designed on the fail-safe concept and completed installation safely while securing the performance of seismic durability.
In the development of this method, we carried out tests using scaled-down test pieces for various studies. Fig. 5 shows some of the test results. The results demonstrate that filling the inside of steel tubes with concrete improves both load bearing capacity and deformation performance compared with a steel tube with no reinforcement. It also shows that spiral reinforcement alleviates drop in load bearing capacity after being applied with the maximum load, greatly improving deformation performance. Fig. 6 shows the inside of the steel tubes of the reinforced test pieces after the test. The photos clarify that deformation performance of the test piece with spiral reinforcements was improved because the core concrete inside the spiral reinforcements remained sound, while concrete of the test piece only filled with concrete was crushed.

3.2 Effective Use of Existing Structures (Slab Covering on Ground Surface Method)

In the approaches on the Tokyo side and Akihabara side, there were RC rigid frame viaducts that were built in 1950 and used until 1983. It would be possible to remove those and newly build viaducts; however, it would be better in terms of cost and construction time if those could be renovated to meet the present design standards. After consideration, we decided to reuse some of viaducts on the Tokyo side (Fig. 7). The issue in reusing the viaducts was securing aseismic performance of the members of the pile foundation, which had not been taken into account when they were originally constructed. We thus developed a method of reinforcing from inside square steel columns.

In that method, small-diameter spiral reinforcements are placed in plastic hinges in the steel column and concrete is filled inside to make the column a CFT (Concrete Filled Steel Tube, Fig. 4). By placing spiral reinforcements, concrete on the inside surrounded by reinforcement can remain stable without damage even in areas with large deformation, and sharp drop of load bearing capacity can be prevented. That enabled considerable improvement of deformation performance.

In the development of this method, we carried out tests using scaled-down test pieces for various studies. Fig. 5 shows some of the test results. The results demonstrate that filling the inside of steel tubes with concrete improves both load bearing capacity and deformation performance compared with a steel tube with no reinforcement. It also shows that spiral reinforcement alleviates drop in load bearing capacity after being applied with the maximum load, greatly improving deformation performance. Fig. 6 shows the inside of the steel tubes of the reinforced test pieces after the test. The photos clarify that deformation performance of the test piece with spiral reinforcements was improved because the core concrete inside the spiral reinforcements remained sound, while concrete of the test piece only filled with concrete was crushed.
ground surface method (Fig. 8). In that method, slabs are set on the ground surface and propagation of horizontal seismic motion to the foundation is reduced by securing those slabs using small-diameter piles. We carried out centrifugal model tests to confirm the effect of this reinforcement method and proposed the design method.

Building an additional level to viaducts on existing viaducts increased load to upper structures. Since only middle-sized seismic motion was taken into account in the design standards at that time, existing piles yielded first in Level 2 seismic motion and the models finally collapsed with structure models having only existing piles and without reinforcement. In contrast, employing the slab covering on ground surface method changed the fracture mode to one where columns yield first, successfully fulfilling the prescribed aseismic performance. Additionally, we increased the cross-sectional width of the columns of existing viaducts by 200 mm, applied bending reinforcement by placing 12 D19 main reinforcements per column, and applied shear reinforcement by wrapping the columns with steel sheets.

4. Multi-level Section

4.1 Installing Steel Frames of Steel Rigid Frame Abutments and Piers

4.1.1 Method of Installing Steel Frames for Abutments and Piers

The construction space of the Shinkansen viaduct in the multi-level section near Kanda Station was very narrow, situated between conventional lines running parallel to each other and a narrow side road. That meant steel frame members had to be divided into pieces for construction from outside of the track using a crane, greatly lowering workability. We therefore decided to bring a 1,000 kN hoisting truck crane (1,000 kN \textasciitilde{} 100 t; hereafter, “100 t crane”) into the Shinkansen track and install steel frames using that, except for steel abutments SA1 AND SA8 (see Fig. 2). However, since there was no place near Kanda Station from which we could bring the crane onto the Shinkansen track, we built an entry yard at the south end of the No. 23 platform of Tokyo Station on Tohoku Shinkansen Line, approx. 1.5 km away from the installation site. From there, we carried the 100 t crane and steel frame members using a dedicated wagon that can run on the track. Due to the limitation of the entry yard space, we adopted a wagon set of the shortest total length (Fig. 2 and 9).

At the same time, steel frame members needed to avoid obstructing clearance while being carried by the wagon running on the Shinkansen track, and they needed to be of a maximum width less than 4.0 m to enable them to be lifted up between the overhead contact lines laid between the Shinkansen inbound and outbound lines. We therefore divided piers into 7 to 9 parts each and abutments into a maximum of 36 large and small parts such as column parts, corner parts, girders, and vertical beams (Fig. 10). In total, the number of divided parts reached 263 parts for a total of 16 abutments and piers. Weight of individual parts was 50 kN to 200 kN. At the installation site, we laid concrete covering plates to use at the subsequent site (Photo 1).
three months. Track work in one night can be done in the five hours from 0:00 to 05:00, and actual work time allowed was only approx. three hours due to the travel time of the crane back and forth from the entry yard at the south end of Tokyo Station to the installation site (one hour each before and after installation work). Within those three hours we set the crane, transported the steel frame carrier wagons in, installed the steel frame members, and performed quality control (Photo 2). Delivery wagon set formation in particular was restrained by the small size of yard, so formation was done at the installation site instead. In that, we moved the wagons to the rear of the crane for installing steel frame parts of abutments and piers.

4.1.2 Securing Aseismic Performance when Installing
In the construction work, we had to secure clearance for the Shinkansen and we could not use temporary supports for installing the steel frame because Shinkansen operation continued when installing that. Furthermore, due to the capacity of the crane and work time restraints, we could install only a part of the steel frame in one night’s work time, and thus the steel frame members were kept a cantilevered state while their installation was underway. JR East standards stipulate that structures being installed and temporary structures must not collapse in seismic motion of about half L2 seismic motion (large earthquake) when such structures are within the over-track space (space over commercial lines). Joints of the steel frame in a cantilevered state therefore needed to maintain load bearing capacity in the specified seismic motion.

We accordingly used high-strength bolts as temporary bolts and connected the joints with the required number of bolts (14% of the total splice part bolts) to make the splice parts meet the aseismic performance required for steel frame members as friction joints (Photo 3 and Fig. 11). As a result, we could reduce the number of bolts tightened in the nighttime installation work over the number when using ordinary temporary bolts (25% of the total number of bolts for the splice part with ordinary bolts), reducing the bolt tightening time too.

Furthermore, in order to check the effect of humidity on the part spliced with high strength bolts on rainy days, we produced a joint test piece. Using that test piece, we tightened the high-strength bolts and carried out tensile tests on the joint in the condition where the surface of the splice plate and the base material were wet. The results confirmed that joint slip factor of 0.4 or greater could be secured. All temporary bolts were replaced with permanent high-strength bolts later on a sunny day.

4.1.3 Installation Quality Control
Steel frames of the new part were installed by adding members one by one to the connection of the existing structure and closing the connection with the last member. The accuracy of production and installation of the connection of the existing structure thus greatly affects the accuracy of installing the steel frame of the new part. We reflected the construction accuracy of the connection of the existing structure (height, direction, position of bolt holes, etc.) in design in advance, and we created a full-scale film of bolt hole positions to achieve harmonization with members for the new part.

However, it was difficult to completely reflect to design of members for the new part the accuracy information of the connection of the existing structure, and we were worried that we could not sufficiently manage production accuracy of members for the new part, too. We were concerned that accumulated
construction errors of individual members could lead to the last closing member not being attachable. We therefore made the beam, the last closing member, reverse trapezoid-shaped with 10 mm bevels at both ends and also secured construction margin (Fig. 11). We also drilled the splice plate of the closing member at the measured intervals of the steel frame members installed before the closing member to absorb errors in installation. Furthermore, we made the bore holes for the splice part of the closing enlarged holes and measured column torsion, connection cross-sectional squareness, and other data in detail, mainly for the joint part with the connection of the existing structure in the temporary installation at the steel frame factory ahead of actual installation. However, even with those measures to secure accuracy of installation, it was difficult to completely absorb production and installation errors. We thus inserted a filler plate to the splice part when error occurred in the alignment of the closing beam.

Steel frame installation for the multi-level section started in September 2009 and installation of a total of 263 steel frame members was completed in October 2011.

4.2 Installation of PC and Steel Girders

4.2.1 Overview of the Installing Machine

The multi-level section near Kanda Station consisted of 17 PC girders and 2 steel girders. In the installation of those girders, we adopted an installation method using a movable installing machine. Fig. 12 shows an overview of that machine. The machine was composed of a running girder, an extender, and a lifting girder, and it was propelled forward by alternating motion of built-in propelling jacks. The lifting girder was moved up and down, suspended from the front and rear towers via a long-stroke jack. The total weight and length of the movable installing machine varied, being up to approx. 17,800 kN and 210 m respectively depending on the girder to be installed.

The reason for adopting this machine was based on the fail-safe concept. Fig. 13 is a comparison between the usual girder installation method and this method. In the usual method (installing a girder laterally to the track), the girder to be installed is immediately over the track on which trains run until it is installed at the specified location. On the other hand, the movable installing machine we used is composed of an extender (device body, front tower, lifting girder, and rear tower) that reaches the specified location first and a running girder that moves the girder to be installed to that location. The extender and the running girder are connected with the propelling jack, and either the extender or the running girder is always secured to the lower structure. This design prevents the machine from collapsing as a whole. As the girder to be installed moves on the running girder, the running girder always functions as a protecting girder for trains running under the girder to be installed. In terms of girders falling off, prevention of machine collapse and the train protection function became a double safety measure, reducing the risk to safe and stable train operation. We adopted this machine construction method because the installation was unprecedented work where girders were installed in the section approx. 750 m long in the track longitudinal direction over a long time.

The machine was designed to be resistant against seismic motion of about half L2 level seismic motion in the train operation hours without construction work, and it was used in work under the condition of being secured to the existing viaduct.

Even in the Earthquake off the Pacific Coast of Tohoku on March 11, 2011, the installing machine, the existing viaduct to which the machine was fixed, and temporary structures were...
not seriously affected, and that proved validity of those aseismic measures.

4.2.2 Installation Using the Girder Installing Machine
As mentioned above, PC and steel girders were installed over the Shinkansen and Keihin-Tohoku Line southbound track near Kanda Station for a length of approx. 750 m. Fig. 14 and 15 shows the installation equipment and photos of actual girder installation.

In PC girder assembly, we separated and carried in the precast segments produced in the factory (11 to 19 segments per girder) and pulled them together and tensioned PC using a 400 kN crane and a 300 kN crane on the viaduct already completed on the Tokyo side and at the assembly yard on the PC girder. After assembling, we carried the assembled girder in to the construction site those using self-propelled wagons, lifted it up the lifting girder of the girder installing machine, and moved it onto the running girder. Next, we lifted the PC girder using the lifting girder, moved the running girder in the Ueno direction, then placed the PC girder at the specified place by lowering the lifting girder. After completing installation of a PC girder, we moved the girder installing machine to the next installation location using the propelling jack in the extender and the wagons behind the machine. We repeated this work cycle to install all PC girders. Steel girders were also installed in the same procedure, while the girder assembling method was different.

We started construction of the first girder, Cbp-1, in December 2010 and finished construction of a total of 19 girders in April 2013.

Conclusion
The Ueno Tokyo Line started operation on March 14, 2015, and many passengers have been using the line since that. This construction project was a very difficult and unprecedented effort directly over Shinkansen lines. However, we proceeded with the project while taking every safety and risk control measure possible and paying attention to surrounding environment.

We hope the civil engineering technologies we amassed in this difficult work will help construction works in future and be further advanced.

Reference: