Japan's First Technique for Box Culvert to Increase the Span and Replace an Existing RC Viaduct

(Construction Project of a New Railway Bridge on the Outer Ring Road between Ichikawa and Motoyawata on the JR Sobu Line)

1. Introduction

Tokyo Outer Ring Road (hereafter referred to as "Outer Ring Road") that links the area at a radius of 15 km from the city center is being constructed with the objective of improving the traffic environment in the center of Tokyo. In the section in Chiba Prefecture, the Outer Ring Road intersects the JR Sobu Line (between Ichikawa and Motoyawata). This project was to allow the existing viaduct on the JR Sobu Line, the Outer Ring Road below ground, and the normal road on the ground to intersect (Fig. 1).

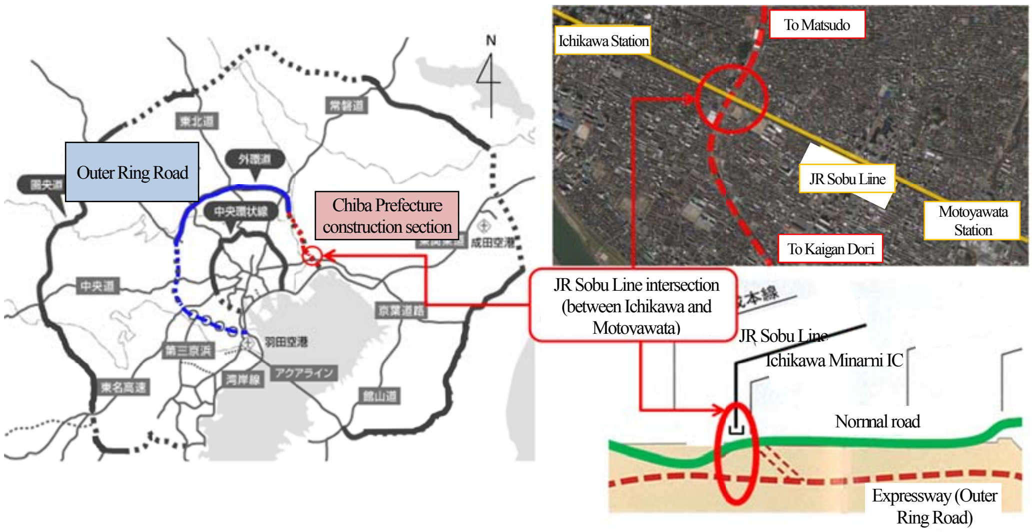

Fig. 1 Construction location

The JR Sobu Line is an important railway line with an extremely high frequency of trains, and the Narita Express that connects the city center with Narita Airport also runs on this line. Under this environment, the railway viaduct and the 2 layer road space of the Outer Ring Road and the normal national road were constructed without hindering operation of the trains (Fig. 2, Fig. 3).

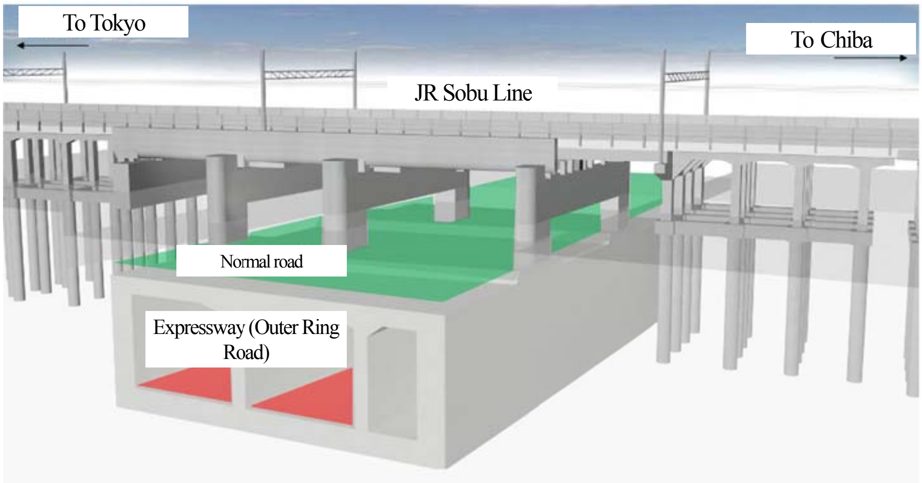

Fig. 2 Outline of the project (perspective view when completed)

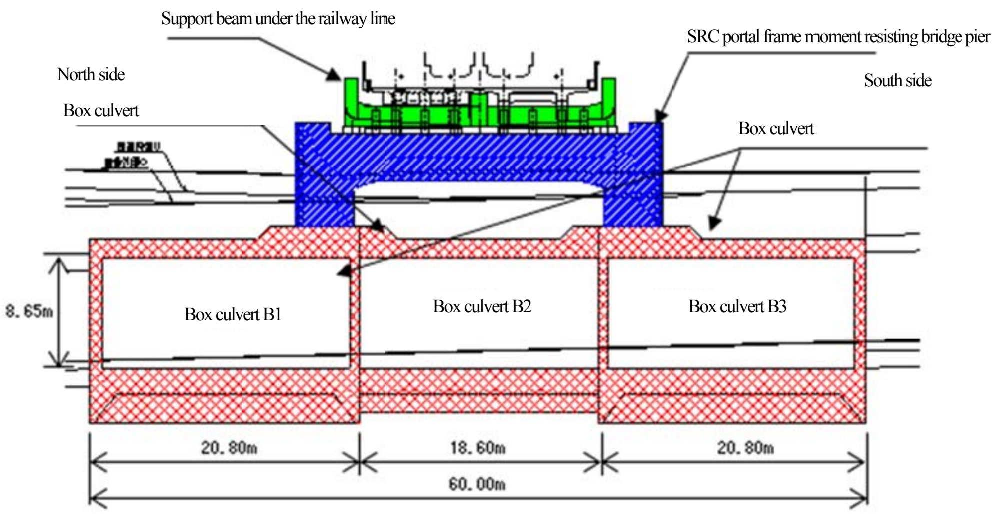

Fig. 3 Outline of the structure (normal to the road)

2. Outline of the Project

The Sobu Line was elevated in the 1970s, during which this intersection was constructed from an RC moment resisting viaduct and single T beams. Initially the Outer Ring Road scheme had the Outer Ring Road passing over the railway, so the space of the intersecting road did not take into consideration the span divisions of the viaduct. Thereafter the scheme of the Outer Ring Road was changed to an underground scheme due to considerations of the surrounding environment, so in order to achieve this grade separated intersection, it was necessary to modify the viaduct to a long span beam format, to ensure the space for the underground road box culvert and the above ground normal national road.

In the past this type of construction was frequently carried out by a combination of installing steel beams directly below the tracks of the railway, and large-scale excavation directly below the tracks by the cut and cover method. However, this construction method would require much work within the railway lines, and would be carried out over a period of several hours during the night when the trains were stopped, and the work would be carried out in a narrow space, which had the problems of degradation of the surrounding environment, lengthening the construction, and increasing the cost. In order to deal with these problems, in this project a method of combining a technique to replace the beams in order to increase the span of the existing viaduct, and a technique for constructing the underground box culvert to support the long span beams was investigated (Fig. 4). Fig. 5 summarizes the change in the division of spans of the viaduct at the location of the intersection. The structure consists of the following parts (1) to (3).

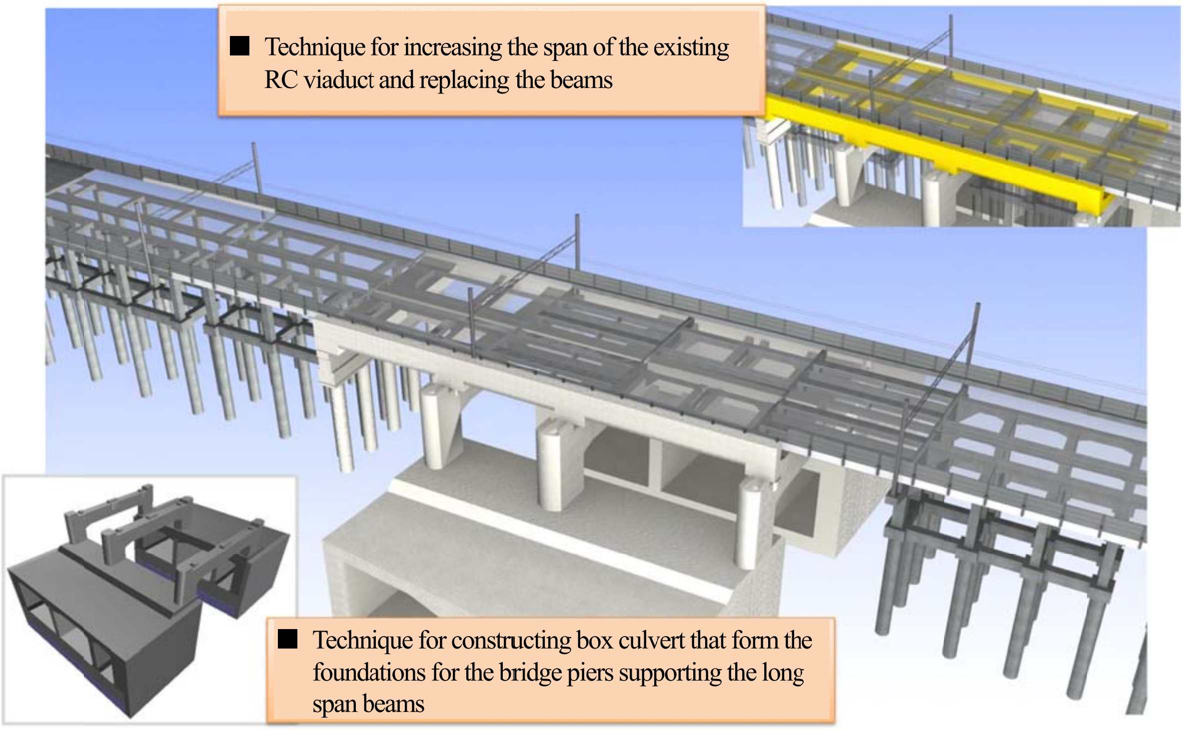

Fig. 4 Techniques applied

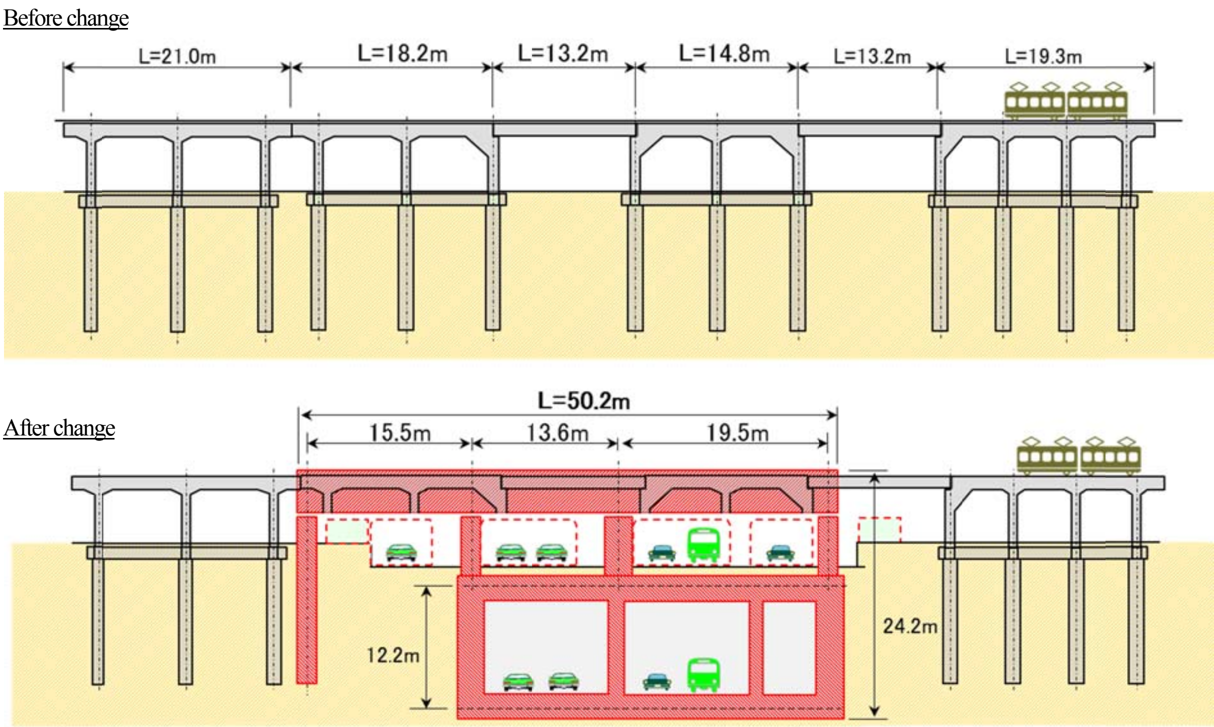

Fig. 5 Increasing the span of the viaduct (above: before change, below: after completion)

(1) Box culvert structure

This is a single layer 3 span box culvert 35.5 m wide, and about 12 m high (internal height about 8.6 m). Three box culverts were constructed: Box culvert B1 (L = 20 m) on the north side of the viaduct, Box culvert B2 (L = 20 m) directly below the viaduct, and Box culvert B3 (L = 20 m) on the south side.

(2) Supporting beam below the railway line

This was installed to replace the beam and slab of the viaduct, which was removed as it was an obstruction to the national road at ground level. This was a continuous beam with a total length of about 50 m formed in a lattice shape. The main beams are arranged in three rows, north, center, and south, made from a PRC structure.

(3) Portal frame type bridge piers

Four of these were constructed to support the supporting beams below the railway line. Of the four sets of bridge piers, the set on the Tokyo side was an RC type with in situ driven piles as the foundations. The 3 sets on the Chiba side were SRC structure portal frame type moment resisting piers, supported by Box culvert B1 and Box culvert B3 via anchor frames.

3. Construction steps

The main construction steps in this project were as follows.

(1) Construct the box culverts on both sides of the existing viaduct, the inside of which is to be used as the Outer Ring Road and which form the support structure for replacement of the existing viaduct, (hereafter referred to as Box culvert B1 and Box culvert B3) (Fig. 6). The pneumatic caisson method was adopted as the method of construction of Box culverts B1 and B3, in order to minimize any large-scale temporary works and measures against groundwater.

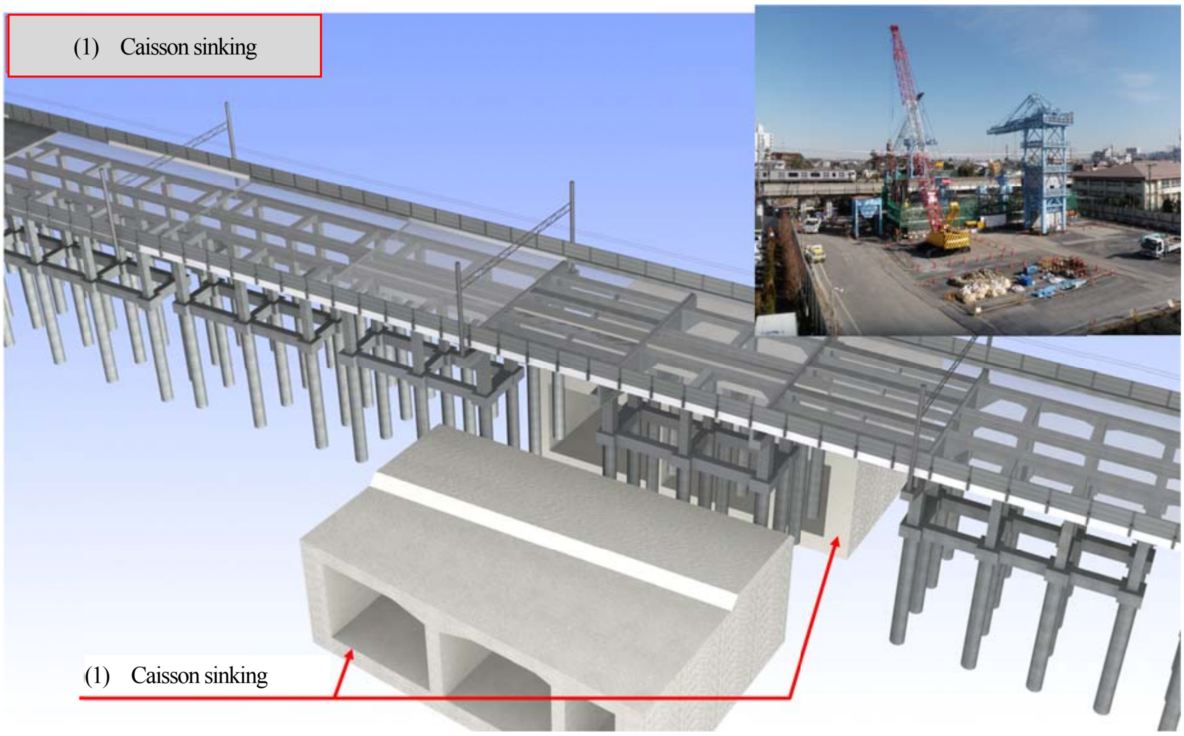

Fig. 6 Step 1 (caisson sinking)

(2) After the caissons were completed, the supporting beams below the railway line and the portal frame type bridge piers were constructed (Fig. 7, Fig. 8). The center main beam of the supporting beams under the railway line was installed in a position surrounded by the longitudinal beams and slab of the existing viaduct, so it was difficult to construct at the installation position. Therefore, after constructing it directly below the installation position, it was lifted up and installed in its final position. After installation of the center main beam, the portal frame type bridge piers were constructed with an SRC structure. The structural steel of the portal frame type bridge piers was divided, and erected by the method of pulling it up to under the viaduct using a 500 t crane from a cradle on a caisson box culvert, and after erection the concrete was poured inside and around the structural steel.

Then the outer main beams of the support beams under the railway line were constructed, and then the transverse beams that connect the outer main beams and the center main beam were constructed. The transverse beams were installed sandwiching the bridge piers of the existing viaduct on both sides in the axial direction of the bridge, and integrated with the bridge piers by removing cores, inserting PC steel, and tensioning.

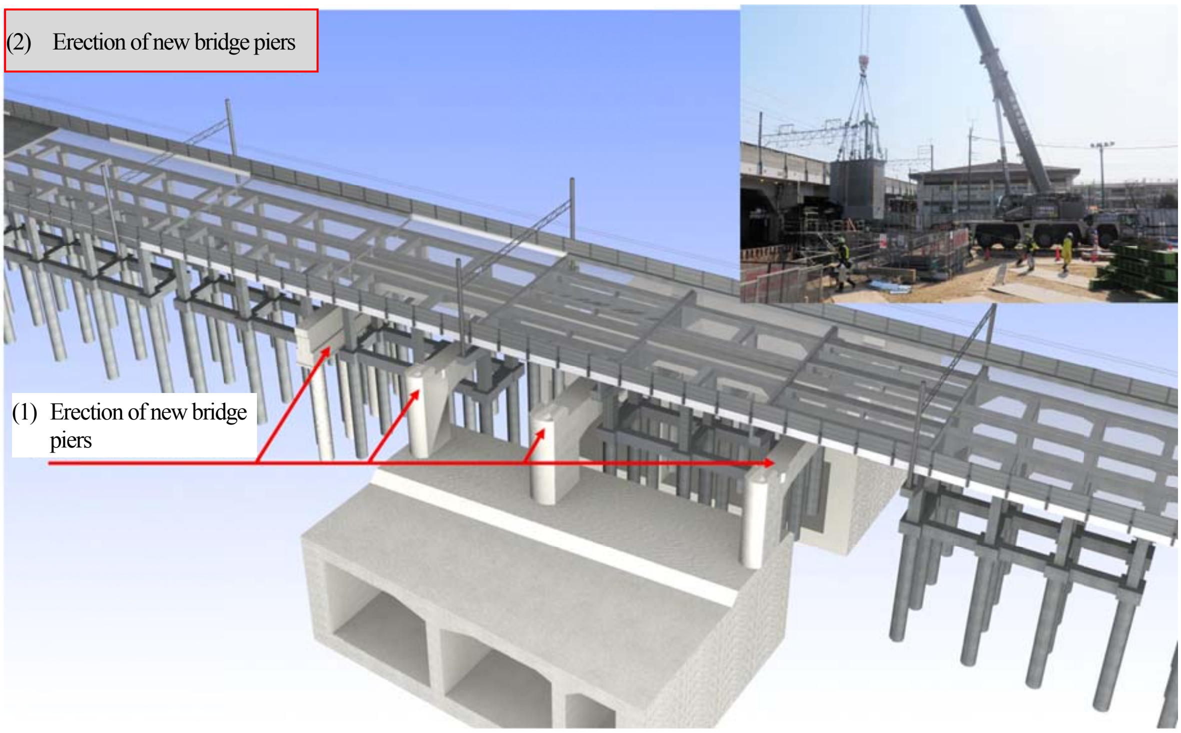

Fig. 7 Step 2: Construction of new bridge piers

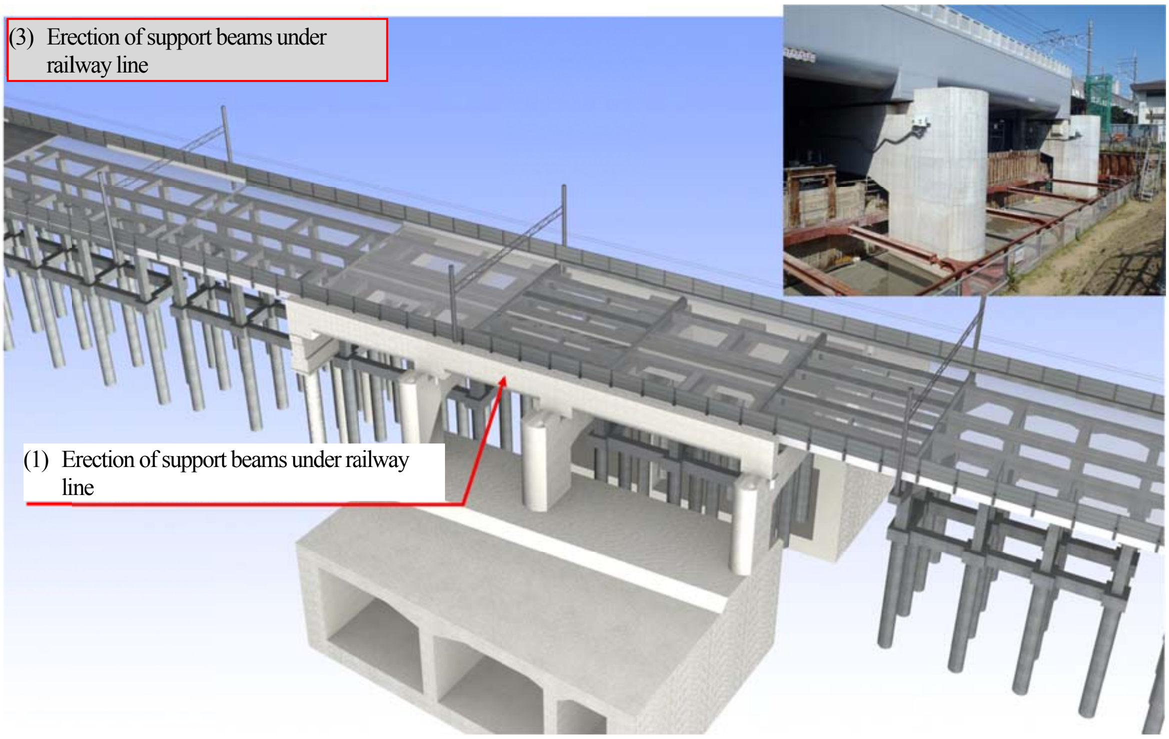

Fig. 8 Step 3: Construction of support beams under the railway line

(3) After completion of the support beams under the railway line, the load of the existing viaduct was taken by the new bridge piers. (Hereafter this operation is referred to as "underpinning".) (Fig. 9) In this operation, the positions of the beams of the existing viaduct and the SRC portal frame type moment resisting bridge piers were displaced relative to each other, in order to ensure space for the road on the ground. This was accomplished using a "top surface jack" installed

between the beams of the existing viaduct and the support beams under the railway line, and a "bottom surface jack" installed between the support beams under the railway line and the portal frame type bridge piers. After transferring the load of the existing viaduct onto the new bridge piers by underpinning, the columns of the existing viaduct (24 No.) were cut by wire saw and removed.

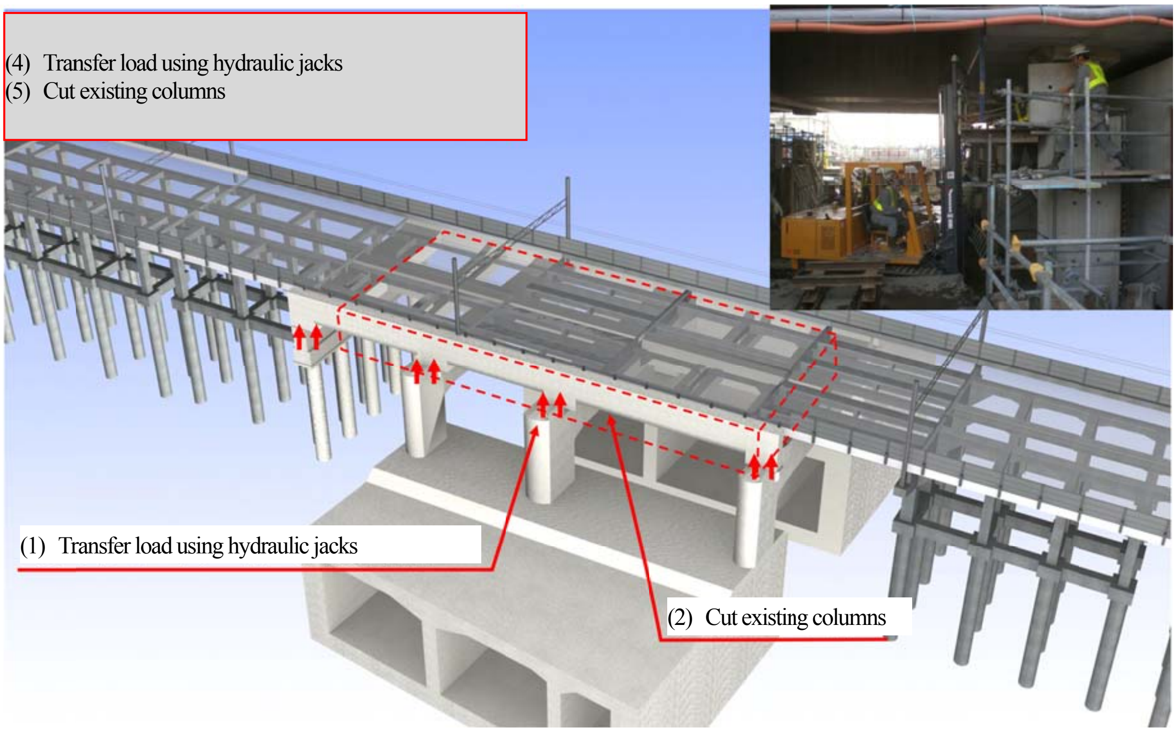

Fig. 9 Step 4: Underpinning

(4) After removal of the columns the bearing structure was installed. After rubber bearings were installed under the main beams and non-shrink mortar poured, the bottom surface jacks were removed. The top surface jacks were fixed, the hydraulic pressure removed, and jacketed in 3 directions with non-shrink mortar.

(5) After replacement of the viaduct, Box culvert B2 directly underneath the viaduct was constructed by the cut and cover method. In order to minimize any displacement of Box culverts B1 and B3 due to this excavation, the top deck of Box culvert B2 was constructed first, and completed by inverted construction method. The box culverts were integrated by connecting distribution reinforcement using mechanical joints.

4. Techniques used in construction

(1) Construction of the lattice PC beams to integrate with the beams and slab of the existing viaduct (Fig. 10).

To construct the long span beams, first the center main beam was constructed. Next the outer main beams on both sides and finally the transverse beams were constructed in that order, thereby constructing the lattice PC beams below the beams and slab of the existing viaduct. Here, in order to construct the new PC beams, it was necessary to introduce the prestress in each of the members in accordance with the design, and integrate the existing viaduct and the new beams with the tension force. Therefore, the construction of each member was carried out in stages, and the tensioning operation was carried out in stages in 7 steps, to rationally convert the existing viaduct into a long span. Also, the weight of the beams was reduced with this structural form.

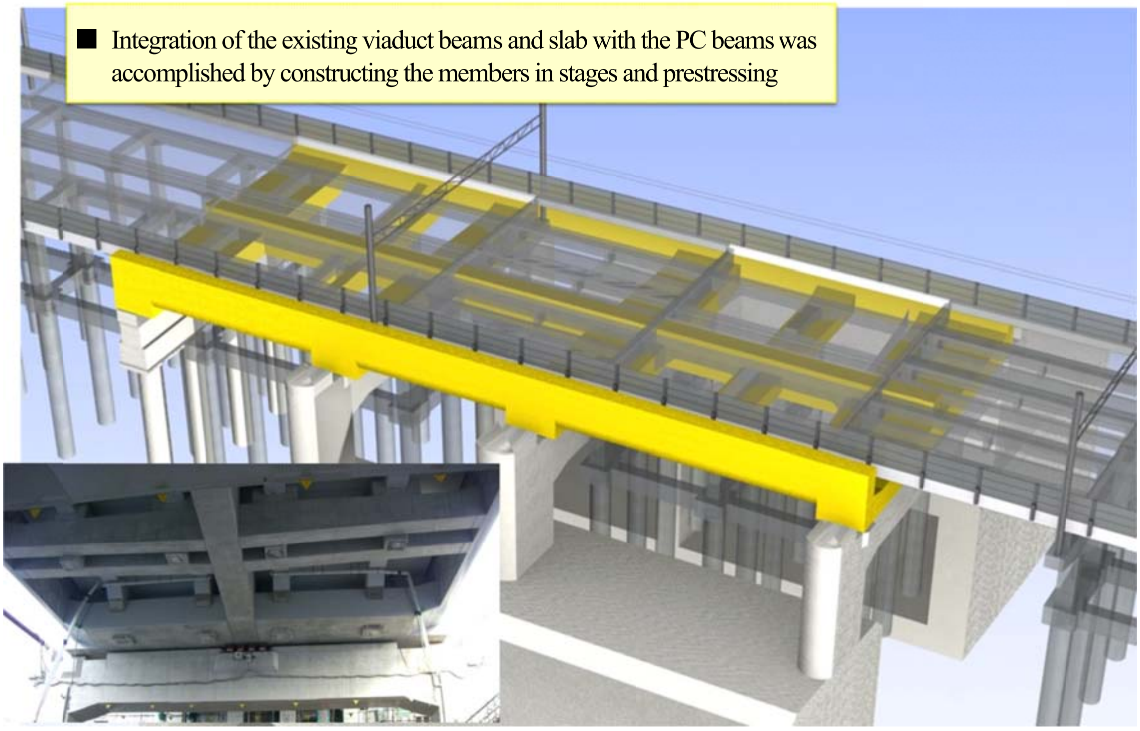

Fig. 10 Lattice PC beam structure

(2) Transfer of load to the new bridge piers using jacks (Fig. 11)

In order to minimize any displacement of the tracks on the viaduct, a total of 52 of the upper surface jacks and bottom surface hydraulic jacks were installed, and the load was transferred in stages to the new bridge piers. After transferring the load, rubber shoes and stoppers were installed at the bearing locations, and after completion of the beam structure, the columns of the existing bridge piers were cut, thereby smoothly completing the transfer. The displacement of the tracks during construction due to transfer of load to the beams was maintained within 20% (3 mm) of the maintenance standard value to enable the trains to operate. Also, transfer of the load was completed without generating unacceptable cracking in the long span beams of the new structure.

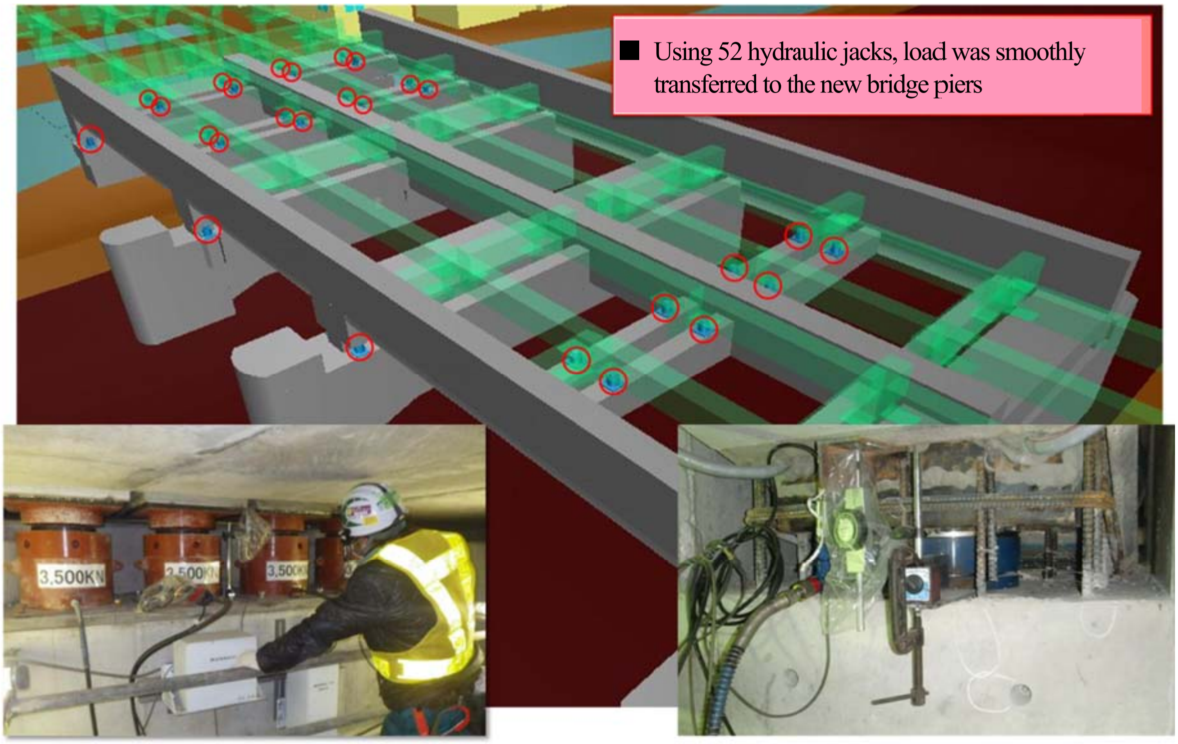

Fig. 11 Underpinning

(3) Minimization of deformation to existing structures when sinking the caisson (Fig. 12)

In this project, the caisson box culverts were sunk at positions extremely close to the existing viaduct. As a result of FEM analysis carried out in advance, it was anticipated that a large pull-in force would be produced on the foundation soil of the viaduct due to the effect of sinking the caisson, which would cause displacement of the viaduct. Therefore, a wall formed from a row of BH columns was installed to isolate the existing viaduct from the caisson. Also, in order to increase the caisson sinking accuracy, a hydraulic system using ground anchors and hydraulic jacks was adopted for control of the caisson attitude. As a result of these measures, it was possible to maintain the displacement of the viaduct due to sinking the cutting edge of the caisson to within 15% (2 mm) of the track maintenance standard value.

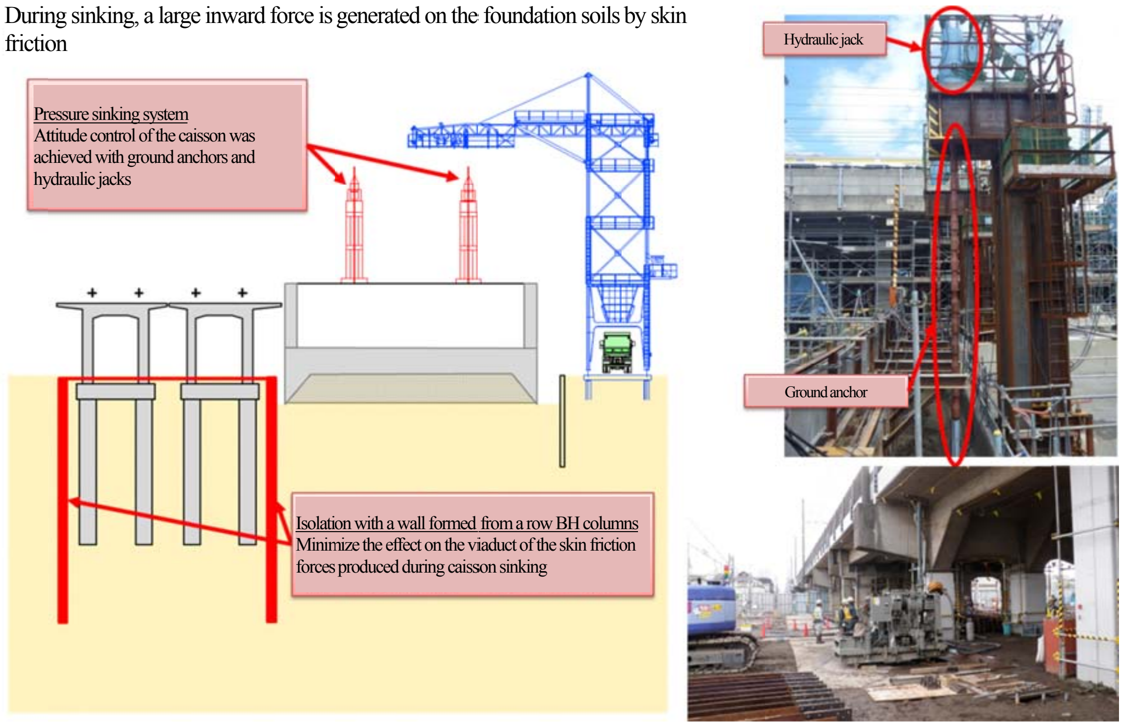

Fig. 12 Minimizing the effect of caisson sinking

5. Results and Outlook for the Future

The following is a comparison of the method used in this project with the conventional method. By carrying out underpinning and effectively using the structure of the existing viaduct, it was possible to greatly reduce the environmental load due to the construction. Also, it terms of construction period and economics, it was possible to shorten the construction period by about 14 months and reduce the cost by about 15%. In addition, it was possible to complete the construction without any stoppage or slowing of trains during construction, and to increase the safety of operation of the trains.

By using this technique, it was possible to rationally increase the width of the road intersecting an elevated railway in an area with high density of trains. In addition, it can be applied as a technique to realize the intersection of new planned roads and the Shinkansen (bullet train), which has strict control standard values for displacement and deformation during operation. It is expected that this technique can be widely used to greatly change the form of intersecting infrastructure, without changing existing spatial usage.

Fig. 13 View when completed (when underpinning is completed)