

# Initiatives for and a Case Study on Maintenance Work for Metropolitan Expressway Bridges

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Social interest in the aging of domestic infrastructure is growing. With many different types and degrees of damage having been found on bridges along the Metropolitan Expressway — which has a network exceeding 300 km in length — because they have aged under the severe environment caused by heavy traffic, various countermeasures have been implemented. In addition to continuing to carry out maintenance work, including repairing, reinforcing, and rebuilding bridges along the Metropolitan Expressway, IHI Infrastructure Systems Co., Ltd. has devoted itself to the study of technologies based on its wealth of experience and achievements. In this paper, we describe some of the initiatives that we have introduced and introduce a case study on the maintenance work that we have carried out on Metropolitan Expressway bridges.

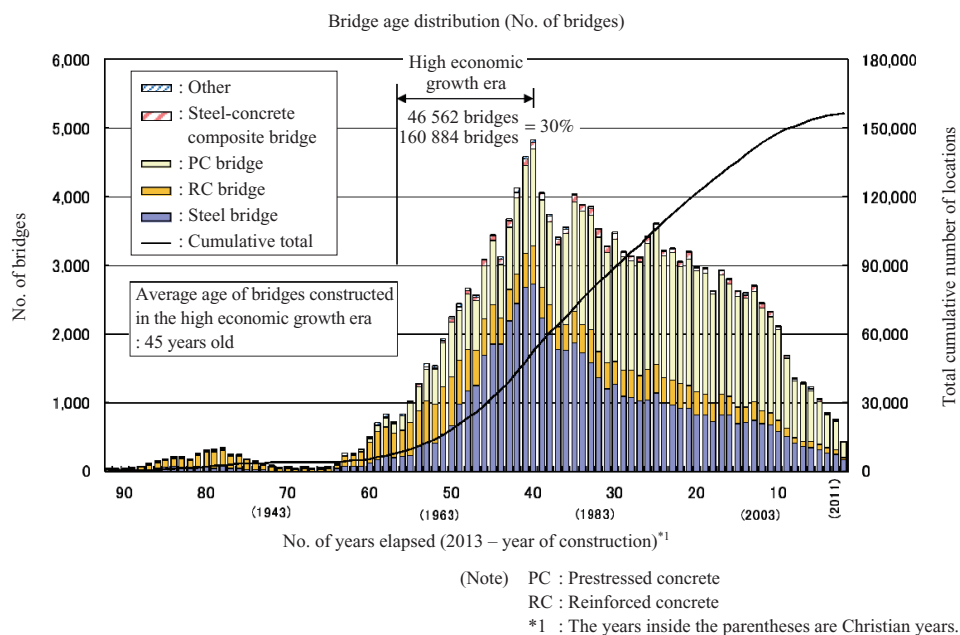
## 1. Introduction

Due to accidents such as the ceiling collapse in the Sasago Tunnel (Yamanashi Prefecture) of the Chuo Expressway in 2012, there is increasing interest in infrastructure aging issues. Among the bridges constructed in the high economic growth era, the ratio of those that have been in service for more than 50 years has begun to increase at an accelerated pace. **Figure 1** shows the actual situation of highway bridge stocks<sup>(1)</sup>.

With the aim of alleviating chronic traffic congestion, the

construction of the Metropolitan Expressway was started in 1959, and by the time the Tokyo Olympic Games of 1964 were held, 32.6 km had been completed. The total service length was subsequently increased, exceeding 300 km as of the end of 2017. As for the routes currently in service, sections of elevated structure account for 76% of the total length, with steel girders accounting for about 84%. The severity of the Metropolitan Expressway's use environment — including high traffic volume and a high proportion of heavy vehicles — has caused damage to progress significantly in some cases.

Given this situation, IHI Group has been engaging in



**Fig. 1** Current state of highway bridge stock<sup>(1)</sup>

maintenance of the Metropolitan Expressway on a continuing basis. Maintenance works for the Metropolitan Expressway have the following characteristics and requirements:

- (1) A proximity inspection conducted on a structure to be repaired often reveals unexpected damage, causing changes in the number of repairs, budget, process flow, and design specifications. In addition, other factors — including consultation about design or execution of works, coordination with other works within areas under the jurisdiction of Metropolitan Expressway operators, and strengthening of safety measures resulting from accidents associated with other works — may also cause changes in conditions for executing works. A management system must be in place whereby projects can be successfully carried out while responding flexibly to such changes.
- (2) Since the Metropolitan Expressway is the main artery of the Metropolitan area road traffic network, works are executed while the expressway remains available to traffic in most cases. This means that people not involved in works are ever in proximity to the site of works. In such an environment, even minor errors can immediately lead to an accident involving such people. In addition, works are often executed under extremely tight spatial or temporal restrictions. Hence, careful planning and arrangements are required.
- (3) Since processing is performed on existing structures that are constantly subjected to a load, it is imperative to ensure the safety of such structures and people not involved in works for each and every step of the repair or reinforcement, making careful coordination between design and execution is of great importance.
- (4) Various ways of diagnosing and repairing must to be taken even if the appearances of the damages are similar, and consideration should be given to various matters, including the standards, structures, materials, and manufacturing methods that were used at the time of construction or previous repairs or reinforcement, as well as to the degree and extent of damage. Moreover, the ability is required to imagine the risks of more serious damage that might exist behind the superficial damage detected in inspections. In other words, there is a need for a system that allows for the accumulation and utilization of knowledge and insights about, and experience in, maintenance works.

With the objective of responding to these requirements, IHI Infrastructure Systems Co., Ltd. (hereinafter referred to as “IIS”) established a project-oriented organization specialized in maintenance, which differs from the traditional functional organizations intended for efficient execution of bridge construction works, and the organization has been engaging in maintenance and reconstruction projects mainly for the Metropolitan Expressway.

In the rest of this article, we will describe case examples of maintenance and reconstruction works previously executed on the Metropolitan Expressway.

## 2. Project for Reinforcing Beam-to-column Connection Areas of Steel Piers 1-9 (Tokyo)

### 2.1 Project overview

The bridges covered by this project (10 piers in total at C4026, C4053 and C4054, and C4056 through C4062) are situated near Takebashi Junction, where Inner Loop and Route No. 5 Ikebukuro Line make a multi-level crossing. The bridges were constructed in 1964, the year in which the Tokyo Olympic Games were held. This project was launched after about 40 years had elapsed since the expressway opened to traffic. In this project, fatigue cracks were found not only in beam-to-column connection areas (81 beam-to-column connections in total), but also in notched portions of main girder edges and support brackets of piers subjected to the load of the superstructure, requiring countermeasure to every kind of fatigue damage to be implemented. Moreover, replacement of bridge supports and installation of seismic joints were also desired because aseismic reinforcement compliant with the “1996 Specifications for Highway Bridges and Commentaries on the Specifications” was yet to be started and because bridge supports were eroded and damaged due to water leaking from expansion joints.

With the junction constructed above a river, streets, and other expressways, as well as near buildings, the project site was extremely complicated in structure due to various factors including ① curves and skews; ② branching and widening; ③ multi-stored structure; ④ rigid structure; ⑤ notched main girders; and ⑥ use of round and square columns. In addition, spatial restrictions due to the clearance limits and estimated high-water level as well as the detection of many different types of damage at numerous locations rendered the design and execution of repair and reinforcement works extraordinarily difficult. **Figure 2** provides a schematic diagram of the reinforcement works (excerpt). Thus, this project lasted an unprecedented 89 months (from August 2003 to December 2010). We were able to overcome such difficulties by adopting several types of repair and reinforcement structures and methods, examples of which will be described below.

### 2.2 Installation of additional support beams and modification of main girder edges (full-webization, notched main girders)

At each location with enough space under girder, full-webization of the notched portions of the main girders was implemented to change the structure to allow the main girders to be borne by an additional support beam. As a result, we were able to remove the cracked support bracket, and as the superstructure reaction force came to act on the column via the additional support beam, the stress acting on the beam-to-column connection area was able to be reduced. There were actual cases preceding this project in which an additional support beam was attached to round columns and in which full-webization was implemented on an I-section plate girder, but there were no prior cases of attaching this kind of beam to square columns or of full-webization of a box girder. Attachment of an additional support beam to square columns and full-webization of a box girder implemented at C4060 (lower

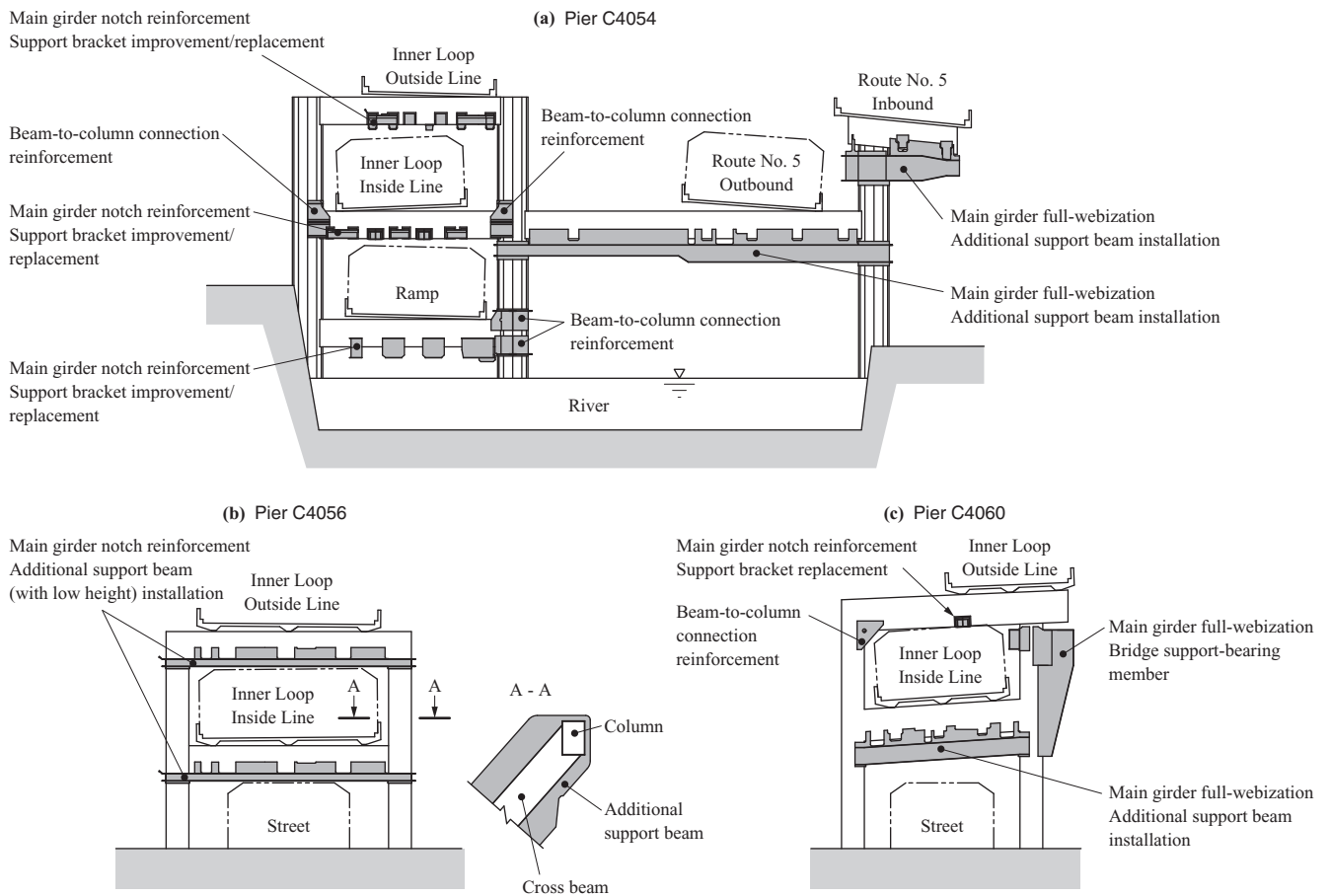


Fig. 2 Overview of reinforcements

portion) became the pilot work. **Figure 3** shows the additional support beam and full-webization in the lower portion at C4060. For the attachment of an additional support beam to a round-column pier, a structure surrounding the perimeter of the round column was built. For attachment to a square column, however, we conducted a Finite Element Method (FEM) analysis for verification and adopted a structure that only connected to the surface of the column subjected to webzation. A structure for reinforcing both a square column and a box girder subjected to full-webzation with this additional support beam.

For pier C4056 (upper and lower portions), it was difficult to construct a support bracket structure with a skew angle of 40 degrees due to the small space under girder. For this



Fig. 3 Lower portion of Pier C4060 : Additional support beam and full-webzation of the box girder

reason, additional support beams with low height (approx. 500 mm) were adopted. **Figure 4** shows a low-height additional support beam with skew angle at C4056. A box section was adopted for the additional support beams in order to ensure rigidity, and the lower flanges were provided with an opening through which works were executed. At the beam-to-column connections, which are critical parts, the beam height was increased to the extent the clearance limits were not affected, and a structure surrounding the perimeter of a square column was adopted. In addition, a reinforced notched structure, rather than full-webzation of the main girders, was adopted in order to secure space for executing works and



Fig. 4 Pier C4056 : Additional support beam with low height and a bevel angle

conducting maintenance.

### 2.3 Bridge support replacement and support bracket improvement/replacement

It was impossible to adopt an additional support beam at locations with a small space under girder. That is why we developed a method of replacing bridge supports and improving support brackets. Due to the inability of this method to reduce the stress acting on the beam-to-column connection of a pier, beam-to-column connection reinforcement was separately provided at locations with cracks.

#### (1) Jack position moving method

Due to the completed system designed to have bridge supports and support brackets immediately below the main girders, it was difficult to determine jack positions for bridge support replacement, the component layout during temporary installation and during final installation, and component replacement procedures. We therefore conducted various studies and decided to adopt a method that allowed component replacement as well as repair and reinforcement works to be performed while the jack height is adjusted for each step of the works, and that allowed the final installation of bridge supports directly below the main girders. **Figure 5** shows the jack position moving method. Moreover, edge cross girders were also replaced out of consideration for maintainability.

#### (2) Outrigger installation method

The method described in (1) above involves support point transfer, which contributes to there being a large number of steps. For this reason, improvements including reducing the number of steps and simplification of the reinforcing materials were required at locations on an expressway or street where traffic control was implemented. We therefore improved this method to be able to perform jack-up by installing outriggers outside the outer girders (G1, G3) (and an intermediate cross girder between main girders). **Figure 6** shows the outrigger installation method. Among the three jack-up points, two at the bottoms of the outriggers (one per outrigger) were fixed and the remaining one was transferred from the G1–G2 section to the G2–G3 section, which allowed us to continue the work.

### 2.4 Special reinforcement structures

At C4060 (upper portion), none of the methods we had previously used were applicable because of the following: ① clear space under girder having no margin at all; ② superstructure biased toward one of the columns and support bracket located in the beam-to-column connection area; ③ inconsistencies between one end and the other in the main girder type, as well as in support quantity and position. We therefore installed a bridge support-bearing member around the column at a location outside the clearance limits

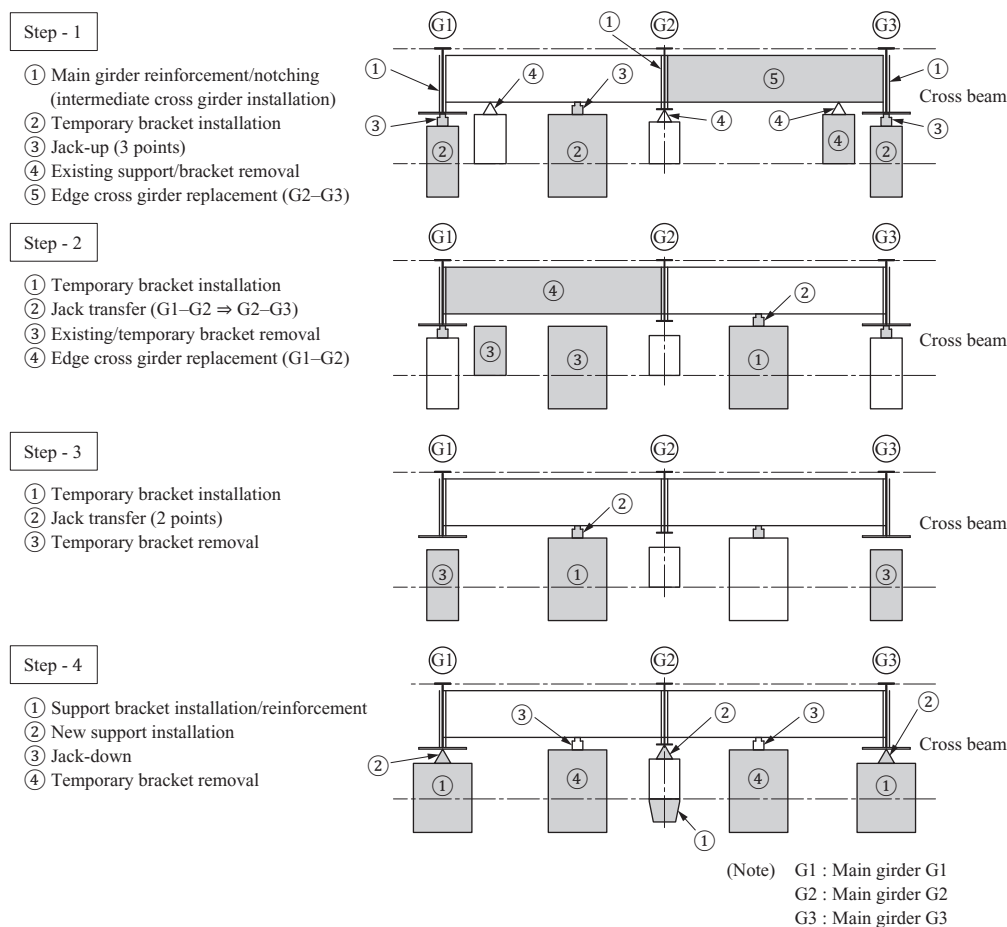


Fig. 5 Jack-up position moving method



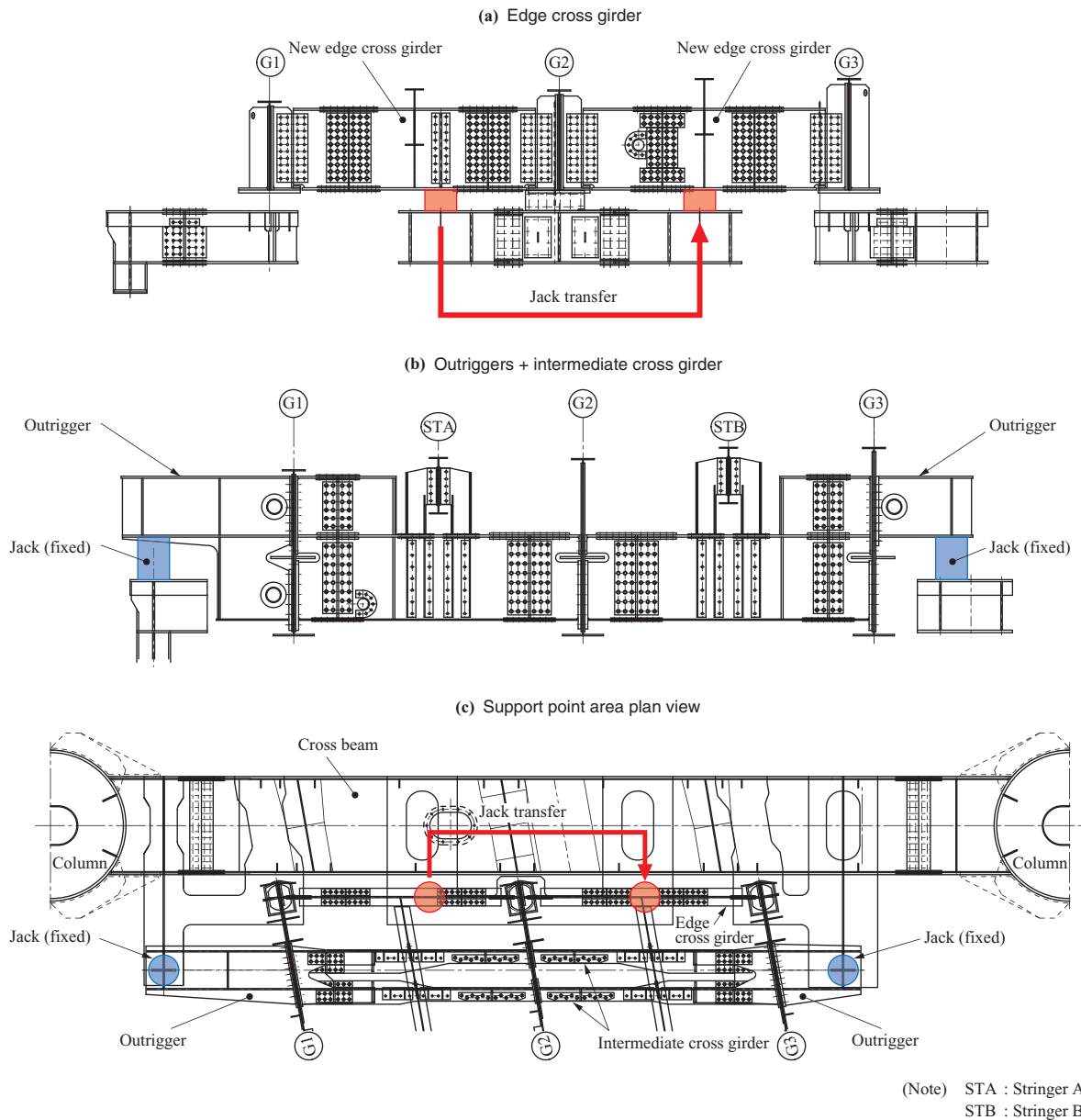


Fig. 6 Outrigger installation method

for the expressway (below the beam-to-column connection area) and implemented full-webization of the main girders. **Figure 7** shows the special support reinforcement for the upper portion at C4060. However, the notched structures of the main girders located on the expressway were reinforced and the support bracket was replaced by using temporary outriggers.

At C4061 and C4026, two main box girders and round columns constitute a rigid structure. The interiors of the beam-to-column connections are narrow with plates assembled in a special and complicated manner. In this narrow area, a number of cracks were detected. We used dynamic strain measurements taken from actual bridges and 3-dimensional FEM analyses to identify the cause and determine repair/reinforcement measures and work execution steps. Three types of reinforcement were used in combination: reinforcement called “BOOKEND” consisting of a



Fig. 7 Upper portion of Pier C4060 : Special support reinforcement

combination of fillets, reinforcement with a stiffening plate wrapped around a pier, and cross beam joint. **Figure 8** shows the beam-to-column connection reinforcement at C4061.

**Figure 9** shows the special reinforcement structures at C4062, which is comprised of three piers: one for Inner Loop Inside Line and Route No. 5 Inbound (low-profile portal pier) as shown in **Fig. 9-(a)**; another for Inner Loop Outside Line (rigid coupling with a box girder on one side and support by an I-section plate girder on the other side) as shown in **Fig. 9-(c)**; and the remainder for Route No. 5 Ikebukuro Line (Outbound) (portal pier supported by a box girder on one side

and by an I-section plate girder on the other side) as shown in **Fig. 9-(d)**. We determined the reinforcement structures taking into account the characteristics of the respective existing structures, damage situations, and work site conditions. **Figure 9-(b)** shows an additional steel pier installed between existing columns and integrated with them to support the superstructure. **Figure 9-(c)** shows a special additional support beam bolted only on the column web, which was adopted due to the rigid structure on only one side formed by the reinforcement structure along with the main girder. **Figure 9-(d)** shows a reinforcement structure on one side of

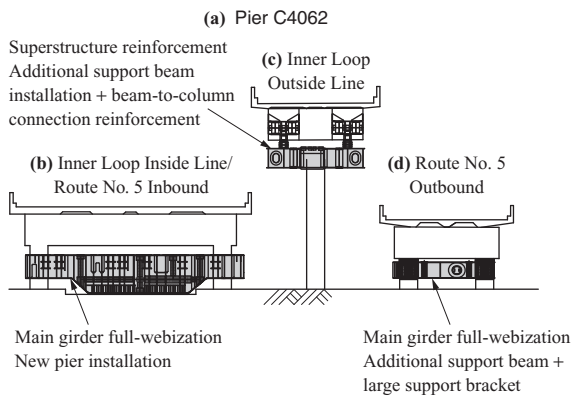
(a) Panoramic view of pier C4061



(b) Enlarged view of A



**Fig. 8** Pier C4061 : Reinforcement at beam-to-column connection



(b) Inner Loop Inside Line/Route No. 5 Ikebukuro Line (Inbound)



(c) Inner Loop Outside Line



(d) Route No. 5 Ikebukuro Line (Outbound)



**Fig. 9** Pier C4062 : Special reinforcing structure



which discrete large support brackets were adopted as columns supporting a box girder and on the other side of which an additional support beam was adopted.

### 3. Project for Reinforcing Beam-to-column Connection Areas of Steel Piers 1-22/ Structure Improvement Project 1-1

#### 3.1 Projects overview

These projects were large-scale works for reinforcing beam-to-column connection areas (total No. of piers, 70; total No. of beam-to-column connections, 122; total reinforcing steel weight, approx. 150 t); the area covered by the projects went from C1001 of the Inner Loop at the northern end to H1187 of the Haneda Line at the southern end, and C2036 of the Inner Loop at the western end. Several conditions needed to be addressed including existing piers situated along a Tokyo Metropolitan road (Kaigandori) with high traffic volume; clearance limits having no margin; and piers that have an enclosed structure with a small cross-sectional area of less than 1 m. Taking into account various conditions, including pier locations, degree of design difficulty, material lead time, the presence of obstacles, and whether or not to control traffic on the expressway, we implemented a series of processes, ranging from design to execution of works, by segmenting the entire project area into six lots, thereby completing the projects four months earlier than originally scheduled (from October 2008 to April 2011 (about 30 months)).

At C1043 through C1051 (nine piers) situated within the aforementioned project area, we found that the steel line bearings had never been replaced since the original construction. At C1044, a weld right below a support point was found to have a through crack, so emergency repair and bearing replacement were implemented (by a non-IIS contractor) separately from these projects. Since the cause of the crack was attributed to deteriorating support (constraint of translation and rotation) and that similar bearing components showed the same problem, bearing replacement was implemented as a separately contracted work.

#### 3.2 Reinforcement of beam-to-column connections with obstacles and those subject to restrictions

For each pier of the enclosed structure, a manhole for access

to the interior of the pier was created (Fig. 10) before reinforcement with a stiffening plate. Out of consideration for restoring the original enclosed structure after the reinforcement and for future accessibility to the interior of the pier, the manhole cover was closed with one-side bolts.

The rest of this section describes some of the cases in which there was an obstacle at a place where reinforcement with a stiffening plate was to be carried out. Where a bracket welded for displacement restriction or widening bridge pier edge was located, such bracket was removed and a stiffening plate for reinforcement and a new bracket were tightened to each other with high-strength bearing bolts in order to avoid damage to the pier (Fig. 11-(a)). Where concrete had been embedded in columns during a previous seismic resistance improvement work, the concrete was cut to install a stiffening plate, and after completion of its installation, the columns were refilled with concrete (Fig. 11-(b)).

For a special beam-to-column connection area, where a column and a cross beam of two different widths cross each other, we adopted a reinforcement structure consisting of a stiffening plate and a member wrapped around the pier for reinforcement. Figure 12 shows reinforcement of the special beam-to-column connection. Although the reinforcement dimensions were maximized to the extent possible under the

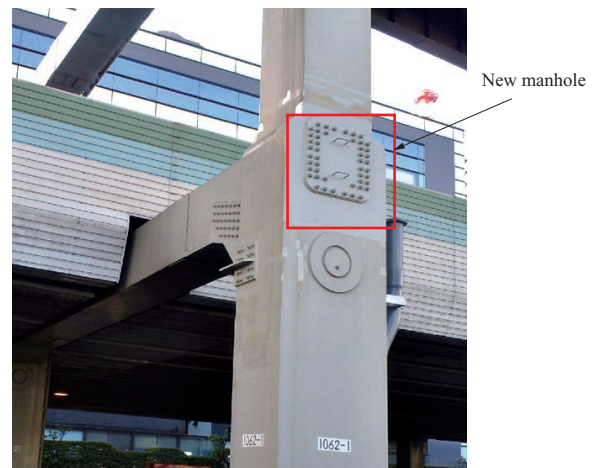


Fig. 10 New manhole

(a) Steel bracket



(b) Embedded concrete

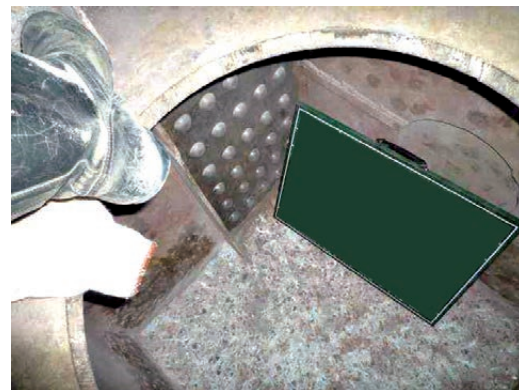


Fig. 11 Obstacle at beam-to-column connection

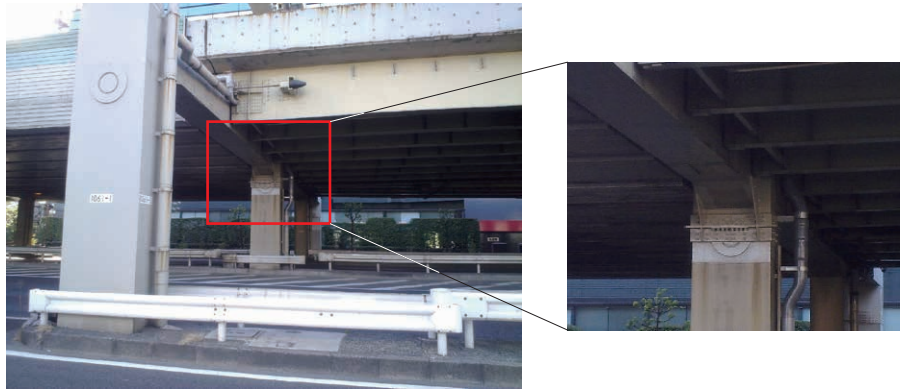


Fig. 12 Special reinforcement at beam-to-column connection

restrictions, a stress reduction rate of 50%, the guideline for reinforcement, could not be achieved.

### 3.3 Replacement of low-height line bearings

Although we considered the feasibility of adopting rubber supports or sealed rubber bearing plate supports for use in spaces wherein low-height steel line bearings (53–82 mm in height) were installed, neither of these supports fit into such spaces. We therefore decided to replace the existing steel line bearings with similar steel line bearings. However, the new line bearings were joined with the girders and pier via bolts from the perspective of ensuring fatigue durability. In addition, the flat dimensions of the lower shoe base plate were increased to ensure the distribution of load on and the rigidity of the upper flange surface of the pier. Integrated-type lower shoe base plate was employed where both ends of main girders align with each other with respect to the lower shoe base plate. **Figure 13** shows the conditions before and after bearing replacement. Moreover, since the distance between the upper and lower bearings was so small that it was difficult to repaint the bearings, hot dip galvanizing was specified for durability and economic efficiency. In parallel with this bearing replacement work, anti-corrosion reinforcement work was executed on the stiffeners on support points and reinforcement work was executed on the support points in the cross beam.

## 4. Project for Improving Seismic Resistance of Supports and Joints 2-44

### 4.1 Project overview

This project consisted of seismic resistance improvement works for the supports and bridge fall prevention systems of the viaduct from a point above the Edogawa River to a point near Koya on the Bayshore Route of the expressway (from B1493 to B1551). Replacement of 220 supports and installation of 210 sets of bridge fall prevention equipment constituted the major portion of the works executed during the period from December 2009 to October 2012 (about 34 months). In addition, for the three-span continuous orthotropic steel deck box girder bridge crossing over the Edogawa River, to which it was planned to connect a junction bridge, we implemented aseismic design and executed support replacement and seismic joint works taking into account the influence of the junction bridge, as well as executed works for widening the concrete bridge supporting the junction bridge. Incidentally, this project was the first project contracted by IIS (which was founded by a merger of three companies).

### 4.2 Support replacement/bridge fall prevention systems

Many of the target bridges were simple I-section plate girder (multi-main girder) bridges with concrete piers, and we

(a) Before bearing replacement



(b) After bearing replacement



Fig. 13 Before and after replacement of bridge support



adopted the following two methods to perform jack-up for support replacement.

Method ①: Jack-up bracket method (Fig. 14-(a))

Method ②: Edge cross girder jack-up method (Fig. 14-(b))

We initially planned to use method ①, which was designed to jack-up the main girders by installing brackets on the front surfaces of piers. These brackets also served as substructure-side connections at bridge fall prevention points, at which the superstructure and the substructure were connected with each other, and step prevention structures were installed on this bracket at locations requiring such structures. Figure 15 shows a bridge fall prevention work and a step prevention structure. Method ② was designed to replace end bracing with a cross girder structure to perform jack-up on piers. It was originally adopted for a location where it was difficult to install a bracket due to emergency stairs in proximity to the front surface of a pier. Having the advantages of eliminating the need for anchor drilling, which prevents damage to existing piers, being free of the risk of interference by reinforcing bars, and shortening the work schedule, this method was applied to locations subject to subsequent design and works.

For the three-span orthotropic steel deck box girder bridge crossing over the Edogawa River, we conducted an aseismic analysis taking into consideration the load of the junction bridge and then executed support replacement and seismic joint works. Replacement at the intermediate support point, located above the river, was performed by transporting a barge type platform bearing a large rubber support (maximum reaction force, > 10 000 kN; mass, approx. 100 kN) to the work site, then lifting up the support to a position right below the girders, and horizontally pulling the support to the support point. Figure 16 shows support replacement at the intermediate support point. At the support points on both ends, a damper was installed for displacement restriction to avoid colliding with the adjoining girder, an increase in junction reaction force, and the durability of the existing piers.

#### 4.3 Widening of concrete piers

Prior to the design and execution of works, we cut beam ends and investigated the conditions of the concrete, reinforcing bars, and sheath tubes, and reflected the investigation results



Fig. 15 Bridge collapse prevention and stepped prevention structure

in the design. In addition, we conducted cracking simulation and temperature control planning based on temperature stress analysis. Some of the sheath tubes for the PC cable that had been buried in anticipation of future plans were found to leak water, posing a concern about the reliability of grout filling. Hence, a polyethylene coated external cable was adopted instead. Moreover, due to the inshore locations of the bridges, rust preventive reinforcing bars were adopted and concrete coating was applied. For this bridge pier widening, we conducted design and executed works with cooperation from IHI Construction Service Co., Ltd., an IHI Group company (Fig. 17).

### 5. Project for Reinforcement against Earthquakes for Arakawa Wangan Bridge<sup>(2)</sup>

#### 5.1 Project overview

The Arakawa Wangan Bridge was constructed in 1975 by a Yokogawa, Mitsubishi, and Ishikawajima-Harima joint venture (JV). It is a steel seven-span cantilever truss bridge constituting the Bayshore Route of the expressway. The daytime traffic volume (traffic volume per 12 hours of daytime) on the Bayshore Route is about 120 000 vehicles, which is extremely high compared to the traffic volumes on other routes or lines of the Metropolitan Expressway. In this project, we designed and executed works with the objective of ensuring aseismic performance against level 2 earthquake

(a) Jack-up bracket method



(b) Edge cross girder jack-up method



Fig. 14 Jack-up method

(a) Horizontal pulling of a new support



(b) Installation of a new support



Fig. 16 Replacement of steel bridge support at intermediate support point

(a) Scaffolding erection



(b) Prestress introduction



(c) After completion



Fig. 17 Additional concrete beam at Pier B1516

ground motion in accordance with the “2002 Specifications for Highway Bridges and Commentaries on the Specifications.” **Figure 18** provides a general diagram of the reinforcements against earthquakes (half of all reinforcements implemented).

During the term of reinforcements against earthquakes, an earthquake occurred off the Pacific coast of the Tohoku region on March 11, 2011 and some of the already installed components became damaged. Restoration was implemented in two steps: emergency restoration immediately after the

occurrence of the earthquake intended for early reopening of the bridge to traffic; and permanent restoration intended to restore and maintain the bridge functions as they had been before the occurrence of the damage.

This project lasted for 57 months from June 2008 until March 2013. It was a large-scale seismic retrofit project for a long-span truss bridge with the following results: steel weight, 2 360 t; quantity of high-strength bolts, approx. 270 000; quantity of dampers, 62; quantity of bridge fall





prevention equipment, 286 sets; area of on-site painting, approx. 30 000 m<sup>2</sup>; and area of scaffolding, approx. 55 000 m<sup>2</sup>. We were able to finish this project with no disasters as we overcame a number of difficult situations including the Great East Japan Earthquake.

### 5.2 Reinforcements against earthquakes

It was decided to implement reinforcements against earthquakes to ensure level 2 aseismic performance, which limits seismic damage against level 2 earthquake ground motion — the probability that this level of earthquake ground motion may occur is low during the service period of the bridge but the intensity of this motion is high — and which allows for early restoration of bridge functions. For the superstructure, we established a policy of maintaining the elastic region for primary members and to accept plasticization for secondary members and conducted design in accordance with this policy. Stiffening plates were applied to the main chord members of the truss that would be caused by an earthquake to have an elasticity exceeding the elastic limit, and bypass members were installed so that they crossed existing splice plates. **Figure 19** shows the situations before and after application of a stiffening plate.

In the basic design phase, we planned to install dampers in movable support point zones to reduce the response of the entire bridge to earthquakes and to reduce the load acting on the substructure. As a result of our study conducted during the project, however, it was found that dampers installed at the movable parts of suspended girders of the cantilever truss would work effectively. For this reason, we installed more dampers than originally intended, becoming able to reduce the number of stiffening plates. This contributed to reducing the cost of the reinforcement works.

Since the impact of bending moment in the support point zones was not negligible due to the large height of the supports, we conducted design taking into consideration such eccentric bending moment. Based on this design, large V-shaped stiffening plates were applied. In addition, dampers were installed in the movable support point zones. **Figure 20** shows a reinforcement for a support point zone. In this damper installation site, an inspection pathway for use in maintenance was also constructed.



Fig. 20 Reinforcement at bridge support

### 5.3 Post-earthquake recovery

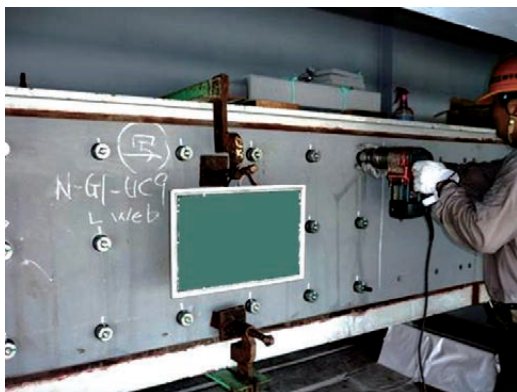
During emergency restoration, we conducted an inspection promptly after the occurrence of the earthquake in order to identify damaged parts. In addition, we determined feasible reinforcing methods through close communication with the owner and other stakeholders. Moreover, during fabrication and execution of works, we diverted materials, made structures labor-saving, and executed works on a round-the-clock basis. As a result, it took only 12 days to complete restoration, and the bridge was reopened to traffic at 3:00 a.m. on March 22. **Figure 21** shows gusset plate restoration.

## 6. Rainbow Bridge Main Cable Repair Project<sup>(3)</sup>

### 6.1 Project overview

Rainbow Bridge (Tokyo Port Connecting Bridge) is a suspension bridge that was completed and brought into service in 1993. With about 20 years having elapsed since it went into service, the white top coats of the main cables deteriorated exposing a large portion of the reddish brown undercoats. Thus, repainting was required. It was then decided to repaint the cables and introduce a dry air injection system as corrosion prevention measures. With the area subject to these works divided into two zones (the Daiba Line and Shibaura zones), IIS undertook repainting in the Daiba Line zone (about half the entire work area). **Figure 22** shows situations before and after repainting. Repainting in the

(a) Stiffening plate application in progress



(b) Completed stiffening plate application



Fig. 19 Reinforcement plate



Fig. 21 Restoration of gusset plate

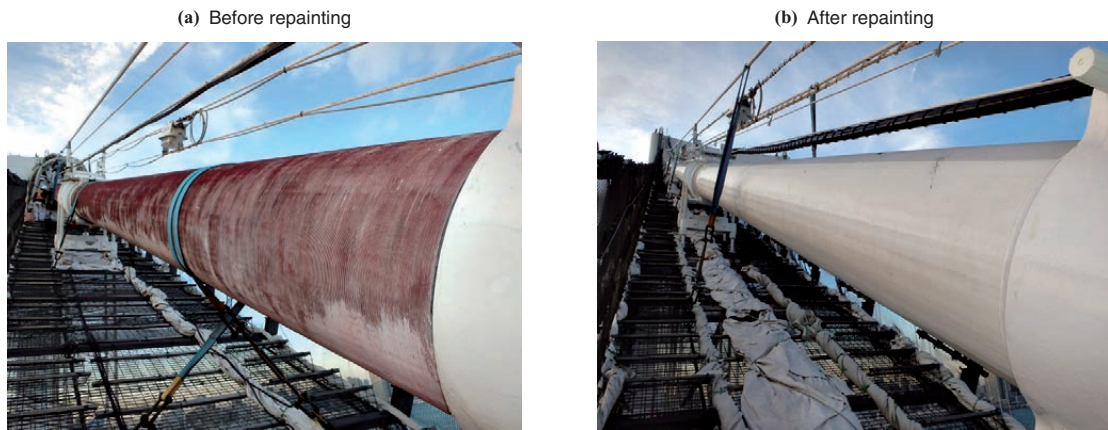


Fig. 22 Before and after repainting

Shibaura zone and installation of a dry air injection system (across the entire work area) were undertaken by non-IIS contractors. The term of this project was 43 months from March 2013 to September 2016. During this period of time, the following works were executed: ① erection of a set of scaffoldings for repainting; ② repainting of the main cables (approx. 2 200 m<sup>2</sup>); ③ repainting of cable accessories (approx. 1 700 m<sup>2</sup>); and ④ repair of cable band caulking (approx. 700 m).

During the project, two fire accidents and a lead poisoning

issue occurred at the other contractors' work sites, causing our work to be suspended and creating the need for fire prevention and for the development of lead poisoning countermeasures. In addition, repainting operations on the scaffolding at a height of about 100 m above sea level were often prevented by the wind, causing the operating rate to decline more significantly than expected. For this reason, the original term of the project of 22 months was extended to 43 months (almost twice the original term). Since the repainting operations were performed while the bridge



remained open to traffic, the operation sites had to be covered with sheets for dispersal prevention. Moreover, operations were often suspended even at a wind speed of 7–8 m/s, less than the wind speed serving as a criterion for suspending operations, due to the difficulty in covering the operation sites with sheets. Therefore, it will be a major challenge to establish countermeasures against the wind for similar works in the future.

### 6.2 Scaffolding erection

A catwalk scaffolding was erected under the main cables in order to repaint them. In order to erect the catwalk scaffolding, an above-upper-chord-member scaffolding and a tower top scaffolding were erected.

The above-upper-chord-member scaffolding was erected on the upper side of the truss upper chord on each side of the expressway in order to function as a stockyard and a passageway. In order to minimize the impacts on vehicles not involved in the project, a panel structure was adopted, and the scaffold was erected at night while one lane of the expressway was subjected to traffic control. The tower top scaffolding was erected in the following way. While one lane of the expressway was subjected to traffic control at night, scaffolding members were brought into the erection site and assembled on the ground. Lifting to the tower top was

performed in the daytime of a windless day under stable weather conditions. It took about 20 hours to erect this scaffolding. The catwalk scaffolding was erected in the following way. Wire ropes were stretched from the tower top scaffolding to the above-upper-chord-member scaffolding and then to the predetermined aerial or overhead positions. Then, a work floor comprised of a flooring material (wire mesh), floor beams, net, etc. was constructed on the ropes using a movable protection device (Fig. 23).

### 6.3 Repainting

For coating, the optimum application amount per layer was determined based on the pre-work testing conducted before order placement. The number of layers and the type of paint for each coat were as follows: for the undercoat, 10 layers of chloroprene rubber-based paint; for the top coat, 3 layers of chlorosulfonated polyethylene-based paint. In addition, one layer of nonslip top coat was specified for the cable upper surfaces.

Since the existing coating contained a lead component, lead poisoning countermeasures were implemented for surface preparation. Surface preparation and painting operations were performed in dispersal prevention equipment. Figure 24 shows the dispersal prevention equipment and the painting operation. Since the dispersal prevention equipment had a

(a) Catwalk scaffolding erection



(b) Catwalk scaffolding removal



Fig. 23 Movable protection device

(a) Dispersal prevention equipment



(b) Operation state

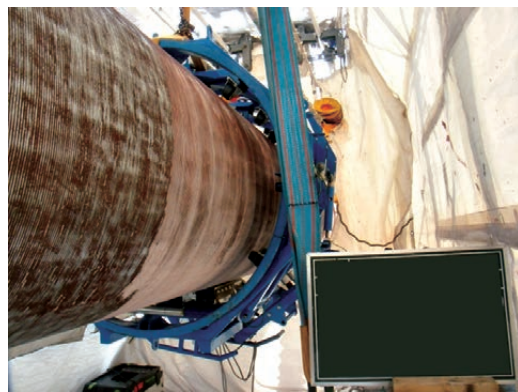


Fig. 24 Work status for dispersal prevention equipment



risk of being blown down by strong winds, it was erected and removed at the start and end of the operation on a daily basis. In order to reduce the effort for the surface preparation operation, we developed a simple scraping machine and utilized it in some locations.

## 7. Superstructure Reinforcement Project 1-5/1-113

### 7.1 Project overview

This project covered three sections on the Metropolitan Expressway: one on Route No. 3 Shibuya Line (between pier S440 and pier S497); another near Iidabashi Entrance and Exit on Route No. 5 Ikebukuro Line (between pier I89 and pier I30); and the remainder near Itabashi Junction on Route No. 5 Ikebukuro Line (between pier I623 and pier I652). The project was wide-area repair works in which various types of damage were handled. Specific works executed in this project include ① repairs and reinforcements against cracks and corrosion of steel members; ② support replacement; ③ reinforcements for back side sound absorbing boards; ④ prevention of concrete delamination; ⑤ concrete slab repairs and carbon fiber reinforcements; and ⑥ slab anchor repairs. Due to an increase in the works to be done, the term of the project was extended (47 months from December 2012 to November 2016).

### 7.2 Crack repairs

Cracking damage accounted for the largest portion of the cracks handled in this project and were present on web-gap plates. The method of repair was to replace damaged members with new ones, which involved welding. In order to ensure welding quality and the safety of existing structures, we conducted preliminary surveys and tests, including vibration checking for existing structures, management of the maximum welding heat input, and condition checking through welding tests. Advanced cracking damage was often found on a base material after removal of an existing member. In such cases, crack repair was performed in a reliable manner and then a new member was installed. **Figure 25** shows situations before and after web-gap plate replacement.

### 7.3 Support replacement<sup>(4)</sup>

Previously, support replacement had been implemented with

the primary objective of improving aseismic performance in many cases. In this project, however, support replacement was implemented to counter cracking damage or corrosion damage present in bridge support sections (six locations in total). The rest of this section will describe the support replacement work conducted at Iidabashi Exit (**Fig. 26**), which was the most difficult to execute among the support replacement works executed in this project.

Borne by the box culverts constituting the revetment of the Kandagawa River and steel piers of the Metropolitan Expressway, Iidabashi Exit has an extraordinary planar structure. The 24 supports installed on the revetment side had not previously been replaced due to their structure not allowing their back surfaces to be accessed. Due to the corrosion of lower shoes and set bolts as well as damage to bearing plates, however, it was decided to replace the supports. **Figure 27** shows the situation before support replacement (on the Kandagawa River revetment side) and **Fig. 28** shows the situation after support replacement. The following are the problems associated with the support replacement and solutions for them.

- (1) Due to the narrow clearance between the superstructure and the estimated high-water level for the river, it was decided to install jack-up equipment below that water

Revetment-side support line (24 supports)

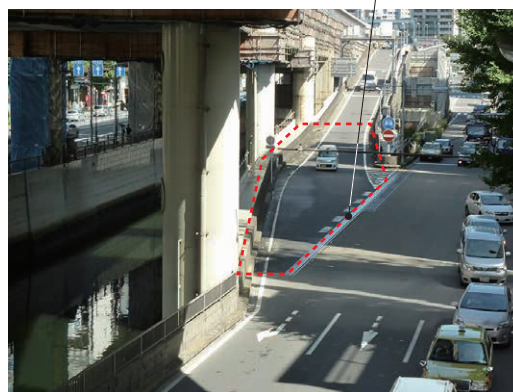


Fig. 26 Overview of Iidabashi exit

(a) Before replacement



(b) After replacement



Fig. 25 Before and after replacement of web-gap plate



Fig. 27 Before replacement of bridge support (unit : mm)



Fig. 28 After replacement of bridge support

level. Safety measures against the rising of the river were therefore required. We introduced arrangements causing an alarm to be issued to the work sites in the event the upstream side of the river rose and adopted a structure designed to pull up the scaffoldings to positions above the estimated high-water level.

- (2) In order to enable works to be executed on the back surface of each support, we cut off the edge cross ribs on the support and adopted a structure and a method allowing the ribs to be restored after the execution of works. Due to the inability to paint the back surface after restoration of the edge cross ribs, hot dip galvanizing

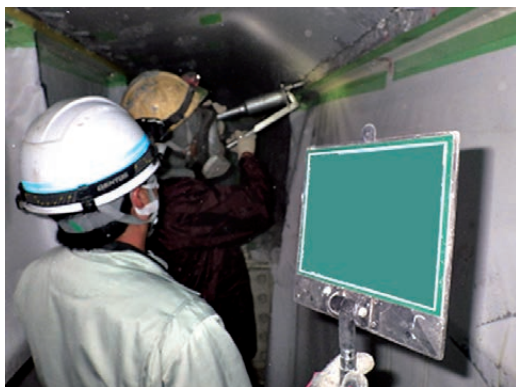
was specified for rust prevention. For supports with more serious corrosion damage, two additional layers of solvent-free inorganic coating material (product name: Ceramax #1000AL) were applied to the surfaces subjected to hot dip galvanizing in order to improve their durability.

#### 7.4 Slab anchor repairs

The slab anchor joining the steel superstructure and the concrete slab had fractured due to the fatigue damage, causing the formation of a gap between the steel and concrete boundary surfaces. Due to this gap, abnormal noise had been produced every time a vehicle passed. Although the slab anchor fracture seemed to be attributable to the deflection difference between the main girders and to repeating fluctuations in the intersection angle between flange and web resulting from the deflection of the concrete slab, it was difficult to come up with measures to reduce such deflection difference and deflection. In the end, we placed a metal anchor in the existing gap and injected epoxy resin into the gap in order to restrict displacement. **Figure 29** shows the situation of resin injection and the situation after repair.

Due to the limited work space, it was difficult to ascertain the injectability of resin, which was to be injected onto one side of an extremely narrow gap. For this reason, we conducted a preliminary welding test, determining work processes providing high injectability and reflecting them in

(a) Resin injection



(b) After completion of repair



Fig. 29 Resin injection and after repairs



the actual work.

### 7.5 Carbon fiber reinforcements for the concrete slab

The concrete slab in the sections covered by the works executed in this project had multiple types of damage, including cracks and sectional deficits. Although such damage did not seem to immediately cause a critical defect, such as the falling of the concrete slab, carbon fiber reinforcements were implemented to suppress the advancement of deterioration from the perspective of preventive maintenance (Fig. 30).



Fig. 30 Work status for carbon fiber reinforcement

## 8. Conclusion

In the preceding sections, we have described some of the numerous repair and maintenance works for the Metropolitan Expressway in which IIS has been engaging on a continuing basis. In addition to such maintenance and repair works, we have been engaging in reconstruction works as well — including reconstruction work for the Shiodome Viaduct on the Yaesu Line<sup>(5)</sup> (Fig. 31) and works for renovation Pier 82 into a rigid-frame pier<sup>(6)</sup> (Fig. 32) in the Komatsugawa Junction River Section Project — on a continuing basis. Furthermore, we have carried out overseas repair and reconstruction works as well.

Currently, orders for large-scale renewal works and large-scale repair works based on the Metropolitan Expressway Renewal Plan are placed from time to time, and IIS is also engaging in and executing some of such works. This article has chronologically described examples of the maintenance works undertaken by us. Along with the properties of damage and the needs of the times, needs for maintenance works are diversifying (Figs. 33 and 34). As a result, the technologies expected by clients are changing and domains to be addressed are increasing.

Other expressway companies as well as the national and local governments are also facing accelerated changes in



Fig. 31 Shiodome Viaduct reconstruction for the Yaesu Route on the Metropolitan Expressway<sup>(5)</sup>

(a) Before reconstruction



(b) After reconstruction



Fig. 32 Reconstruction of Bridge Pier 82 at Komatsugawa junction<sup>(6)</sup>



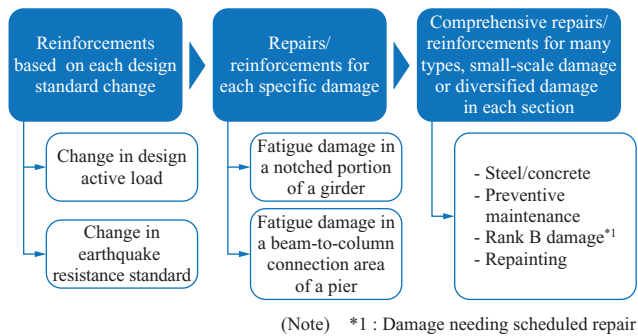


Fig. 33 Change and diversification of needs

① contract system, ② scale of works, ③ project domain, ④ value chain, and accelerated ⑤ integration.

In order to keep up with such changes and integration and to change ourselves more quickly than they do, we will gather and consolidate technical and managerial capabilities that have been built up based on the achievements of IHI Groups and make further endeavors from now onward to maintain aging infrastructures and improve their functionality thereby contributing to the development of society.

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Fig. 34 New needs : Permanent scaffolding

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