INVESTIGATION AND COUNTERMEASURES FOR FATIGUE CRACKS THAT EMERGED ON THE FINGER JOINT OF THE CABLE-STAYED BRIDGE "TSURUMI-TSUBASA BRIDGE"

Tsuyoshi KOSUGI[1]
Masakatsu TAKANO[2]
Masanori TAKAHASHI[3]

Abstract

As a result of a follow-up investigation for fatigue crack damages of the finger joint of the Tsurumi-tsubasa Bridge in 2012, where emergency repair had been carried out from 2008 to 2010, 140 cracks were found along the root of the welded part of the face-plates. Due to analysis of tendency for crack causing, it was confirmed that weld detail at the time of fabrication was one of the factors for crack causing.

As for the blocks of the face-plates with serious damages, they were replaced by blocks having been installed under the road shoulders as an emergency measure before they were replaced by newly fabricated ones. For face-plates which could be re-used, they were repaired by shop welding.

Introduction

Tsurumi-tsubasa Bridge on the Metropolitan Expressway is a 3-span continuous steel cable-stayed bridge, approx. 1 km long in length. The average volume of daily traffic is more than 40,000 vehicles, and the percentage of over-sized vehicle traffic is more than 25%. As for the Tsurumi-tsubasa Bridge, fatigue cracks of the finger joint were found for the first time in 2004. Since then, cracks and fractures have been found intermittently. For these damages, exchange and/or replacement of blocks of the face-plates have been conducted so far. A lateral-view of the Tsurumi-tsubasa Bridge is shown in Fig.1 and a complete view is shown in Fig.2.

In the follow-up investigation for the finger joint of the Tsurumi-tsubasa

[1] Senior Staff of Third Management Division, Structural Management Department, Shutoko Engineering Co., Ltd.
[2] Manager of First Management Division, Structural Management Department, Shutoko Engineering Co., Ltd.
[3] Deputy Manager of First Maintenance Design Division, Kanagawa Operation Bureau, Metropolitan Expressway Co., Ltd.

Bridge intended for serial observation in 2012, 140 crack damages were found along the root of the welded part of the face-plates and it was affirmed that damages tended to increase. So, repair by shop welding was carried out as a practical measure against crack damages, by analyzing occurrence tendencies of the damages and weld detail in time of fabrication. In this script, crack investigation and countermeasures taken for the damages will be described.

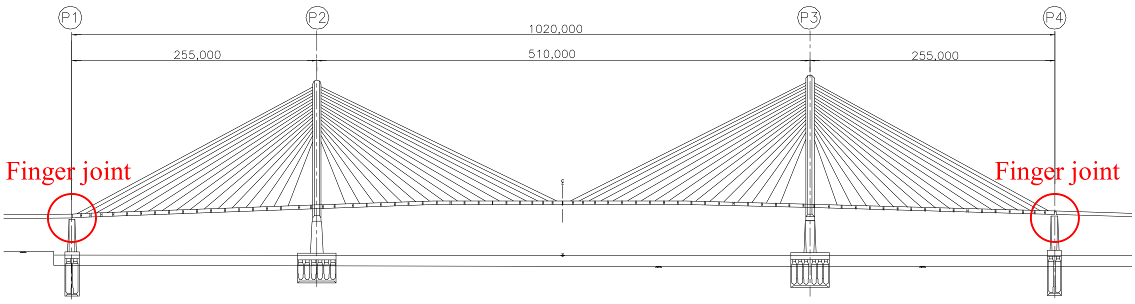


Fig.1 Lateral-view of the Tsurumi-tsubasa Bridge

Fig.2 Complete view of the Tsurumi-tsubasa Bridge

Structure of finger joints

As for the finger joint of the Tsurumi-tsubasa Bridge, joint clearance is 3220mm, the length of design movement is ±320mm on a steady basis, and ±700mm in times of an earthquake. The length of the finger joint is approx. 2000mm, and as the cantilevered length is long, approx. 1700, it is designed as a simple beam with an intermediate supporting beam. Structure of the finger joint is shown in Fig.3.

The face-plate block of the finger joint is composed of face-plates cut out from thick steel plates and spacing-plates that are welded mutually. Weld structure of the face-plate block is shown in Fig.4. As for a the blocks of the face-plate, welding is done around the spacing-plate by fillet weld with the leg size of 9mm, but welding was not fully done in narrow spaces sandwiched between the face-plates, because it was physically difficult to weld in narrow spaces at the time of fabrication. Crack damage found during this investigation all generated from such parts.

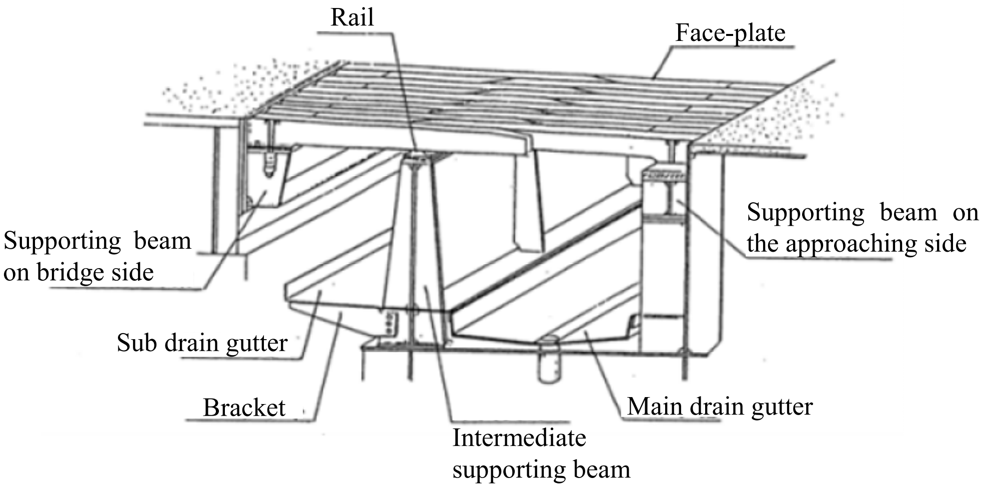


Fig.3 Structure of finger joint

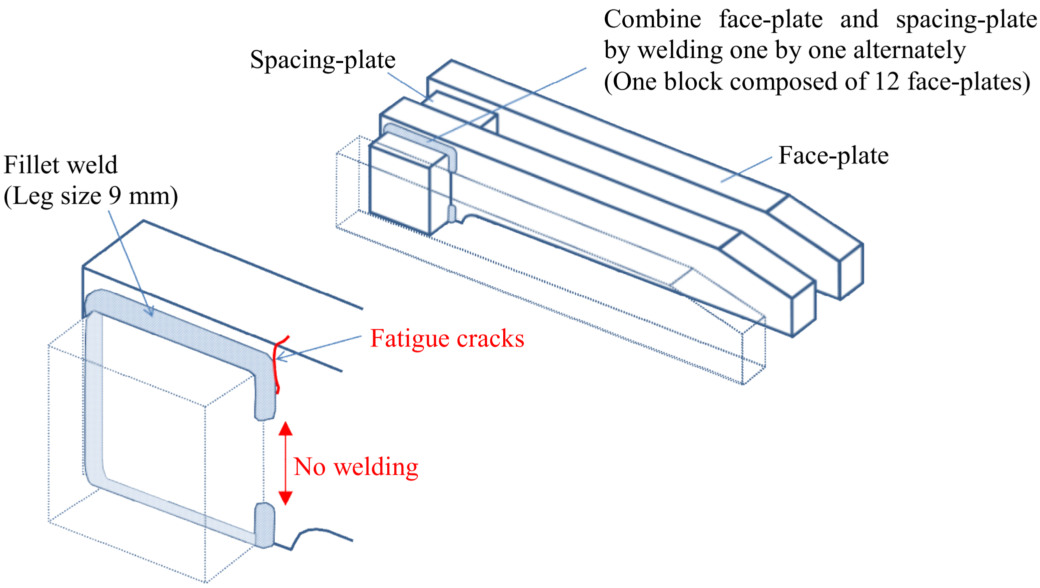


Fig.4 Weld structure of the face-plate block

Sequence of events so far

Fatigue cracks were found on the finger joint of Tsurumi-tsubasa Bridge for the first time during the inspection in 2004 (Fig.5). The cracks which could be observed visually generated from the parts welded to the root of the top surface of the face-plate. Subsequently, an emergency inspection was carried out for these parts, and approx. 80 cracks were found. As a countermeasure, removal of the cracks by machining and replacement of the face-plate blocks were implemented.

Since then, follow-up investigations and support for damages were carried out repeatedly, but a fracture of the face-plate occurred in 2010 (Fig.6). Fortunately, it did not affect traffic, because it was only one face-plate that fractured. The cause of this fracture was a new type of crack that generated from the corrosion part of the bottom surface of the face-plate (Fig.7). At that point, an emergency inspection was carried out against the corrosion part of the bottom surface of the face-plate and the same type of cracks generated from the corrosion part were found at approx. 10 points besides the fractured face-plate. This time as well, replacement of the face-plate blocks was carried out as a countermeasure.

Fig.5 Cracks from the root of the welded part of the face-plate found in 2004

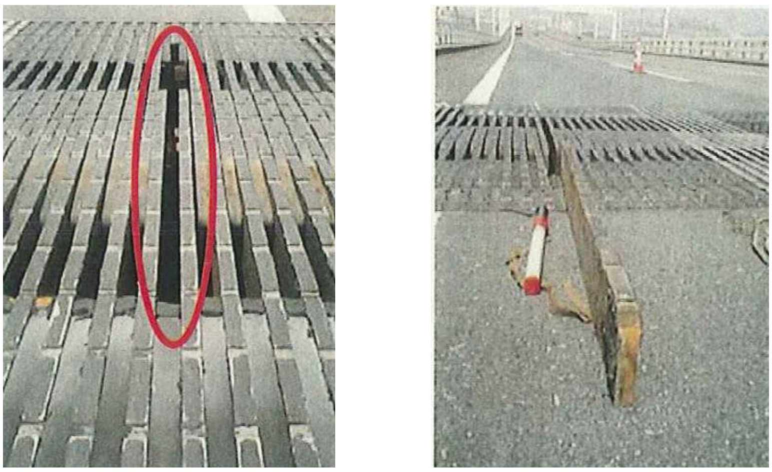


Fig.6 Fracture of the face-plate that occurred in 2010

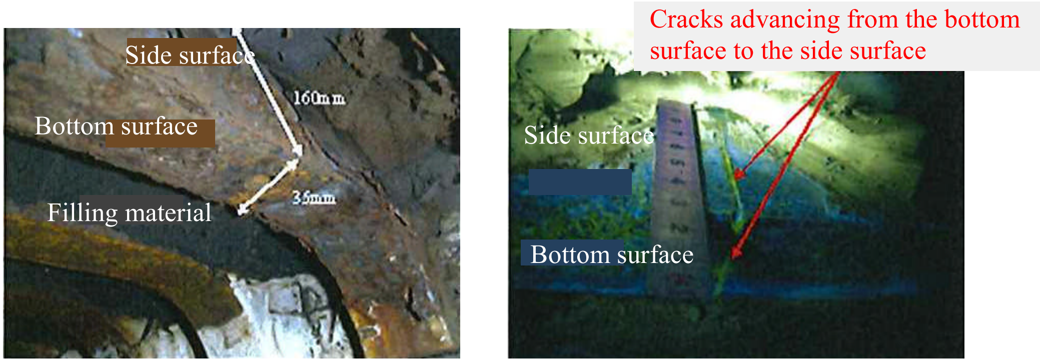


Fig.7 Cracks generated from the corrosion part of the bottom surface of the face-plate

Investigation of cracks

Content of investigation

In this follow-up investigation, magnetic particle examination for crack investigation was applied to the root of the top and bottom surface of the face-plates, where crack damages had been found up until then. Examinations were applied to all parts of welding done to the root of the top surface of the face-plates, except for those having been installed under the road shoulders, as well as the bottom surface of the face-plates where corrosion was remarkably serious and loading positions of the wheels of over-sized vehicles. In total, there were 1500 investigation points, including 1100 points on the top surface and 400 points on the bottom surface. Research status of the investigation is shown in Fig.8 and 9.

As for the corrosion of the bottom surface, it had not advanced or prevailed compared to the status when the inspection for the corrosion of the bottom surface was carried out two years ago, in 2010. This might be because cover plates on the bottom surface of the face-plates were removed during that inspection, and there was no place for water to gather.

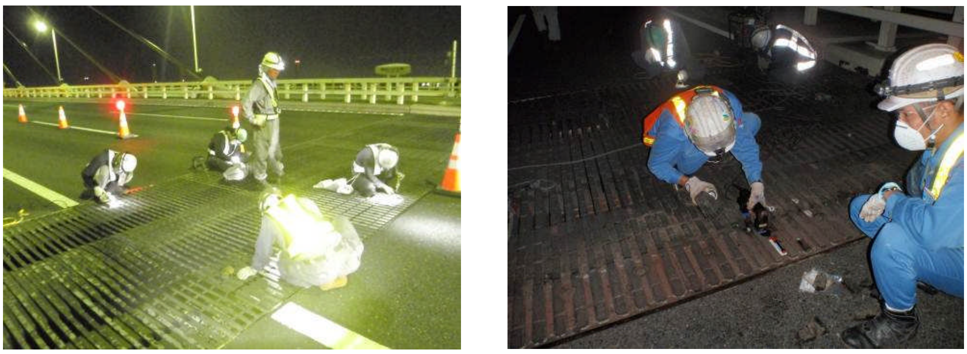


Fig.8 Research status of investigation for the top surface of the face-plate

Fig.9 Research status of investigation for the bottom surface of the face-plate

Results of the investigation

As a result of a magnetic particle examination conducted at 1500 points on the top and bottom surface of the face-plates, 140 cracks were found at the root of the welded part of the top surface. Genesis location of the cracks is shown in Fig.10 and the breakdown of the number of cracks is shown in Table.1. During this investigation, a flaw indicating pattern was not found on the bottom surface of the face-plates.

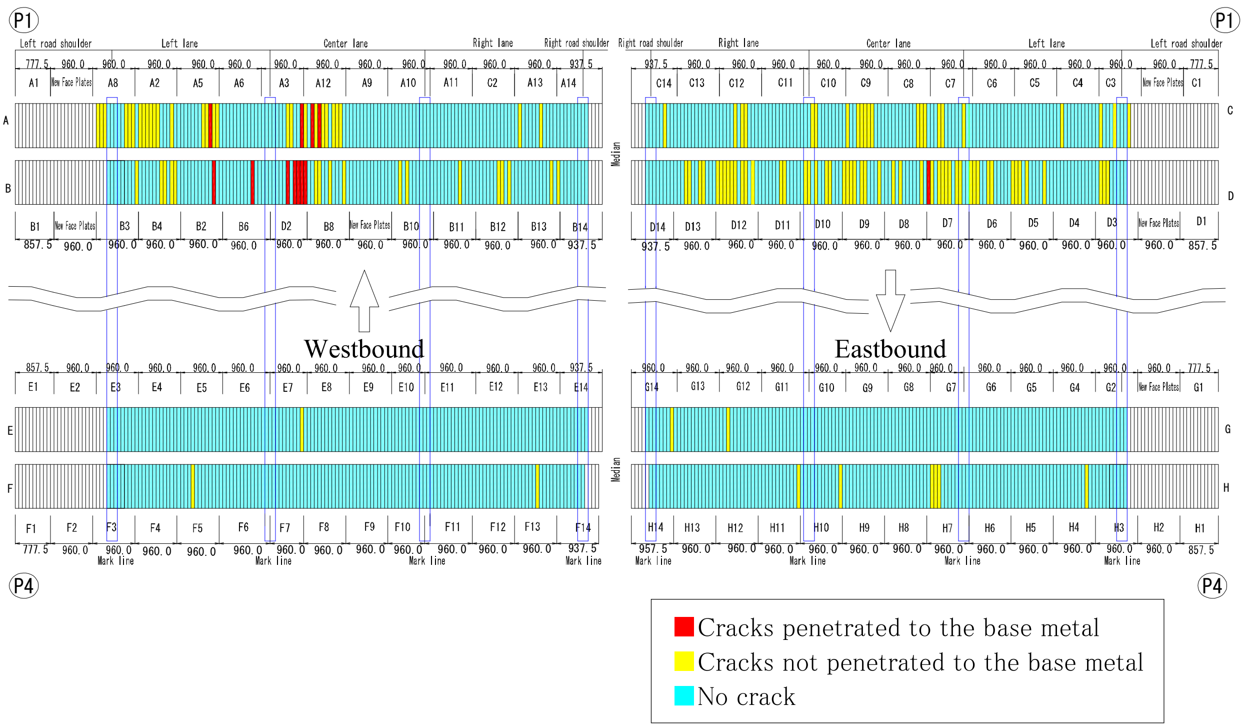


Fig.10 Genesis location of cracks

Table.1 Breakdown of discovered number of cracks

Place	Direction	Discovered number of cracks (Points)		Total
		Cracks penetrated to the base metal	Cracks not penetrated to the base metal	
P1	Westbound	11	45	56
	Eastbound	1	72	73
P4	Westbound	-	3	3
	Eastbound	-	8	8
Total		12	128	140

Most cracks which were found during this investigation generated at the finger joint on P1 pier. Of all 140 points, cracks penetrated to the base metal were found at 12 points, and cracks penetrated from the welded part of both sides of the face-plate to the base metal were found at 4 points, which could lead to fracture. The most severe damage is shown in Fig.11. As for the blocks of the face-plate with remarkably serious damages, they were replaced as an emergency measure by robust ones which had been installed under the road shoulders, and thereafter were replaced by newly fabricated blocks as a permanent measure.

In this investigation, an unprecedented number of cracks were found at 140 points, and it was confirmed that the number of cracks were continuing to increase. In particular, although substantial replacement of blocks had been carried out in 2010, more than 50 cracks were found at the face-plate blocks under the lane bound for west on P1 pier. So it is considered that the cracks in these places generated two to four years after the replacement. On the other hand, many cracks were found in other places where block replacement had not been carried out. Cracks also generated at the right lane where traffic of over-sized vehicles is light. This indicates exteriorization of accumulated damages at the finger joint of the Tsurumi-tsubasa Bridge, which has already passed 18 years since it was placed to service.

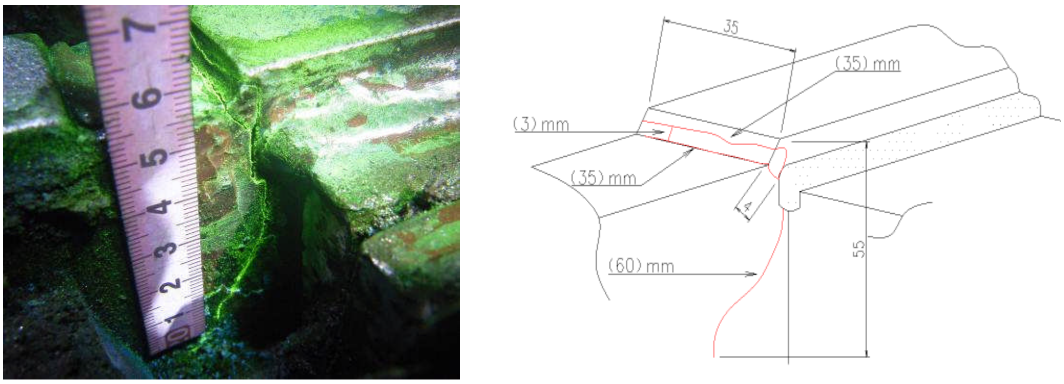


Fig.11 Cracks penetrated to base metal

Consideration

All cracks generated from the root of the welded part of the face-plate, and most of them generated from the weld toe. This type of crack tends to penetrate to the base metal if they remain untouched (Fig.12).

The finger joint on the P1 pier had an overwhelmingly larger number of crack damages compared to the P4 pier, which may be attributed to the difference of quality made by its fabricating companies. Furthermore, as abrasion was confirmed during the past inspections on the rail of the intermediate supporting beam installed under the face-plates, it can be considered that this abrasion is the cause of the increase of amplitude of the face-plates.

Focusing on traffic lanes, a large number of serious damage were found in the center lane among three. This may be because over-sized vehicles running at high speed on the center lane have recently increased.

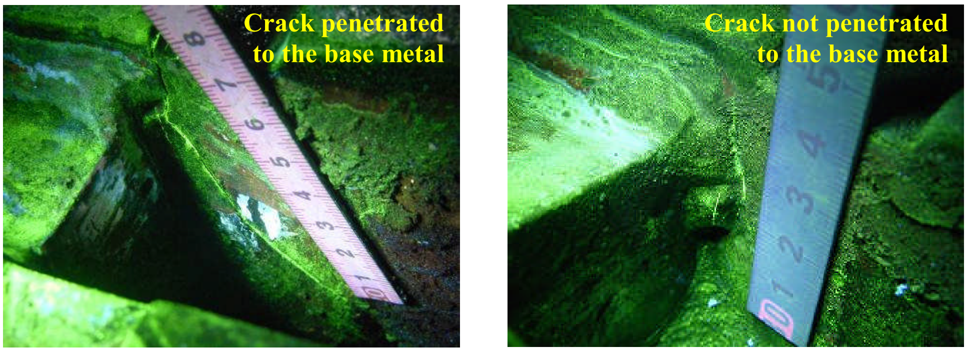


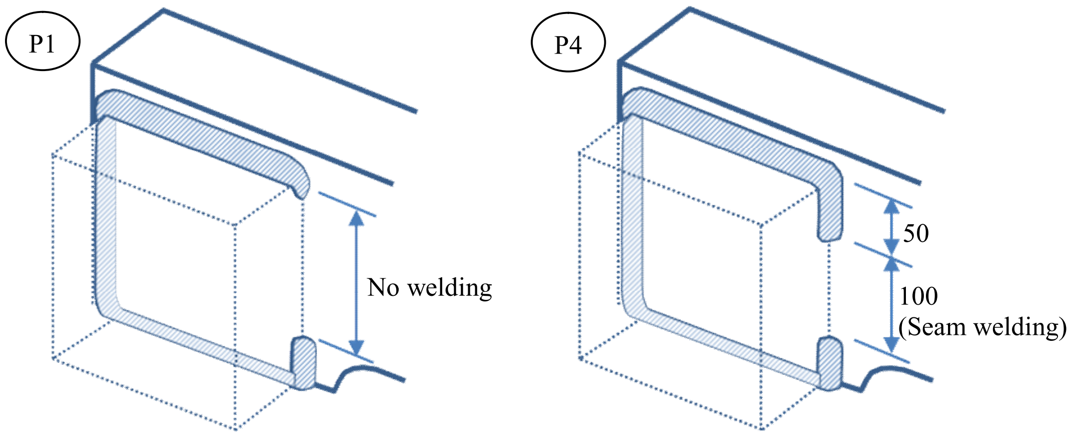
Fig.12 Cracks with (left) and without (right) penetration to base metal

Analysis of damage

Of all the 140 damages found during this investigation, 129 damages were found at the finger joint on P1 pier. By confirming detailed fabricating structure, difference of welding status of the finger joint on the two piers was identified, as shown in Fig.13, and an un-welded spot was left between face-plates on both piers. At the finger joint on P4 pier where there were few cracks, welding was done vertically within approx. 50mm from the corner of the spacing-plate. However, at the finger joint on the P1 pier where there were many cracks, welding was done only at the corner of the spacing-plate. Furthermore, finishing process or the weld toe on both piers was not conducted sufficiently. So, causing factors for the crack damages are considered as the following;

・ A breakpoint was installed in the weld structure with an overlapping joint, and of low fatigue durability.

- A start/end position of welding subject to damage was installed at the corner of the spacing-plate, a point of stress concentration where stiffness changes.
- Finishing process was not sufficiently provided at the weld toe.



Weld detail on the P1 side   Weld detail on the P4 side

Fig.13 Weld detail of the root of the face-plate

<u>Countermeasure for damages</u>

Of the140 crack damages found during this investigation, as for the 12 damages which penetrated to the base metal of the face-plate, an emergency measure by replacing the blocks by robust ones that are installed under the road shoulders, was rapidly carried out from the aspect of ensuring safety for vehicles, then a permanent measure of replacing them by newly fabricated ones was applied.

On the other hand, concerning the points of crack damages without penetration to the base metal, as the number of blocks amounted to 37, fabrication of new blocks was not realistic from the view point of period of production time and cost. Blocks were temporarily removed and replaced one after another, and weld repair was carried out within the factory, not targeting restitution but bearing in mind improvement of fatigue durability, considering the causing factors for the crack damages, as the following.

- Remove all crack damages by machining, and restoring by fillet weld ensuring enough length of bead.
- Leaving no insufficient welded places, not-welded and/or seam-welded
- Not to leave the start/end position of welding.
- Conduct finishing process for the welded toe.

Details of the weld repairing work are described as follows.

Weld in narrow spaces

Welding repair for crack damages was restored by re-weld, after weld bead of the cracks were completely removed by machining, and at the same time, insufficient welded places were restored by welding ensuring enough leg length of the bead. As for the welding work, the finger joint was fixed upright and a downward stance of welding which causes less flaw was adopted. Also, coated arc welding was implemented for narrow spaces using a longer weld rod than usual. The welding status restored by this process is shown in Fig.14, and the restored weld bead is shown in Fig.15. As for start/end position of the restored weld bead, a new bead was welded onto the existing one and then was removed by a grinder.

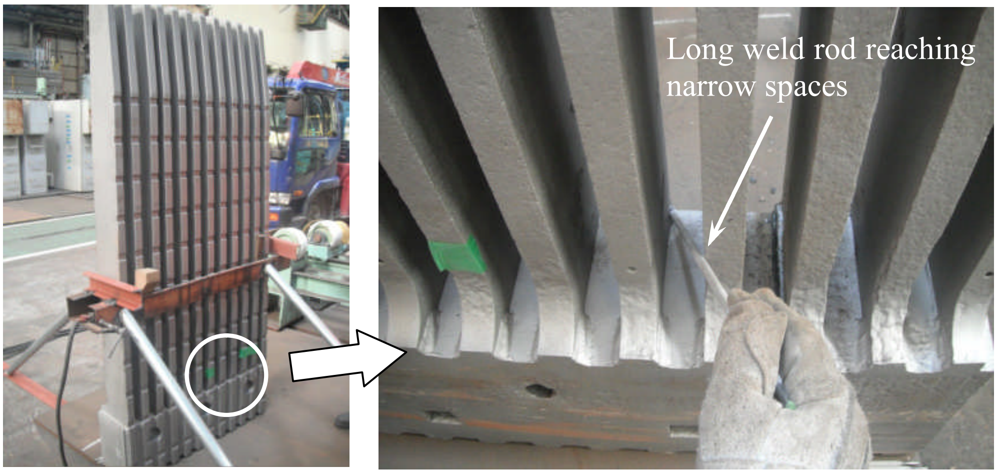


Fig.14 Working conditions and weld rod used for this work

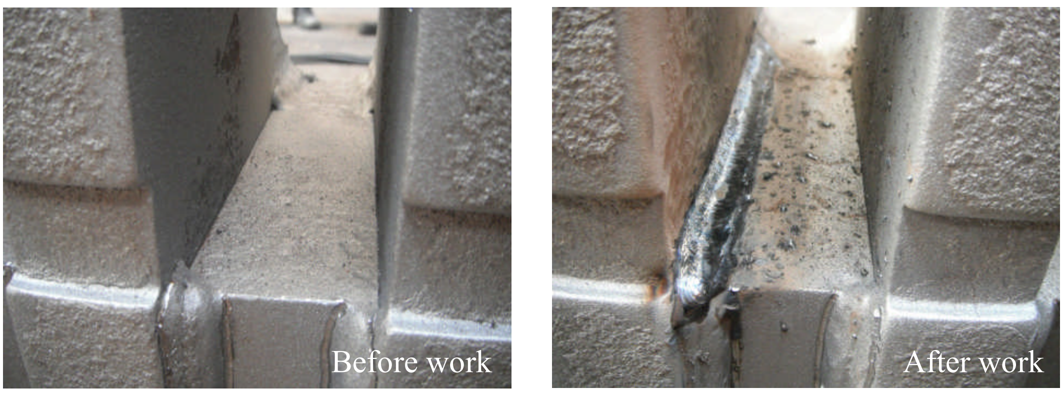


Fig.15 Restored status of welding for narrow spaces (before work, after work)

Process of weld toe

As for the processing the of the weld toe, welding start/end position in narrow spaces between the face-plates were finished by a grinder, and the scope within 50mm from the edge of the top surface of the spacing-plate was processed furthermore by peening. The status of processing the weld toe is shown in Fig.16.

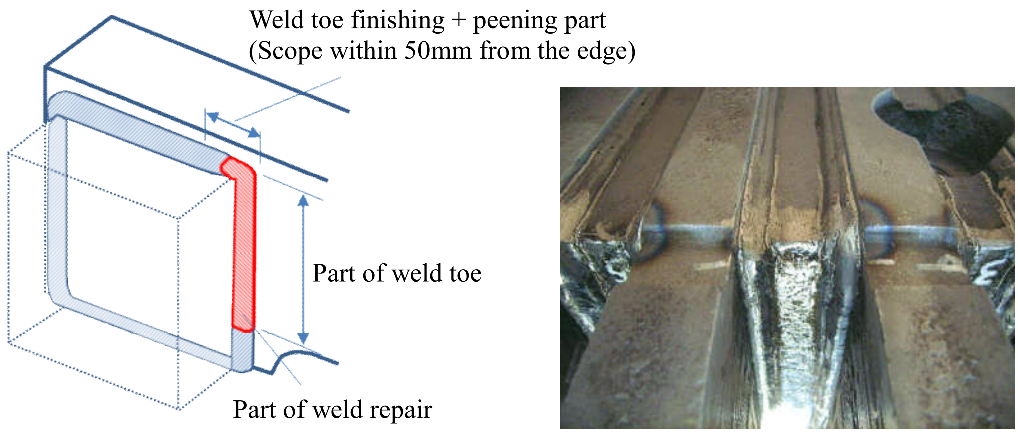


Fig.16 Status of processing the weld toe (final status)

Summery

Cracks of the face-plates which were found during this investigation generated from the welding point done to the root on the upper surface of the face-plate. Most cracks that generated from the weld toe tend to penetrate to the base metal over time.

Cracks on the face-plate were found more on P1 pier. As the length of the welded part of the root was different between on P1 pier and on P4 pier, it is considered that this is attributed to the difference of weld detail in time of fabrication.

In this investigation, cracks from the bottom surface of the face-plate were not found. The reason is considered that corrosion had not proceeded since the cover plate was removed from the bottom surface of the face-plate during the temporary inspection in 2010.

A countermeasure for crack damages generated in the finger joint was examined according to the degree of damages and a corresponding policy was determined. As for the blocks where cracks penetrated to the base metal, they were replaced by newly fabricated ones, because re-use of existing blocks was impossible. On the other hand, blocks without penetration to the base metal were temporarily removed, then weld repair was carried out at the factory, considering economical efficiency. In repairing the blocks, a welding method was devised in consideration for the improvement of fatigue durability and such possibility was confirmed.

Conclusion

This follow-up investigation was carried out two years after the last investigation in 2010. As some critical damages were found this time, it was a significant result to discover damages of the face-plates before they might fracture.

The Metropolitan Expressway is now implementing a weld repair for these damages. It is considered that fatigue durability of the existing face-plates will be improved if an appropriate weld is applied, even if the face-plate is a re-used one. The weld repair has been completed approx. up to 60% at the end of August 2013, and the entire work is scheduled to be completed by the end of the year.

However, as for the finger joint on the P4 pier, its quality is relatively high, but it cannot be said that no damage has been caused until now, so periodical inspection is scheduled to be conducted after the repair.

Acknowledgments

We especially thank all members related to the maintenance management in the Metropolitan Expressway Co., Ltd. for their appropriate advice and guidance as well as their support throughout the entire process to complete this paper.