Japan's Infrastructure Situation and Peening

Proposal of Pre-post Fatigue Crack Maintenance that Can Be Carried out during Repainting Process on Existing Steel Bridges

Fukuoka University Koji Kinoshita, Gifu University Yuki Banno
Yamada Infra Technos Co., Ltd. Shohei Yamada, Motohiko Tsuruta
Toyoseiko Co., Ltd. Yoshihiro Watanabe

1. Background

The aging of infrastructure, particularly steel bridges constructed during Japan's period of rapid economic growth (1955-1973), is accelerating and has become a pressing social issue. According to infrastructure maintenance data published by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), of the approximately 730,000 road bridges (with a length of 2 meters or more) whose construction year is known, it is estimated that around 30% will be over 50 years old by March 2020, about 55% by March 2030, and approximately 75% by March 2040[1]. MLIT's estimates indicate that, for infrastructure under its jurisdiction, total maintenance costs over a 30-year period could be reduced by about 30%[2]. "Preventive maintenance" is projected to cost approximately $1.2 to $1.3 trillion, compared to $1.7 to $1.9 trillion for "post-defect maintenance." In response to this situation, MLIT highlighted the importance of shifting toward preventive maintenance in their 2024 New Year's address.

This paper presents a case study involving both post-defect and preventive maintenance of fatigue cracks on an existing steel bridge under MLIT's jurisdiction. Fatigue cracks identified during the repainting process were addressed through post-defect maintenance using needle peening, while shot peening was applied as a preventive measure in areas without cracks. Based on the results of this case study, a series of processes necessary for future infrastructure maintenance is proposed.

2. Current situation and issues of bridge maintenance

The main repair methods for fatigue cracks as post-defect maintenance have been rewelding and reinforcement using bolted steel plate joints. These methods have proven effective for repairs. However, similar welded joint details where no fatigue cracks have yet been observed could potentially have new cracks in the future unless preventive maintenance is carried out. In fact, in the case of the existing steel bridge discussed in this paper, reinforcement using bolted steel plate joints was carried out in 2017, but new fatigue cracks were found during construction in 2023, highlighting the need for fundamental preventive maintenance measures rather than relying solely on post-defect maintenance. Reinforcement using bolted steel plate joints is typically used in urgent cases where cracks have progressed to the base material. Therefore, applying this method to cracks that are in their early stages and have not yet affected the base material may be considered an excessive repair. Streamlining post-defect maintenance will allow for better allocation of budget to preventive measures, ultimately reducing the Life Cycle Cost (LCC) of maintenance (Fig.1).

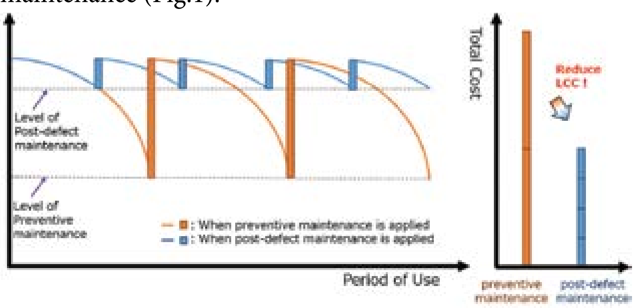

Fig.1 Reducing LCC of maintenance

3. Overview of bridge construction projects

3.1 Target bridge

The bridge targeted in this paper is shown in Fig.2, and its specifications are listed in Table 1. The bridge was constructed in 1974, approximately 50 years ago, and is part of a regional expressway. It is a heavy traffic route with frequent trailer traffic, and fatigue damage has been confirmed.

3.2 Construction history

Fatigue cracks were not detected until the 2014 inspection, during which cracks rated as S1 (requiring further

Fig.2 Bridge appearance

Table 1 Bridge specifications

	SPECIFICATIONS
Year of completion	1974
Name of road	National Route 1
Regulations applicable to superstructures	Specifications for highway bridges (1972)
Length of bridge	46 m
Width of bridge	18.4 m
Superstructure	Steel I-girder

investigation[3)]) were identified. In 2017, fatigue cracks were confirmed by magnetic particle testing (MT) and repaired using bolted steel plate joints. In the 2019 inspection, no new fatigue cracks were found, although corrosion and a decline in corrosion prevention function were observed.

3.3 Construction overview

Following the 2019 statutory inspection, repainting work was conducted in 2023 to restore corrosion protection. During the work, cracks were found on the paint, suggesting possible damage to the base metal. After blasting off the paint, MT revealed fatigue cracks. As shown in Fig.3(a), seven new fatigue cracks were identified. They were located at welded joints similar to those reinforced with bolted steel plate joints in 2017 where no cracks had been found at that time. The cracked joints, shown in Fig.3(b) and 3(c), were at intersections of main girders with cross beams or lateral bracings. These areas are prone to fatigue due to stress from differential deflection between girders and deck plates[4)]. Because the bridge has many similar details where cracks have previously occurred, MLIT requested not only post-defect maintenance for the cracked areas, but also preventive maintenance at similar locations without cracks to prevent further fatigue damage.

3.4 Proposed post-defect and preventive maintenance methods during repainting construction

In this paper, post-defect maintenance without the use of bolted steel plate joints and preventive maintenance were proposed and implemented:

- As a post-defect maintenance measure, crack closure treatment using portable pneumatic needle peening* (PPP) was proposed to suppress fatigue crack propagation. A PPP device developed by Toyo Seiko was used for the treatment, as shown in Fig.4.
- As a preventive maintenance measure, a shot peening method was applied to improve the fatigue strength of welded joints with the same shape as those where cracks had occurred. A circulating shot peening method* (Fig.5), which can be applied in parallel with repainting work, was used.

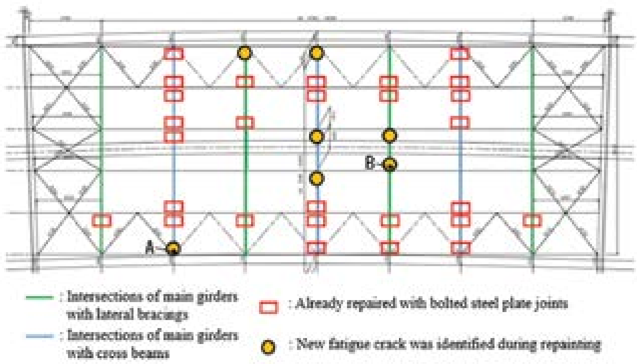

Fig.3(a) Found fatigue cracks during blast

Fig.3(b) Fatigue crack (main girders with cross beams)

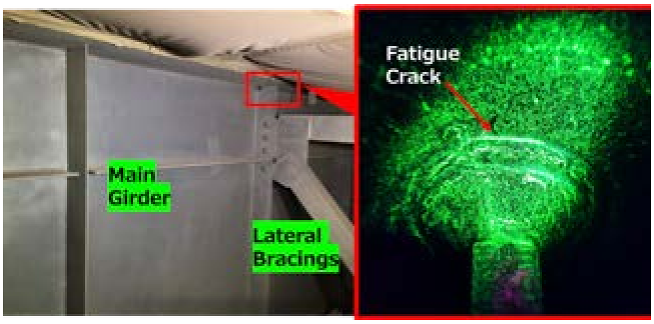

Fig.3(c) Fatigue crack (main girders with lateral bracings)

Fig.4 Portable pneumatic needle peening device

**Note: The portable pneumatic needle peening device is a patented product developed by Toyo Seiko in Japan (No.5719032). The circulating shot peening method is a patented technology of Yamada Infra Technos Co., Ltd., registered in Japan (No.6304901, No.6501718), the United States (US 11,959,148 B2), and South Korea (10-2025-0019722).*

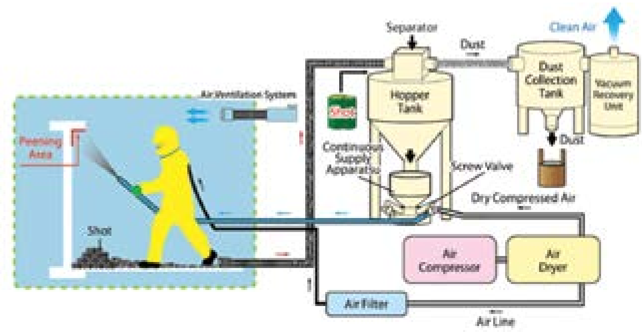

Fig.5 Circulating shot peening method

4. Post-defect maintenance for cracked areas

4.1 Comparison of crack closure treatment with conventional methods

Post-defect maintenance methods for fatigue cracks are summarized in Table 2. Conventional techniques include:

- grinding out small cracks using a grinder.
- installing bolted steel plate joints to bypass stress at the crack location.

Table 2 Post-defect maintenance methods for fatigue cracks

	Conventional technology		New technology
	Rotary Grinder	Bolted Steel Plate	Portable Pneumatic Needle Peening (PPP)
Feature	Cracks that have occurred from weld toes are removed by cutting, and the shape is made smooth to reduce stress concentration.	Bolted Steel Plate is bolted steel plate using high-strength bolts to bypasses the stress at the fatigue crack location.	A portable pneumatic needle peening device is used to strike and close microscopic cracks found at the weld toes.
Constructability	The work requires personnel skills, because it must be carried out under vibration caused by the traffic load. It is difficult to access the narrow areas because of device size.	Sufficient space is needed to install the bolted steel plate and tighten the bolts. On-site drilling of holes is required.	The system can apply a constant impact force to the target area with a certain degree of flexibility in the construction angle, allowing access to narrow areas. Moreover, the device enables stable operation regardless of the operator's skill level. It is also equipped with a vibration-absorbing mechanism that reduces the risk of vibration-related disorders for the operator.
Number of constructions possible per day[*1, *2]	8 Location/day	3.3 Location/day	**23.9** Location/day
Cost[*1, *2] (per location)	$161	$706	**$50**

*1) Calculation are based on NETIS(MLIT's New Technology Information System) unit price data
*2) Calculated at 150 yen/1 dollar

Grinding requires a high level of operator skill to avoid over-grinding and cannot be applied in tight spaces where access is restricted. Installing bolted joints takes time from crack detection to installation and tends to increase the cost per repair location. Furthermore, on-site drilling is required with strict tolerances, posing a risk of cross-sectional loss in structural members.

4.2 Methods implemented in this paper

The needle peening method proposed in this paper closes fatigue cracks by inducing plastic flow and generates compressive residual stress. The system uses a 60 mm-long needle pin with a tip curvature radius of 1.5 mm, enabling access to narrow areas such as scallops. Moreover, the device is equipped with a control box that regulates compressed air flow to control the needle impact force, allowing stable operation regardless of the operator's skill level. When applied to fatigue cracks that have not yet reached the base metal, this method can extend the fatigue life of the component by a period equal to or longer than the time it took for the crack to form as shown in Fig.6[5)]. In this construction, since the cracks had not progressed to the base metal, the method provided advantages in both construction speed and cost. By adopting this technique, fatigue cracks can be repaired quickly and cost-effectively, enabling efficient and effective post-defect maintenance.

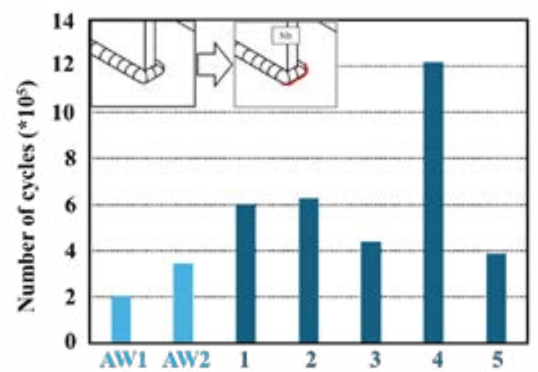

Fig.6 Effect of PPP treatment [5)]

4.3 Implementation procedures

The construction process is shown in Fig.7. The locations and extent of the cracks were identified in advance using MT. Before the treatment, the areas to be peened were marked with a special pen-type highlighter (PEENSCAN PEN 220-6) from Electronics Inc. to visually confirm whether the treatment had been properly applied. Peening was performed on the crack area, within ±2 mm of the crack line, and a black light was used to detect any untreated regions. As shown in Fig.6, this method is expected to be highly effective in extending the service life of structures by repeatedly striking and closing fatigue cracks[5)]. If any untreated areas were found, the cracks were retreated to ensure complete closure. Finally, penetrant testing (PT) was conducted to confirm that all treated areas had been fully closed.

Fig.7 Crack closure treatment status

5. Preventive maintenance for areas where fatigue cracks are expected to occur

5.1 Circulating shot peening process

Preventive maintenance methods for welded joints to avoid fatigue cracks generally fall into two categories:

- inducing compressive residual stress to counteract tensile residual stress
- relieving structural stress concentration

In this paper, the circulating shot peening method was adopted to introduce compressive residual stress into welded joints and thereby improve fatigue strength. The circulating shot peening method utilizes the same circulating blast method® used during repainting for paint removal. By replacing the abrasive media with conditioned cut wire conforming to JIS G 0951, and using existing scaffolding and protective equipment, this method can be implemented efficiently. It is an environmentally friendly maintenance technology for existing steel bridge welded joints, enabling the recovery and reuse of shot. This method is less dependent on operator skill than grinder finishing, and consistent construction quality can be achieved by managing the shot and peening conditions. Fatigue test results[6)7)8)] on out-of-plane gusset welded joints show that this method improves fatigue strength from FAT50 to FAT90, according to the classification defined by the International Institute of Welding (IIW) as shown in Fig.8. These results satisfy the fatigue design curves proposed for HFMI treatment in the IIW recommendations[9)].

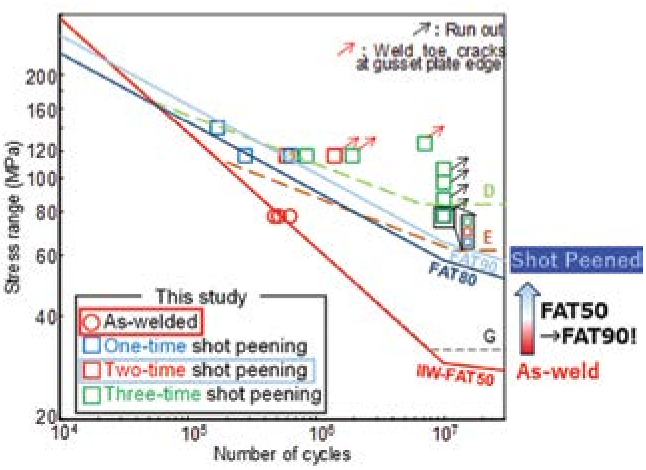

Fig.8 Fatigue test results of shot peening 6)7)8)

5.2 Implementation procedures

The construction process is shown in Fig.9. Before shot peening, a fluorescent tracer was applied to the target areas. After peening, coverage was inspected using UV-CC (Coverage Checker, UV light version) manufactured by Toyo Seiko. The advantage of UV-CC is that it enables accurate coverage measurement even in low-light environments. The inspection process is shown in Fig.10. Shot peening was

Fig.9 Circulating shot peening method status

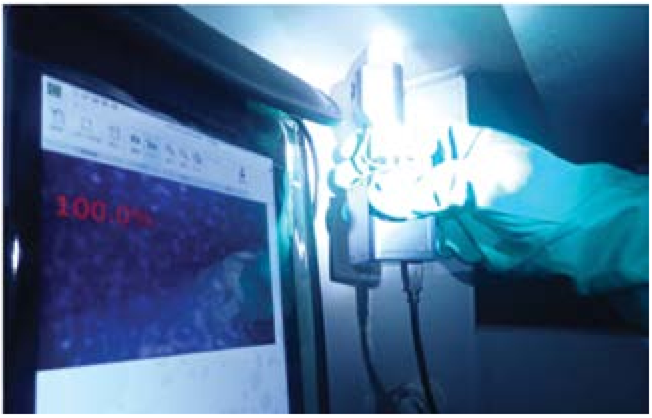

Fig.10 Inspection with UV-CC

carried out under treatment conditions (a coverage rate of 90% or more and a nozzle speed of 72 seconds per meter (Table 3)) that satisfy the fatigue test results shown in Fig.8.

Table 3 Condition of shot-peening

Inner diameter of nozzle	8mm	
Degree of rust	ISO Sa2.5	
Shot	RCW10PH	
	Hardness	600HV
	Diameter	0.8–1.0 mm
Compressed air	Over 0.6 MPa	
Shot coverage	Over 90%	
Shot distance	5–10 cm	
Nozzle angle	60-80 degree	
Shot flow	7 kg/min	
Roughness	Under 80 µm	

As of the end of April 2025, the implementation record for the Portable Pneumatic Needle Peening and Circulating Shot Peening methods by Yamada Infra Technos Co., Ltd. is as follows:

- Portable Pneumatic Needle Peening
  Total: 5 projects
  MLIT projects: 4
  Expressway company projects: 1
- Circulating Shot Peening Methods
  Total: 29 projects
  MLIT projects: 15
  Expressway company projects: 7
  Local government projects: 6
  private contractor projects: 1

7. Summary

Reinforcement with bolted steel plate joints has been a widely adopted post-defect maintenance method for repairing fatigue cracks in steel bridges. Alternatively, the simpler repair method presented in this paper can be applied to cracks found during repainting work, helping to bridge maintenance costs. The effectiveness of the crack closure treatment can be verified through statutory inspections conducted every five years. This approach allows post-defect maintenance costs to be reallocated toward preventive maintenance thereby further promoting a shift to preventive maintenance practices. The post-defect and preventive maintenance methods described in this paper are expected to be applied to other bridges in the future.

1) "Current and Future of Aging Social Capital", Infrastructure Maintenance Information, MLIT, https://www.mlit.go.jp/sogoseisaku/maintenance/02research/02_01.html, 10 Apr 2025. (In Japanese)
2) MLI : MLIT Infrastructure Life Extension Plan (Action Plan), 2021. (In Japanese)
3) MLIT: MLIT Road Inspection Manual, 2024. (In Japanese)
4) Chitoshi Miki et.al.: Repair of Fatigue Damage in Cross Bracing Connections in Steel Girder Bridge, Structural Eng, vol.6, No.1, 31s-39s, pp.53-61, 1989.3.
5) Koji Kinoshita et.al.: Fatigue Strength Improvement and Fatigue Crack Closure by Portable Pneumatic Needle-Peening Treatment on Welded Joints, International Journal of Steel Structures, Vol.19, No.3, pp.693-703, 2019.
6) Koji Kinoshita et.al.: Application of Shot Peening for Welded Joints of Existing Steel Bridges, Welding in the World, Vol.64, pp.647-660, 2020.
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