ASSESSMENT OF THE INTEGRITY OF STEEL RAILROAD BRIDGES RENEWED WITH POLYMER CEMENT AFTER 10 YEARS

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Renewal of a steel railroad bridge using polymer cement and fast-strength lightweight concrete has been proposed. This is referred to as the renewal of an existing steel railroad bridge with composite construction. This enabled a reduction in stress amplitude and a longer service life of more than 50 years. At the same time, a reduction of about 10 decibels in noise and vibration was achieved, improving environmental compatibility. This renewed structure was actually applied to a steel railroad bridge in Japan 10 years ago. This steel railroad bridge is the Kawashima overpass of Sagami Railway in Yokohama. After the renewal construction, the bridge has continued to be used under heavy traffic in Japan and is still in service 10 years later. This report describes the condition of this steel railroad bridge after 10 years and investigates the durability of this renewed structure. This report proves that this renewal structure is effective.

Keywords: Railway steel bridge, Hybrid Structure, Composite revamping, Durability.

1 INTRODUCTION

Many of Japan's railroad bridges are past their design life but continue to be used under their current conditions. Steel bridges on main lines may be renewed, but existing structures on local lines with low profitability are required to extend their service lives at the lowest possible cost. On the other hand, steel bridges for railroads often have open grating structures without floor plates, and in addition to the noise caused by the steel members, acoustic noise generated by the rails (rolling noise) and the vehicle itself is directly transmitted to the outside, resulting in higher vehicle noise when trains pass than on other road bridges or concrete bridges (Hansaka et al. 2007).

As a countermeasure to extend the service life and reduce the noise level of such structures, we have investigated the use of composite structures for existing steel bridges. Composite structuring is performed to prevent corrosion of existing steel girders, to improve beam stiffness, to reduce stress amplitude during response to acting forces, and ultimately to extend fatigue life. In addition, acoustic noise caused by steel members can be reduced at the same time.

2 SUMMARY OF HYBRID STRUCTURE

Figure 1 provides an overview of the composite structuring proposed in this study. We propose it from the viewpoint of constructability to prevent corrosion of existing steel bridges and minimize its effects. This composite structuring is characterized by the fact that no drilling or welding is required. The following new mechanisms are used in this structure: (1) rubber latex mortar (for covering), (2) FRP formwork (for burial), and (3) fast-hardening lightweight concrete (for floor slab). These mechanisms were used for the following purposes:
Rubber latex mortar (for application) (Taniguchi et al. 2009)
* Compositing of concrete and floor slabs.
* Corrosion prevention of steel frames.
* Low noise of bridges.
* Reduction of maintenance costs.

FRP foam (for burial)
* Easier construction
* Reduced dead load weight

Fast hardening lightweight concrete (for floor slabs)
* Improved stiffness by compositing
* Lighter dead load
* Short construction period while in service
* Noise reduction

Rubber latex mortar refers to mortar mixed with a rubber latex additive. It is a material used in waterproofing structures. Its adhesion strength to concrete and steel is high performance. Typically, an adhesion strength of about 5.0 N/mm² is obtained at 7 days of material age. In the past, a structure in which this material is cast on steel slabs has been proposed as a fatigue prevention measure for steel slabs of road bridges. In this composite structure, prevention of corrosion deterioration and compositing with concrete slab will be achieved by these excellent performances. Furthermore, it has been confirmed that the adhesion of rubber latex mortar to steel members can reduce noise and vibration. The Young's modulus of rubber latex mortar is about 2.00 x 10⁴ N/mm².

In recent years, FRP has also been widely utilized; FRP is known for its light weight and high strength. Therefore, in this structure in service, it is necessary to keep the increase in dead weight due to construction to a minimum, and GFRP, which meets the strength requirements and is economically advantageous, was used as the buried type. GFRP is also lightweight and easy to cut and otherwise process. Therefore, the use of these materials is very advantageous for this structure.

The quick-hardening lightweight concrete is a material that ensures the required strength in a short time, assuming construction during the time when the railroad is out of service. It is also a material that can reduce dead loads, achieving a unit mass of approximately 2.03 kg/L and a Young's modulus of approximately 2.30 x 10⁴ N/mm². In addition, the concrete of this slab was arranged with a grid of reinforcing bars to prevent cracking.
3 CONSTRUCTION PROCEDURE CONFIRMATION TESTS

Confirmation tests were conducted using actual test beams (Figure 2):

1. Coating removal (daytime work)
2. Installation of rubber latex mortar (nighttime work)
3. Installation of FRP formwork and lattice rebar (daytime work)
4. Installation of quick-hardening lightweight concrete (nighttime installation)

In these construction tests, the time required for installation was measured in order to examine whether the construction method is suitable for nighttime work on railroads. The results showed that each of the nighttime operations could be divided into one-hour operations, and the mortar could be cured in three hours, which was safe enough for composite construction.

Figure 2. I-section beam for railway. Figure 3. The spraying operation.

3.1 Construction Work of Coating with Rubber Latex Mortar

Mortar coverage with rubber latex mortar was applied by a thickness of 5 mm. This thickness was determined from existing studies based on durability and workability. Without moving the bridge, the coating was applied using a sprayer by nighttime construction during train service suspension (Figure 3). The mortar was sprayed to a thickness of at least 5 mm, using a technique that divided the spraying into several parts. This installation required the experience and skill of the operator. The sprayed mortar was measured for thickness at several locations to ensure that all measurements were within acceptable limits. This quality control is critical for durability and stiffness.

According to preliminary plans, the work time was simply 4 hours for spraying alone. This work time could not be completed within the time frame envisioned for night work on the railroad. However, it was confirmed that the work could be completed within the allotted time by using multiple sprays or by dividing the work area into several sections and performing the work in stages. The compressive strength of the rubber latex mortar used for spraying is 24.9 N/mm² (after 1 day) and 33.1 N/mm² (after 7 days), and the bond strength is 3.0 N/mm² (after 1 day) and 4.6 N/mm² (after 7 days).

3.2 Installation of FRP Forms and Grid-pattern Reinforcing Bars

Figure 4 shows a buried formwork made of FRP, which was divided and fitted into sections. In this construction, the panels were divided into seven sections, and the bridge structure and FRP were glued together using methacrylate resin (curing time: 90 minutes). This adhesive is also expected to function as waterproofing during concrete placement. On railroads in service, sleepers
and tracks exist above bridges. Therefore, FRP formwork and lattice rebar were brought in from the bottom of the bridge in order to be constructed as daytime work under these conditions. In other words, this indicates that the work was devised so that it could be performed without moving the sleepers and tracks. These innovations ensured that the work could be easily performed during daytime train operating hours, rather than at night when trains are suspended. The GFRP material used in this study has a tensile modulus of elasticity of 18.4 N/mm² and tensile strength of 334 N/mm² (Japan Industrial Standard: JIS K 7164), flexural modulus of 14.9 N/mm² and flexural strength of 366 N/mm² (Japan Industrial Standard: JIS K 7017), and a theoretical deflection value of approximately 2.5 mm during concrete installation.

3.3 Casting of Quick-hardening Lightweight Concrete

Care was taken to ensure that the concrete placement work, which was performed at night, could be completed in approximately 1 hour. During the four hours before the first train, the concrete was able to reach a compressive strength of 17.7 N/mm². At this strength, the concrete was strong enough not to crack when the train passed. This proves the safety of the composite structure. Since the rate of strength development can be adjusted for this material, this casting test can be applied to nighttime construction of railroads. On the other hand, this concrete is known to exhibit expansion behavior of approximately 250μ at material age of 28 days after shrinkage, and it also functions to prevent cracking.

3.4 Tests to Confirm the Rigidity Increase Effect

In order to confirm the degree of stiffness improvement due to the composite construction, loading tests were conducted on the bridge by train (Figure 5). Loading tests were conducted before and after the composite construction. The tests were conducted six months after the concrete was placed, a time course that ensured adequate train passage on the bridge and stability of the structure. The validity of the test results was verified by the close agreement between the measured and theoretically calculated values. The average of the measured values (after composite construction) showed higher stiffness than the theoretical values for the steel frame only. This can be considered from previous experimental results that the concrete floor slab behaves as a composite structure (Lin et al. 2017).

Regarding the effect of this construction on the stiffness increase, a factor of 1.5 was shown. For steel structures, it is known that the service life is calculated based on the degree of fatigue damage accumulation. According to this theory, the life of a structure is proportional to the cube
of the stress amplitude. Therefore, applying this theory to the stiffening effect of this study proves that the life of the structure can be increased by at least a factor of three. This shows that this construction had a significant effect on extending the service life of the structure.

4.2 Impact Test (Confirmation of the Effects of the Composite Structuring)

This structure is also expected to reduce noise and vibration. To understand the effects of noise and vibration, the authors conducted impact tests. Vibration and noise accelerograms were measured. Accelerometers were placed in the center of the bridge span, at the center of the web. The sensors were installed because noise and vibration are known to be higher at this location. Measurements were taken by allowing actual trains to pass through. Figures 6 and 7 show the average values of the measurements on the y-axis, calculated with $10^{-5}$ ms$^{-2}$/N as 0 dB, and the frequencies per 1/3 octave band on the x-axis.

![Figure 6. Results of impact tests (Vibration).](image1)

![Figure 7. Results of impact tests (Noise).](image2)

Figures 6 and 7 show that the measures reduce vibration levels by about 10 to 35 dB and all-pass (AP) values by about 30 dB. In past tests conducted by the authors using only specimens coated with rubber latex mortar only, it was confirmed that the noise level was reduced by about 10 dB. These results indicate that the noise and vibration reduction effect of this measure is very effective, and that this construction can contribute to environmental measures.

5 DURABILITY AFTER 10 YEARS

The bridge on which this work was performed has been in service for 10 years under heavy traffic in central Yokohama, Japan. In order to verify the durability of the structure under these conditions, we conducted a detailed investigation of the structure (Figure 8). As a result of this detailed investigation, the structure was found to be free of delaminated mortar, cracked concrete, damaged FRP formwork, and leaks (Figure 9). Therefore, it was confirmed that the durability improvement and noise reduction effect brought about by this structure are still maintained in the present condition. Further investigation is planned to confirm the durability of this structure.
6 CONCLUSIONS

From this paper, the following conclusions were drawn:

(1) This composite construction method is intended for use on bridges in service. With every possible measure, sufficient curing time can be ensured for the concrete and mortar. In other words, daytime and nighttime work can be combined appropriately to complete the work safely in a short period of time.

(2) Experimental studies have shown that this construction method was effective in reducing noise levels by approximately 15 dB. Thus, the effectiveness of this technology as a countermeasure against noise generated by structures was confirmed. The effectiveness of this construction as an environmental countermeasure within the city was proven.

(3) Tests during train running showed that the subject bridge increased its remaining service life by a factor of three by using this construction method. This significantly increased the remaining service life of the aging steel railroad bridge. This construction method is also beneficial as a maintenance management measure.

(4) This improvement method is still sound after 10 years, proving that it is sufficiently durable.

References


