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Preventive maintenance on welded connection joints in aged steel railway bridges

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ABSTRACT

Structural repairing or maintenance technique has been a hot issue in recent years due to the increasing aging problems of old railway bridges. A strengthening method for welded joints in old steel railway bridges by integrating the rapid hardening concrete, rubber-latex mortar, and reinforcing bars is introduced in this paper. The purpose of the present study is to investigate the mechanical performance of the strengthened connection joints in old steel railway bridges. Depending on the locations of the concrete and possible loading conditions, the joint needs to sustain both negative and positive bending moment, therefore, two experimental plans were employed. The static loading tests on the steel joints before and after strengthening were performed to confirm the effects of the present strengthening method. Moreover, three-dimensional FE models were built to make a comparison study between the strengthened and original steel joints. Load versus deflection relationship and strain development process on the web of the joints were measured and compared between the original joints and the strengthened joints. Both experimental and numerical results indicate that the present strengthening method can greatly enhance the stiffness and reduce the stress levels of steel joints, resulting in the extension service life of aged steel railway bridges.

1. Introduction

In Japan, the construction of new steel bridges has been decreasing. On the contrary, old bridges have been increasing rapidly, and it has been reported that in 20 years, a half or even more of the existing bridges with a span exceeding 15 m were predicted to be over 50 years old [1]. It was also reported that more than 60% of the railway bridge stock in Europe was over 50 years old and more than 30% was over 100 years old [2]. These bridges are subjected to higher loads and speeds than those for which they were designed. To satisfy the present and future demands, some bridges are in need of strengthening or replacement. Meanwhile, due to their high transport capacity and effective use of energy with lowest damage to the environment, railways are one of the most important means of transportation in the world, in which steel bridges have been widely used. After tens of years' service, many of steel railway bridges become old and need to be strengthened integrally for the whole bridge or repaired locally for certain steel members. Considering the relatively high cost for replacing or strengthening integrally, as well as the great impact on the public transportation, preventive maintenance on the old steel members is an effective way.

In recent years, engineers all over the world have been working on repairing or strengthening of old steel railway bridge structures. Wallin et al. [2] investigated two different strengthening methods for a through-girder steel railway bridge (Soderstrom Bridge) in the city of Stockholm, Sweden. Experimental and numerical investigation was performed by Lin et al. [3,4] on an old steel railway bridge which had been used for 100 years in Japan. The results demonstrate that the use of rapid hardening concrete, GFRP, and reinforcing bars can effectively improve the fatigue strength, reduce the structural noise, and extend the residual service life of the old railway bridges. Fischer and Lorenz presented a study on a historic steel bridge which served traffic for nearly 100 years in Germany [5]. Linghoff et al. [6,7] performed both experimental and numerical studies on steel beams strengthened with CFRP laminate in both the serviceability and ultimate limit states. Harald described strengthening of a continuous steel plate girder bridge built in 1939 by using additional main girders, which were connected by prestressed tension rods for unloading the existing structure [8]. Sugimoto and Ichikawa conducted a study to extend the fatigue life of the railway bridges [9]. From the past experience we can conclude that, it is the common choice for engineers to strengthen the old structures by integrating with new structural members or materials.

In the engineering practice, the damage of the steel bridges frequently occurs on the longitudinal and horizontal beam connection joint due to severe corrosion and fatigue. For steel railway bridges subjected to large train impact and vibration, fatigue is more critical

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than corrosion. Besides, as welded structures have been widely used for railway line including bridges, various fatigue damage problems have been reported. In order to avoid the unrecoverable damage of the railway bridge, high cost of the rail line owners and the great impact on the public transportation, effective preventive maintenance methods on the old steel railway bridges are necessary. On this background, this paper presents a new strengthening method to improve the fatigue performance of the welded joints between longitudinal and horizontal beams in steel railway bridges, as shown in Fig. 1 (a). FRP plates, rubber-latex mortar, rapid hardening concrete, as well as the reinforcing bars are used for preventive maintenance on the joint to enhance the loading capacity as well as the durability of existing steel railway bridges (Fig. 1 (b)).

Fig. 2. An old steel railway bridge.

2. Proposed maintenance strategy

A typical steel railway bridge with this kind of joints is shown in Fig. 2, which has been used in service for tens of years. The longitudinal beam and horizontal beam connection joints in this bridge is shown in Fig. 3 (a). In order to avoid the possible damage, fracture or failure caused by fatigue and corrosion, preventive maintenance on this connection joint is necessary. By considering the constructability, anticorrosion, and less damage for existing structural members, FRP plates, rubber-latex mortar, rapid hardening concrete and reinforcing bars were used in this method.

Concrete and mortar, including SBR latex, show various abilities especially in adhesion bonding, waterproofing, shock absorption and abrasion resistance. The rubber-latex mortar was used for steel structures to reduce the noise as well as the interface slip, enhance the integrity and improve the durability of the composite structures [3,10,11]. Rubber-latex mortar was used in this study not only for increasing the bond strength on the steel–concrete interface, but also for reducing the noise and avoiding the structural steel corrosion in the service stage.

Rapid hardening concrete was applied for rapid construction, to reduce the stress levels of the joints and their vibration noise. For the maintenance or repairing of the railway structural members, rapid construction was a key point. Therefore, rapid hardening concrete with relatively high early-strength and light weight is the special choice for this strengthening method. In this strengthening method, the concrete casting was scheduled in the night time. FRP plates were used as the formwork for concrete casting, but in order to confirm the effect of the concrete, FRP plates were not used in this experimental study. Besides, reinforcing bars were used for controlling the crack width after concrete cracking.

The sequence of the present strengthening method for old steel joints includes structural steel cleaning, rubber latex mortar spraying, reinforcement arrangement, and finally the concrete casting, as shown in Fig. 3. Generally speaking, the total procedures can be finished within two or three nights and will not affect the railway traffic.

3. Experimental programme

A specimen was designed according to the real size dimension of the connection joint in Figs. 1 and 2. The longitudinal beam was kept to perform the loading test, but the transverse beam was cut short and used to transfer the load in the experiment for simulating the truck load from the rail. Each of the specimens was 2.1 m in length and was simply supported at a span length of 2 m. Vertical stiffeners were welded at support points to prevent shear buckling failure and crippling of the web before flexural failure. The typical geometry and design details of test specimen before and after strengthening are shown in Figs. 4 and 5, respectively. The test specimen was supported by a roller system at two ends. Setup of the specimen in the experiment is shown in Fig. 6. It should be noted that the joints were connected by welding four sections only on the web between the longitudinal and transverse beams and the flanges of the longitudinal beam were discontinuous, as shown in Fig. 7.

Totally 2 steel joints were prepared for the test, one of them was subjected to positive bending moment, and the other one was designed for negative bending moment. Before strengthening, a static loading test was performed on the original connection joint (applied load was only up to 8kN to avoid damage or plasticity of the structural steel). Thereafter, the steel joint was strengthened by using the method described above and tested again to compare with the original steel joint without strengthening. For this reason, totally four specimens were used in this study, and named as SJ-P-1, SJ-P-2, SJ-N-1, and SJ-N-2, respectively, with the details listed in Table 1.

Linear variable differential transducers (LVDTs) were used to measure the vertical deformation at the mid-span and support locations, as shown

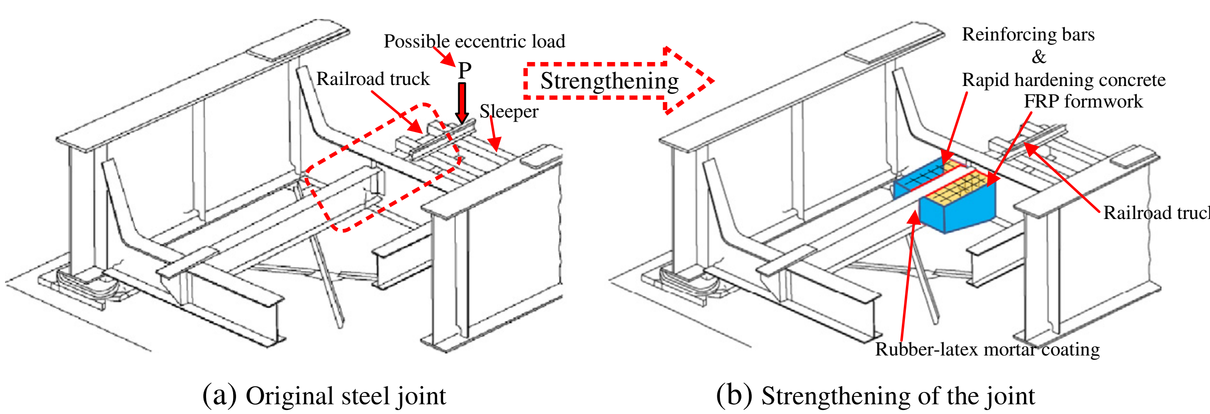

Fig. 1. Images of strengthening of longitudinal and transverse beam connection joint in steel railway bridges.