Numerical Study on Strengthening of Connection Joint in Steel Railway Bridges

Waseda University, Department of Civil and Environmental Engineering Member ○ Weiwei Lin Fellow Teruhiko Yoda
Maebashi Institute of Technology, Department of Civil and Environmental Engineering Member Nozomu Taniguchi

1. Introduction

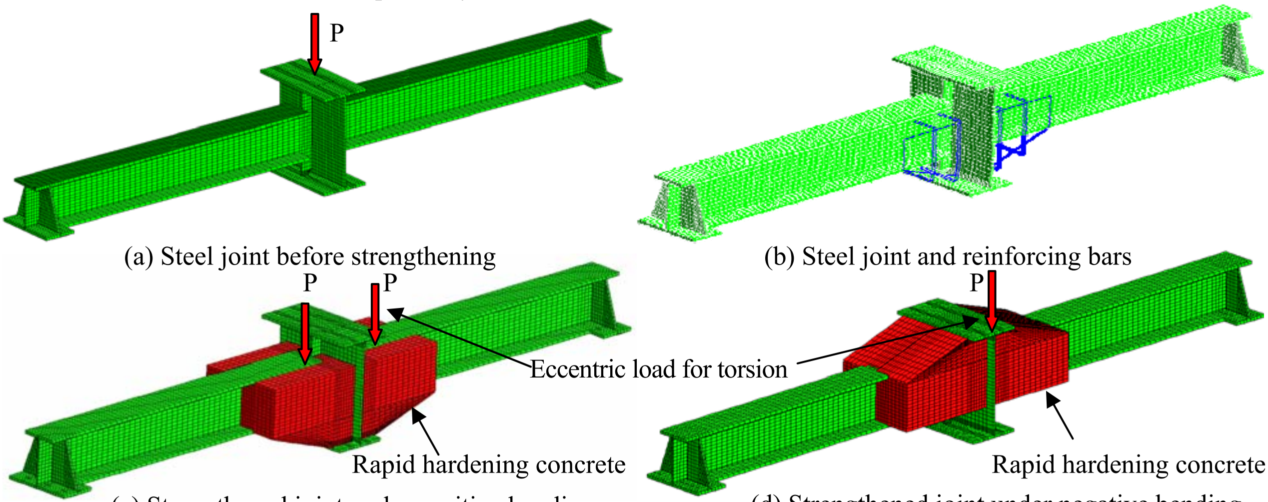
Due to relatively high transport capacity and effective use of energy with lowest damage to the environment, railways are one of the most important means of transportation in the world[1)], in which steel bridges have been widely used. After tens of years' service, many of steel railway bridges become old and need to be strengthened integrally for the whole bridge or repaired locally for certain steel members. Considering the relative high cost for replacing or strengthening integrally, as well as the great effect on the public transportation, preventive maintenance on the old structural members is an effective way.

In the engineering practice, the damages of the steel bridges are frequently appeared on the longitudinal and horizontal beam connection joint due to serious corrosion or fatigue problem. For steel railway bridges subjected to large train impact and vibration, fatigue is more important 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 method on the old steel railway bridges are necessary. On this background, this paper presents a new integration method to improve the fatigue performance of the welded connection joint between longitudinal and horizontal beams in a typical steel railway bridge. Rapid hardening concrete and reinforcing bars are used for preventive maintenance on the connection joint to enhance the load carrying capacity as well as the durability of existing old steel railway bridges.

2. Experimental Programme

Totally 2 steel joints were prepared for the test, one of them subjected to positive bending moment, and the other one was designed for sustaining negative bending moment. Each of the specimens was 2.1m in length and was simply supported at a span length of 2m. Vertical stiffeners were welded at supports to prevent shear buckling failure and crippling of the web before flexural failure. Before strengthening, a static loading test was performed on the original connection joint (applied load was only up to around 8kN to avoid damage or plasticity of the structural steel). Thereafter, the steel joint was strengthened by using rubber-latex, rapid hardening and reinforcing bars, and then tested again to compare with the original steel joint without strengthening. For this reason, totally four specimens were used in this study, and were named as SJ-P-1, SJ-P-2, SJ-N-1, and SJ-N-2, respectively.

Fig.1 Test set-up



(a) Steel joint before strengthening (b) Steel joint and reinforcing bars
(c) Strengthened joint under positive bending (d) Strengthened joint under negative bending

Fig.2 FE model of the steel joint before and after strengthening

3. Numetical Model Building

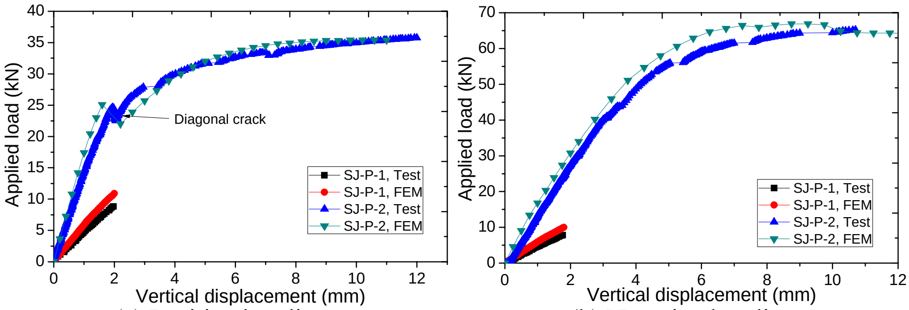
The modeling of the test specimen is carried out in three dimensions by using the finite-element method and the *DIANA* software. Solid elements, shell elements and bar elements are used to simulate the concrete, steel girder and reinforcing bars, respectively. Also, in order to account for the slip between concrete and steel girder, interface elements are used in this model. The material tests for concrete and steel are performed, and the generated data are employed in the finite element analysis. Interface data used in previous numerical studies are also adopted[2~3)]. Finite element model used in this study is shown in **Fig.2**. [1]

Keyword: Old railway bridges; Steel connection joint; Rapid hardening concrete; Numerical study
Address: 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555 Japan. Tel: 03-5286-3399. E-mail: linweiwei@aoni.waseda.jp

4. Results and Discussion

4.1 Applied load-deflection response

The load-displacement curve obtained from the numerical analysis is compared with the experimental data as shown in **Fig.3**. Both numerical and experimental displacements are taken from the vertical deflection at the bottom mid-point of each test specimen. It is found that for the steel joint before strengthening, the load-displacement curve from numerical studies agrees well but a little strong in comparison with the measured results. This is presumably because the residual stress in the welding sections was not considered in the numerical analysis, resulting in a little bit stronger stiffness of the numerical model. Moreover, when the strengthened joint subjected to positive bending moment, the numerical results has similar cracking loading and ultimate load carrying capacity with the experimental results. However, the rigidity of the strengthened joint is about 2.5 times of the original steel joint. Similar results were also observed for strengthened beams under negative bending moment, as shown in **Fig. 3**(b). But it should be noted that the load carrying capacities of the strengthened beams under negative bending moment is about twice of the strengthened joint under positive bending moment. This is due to the compressive strength of the concrete is much larger than its tensile strength.

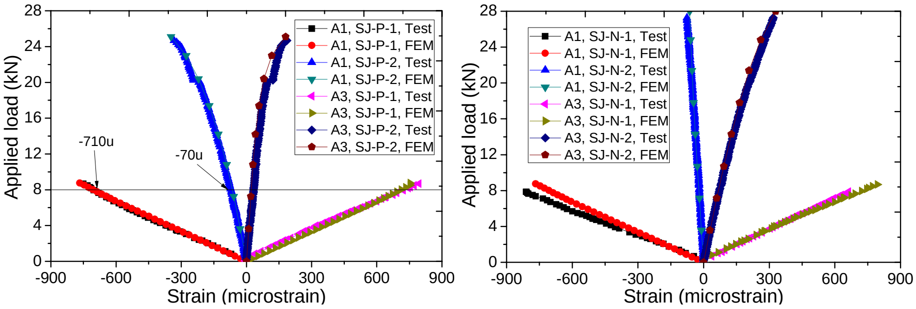


(a) Positive bending moment (b) Negative bending moment

Fig.3 Load-deflection relationship

4.2 Applied load-strain response

Fig.4 illustrates the sectional strain results of the steel connection joint before and after strengthening. Measured section locates at 4 cm from the span center section. It can be seen that when load is smaller than the 25kN (diagonal cracking load), the longitudinal strain results from the numerical analysis are quick close to the experimental results. After strengthening, the sectional strain became 1/10 of the steel joint before strengthening. Similar results were also confirmed for steel joints subject to hogging moment, as shown in **Fig.4** (b). Therefore, the fatigue life of the steel connection joint can be greatly extended, and the effects of the present strengthening method can be confirmed.

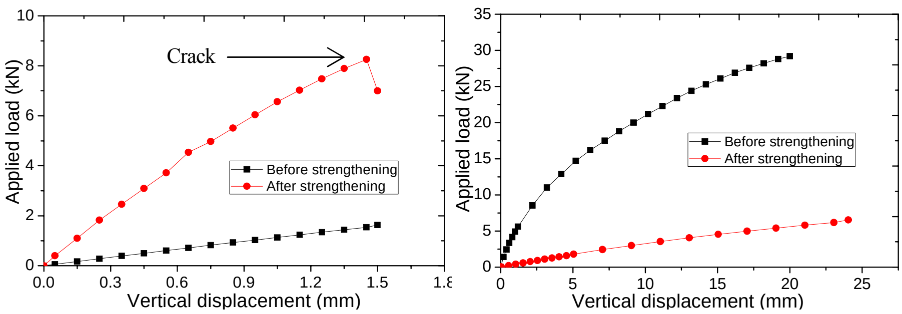


(a) Positive bending moment (b) Negative bending moment

Fig.4 Load-longitudinal strain response

4.3 Effects of torsion moment

In the real condition, the steel joint may subject to torsion moment due to the eccentric load transferred from the sleeper. In order to confirm the effects of the present strengthening method for steel joint under combined bending and torsion, eccentric load was applied on the numerical model. For steel joint subject to positive bending, two eccentric loads were applied at the edge of the top flange, which are 7.5cm from the span center and 5 cm from the web (**Fig.2** (c)). In the case of steel joint subjected to hogging moment, the load was applied on the edge of the transverse beam, as shown in **Fig.2** (d). The load-vertical deflection response curves are given in **Fig.5**. The results clearly demonstrated that the torsion stiffness of the strengthened beams is much larger than the original steel joint.



(a) Positive bending and torsion (b) Negative bending and torsion

Fig.5 Load-deflection relationship of steel connection joint under eccentric load

5. Conclusions

On the basis of the numerical and experimental results, conclusions can be drawn as follows: (1) The present method was proved to be effective for increasing both rigidity and ultimate loading capacity of steel connection joints, and stress levels was greatly reduced after strengthening; (2) Numerical models used in this study were demonstrated to be effective for simulating the present strengthening method; (3) Torsion stiffness of the steel joint was also increased by using the present method.

6. References

1. Lin, W., Yoda, T., Taniguchi, N., and Koide, N. (2012). ‘‘Numerical Study on Hybrid Structures Renovated from the Old Railway Steel Bridges.’’ Journal of Structural Engineering, JSCE, Vol. 58A. pp. 925-934.
2. Lin, W., Yoda, T., Taniguchi, N., and Hansaka, M. (2013). “Performance of Strengthened Hybrid Structures Renovated from Old Railway Steel Bridges.” Journal of Constructional Steel Research. (Accepted, in print)
3. Lin, W., and Yoda, T. (2013). ‘‘Experimental and Numerical Study on Mechanical Behavior of Composite Girders under Hogging Moment.’’ International Journal of Advanced Steel Construction. (Accepted to be published on Vol. 9, No. 4, 2013)