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Improvement of a Bolt-Retightening-Free Rail Fastening System

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Abstract

In this study, the authors aimed to develop a rail fastening system requiring no bolt retightening by identifying issues associated with a rail fastening system developed in a previous study. First, as a result of trial installation of the previously developed rail fastening system on the test track, the authors confirmed that, at locations with unsupported sleepers, washer insertion was not possible in some cases because the sleeper dropped onto the ballast. To resolve this issue, the authors proposed a fastening method in which the sleeper and bolt are lifted together by using the bolt head as a reaction force. This method secures sufficient clearance for washer insertion even at locations with unsupported sleepers. Based on this concept, the authors fabricated an improved rail fastening system and a fastening tool. Assembly tests confirmed that washers could be inserted even at unsupported sleeper locations. In addition, static and dynamic loading tests confirmed that the improved rail fastening system satisfies the safety requirements against fatigue failure. Finally, the authors conducted a trial installation on an operational line. Visual inspection after approximately three months confirmed that no abnormalities, such as bolt loosening or washer dislodgement, were observed.

Keywords: rail fastening system, bolt retightening, leaf spring, unsupported sleeper, washer, rail clamping force, fatigue failure, trial installation.

1 Introduction

Rail fastening systems developed and widely used in Japan generally adopt a structure in which metal leaf springs are clamped by bolts. Figure 1 presents a representative example of the bolted type, namely the 5N rail fastening system used in ballasted track [1]. A key advantage of the bolted type is that the rail clamping force can be adjusted by controlling the bolt tightening torque. Accordingly, even when changes such as wear or relaxation of the component parts occur, the rail clamping force can be maintained by retightening the bolts. However, the bolted type is susceptible to bolt loosening and bolt seizure due to corrosion. Therefore, regular maintenance is required, including periodic bolt retightening and reapplication of anti-corrosion oil.

In contrast, some rail fastening systems developed overseas adopt a non-bolted type, in which no bolt tightening is required. An advantage of the non-bolted type is that such bolt-related maintenance is not required. A representative example of the non-bolted type is the Pandrol-type rail fastening system (Figure 2), which secures the rail by inserting a fastening spring, commonly referred to as a wire spring, into a shoulder fixed to the sleeper [2]. The Pandrol-type rail fastening system has also been introduced in Japan since the 1980s.

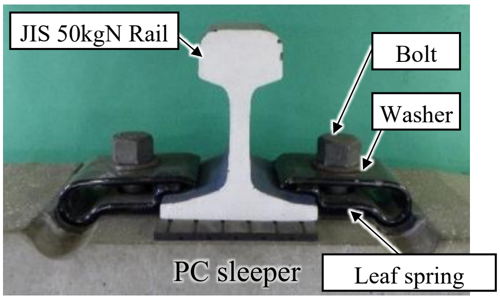

Figure 1: 5N rail fastening system (Bolted type).

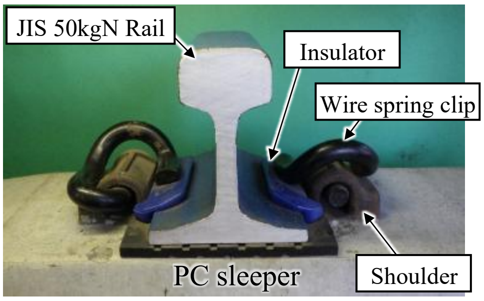

Figure 2: Pandrol rail fastening system (Non-bolted type).

In cases where rail fastening systems of the bolted type, which are already widely implemented in Japan, are replaced with non-bolted rail fastening systems, it is generally necessary to replace the existing sleepers. Consequently, in addition to the material cost of the rail fastening systems, the material cost of the sleepers and the cost of sleeper replacement are required, resulting in high overall costs. Therefore, the authors are developing a rail fastening system that eliminates the need for bolt retightening without replacing the existing sleepers [3]. Figure 3 shows the rail fastening system developed by the authors. This rail fastening system consists of a leaf spring, washer, bolt, and adhesive. Figure 4 illustrates the rail fastening method using the proposed rail fastening system. In the proposed method, a bolt coated with an adhesive is first screwed into the existing sleeper and bonded to the sleeper. Next, a leaf spring is installed, and its upper surface is pressed downward to create a clearance between the spring and the bolt head, into which a washer is inserted. Finally, the applied force is released, thereby completing the fastening. In order to realize this fastening method, a dedicated fastening tool, shown in Figure 5, has been developed. This tool incorporates a mechanism based on the lever principle, by which the upper surface of the leaf spring is pressed downward using the rail as a reaction force.

In this study, the issues associated with the rail fastening system shown in Figure 3 were identified, and an improved rail fastening system was designed and fabricated. In addition, laboratory tests and trial installations were conducted to examine the feasibility of practical application of the proposed rail fastening system.

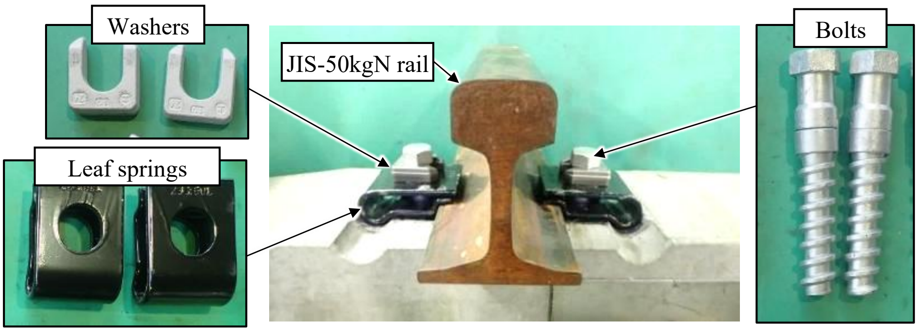

Figure 3: Rail fastening system requiring no bolt retightening developed in a previous study [3].

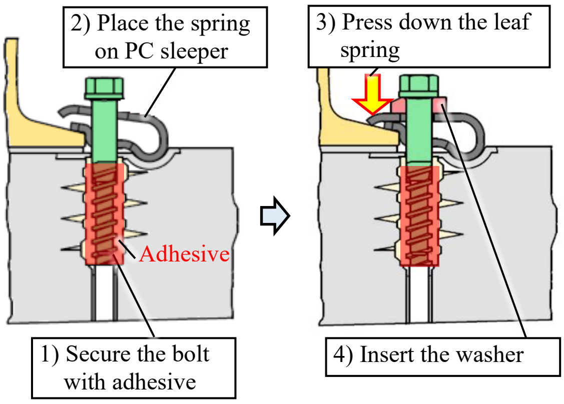

Figure 4: Rail fastening process [3].

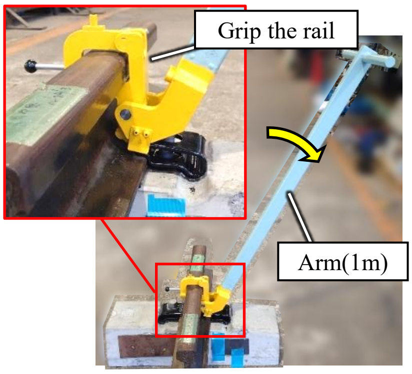

Figure 5: Rail fastening tool [3].

2 Issues and improvements

2.1 Trial installation and issues

An attempt was made to install the rail fastening system described in the previous chapter on a test track at the Railway Technical Research Institute (RTRI). As a result, it was found that, in some rail fastening systems, the washer could not be inserted. At the locations where washer insertion was not possible, a gap was observed between the rail and the rail pad. This gap was caused by an unsupported sleeper, which dropped onto the ballast when the leaf spring was released. Consequently, it became clear that the reason the washer could not be inserted was that the clearance required for washer insertion was reduced due to the unsupported sleeper. Unsupported sleepers inevitably occur in ballasted track. Therefore, for the practical application of the proposed rail fastening system, it was found that improvements are required to enable fastening even at locations where unsupported sleepers are present.

According to the results of the laboratory tests conducted on the previously developed rail fastening system, the rail clamping force per leaf spring was 4.1 kN. Based on this clamping force, the rail creep resistance per fastening assembly was calculated to be 7.4 kN. When this value is divided by the sleeper spacing of 0.6 m, the rail creep resistance per unit length is 12.3 kN/m. This value exceeds the typical ballast longitudinal resistance, which is generally 6–10 kN/m [4].

In general, for rail fastening systems used in ballasted track, a larger rail clamping force is preferable, and such systems are generally designed to provide 5 kN or more per leaf spring. This design approach aims to ensure that the rail creep resistance is sufficiently greater than the ballast longitudinal resistance, thereby preventing track pad pull-out and reducing maintenance work, such as gap adjustment associated with the rail creep. Therefore, considering practical application, it is desirable to increase the rail clamping force of the rail fastening system developed in this study compared with that of the previously developed rail fastening system, and a target value of 5 kN or more was adopted.

2.2 Concept of the improved rail fastening system

Based on the issues identified in the previous section, the following improvements were adopted.
(a) The bolt was separated into a head and a shank with an enlarged section, and a fastening method was adopted in which the leaf spring is pressed down using the bolt head as a reaction force.
(b) The under-head length of the bolt was extended to increase the allowance for washer insertion.
(c) The thickness of the leaf spring and its initial opening were increased to enhance the rail clamping force.

Improvement (a) represents a fundamental change from the fastening method used in the previously developed rail fastening system. Figure 6 shows the improved fastening process. By pressing down the leaf spring using the bolt head as a reaction force, the sleeper and the bolt can be lifted together, thereby addressing the issues caused by unsupported sleepers described above. Improvement (b) increases the washer insertion allowance, thereby mitigating the effects of the posture of the leaf spring when installed on the sleeper and dimensional tolerances. Furthermore, improvement (c) aims to increase the rail clamping force compared with the previously developed rail fastening system by increasing the thickness of the leaf spring and the opening between the tips of the upper and lower leaf springs before fastening.

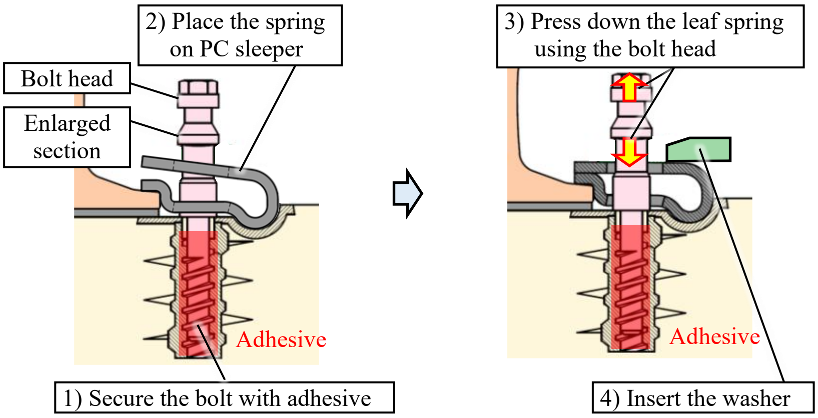

Figure 6: Improved rail fastening process.

2.3 Fabrication of the improved rail fastening system

Figure 7 shows the improved rail fastening system fabricated based on the concept presented in the previous section. The leaf spring is designed with a plate thickness of 8 mm and an initial opening at the tip of 10 mm in order to increase the rail clamping force. The bolt is provided with a head that serves as a reaction point during washer insertion, as well as an enlarged section on the shank where the washer is inserted.

In addition, a fastening tool was newly developed to implement the above fastening method. By rotating the upper hexagonal bolt using a wrench or a bolt-tightening device, the point of contact with the bolt head moves upward, thereby pressing down the leaf spring and simultaneously lifting the bolt together with the sleeper. As a result, a gap is created between the enlarged section of the bolt shank and the upper surface of the leaf spring, allowing insertion of the washer.

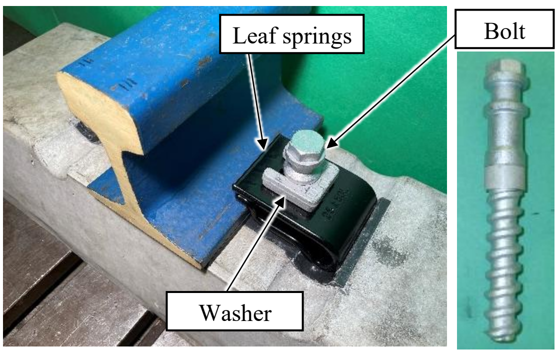

Figure 7: Improved rail fastening system.

3 Performance test

3.1 Assembly test and rail clamping force test

First, the improved rail fastening system was assembled using the fastening tool, and the clearance for washer insertion was measured. As a result, the measured clearance was 1.5 mm on both the gauge and field sides, confirming that sufficient clearance was available relative to the washer thickness. In addition, it was confirmed that the bolt did not bend even after repeated fastening and release operations.

Next, a rail clamping force test was conducted. In this test, the rail fastening system was assembled, after which a vertical upward load was applied to the rail. The rail pad was then removed, the load was released, and the rail was again subjected to a vertical upward load. The load was measured when the rail returned to its initial assembled position. As a result, the rail clamping force per leaf spring was found to be 6.4 kN, confirming that it exceeded the target value of 5 kN.

3.2 Rail creep resistance test

A rail creep resistance test of the rail fastening system was conducted. In this test, after assembling the rail fastening system, a longitudinal load was applied to the rail, and the creep resistance force was determined from the relationship between the applied load and the longitudinal displacement of the rail. As a result, the creep resistance force was 13.4 kN. When this value is divided by the sleeper spacing of 0.6 m, the creep resistance per unit length is 22.3 kN/m, which is well above the typical longitudinal ballast resistance of 6–10 kN/m.

3.3 Static and dynamic biaxial loading tests

To verify the safety against fatigue failure, static and dynamic biaxial loading tests were conducted. These tests were carried out in accordance with the Japanese Design Standards for Railway Structures and Commentary (Track Structures) [4]. In the static loading test, after assembling the rail fastening system, a test load P_A=39.9 kN (Design Load A) was applied from the gauge side at an angle of θ_A=49.2°, and a test load P_B=31.0 kN (Design Load B) was applied from the field side at an angle of θ_B=59.9°. The lateral displacement of the rail head and the stress in the leaf spring were measured. The test loads were calculated [5] based on the design conditions and the results of various spring constant tests.

From the results of the static loading test, the maximum lateral displacement of the rail head was 0.73 mm, which was within the limit of 7.0 mm. In addition, the stress in the leaf spring remained within the limit lines.

Next, a dynamic loading test was conducted in which the test loads P_A and P_B were applied alternately for one million cycles. In the dynamic loading test, adhesive was applied to the bolt to bond it to the sleeper prior to testing. As a result of the dynamic loading test, no significant changes were observed in the vertical or lateral displacement of the rail, or in the stress of the leaf spring during the test. The one million loading cycles were successfully completed. Furthermore, after one million cycles, no bolt loosening, rotation or movement of the washer was observed, and no damage such as bending or fracture was found in any of the components. From these results, the rail fastening system was confirmed to satisfy the fatigue failure safety requirements specified in the Japanese design standards for railway structures.

3.4 Trial installation on an operational line

A test installation was conducted on an operational line to verify the performance of the improved rail fastening system under actual installation conditions. The trial installation site is located on a straight track section with an annual gross tonnage of approximately 7.4 million tons. The rail fastening system was installed on five PC sleepers, corresponding to ten fastening systems. These were arranged at every other sleeper. To confirm that washer dislodgement or bolt rotation does not occur due to vibrations when vehicles pass over rail joints, two of the five PC sleepers described above were selected as the PC sleepers located immediately before and after the rail joint.

Figure 8 shows the condition of the rail fastening system three months after installation on an operational line. Visual inspection confirmed that no washer dislodgement or bolt loosening was observed in the rail fastening system installed on the operational line, indicating no apparent issues. As a next step, the authors will make efforts to reduce the manufacturing cost of the prototype components and continue investigations toward practical application.

Figure 8: Condition of the rail fastening system several months after trial installation.

4 Conclusions and Contributions

In this study, the authors identified issues related to the practical application of a rail fastening system requiring no bolt retightening, which was developed in a previous study, and developed an improved rail fastening system. The main findings are summarized as follows.

(1) As a result of trial installation of the previously developed rail fastening system on the test track at the RTRI, the authors confirmed that, in the presence of

unsupported sleepers, washers could not be inserted in some cases due to the sleeper dropping onto the ballast.

(2) To resolve the above issues, the authors proposed a fastening method in which the sleeper and the bolt are lifted together by using the bolt head as a reaction force, thereby securing sufficient clearance for washer insertion even at locations with unsupported sleepers.

(3) After fabricating the rail fastening system incorporating the above improvements and the fastening tool, the authors attempted rail fastening at locations with unsupported sleepers and confirmed that washers could be inserted even at such locations.

(4) The rail clamping force of the improved rail fastening system was measured and confirmed to exceed the target value of 5 kN. In addition, static and dynamic loading tests conducted in accordance with the Japanese design standards for railway structures confirmed that the rail fastening system satisfies the safety requirements against fatigue failure.

(5) The improved rail fastening system was trial-installed on an operational line. A visual inspection conducted approximately three months later confirmed that no abnormalities, such as bolt loosening or washer dislodgement, were observed.

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