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Experimental study on High strength One-side bolted joints

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ABSTRACT: High strength one-side bolts, which enable construction only from one side, are effective for repairing or strengthening closed-section members or for connecting steel pipes as joints. In this study, experiments were conducted to verify the fatigue strength and other basic characteristics of high strength one-side bolted joints. As a result, it was revealed that high strength one-side bolted joints have fatigue design curve to those of joints using conventional high strength bolts. Also presented in this paper are case studies of application of high strength one-side bolted joints to strengthening of steel truss bridge and arch bridges.

1. INTRODUCTION

High strength one-side bolts (hereinafter referred to as the OS-Bolt) are bolt that construction is possible from one side. Also, OS-Bolt are effective for repairing or strengthening closed-section members. They enable the connection of members requiring no field welding. Then, quality reliability of connection and construction property improve. Also, those secure safety and the period of construction is shortened. OS-Bolt has been frequently used for repairing or strengthening steel bridges under construction constraints.

An increasing number of steel highway bridges have recently been repaired or strengthened with the increase of traffic volume and vehicle size, deterioration of bridges and requirements for greater seismic resistance [1], [2]. OS-Bolt are frequently used a connection method requiring no field welding because neither curing and ultrasonic testing involved in field welding nor welder qualifications are required.

As for the basic performance of OS-Bolted joints used for the structural characteristics of connections, verifications have been made when the bolts were applied to architectural structures or steel highway bridges [3]-[5] and their effectiveness have been identified.

In the initiation design of steel highway bridges, considering the effects of fatigue were determined unnecessary unless the steel plate deck or highway bridge also street railway. The occurrence of fatigue cracks have, however, been reported recently at numerous positions of steel highway bridges [6] and future fatigue damage has been of concern. Then, the "Fatigue Design Guidance for Steel Highway Bridges"[7] was published in 2002, which made the adoption of fatigue design mandatory also on steel highway bridges. No fatigue strength has, however, been verified for OS-Bolted joints.

In this study, experiments were conducted to verify the slip coefficient, relaxation of axial force OS-Bolted joints and fatigue strength, which represent the basic characteristics of OS-Bolted joints. Also presented in this paper are case studies of application of OS-Bolted joints to seismic retrofit and strengthening of steel highway bridges.

2. OUTLINE OF HIGH STRENGTH ONE-SIDE BOLT

2.1 *Characteristics of OS-Bolt*

The components of OS-Bolt are shown in Figure 1.

Figure 1. Components of High Strength One-Side Bolt

Six parts constitute OS-Bolt: bulb sleeve that forms the bolt head behind the member, shear washer and grip sleeve that support the bulb sleeve, bearing washer that secures the grip range, core pin with a special trapezoidal screw and nut. OS-Bolt are used in all kinds of steel structures for repairing bridges. Members can be fastened from one side using a dedicated electric shear wrench regardless of the field environment or human skill. Strength equivalent to F8T can be secured by high strength bolt for friction joint.

2.2 *Fastening mechanism*

The process of fastening OS-Bolt is outlined in Figure 2. The conditions before and after fastening are shown in Photograph 1. A cross section of fastened OS-Bolt is shown in Photograph 2.

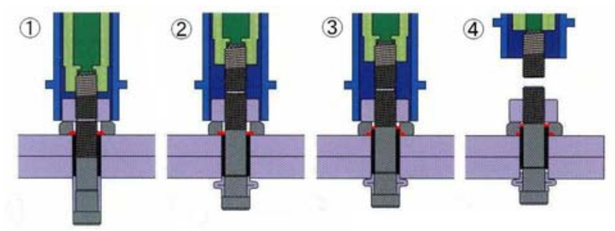
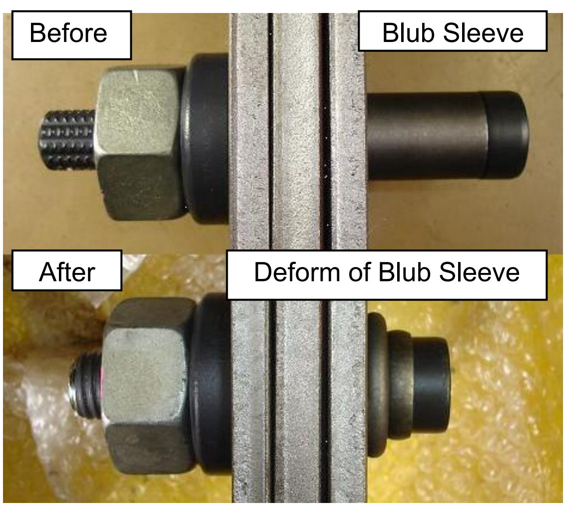
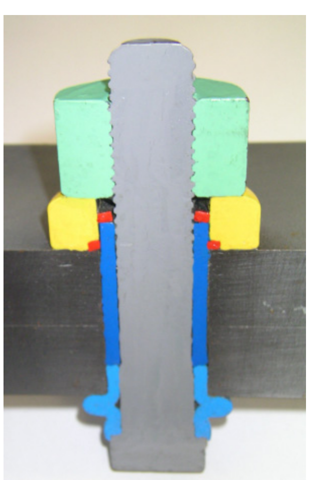


Figure 2. Outline of fastening system



Photograph 1. Before and after of fastening



Photograph 2. Cross section

The steps of fastening are described below.
(1) OS-Bolt is inserted into the bottom hole and fastening is started using a dedicated shear wrench.

(2) The bulb sleeve is deformed behind the member, forming a bulge (bolt head).

(3) The shear washer is sheared by the axial force and the introduction of axial force to the member is started.

(4) The tail of the core pin is barked, and thereby designated axial force is introduced. Then, fastening is completed.
The axial force required for deforming the bulb sleeve is temporarily released due to the shearing of the shear washer at the same time as a bulge is formed. Then, the designated axial force is introduced to the member due to the fracture of the pin tail as for a torque-shear high strength bolt. Thus, axial force is introduced at two stages in the fastening mechanism for OS-Bolt.

3. SLIP TESTS

3.1 *Experimental procedure*

Specimens were designed for friction joints (Plate: 22mm, SN490B, OS-Bolt:φ27) in Figure 3. The friction surface was subjected to either shot blasting or grid blasting. Surface roughness was set at 50 μm Rz or higher. Slip tests were conducted also for standard specimens of high strength bolted joints (M22-S10T) for comparison with OS-Bolt joints.

In the slip test, an Amsler type testing machine was used for tensile loading. The slip load under which clear slip sound was created was considered to be the main slip load. Three slip tests specimens were developed. For the conventional bolt axial force for calculating the coefficient of slip, the mean of axial force measurements for five bolts in the same lot as that contained the one used in the slip test was used. (OS bolt: 291 kN, high strength bolt: 230 kN.)

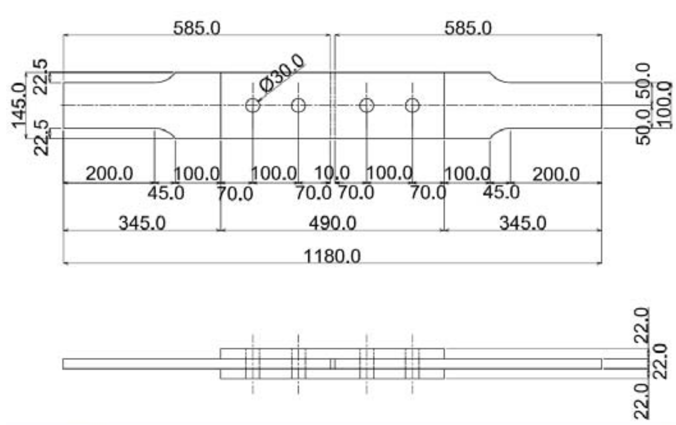


Figure 3. Slip experiments specimen

3.2 *Experimental results*

Tables 1 through 3 show results of slip tests. The slip coefficient (μ) for OS-Bolt joints (mean values for three specimens) was 0.62 for bolts subjected to grid blasting and 0.57 for those subjected to shot blasting. The slip coefficient (μ) for high strength bolted joints was 0.60 (mean values for three specimens). All exceeded a slip coefficient (μ) of 0.40 in Japan Road Association.

Table 1. High strength one-side bolt (grid blasting)

	Specimen No-1	Specimen No-2	Specimen No-3
Slip loads(kN)	710	759	707
μ	0.610	0.652	0.607

Table 2. High strength one-side bolt (shot blasting)

	Specimen No-1	Specimen No-2	Specimen No-3
Slip loads(kN)	682	622	698
μ	0.586	0.534	0.600

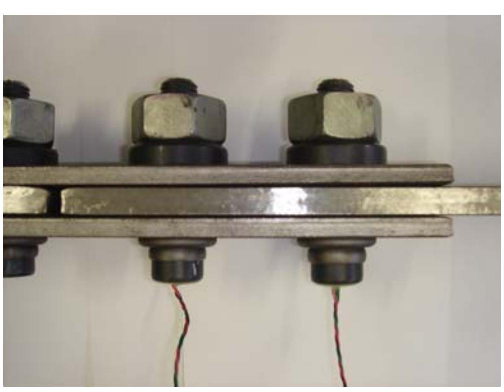
Table 3. High strength bolt (shot blasting)

	Specimen No-1	Specimen No-2	Specimen No-3
Slip loads(kN)	575	550	531
μ	0.625	0.598	0.577

4. RELAXATION TESTS

4.1 *Experimental procedure*

For obtaining the axial force of the OS-Bolt in the relaxation tests, the strain gauge of the axial force embedded in the core pin was measured. The stress-strain relationship and the cross sectional area of the bolt were examined for conversion. The gauges installed are shown in Photograph 3. In the test specimen shown in Figure 4, two bolts were fastened first on the inside and then on the outside of the joint. OS-Bolt were fastened to the specimen and the axial force was measured until 14 days passed.



Photograph 3. Gauge position

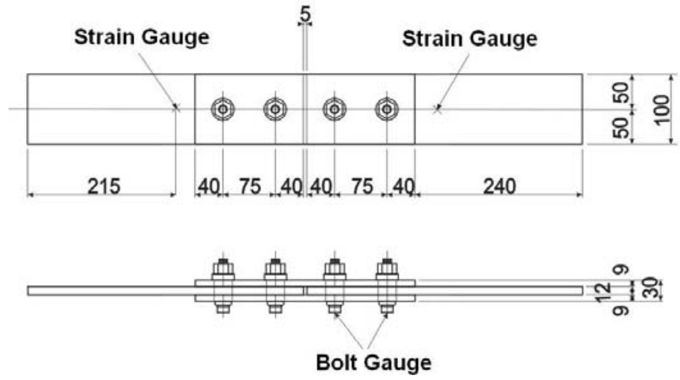


Figure 4. Test specimen

4.2 *Experimental results*

The axial force of OS-Bolt and the time elapsed are shown in Figure 5. The bolt axial force dropped drastically in about one day after the bolt was fastened, and was gradually reduced thereafter. After the elapse of about one week, the axial force became stable at a certain level. At a point when 14 days passed, the reduction of axial force was about 4.5% of that at the time of fastening.

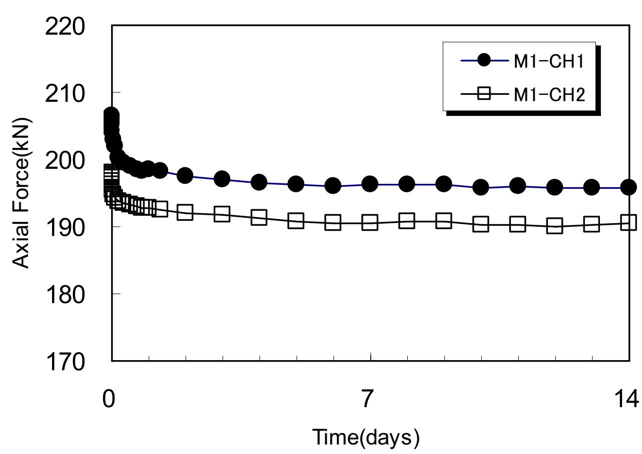


Figure 5. Axial force relaxation

4.3 *Effect of bolt length*

The Axial force was measured for one year for four types of OS-Bolt in order to verify the effects of axial force relaxation and long time relaxation where the length of OS-Bolt varied.

Figure 6 shows the long time measurements of axial force relaxation. A strain gauge was attached to the bolt head in a constant temperature and humidity testing machine at a room temperature of 20°C to measure changes in longitudinal strain of the bolt with time. The rate of axial force relaxation after one year was 2.1 to 4.9% of the axial force introduced right after the bolt was fastened.

The results show that the axial force relaxation of OS-Bolt was similar to the results of relaxation test for conventional high strength bolts [8] and that no special consideration was required for the design axial force or the axial force to be introduced.

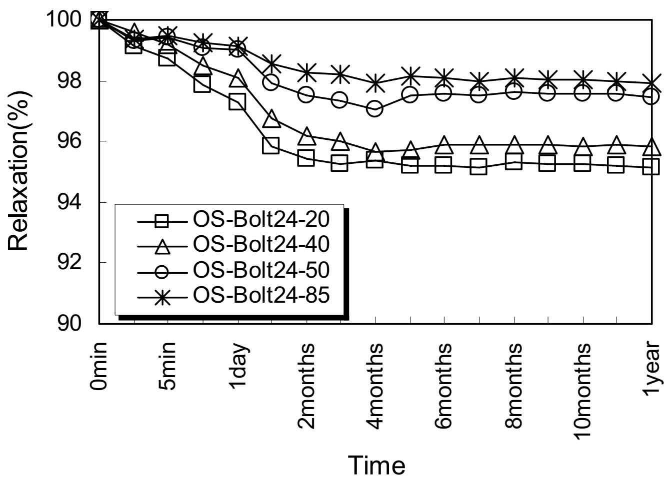
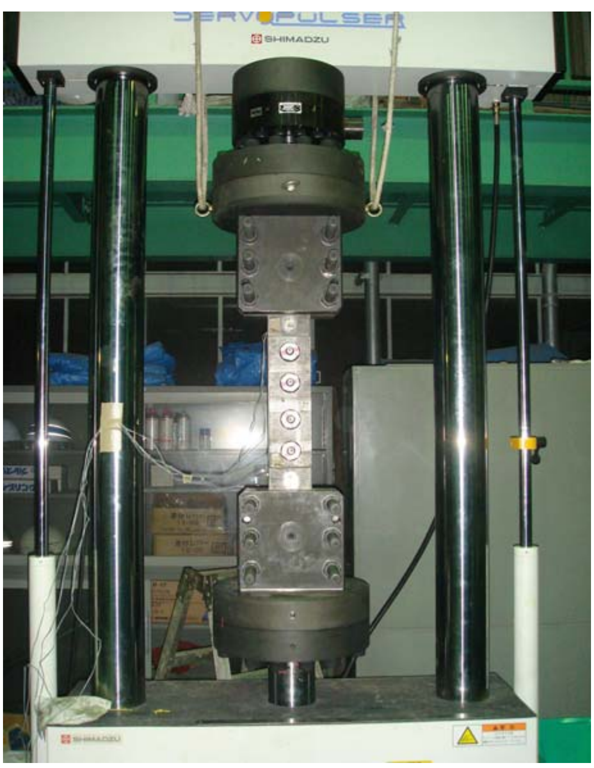


Figure 6. Axial force relaxation

5. FATIGUE TESTS

5.1 *Experimental procedure*

Three sets of specimens (M1, M2 and M3) were designed for friction joints by double friction in Figure 4. The bolt-hole had a diameter of 26.0 mm. Shot blasting was applied on the friction surface of the base plate and splice plate. A strain gauge was installed 215 mm from the end of the base plate, and the stress to be applied in the fatigue test was measured in static loading tests.



Photograph 4. Fatigue experiment

The "Fatigue Design Guidance for Steel Highway Bridges"[7] specifies class B for the strength of high strength bolted joints and a base stress range of 155 MPa. In the tests, however, stress grade was raised to class A and the stress range was set to be 190 MPa because comparison was made in fatigue strength between OS-Bolted joints and conventional high strength bolted joints.

In the fatigue test, an electro hydraulic servo test machine in Photograph 4 was used for pulsating tensile fatigue test. Tension was applied cyclically at a rate of 6 Hz. The Tests were repeated until the fracture of the base plate with the maximum number of cycles set at 10 million times. The mechanical properties of steel plates are listed in Table 4. The materials of OS-Bolt (φ24) and the mechanical properties of core pin are shown in Tables 5 and 6, respectively.

Table 4. Mechanical properties of steel plates

	Splice Plate	Base Plate
Material	SS400	SM400A
Thickness(mm)	9	12
Yield Stress(MPa)	311	333
Tensile Strength(MPa)	442	458
Elongation(%)	29	30

Table 5. Materials of High Strength One-Side Bolt

Core Pin	Nut	Washer
SCM440	SCM440	SCM430

Shear Washer	Grip Sleeve	Bulb Sleeve
SCM430	SCM430	AISI1018

Table 6. Mechanical properties of core pin

	Standard Value	Measurement
Strength（MPa）	Min 1006	1111
Tensile Strength （MPa）	1118-1216	1195
Drawing(%)	Min 40	54
Elongation(%)	Min 14	16

5.2 *Experimental results*

Figure 7 shows the results of fatigue tests for OS-Bolted joints. The line shows an S-N curve (strength class B) for conventional high strength bolted joints presented in the "Fatigue Design Guidance for Steel Highway Bridges"[7]. The stress range for high strength bolted joints was calculated using a formula specified in the "Fatigue Design Guidance for Steel Highway Bridges" [7].

The result was 190 MPa at strength class A, approximately 1.8 times 155 MPa at strength class B. The number of cycles for a stress range of 190 MPa was more than 2.5 times two million cycles, the fatigue limit. The results have revealed that OS-Bolted joints have fatigue strength to the same level as conventional high-strength bolted joints [7].

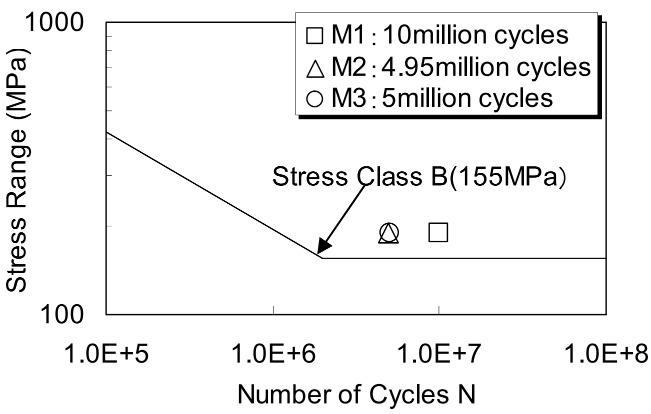


Figure 7. Fatigue test results

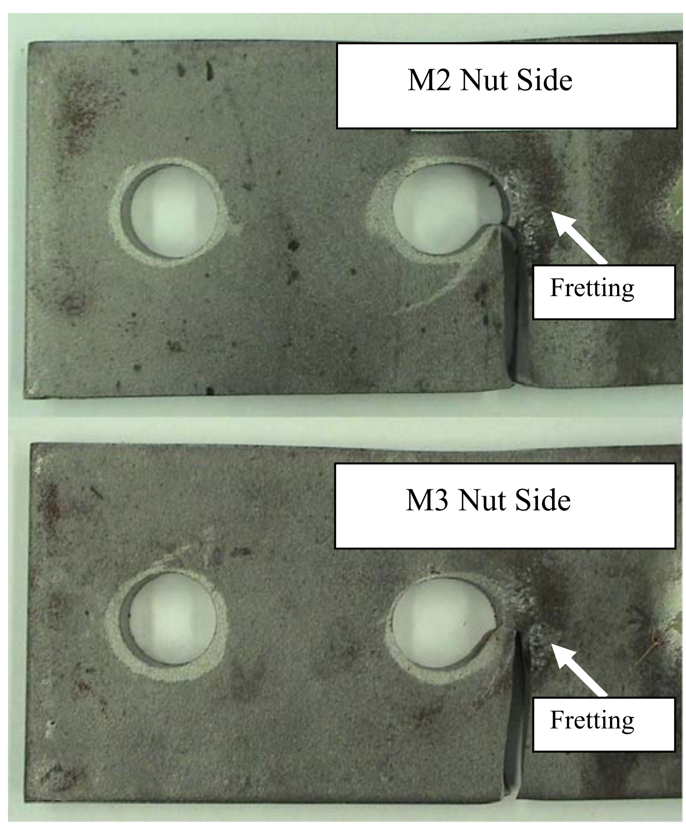

Photograph 6. Fracture of base material (M3)

5.3 *Fracture of specimen*

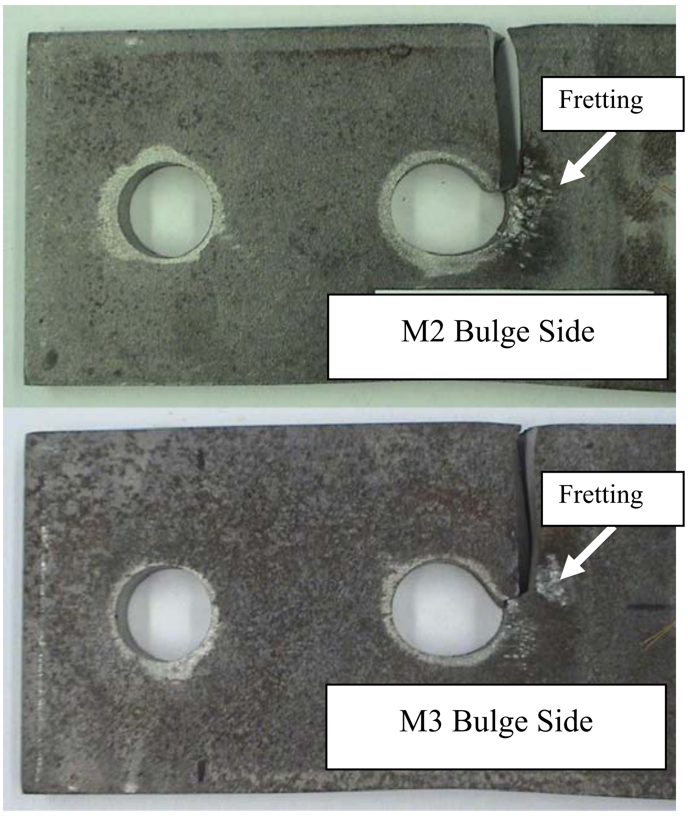
In specimen M1, the base plate did not fracture until the number of cycles reached 10 million. Then, the test was discontinued. The base plate fractured from around the bolt-hole along the width of the plate after approximately 4.95 million cycles in specimen M2 and after approximately 5.00 million cycles in M3. The state right after the fracture is shown in Photographs 5 and 6 for M2 and M3, respectively.

Photographs 7 and 8 show the fracture of the base plate on the bulge and nut sides after the dismantling of M2 and M3. The fracture of the base plate progressed from the end of the bolt-hole. Fretting was observed on the surface due to cyclic loading. Fatigue-induced cracks that occurred on the surface around the bolt-hole subjected to fretting may have caused the base plate to fracture.


Photograph 5. Fracture of base material (M2)



Photograph 7. Fracture of base material (Nut side)

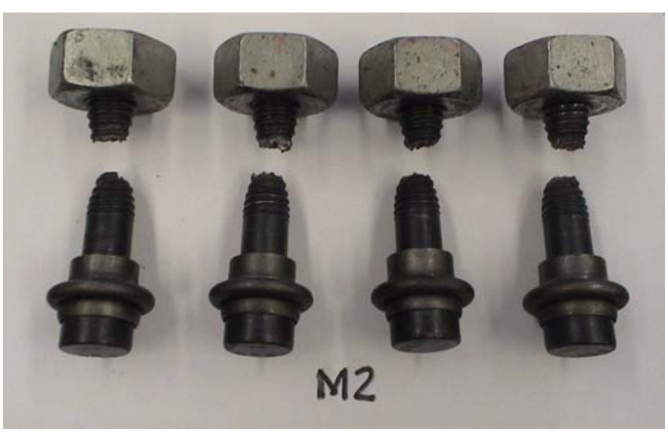


Photograph 8. Fracture of base material (Bulge side)

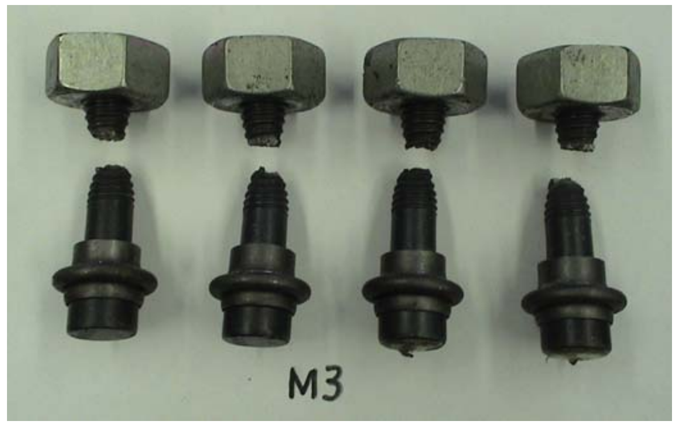
6. TENSILE TESTS

In order to verify the strength of the OS-Bolt (φ24) after the fatigue test, specimens M2 and M3 were dismantled and tensile tests were conducted for bolts. The results of tensile tests for OS-Bolt at the time of shipment and after the fatigue test are shown in Table 7. Photographs 9 and 10 show how the bolts fractured.

After the tensile test, OS-Bolt all fractured at the screw of the bolt. It is therefore evident that the bulge (bolt head) that was deformed had sufficient strength. Tensile strength remained unchanged after the fatigue test. It was verified that no strength reduction occurred in OS-Bolt after cyclic loading was applied approximately five million times.



Photograph 9. After tensile test(M2)



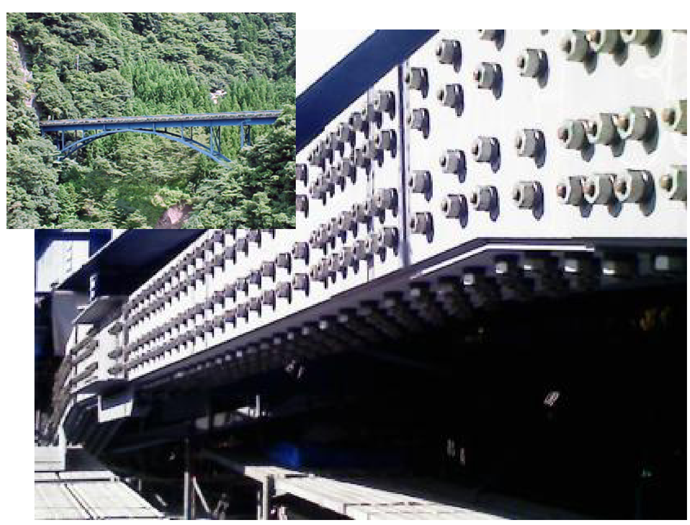
Photograph 10. After tensile test(M3)

Table.7 Results of tensile test before and after fatigue test

	Maximum (kN)	Minimum (kN)	Average (kN)
Before Fatigue	270.9	269.2	269.9
After Fatigue	270.8	269.2	270.0

7. CASE STUDIES OF OS-BOLT

OS-Bolt has been frequently used for repairing or strengthening steel bridges under construction constraints. In recent years, OS-Bolt has been adopted in an increasing number of cases for seismic retrofit of relatively large bridges such as arch bridge and truss bridge. The example is strengthening steel bridge of arch rib in Photograph 11 and 12, 13 and strengthening steel truss bridge in Photograph 14.



Photograph 11. Strengthening a steel arch bridge

Photograph 12. Strengthening a steel arch bridge

Photograph 13. Strengthening a steel truss bridge

Photograph 14. Strengthening a steel truss bridge

An example of connecting a strengthening member on a U-shaped rib of a steel slab using OS-Bolt is shown in Photograph 15.

Photograph 15. Strengthening a U-Rib of steel slab

Research and development has been made in recent years concerning a method for replacing bolts buried [9] in concrete members with OS-Bolt. It enable construction from one side, and the method has been put to practical use. The replacement of high strength bolts F11T using OS-Bolt is shown in Photograph 16.

Photograph 16. Replacement of OS-Bolt

8. CONCLUSIONS

Experiments were conducted to verify the slip factor, relaxation of axial force and fatigue strength, which represent the basic characteristics of OS-Bolted joints. Tensile strength after fatigue test was also verified. The findings are described below.

(1) Slip tests were conducted for friction surface that was subjected either to shot blasting or grid blasting.

As a result, a slip factor of 0.40 or higher was obtained. Performance the same level to that of conventional high-strength bolted joints can be obtained by properly cleaning the friction surface.

(2) Relaxation of axial force was approximately 5%. The relaxation of axial force of OS-Bolt is similar to that for conventional high strength bolts. No special consideration is required for the design axial force or the axial force to be introduced.

(3) The number of loading cycles for a stress range 1.8 times the stress range for high strength bolted joints was five million, more than 2.5 times two million, the fatigue limit. OS-Bolted joints have fatigue design curve to conventional high strength bolted joints.

(4) It was verified in tensile tests before and after fatigue tests that no strength reduction occurred in OS-Bolt after cyclic loading was applied approximately five million times.

9. ACKNOWLEDGMENT

This bolt is a patent of Huck International,lnc in USA. In addition, Fuserashi co., LTD produces it in Japan.
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