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Basic Characteristics of High Strength One-Side Bolted Friction 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 friction joints. As a result, it was revealed that high strength one-side bolted friction 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 friction joints to box steel pipe columns and of seismic retrofit of steel truss and arch bridges.

Keywords: Slip Coefficient, Fatigue, Relaxation, Friction Joint

1. Introduction

High strength one-side bolts (hereinafter referred to as the HOB), which enable construction only from one side, are effective for repairing or strengthening closed-section members or for connecting box steel pipes. They enable the connection of members requiring no field welding and therefore improve confidence in quality of connection, facilitate construction, ensure safety and reduce the period of construction. The connection method is also friendly to the environment because steel members can be recycled or reused simply by removing bolts. 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]. HOB are frequently used also in seismic retrofit of architectural structures as 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 HOB used for friction joints and 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 carries a tramway or 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 HOB friction joints. In this study, experiments were conducted to verify the slip coefficient, relaxation of axial force HOB friction joints and fatigue strength, which represent the basic characteristics of HOB friction joints. As a result, it was revealed that HOB have basic characteristics equal or higher to those of joints using standard high-strength bolts. Tensile strength was also verified before and after fatigue experiments. Also presented in this paper are case studies of application of HOB friction joints to box steel pipe columns, of seismic retrofit of strengthen concrete columns and of seismic retrofit and fatigue strength of steel highway bridges.

2. Outline of High Strength One-Side Bolt

2.1 Characteristics of HOB

The components of a HOB are shown in Figure 1. Six parts constitute a HOB: 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.

HOB are used in all kinds of steel structures for repairing bridges, seismically retrofitting or renovating buildings, erecting buildings and constructing plants. Members can be fastened from one side using a dedicated electric shear wrench regardless of the field environment or human skill.

Figure 1 Components of High Strength One-Side Bolt

2.2 Fastening mechanism

The process of fastening a HOB is outlined in Figure 2. A cross section of the fastened HOB is shown in Photograph 1. The steps of fastening are described below.

(1) A HOB 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 fractured, 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 HOB.

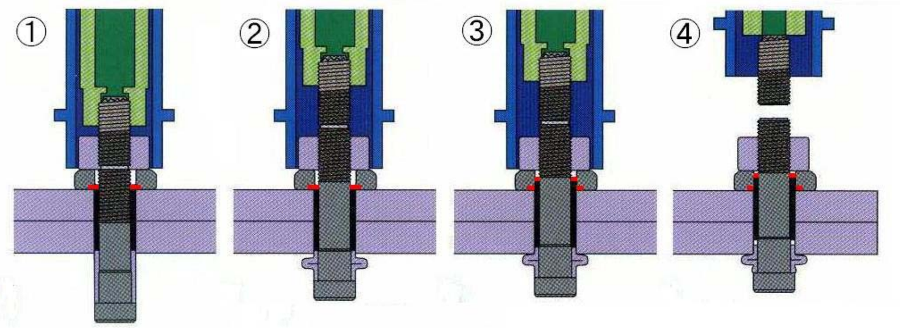

Figure 2 Outline of fastening of high-strength one-side bolt

3. Slip experiments

3.1 Experimental procedure

Specimens were developed simulating the connection of a box column (t = 22 mm, SN490B) (Figure 3).

The friction surface was subjected to either shot blasting or grit blasting. Surface roughness was set at 50 μm Rz or higher. Slip experiments were conducted also for standard specimens of high-strength bolted joints (M22-S10T) for comparison with HOB 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 experiments specimens were developed.

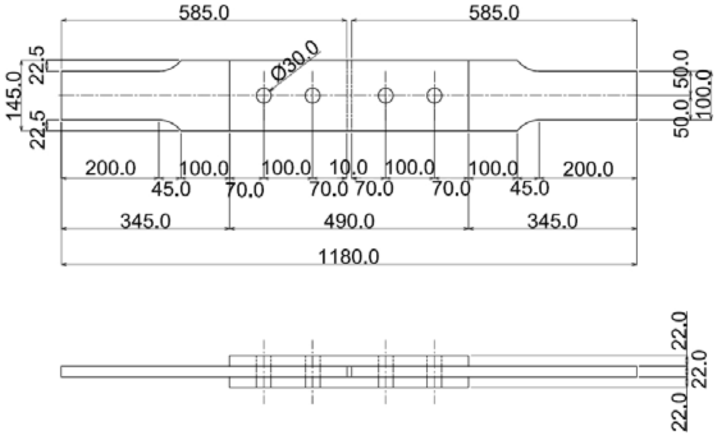

Figure 3 Slip experiments specimen

3.2 Experimental results

Tables 1 through 3 show the results of slip experiments. The slip coefficient for HOB joints (mean of the values for three specimens) was 0.62 for bolts subjected to grit blasting and 0.57 for those subjected to shot blasting. The slip coefficient for high-strength bolted joints was 0.60 (mean of the values for three specimens). All exceeded a slip coefficient of 0.40.

Table 1 High strength one-side bolt (grit blasting)

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

4. Relaxation experiments of Axial force

4.1 Experimental procedure

For obtaining the axial force of the HOB in the relaxation experiments, the train gauge of the axial force embedded in the core pin was measured and the stress-strain relationship and the cross sectional area of the bolt were examined for conversion.

In the fatigue experiment specimen shown in Figure 4, two bolts were fastened first on the inside and then on the outside of the joint. HOB were fastened to the specimen and the axial force was measured until 14 days passed.

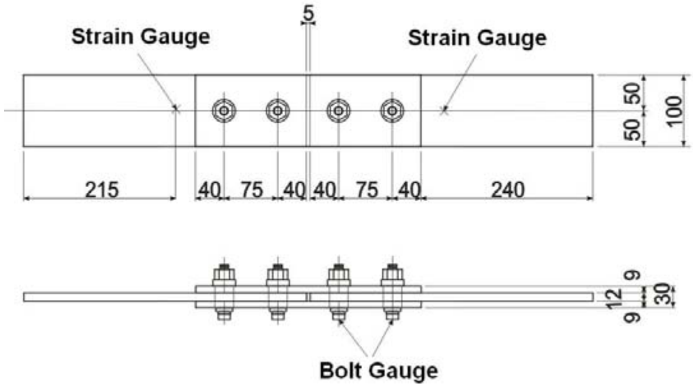

Figure 4 Shape of specimen

4.2 Experimental results

The axial force of HOB and the time elapsed are shown in Figure 4. The bolt axial force dropped drastically in about one day after the bolt was fastened, and was gradually reduced thereafter. After the lapse 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. The results show that the axial force relaxation of HOB was similar to the results of relaxation experiment 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.

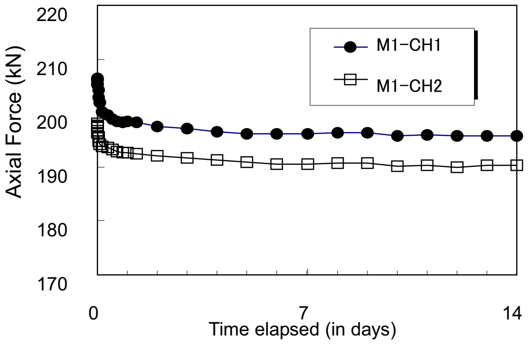

Figure 5 Axial force relaxation

5. Fatigue experiment

5.1 Experimental procedure

Three sets of specimens (M1, M2 and M3) were developed simulating the connection created by double friction (Figure 4). The bolt-hole had a diameter of 26.0 mm. Shot blasting was applied on the friction surface of the base material and splice. A strain gauge was installed 215 mm from the end of the base material, and the stress to be applied in the fatigue experiment was measured in static loading tests. The "Fatigue Design Guidance for Steel Highway Bridges"[7] specifies class B for the strength of high-strength bolted friction 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 HOB friction joints and conventional high-strength bolted friction joints. In the fatigue experiment, an electro-hydraulic servo testing machine of Meisei University (Photograph 1) was used for pulsating tensile fatigue experiment. Tension was applied cyclically at a rate of 6 Hz. Tests were repeated until the fracture of the base material 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 HOB and the mechanical properties of core pin are shown in Tables 5 and 6, respectively.

Photograph 1 Fatigue experiment

Table 4 Mechanical properties of steel plates

	Material	Thickness (mm)	Yield Stress (N/mm^2)	Tensile Strength (N/mm^2)	Elongation (%)
Splice	SS400	9	311	442	29
Base Material	SM400A	12	333	458	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

	Strength (N/mm^2)	Tensile Strength (N/mm^2)	Drawing (%)	Elongation (%)
Standard Value	Min 1006	1118-1216	Min 40	Min 14
Measuement	1111	1195	54	16

5.2 Fatigue experimental results

Figure 6 shows the results of fatigue experiments for HOB friction joints. The figure shows an S-N curve (strength class

B) for conventional high-strength bolted friction joints presented in the “Fatigue Design Guidance for Steel Highway Bridges”[7] .

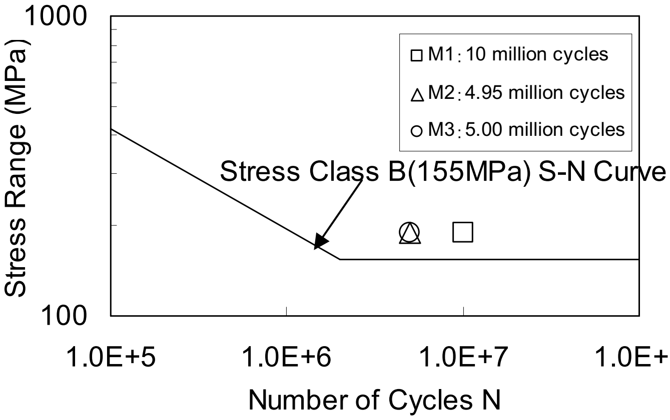

Figure 6 Fatigue experiment results

The stress range for high-strength bolted friction 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 times, the fatigue limit. The results have revealed that HOB friction joints have fatigue strength to greater than that of standard high-strength bolted joints [7].

5.3 Fracture of specimen

In specimen M1, the base material did not fracture until the number of cycles reached 10 million. Then, the test was discontinued. The base material 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.

6. Tensile tests

In order to verify the strength of the HOB after the fatigue experiment, specimens M2 and M3 were dismantled and tensile tests were conducted for bolts. The results of tensile tests for HOB at the time of shipment and after the fatigue test are shown in Table 7.

Table 7 Results of tensile test before and after fatigue test

	Maximum (kN)	Minimum (kN)	Average (kN)
Before Fatigue (N=10)	270.9	269.2	269.9
After Fatigue (N=8)	270.8	269.2	270.0

After the tensile test, HOB 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 HOB after cyclic loading was applied approximately five million times.

7. Case studies of application of HOB

HOB have been frequently used for repairing or strengthening steel highway bridges under construction constraints. In recent years, HOB have been adopted in an increasing number of cases for seismic retrofit of relatively large bridges such as arch and truss bridges. The example is the seismic retrofit of the corner of an arch rib [1], [4] (Photograph 2) and Photograph 3.

Photograph 2 Strengthening a steel arch bridge

Photograph 3 Strengthening a steel arch bridge

Recent works also present case studies of adoption of HOB for strengthen against fatigue cracking at intersection of the U-shaped and transverse ribs of a steel slab [9]. An example of connecting a reinforcing member on the bottom surface of a U-shaped rib of a steel slab using HOB is shown in Photograph 4, and strengthen a steel pipe piar Photograph 5.

Photograph 4 Strengthening a steel slab U rib

Photograph 5 Strengthening a steel pipe piar

8. Conclusions

Tests were conducted to verify the slip factor, relaxation of axial force and fatigue strength, which represent the basic characteristics of high-strength one-side bolted friction joints. Tensile strength after fatigue experimenting was also verified. The findings are described below.

(1) Slip tests were conducted for faying surface that was subjected either to shot blasting or grit blasting. As a result, a slip factor of 0.45 or higher was obtained. Performance grater to that of standard high-strength bolted friction joints can be obtained by properly cleaning the friction surface.

(2) Relaxation of axial force was approximately 5%. The relaxation of axial force of HOB is similar to that for standard 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. HOB friction joints have fatigue design curve to conventional high-strength bolted joints

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

9. Acknowledgment

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