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## EXPERIMENTAL STUDY ON CHARACTERISTICS OF HIGH STRENGTH BLIND BOLTED JOINTS

### BADANIA DOŚWIADCZALNE CECH POŁĄCZEŃ WYKONANYCH ZE ŚRUB JEDNOSTRONNYCH WYSOKIEJ WYTRZYMAŁOŚCI

**Abstract** High strength blind bolts, which enable construction only from one side, are effective for repairing or strengthening closed-section members in existing structures or for connecting box steel pipes in new structures. In this study, experiments are conducted to verify the fatigue strength and other basic characteristics of high strength blind bolted friction joints. As a result, it is revealed that characteristics of high strength blind bolted friction joints are not less than those of joints using conventional high strength bolts.

**Streszczenie** Śruby jednostronne wysokiej wytrzymałości stosowane są w konstrukcjach, do których możliwy jest dostęp tylko z jednej strony. Są one efektywne w przypadku napraw lub wzmocnienia przekrojów zamkniętych w istniejących konstrukcjach lub w przypadku mocowania stalowych rur prostokątnych w konstrukcjach nowych. W niniejszej pracy przedstawiono wyniki eksperymentów przeprowadzonych w celu zweryfikowania wytrzymałości zmęczeniowej oraz innych podstawowych charakterystyk połączeń ciernych wykonanych za pomocą śrub jednostronnych. Ustalono, że charakterystyki połączeń ciernych wykonanych za pomocą śrub jednostronnych są nie gorsze niż charakterystyki połączeń konwencjonalnych wykorzystujących śruby wysokiej wytrzymałości.

#### 1. Introduction

High strength blind bolts, which enable construction only from one side, are effective for repairing or strengthening closed-section members in existing structures or for connecting box steel pipes in new structures. 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. In Japan, 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]. Blind bolts 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 blind bolts 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 former design of steel highway bridges in Japan, considering the effects of fatigue were determined unnecessary unless the steel deck plate or highway bridge also carries street

railway. The occurrence of fatigue cracks, however, reported at numerous positions of steel highway bridges [6] and the increase in fatigue damage was 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 blind bolted friction joints in the Guidance[7].



Figure 1 Components of high strength blind bolt

In this study, experiments are conducted to verify the slip coefficient, relaxation of axial force of blind bolts and fatigue strength, which represent the basic characteristics of blind bolted friction joints.

## 2. Outline of High Strength Blind Bolt

### 2.1 Characteristics of blind bolt

The components of a blind bolt are shown in Figure 1. Six parts constitute a blind 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.

Blind bolts 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 a blind bolt is outlined in Figure 2. The steps of fastening are described below.

- 1) A blind bolt is inserted into the bolt hole and fastening is started using a special 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 core pin 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 core pin 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 blind bolts.

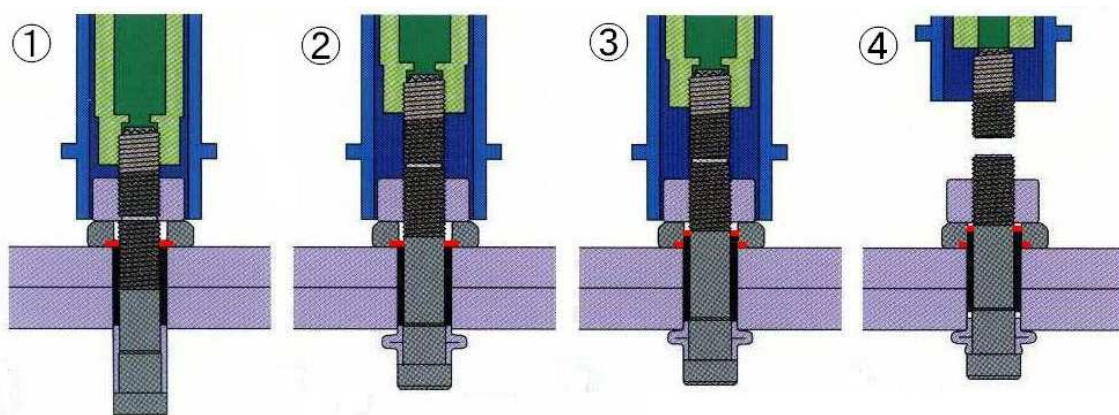


Figure 2 Outline of fastening of high-strength blind bolt

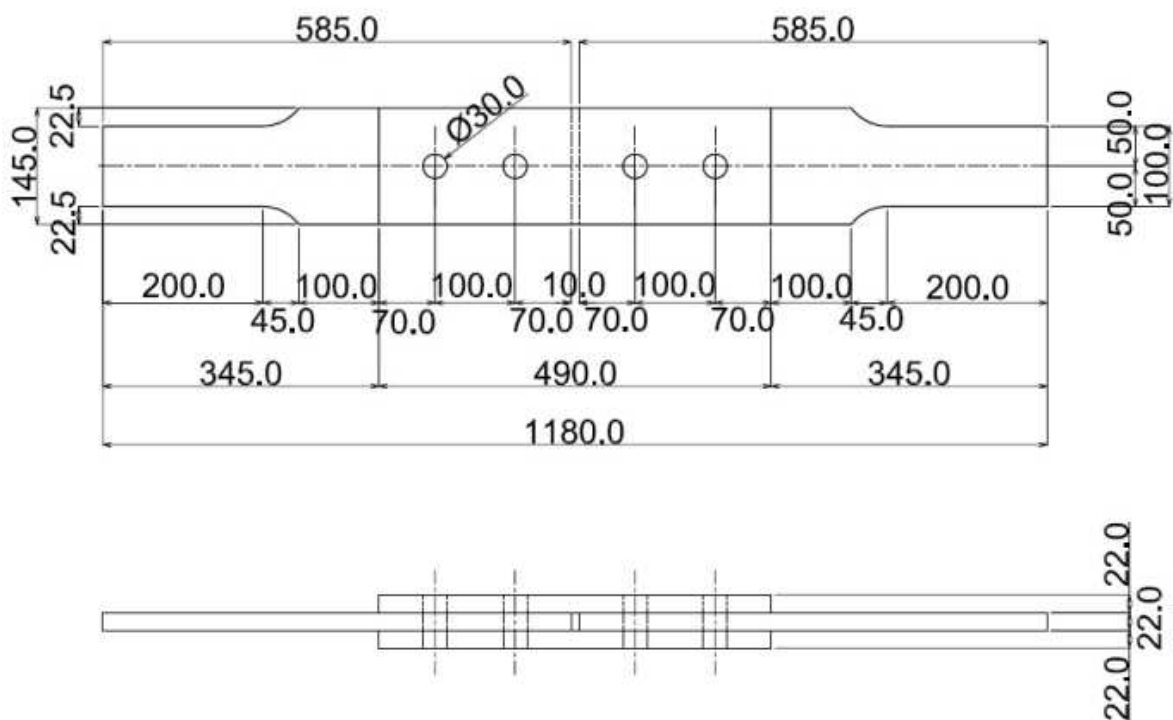


Figure 3 Specimen configuration

### 3. Slip Tests

#### 3.1 Test procedure

Specimens is shown in Figure 3. Material of specimen is SN490B. The friction surface was subjected to either shot blasting or grid blasting to set surface roughness at  $50 \mu\text{m Rz}$  or higher. Slip tests were conducted also for specimens of conventional high-strength bolted joints (M22, S10T) for comparison with blind bolted joints. The load under which clear slip sound was created was defined to be the main slip load. Three specimens per one type were tested.

### 3.2 Test results

Tables 1 through 3 show the results of slip tests. The slip coefficient for blind bolted joints (average of three specimens) is 0.62 for joints subjected to grid blasting and 0.57 for those subjected to shot blasting. The slip coefficient for conventional high-strength bolted joints is 0.60 (average of three specimens). All exceeds slip coefficient of 0.40 in Specifications for Highway Bridges in Japan.

Table 1 High strength blind bolt (grid blasting)

	Specimen No-1	Specimen No-2	Specimen No-3
Slip Load (kN)	710	759	707
$\mu$	0.610	0.652	0.607

Table 2 High strength blind bolt (shot blasting)

	Specimen No-1	Specimen No-2	Specimen No-3
Slip Load (kN)	682	622	698
$\mu$	0.586	0.534	0.600

Table 3 High strength bolt (shot blasting)

	Specimen No-1	Specimen No-2	Specimen No-3
Slip Load (kN)	575	550	531
$\mu$	0.625	0.598	0.577

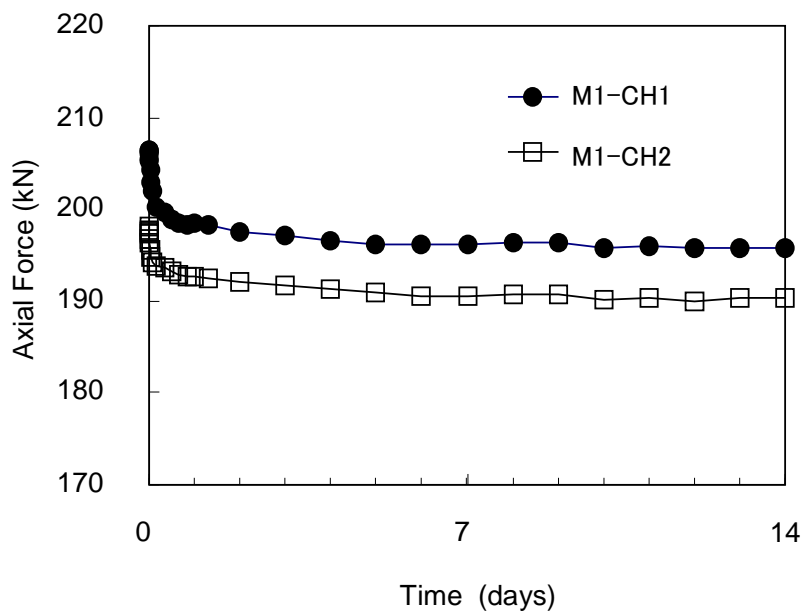


Figure 4 Relaxation of axial force

### 4. Relaxation Tests of Axial Force

For obtaining the axial force of the blind bolts in the relaxation tests, the special strain gauge embedded in the core pin. The axial force was measured until 14 days passed.

The axial force of blind bolts and the time elapsed are shown in Figure 4. The bolt axial force drops drastically in about one day after the bolt was fastened, and is gradually reduced thereafter. After the elapse of about one week, the axial force becomes stable at a certain level. At a point when 14 days passed, the reduction of axial force is about 4.5% of that at the time

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

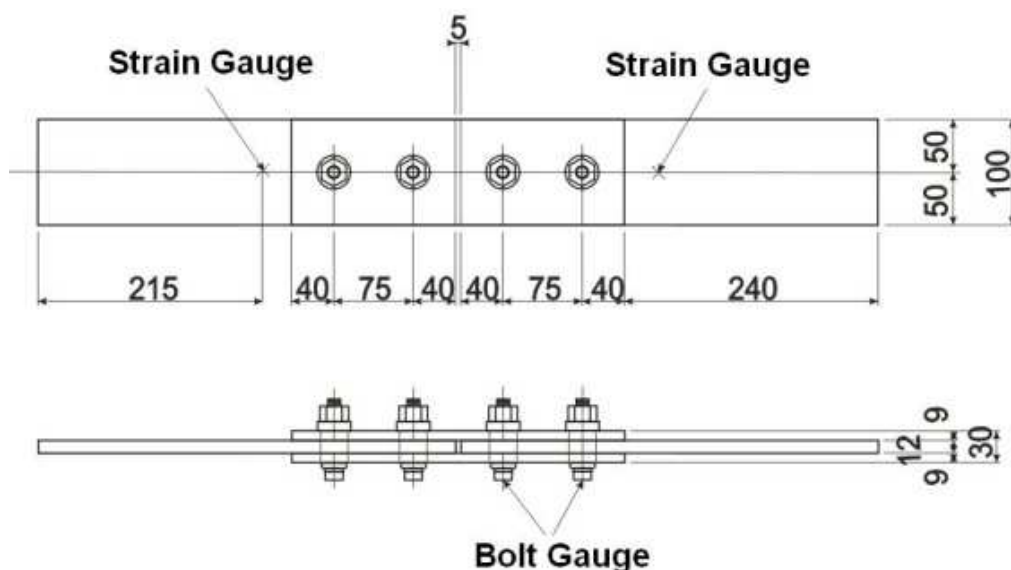


Figure 5 Specimen configuration

Table 4 Mechanical properties of steel plates

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

Table 5 Materials of High Strength blind bolt

Core Pin	Nut	Washer	Shear Washer	Grip Sleeve	Bulb Sleeve
SCM440	SCM440	SCM430	SCM430	SCM430	AISI1018

Table 6 Mechanical properties of core pin

	Proof Stress (MPa)	Tensile Strength (MPa)	Reduction of Area (%)	Elongation (%)
Standard Value	Min 1006	1118-1216	Min 40	Min 14
Measurement	1111	1195	54	16

## 5. Fatigue Test

### 5.1 Test procedure

Specimen configuration is shown in Figure 5. Three specimens (M1, M2 and M3) were tested. The bolt-hole has a diameter of 26.0 mm. Shot blasting was applied on the friction surface of 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. The stress range was set 190 MPa. A rate of cyclic loading was 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 blind bolts and the mechanical properties of core pin are shown in tables 5 and 6, respectively.

## 5.2 Fatigue test results

Figure 6 shows the results of fatigue test for blind bolted friction joints. The fatigue life of average of three specimen is 6.65 million cycles. The “Fatigue Design Guidance for Steel Highway Bridges” [7] specifies class B for the strength of conventional high-strength bolted friction joints and basic fatigue strength of two million cycles is 155 MPa. The S-N curve of strength class B is also shown in Figure 6. In the tests, however, stress grade was raised to class A and the applied stress range was set 190 MPa. 190 MPa is basic fatigue strength of two million cycles of the class A. In spite of having raised the applied stress range to 190 MPa, number of cycles to fracture was 3.3 times of two million cycles which is a standard of the number of cycles in basic fatigue strength. The number of cycles can be converted under a certain condition using a formula specified in the “Fatigue Design Guidance for Steel Highway Bridges” [7]. It becomes 1.8 times if the number of cycles of stress range of 190 MPa is converted into the number of cycles of stress range of 155 MPa. That is, 6.65 million cycles in 190 MPa turn into 12 million cycles in 155 MPa. The results reveal that fatigue strength of blind bolted friction joints is not less than that of conventional high-strength bolted joints [7].

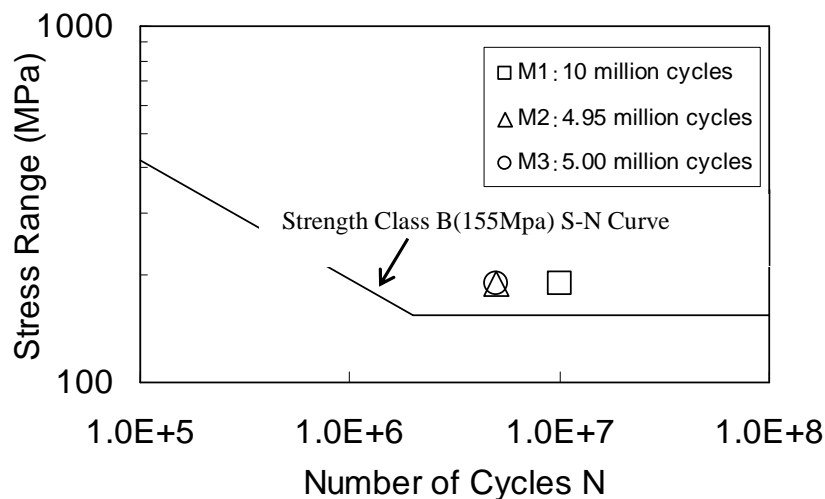


Figure 6. Fatigue test results

## 5.3 Fracture of specimen

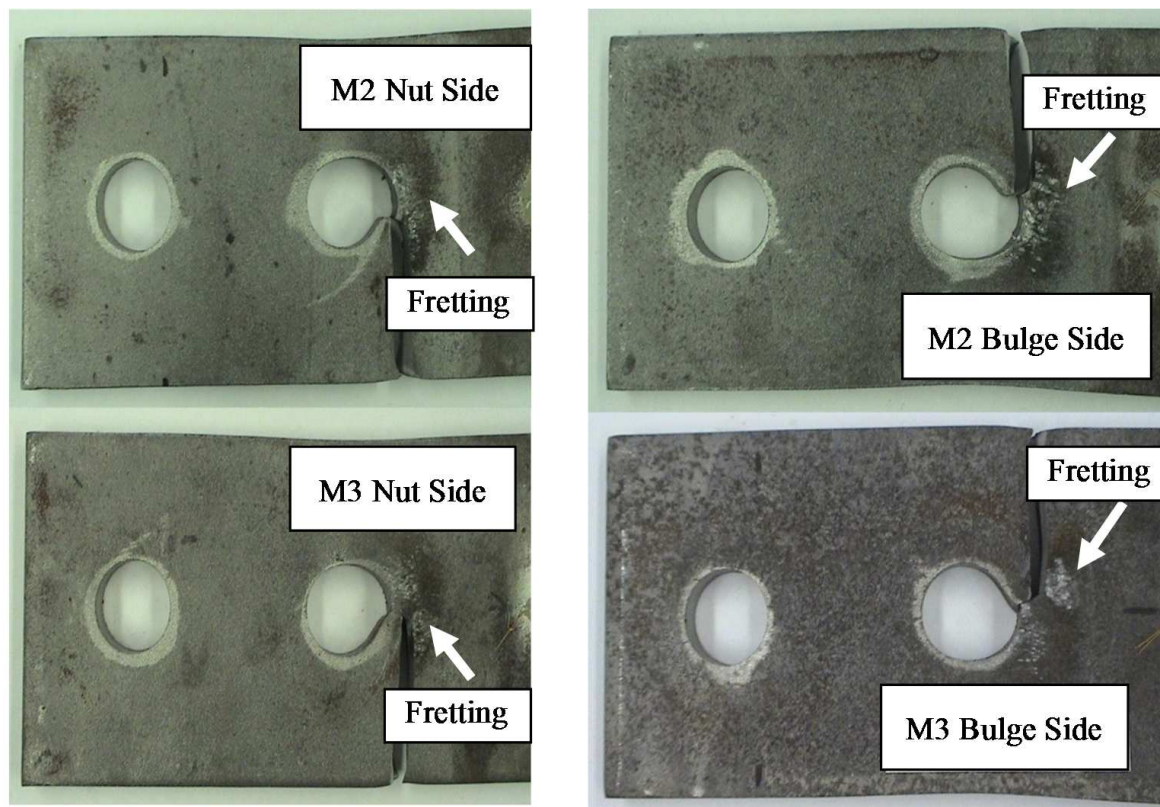
In specimen M1, the base plate did not fracture until the number of cycles reached 10 million. Then, the test was discontinued. The base plate fractured from around the bolt-hole along the width of the plate after approximately 4.95 million cycles in specimen M2 and after approximately 5.00 million cycles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

Photographs 1 and 2 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 near 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.

## 6. Tensile Tests

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

After the tensile test, blind bolts 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 is verified that no strength reduction occurs in blind bolts after cyclic loading was applied approximately five million times.



Photograph 1 Fracture of base material (Nut side) Photograph 2 Fracture of base material (Bulge side)

**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

### 7. Conclusions

Tests were conducted to verify the slip factor, relaxation of axial force and fatigue strength, which represent the basic characteristics of high-strength blind bolted friction 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 grit blasting. As a result, a slip factor of 0.45 or higher was obtained. Performance similar to that of conventional high-strength bolted friction joints can be obtained by properly blasting the friction surface.
- 2) Relaxation of axial force was approximately 5% after 14 days. The relaxation of axial force of blind bolts is similar to that of conventional high-strength bolts. No special consideration is required for the design axial force or the axial force to be introduced.
- 3) Fatigue strength of blind bolted friction joints was similar to that of conventional high-strength bolted joints.

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

### **Acknowledgment**

This bolt are a patent of Huck International, Inc in USA. In addition, Fuserashi co., LTD produces it in Japan. The authors would like to express their gratitude to the staff concerned of Fuserashi Co., Ltd. for providing high-strength blind bolts and supporting in tensile tests.

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