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Structural Behavior of Bolted Joints in Metal Construction

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Abstract— **In bolted joints of non-structural exterior walls to structural frames, slotted holes are often used to improve the workability. In this study, monotonic tension tests of bolted connections which are specific to non-structural components were carried out. From the test results, it was found that the slip coefficient of slotted holes was evaluated from 0.70 to 0.80 times as much as that of conventional holes.**

I. Introduction

In recent years, it is realized that in order to continually use a building after being hit by an earthquake, the seismic performance of non-structural components should be improved. As the non-welding type of metal exterior wall (Fig. 1), the bolted connection has been widely studied because it is more appropriate to guarantee the quality and structural performance. Unlike the main structural members, these non-structural components require the use of slotted holes to accommodate the construction error. Also, the surface is often treated to improve corrosion- and rust-resistance. Moreover, the force given to tighten the bolt cannot be controlled accurately in the site. Based on these backgrounds, it is necessary to build a method to secure the structural safety in the metal construction of non-structural components.

In this paper, a slip coefficient evaluation test on bolted connection is described. From the experimental results, the effect of bolt-hole-shape, surface treatment, and initial tension of bolts to the mechanical behaviour of bolted joints are evaluated.

II. Experimental Plan

A. Specimen

The overview of the test setup and standard specimen (Type 1) are shown in Fig. 2. The specimens symbolise bolted connections commonly adopted for the metal exterior wall. The bolted connection consists of an inner plate, two outer plates, and one or two bolts. The thickness of inner plate is 12 mm and that of outer plate is 6 mm. The width of both plates is 65 mm[1]. Considering joints for non-structural components, the steel grade for general steel structure (SS400; F_y=235 N/mm^2) or austenitic stainless steel (SUS304; F_y=255 N/mm^2) is used. Five kinds of surface treatments are chosen, i.e., hot dip galvanizing (HDZ), HDZ with phosphate coating (HDZP), electroplated zinc colored chromate coating (EP), EP with rust resisting paint (EPJP), and satin finished de sign coating of stainless steel (SUS). High-strength bolt with diameter of 12 mm (M12) and tensile strength of over 800 to 1000 N/mm2 (F8T) is used in this test.

B. Test parameter

In addition to surface treatment, the other test parameters are shape of bolt holes and initial tension of bolts. The specimen classification according to the shape of bolted holes is shown in Fig. 3. First, Type 1 in Fig. 2 has the dimension based on *Recommendation for Design of Connections in Steel Structures*[1]. Type 1 is prepared for every surface treatment type and it is a benchmark to evaluate the mechanical behaviour. Whereas, in metal construction, the number of bolt hole in the stress direction is mostly one and the slotted hole is used. Hereinafter, the slotted hole whose long diameter is parallel with the stress direction is called " vertical slotted hole" and the other one whose long diameter is orthogonal with the stress direction is called "horizontal slotted hole". Major diameter of slotted holes has a plus or minus 15 mm (3*d*) to accommodate the construction error of building frames. To verify the influence of the bolt-hole-shape in the stress direction, one round hole is provided in the outer plates for Type 2 (Fig. 3. (a)), and in a similar way, one vertical slotted hole and one horizontal slotted hole is provided in the outer plates for Type 3 (Fig. 3. (b)) and Type 4 (Fig. 3. (c)) respectively. By comparing these

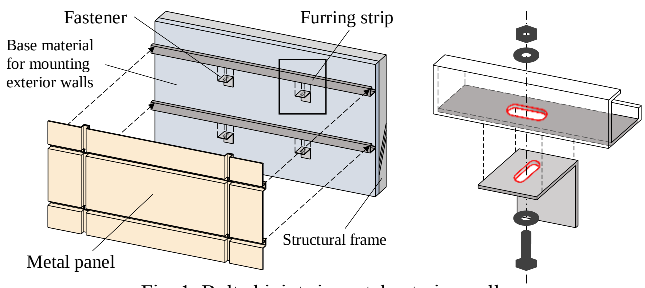


Fig. 1 Bolted joints in metal exterior wall

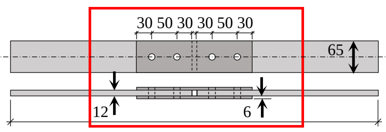
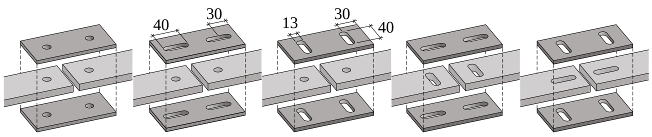


Fig. 2 Standard specimen (Type 1)

TABLE I
Specimen List

Type	Surface treatment				
	HDZ	HDZP	EP	EPJP	SUS
1	5	5	5	5	5
2	5	-	-	-	-
3	5	-	-	-	-
4	5	-	-	-	-
5	5	5	5	5	5
6	5	5	5	5	5



(a) Type 2 (b) Type 3 (c) Type 4 (e) Type 5 (f) Type 6

Fig. 3 Shape of bolted hole

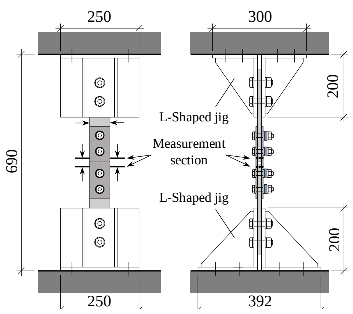


Fig. 4 Setup

parameters with the standard specimen, the effects of the slotted hole and the number of bolted hole in the stress direction can be confirmed. Considering the actual bolted connection in the metal exterior wall, the specimen Type 5 and Type 6, which have slotted holes in both outer plates and inner plates, are introduced. The test specimen list is shown in TABLE 1. In this table, the rows show six types of specimens while the columns show the surface treatment types of the specimens. For each combination of the bolt-hole-shape and the surface treatment, five same specimens are prepared. Then, these five specimens are tested with the five different level of initial tension of bolts, which is 10, 20, 30, 40, and 50 kN. These variation of values are considered because initial tension cannot be strictly controlled in the actual construction sites. The upper limit is chosen by referring to the standard bolt tension of 50.38 kN for M12 high-strength bolt.

C. Setup

The upper and lower part of the specimen respectively is fixed to the test machine through the L-shaped jigs as shown in Fig. 4. In the experiment, firstly, two inner plates are connected to L-shaped jigs. After that, the outer plates are fastened using the M12 high-strength bolts. The test is a monotonic tensile test. The loading is continued until the bolted joints start to slip and a decrease of strength after the maximum strength is confirmed. The loading rate until slip amount of 0.2 mm is set to 0.1 mm/min; and beyond 0.2 mm, it is set to 2.0 mm/min.

D. Measurement plan

During the experiment, the tensile force P is measured by the load cell incorporated in the test machine. The relative displacement between the inner plates and outer plates is measured on the upper and lower parts, and on the front and back sides, resulting in the total of eight points. In addition to these, when the inner plate and outer plates are connected, the initial tension of bolts is measured by the washer-type load cells. It is inserted between the nut and the outer plate through the upper and lower washers. The slip coefficient μ is calculated by the following equation using the slip proof strength P_s obtained experimentally.

$$\mu = \frac{P_s}{m(N_{01} + N_{02})} \qquad (1)$$

m : the number of friction surface

N_{01}, N_{02} : the initial axial tightening forces

III. Conclusion

A. Slip coefficient and shape of bolted holes

The slip coefficient for each combination of surface treatment and shape of bolted hole is shown in Fig. 5. The vertical axis of the figure is the slip coefficient and the horizontal axis is the shape of bolted holes. Further, ● represents each experimental data and ● represents the average value of each combination of surface treatment and shape of bolted holes. Although experimental results are very uneven, the slip coefficient of Type 1 is the largest in most cases of the surface treatment types. In case of HDZ type, the slip coefficient of Type 2 is nearly equal to that of Type 1. On the other hand, the slip coefficient of other type specimens, which have slotted holes, is lower than that of Type 1. These trends are similar regardless of the difference in the surface treatment types, except for the EP type. Moreover, in order to consider the reduction of the slip coefficient due the shape of bolted hole, Fig. 6 shows the standardized experimental results normalized by the average slip coefficient of Type 1. The reference[1] introduces a reduction factor of 0.7 on condition that the major axis of slotted hole is within 2.5d. The range that fulfills the requirement of this reduction factor is

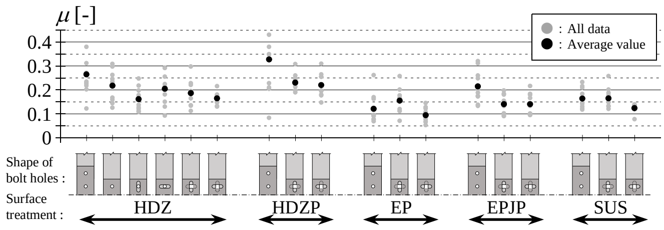


Fig. 5 Slip coefficient

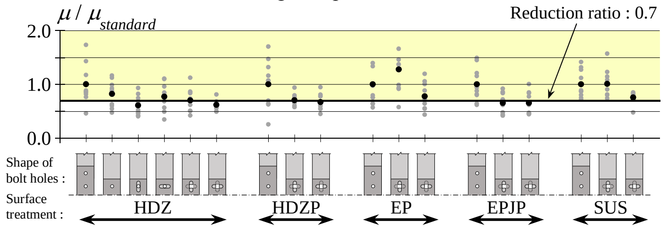


Fig. 6 Test results standardized by slip coefficient of standard specimen

hatched in yellow in the Fig. 6. In every surface treatment, the average slip coefficient of Type 5 and Type 6 is more than or around 0.7 times that of the standard specimen Type 1.

B. Slip coefficient and shape of bolted holes

The relationship of slip coefficient and surface roughness is shown in Fig. 7. The vertical axis of this Figure is slip coefficient and the horizontal axis is maximum height roughness R_z, which is one of the parameters of surface roughness. There are the data not only from this test but also from previous studies[2]-[4] in Fig. 7. Moreover, the blue solid line shows the regression equation by the previous research[2].

$$\mu = 0.26 + 0.004R_z \qquad (2)$$

The dashed line is 0.7 times of Eq. (2) as the reduction factor of slotted holes. For steel members in Japan, 0.45 or more slip coefficient and 50 μm or more R_z should be ensured. From this Figure, the slip coefficient and surface roughness in the metal components are found to be about half of those in the steel structural components without regard to the surface treatments.

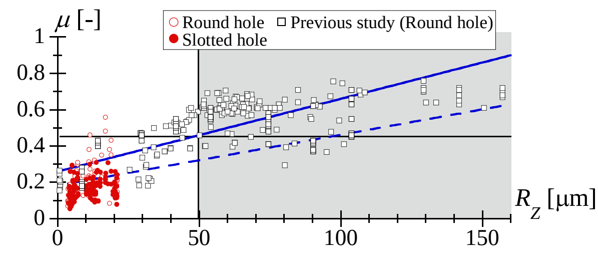


Fig. 7 Relationship of slip coefficient μ and surface roughness R_z

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