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Study on improving the slip strength of long high-strength bolted frictional joint with bearing-type bolts

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1. Introduction

In recent years, due to the increase in load and the need for rationalization of steel components, there has been a tendency for High-strength bolt (HSB) frictional joints to become larger and longer.[1] In contrast, as the length of the joint increases, the actual force that can be withstood is less than the design strength because the load sharing of bolts within the joint becomes uneven. On the other hand, due to the presence of the secondary member in steel structure, there are many cases where the bolted joint splice plates are too long and cannot be installed.

To resolve this problem, we propose a method to improve the slip strength of a long friction-bolted joint by combining it with a bearing-type joint (hereafter referred to as the hybrid joint). For hybrid joints, previous studies[2] have shown the possibility of combining friction-type bolts and bearing rivets. However, the riveted joints have low and uncontrollable slip coefficients that make it difficult to effectively design hybrid joints with friction-type bolts and rivets. The present study focused on the slip strength of the hybrid joint, and a finite element (FE) analysis was performed to clarify the slip strength and the possibility of shortening the long bolted joint length.

2. FE analysis

A general-purpose structural analysis software, Abaqus / Standard 2020 was used to perform three-dimensional elasto-plastic finite displacement analysis.

2.1. Introduction of the model

The analytical model is based on a 12-row bolted friction joint, as shown in Figure 1. The thickness of the main plate was 75 mm, that of the splice plates was 38 mm, the load was applied by forced displacement from the edge, and the analysis was set up as a one-half model with the center of the joint in the longitudinal direction as the axis of symmetry. The mesh division of the analytical model is shown in Figure 2. Three-dimensional eight-node solid elements with reduced integration (C3D8R) are used for the model.

All the material properties were modeled using a trilinear model with a quadratic gradient of $E/100$, and the ultimate strength was considered as shown in Table 1.

For boundary nonlinearity, contact was modelled using the penalty method and friction was modeled using isotropic Coulomb friction. The analysis was based on the specifications for road bridges, and the friction coefficient was set to a minimum value of 0.4. The original case's ratio β of design slip strength and design cross-section yield strength was 0.85.

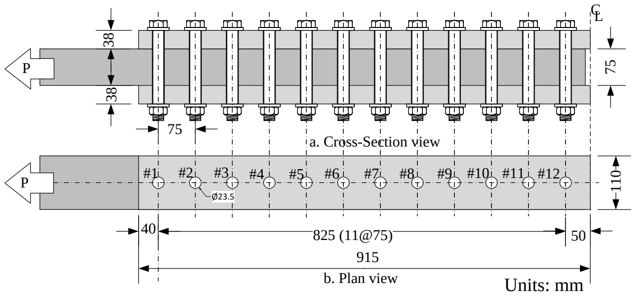

Figure 1: Dimensional drawing of the original case

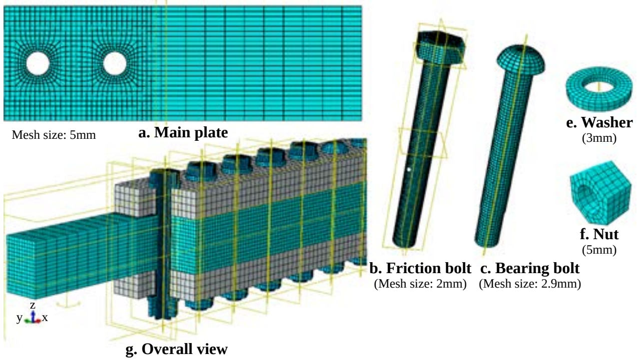

Figure 2: Schematic illustration of the FE model and mesh

Table 1: Summary of material properties $[N/mm^2]$

Member	Material	Yield strength σ_y	Ultimate strength σ_u
Plate	SM490Y	355	490
HSB	F10T	900	1090

Table 2: Summary of FE cases

	Fastener number (#)											
	1	2	3	4	5	6	7	8	9	10	11	12
Original	○	○	○	○	○	○	○	○	○	○	○	○
B1#1	⚙	○	○	○	○	○	○	○	○	○	○	○
B1#6	○	○	○	○	○	⚙	○	○	○	○	○	○
B1#12	○	○	○	○	○	○	○	○	○	○	○	⚙
B2	⚙	○	○	○	○	○	○	○	○	○	○	⚙
B4	⚙	⚙	○	○	○	○	○	○	○	○	⚙	⚙
B12	⚙	⚙	⚙	⚙	⚙	⚙	⚙	⚙	⚙	⚙	⚙	⚙
R10B2	⚙	○	○	○	○	○	○	○	○	⚙	-	-
R10B4	⚙	⚙	○	○	○	○	○	○	⚙	⚙	-	-

○: Friction bolt, ⚙: Bering bolt

2.2. FE cases

The analysis cases are listed in Table 2. The parameters were the placement of the bearing-type bolt and friction-type bolt, and number of row in the hybrid joint. B1 represents the number of bearing-type bolt was used is 1, B1#1 represents the bearing-type bolt installed in bolt #1. In B2, the outer #1 and inner #12 are placed on the bearing-type bolt.

Keywords: Long bolted joint, High-strength bolt, Bearing-type bolt, Hybrid joint, Finite element analysis

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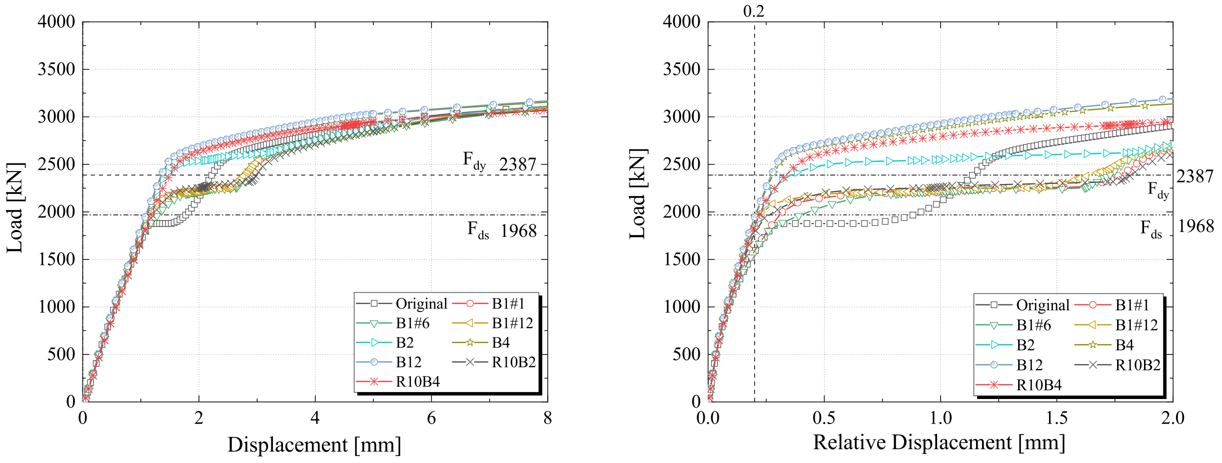

(a) Total displacement (b) Relative Displacement

Figure 3: Relationship between load and displacement
(F_{dy}: Design cross-section yield strength, F_{ds}: Design slip strength of Original case)

3. Results and discussion

3.1. Displacement of joint

Slip load is defined as the load when the relative displacement reaches 0.2 mm. where the relative displacement for the main and splice plates was measured from a position 20 mm from the center of the joint.

The relationship between the total displacement of the joint and the load is shown in Figure 3(a), where the total displacement was determined from the front end of the main plate. From Figure 3(a), it can be seen that all cases have almost the same overall initial stiffness. However, the gradient change points of the curves differed from each other. The first case to show a nonlinear change was the original case, then was the case with 1 bearing-type bolt. The gradient change point is the same in the B4 and B12 case due to the cross-sectional yielding was first occurred.

Since the joints end up with cross-sectional failure, the stiffness converges to the same value after slip occurs. We also found that the clamping force fasting of the bearing-type bolts slightly increase the slip load but has little effect on the overall load sharing.

The relationship between the relative displacement and load of the joint is shown in Figure 3(b). Due to the unbalanced load share, the original case experienced load decrease (1858 kN) before it reached the designed slip strength (1968 kN), and the slip load of original case was 1594 kN when the relative displacement was $0.2mm$. However, the hybrid joint (B2 to R10B4 case) did not experience load decrease, and the nonlinear change in the curve occurred at approximately 2387 kN, which can be judged as a change in gradient because of the yielding of the cross-section.

3.2. Slip load of each case

The relationship between the slip load/designed slip strength for each case is shown in Figure 4. From the results of the present analysis, all cases of hybrid joints, except B1, improved the slip load of the original case, which is a long-bolted friction joint. Among them, the R10B2 case, which shortens the joint length to 10 rows, also has a 10% higher slip load than the long frictional bolted joint (Original) due to the load transmit mechanism is friction-bearing hybrid, and the local slip would not occur.

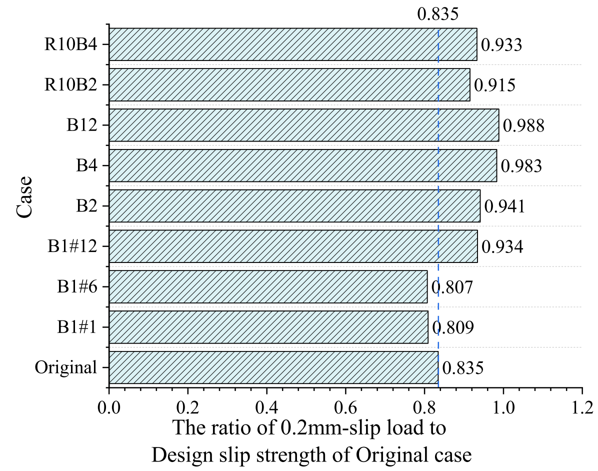

Figure 4: The ratio of 0.2mm-slip load to Design slip strength of Original case

4. Conclusions

In this study, we propose a method to improve the slip strength of a long friction-bolted joint by combining it with a bearing-type joint. Based on the obtained results, the following conclusions were drawn.

1. The hybrid joint which was installed bearing-type bolts at each end of the joint would not occur slip locally, therefore the hybrid joint has a higher slip load than the long frictional bolted joint.
2. Due to the friction-bearing hybrid load transmit, even though the long bolted joint length shortens to 10 rows hybrid joint, the hybrid joint has a 10% higher slip load than the long bolted frictional bolted joint. It can be concluded that the shortening of the long bolted joint length can be realized by installing the bearing-type bolts.

Acknowledgment

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References

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