Experimental study on the slip strength of friction bolted joint combined with knurling bearing-type bolt

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1. Introduction

In recent years, there has been a trend towards larger and longer High-Strength Bolt (HSB) friction joints, due to increased load and the need for rationalization of steel components.[1] However, as the joint length increases, the actual force that can be supported is less than the design strength, because the load sharing of bolts within the joint becomes uneven. Additionally, many steel structures have secondary members that make it difficult to install splice plates for bolted joints that are too long.

To address this issue, we referred to previous research[2] on rivet-bolt combined joints and proposed a method for enhancing the slip strength of a long friction-bolted joint by combining it with a bearing-type joint, which we refer to as the hybrid joint. In this study, we focus on the slip strength of the hybrid joint and perform an experiment to clarify its slip strength and the possibility of shortening the length of the long bolted joint.

2. Experiment

2.1. Specimen dimension

The specimen was designed as a single column of 10 rows as shown in Fig.1, and the size was reduced to 16/22 due to the loading capacity of the universal testing machine (max 2000kN). An M16 bolt was used instead of an M22 bolt. The friction-type bolt used was the common hexagonal M16(F10T), and the bearing-type bolt used was the knurling-bolt with M22(B10T) as shown in Fig.2. For friction-type M16 bolts, the bolt hole diameter was set at 17±0mm, and for the bearing-type bolts, the bolt hole diameter was set at 23.5±0mm, which is equal to the outer diameter of the bearing bolt. Although the sizes of the bolts were different, the M22 bearing-type bolt was tensioned with the same design axial force as the M16 bolt (i.e. 116 kN) in this experiment.

The main and splice plates of the specimen were made of SM570 steel, and the material characteristics of the steel were obtained through material testing, as shown in Table1.

2.2. Case

The experiment case is shown in Table2. Hybrid case refers to the arrangement of two bearing-type knurling bolts at each end of a joint. Hybrid-NAF refers to the base hybrid case, where the bearing-type bolt did not tension any axial force. The design strength of the original friction joint is shown in Tab.3. The design slip strength was calculated using the bolt axial force before loading, and the slip coefficient was determined using the standard slip test.

2.3. bearing status

As shown in Fig.3, Cross-sectional cutting was performed on the installed bearing-type bolt to confirm whether it was in a bearing state (with the axis closely adhering to the hole wall) before loading. The knurling part has undergone good plastic deformation, so it can be confirmed that it is tightly adhered to the hole wall. However, the area of adhesion is only the deformed part.

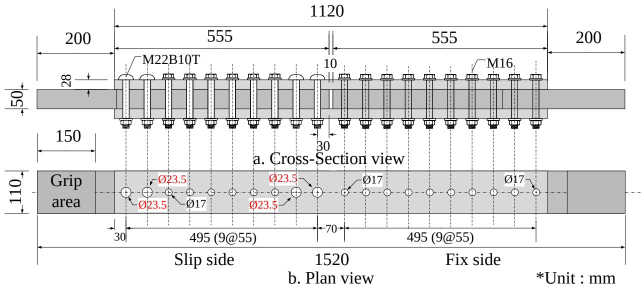

Figure 1: Dimensional drawing of the original case

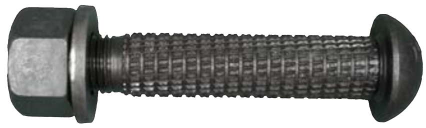

Figure 2: Knurling bearing-type bolt (Made by Kobelco Bolt, Ltd.)

Figure 3: Bearing status when drill in the knurling bolt

Table 1: Material testing results (SM570)

Thickness [mm]	Yiled Strength $[N/mm^2]$	Ultimate Strength $[N/mm^2]$	Elongation [%]
t50	548.6	635.5	26
t28	529.5	619.5	46

Table 2: Summary of experiment specimens bolt arrangement

	Bolt number (#)									
	1	2	3	4	5	6	7	8	9	10
Friction	○	○	○	○	○	○	○	○	○	○
Hybrid	✿	✿	○	○	○	○	○	○	✿	✿
Hybrid-NAF	✿	✿	○	○	○	○	○	○	✿	✿

○: Friction-type bolt, ✿: Bering-type bolt

Table 3: Design strength of friction joint

	Slip coefficient	Design slip strength F_{ds}	Cross-section yiled strength F_{dy}	β
Slip side	0.8	1716	1953	0.65
Fixed side		1856	1953	0.85

Keywords: Long bolted joint, Bearing-type bolt, hybrid joint, High strength bolt, Knurling bolt
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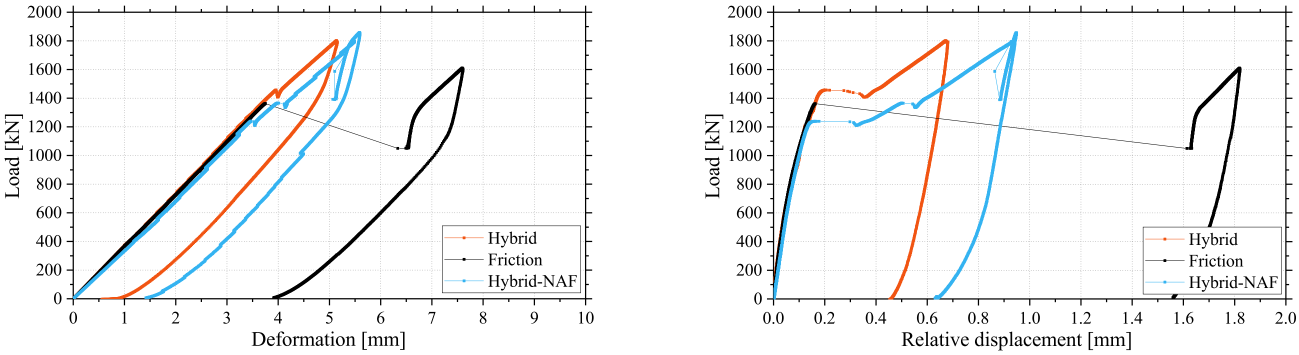
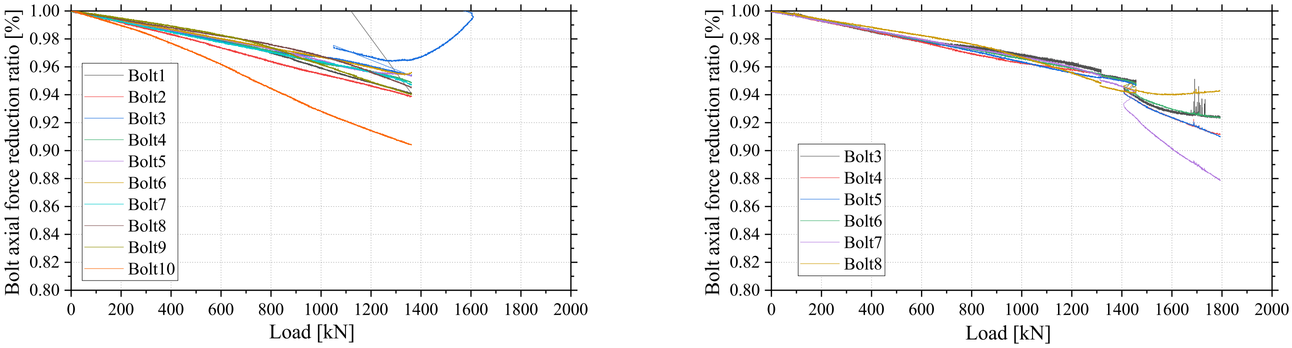


(a) Deformation of joint (b) Relative displacement

Figure 4: Relationship between load and deformation / relative displacement



(a) Friction bolted joint (b) Hybrid joint

Figure 5: Relationship between load and bolt axial force reduction ratio

3. Results and discussion

3.1. Deformation and Relative displacement

Fig.4 shows the each case's relationship between load - deformation of joint and load - relative displacement. The deformation refer to the whole joint deformation. The relative displacement was taken from the side of the main plate and the splice plate at the center of the joint's #10 bolt. As shown in Fig.4(b), all three specimens had almost the same initial stiffness, which can be attributed to the dominant role of friction resistance at the interface before slip occurred. The friction specimen experienced major slip near 1360 kN, and the relative displacement reached about 1.4 mm. Since the clearance between the bolt and the bolt hole wall was 1 mm, it can be assumed that the friction joint immediately entered a bearing state after the major slip occurred.

For hybrid joints, their initial stiffness is the same regardless of whether the axial force is tightened. However, they experience load reduce and slip-like phenomena after reaching a certain load (Hybrid is 1456kN, Hybrid-NAF is 1239kN). Before the load increases, the slip displacement is only 0.2mm, which may be due to further plastic deformation of the bearing-type bolt's knurling part. The specific reason for this needs further confirmation.

The slip load of hybrid joints with bolt axial force was at least 10% large than friction case. And hybrid joint have almost no significant deformation in terms of the entire joint's deformation. After the load reduction occurs, the joint's stiffness remains unchanged until it is manually unloaded as shown in Fig.4(a).

3.2. Bolt axial force

Fig.5 shows the relationship between the bolt axial force reduction rate and load for friction joints and hybrid joints. The bolt reduction rate is obtained by dividing the current axial force by the axial force when the load is 0kN. From the Fig.5, it can be found that due to uneven load distribution of friction joint, the reduction degree of each bolt load is different, especially the #10 end bolt, which drops quickly due to the decrease in the net cross-section of the steel plate. When the major slip occurs, the strain gauge attached to the bolt axis is damaged and the data cannot be obtained. On the other hand, the axial force reduction of each bolt in the hybrid joint is relatively uniform. When the load is around 1200kN, almost all friction bolts have dropped to 96%. When the load reaches 1456kN (when the load was reduction), although the trend of bolt axial force changes, there is no drastic change.

4. Conclusion

This study result that for hybrid joints, the slip load was about 10% large than the friction case, and after slip the changes in stiffness are also small. Future research will clarify the serviceability limit state of hybrid joint and further parameter study analysis of the bolt configuration will be conduct.

Acknowledgment

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References

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[2] Y. Chen, T. Yamaguchi, M. Yamauchi, K. Ueno, and G. Hayashi, "Study on the mechanism of load transferring of riveted joints with high strength bolts as frictional joints," *Journal of Steel Construction engineering (in Japanese)*, vol. 29, pp. 1–14, 3 2022.