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BEHAVIORS OF SLIP-CRITICAL BOLTS IN COMBINATION WITH FILLET WELDS

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According to the Specification for Structural Steel Buildings (AISC 2010), slip-critical bolts can only share load with longitudinal welds in a joint. Moreover, the bolt available strength shall not be taken greater than 50% of the bearing-type. This paper presents the result of a series of joint tests verifying the specification. The joints were tested in a manner similar to previous work (e.g. Manuel and Kulak 2000). The slip strength values of JIS F10T and F14T bolts were tested and compared. Transverse and longitudinal fillet welds with a leg size of 12 mm and the same amount of weld material were adopted and tested respectively. The strength ratio between bolts and welds changes from 5/8 to 6/9 in the combination joints. The result shows that in the combination with longitudinal welds, the bolts tend to slip and contact the plates, developing greater bearing strength. In the combination with transverse welds, the bolts slip and the pretension decreases greatly. But the combination also causes the fracture surfaces of transverse welds to change, providing additional strength to compensate the decrease in bolt slip strength. The combination joints therefore can develop strength greater than the sum of slip strength and fracture strength.

Keywords: High strength bolt, Fracture surface, Combination joint.

1 INTRODUCTION

High strength bolts and welds are the two important elements connecting steel components. In some cases, these two elements share load in a single joint. Previous work (Manuel and Kulak 2000) indicates that the orientations of fillet welds and bearing conditions of bolts can play key factors determining the extent of load sharing in combination joints. That affects the Specification for Structural Steel Buildings (AISC 2010), in which slip-critical bolts can only share loads with longitudinal welds in a joint. Moreover, the bolt available strength shall not be taken greater than 50% of the bearing-type. But no similar limitations are set in the Recommendation for Design of Connections in Steel Structures (AIJ 2012). Instead, it is recommended to estimate the strength of combination joints by summing up the slip strength and fracture strength, regardless of the orientations of fillet welds. This paper presents the result of a series of joint tests verifying the specification. The joints have been tested in a manner similar to previous work (Manuel and Kulak 2000). In addition, the pretension of bolts is monitored using bolt gauges. The strain measurement will help confirm the extent of pretention loss and bearing conditions of bolts in the combination joints.

2 EXPERIMENT PROGRAM

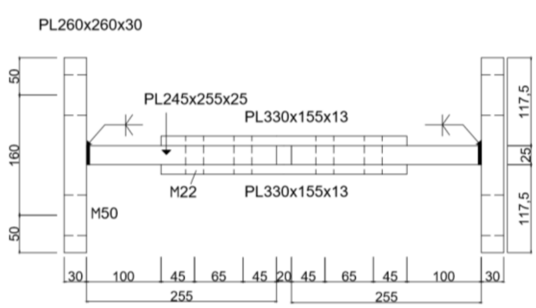
A series of joint tests have been made to investigate the behavior of slip-critical bolts in combination with fillet welds. For comparison, the same types of joint specimens were also used to test the slip-critical strength for high strength bolts and the fracture strength of fillet welds respectively. The experimental setup and specimen details are summarized in the following.

2.1 Experimental Setup

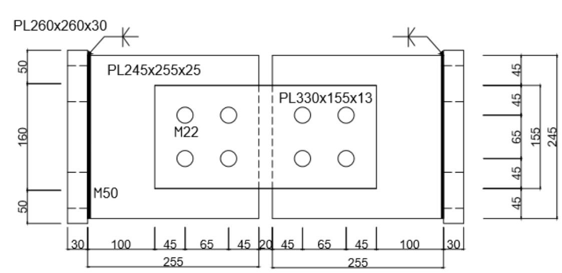
As illustrated by Figure 1(a), three pairs of SM570 steel plates have been used to make a joint specimen. In detail, the 13-mm thick cover plates and 25-mm middle plates are bolted together. In the two ends, the middle plates are welded to the 30-mm thick base plates. That allows fixing the joint specimen and applying tension force in a universal machine. There are total eight bolts arranged in four rows and equally placed in the two parts of the joint specimen, as shown in Figure 1(b). The arrangement allows testing the slip strength of four bolts with two shear planes. The interfaces have been treated using a standard sandblasting process.

For SM570 steel, the nominal values of yield strength and tensile strength are 450 MPa and 570 MPa respectively. As illustrated by the figures, the plate thickness and width of the two cover plates are 13 mm and 155 mm respectively. The yield strength of the cross section was estimated to be 2297.1 kN. As also depicted, there are total eight bolts arranged in four rows. In other words, there are 2 bolts in a row. The bolts have a diameter of 22 mm, and the standard holes have a diameter of 23.5 mm. The plate thickness and width of the middle plates are 25 mm and 245 mm respectively. The fracture strength of net section was estimated to be 2821.5 kN. To avoid the effects of plate yielding or plastic deformation, the max load was controlled under 2000 kN.

The joint strength was measured using the load cell in the universal machine. The relative displacement between cover plates and middle plates (i.e., bolt slip) was measured using two sets of diagauges in the two sides of the joint specimen. The pretension of high strength bolts and the loss were monitored using bolt strain gauges. The weld deformations were also tracked using a 3D optical measurement system.



(a)



(b)

Figure 1. Details of a joint specimen: (a) side view, and (b) top view.

2.2 Specimen Details

The slip strength and deformations were tested for JIS F10T and F14T bolts (AIJ 2012), as shown in Figures 2(a) and (b). Table 1 summarizes and compares the mechanical properties and strength values. In the table, the slip coefficient 0.45 is used to calculate the slip strength and shear strength for one bolt in double shear. As can be seen, the effective areas of the two bolts are slightly different. As also can be seen, for slip strength, the ratio between F10T and F14T bolts approximates to 1.5.

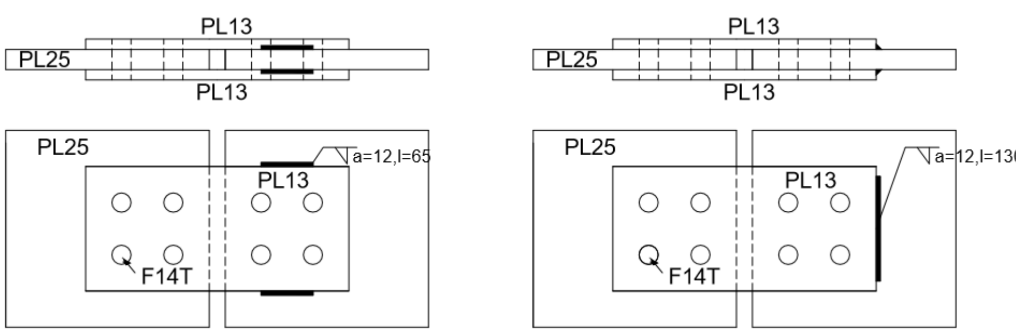
The fracture strength and deformation capacities were also tested for two types of weld joints. As depicted in Figures 2(a) and (b), both the longitudinal weld (WL) and transverse weld (WL) have a leg size of 12 mm. In addition, the weld joints have the total amount of weld material. In detail, the WL specimen has four 65-mm long welds, and the WT specimen has two 130-mm long welds (Figure 3). All the welds were made using KFX-81TN wire, designed for welding for 590 N/mm^2 grade steel with 100% CO_2 gas.

Table 1. Mechanical properties of high strength bolts F10T and F14T.

	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Area reduction (%)
F10T	≧900	1000~1200	≧14	≧45
F14T	≧1260	1400~1490	≧14	≧45
M22	Effective area (mm^2)	Pretension (kN)	Slip strength (kN)	Shear strength (kN)
F10T	303	209	171	439
F14T	316	299	260	639

(a) (b)

Figure 2. High strength bolts: (a) F10T bolt and (b) F14T bolts.



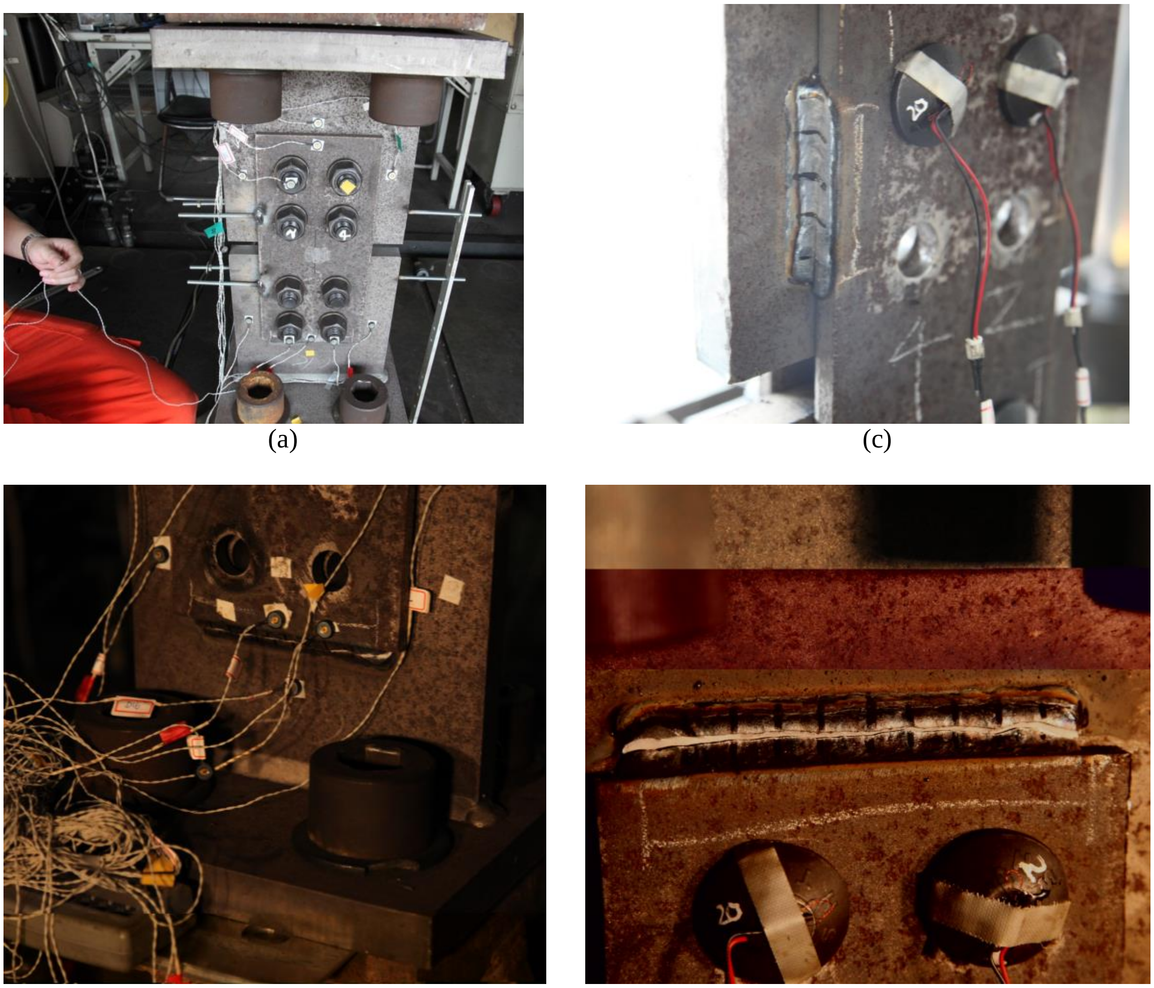
(a) (b)

Figure 3. Details of weld joints: (a) longitudinal weld (WL), and (b) transverse weld (WT).

3 EXPERIMENT RESULTS

3.1 Joint Strength

Using the same types of joint specimens, the slip strength of four bolts and fracture strength of were tested first, as shown in Figure 4(a) and (b). The strength values obtained above were then used to estimate the strength of combination joints. To control the tension force under 2000 kN, the combination joints have two F10T or F14T bolts and longitudinal or transverse welds, as shown in Figure 4(c) and (d). The strength of combination joints was finally verified by testing and compared to the estimation by calculation.



(a) (c)

(b) (d)

Figure 4. Joint tests: (a) a slip-critically F10T bolted joint; (b) a transverse welded joint (WT); (c) a joint of two F14T bolts in combination with longitudinal welds (2F14T+WL); and (d) a joint of two F14T bolts in combination with longitudinal transverse welds (2F14T+WT).

Table 2 summarizes the values of joint strength. In Case (J4), two F14T bolts have been located close to the center of the joint specimen, as shown in Figure 4(d). In the case (J5) and the other cases, as shown in Figure 4(c), the two bolts were placed near the base plates. Comparing the strength values of Cases (J4) and (J5) enables to know that the location of bolts can only make a small difference. In Case (J3), one of the four longitudinal welds has a fracture failure at an early stage. In this case, the combination joint cannot develop a strength larger than the sum of slip strength and fracture strength (i.e., (T4) < (C3) = (T1) + (T2)). In the other four cases, the welds fracture after the combination joints develop the max strength (i.e., (T4) > (C3) = (T1) + (T2)), regardless of the types of bolts and welds.

Table 2. Strength of slip-critical bolted joints in combination with fillet welds.

Case		(T1)	(T2)	(C3) = (T1) + (T2)	(T4)
		Bolted Joint	Welded Joint	Combination Joint*	Combination joint
(J1)	2F10T+WL	504.42	897.40	1401.82	1860.25
(J2)	2F10T+WT	504.42	955.25	1459.67	1613.90
(J3)	2F14T+WL**	628.54	897.40	1525.94	1482.80**
(J4)	2F14T+WT	628.54	955.25	1583.79	1588.05
(J5)	2F14T+WT	628.54	955.25	1583.79	1606.35

*strength by estimation; ** early fracture failure in one of the 4 longitudinal welds.

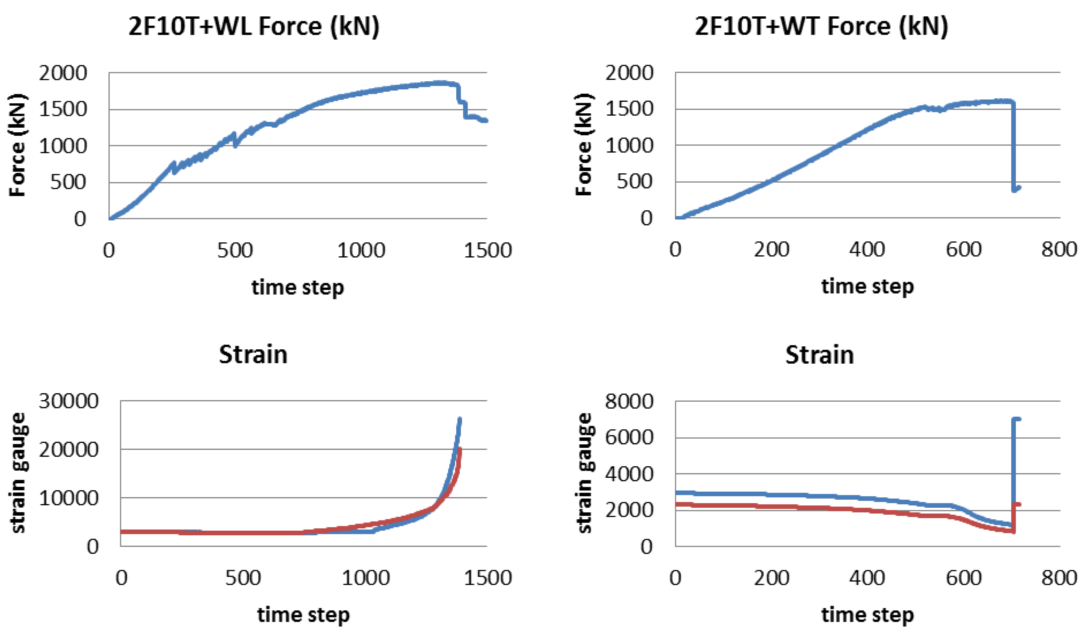


Figure 5. Strength development of combination Joints and the pretension and loss of bolts.

3.2 Bolt Behavior

The pretension of bolts has been monitored using bolt gauges. The strain measurement decreases as the bolt slips. The measurement turns to increase after the bolt contacts the plates and develops bearing strength. In the combination with longitudinal welds (WL), for example Case (J1), the bolts develop greater bearing strength before the max strength of the combination joint, as shown in Figure 5(a). That explains why the combination joint can develop strength more than the sum of slip strength and fracture strength.

In the combination with transverse welds (WT), for example Case (J2), the strain measurements decrease to a great extent, as shown in Figure 5(b). Table 3 summarizes the loss of pretension and bolt behavior at the max strength of combination joints. As can be seen, the combination with transverse welds causes a greater loss in bolt pretension and slip strength. But the combination also causes the fracture surfaces of transverse welds to change, as illustrated by

Figures 4(b) and (d). That has provided additional weld strength to compensate the decrease in bolt slip strength.

Table 3. Loss of pretension and bolt behavior at the max strength of combination joints.

Case		Bolt A		Bolt B	
		Pretension loss (%)	Bolt behavior	Pretension loss (%)	Bolt behavior
(J1)	2F10T+WL	7	Bearing	9	Bearing
(J2)	2F10T+WT	59	Slipping	63	Slipping
(J3)	2F14T+WL	8	Bearing	11	Bearing
(J4)	2F14T+WT	59	Slipping	72	Slipping
(J5)	2F14T+WT	34	Slipping	46	Slipping

4 CONCLUSION

A series of joint tests have been made to investigate the behavior of slip-critical bolts in combination with fillet welds. For comparison, the same types of joint specimens were also used to test the slip-critical strength for high strength bolts and the fracture strength of fillet welds respectively. The results indicate that the combination joint can develop strength greater than the sum of slip strength and fracture strength. That suggests a necessity of reviewing and modifying the design standard of steel structures about slip-critical bolts in combination with fillet welds.

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