PERFORMANCE ON SPLIT TEE TYPE W.F. BEAM-TO-R.H.S. COLUMN CONNECTION USING PLUG WELD

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ABSTRACT: This paper presents an experimental investigation, dealing with mechanical property on a newly developed split tee type WF beam-to-RHS column connection using both plug and fillet welds in steel moment resisting frame. Initially, strength of plug weld subjected to tensile load has been evaluated from the test result of simple T-T joint experiment. Next, experiment of subassembly being welded split tee bracket to RHS column by means of plug weld and/or fillet weld has been conducted. And it has been shown that the proposed design formulae can predict fairly well the yield and ultimate strengths of the connection, after comparing with the experimental result.

Keywords: Steel moment resisting frame; beam-to-column connection; plug weld; fillet weld; bearing strength; loading experiment

1. INTRODUCTION

As an effective solution in order to avoid premature and brittle failure at the beam end due to weld defect and/or excessive strain concentration of welded beam-to-column connection in weak beam type steel moment resisting frame, it may be desired to adopt design method to share damage due to seismic inelastic behavior among the components of the connection, instead of applying conventional method to limit plastic zone only to beam end. For this reason, a newly developed beam-column connecting method is proposed here. In the connection, only tee shaped brackets are incorporated between WF beam and RHS column, as shown in Figure 1. The flange of the bracket is connected to the column face by means of plug welding as well as fillet welding at the corners. The bracket web is bolted together with the beam flange in order to transfer the beam bending moment and shear force to the column. The beam web, if necessary, can be connected to the column through a gusset plate, by using high strength bolts, to transfer beam shear, when the shear is dominant among beam stresses. The present work is intended to verify performance of the proposed connection using both plug and fillet welds, as shown in the figure.

Figure 1. WF Beam-to-RHS Column Connection using Tee Bracket

2. TEST ON PLUG WELDED T-T JOINT SUBJECTED TO TENSION

2.1 Experimental Procedure

Plug weld is not commonly used as practical method to join members together in steel building structures, since such welding method is only applicable to shear joints in which the members are subjected to in-plane shear force, in many design standards as A.I.J. 1979[1] and 2005 [2], A.W.S. 2000[3] and A.I.S.C. 2005[4]. However, it seems to be useful to adopt the method to the connections of main members like as columns and beams, because of ease of fabrication and economy in comparison with ordinary beam-to-column connection with through diaphragm in seismic moment resisting frame, if the welding procedure would be adequately performed. For this reason, simple T-stub test was carried out in order to evaluate strength and deformation capacities as well as welding performance of plug welded connection.

Grade SM490B steel plates of JIS G3106 rolled steels specified for welded structure were used for the test. The plates were fabricated and assembled. And then, the flange plates were connected by plug welding, so as to shape T-T joint as illustrated in Figure 2. Mechanical properties of the plates obtained by coupon test are tabulated in Table 1. The lower T-stub was shaped so as to behave as rigid throughout the monotonic tensile experiment, by adding a pair of stiff rib plates between the flange and the web. The upper flange plates of 22 and 32 mm thick were used and connected to the lower flange plates of 32 mm thick, by means of plug welding of 28 mm diameter. CO₂ shielded arc welding, using JIS Z3312 YGW11 as MAG welding solid wire for mild and high strength steel up to the tensile strength of 490 N/mm², was performed for jointing both the upper and the lower flange plates. Welders belonging to two different fabricators performed plug welding, in order to examine the effect of difference of welding performance on the mechanical properties of the joint. The welding condition by every welder, named as T or W, is tabulated in Table 2. Specimen types, named as T22 to W32, are identified in Tables 1 and 2.

Figure 2. Geometrical Property of T-T Joint Specimen (unit : mm)

Universal testing machine (capacity 2000 kN) was used so that the specimen was statically loaded under monotonic loading condition by pulling the tip of the web until failure. Clip gauge type extensometers were set on the points shown as triangular symbols in Figure 2, in order to detect local distortion of the specimen during the experiment. The test set-up is shown in Figure 3.

Table 1. Mechanical Properties of Steel Plates used for T-T Joint

specimen type	plate thickness (mm)	yield strength (N/mm ²)	tensile strength (N/mm ²)	yield ratio (%)	elongation (%)
T22	22	397	554	72	21.2
T32	32	339	523	65	22.8
W22	22	390	537	73	22.5
W32	32	350	534	65	22.7

Table 2. Types of T-T Joint Specimens and Welding Conditions

specimen type	fabricator	t_f (mm)	plug welding condition		
			current (A)	voltage (V)	arc time (sec)
T22	T	22	280	32	77
T32		32	280	32	107
W22	W	22	240	34	76
W32		32	240	34	104

Figure 3. Specimen mounted on the Testing Machine

2.2 Experimental Result

The typical load-local distortion relations are schematically shown in Figure 4. In accordance with that the abscissa of the figure gives positive in tension, it is recognized that the edge of flange (tip of flange) is subjected to compressive force. In addition, it can be observed that the load carrying capacity depends on the thickness of upper tee flange.

At the final stage of experiment, the plug welds fractured for every specimen after the upper tee flange deflected due to out of plane bending. Fracture surface in Figure 5, shows that the weld metal is pulled out throughout the cross section of plug weld without any defect like as incomplete penetration. In order to inspect weldability in the above proposed method, macro-structure test was performed, prior to T-T joint test. The example of test result is shown in Figure 6. From the figure, it can be observed that penetration is well achieved both in the upper and the lower flanges.

Figure 4. Load-Local Distortion Relation of T-T Joint Specimen

(a) T22-1

(b) T32-2

(a) W22-3

(b) W32-3

Figure 5. Fracture Surface of Plug Weld

Figure 6. Macro-Structure Test Result of Plug Weld

2.3 Discussion

In this section, the strength of plug weld is evaluated based on the test result. From Figure 4, it can be recognized that force due to prying at the tip of tee flange is generated for every specimen. For this reason, the experimental resisting force of plug weld has to be evaluated in taking into consideration the effect of so called prying action.

Procedure to evaluate the experimental yield strength is as follows.

- I. Prepare experimental data set of load T and the corresponding local distortions.
- II. Formulate a model in which the upper flange plate is composed of a pair of uniform cantilever beams fixed at the point $size/2$ apart from the face of tee web. Where $size$ is the size of fillet weld for reinforcement. Assume the loading condition where each beam is subjected to the loads P_p and P_r at the plug welded point and the tip of the beam, respectively, and that the reaction $T/2$ is generated at the fixed point. The above assumption is schematically shown in Figure 7. In the figure, δ_c , δ_p and δ_r are the distortions at the center, the point of plug weld and the edge of the flange, respectively. Derive elastic load-deflection relation of the beam under bending and shear, to formulate P_p as a function of T and the local distortion.
- III. Estimate load P_p by substituting the experimental data of load $T/2$ and local distortions in step I for the analytical relation in step II.
- IV. Plot the points with co-ordinates, (P_p, T) , on a graph.
- V. Draw the linear regression line of P_p-T plots from the origin to the proportional limit. Draw again a line with a slope of $1/3$ of the regression line, and tangent to the P_p-T curve.
- VI. Define the ordinate of intersection point of the linear regression line and the tangential line, to the experimental yield strength of plug weld, $P_{py(ex)}$. After evaluating $P_{py(ex)}$, it is necessary to confirm that beam yielding occur only after yielding of plug weld. The yield load T_y can be found as the abscissa of intersection point.

The procedure from step IV to VI is illustrated in Figure 8. T_y in Figure 4, shows the example of experimental yield load obtained from the above procedure.

Figure 7. Cantilever beam model of actual tee flange subjected to tension

Figure 8. Evaluation of $P_{py(ex)}$ and T_y from Experimental Result

The experimental ultimate strength of plug weld can be evaluated by the following procedure.

- VII. Perform step-by-step elasto-plastic analysis of the cantilever beam in the manner of numerical integration. Calculate the bending moment corresponding to the rotation angle at the fixed end, under the assumption where a bi-linear moment-curvature relation with the second flexural rigidity of 0.005 times the initial one is applicable to the material of beam.
- VIII. Perform bi-linear approximation of the fixed end moment-rotation relation of the beam, in order to derive the moment-rotation relation in the continuous form.
- IX. Calculate the rotation angle, θ_{end} , from the experimental local distortion by using Eq. 1, and evaluate the fixed end moment by substituting the rotation angle for the bi-linear moment-rotation relation.

$$\theta_{end} = (\delta_c - \delta_p) / l_2 \quad (1)$$

where l_2 is the distance between fixed end and the center line of plug weld.

- X. Estimate P_p so as to satisfy equilibrium condition.
- XI. Find the maximum value of P_p , and define the value as the experimental ultimate strength of plug weld, $P_{pu(ex)}$.

As pointed out in the fracture surface observation in Figure 5, it is rational to consider that plug weld can resist over the cross section until the fracture. Therefore, the estimated strength of plug weld, $P_{ps(cal)}$, can be derived in Eq. 2.

The experimental strength of plug weld, $P_{ps(ex)}$, derived from above described procedure, is compared with the estimated value, $P_{ps(cal)}$.

$$P_{ps(cal)} = \frac{\pi d_p^2}{4} \sigma_{ps} \quad (2)$$

where the letter, s , of subscript, ps , is rewritten to y in the case of yielding, or u at the ultimate state. Notations, σ_{ps} and d_p , indicate the yield or the ultimate strength of plug weld

metal, and the diameter of plug weld, respectively. However, in the present case, the material strength of upper flange plate, σ_{fs} , is used in place of the actual strength of weld metal because of difficulty of direct measurement.

The experimental strength of plug weld, $P_{ps(ex)}$, derived from above described procedure, is compared with the estimated value, $P_{ps(cal)}$, and the results are shown in Figure 9. From the figure, it can be recognized that $P_{py(cal)}$ estimates the yield strength fairly well, though $P_{pu(cal)}$ is comparatively lower than $P_{pu(ex)}$ at the ultimate state, in spite of difference between two welding conditions.

Figure 9. Comparison of Experimental and Estimated Strengths of Plug Weld

3. TEE BRACKET-RHS COLUMN SUBASSEMBLAGE TEST

3.1 Objective of Experiment

In order to confirm the applicability utilizing the proposed connecting method, subassembly specimens composed of RHS column and split tee bracket were fabricated and used for monotonic tensile loading test.

3.2 Specimen and Experimental Method

Figure 10 illustrates the general view of specimen. The columns were cold formed rectangular hollow sections for steel building structure, specified as BCR295, whose yield and tensile strengths in the specification were greater than 295 and 400 N/mm², respectively. Tee brackets were made from JIS SS400 wide flange sections. As tabulated in Table 3, the specimens were classified into two groups such as A and C-types, and B and D-types, in accordance with whether the tee flanges were fillet welded to the columns additionally, or not. Their details of welding are shown in Figure 11 and Table 4. When fillet welding, the specimens were tilted to an angle of 45 degrees, so as to shape the bead into right isosceles triangle. Three identical specimens for each type were prepared and tested. Several extensometers were installed in order to measure both global and local deformations of the specimens, as shown in Figures 12 and 13. Specimens set on a universal testing machine (capacity of 1000 kN) in Figure 12, were loaded along the direction as shown in Figure 13, until they were torn out or deformed excessively so that interruption of the test was indispensable.

Figure 10. Overall View of Subassembly Specimen

Figure 11. Plug and Fillet Welds of Subassembly Specimen (unit : mm)

Table 3. Geometrical properties of component members

specimen type	component member		t_f^*	t_w^*	r^*	B_c^*	H_c^*	l_w^*
	tee bracket	column	(mm)					
A	T-220x125x6x9 (cut from H-250x125x6x9)	SHS-200x200x9	9	6	8	200	250	52.5
B								-
C	T-220x90x16x16 (cut from H-900x300x16x28)	SHS-300x300x16	16	16	18	300	350	39.5
D								-

*: Notations in the table are identified in Figures 10 and 11.

Table 4. Welding Condition

specimen	welding condition	
	fillet weld	plug weld
A	size 7 mm, 1 pass	diameter 15 mm depth : 9 mm
B	-	
C	size 12 mm, 3 passes	diameter 15 mm depth : 16 mm
D	-

Figure 12. Test Set-Up

Figure 13. Test Set-Up and Instrumentation of Displacement Transducer and Strain Gauge

3.3 Mechanical Properties of Materials

In order to examine the mechanical properties of the component materials, the coupon test was carried out. The obtained results are tabulated in Table 5.

Table 5. Mechanical Properties of Materials

Specimen type	component	yield strength	tensile strength	yield ratio	elongation
		(N/mm ²)	(N/mm ²)	(%)	(%)
A,B	tee flange	303	450	67	23.6
	tee web	356	464	77	19.3
	column	347	418	83	23.2
C,D	tee flange	287	446	64	23.8
	tee web	321	456	70	22.3
	column	417	488	85	20.3

3.4 Calculated Design Strength of Specimen

As seen in Figures 10 and 11, the specimen consists of three or four component members like as split tee, column, plug weld and/or fillet weld. For this reason, in order to estimate the strength of the subassembly specimen as one unit, the strength of each component member initially has to be evaluated. The strength of individual member can be found as the minimum value among the strengths, which have been computed for considerable failure modes, as will be described in following sections. Finally, the overall strength of the subassembly specimen can be estimated by adopting the lowest of the strengths of the component members.

3.4.1 Strength of plug weld

In designing the specimen, three types of failure modes like as mode 1 to 3, that is, plug weld fracture (mode-1), shear failure of plug weld (mode-2) and punching shear failure of plate (mode-3), were assumed. These three modes are illustrated in Figure 14, and the corresponding design equations to three failure modes are formulated as follows.

Figure 14. Failure Mechanisms of Plug Weld

For mode 1, Eq. 3, the identical equation with Eq. 2, can be formulated. When the thickness of tee flange plate is comparatively thin, shear yielding or failure of the plate will occur around the plug weld as shown in mode 2, and the strength per single plug weld can be formulated in Eq. 4. On the other hand, in the case of the connection with the column plate thinner than the tee flange plate, so called punching shear will occur as shown in mode 3, the corresponding strength can be formulated in Eq. 5.

$$P_{p1s} = \frac{\pi d_p^2}{4} \sigma_{ps} \quad (3)$$

$$P_{p2s} = \pi d_p t_f \frac{\sigma_{fs}}{\sqrt{3}} \quad (4)$$

$$P_{p3s} = \pi d_p t_b \frac{\sigma_{cs}}{\sqrt{3}} \quad (5)$$

where σ_{ps} and σ_{cs} are the yield or tensile strength of plug weld and the column plate, respectively. In Eq. 3, the strength of plug weld refers to the lower of the strengths of tee flange plate and column plate. Finally, the design strength of plug weld in tension can be decided as the minimum among Eqs. 3, 4 and 5, as formulated in Eq. 6.

$$P_{ps} = \min\{P_{p1s}, P_{p2s}, P_{p3s}\} \quad (6)$$

After substituting the material strengths shown in Table 5 for Eqs. 3 to 5, the design strengths of single plug weld for type-A to D specimens can be calculated as in Table 6.

Table 6. Calculated Strength of Single Plug Weld in Tension

specimen type	yield strength				ultimate strength			
	P_{p1y}	P_{p2y}	P_{p3y}	P_{py}	P_{p1u}	P_{p2u}	P_{p3u}	P_{pu}
	(kN)			(kN)	(kN)			(kN)
A, B	54	69	86	54	80	103	104	80
C, D	51	134	180	51	79	208	211	79

□ : show the lowest of the strengths which result in P_{ps} .

3.4.2 Strength of tee bracket

It is well known that three failure modes, like as shown in Figure 15, can be assumed in response of the strength of the component, when bolted T-stub is subjected to tensile force, as has already been reported by Faella et al. [5] and [6]. After substituting the bolt for plug weld, the conventional equations can be applied for strength prediction of the presented connection.

Figure 15. Failure Mechanisms of Tee Bracket

When the tee bracket is loaded in tension, it is assumed that the flange behaves like as a pair of cantilever beams as shown in Figure 16. In the figure, r denotes the radius of web fillet. Depending on the stiffness and the strength of tee flange, it can be drawn that there are three failure modes as in Figure 15.

length, M_{fws} , as equated in Eq. 12, has to be accounted in Eq. 10. The total length of bracket flange as a cantilever beam, l , can be equated as in Eq. 13.

$$M_{0s} = \frac{t_f^2 \sigma_{fs}}{4} \quad (11)$$

$$M_{fws} = \frac{a^2 \sigma_{fws}}{4} \quad (12)$$

$$l = l_1 + l_2 \quad (13)$$

If yielding does occur only at the bracket flanges as shown in Figure 15, the strength of tee bracket in mode 6, T_{s3} , can be equated as follows.

$$T_{s3} = \frac{4wM_{0s}}{l_2} \quad (14)$$

After applying the above formulae and the material strengths to every type of subassembly specimen, the design strength of tee bracket, T_s , can be estimated from Eq. 15, as the lowest of the strengths of three types of failure modes in Table 7.

$$T_s = \min\{T_{s1}, T_{s2}, T_{s3}\} \quad (15)$$

Table 7. Calculated Strength of Tee Bracket

specimen type	yield strength (kN)				ultimate strength (kN)				failure mode
	T_{y1}	T_{y2}	T_{y3}	T_y	T_{u1}	T_{u2}	T_{u3}	T_u	
A	466	185	120	120	666	270	179	179	mode 6
B	214	138	82	82	318	205	122	122	mode 6
C	511	404	1260	404	794	627	1970	627	mode 5
D	203	314	1260	203	315	488	1970	315	mode 4

□ : show the lowest of the strengths which result in T_s .

3.4.3 Strength of column due to out-of-plane bending

Since the width-thickness ratio of column used in this experiment, is comparatively large, the plate of the column attached to the tee bracket tends to deform out of plane. It is well known that strength of RHS column due to out-of-plane bending can be well predicted by applying yield line theory, as has been reported by Morita et al. [7], Yamamoto et al. [8] and Harada et al. [9]. Taking into consideration existence of fillet weld at the corners of tee flange, two types of failure mechanism can be assumed, as shown in Figure 17.

Figure 17. Failure Mechanisms of RHS Column

As a result, the tensile force transferred to the column through the tee bracket, ${}_cT_{sm}$, can be derived from Eq. 16. The subscript m is set to 1 or 2, for mode 7 or 8, respectively.

$${}_cT_{sm} = \frac{t_c^2 \sigma_{cs}}{2} \left(\frac{2Y_m + B_m}{X_m} + \frac{4X_m + 2H_m}{Y_m} \right) \quad (16)$$

X_m and Y_m in Eq. 16 can be calculated by Eqs. 17 and 18.

$$X_m = \frac{1}{2} \sqrt{Y_m (B_m + 2Y_m)} \quad (17)$$

$$Y_m = \frac{1}{2} (B_c - B_m - 2r_c t_c) \quad (18)$$

where t_c and r_c denote the thickness and the corner radius of column, respectively. Notations, B_m and H_m , are the lengths shown in Figure 17.

After substituting the specific values for Eq. 16, the column strength due to out-of-plane bending, ${}_cT_s$, can be evaluated by applying the corresponding m to Eq. 19. The results are tabulated in Table 8.

$${}_cT_s = {}_cT_{sm} \quad (19)$$

Table 8. Calculated Out-of-Plane Bending Strength of Column

specimen type	cT_y	cT_u	m	failure mode
	(kN)	(kN)		
A	359	433	1	mode 7
B	171	206	2	mode 8
C	877	1026	1	mode 7
D	514	602	2	mode 8

Finally, the calculated strength of connection for every specimen, $_{cal}T_s$, can be evaluated as the lowest strength in Tables 7 and 8, by adopting Eq. 20, and the calculated result is summarized in Table 10.

$$_{cal}T_s = \min\{T_s, cT_s\} \quad (20)$$

3.4 Experimental Result

The test was terminated after fracture due to bending of tee flanges for A-type specimens, or after rupture due to tearing of plug welds for D-type specimens, whereas the test of B or C-type specimens was interrupted because of excessive deformation due to out of plane bending of column flanges. Typical load-displacement relations obtained from the test result are illustrated in Figure 18. The figure shows responses of the global as well as the local displacements such as the inside measurement of column, the distance between the upper or the lower tee flange and the column detected by displacement transducers shown in Figure 13. From the Figure 18, it can be observed that the load-inside measurement of column relation is very close to the load-global displacement relation in the cases of B and D-type specimens, whereas for A and C-type specimens, the inside measurement of column is comparatively smaller than the global displacement. Since each tee bracket flange of B and D-type specimens is connected to the column at only 4 points by means of plug weld, the global displacement of the specimen is governed by the deformation of column due to out-of-plane bending and it results in lower rigidity of the connection. On the other hand, the stiffness of the connection becomes comparatively higher for A and C-type specimens with fillet welds added to each tee bracket flange at the corner, because the tee bracket can efficiently resist against out-of-plane bending of column plate. Figure 19 shows the typical example of geometrical configuration of the connection after finishing of the test. As observed in (a) of the figure, tee bracket flange of specimen A3 is torn out near the plug weld and the fillet welds are ruptured, with excessive deformation of the tee flange at the center. On the contrary, specimen B2 in (b), whose component members are identical with those of specimen A3, deflects due to excessive out-of-plane deformation of the column, because of absence of fillet welds at the corners of tee bracket flange. Comparison of test results of specimen C1 in (c) and D3 in (d) suggests that fillet welds at the corners of tee flanges are effective in increase of both strength and rigidity of connection.

C and D-type specimens consist of thicker plates of members but lower contact areas between tee flange plates and column faces in comparison with those of A and B-type specimens. Findings obtained from experimental results of 4 types specimens will lead to essential guidelines required in designing the proposed connection illustrated in Figure 1, like as proportioning tee brackets and columns in respect to rigidity of the connection. However, in the present study, the attention is only focused on evaluating the strength of subassembly specimens. For this reason, further research concerning with rigidity of the subassembly with different proportions will be needed.

Figure 18. Result of Load-Displacement Relation of Subassembly Specimen

(a) rupture of bracket flange and fillet weld (specimen A3)

(b) deformed column and flexure of tee bracket flange (specimen B2)

(c) deformed column and detail of fillet weld (specimen C1)

(d) deformed column and fracture surface of plug weld (specimen D3)

Figure 19. Test Result of Subassemblage Specimen

3.5 Discussion

The experimental yield strength for each specimen is defined as follows: In the load-global displacement relation, let draw a straight line having a slope of initial stiffness through the origin, furthermore, draw a tangential line having a slope of one thirds of initial stiffness on the load-global displacement curve and get the intersection point between the above two lines. Set the ordinate of the intersection point as the yield strength. Such procedure is schematically shown in Figure 20.

Figure 20. Definition of Experimental Yield Load of Specimen

It is evident from the test result of B -type specimen as shown in (b) of Figure 19 that the failure mode observed after the test termination is somewhat different from the initially predicted mode. That is, the column plate was folded at the center like as house roof along the longitudinal direction. For this reason, other failure modes consisted of three or four yield lines along the longitudinal direction of the column have been considered for four types of specimens, as illustrated in Figure 21. The locations of plastic hinge lines have been identified from the bending moment distribution of the columns which can be idealized as rigid frames. Since the tee bracket flanges are rigidly connected to the columns in the manner of both plug and fillet welds for A and C-type specimens, plastic hinge lines along the longitudinal directions of the columns will be formed just outside the fillet weld lines (mode 9). In the cases of B and D-type specimens, the plastic hinge lines will be formed at the centers of the column faces beneath the tee bracket flanges (mode 10), because the bracket flanges are connected to the columns only at the points of plug welds. For this reason, the number 3 or 4 is added to notation m , to identify mode 9 or 10, respectively. From the above consideration, the strength of the connection for two additional failure modes can be evaluated as tabulated in Table 9.

Figure 21. Additional Failure Mechanisms of Column

Table 9. Additional Out-of-Plane Bending Strength of Column

specimen type	yield strength (kN)	ultimate strength (kN)	m	failure mode
	cT_y	cT_u		
A	150	180	3	mode 9
B	93	112	4	mode 10
C	397	464	3	mode 9
D	290	338	4	mode 10

Table 10 summarizes the calculated and the experimental strengths, and the accuracy of prediction. These specific strengths are also shown in Figure 18, as $_{exp}T_s$ and $_{cal}T_s$.

Table 10. Comparison with Calculated and Experimental Strengths of Subassemblage Specimen

specimen		$_{cal}T_y$	$_{exp}T_y$	$_{exp}T_y / _{cal}T_y$	$_{cal}T_u$	$_{exp}T_u$	$_{exp}T_u / _{cal}T_u$	failure mode	
		(kN)			(kN)			predicted	exp.
A	1	117	132	1.13	173	184	1.06	mode 6	mode 6
	2		133	1.14		196	1.13		
	3		117	1.00		178	1.03		
B	1	82 (93)	93	1.14	(112)	146<	(1.30)<	mode 6 (mode 10)	-
	2		102	1.25		165<	(1.47)<		
	3		102	1.25		167<	(1.49)<		
C	1	397	417	1.05	(464)	585<	(1.26)<	mode 9	-
	2		417	1.05		578<	(1.25)<		
	3		417	1.05		562<	(1.21)<		
D	1	203	272	1.34	315	377	1.20	mode 4	mode 4
	2		272	1.34		330	1.05		
	3		278	1.37		374	1.19		

In the case of B-type specimen, the calculated yield strengths for modes 6 and 9 are not so far apart from each other. For this reason, it is conjectured that after the specimen yields initially at mode 6, the deflection of the column becomes significantly so as to form mode 10. After forming such yield mechanism, the specimen resists against external tensile force, but deforms excessively from the original shape, because of sufficient axial resistant capacity of column webs parallel to the longitudinal direction of the specimen. In the case of C-type specimen, since the tee bracket web yields at 468 kN, the specimen deforms both at the column and the web. From the table, the design formulae may be applicable for prediction of strength of subassemblage specimen.

4. CONCLUSIONS

Performance on split tee bracket-to-RHS column connection using both plug weld and fillet weld has been investigated by conducting two series of tests. The following conclusions can be deduced from the test results:

- [1] Strength of plug weld alone has been initially examined by using simple T-T specimen, and it has been shown that the yielding can be predicted fairly well by proposed design equation, although the ultimate strength by design equation evaluates considerably lower than the experimental result.
- [2] Strength of the subassembly composed of split tee, RHS column and plug welded portion as well as fillet welded portion has been evaluated by comparing the design strength with the experimental result. The result of comparison has shown that the proposed design formulae give fairly well prediction of yield strength. This conclusion can be applied to the subassemblies composed of the columns of width-thickness ratio of about 20.
- [3] Fillet welding arranged at the corners of tee flange, is effective so that the connection, which consists of split tee bracket and RHS column, can behave integrated until the ultimate state.
- [4] The plug weld alone appears to give greater ductility.

NOTATIONS

Lower cases

a	throat thickness of corner fillet weld
d_p	diameter of plug weld
l	effective length of each projection of tee bracket flange
l_1	distance between the center of plug weld and the end of flange
l_2	distance between the center of plug weld and the center of fillet weld
l_w	effective length of corner fillet weld
l_{w1}	effective length of corner fillet weld along transverse direction of tee bracket flange
l_{w2}	effective length of corner fillet weld along longitudinal direction of tee bracket flange
m	numeral from 1 to 4, corresponding to mode 7 to 10
n	number of plug weld at each projection of tee bracket flange
p_{fws}	specific strength of corner fillet weld per unit length
r	radius of fillet of wide flange section
r_c	corner radius of RHS column
s	letter indicating yielding state y or ultimate state u
$size$	size of fillet weld
t_c	thickness of SHS column
t_f	thickness of tee bracket flange or upper flange of T-T specimen
t_w	thickness of tee bracket web
w	width of tee bracket

Upper cases

B_c	outside dimension of RHS column
B_m	partial length of yield line parallel to transverse direction of subassembly specimen

H_c	length of RHS column used for subassemblage specimen
H_m	partial length of yield line parallel to longitudinal direction of subassemblage specimen
M_{0s}	fully plastic or ultimate moment per unit width of bracket flange
M_{fws}	fully plastic or ultimate moment of fillet weld per unit length
P_p	tensile force of plug weld
P_{p1s}	specific tensile force of plug weld
P_{p2s}	specific tensile force caused by shear yielding or failure of plug weld
P_{p3s}	specific tensile force due to punching of RHS column plate
$P_{py(ex)}$	experimental yield tensile force of plug weld
$P_{ps(cal)}$	estimated specific tensile force of plug weld
$P_{ps(ex)}$	specific tensile force of plug weld obtained from experiment
$P_{pu(ex)}$	experimental ultimate tensile force of plug weld
P_r	prying force
T	applied tensile force
cT_s	specific tensile force transferred to the column through the tee bracket
cT_{sm}	specific tensile force transferred to the column through the tee bracket for mode 7 to 10
$calT_s$	estimated specific tensile strength of subassemblage
T_s	specific tensile strength of tee bracket
T_{s1}	specific tensile strength of tee bracket stipulated by mode 4
T_{s2}	specific tensile strength of tee bracket stipulated by mode 5
T_{s3}	specific tensile strength of tee bracket stipulated by mode 6
T_y	applied tensile yield force
X_m	projected length of yield line along longitudinal direction of subassemblage specimen
Y_m	projected length of yield line along transverse direction of subassemblage specimen

Greek letters

δ_c	local distortion at the center of T-T specimen
δ_p	local distortion at plug weld
δ_r	local distortion at the end of upper flange of T-T specimen
θ_{end}	rotation angle evaluated from $\theta_{end} = (\delta_c - \delta_p)/l_2$
σ_{cs}	specific tensile strength of RHS column plate
σ_{fs}	specific tensile strength of tee bracket flange
σ_{fws}	specific strength of corner fillet weld per unit area
σ_{ps}	specific tensile strength of plug weld

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