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Experimental Investigation of Cold-formed Steel Screw Connection

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***Abstract*—This paper presents a test program on screw connections of thin steel sheets using single shear connection and moment connection tests. The structural behavior of the screw connections were studied by varying the thickness of the steel sheets, number and arrangement of screws for each connection. The failure loads and failure modes were obtained from the tests. The failure modes observed were net section tension, tilting and bearing failure. No buckling was observed in the moment connection joint. The test strength was compared with the predicted strength using the current specifications for cold-formed steel structures. It is shown that the strength of the single shear screw connection predicted by the current specifications is generally conservative. However, the strength predicted for the moment connection joint is not conservative.**

***Keywords*—cold-formed steel, screw connection, experimental tests, single shear, moment connection**

I. Introduction

Cold-formed steel (CFS) sections such as C-channels and Z sections have been used in the local construction industry. However, its usage has seen a significant growth in year 2008 when the government started to promote the implementation of Industrialized Building Systems (IBS) construction concept [1]. This type of construction has the advantage in terms of cost and time. This is because it is easy to fabricate and fast to install. Besides that, the use of 'pre-fabricated' structures produces uniform quality and more accurate detailing in construction. Furthermore, limited skill workers are required in its construction. In addition, CFS structural member also has a high strength to thickness ratio, is noncombustible and termite proof which is ideal for our local climate [2]. These valuable qualities qualify CFS structures as a type of IBS [3].

Although bolted and welded connections have been predominantly used in steel connections, screw connections are used in CFS structures due to the ease of fabrication and erection. Different from bolted connections, screw connection is fastened by self-tapping and self-drilling method where the screw drills its own hole and forms its mating thread in one operation. It does not require pre-drill holes and also eliminates the use of nuts in its construction. Apart from simple connections, screw connections have also been used in moment joints where bolted connections were normally used. A lot of studies have been made to determine the capacity of screw connection in shear and bolted moment connections [4,5,6,7]. However, limited work has been done to study the behavior of screw connections subjected to moment.

As reflected in the American design specifications [8] and the Australian/New Zealand design standard [9], structural steel screw shear connections failure may occur when either the screw shear or bearing resistance or the resistance of the connected parts is exceeded. And when the screw connections are subjected to tensile stress, the screws may also be pull-out or pull through. Apart from these independent failure modes, Dunai and Fóti [10] stated that interactive failure modes that are affected by both screw and the material properties can also occur. The possible interactive failure modes are tilting and pull-out, tilting and bearing, tilting and shearing, and tilting and tension failure of fastener. Besides that, local buckling of the members and distortion may also occur in the joint.

The structural behavior of screw connections was investigated in this study. Two types of experimental test were conducted. They were the single shear connection test and the moment connection test. Both the screw connection tests were conducted using the same universal testing machine (UTM) under different test setups. The failure modes for each of the tests were observed. The test strength of the screw connections were compared with the current design specifications prediction.

II. Experimental Tests

Two types of experimental test were conducted in this study. They were the single shear connection test and the moment connection test.

A. *Single Shear Connection Test*

The steel specimens used in this test were cut from a few CFS sections that have been commonly used in the local construction industry. The sections were labeled as C07508, C07510 and C07512 respectively where the first letter C refers to C-channel, the following three digits represent the nominal depth of the section and the last two digits indicate the nominal thickness of the section. The details of the sections used are shown in Table I.

TABLE I. DETAILS OF CFS SECTIONS

Section	Grade	Thickness, t (mm)	Web depth, w (mm)	Flange width, f (mm)	Lip length, l (mm)
C07508	G550	0.8	75	40	14
C10012	G550	1.2	98	50	19
C10016	G450	1.6	98	50	19

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To determine the actual capacity of the material, tensile coupon test was conducted. Fig. 1 shows the dimensions of the coupons tested. The mechanical properties obtained from the tensile coupon test are tabulated in Table II.

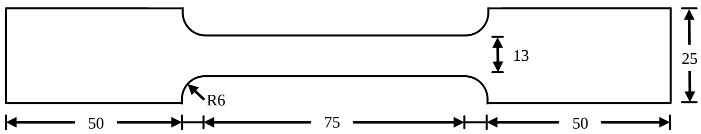

Figure 1. Dimensions of tensile coupon (in mm)

TABLE II. MECHANICAL PROPERTIES OF TEST SPECIMENS

Tensile Coupon Specimens				
Section	**Nominal Yield Strength, fy (MPa)**	**Plate Thickness, t (mm)**	**Yield Strength, $\sigma_{0.2}$ (MPa)**	**Ultimate Strength, σ_u (MPa)**
C07508	550	0.8	567	569
C10012	550	1.2	585	587
C10016	450	1.6	512	529

The self-drilling screws used were RedPoint A2S Fasteners electroplated with zinc coating as shown in Fig. 2. The diameter of the screw was 5.5mm (include thread) and the diameter of the build-in washer was 15mm. According to the manufacturer report, the nominal shear strength of the screw was 9kN.

Figure 2. RedPoint A2S fastener

The behaviour of the screw connection under single shear test was investigated by varying the thickness of thin steel sheets and the number of screws used in a connection. Details of the test configurations are shown in Table III. Each set of specimen was labeled by three segments in order to identify the number of screws and the nominal thickness of the two pieces of steel sheets. The first two letters indicate the number of screws; the following two numbers indicate the thickness of the thin steel sheet that was in contact with the screw head and the last two numbers indicate the thickness of the thin steel sheet that was not in contact with the screw head. At least three sets of specimen were fabricated for each configuration and the average value was used in the analysis. If the results obtained from any specimen differed by more than 10%, a fourth set of specimen was tested. Fig. 3 shows the fabricated specimens for the single shear connection test.

TABLE III. CONFIGURATION OF TEST SPECIMENS

Specimen	**No. of Screws**	**Thickness of steel plate in contact with screw head, T1 (mm)**	**Thickness of steel plate not in contact with screw head, T2 (mm)**
S112/12	1	1.2	1.2
S212/12	2	1.2	1.2
S212/08	2	1.2	0.8
S208/12	2	0.8	1.2
S212/16	2	1.2	1.6
S216/12	2	1.6	1.2

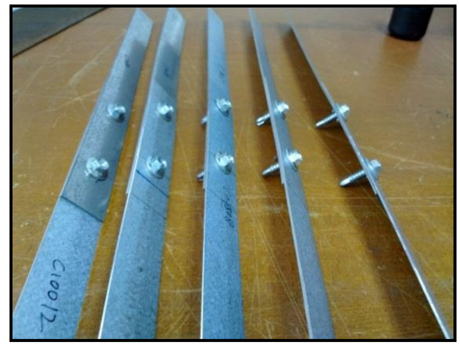

Figure 3. Tensile test specimens

The test setup of the single shear screw connection is shown in Fig. 4. Three linear variable differential transducers (LVDTs) were used to measure the displacement of the test specimens. Two of the LVDTs were placed at the upper segment of the specimen to capture the elongation of the specimen under load without the slip in the upper grip. The third LVDT was placed at the lower segment of the specimen to capture the slip in the lower grip. The displacement value collected from the top LVDT was deducted by the value collected from the bottom LVDT to get the net elongation without slip at the grips.

Figure 4. Single shear connection test setup

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B. *Moment Connection Test*

The moment connection test focused on right angle beam-to-column joint. The section chosen for this test was C-channel, C10012 which was identical to the section used for the single shear connection test. The section was used as both the vertical and horizontal members. The behavior of screw connection under the moment connection test was investigated by varying the number of screws and arrangement of the screws. Two types of beam-to-column joints were tested; one with three screws and one with four screws. The screw connections were designed such that the distance measured from the center of the screw hole to the center of an adjacent screw hole was 40mm for both configurations. Besides that, the distance of the applied point load to the centroid of the screw group, d was 550mm. The details of the test configurations are tabulated in Table IV and the design details of the specimen are shown in Fig. 6.

TABLE IV. DETAILS OF TEST SPECIMENS

Specimen	Beam Length, l_b (mm)	Column Length, l_c (mm)	No. of Screws	Distance, d (mm)
BC3	700	450	3	550
BC4	700	450	4	550

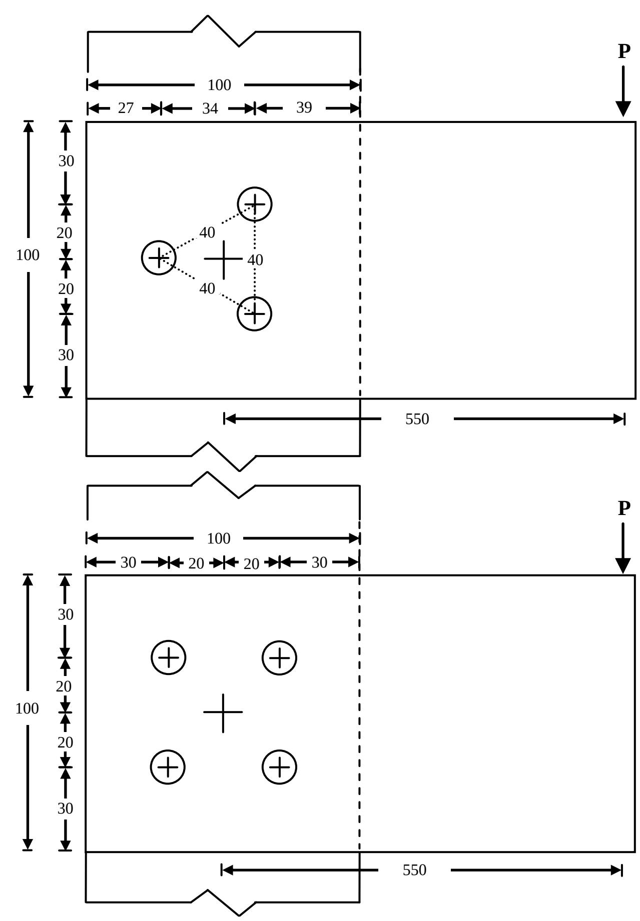

Figure 6. Design details of screw connection specimens (in mm)

A holding rig was designed to support the vertical member of the test specimen. The member was bolted to the rig using six M12 bolts and nuts at the upper and lower sections of the connection to prevent the member from moving during test. Besides that, a loading rig was also designed to apply a concentrated load at a point on the horizontal member using half-round. Bearing plate was placed at the loading point to prevent local buckling of the thin-walled section. Furthermore, the loading rig was attached with steel plates to restraint lateral buckling of the horizontal member when it was loaded. Teflon pads were used to provide smooth contact between the loading rig and the test specimens. Two horizontal LVDTs were installed at the upper and lower section of the vertical member to monitor if there was any slip in the vertical member during the test. A third LVDT was installed vertically in between the vertical member and the loading point to measure the vertical displacement of the horizontal member. The test setup is shown in Fig. 7.

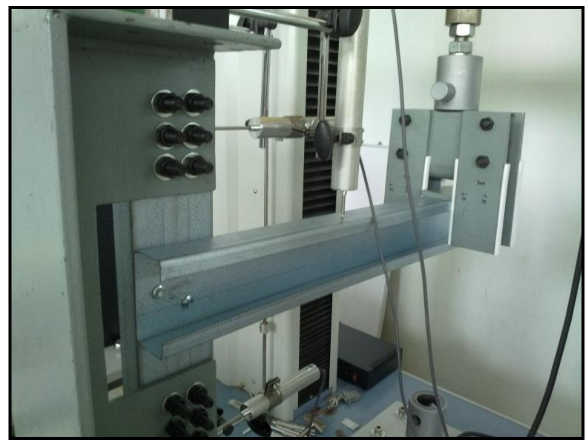
Figure 7. Moment Connection Test Setup

III. Results and Discussion

A universal testing machine was used to apply load for both the tensile and moment connection tests. Load was applied slowly at a rate of 5mm/min until the specimens fail. The behavior of the specimens was observed throughout the tests and the failure mode of each of the specimens was recorded.

A. *Single Shear Connection Test*

It was observed that all the test specimens experienced tilting of screw followed by the elongation of screw hole before failure occurred. Different failure modes including net section tension, and tilting and bearing were observed from the tests. Fig. 8 shows the bearing and tilting failure for specimen S112/12. Fig. 9 shows the net section tension failure for specimen S208/12.

The data collected from the tests were plotted in force displacement graphs for analysis as shown in Fig. 10 and Fig. 11. The test strength was taken as the peak load in each curve of single shear screw connection. The test results are tabulated in Table V.

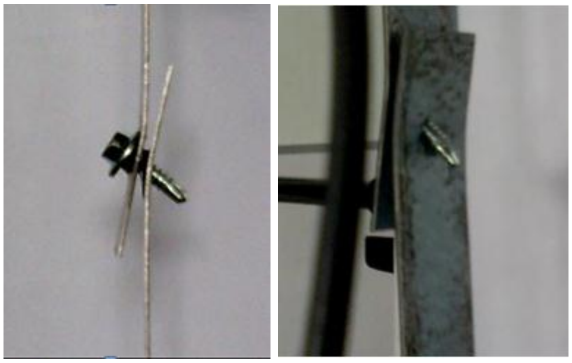

Figure 8. Bearing and tilting failure (S112/12)

Figure 9. Net section tension failure (S20812)

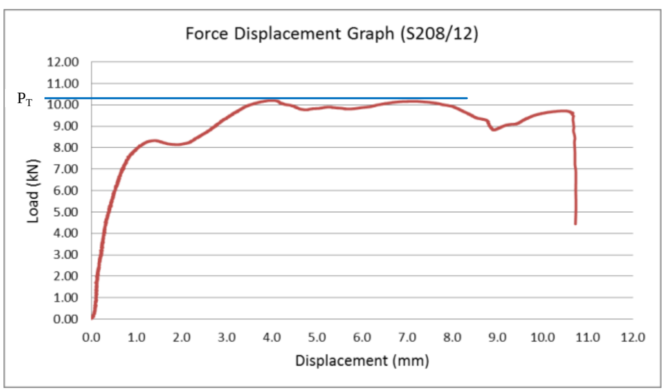

Figure 10. Force displacement graph (Bearing and Screw Tilting failure)

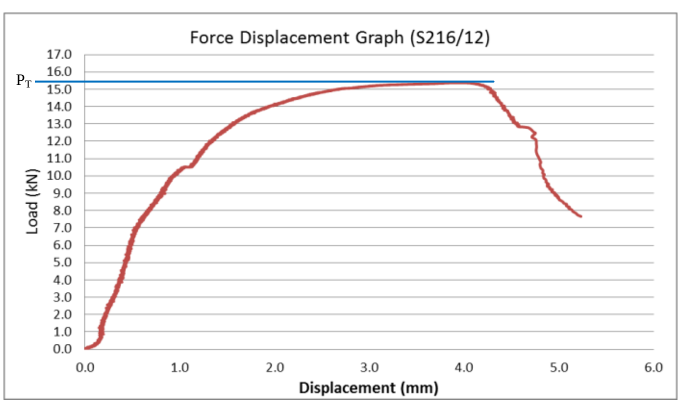

Figure 11. Force displacement graph (Net section tension failure)

TABLE V. SINGLE SHEAR CONNECTION TEST RESULTS

Specimen	Connection Capacity (kN)		P_T/P_A	Failure Mode	
	Test, P_T	AISI and AS/NZS, P_A		Test	AISI and AS/NZS
S112/12	7.60	7.60	1.00	BT	B
S212/12	15.06	13.74	1.10	N	N
S212/08	8.72	8.02	1.09	BT	B
S208/12	10.13	8.88	1.14	N	N
S212/16	16.99	13.74	1.24	N	N
S216/12	15.74	13.74	1.15	N	N

Note: B = Bearing Failure, T = Net Section Tension Failure, BT = Bearing Failure Accompanied with Screw Tilting

The test strength was compared with the predicted strength using the current specifications for cold-formed steel structures. It is shown that the strength of the single shear screw connection predicted by the current specifications is generally conservative.

B. ***Moment Connection Test***

No buckling occurred in this test. Only slight tilting of screws was observed at the end of the test as shown in Fig. 12 and Fig. 13. The force and displacement data recorded was converted to moment and rotation before being plotted into moment rotation graphs as shown in Fig. 14 and Fig. 15. The capacity of the moment connection was taken at 0.05 rad as recommended by Chung and Lau [11].

Figure 12. No buckling failure (BC4)

Figure 13. Screw tilting (BC4)

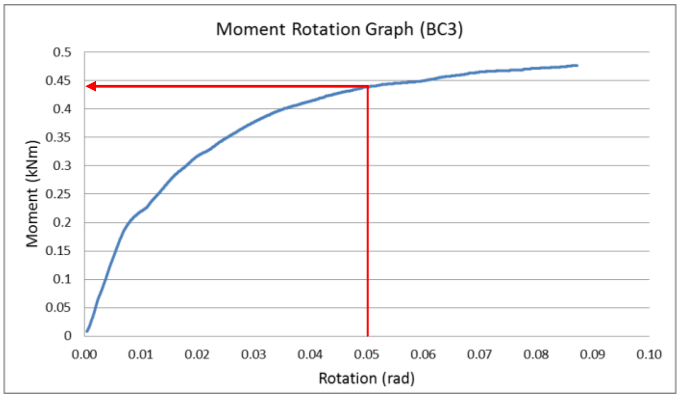

Figure 14. Test curve (BC3)

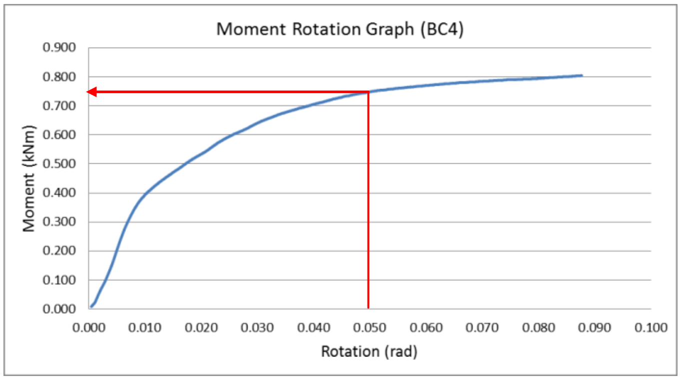

Figure 15. Test curve (BC4)

The test capacity of the connection is tabulated in Table VI. As no buckling was observed in the test, the strength of the connection was not affected by the buckling in the section. The resultant force acting on the screw was calculated and compared to the capacity of a single screw. It is shown that the strength predicted by the current specifications is not conservative for screw moment connection.

TABLE VI. MOMENT CONNECTION TEST RESULTS

Specimen	Failure Mode	Test Strength, M_T (kNm)	Resultant Force on Screw, F_R (kN)	Screw Capacity, P_A (kN)	F_R/P_A
BC3	T	0.45	6.62	7.60	0.87
BC4	T	0.73	6.69	7.60	0.88

IV. Conclusion

A series of single shear screw and moment connections of thin steel sheets was tested. The behavior of the specimens was tested by varying the steel sheet thickness, number and arrangement of screws. The connection strengths, failure modes and force displacement curves of the specimens were obtained. The test strength of single shear screw connection was compared with the coupon test results and predictions from the current design specifications. It was found that the strength of the single shear screw connection predicted by the current specifications is generally conservative. The resultant force acting on the screw in the moment connection joint was calculated and compared with the strength of the screw predicted from the current design specifications. It was found that the strength predicted for the moment connection joints is not conservative.

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