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BEHAVIOR AND STRENGTH OF COLD-FORMED STEEL LIPPED C-SECTION WITH TRACK UNDER COMPRESSION

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ABSTRACT

The main objective of this paper is to present the compressive behavior of cold-formed steel lipped channel section (stud) connected by plain channel section (track) at both ends, called stud-track. Compression tests were conducted on 19 specimens for 300mm and 800mm length cold-formed steel columns with stud and stud-track. The specimens are tested with friction-bearing boundary conditions where the columns ends are borne directly on steel plates. Additionally, a non-linear finite element analysis was also conducted so that the ultimate strength, stress distribution, load-displacement response and failure mode could be captured. Material non-linearities, initial geometric imperfection and inclined section imperfection were included in the analysis model. The ultimate compressive strength obtained from the experiment results were 56-82% of the estimated strength based on the Direct strength method (AISI 2007). The reduction of compressive strength indicates that just a little bit of inclined section imperfections may significantly reduce the ultimate strength of the short stud. Moreover, the results of stud-track specimens indicate that the ultimate compressive strength of stud can be increased by connecting the studs with tracks at both ends. The finite element models of 300mm length stud include inclined section imperfection which indicate good agreement with the experiment results. This included comparison of ultimate loads, load-displacement curves and failure mechanism.

Keywords: Cold-formed steel lipped channel studs, Stud to track, Shell finite element analysis, Experimental results

1. INTRODUCTION

Even if the compressive behavior of the cold-formed steel lipped channel section column can be explaind by elastic theory, the compressive behavior of cold-formed steel lipped channel sections (stud) with track (plain channel section) at both ends, so called stud-track which is widely use for load-bearing wall system, is not yet clearly explained. The main objective of this paper is to present

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the compressive behavior of stud-track. Compression tests were conducted on 19 specimens for 300mm and 800mm length cold-formed steel columns with stud and stud-track. Additionally, 300mm length stud specimen, a non-linear finite element analysis was also conducted so that the ultimate strength, stress distribution, load-displacement response and failure mode could be captured. The ultimate experimental strengths of the studs are compared with the design strengths calculated, using the direct strength method of North American Specification (AISI 2007) for the design of cold-formed steel structural members. The influence of inclined section the imperfection on the load-carrying capacities of stud was also discussed.

2. EXPERIMENTAL INVESTIGATION

2.1. Test specimens

Two different test setups were utilized in this experimental study. First test setup was a stud which both ends are borne directly on the steel plates as shown in Fig.1 (a). The second test setup was comprised of a stud connected to the tracks at both ends by screw, Fig.1 (b). The cold-formed steel lipped channel section column has the nominal dimensions of t, H, B and D which are 1.6, 100, 50 and 20 mm respectively as shown in Fig.2 (a). The lengths of the column (L) are 300 and 800mm. The plain channel section track with nominal dimensions of t, H, B are 1.6, 105 and 50 mm, respectively, as shown in Fig.2 (b). The measured cross-section dimensions of the specimens are given in Table 1. The cross-section dimensions, measured by vernier caliper, are the average of the measured valued at each end and mid-height section. The actual average metal thickness is 1.43 mm and 1.53 mm for lipped and plain channel section, respectively. The rounded inside corner radius (r) is 3.0 mm for all specimens. Only the plain channel section was manufactured by brake forming.

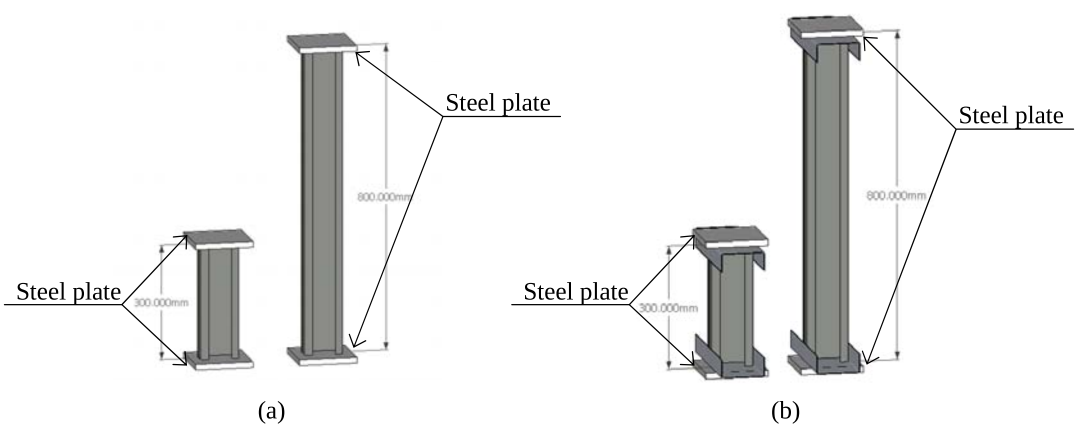


Figure 1: Type of test specimens (a) stud (b) stud-track.

Table 1: Geometries, maximum of initial imperfections, ultimate strength and failure mode

Specimen	H (mm)	B (mm)	D (mm)	L (mm)	Δ_{fl} (mm)	Δ_w (mm)	Δ_{fr} (mm)	P_u (kN)	Failure modes
C300-1	101.72	50.98	21.51	300.0	0.422	1.283	1.021	62.98	L
C300-2	101.37	51.01	20.25	299.0	0.507	0.594	0.714	61.70	L
C300-3	101.87	50.45	21.48	298.0	1.217	0.541	1.005	44.46	L
C300-4	101.80	50.217	21.18	299.5	0.581	0.388	0.753	62.05	L
C300-5	102.15	50.77	21.72	298.1	0.375	0.728	0.736	49.93	L
C300-6	101.20	50.02	21.55	299.5	0.898	1.775	0.836	42.96	L
							Mean	54.01	
CT300-1	101.60	50.44	21.03	299.0	0.523	0.498	0.576	66.68	L
CT300-2	102.18	51.14	21.03	298.3	0.673	0.692	0.894	65.46	L
CT300-3	101.93	51.20	20.89	300.0	0.345	1.056	0.378	60.36	L
CT300-4	100.14	49.78	20.17	299.1	0.213	0.929	0.984	58.70	L+D
CT300-5	100.14	49.78	20.17	299.6	1.135	0.335	0.562	69.19	L
CT300-6	100.14	49.80	20.17	299.5	0.983	1.212	0.387	66.68	L
CT300-7	100.14	49.80	20.17	299.0	0.811	0.873	1.102	66.86	L
							Mean	64.85	
C800-1	100.16	50.29	21.25	802.0	0.684	0.534	1.354	52.40	L
C800-2	100.12	50.25	20.53	800.0	0.812	0.419	0.828	52.44	L
C800-3	102.00	51.25	21.90	796.0	1.125	0.620	0.567	47.43	L
							Mean	50.76	
CT800-1	100.20	50.38	20.19	798.3	0.782	0.642	1.196	62.23	L
CT800-2	100.19	50.43	21.56	799.0	0.998	0.451	0.959	63.18	L
CT800-3	100.15	50.71	20.99	799.0	0.727	0.411	1.057	67.92	L
							Mean	64.44	

Remarks: 1. Cxxx-x is pure stud, 2. CTxxx-x is stud-track, and 3. Actual dimensions of all track section is 107.33x48.54 with length 300 mm

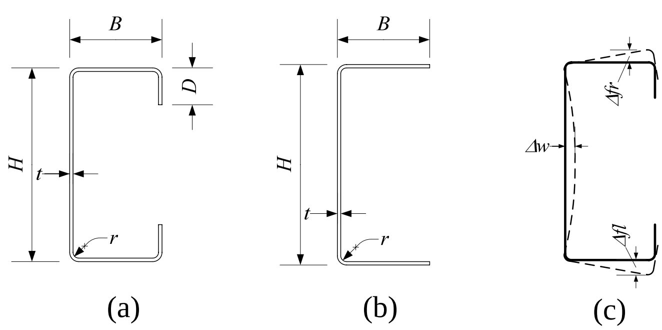


Figure 2: Cross section and definition of symbols (a) lipped channel section (b) plain channel section and (c) initial imperfection

2.2. Material properties

The material properties of the test specimens were determined by coupon tests. The coupons were prepared and tested according to the JIS Z 2241-1998, having a gauge length of 50 mm and a width of 25 mm. The coupons were tested in a universal testing machine model: AG-100KNI M2. The test results of coupons are shown in Table 2. The table contains the yield stress (f_y), the ultimate strength (f_u), the modulus of elasticity (E), and the elongation based on a gauge length of 50 mm.

Table 2: Average of material properties obtained from coupon tests

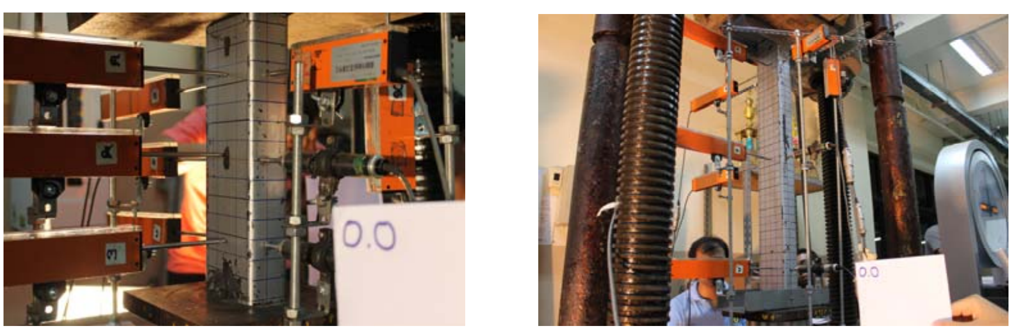
Coupon	f_y (MPa)	f_u (MPa)	E (MPa)	Elongation (%)
Stud	292.25	358.68	218385	40.6
Track	280.64	345.82	190426	39.4

2.3. Initial geometric imperfection

The initial local geometric imperfections of the specimens were measured systematically using LVDT displacement transducers prior to testing. As shown in Fig.2 (c), the local imperfection mainly includes imperfection of the web (Δ_w) and the flanges. Table 1 summarizes the maximum values of the local initial imperfections at web and both flanges. Table 1 shows the largest initial imperfection of web and flange are 1.775 mm and 1.217 mm, respectively.

2.4. Test rig and gauge arrangement

Compression tests were carried out using a 1000 kN universal testing machine. In this system, the load and displacements were recorded automatically by a data acquisition instrument. The specimen was put directly on the bottom bearing plate of the testing machine. The crosshead of the testing machine was moved slowly toward the specimen until the top bearing and the bottom bearing plate were in full contact with the end of the specimen. Ten transducers were installed to record the displacements of the specimen under the progressive increase in the axial compression. The test rig and the test setup of some stud and stud-track specimens are shown in Fig. 3



(a) (b)

Figure 3: Test setup for stud and stud-track specimens (a) C300-1 and (b) CT800-1

2.5. Stud test results

The ultimate experimental loads (P_u) and failure modes at ultimate load of the studs are given in Table 1. Only the local buckling mode was observed in these studs. Moreover, as shown in the Table 1, the ultimate load of 300mm length studs fluctuate (about 31.8% between minimum and maximum). Observation during testing found that the visible deformation often starts at around the end of stud as shown in Fig. 4. It is result from the incline of the section. It also shows that a little of an incline on the section (inclined section imperfection) results a significant reduction of the ultimate load and stiffness of the columns. While the ultimate load of 800 mm columns is less than 300 mm columns, which is about 6%.

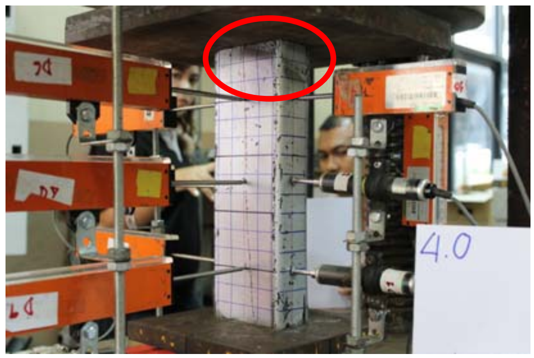
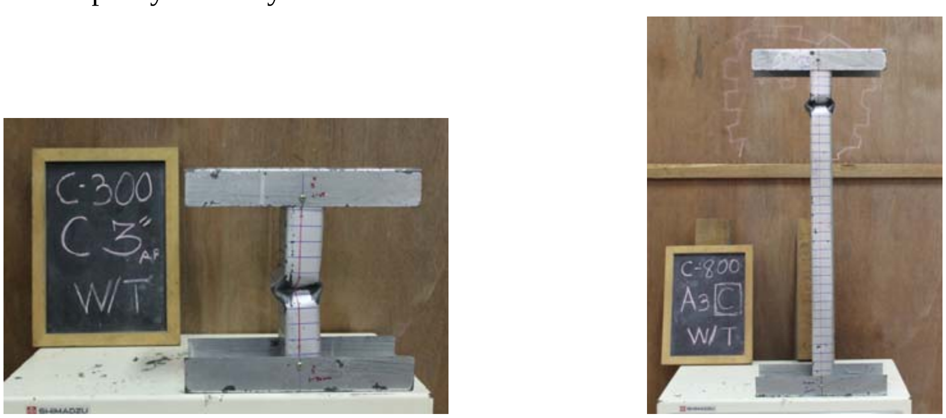


Figure 4: Initial deformation at corner of C300-3

2.6. Stud-track test results

The ultimate load results of stud-track specimens are also shown in Table 1. Most of the failure mode is local buckling, which can occur at any position in the range of the studs between both end tracks (see Fig. 5). Only CT300-4 failed in combined local and distortional (D) buckling mode. Additionally, the results indicate that tracks give more compressive strength and more consistency for the stud when compared with the stud without track. Especially for stud-track length of 800 mm, the axial load capacity is clearly increased.



(a) (b)

Figure 5: Local buckling failure mode of (a) CT300-6 and (b) CT800-3

3. FINITE ELEMENT ANALYSIS

The finite element analysis program ABAQUS version 6.11 was used to simulate the compressive behavior of channel columns. In this paper, the first step is investigating the influence of initial local imperfection and inclined section imperfection on the compressive behavior of studs with length of 300 mm. Elastic buckling and non-linear analyse were used in this study. The elastic buckling analysis was used to establish the buckling mode which will scaled to be the representative of the geometric imperfection. Following the buckling analysis, the non-linear analysis of the column with inclined section imperfection is performed to obtain the ultimate load capacity, load-displacement history, and failure mechanism of the studs. The material and geometric nonlinearity also considered in the analysis

3.1. Finite element model

The simulations use the S4R quadrilateral shell element to discrete the sections and to formulate the finite element models. The aspect ratio of the mesh was kept closer to 1.0 throughout. Analytical rigid plate was modeled as steel plates at both ends of the stud by defining the coefficient of friction for contact surface between stud ends and steel plates as 0.3. Boundary conditions were applied at both plates. At the bottom plate, translations and rotations were constrained in all directions. At the top plate, only translation in axial direction of the stud is allowed. For material nonlinearity, the stress-strain data from coupon tests were converted to the true stress and used as an input.

The behavior and strength of thin-walled steel column are obviously influenced by geometric imperfection. Schafer and Pekoz (1998) recommended the use of a maximum deviation that is approximately equal to the plate thickness as a simple rule of thumb, which is consistent with the maximum value from measurement as shown in Table 1. In this study, the maximum deviation of the perturbed initial imperfection from the perfect geometry are at 10%, 100% and 200% of the plate thickness. The buckling shape of Mode 1 is used in the postbuckling analysis. Section imperfection, incline of stud section, are other types of perturbation that affect the strength and behavior of the stud specimens. Two inclined planes at top end of the stud were studied by varying the degree of inclination from 0.15, 0.25 to 0.50 degree, see Fig 6.

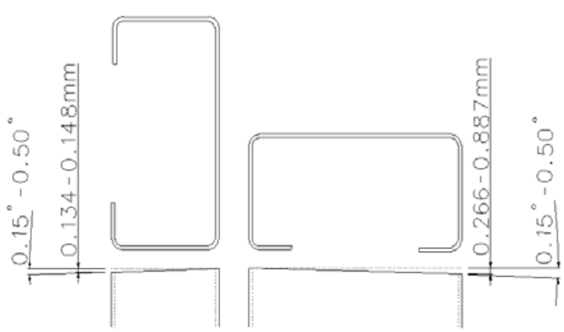


Figure 6: Inclined section imperfection

3.2. Finite element study results

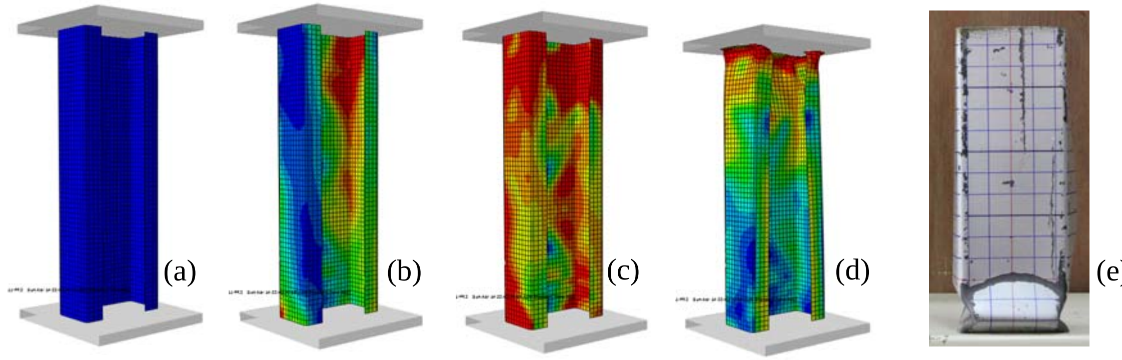
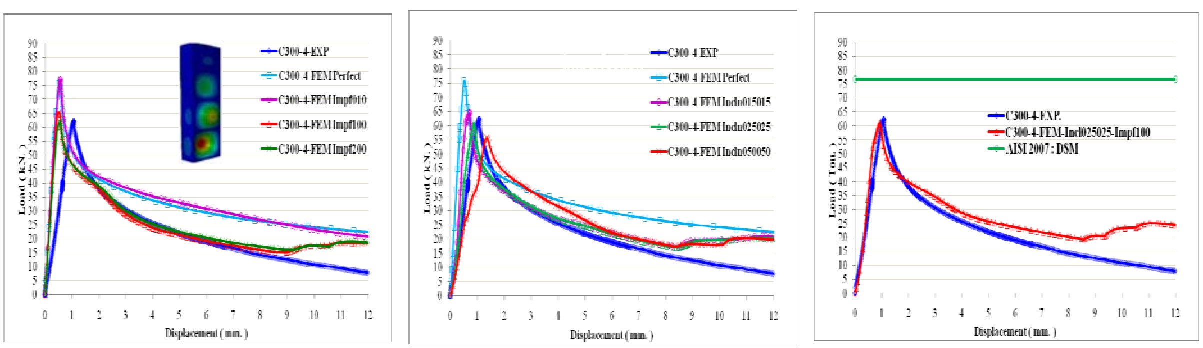


Figure 7: Load-displacement progression for C300-4 (a) P = 0 kN (b) P = 33.6 kN (c) P = 61.0 kN (peak load) (d) P = 24.2 kN and (e) actual failure mode

The loading progression for the C300-4 is depicted in Fig. 7(a-d). The stud exhibit deformation started at the highest corner due to the effect of section imperfection, then local buckling of the web was formed at the peak load and led to final failure mode. It can be seen that final failure mode is the same for FEA and the experiment, (Fig. 7(e)), but occurred at the opposite end.



(a) (b) (c)

Figure 8: Comparison of exp. And FEA load vs. displacement of C300-4 (a) local imperfection (b) inclined section imperfection (c) combine local & inclined section imperfection

The load-displacement curves from FEA are shown in Fig. 8(a-c), together with the one from the experiment. It can be seen from these figures that the experimental and FEA load-displacement curves agree well for an imperfection magnitude of 100% of thickness, Fig. 8(a), and inclined section imperfection of 0.25 degree, Fig. 8(b). While the load-displacement curve for this specimen matched perfectly using a combination of the both imperfections, Fig. 8(c). The ultimate load based on FEA is also in good agreement with the experiment result. However, the results of 300 mm studs in Table 1 and Fig. 8(c) found that the ultimate strength obtained from the experiment is 56-82% of the calculation value (76.7 kN) according to the direct strength method (AISI 2007). AISI 2007 does not take into account the effect of incline section imperfections.

4. CONCLUSION

A total of 19 stud tests and stud-track tests were performed in this study together with a simulation of 300mm length stud by a non-linear finite element analyses. The results indicated that the ultimate compressive strength obtained from the experiment results were only 56-82% of the estimated strength based on the Direct strength method (AISI 2007) at 76.7 kN. The reduction of compressive strength indicates that just a little bit of inclined section imperfections may significantly reduce the ultimate strength of the short stud. Moreover, the results of stud-track specimens indicate that the ultimate compressive strength of stud can be increased and more consistency by connecting the studs with tracks at both ends. The finite element model of 300mm length stud include inclined section imperfection indicate good agreement with the experiment results.

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