Experiments on Cold-Formed Steel Lipped Channel Columns with End-Track in Compression

Watanapong Hiranmarn[1]
Prakit Chomchuen[2]
Nuthaporn Nuttayasakul[3]

[1]*Department of Civil Engineering, Mahanakorn University of Technology,*
E-mail: watanapong@gmail.com
[2]*Department of Civil Engineering, Mahanakorn University of Technology,*
E-mail: cprakit@gmail.com
[3]*Department of Civil Engineering. Chulachomklao Royal Military Academy,*
E-mail: nuthaporn.crma@gmail.com

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 46 specimens for 300, 800, 1200, 1800 and 2400 mm length cold-formed steel columns with stud and stud with track. The specimens are tested with friction-bearing boundary conditions where the columns ends are borne directly on steel plates. The results of stud-track specimens indicate that the ultimate compressive strength of short stud 300, 800 and 1200 mm length can be increased about 20% by connecting the studs with tracks at both ends. While the ultimate compressive strength of the 1800 and 2400 mm columns increase only 4-5%. In other words, the end-track supports influence significantly on the compressive behavior of the studied columns, especially for the short column. The results also show that its effects decrease when the column height increase. Observation during testing found that only slightly inclined section imperfections may significantly reduce the ultimate strength of the short stud. The ultimate compressive strength of column length 300, 800 and 1200 mm obtained from the experiment results were 67-85% of the estimated strength based on the Direct Strength Method (AISI 2007). While the results from experiment and calculation of column length 1800 mm was very close. For testing of 2400 mm column length specimens, the experimental ultimate compressive strength is higher than the estimated strength about 33%.

Keywords: Cold-formed steel lipped channel studs, Stud to track, Experimental results

1. Introduction

Even if the compressive behavior of the cold-formed steel lipped channel section column can be explained 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 the compressive behavior of stud-track. Compression tests were conducted on 46 specimens by dividing into two groups of 300, 800, 1200, 1800 and 2400 mm length cold-formed steel columns stud and stud-track. The experimental ultimate strengths of the studs are compared with the calculated design strengths according with the design method for cold-formed steel structural members called direct strength method [1] of North American Specification (AISI 2007) [2]. The compressive capacities, failure modes and behavior of specimens during loading were also discussed.

2. 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, 800, 1200 and 2400 mm. The plain channel section track with nominal dimensions of t, H, B is 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 values 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.

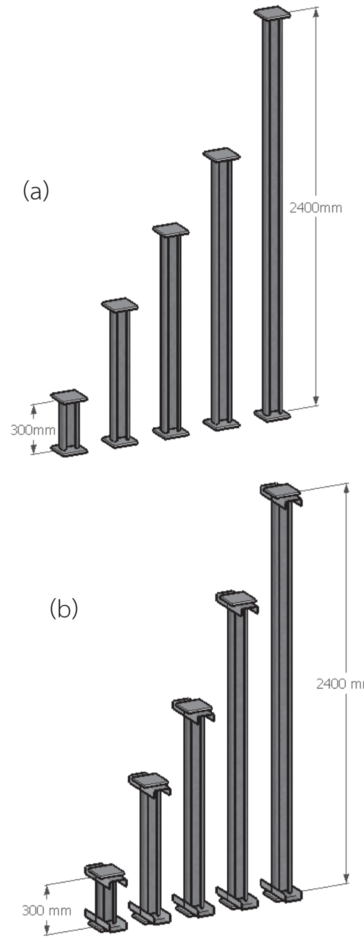


Figure 1: Type of test specimens (a) stud (b) stud-track.

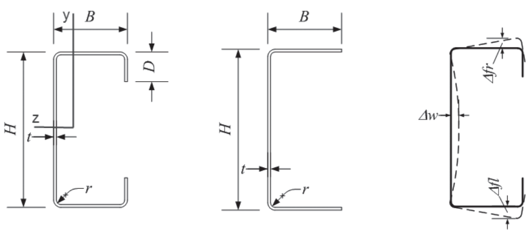


Figure 2: Cross section and definition of symbols (a) lipped channel section (b) plain channel section and (c) initial local imperfection

3. 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 (fy), the ultimate strength (fu), the modulus of elasticity (E), and the elongation based on a gauge length of 50 mm.

Table 2: Average values of material properties obtained from coupon tests

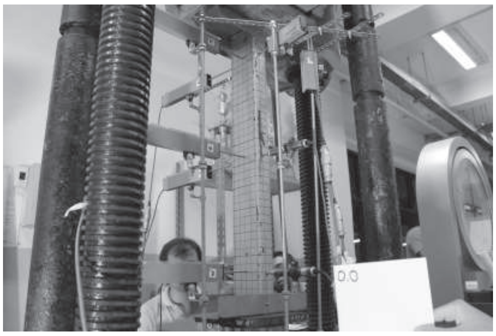
Coupon	f_y (MPa)	f_u (MPa)	E (MPa)	Elongation (%)
Stud	292.25	358.68	218385	40.6
Track	280.64	345.82	190426	39.4

4. 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_f) and the flanges (Δ_W). The initial global imperfections also were measured about main axis (Δ_z) and minor axis (Δ_y) of the section, as shown in Fig. 2 (a), using theodolite for column length 1200, 1800 and 2400 mm. Table 1 summarizes the maximum values of the initial imperfections.

5. Test Rig and Gauge Arrangement

Compression tests were carried out using a 1000 kN universal testing machine for specimens length 300, 800 mm and length 1200, 1800 and 2400 mm specimens were tested by using rigid steel frame on strong floor with 3500 kN hydraulic jack. In both systems, 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-track specimens (a) CT800-1 (b) C1800-2

6. Stud Test Results

The ultimate experimental loads (Pu) and failure modes at ultimate load of the studs are given in Table 1. Studs length of 300, 800 and 1200 mm only the local buckling mode was observed in these studs, as shown in Fig. 4, and average ultimate load were about 50-54 kN. For the ultimate load of 300 mm length studs, the results vary 31.8% between minimum and maximum capacities.

Table 1: Geometries, max. of initial imperfections, ultimate load, failure mode and design load

Specimen	H (mm)	B (mm)	D (mm)	L (mm)	Δ_{fl} (mm)	Δ_{w} (mm)	Δ_{fr} (mm)	Δ_{z} (mm)	Δ_{y} (mm)	P_u (kN)	Failure modes	P_{Design} (kN)
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		76.65 (L)
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		76.65 (L)
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		76.65 (L)
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		76.65 (L)
C1200-1	103.1	52.6	20.25	1199.5	0.064	0.516	0.083	0.000	0.379	54.34	L	
C1200-2	103.2	53.25	19.88	1198.8	0.066	0.639	0.061	-	-	53.44	L	
C1200-3	103.2	53	20.00	1199.6	0.587	1.085	0.513	-	-	47.79	L	
C1200-4	103.4	52.6	19.89	1200.1	0.454	0.769	0.413	0.175	0.911	54.12	L	
C1200-5	103.1	52.75	20.25	1200	0.475	0.607	0.662	0.526	0.759	53.84	L+F	
C1200-6	103.3	53	20.00	1198.8	0.266	1.420	0.464	0.526	1.593	51.90	L	
									Mean	52.57		63.92 (L+F)
CT1200-1	103.5	52.8	20.00	1199.6	0.876	2.942	1.252	3.054	0.613	66.12	L	
CT1200-2	103.5	52.85	20.00	1200.5	1.082	1.421	1.294	1.096	0.175	59.25	L	
CT1200-3	103.2	52.95	20.25	1199.6	1.358	0.730	1.408	0.783	0.351	63.67	L	
CT1200-4	103.3	52.9	19.50	1199.9	1.210	1.200	1.029	0.392	1.840	58.57	L+F	
CT1200-5	103.2	52.95	19.50	1198.7	0.466	0.867	0.557	0.705	0.701	60.14	L+F	
CT1200-6	103.2	52.6	19.88	1198.3	0.576	1.146	0.740	0.861	0.438	58.37	L	
CT1200-7	103	52.75	20.00	1198.7	0.554	1.288	0.592	-	-	61.80	L+F	
									Mean	61.13		63.92 (L+F)
C1800-1	103.4	52.65	19.50	1799.9	1.248	0.066	0.891	0.613	0.607	55.49	L+FT	
C1800-2	103.2	52.75	20.00	1800.1	0.872	1.250	0.775	0.964	0.873	51.89	L+F	
C1800-3	103.1	52.6	20.00	1798.9	0.926	1.306	0.719	0.351	1.138	52.97	FT	
									Mean	53.45		51.10 (L+F)
CT1800-1	102.7	52.7	20.00	1799.1	0.581	0.811	0.869	0.438	0.607	57.41	L+FT	
CT1800-2	103.1	52.5	20.00	1798.3	0.979	0.959	0.743	0.526	0.304	56.77	L+FT	
CT1800-3	102.7	52.85	20.25	1800.2	0.700	1.085	0.597	1.139	0.607	54.11	L	
									Mean	56.10		51.10 (L+F)

Table 1: Geometries, max. of initial imperfections, ultimate load, failure mode and design load (cont.)

Specimen	H (mm)	B (mm)	D (mm)	L (mm)	Δ_{fl} (mm)	Δ_{w} (mm)	Δ_{fr} (mm)	Δ_{z} (mm)	Δ_{y} (mm)	P_u (kN)	Failure modes	P_{Design} (kN)
C2400-1	103.1	52.55	20.2	2400.3	2.173	1.773	1.139	0.438	0.152	48.28	FT	
C2400-2	103.3	52.45	20	2399.6	1.008	3.246	1.406	0.526	0.645	47.08	FT	
C2400-3	103.1	52.6	19.88	2399.2	1.798	2.114	1.636	0.876	0.190	48.67	L+FT	
C2400-4	103	52.5	20	2399.6	1.889	1.598	1.469	1.928	0.304	51.74	L+FT	
									Mean	48.94		33.75 (F)
CT2400-1	102.9	52.65	20	2400.2	1.403	2.665	1.215	1.018	1.665	49.78	L+FT	
CT2400-2	103.3	53	19.5	2400.2	0.675	2.276	0.471	0.861	1.052	53.39	L+FT	
CT2400-3	103.2	52.85	19.89	2399.2	1.802	2.266	2.194	0.705	1.840	49.28	L+FT	
CT2400-4	102.9	52.7	19.89	2399.6	2.286	1.867	1.307	0.783	1.840	50.66	L+FT	
									Mean	50.77		33.75 (F)

Remarks: *1. Cxxx-x is pure stud, 2. CTxxx-x is stud-track, 3. Actual dimension of all track section is 107.33x48.54 with length 300 mm, and 4. Failure modes L= Local buckling D = Distorsional buckling FT = Flexural torsional buckling and F = Flexural buckling*

Observation during testing found that if there is only small incline in the cross section (inclined section imperfection), the ultimate load will have a significant reduction. Figure 5 shows initial deformation at the corner section of the specimen which led to reducing the column capacity. While the ultimate load of 1800 and 2400 mm columns were about 49-53 kN, which is, as expected, slightly less than those in short columns. Most of failure modes were flexural torsional buckling combined with local buckling, as shown in Fig. 6.

7. Stud-Track Test Results

The ultimate load results (Pu) and failure modes of stud-track specimens are also shown in Table 1. For short column (length 300, 800, and 1200 mm) most of the failure mode was local buckling, which can occur at any position in the range of the studs between both end tracks (see Fig. 7). The results also show that three out of seven 1200 mm specimens failed in local-flexural buckling mode (see Fig. 8). Therefore, the influence of column length began to affect the column failure mode. Additionally, the results indicate that tracks could help in providing more compressive strength (about 61-65 kN or by approximately 20%). The tracks also reduce the effect of inclined section imperfection on the capacity of the column.

Most of columns, with length 1800 and 2400 mm, failed by local-flexural torsional buckling, same as the stud without track at the ends. This result can be expected because the influence of slenderness ratio and shape of the open section as shown in Fig. 9. However, if the ultimate loads are considered, the results showed that the stud with track failed at 51 to 56 kN or with an increase of 4-5% when compared with stud without tracks. The results show that the influence of the tracks is reduced when the column length is longer.

8. Comparison of Ultimate Load Capacities Between Experiment and Design Results

Ultimate design load (PDesign) of each column lengths which is calculated according to the AISI 2007 standard [1]. The Direct Strength Method was used and calculated using the CUFSM v.4.05 [2] as the analytical tool with pined-end boundary condition. The analyses are shown in Table 1. The results of 300, 800 and 1200 mm for both studs with and without tracks indicate that the ultimate load obtained from the experiment were 67-85% of the values obtained by the direct strength method (76.7 kN). The fact that AISI 2007 does not take into account the effect of inclined section imperfections is the explanation for the differences in results. While 1800 mm stud and 2400 mm studs have experimental loads higher than calculated by 10% and 33%, respectively.

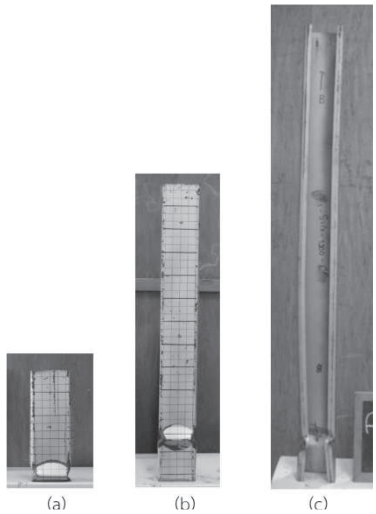


Figure: 4 Local buckling failure at end zone of stud columns (a) 300 mm column (b) 800 mm column and (c) 1200 mm column

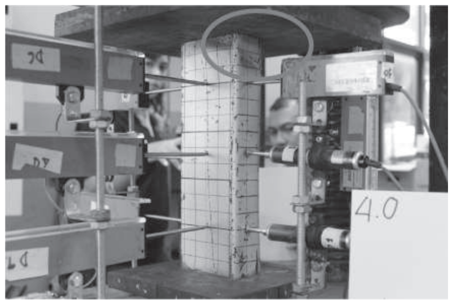
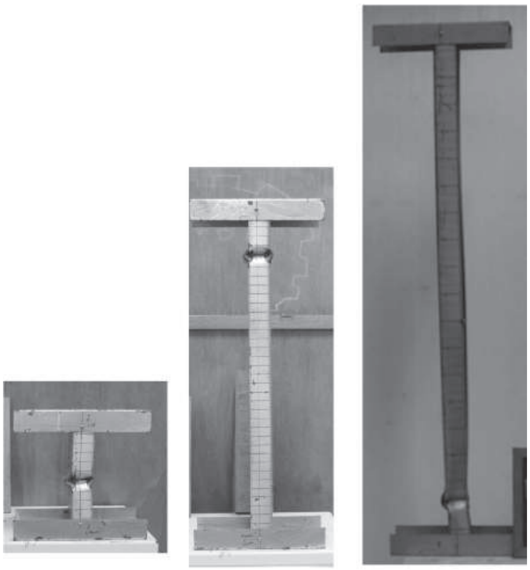


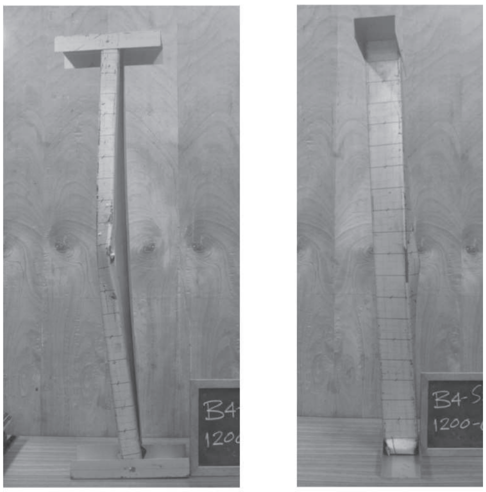
Figure: 5 Initial deformations at corner of C300-3

Figure: 6 Flexural torsional buckling combined with local buckling in studs (a) 1800 mm column and (b) 2400 mm column.



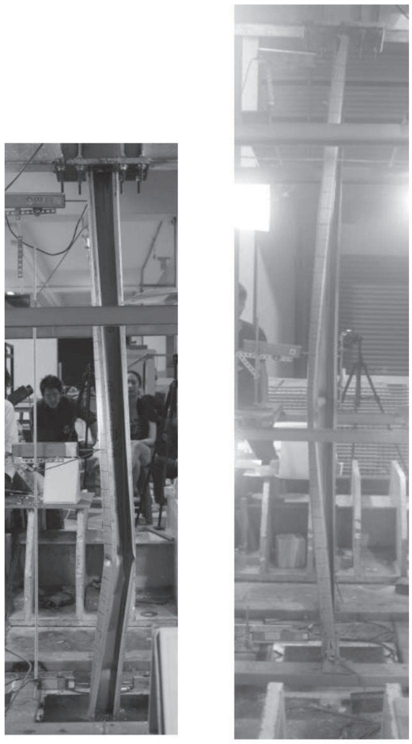
(a) (b) (c)

Figure: 7 Local buckling failure at end zone of stud-track columns (a) 300 mm column (b) 800 mm column and (c) 1200 mm column



(a) (b)

Figure: 8 Local-flexural buckling of stud CT1200-5 (a) side view and (b) front view



(a) (b)

Figure: 9 Local-flexural torsional buckling of stud with tracks (a) 1800 mm column and (b) 2400 mm columns.

9. Conclusion

A total of 46 specimens for 300, 800, 1200, 1800 and 2400 mm length cold–formed steel lipped channel section stud and stud-track tests were performed in this study. The specimens were tested with friction-bearing boundary conditions where the columns ends are borne directly on steel plates. The results of stud-track specimens indicate that the ultimate compressive strength of short stud 300, 800 and 1200 mm length can be increased about 20% by connecting the studs with tracks at both ends. While the ultimate compressive strength of the 1800 and 2400 mm columns increase only 4-5%. In other words, the end-track has significant influence on the compressive behavior of the studied columns, especially for the short column. The results also show that its effects decrease when the column length increases. Additionally, observation during testing found that only small incline in cross section imperfections will result in significant reduction of the ultimate strength of the short stud.

Finally, the ultimate compressive strength of column length 300, 800 and 1200 mm obtained from the experiment results were 67-85% of the calculated strength based on the Direct Strength Method (AISI 2007). While the results from experiment and calculation of 1800 mm column were very close, the experimental ultimate compressive strength of 2400 mm column was approximately 33% higher than the calculated strength.

References

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