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Experimental Investigation of Optimized Cold-formed Steel Compression Members

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Experimental Investigation of Optimized Cold-Formed Steel Compression Members

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Abstract

In the past, standard C-shaped metal studs have been the only option for designers and contractors when selecting a cross section for load bearing compression members. The sigma shaped section has recently emerged as an alternative to the C-section. The sigma shaped section is very similar to the C-shape, with the exception of having an intermediate web return and complex stiffeners. The experimental results of concentric axial compression tests of fifty-eight sigma shaped members are reported. Specimens were tested at various lengths to force global, distortional, and local buckling failure modes. Additionally, the test program contained members with and without web holes. Comparisons of experimental results with the American Iron and Steel Institute (AISI) design methods, Effective Width Method (EWM) and Direct Strength Method (DSM), are discussed.

Introduction

Over the years, extensive research on cold-formed steel (CFS) has proven that the slender nature of these members makes them susceptible to several failure major modes: overall buckling at long unbraced lengths, distortional buckling at medium to long unbraced lengths, and local buckling, which can occur over a wide range of unbraced length. Local buckling has been widely observed and, in many cases, controls the design strength of a CFS compression member. Often, there is interaction between several buckling modes. The complex behavior of these members can induce significant variability in desired (and observed) behavior.

The sigma shaped CFS member has recently been introduced to the US construction market as a compression member. This shape has typically been used in Europe, mainly as a roof purlin. Other research programs [1, 2] have evaluated some aspect of the sigma shape in compression, but this study [3] is the first comprehensive study of sigma shaped compression

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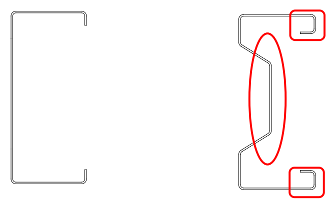
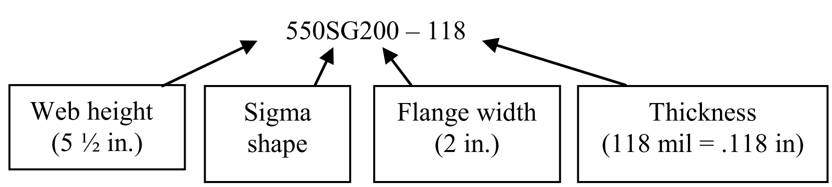
members that are known to the authors. Utilizing this optimized shape as a compression member can provide significant strength advantages when compared to the conventional C-section. The intermediate web return serves to decrease the web slenderness, thereby increasing its resistance to local bucking. Additionally, recent research [4-6] has shown that the complex stiffeners attached to the flange can boost the compression and flexural strengths of the member.



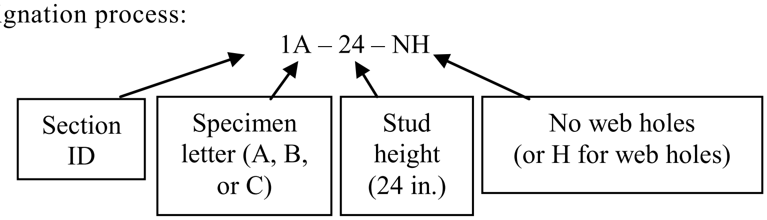
a. b.

Figure 1. a. C-section and b. sigma section

The results reported in this paper are part of a research program to add the sigma shape to the pre-qualified column set of the DSM design specification. These results are only for the sigma shape described in this paper; additional testing was undertaken with conventional C-sections. Full details are contained in [3]. The specimens follow a labeling pattern similar to the SSMA convention:



In this test program, specimen ID labels were generated using the following designation process:



Sigma sections were selected based on geometric ratios, and test lengths were determined by modeling the chosen section in the finite strip software

CUFSM [7]. Table 1 contains the ID labels for the sections reported in this paper.

Table 1. Section ID Labeling

Section	Shape	Section ID
550SG200-118	Sigma	1
550SG300-118	Sigma	2
600SG250-54	Sigma	3
800SG200-33	Sigma	4
800SG300-43	Sigma	5

Experimental Setup

The experimental investigation consisted of both short studs and long studs. The short studs were tested at short (8 or 10 in.) lengths and intermediate (15 or 24 in.) lengths, while long studs were tested at 120 in. lengths.

Short specimen preparation consisted of measuring the actual dimensions, strain gauging the corners at mid-height, and filing the ends to ensure flatness as required by [8]. The specimens were tested in a 220 kips universal hydraulic MTS machine with calibrated displacement accuracy of 0.0001 inches shown in Figure 1. Flange and web displacements were measured with linear potentiometers, and the specimen ends bore directly on steel platens. A scholarly discussion of this end condition is contained in [9], and the boost in strength resulting from this friction bearing condition is calculated as recommended in [10].

Long specimen preparation was very similar to the short specimens. In addition to cross section measurements, long axis imperfection (sweep) was recorded. The studs were tested using an oversized steel frame with hydraulic jack. Strong and weak axis displacements were recorded, as well as mid-height strain on each corner. In an attempt to replicate pinned boundary conditions, a 3 in. diameter saddle (Figure 2) was sandwiched between steel platens, on which the stud bore directly. Post-test analysis revealed that these boundary conditions, coupled with the complex behavior of CFS members, did not result in a pinned configuration. Figure 3 shows the long specimen setup. Both short and long studs were loaded at 3 ksi/minute as prescribed by [8].

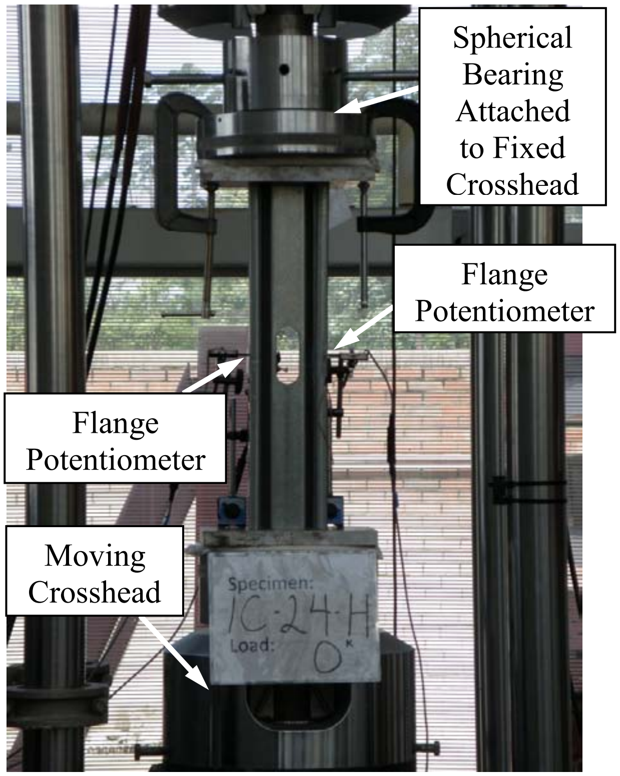


Figure 1. Short test setup

Experimental Results

Multiple buckling modes were observed throughout the test program and in some cases, interaction between buckling modes occurred in the same specimen. In thinner sections, local buckling would develop first, followed by another buckling mode (distortional or global). In thicker sections, distortional or global buckling would control but local buckling could develop as instability increased in the cross section approaching and after failure.

Figure 2. Spherical bearing boundary condition

The results of the test program are displayed in three tables: Table 2 and Table 3 (sigma section without holes), and Table 4 (sigma section with holes). The column of "buckling mode" describes the buckling modes which were observed during each individual test, in the order in which they developed. The terms F, FT, D, and L stand for flexural, flexural-torsional, distortional, and local buckling, respectively. If tests of 8 in. or 10 in. sigma columns revealed no significant difference in strength or behavior compared to the same 24 in. section, only one test was conducted of that series. The exception to this was the 550SG300-118 series, in which 3 tests were conducted to determine the behavior. This was the first 10 in. test series, so three tests were performed. The "DSM" column shows the DSM predicted strength for fixed boundary conditions.

Table 3 contains the results for six 120 in. tests of the 800SG200-33 section. This is because the first test specimen failed prematurely. There was intermediate weak axis displacement prior to the final failure, but there were no defects in the specimen or test setup to explain the early failure. Consequently, six tests were carried out to determine the section strength.

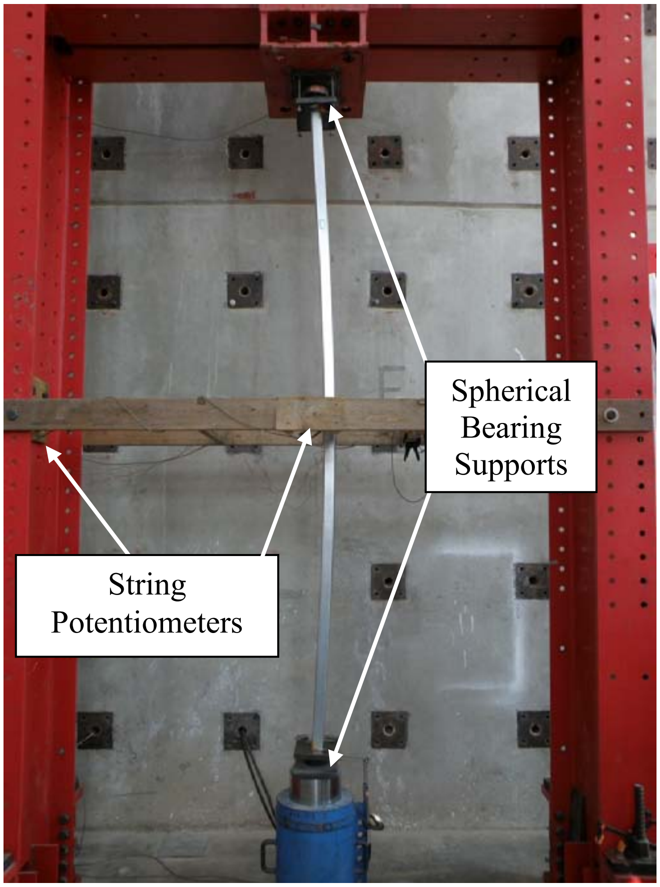


Figure 3. Long test setup

Supplemental Testing

Material property tests were conducted on samples of steel in order to determine the actual properties. Tensile coupon tests were conducted in accordance with [11]. Individual steel samples were provided by the manufacturer for the sigma sections. Actual material properties (yield strength and Young's modulus), along with nominal dimensions, were used to determine the predicted section strengths by the EWM and DSM. Tables 5 and 6 contain results of tensile coupon tests.

Table 2. Sigma section test results (no holes)

Section	Test ID	Buckling mode	Ult. Load (kips)	Avg. (kips)	DSM (kips)
550SG200-118	1A-15-NH	D	86.0	86.0	91.7
	1A-24-NH	D	91.3	91.3	91.7
	1B-24-NH	D	91.0		
	1C-24-NH	D	91.7		
	1A-120-NH	F	32.1	34.3	51.9
	1B-120-NH	F	33.4		
	1C-120-NH	F	37.2		
550SG300-118	2A-10-NH	D	109.7	108.7	103.9
	2B-10-NH	D, L	107.2		
	2C-10-NH	D	109.2		
	2A-24-NH	D	97.4	96.9	103.5
	2B-24-NH	D, L	97.5		
	2C-24-NH	D	95.7		
	2A-120-NH	F	61.2	61.2	78.6
	2B-120-NH	F	52.6		
	2C-120-NH	F	69.8		
600SG250-54	3A-8-NH	D, L	41.7	41.7	38.7
	3A-24-NH	D	40.4	39.8	37.5
	3B-24-NH	D, L	38.9		
	3C-24-NH	D	40.0		
	3A-120-NH	F	18.6	20.0	27.7
	3B-120-NH	F	21.9		
	3C-120-NH	F	21.1		

Strength Predictions

A summary of the strength predictions for the short sigma sections are contained in Table 7. The evaluated predictions, P_{exp} / P_{EWM} and P_{exp} / P_{EWM} as well as the statistical analysis, are computed for fixed boundary conditions and account for the boost in strength for this test setup as recommended in [10]. Results indicate that both methods are good predictors of strength and are consistent with other CFS research programs.

The DSM strength predictions for the short 800SG300-43 section were unconservative and therefore reduced the overall accuracy. If this section is omitted from the accuracy calculation in Table 7, P_{exp}/P_{DSM} becomes 0.99.

Table 3. Sigma section test results (no holes) continued

Section	**Test ID**	**Buckling mode**	**Ult. Load (kips)**	**Avg. (kips)**	**DSM (kips)**
800SG200-33	4A-10-NH	L, D	18.7	18.7	19.5
	4A-24-NH	L, D	17.7	17.9	19.5
	4B-24-NH	L, D	17.8		
	4C-24-NH	L, D	18.2		
	4A-120-NH	D, F	6.8	9.0	16.2
	4B-120-NH	D, F	9.1		
	4C-120-NH	D, F	9.7		
	4D-120-NH	D, F	10.3		
	4E-120-NH	D, F	8.9		
	4F-120-NH	D, F	9.4		
800SG300-43	5A-10-NH	L, D	28.0	28.0	35.6
	5A-24-NH	D	25.9	27.3	35.9
	5B-24-NH	L, D	28.2		
	5C-24-NH	L, D	27.7		
	5A-120-NH	D, FT, L	25.5	24.4	37.2
	5B-120-NH	D, FT	22.9		
	5C-120-NH	D, FT, L	24.9		

Table 4. Sigma section test results (holes)

Section	**Test ID**	**Buckling mode**	**Ult. Load (kips)**	**Avg. (kips)**
550SG200-118	1A-24-H	D	75.2	75.2
	1B-24-H	D	76.3	
	1C-24-H	D	74.2	
	1A-120-H	F	26.5	24.9
	1B-120-H	F	24.3	
	1C-120-H	F	23.8	
600SG250-54	3A-24-H	L, D	34.9	35.5
	3B-24-H	L, D	35.2	
	3C-24-H	L, D	36.3	
	3A-120-H	FT	24.1	23.7
	3B-120-H	FT	22.1	
	3C-120-H	FT	25.0	
800SG200-33	4A-24-H	L, D	15.4	15.5
	4B-24-H	L, D	15.4	
	4C-24-H	L, D	15.6	
	4A-120-H	D, F	7.8	8.2
	4B-120-H	D, F	7.8	
	4C-120-H	D, F	9.0	

Table 5. Sigma section coupon results (no holes)

Profile	ID	F_y (ksi)	F_u (ksi)	E (10^3 ksi)
550SG200-118	A	56.4	75.0	35.7
	B	57.0	76.6	28.8
	C	56.7	74.1	34.0
	Avg.	**56.7**	**75.2**	**32.8**
550SG300-118	A	55.5	67.5	29.9
	B	55.3	67.7	29.9
	C	56.4	70.4	25.7
	Avg.	**55.7**	**68.5**	**28.5**
600SG250-54	A	48.6	77.3	29.9
	B	50.2	80.1	27.8
	C	50.2	79.1	24.5
	Avg.	**49.7**	**78.8**	**27.4**
800SG200-33	A	53.6	66.2	33.3
	B	52.9	64.8	29.9
	C	52.4	65.6	31.4
	Avg.	**53.0**	**65.5**	**31.5**
800SG300-43	A	56.8	82.0	31.8
	B	60.8	87.2	34.8
	C	61.1	86.1	31.6
	Avg.	**59.6**	**85.1**	**32.7**

Table 6. Sigma section coupon results (holes)

Profile	**ID**	**F_y (ksi)**	**F_u (ksi)**	**E (10^3 ksi)**
550SG200-118	A	58.8	72.6	22.8
	B	59.3	72.6	34.1
	C	58.5	71.3	25.6
	Avg.	**58.9**	**72.2**	**27.5**
600SG250-54	A	55.3	66.6	28.8
	B	56.3	60.0	27.4
	C	55.2	66.4	28.2
	Avg.	**55.6**	**64.3**	**28.1**
800SG200-33	A	59.0	67.5	26.0
	B	58.0	67.0	28.8
	C	58.5	67.5	27.1
	Avg.	**58.5**	**67.3**	**27.3**

Table 7. Design method accuracy

	P_{exp} / P_{EWM}	P_{exp} / P_{DSM}
Avg.	0.966	0.948
COV	0.159	0.114
n	22	

Conclusions

The results of an experimental program to evaluate the strength of sigma shaped CFS columns in concentric axial compression are reported. Both AISI design methods (effective width and direct strength) are good predictors of ultimate strength for these sections. These results are part of an effort to pre-qualify the sigma shape as a column in the DSM. Further details and recommendations can be found in [3].

References

[1] Boylan, M., Sumner, E., Rahman, N. and di Girolamo, E. (2006) "Web Crippling of Sigma-Shaped Metal Studs in a Wall Assembly",

Eighteenth International Specialty Conference on Cold-Formed Steel Structures, Orlando, FL.

[2] Neville, K.L. (2006) "Buckling Behavior of Cold-Formed Sigma Shaped Columns: Testing of the SigmaStud", In partial fulfillment of MCE. North Carolina State University, Raleigh, NC.

[3] Klingshirn, D.J. (2009) "Experimental and Analytical Investigation of Optimized Cold-Formed Steel Compression Members", MS Thesis. North Carolina State University, Raleigh, NC.

[4] Schafer, B.W., Sarawit, A., and Pekoz, T. (2006) "Complex Edge Stiffeners for Thin Walled Members", *Journal of Structural Engineering*, 132(2), 212-226.

[5] Yan, J., and Young, B. (2002) "Column Tests of Cold-Formed Steel Channels with Complex Stiffeners", *Journal of Structural Engineering,* 128(6), 737-745.

[6] Young, B., and Yan, J. (2004) "Design of Cold-Formed Steel Channel Columns with Complex Edge Stiffeners by Direct Strength Method", *Journal of Structural Engineering*, 130(11), 1756-1763.

[7] Schafer, B.W., and Ádány, S. (2006) "Buckling Analysis of Cold-Formed Steel Members using CUFSM: Conventional and Constrained Finite Strip Methods", *Eighteenth International Specialty Conference on Cold-Formed Steel Structures*, Orlando, FL.

[8] AISI TS-2-02. (2002) "Stub-Column Test Method for Effective Area of Cold-Formed Steel Column", American Iron and Steel Institute, Washington DC.

[9] Moen, C.D., and Schafer, B.W. (2008) "Experiments on Cold-Formed Steel Columns with Holes", *Thin Walled Structures*, 46(10), 1164-1182.

[10] Moen, C.D. (2008) "Direct Strength Design of Cold-Formed Steel Members with Perforations", Ph.D. thesis, Johns Hopkins University, Baltimore, MD.

[11] ASTM A370-07. (2007) "Standard Test Methods and Definitions for Mechanical Testing of Steel Products", ASTM International, West Conshohocken, PA.