Proceedings of the
Annual Stability Conference
Structural Stability Research Council
Grapevine, Texas, April 18-21, 2012

Effects of splice configuration on web Crippling of Lapped Cold-Formed Steel Channels subjected to interior two-flange loading

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Abstract

Web crippling is a form of localized buckling that occurs at points of transverse concentrated loading or supports of thin-walled structural members. Cold-Formed Steel (CFS) channels that are unstiffened against this type of loading are susceptible to structural failure caused by web crippling. The theoretical computation of web crippling strength is quite complex as it involves a large number of factors such as initial imperfections, local yielding at load application and instability of web. Currently, the North American standards for the design of cold-formed steel structural members (S136) specify an empirical formula for web crippling strength of different joist geometries in case of exterior end and concentrated load locations. However, this formula does not permit an increase in web crippling capacity when lapped cold-formed steel channels are subjected to interior two-flange loading. This may be attributed to the lack of experimental data on web crippling strength at interior support locations. As such, the objective of the current research is to generate experimental data for CFS channels where both flanges of channel members are lapped at the interior support location and being loaded simultaneously. Previous experimental work published by the authors addressed the effects of the lap length of the spliced channels at the interior support, the presence of corrugated steel deck fastened to the top flange and the end support restraint condition. Based on those test results, the authors proposed modifications to the existing web crippling strength formula in North American standards S136. Herein, the experimental program has been extended to cover more related parameters such as the arrangement of fasteners splicing the channels, the bearing length at the interior support as compared to the lap length and the presence of lateral support at the channels splice (i.e clip angles). The details and findings of the extended experimental program are discussed in the present paper.

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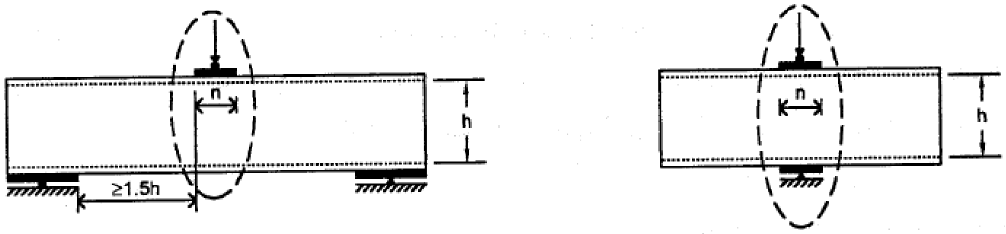
1. Introduction

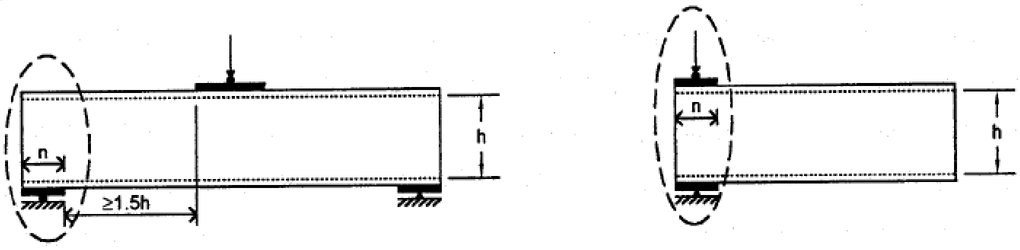
1.1 General

During the last decade, various experimental investigations were conducted on web crippling strength of CFS members (Holesapple and LaBoube 2003, Young and Hancock 2004, Zhou and Young 2007a). Some of these experimental programs focused on the interaction of bending and web crippling in CFS members (Stephens and LaBoube 2003, Zhou and Young 2007b). Recent researches were dedicated to correlate the experimental findings with the results obtained from analytical methods such as the finite-element analysis (Fox and Brodland 2004, Ren et al. 2006) and the yield-line theory (Zhou and Young 2006) to predict the strength of CFS members. Furthermore, the American Iron and Steel Institute developed standard test method for the determination of web crippling strength of CFS members (LaBoube and Schuster 2002). This test method is applicable to all CFS sections and subjected to four loading cases as shown in Fig. 1.



(a) Interior One - Flange Loading (IOF)

(b) Interior Two - Flange Loading (ITF)



(c) End One - Flange Loading (EOF)

(d) End Two - Flange Loading (ETF)

Figure 1: Load Cases for Web Crippling Tests (AISI/CSA136, 2007)

The Two-Flange Loading is the case where both flanges of a section are being loaded simultaneously (Figs. 1b and 1d). The length of the specimen is important in order to simulate a realistic condition as experienced in practice. This is especially important in the case of single-web sections such as C- and Z-sections. If the specimen length is too short, failure would be by complete overall buckling of the web element or lateral torsional buckling for the member, which is not realistic in practice. In the case of multi-web sections such as deck profiles, the test specimen length is not as important in that there are a number of web elements that share the web-crippling load.

The Interior Two-Flange Loading (ITF) case is depicted in Fig. 1b, where the applied load is directly aligned with the support reaction. In this case both the top and bottom bearing plates must be of the same width for any given test. Per the test method, the length of a single-web specimen should be at least equal to five times the section depth and be positioned symmetrically in the test frame. The End Two-Flange Loading (ETF) case is depicted by Fig. 1d, where the bearing plates must be of the same width for any given test. Also, the specimen length of single-web sections should be at least equal to five times the section depth and the specimen should be positioned flush with both bearing plates at the end being tested. The other end of the specimen is typically placed on a support to stabilize the section during testing.

1.2 Available Web Crippling Strength Equation

Currently, The North American Specifications of Cold-Formed Steel Structural Members (AISI/CSA136 2007) specifies an imperial expression for web crippling strength. This expression is developed empirically based on the results of the conducted experimental programs for different joist geometries in case of exterior end and concentrated load locations, with either one-flange loading or two-flange loading, as follows:

$$P_n = Ct^2 F_y \sin\theta \left(1 - C_R\sqrt{\frac{R}{t}}\right)\left(1 + C_N\sqrt{\frac{N}{t}}\right)\left(1 - C_h\sqrt{\frac{h}{t}}\right) \tag{1}$$

Where P_n = nominal web crippling strength, C = regression analysis coefficient, C_h = web slenderness coefficient, C_N = bearing length coefficient, C_R = inside bend radius coefficient. F_y = yield strength, h = flat dimension of the web measured in the plan of the web, N = bearing length, R = inside bend radius, t = web thickness, and θ = angle between the plane of the web and the plane of the bearing surface.

However, the influence on the web crippling capacity when the joists are lapped at the interior support is not presented. The lack of experimental data and research work regarding the web crippling strength for lapped CFS members might have been the reason. As such, Rehman et al. (2008, a, b) conducted experimental tests to generate experimental data for CFS channels where both flanges of channel members are lapped and being loaded simultaneously. This research program included the effects of the lap length of the spliced channels at the interior support, the presence of corrugated steel deck fastened to the top flange and the end support restraint condition. Based on the obtained test results, the authors performed nonlinear regression analysis to update the coefficients for the CFS web crippling strength presented in Eq. 1. The new proposed correction coefficients are listed in Table 1(Rahman et al. 2008 a,b).

Table 1: Proposed design coefficients for single web C section

Support and Flange Conditions		Load Cases		C	C_R	C_N	C_h
Fastened To Support	Stiffened Flanges	Two Flange Loading	Interior Lap	2.5	0.02	1.01	0.001

Notes: The above coefficient apply when h/t ≤172, N/t ≤127, N/h ≤ 0.78, R/t ≤ 1.97 and θ = 90°

In the current paper, the experimental work has been extended to investigate the effects of other parameters on the developed coefficients listed in Table 1. These parameters include the number and arrangement of screws splicing the channels, the bearing length at the interior support, and the presence of lateral support (i.e clip angles) at the channels splice. The details and findings of the conducted experimental program are discussed through the following sections.

2. Experimental Work

An experiment study was performed at the Ryerson University in order to investigate the effect of the above-mentioned parameters on the web crippling capacity of single web sections lapped at the interior support and loaded under an interior two flange condition.

2.1 Test Specimen

The specimens consisted of edge-stiffened "C" section (Fig. 2). The nominal depth of web was 203 mm (8"). The key cross sectional parameters for each tested cross-section are summarized in Table 2.

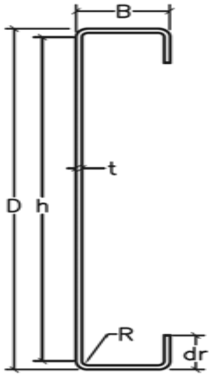


Fig. 2: Typical C-Section

Table 2: Test Specimens Cross Sectional Properties

Specimen	D (mm)	h (mm)	T (mm)	B (mm)	R (mm)	dr (mm)	F_y (MPa)	N (mm)
8C18	203	197	1.196	41	1.78	18	389.6	Varies[1]

[1] Three different values for N were investigated (63.5mm, 92.1mm and 152.4mm)

2.2 Bearing Plate Length

The loads were applied on the channel members at the interior support location by means of bearing plates. All bearing plates were machined to specified dimensions. The thickness of bearing plates was 12.7 mm (0.5"). The bearing plates were designed to act across the full flange width of the channels. The flanges of the specimens were restrained by the bearing plate. In the previous research conducted by authors (Rahman et al, 2008a,b), the length of bearing plate was considered equal to the lap length (N) and taken as 92.1 mm (3.62"). However, in the current research, two other lengths were considered for each of the bearing plate and the lap length, namely: 63.5 (2.5") and 152.4 mm (6"). The made the total number of samples tested herein in the current research equal 6 samples.

2.3 Specimen Labeling

Each specimen was labeled such that the depth, thickness and lap length could be identified from the label. For example, the label “8C18” defines the following specimen:

- The first two letters (8) shows the overall depth of the web in “inches”.
- The letter “C” shows that specimen is of Channel (C) cross section.
- The next two digits (18) show the thickness of section in “gauge”.

2.4 Material Properties

The material properties of the test specimens were determined by tensile coupon tests. For each section tested, the three coupons were taken from the center of the web plate in the longitudinal direction of the undisturbed specimens. The tensile coupons were prepared and tested according to the (ASTM-A370 2005). To measure the actual thickness of specimen, the galvanized coating was removed by hydrochloric acid solution. The average yield stress, F_y, of three coupon tests for each specimen is listed in Table 2.

2.5 Test Procedure

The channel specimens were tested using interior two flange loading conditions (ITF) according to the specifications of the AISI/CSA136 (2007). The test setup is shown in Figs. 3 to 5. The channels were lapped and fastened together with 4 self-drilling screws size #10x25 mm. It should be noted that the two rows of screws are located at the third point of the web depth except for the the specimens tested with different spacing as detailed in section 3.1 of this paper.

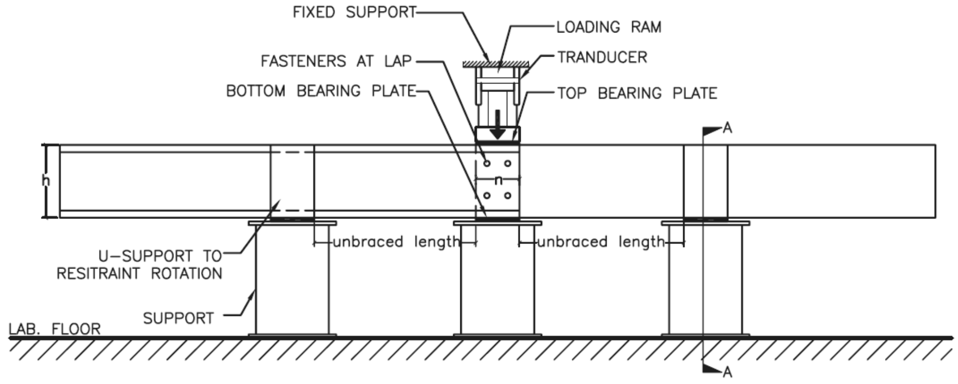
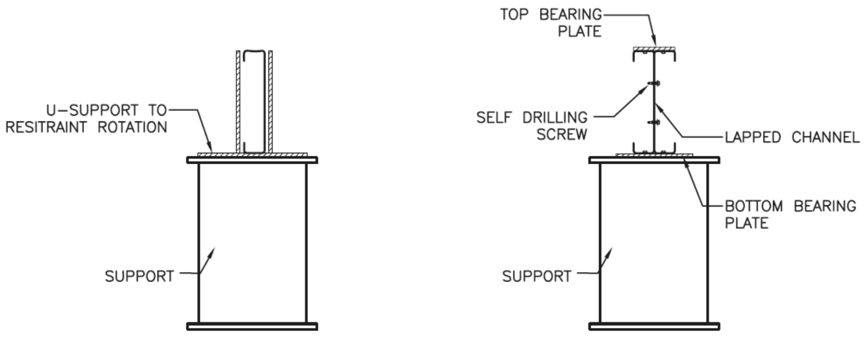


Figure 3: Schematic Diagram of the Test Set-up



a) Section at “A-A” b) Section at lap

Figure 4: Sections through Schematic Diagram

Figure 5: View of the Test Set-up

Two identical bearing plates were placed at top and bottom of the channel at the lap splice location. The length of bearing plate and the length of lap are listed in Tables 3 to 5. The channel rotation at the ends was restrained by inserting their ends into a U-shape steel support system. A hydraulic jack was used to apply a compressive force to the test specimens over the interior support. Web lateral deflection and vertical movement of the channel top flange were recorded using LVDT's. Each specimen was loaded incrementally till failure.

3. Experimental Results

3.1 Effect of bearing length

The channel specimens were tested for different bearing length, N, values of 63.5, 92.1 and 152.4 mm under each investigated lap length of 63.05, 92.1 and 152.4 mm. The configurations of the groups of the tested specimens as well as the web crippling resistance and the corresponding vertical deflection and lateral displacement are listed in Table 3. Also, both vertical and lateral displacement versus the applied load recorded during testing for each specimen of each tested group are shown in Fig. 6 to 11. Results show that change of lap length for different bearing lengths has insigificant effect or trend on the web cripping strength for lap lengths 63.5 and 92.1 mm. However, when the lap length reached a value of 152.4 mm, a consistent increase of the web crippling resistance took place with the increase of the bearing length from 63.5 to 152.4 mm. This improvement of the web crippling resistance was associated with a reduction of the corresponding lateral displacement.

Table 3: Effect of bearing length

Group	Lap length (mm)	Bearing length, N (mm)	Web crippling resistance (kN)	Vertical deflection, Δ_v (mm)	Lateral displacement, Δ_h (mm)
A	63.50	63.50	11.66	4.78	12.38
		92.10	9.43	3.97	7.54
		152.40	10.86	6.31	16.02
B	92.10	63.50	11.79	4.02	7.51
		92.10	13.35	3.59	0.59
		152.40	10.97	5.67	11.56
C	152.40	63.50	11.14	6.25	9.37
		92.10	13.31	4.06	8.84
		152.40	15.98	5.40	8.30

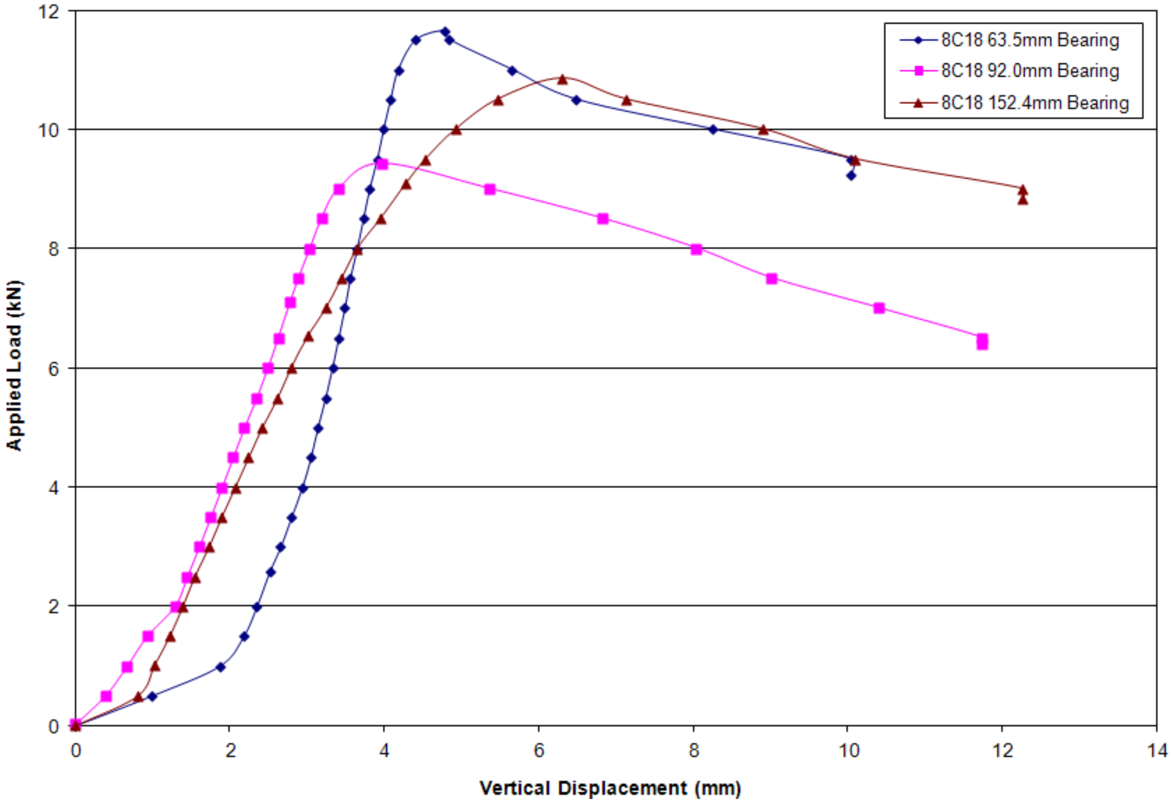


Figure 6: Vertical Displacement Versus Applied Load for Group A (63.05mm lap length)

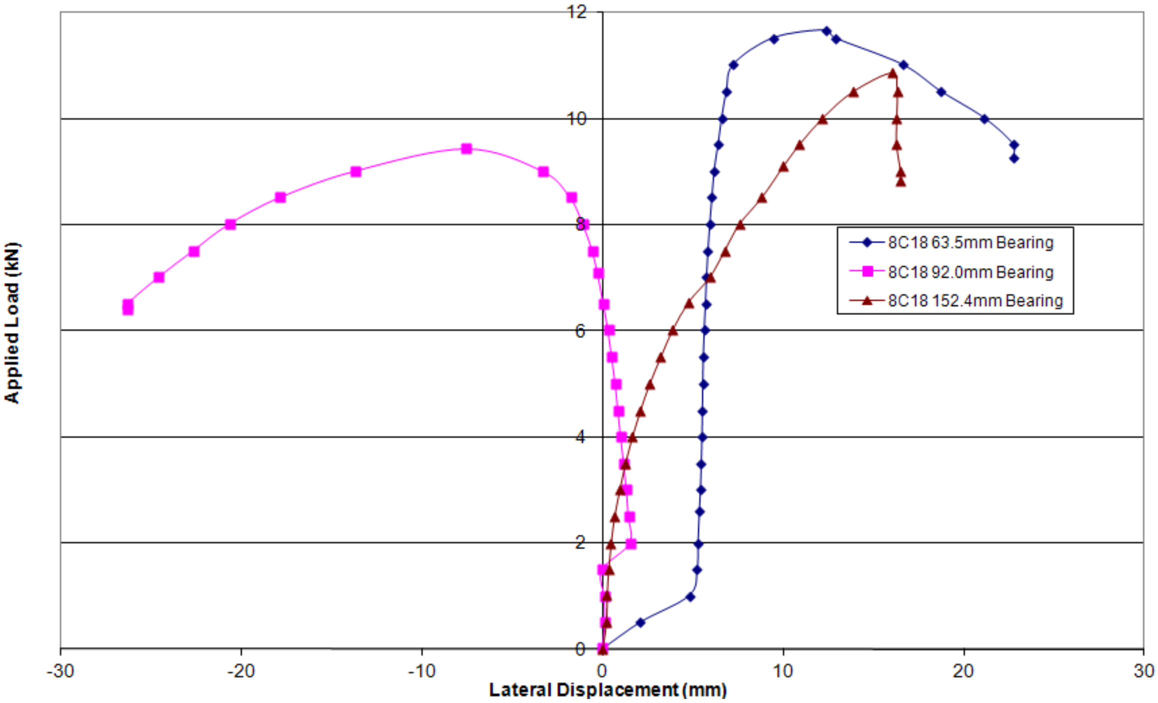


Figure 7: Lateral Displacement Versus Applied Load for Group A (63.05mm lap length)

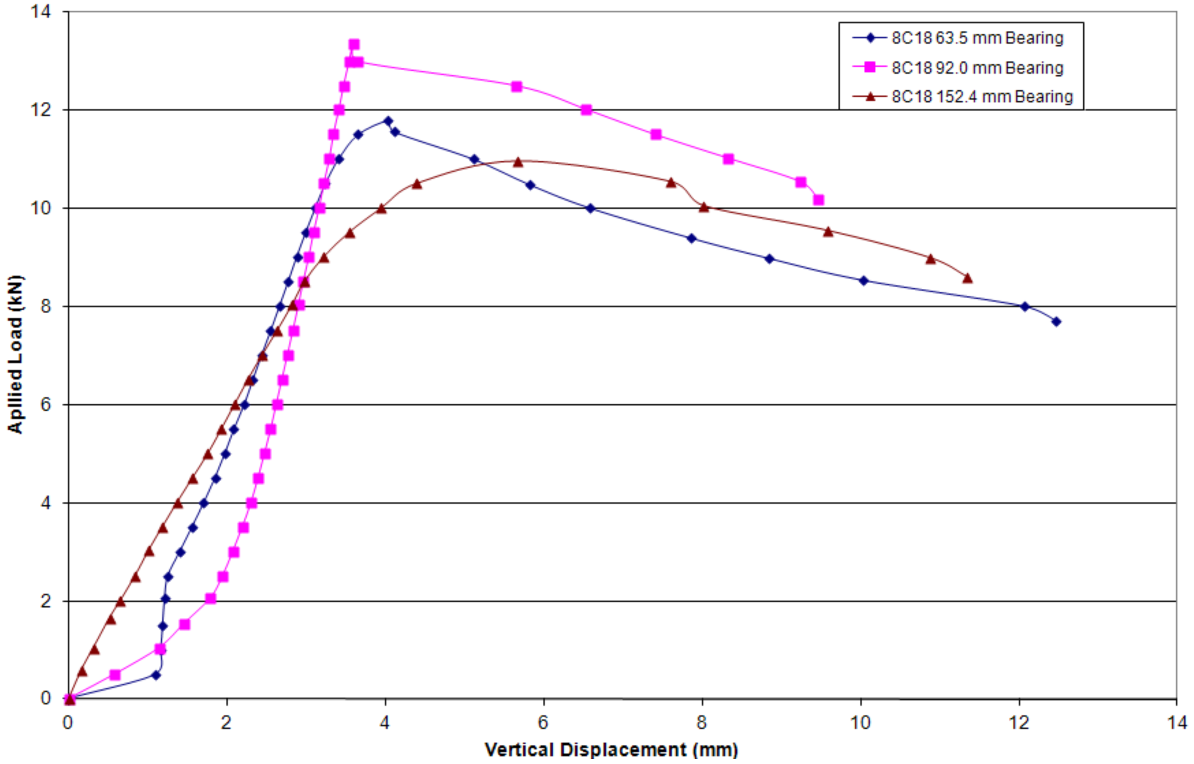


Figure 8: Vertical Displacement Versus Applied Load for for Group B (92.1mm lap length)

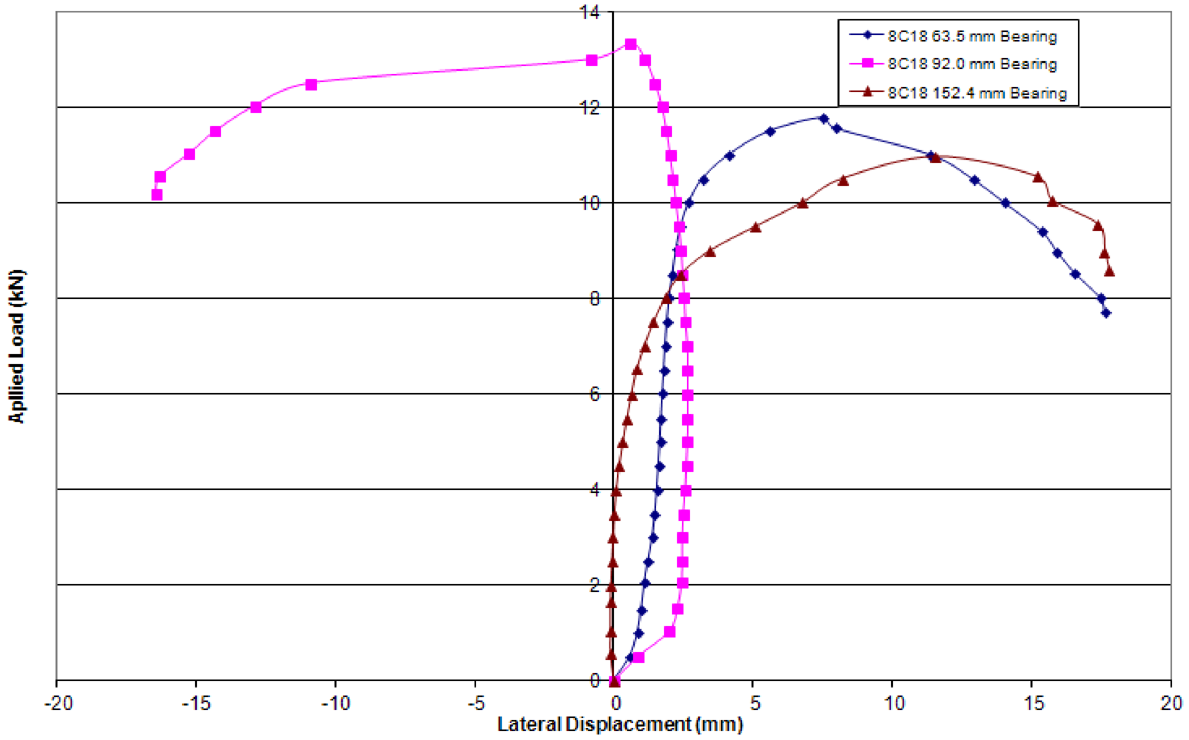


Figure 9: Lateral Displacement Versus Applied Load for for Group B (92.1mm lap length)

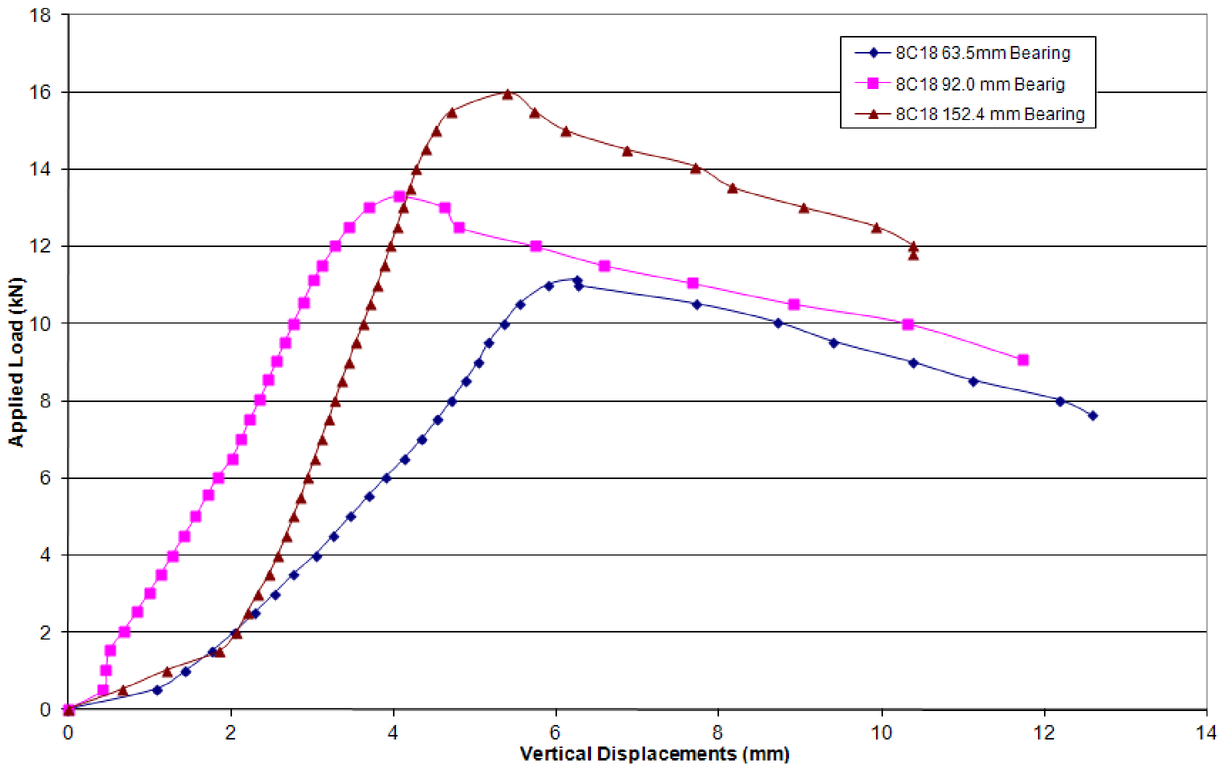


Figure 10: Vertical Displacement Versus Applied Load for for Group C (152.4mm lap length)

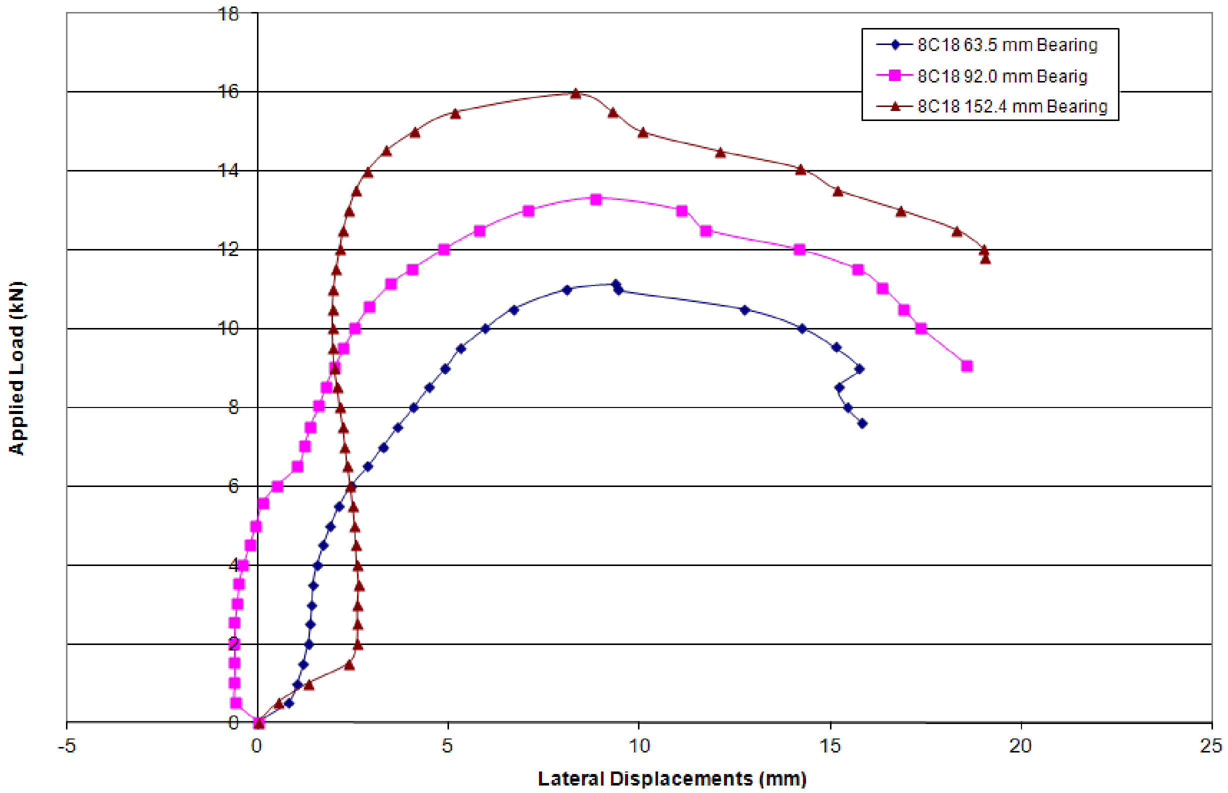
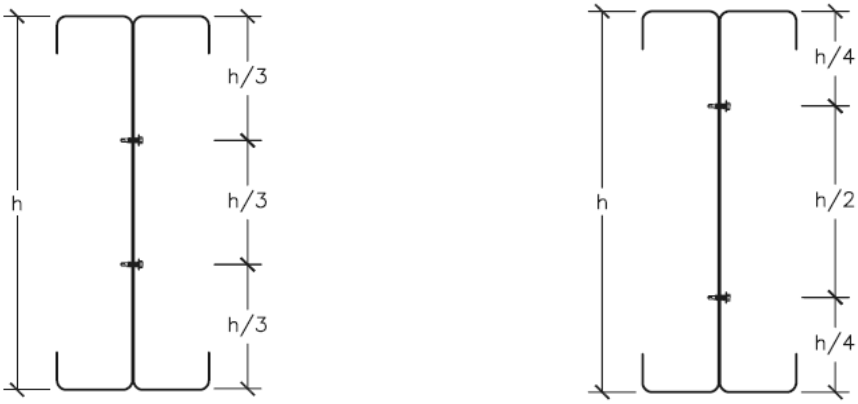


Figure 11: Lateral Displacement Versus Applied Load for for Group C (152.4mm lap length)

3.1 Effect of fasteners arrangement

Two different screw arrangement, used to fasten the channels at their lap splice, were examined where the spacing between the two nail rows along the specimen height changed from h/3 to h/2 as shown in Fig. 12. Three different lap length and bearing length settings (namely: 63.5, 92.1 and 152.4 mm) were associated with each investigated fasteners arrangement.



a) h/3 fastener spacing

b) h/2 fastener spacing

Figure 12: Fasteners (Screws) Arrangements

The configurations of the tested specimens as well as the web crippling resistance and the corresponding vertical deflection are listed in Table 4. Also, the vertical displacement versus the applied load as measured during the testing of each specimen is shown in Figs. 13 to 15 for each lap length and bearing length arrangement considered in this study.

Table 4: Effect of screws arrangement

		h/3 fastener spacing		h/2 fastener spacing	
Lap length (mm)	Bearing length, N (mm)	Vertical displacement, Δ_v (mm)	Web crippling resistance (kN)	Vertical displacement, Δ_v (mm)	Web crippling resistance (kN)
63.50	63.50	4.78	11.66	3.50	11.62
92.10	92.10	3.59	13.35	5.52	10.27
152.40	152.40	5.40	15.98	4.78	14.88

The testing results generally showed a slight reduction of the web crippling resistance when the screws spacing increased while having both lap length and bearing length unchanged. The results emphasized the effect of the maximum web unsupported length at the bearing location (represented by the fasteners spacing) on the web compressive strength. Also, the maximum web crippling resistance (15.98 kN) was obtained for the samller fasteners spacing (h/3) and it was associated with the maximum lap length and bearing length setting of 152.4 mm each.

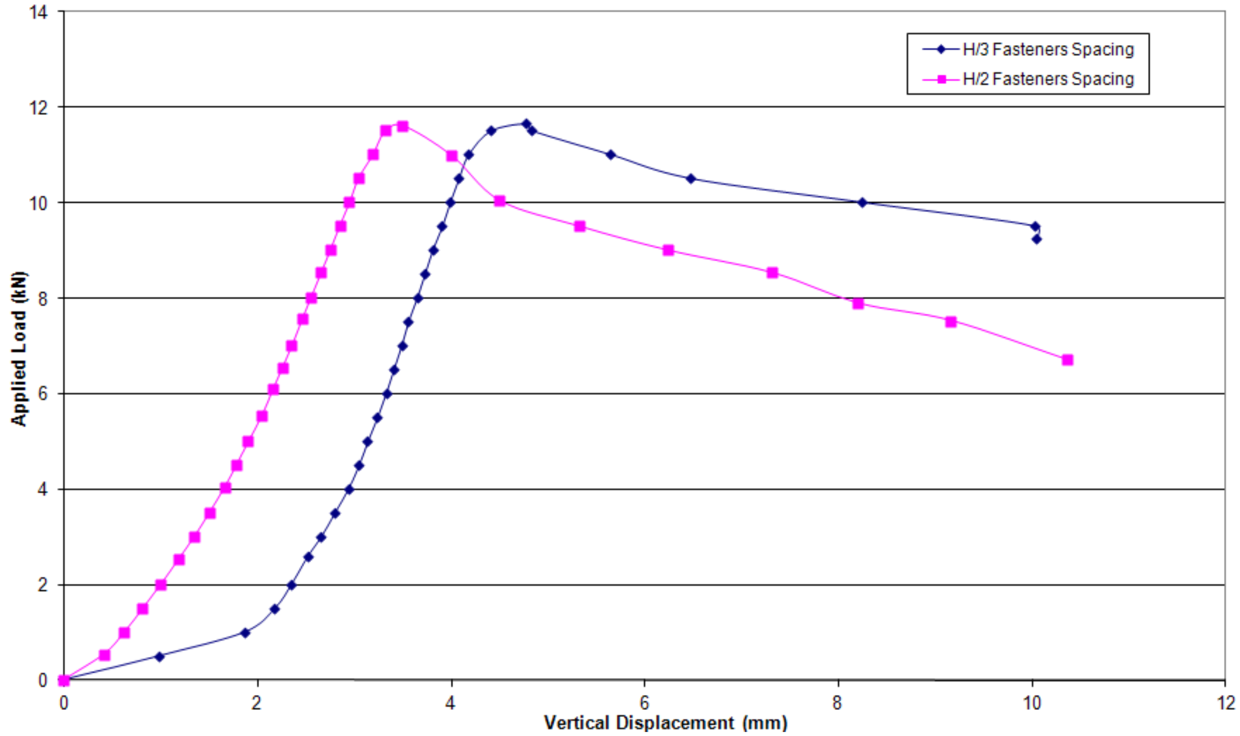


Figure 13: Vertical Displacement Versus Applied Load (63.05mm lap length)

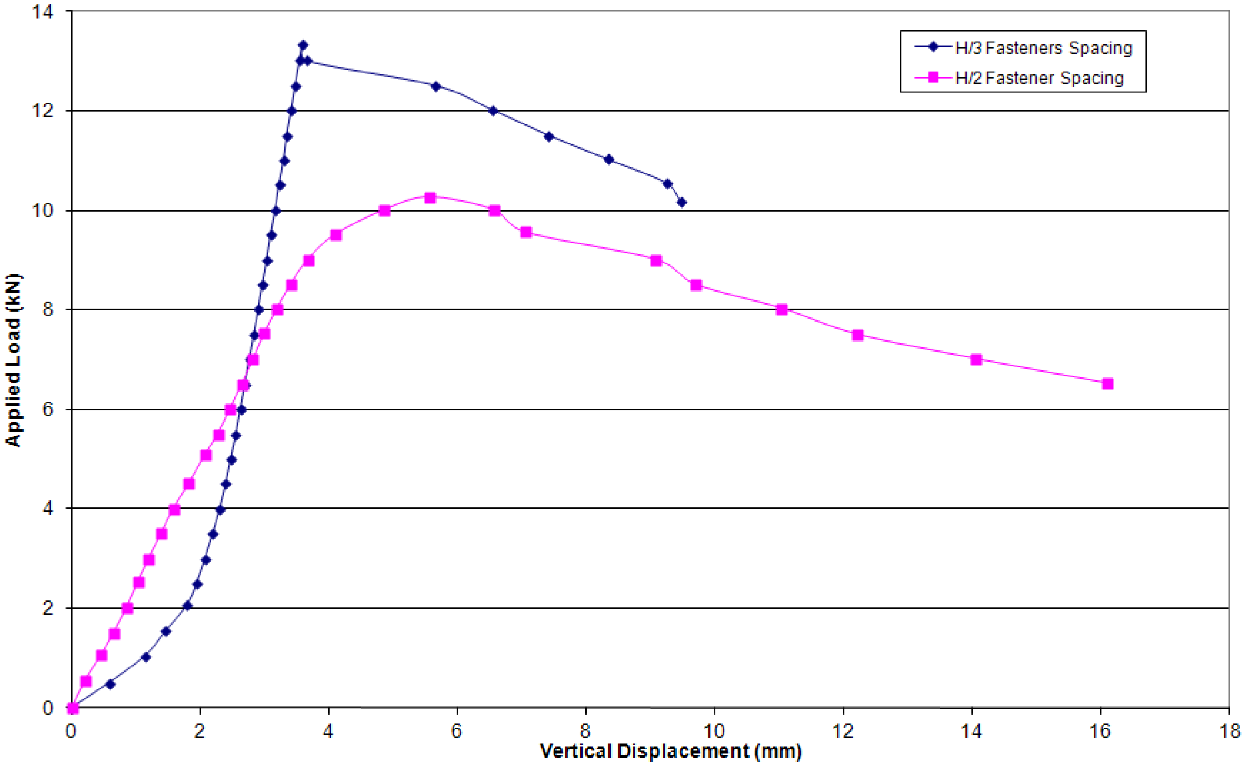


Figure 14: Vertical Displacement Versus Applied Load for for 92.1mm lap length

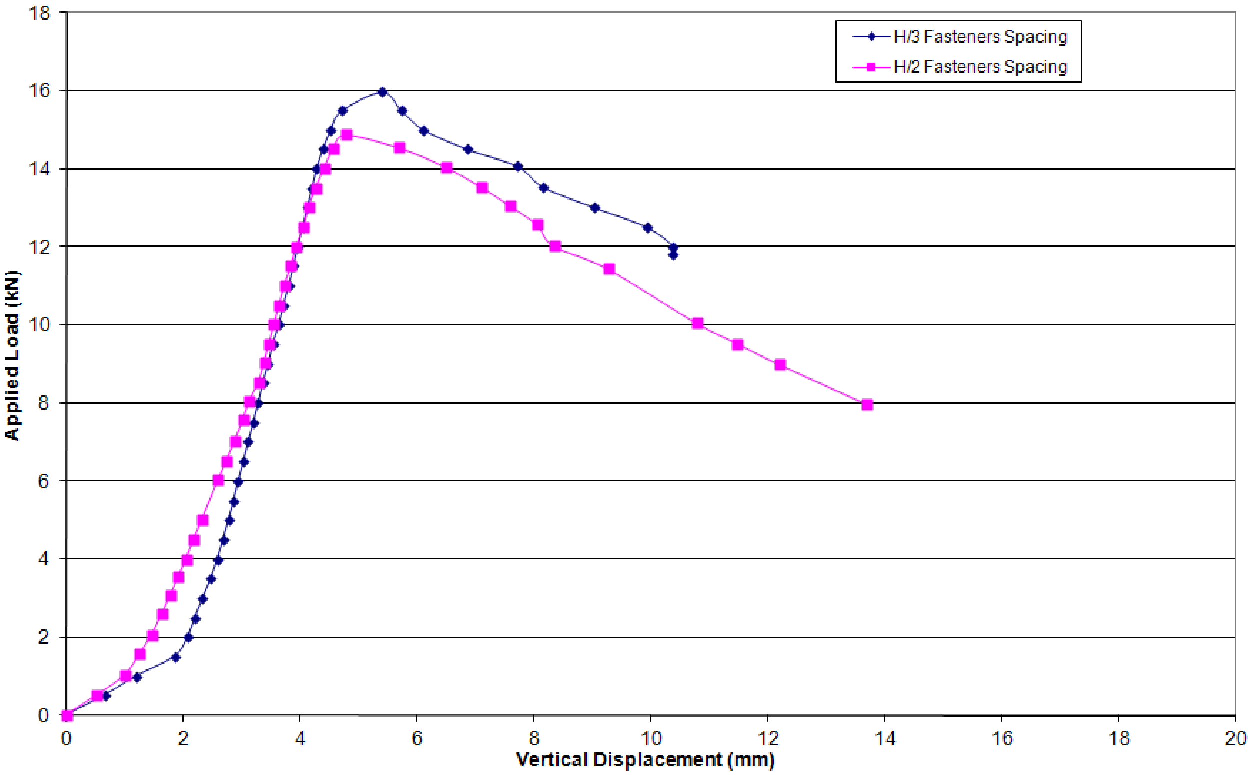


Figure 15: Vertical Displacement Versus Applied Load for for 152.4mm lap length

3.1 Effect of lateral support at the channels splice/interior support

This study examined the effect of the presence of clip angle to simulate the effect of having a lateral support for the channels web at the channels splice/interior support location. The intermediate investigated lap and bearing length values of 92.1 mm each was assigned to the tested specimens to study the effect of the presence of clip angles on the web crippling strength. The test set-up before loading and a closer look at the crippled web at failure are ahown in Fig. 16 and 17, respectively. The web crippling resistance and the corresponding vertical deflection for both test cases as obtained experimantally are listed in Table 5. Also, the vertical displacement versus the applied load as measured during the testing is shown in Fig. 18.

Figure 16: The Test Set-up before Loading the Specimen

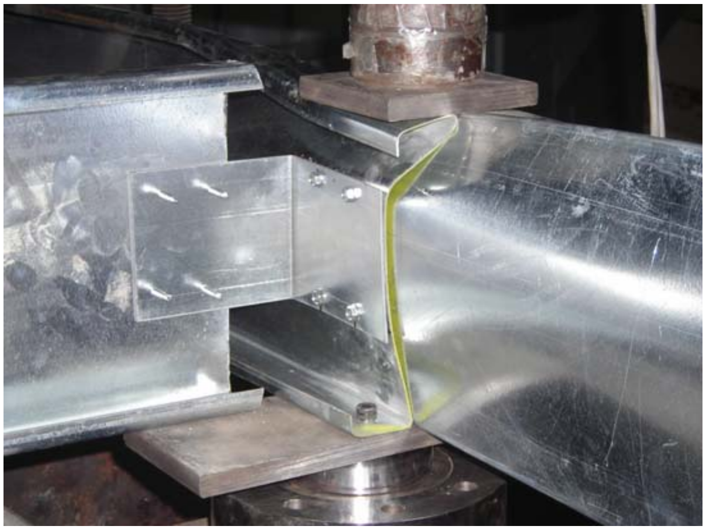


Figure 17: Web Crippling at the Specimen Failure

It can be seen that there was a slight increase of the web crippling resistance due to the presence of the clip angle at the interior support. In other words, having a lateral support for the web at the bearing location had an insignificant improvement of the web compressive strength. However, since the conducted testing was limited to a single arrangement of lap length and bearing length, future research may be required to investigate the the effect of presence of the clip angle as lateral support at the channels splice/interior support under different conditions of lap and bearing lengths.

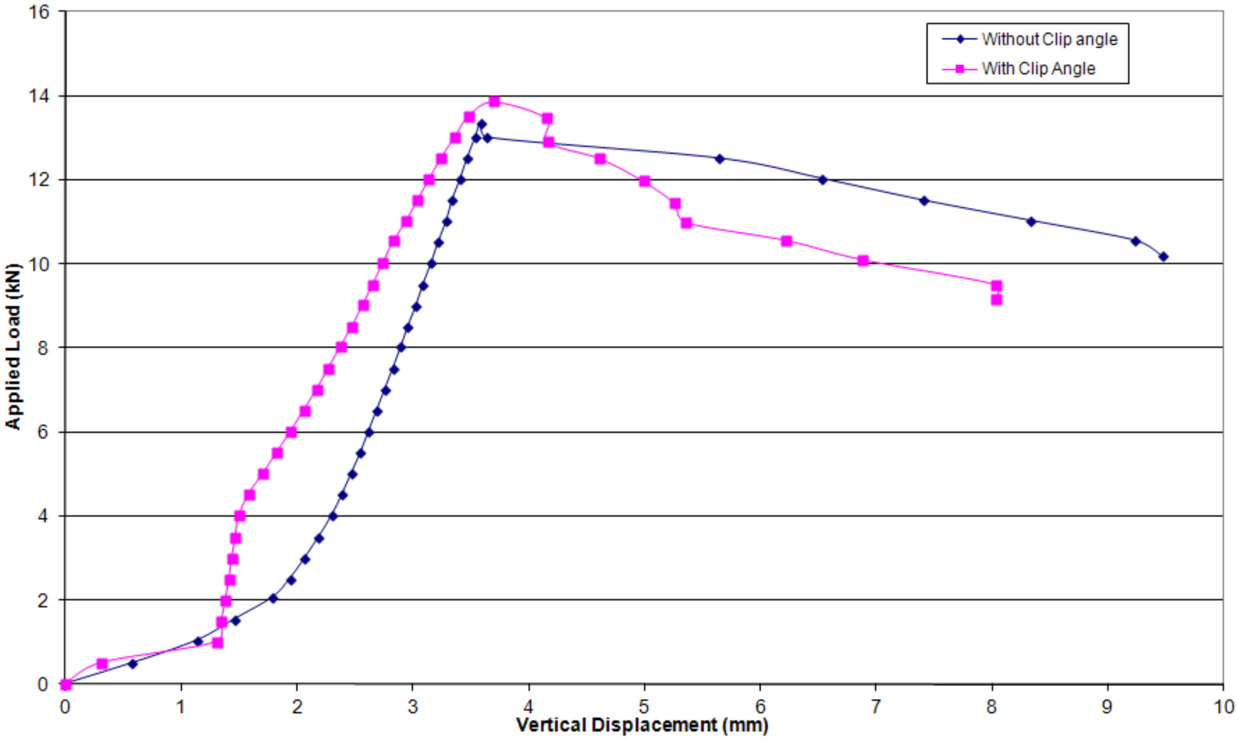


Figure 18: Vertical Displacement Versus Applied Load for for 92.1mm lap length

Table 5: Effect of Clip Angle

Lap length (mm)	Bearing length, N (mm)	Channel without clip angle		Channel with clip angle	
		Vertical displacement, Δ_v (mm)	Web crippling resistance (kN)	Vertical displacement, Δ_v (mm)	Web crippling resistance (kN)
92.10	92.10	3.59	13.35	3.70	13.86

4. Conclusions

An experimental parametric study was carried out to investigate the web crippling strength of Cold-Formed Steel (CFS) lapped channels as affected by the member bearing length at the interior support, the lap splice fasteners arrangement and the presence of a lateral support for the web at the interior support/splice location. The experimental results can be concluded as follows.

- A consistent increase of the web crippling resistance took place with the increase of the bearing length in case of relatively large lap length. This improvement of the web crippling resistance was associated with a reduction of the corresponding lateral displacemnt;
- A reduction of the web crippling resistance was observed when the fastener spacing increased while having both lap length and bearing length unchanged. The results reflects the influence of increasing the web unsupported length (represented by the fasteners spacing) on the web compressive strength;
- Having a lateral support for the web at the bearing location in the form of clip angle connection to the channel web had an insignificant improvement of the web compressive strength. However, the conducted testing was limited to a single arrangement of lap and bearing lengths;
- The maximum web crippling resistance was obtained for a smaller fasteners spacing and it was associated with the maximum lap length and bearing length setting considered in this study; and
- Future research is required to investigate the the effect of the presence of lateral support at the channels splice/interior support under different condition of lap and bearing lengths.

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