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# Numerical Analysis of Web Connected Lipped Channels in Compression with Varying End Distances

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***Abstract***

*This finite element study focuses on the compressive resistance of the cold-formed lipped channels, connected to the base through the web only. The influence of the cross-section geometry, column length and end distance on the ultimate capacity is investigated. The numerical models cover four end distances and three different values for the length of the column, flange width and lip width. A commercial finite element analyses software ABAQUS and a direct strength method (DSM) in were used to determine the nominal capacity of the columns. According to the observations and assumptions, this paper shows that the current DSM distortional equation is not safe for this boundary condition, however, the end distance has positive effect on the column capacity.*

***Keywords:*** End distance, Cold-formed, Web.

## 1. INTRODUCTION

Cold-formed sections (CFSs) are widely used as structural and non-structural members because of their light-weight and ease of fabrication. However, the sections are very sensitive to their boundary conditions and the end-distance of the connected element, if used as structural member. The North American Specification for the Design of Cold-Formed Steel Structural Members(AISI 2012) defines four modes of failure of bolted connection, namely; sheet bearing, sheet tearing, tensile failure in net section and bolt shearing mode of failure. The failure modes were determined from the work of Yu (1982), Zadanfarrokh (1991), Zadanfarrokh and Bryan (1992), LaBoube, Wallace, and Schuster (2002) and Wallace (2009), in which the connected sheets were restrained on both sides by the bolt head and nut, with or without washers. According to SANS 10162-2 (2011), AISI (2012), the minimum end distance of a bolted connection with two or more bolts in the direction of the load, should not be less than 1.5 times the bolt diameter. Kim and Kuwamura (2005) and (2007) has shown that the end/edge distance of bolted thin-walled plates may cause strength erosion if curling of the plates happens before reaching to ultimate strength. However, the strength loss was not significant when the end/edge distance was increased (Kim, Kuwamura, and Cho (2008)).

Recent results of finite element models developed by Sheikholarefin and Dundu (2016) have shown that fixing the edges of the cross-section of cold-formed columns under axial compressive load can cause premature failure due to stress concentrations near the joints of the fixed web, corners and flanges. The material at these areas exceeded the elastic limit and experienced plastic behaviour faster than other areas, resulting in a decrease of the ultimate capacity of the column. The purpose of this paper is to perform a parametric study on columns in order to investigate the effect of the end-distance on the compressive resistance of the cold-formed lipped channel connected through the web only. The end distance, in this case, is the perpendicular length from the edge of the column to the welded connection in the web (Figure 1). Ultimately, the main aim of this study is to find the length of the weld and end distance that produces the largest capacity of the columns.

## 2. MATERIAL PROPERTIES

The material properties were determined from flat and corner areas of the channels. The flat specimens were taken from the areas of the web with the least effect of cold work. To measure the effect of the cold work on the material properties of the corners, the coupons were prepared from the corners of the web and flange. The outer parts of the corner coupons flattened, while causing the least side effect of deforming in the gauge length, to facilitate gripping of the coupons. Both coupons were cut in the longitudinal direction of the channel. The modulus of elasticity, E, and yield stress, $F_y$, of 200 GPa and 330 MPa, respectively, were determined from the average true stress-strain curves of the coupons, shown in Figure 1.

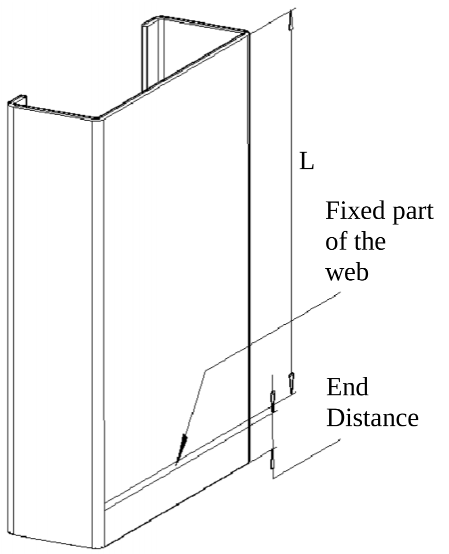



**Figure 1 End distance and length of column**

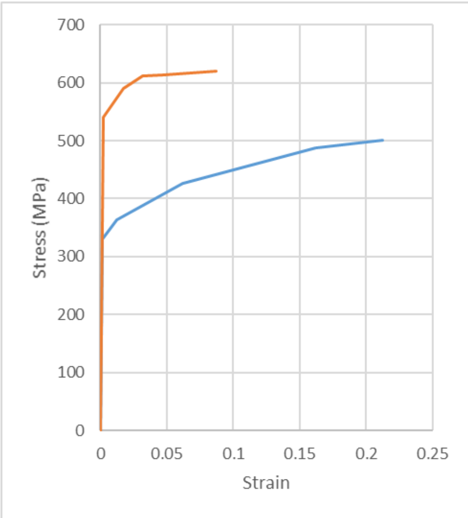



**Figure 2 Material properties**

## 3. MODEL SPECIFICATION

To investigate the effect of the end distance on the column capacities, a total of 108 numerical models of cold-formed lipped channel columns, were tested in four main categories. Each category consists of columns with different length and cross-section but same end distance. As shown in Table 1, the first category has no end distance while the other three categories have end distance of 10, 20 and 30mm. The connection of the column to base was attained through a welded strip in the web. The length of the weld was set equal to the flat part of the web and a weld size of 5 mm. Each category was analysed with three column lengths of 500, 1000 and 1500mm. Figure 1 shows the column length, end distance and connected part of the web to the base.

To study the effect of flanges and lips on the axial capacity of the column, three different sizes of flanges of 50, 75 and 100mm and lips of 15, 20, 25mm were considered. The length of the web, radius of corners and section thickness were taken as dimensions of 250, 10mm and 3 mm, respectively. A typical model combination from the details in Table 1 is E10-C500-F50-L20, where E10 represents the end distance (E) of 10 mm, C500 represents the column length (C) of 500mm, F50 represents the flange width (F) of 50 mm and L20 represents the lip width (L) of 20 mm. Commercial finite element software, Abaqus/CAE, was used to model and analyse the columns. A fully fixed boundary condition was defined at the top of the column. Two types of analysis were performed; “Buckling” analysis to obtain the lowest critical elastic buckling load and “Explicit” analysis to achieve the maximum axial capacity of the column, according to the defined materials. In buckling analysis, a shell edge load was applied on the top cross section of column and in Explicit analysis, by moving the fixed support vertically toward the base, a compressive displacement controlled loading was applied to the top of the column. All flat surfaces were meshed to size of 5mm and curves areas refined to 3 by 5 meshes.

**Table 1 Details of the numerical models**

| E | C | F | L |
|---|---|---|---|
| End distance (mm) | Column length (mm) | Flange width (mm) | Lip width (mm) |
| 0<br>10<br>20<br>30 | 500<br>1000<br>1500 | 50<br>75<br>100 | 15<br>20<br>25 |
| Example: E10-L500-C50-20 | | | |

# 4. CAPACITY OF THE COLUMN

## 4.1. Direct strength method (DSM)

Buckling analysis using Abaqus provides the critical elastic buckling load of the section, according to the load and specimen geometry specifications. However, in the Direct Strength Method (DSM), it is not only the elastic buckling load that should be determined, but also the mode of failure. One major drawback of using the finite element buckling analysis in Abaqus is uncertainty in establishing the failure mode of specimens accurately. A decision was made to estimate the failure mode in Abaqus based on section of the column, which is experiencing the maximum deformation, in both buckling and dynamic analysis. After investigating the deformation of the flanges, corners and lips at the base, it was concluded that distortional buckling can be the dominant buckling mode in all specimens.
The nominal member capacity of a member in compression ($P_{nd}$) for distortional buckling is calculated from SANS 10162-2 (2011) as given in Equations 1 and 2

For $\lambda_d \leq 0.561$ $$P_{nd} = P_y \quad (1)$$

For $\lambda_d > 0.561$ $$P_{nd} = \left(1 - 0.25\left(\frac{P_{crd}}{P_y}\right)^{0.6}\right)\left(\frac{P_{crd}}{P_y}\right)^{0.6} P_y \quad (2)$$

where, $P_y$ is allowable strength, $P_{crd}$ is critical elastic distortional buckling load, $P_{nd}$ is the columns nominal capacity and $\lambda_d = \sqrt{P_y / P_{crd}}$ .
The nominal capacity of the columns calculated using the DSM equations is shown in Figure 3. As illustrated in the figure, an increase in the columns capacity was realized when end distance was increased, however it is not significant.

## 4.2. Effect of the lip and flange

Corners and flanges provide stiffening to the web element. In general, Figure 3 shows that increasing the length of flanges can increase the column's capacity. Although the results from both DSM and ABAQUS agree with this view, ABAQUS models show very close results for the columns with same

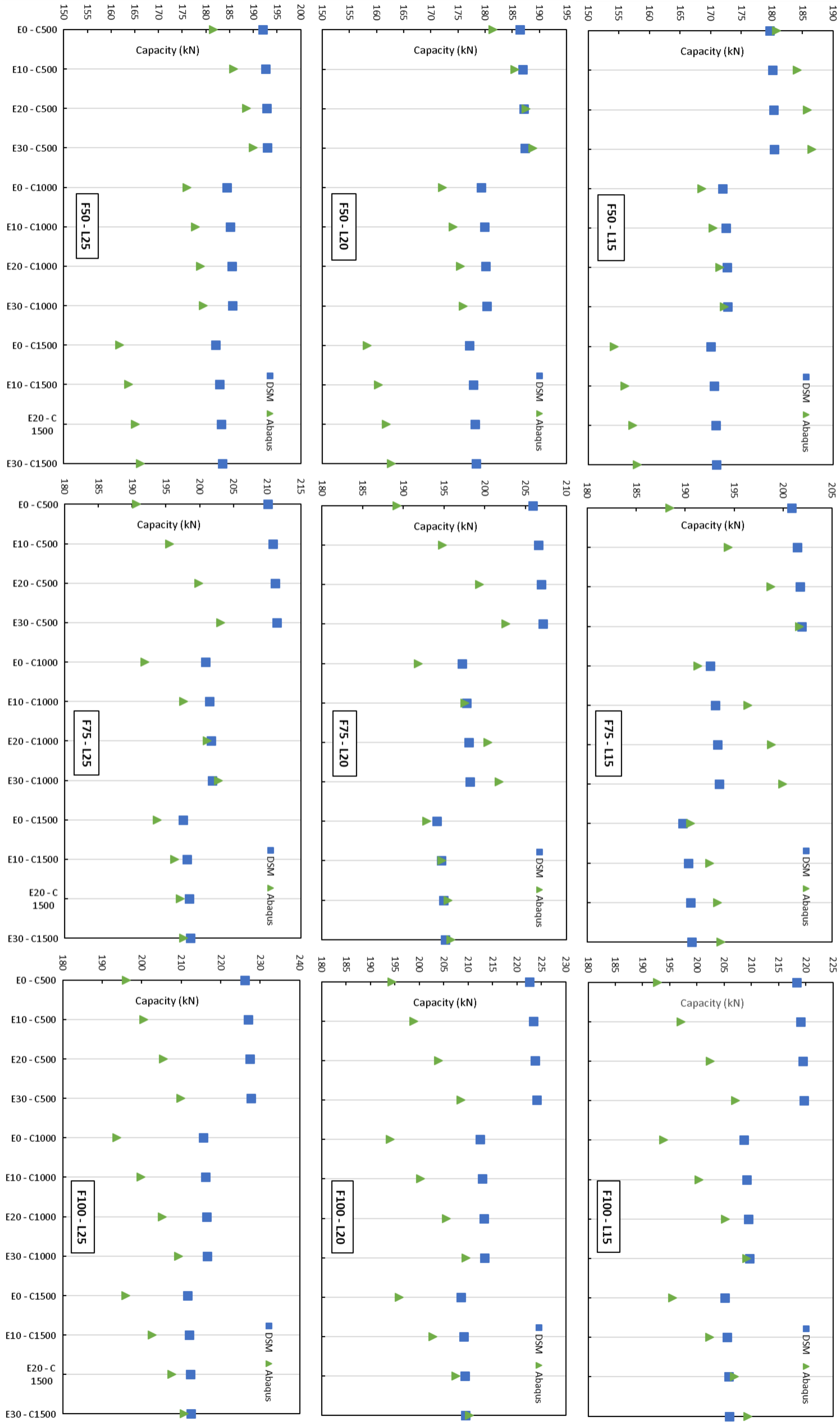
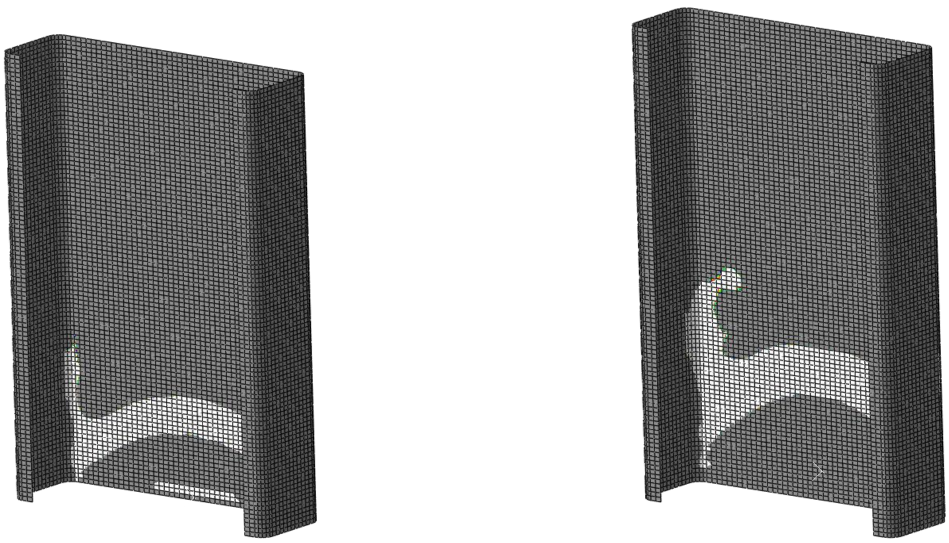



**Figure 3 Axial capacity of the columns from the finite element models and DSM**

end distance and cross section, but different lengths. Increasing the length of the lip, increases the stiffness of the flange, which indirectly increases the stiffness of the web. The nominal yield capacity ($P_{nd}$) in Eq.2 is influenced by an increase in area due to an increase in the lip's width. Obviously, this results in a marginal increase in the capacity of the column. This increase in capacity is shown in Figure 3. Abaqus results do not support this. When the width of the flange is increased, the effect of the lip becomes negligible.

### 4.3. End distance

To investigate the mechanism and effect of the end distance on column capacity, two columns were selected. These columns represent the overall behaviour of the models investigated. Figure 4 show typical stress distributions of a column with no end distance (E0-C500-F75-L20) and that of a column with 30mm end distance (E30-C500-F75-L20) at their maximum axial capacity. The area in a lighter colour indicates the yielded zones of the web. Figure 4(a) illustrates a column without end distance. Considering a cross-section that includes base connection strip, its flanges and lips are connected at top and free at the bottom. Comparing to Figure 4(b), flanges and lips are places in 30mm above the bottom cross-section and are supported by the elements from top and bottom. When a compressive load is applied at the top of the column, free elements of the mentioned cross section of Figure 4(a) have less restrain to resist against opening and deformation than Figure 4(b). Such confinement effect of the end distance let more area of the column to contribute in load bearing before failure. An increase in the end distance in the tested columns with short flange shows a maximum increase of 4 % (about 7 kN) in columns capacity. This increase rises to 8 % (about 15 kN) for the rest of other columns.



**(a) Column with no end distance** **(b) Column with 30mm end distance**

**Figure 4 Stress distribution of yielded area in bottom port of the column**

## 5. CONCLUSION

This study focused on cold-formed lipped channel columns connected to the base through the web only, under axial compression load. A comparison of the ultimate axial capacity of the columns between finite element numerical models and DSM shows that an increase in the cross-section area due to increase in the length of lip, does not have any remarkable influence on the ultimate capacity of numerical models, but gives higher value using DSM. Although in most cases the predicted nominal capacity of the columns by DSM is higher than the ultimate axial capacity of the same column modelled and analysed using ABAQUS, the difference between the reported capacities are less when the maximum considered end distance is taken into account.

# 6. REFERENCES

Iron, A. (2012) *Steel Institute, AISI S100-2012. North American Specification for the Design of Cold-formed Steel Structural Members*. Washington DC: American Iron and Steel Institute.

Kim, T. S. and Kuwamura, H. (2005) 'The effect of curling on bolted connection strength of thin steel plates', in *Annual Meeting Architectural Institute of Japan (AIJ)*, pp. 569–570.

Kim, T. S., Kuwamura, H. and Cho, T. J. (2008) 'A parametric study on ultimate strength of single shear bolted connections with curling', *Thin-Walled Structures*, 46(1), pp. 38–53.

LaBoube, R. A., Wallace, J. A. and Schuster, R. M. (2002) 'Calibrations of bolted cold-formed steel connections in bearing (with and without washers)'. University of Missouri--Rolla.

'SANS 10162-2 Structural Use of Steel: Part2: Cold-formed Steel Structures' (2011) in *South African National Standard*.

Sheikholarefin, S. and Dundu, M. (2016) 'A Finite Element Study Of The Influence Of Boundary Conditions On Cold-Formed Column-Channel Bases', in *8th International Conference on Steel and Aluminium Structures*. Hong Kong: The University of Hong Kong, p. 345 (1-8).

Soo Kim, T. and Kuwamura, H. (2007) 'Finite element modeling of bolted connections in thin-walled stainless steel plates under static shear', *Thin-Walled Structures*, 45(4), pp. 407–421.

Wallace, J. A. (2009) 'Research Report', (March).

Yu, W.-W. (1982) 'AISI Design Criteria for Bolted Connections', in *Sixth International Speciality Conference on Cold-Formed Steel Structures*.

Zadanfarrokh, F. (1991) 'Analysis and design of bolted connections in cold formed steel members'. Available at: http://usir.salford.ac.uk/2141/.

Zadanfarrokh, F. and Bryan, E. R. (1992) 'Testing and design of bolted connections in cold formed steel sections'. University of Missouri--Rolla.