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Behaviour of Perforated Cold-Formed Steel Sections with Trapezoidal Web Stiffeners

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Article Info
Volume 81
Page Number: 2504- 2510
Publication Issue:
November-December 2019

Article History
Article Received: *5 March 2019*
Revised: *18 May 2019*
Accepted: *24 September 2019*
Publication: *12 December 2019*

Abstract

Experimental studies is performed to examine the strength and behavior of perforated cold-formed steel sections with edge and web stiffeners subjected to compression loading. Axially compression load was imposed on fix ended short columns with various perforation series. There are total of 16 specimens was conducted as to observe possibility interaction between them essentially the stability capacity, buck-ling mode and behaviour. The results showed that the ultimate load of the cold-formed steel sections with edge and web stiffeners under compression varied significantly with the perforation position. Under the same condition, the ultimate load-carrying capacity of Σ-section members and conventional C-section members was increased by 10-20 %. The ultimate strength graphs are drawn as well as the failure modes are discussed for different cross-sections and perforations positions.

Keywords: *Cold-formed steel, Column, Stiffeners, Perforation, Buckling*

1. Introduction

Nowadays, cold-formed steel structural products have become increasingly used on modern building constructions due to improvise characteristics over conventional hot-rolled steel structures. Commonly in practice the cold-formed steel structural members used in construction whether for residential or industrial area are thin material and singly axis symmetric open sections (Yu, 2000). Compare to thicker hot-rolled steel shapes, cold-formed steel can be produced into various section configurations by rolling, press and brake or folding cold-forming procedures. Thus, advantageous strength-to-weight ratios which consequently would be more economical.

Through the cold-forming operations, the material properties of the formed sections show significant changes compared to those of bar before forming, plate, or the steel strip. The mechanical properties strength increment due to cold-forming is caused mainly by strain hardening and aging. Cold-formed members show high yield strength around bends compared to flat portions of cross-section (Rhodes, 1991).

Research done by Mandal and Calladine (2000) stated when thin-walled steel structures under compression loading, their strength is limited by buckling which can often be cataclysmic. The design codes for cold-formed steel structures subjected to various types of loading including compression, bending and torsion which can lead to buckling failure for example lateral buckling, web crippling and distortional buck-ling have been developed in different countries

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such as EU Standards (ENV 1993-1-3, 2009), British Standards (BS5950, 1998), North American Specifications (AISI-S100-07, 2007) and Australian/New Zealand Standards (AS/NZS 4600, 2005).

2. Literature Review

Over recent years, rapid development of innovative and complex cold-formed steel sections due to significant development of manufacturing technologies and equipment improvise (Narayanan and Mahendran, 2003). The unique shapes of these sections enhance the ultimate load-carrying capacity of members, but lead the failure mode and design to be controlled by distortional buckling, simultaneously (Casafont, 2011).

In different circumstances, buckling stress of the cold-formed members can be surprisingly increased by intermediate stiffeners because the element width-to-thickness ratio was reduced effectively which leads to an economic design. Precedently, re-searches on web-stiffened channels mainly focused on those with simple edge stiffeners (Yap and Hancock, 2011), few investigations had been undertaken on the behavior of web-stiffened channels with complex edge stiffeners. Over the past decades, cold-formed channel studs is more preferable for the designers and the con-tractors had chosen when selecting a cross section for load bearing compression members. As a result, the sigma-section cold-formed steel has recently practically applied to the channel cold-formed section. This is because the sigma shaped cold-formed section have both web and flange stiffeners. Klingshirn et al. (2010) tested sigma-section specimens subjected to axial compression at different heights to stimulate local, distortional, and global-flexural buckling failure modes. El Aghoury (2014) measured local and distortional for the behavior and strength of singly sigma shaped cold-formed section as columns. The residual stress pattern of the average local and distortional have been determined. Until now, El Aghoury et al. (2017) also carried out research investigations on the strength and behavior of single sigma section as columns due to different sections and member lengths with wide-ranging analysis of ultimate strength curves including various types of failure modes. Eventually, a reliability analysis is carried out. Normally, for standard structural column members, cold-formed steel, thin-walled, open cross-section column members have at least three categories buckling modes namely the local, distortional and Euler (flexural or torsional) buckling.

Cold-formed structural members are typically mass-produced with perforations (holes) to accommodate various services in mechanical and electrical building construction such as electrical, plumbing and heating services. These perforations are varied with reverence to their shape, size, number of perforations and position orientation. Past researchers Sivakumaran (1988), Rhodes and Macdonald (1996) and Shanmugam and Dhanalakshmi (2001) has found that the limitations of present design code procedures for cold-formed steel members with perforations affect the design versatility and decrease the authenticity of cold-formed modern construction industry productions. In assessment of the section properties of members in bending or compression, perforations made specifically for fasteners (connectors) such as bolts, screws, etc., may be ignored as perforations are filled with substantial. However, for other types of perforations, the reduction in cross sectional area caused by theses perforations should be taken into justification (Cristopher and Schafer, 2009). Kulatungan and Macdonald, (2013) did a Finite Element Analysis of cold-formed steel sections with the effects of perforation positions as column subjected to compression loading. The study showed that the ultimate load of the cold-formed steel columns under compression varied greatly with the perforation position.

Therefore, it is significant to do some experimental exploration in order to know the strength and buckling behavior of these new style specimens. The influence of perforation positions on sigma shaped cold-formed section columns is the main study of this research. Recommendations as advice from other researchers such end-supports condition and length of column were taken into account.

3. Testing Program

Short columns of cold-formed C and Σ -sections with various perforation positions were tested under axial compression to failure. The column specimens were tested with fixed ends boundary conditions. The column cross-sections and the multiple various perforation positions are the primary experimental parameters.

3.1Cross-section Types

The cold-formed sections were brake-pressed from steel plate cold rolled common (SPCC) cold rolled sheet which is the standard of Japanese Industrial standard (JIS) "Cold-reduced carbon steel sheets and strips" having the material grade and designation defined in JIS G 3141. The SPCC Steel tensile strength is must be at least 270 MPa. Before forming, the cold-formed sections were then cut to indicated column length. Eight columns of having C-sections and Σ-sections cold-formed steel as shown in Figure 1 have been tested. The cold-formed Σ-sections profile was specially designed with edge and web stiffeners in order to enhance the local buckling stress of a section,. The tested specimens are labeled such that SC103-1.2-A1. The first and second letters represent the section profile (Singly C=Cee or Singly E=Sigma). following numbers reflect the web depth (H=103 mm), the middle numbers is for the nominal sheet thickness of 1.2 mm and the last alpha number is the perforation position series respectively.

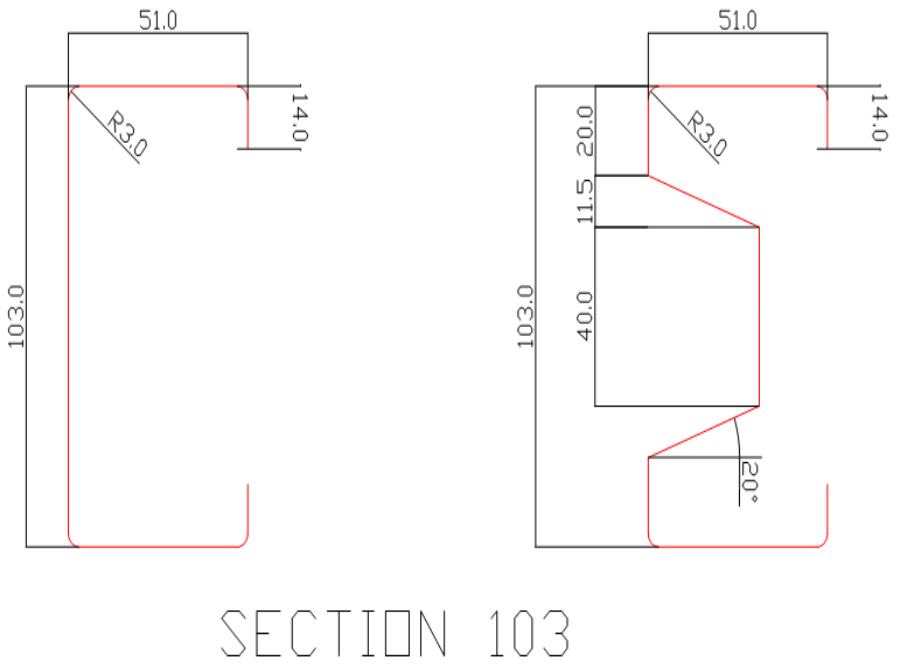

Figure 1: Cross section shape and dimensions of C-sections and Σ-sections

3.2Column Length

The length of the short columns selected in this research is 600 mm also to confirm regardless the multiple local and distortional half-waves pattern can form along the column length.

3.3Perforation Positions

The process of cutout the perforation were been done by using laser cutter. One and three slotted web elongated circle perforation with specific perforation shape, size and position is oriented from the short column mid-height (as shown in Figure 2) whereas distortional buckling cycle-

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patterns are predictable to have their maximum deflection.

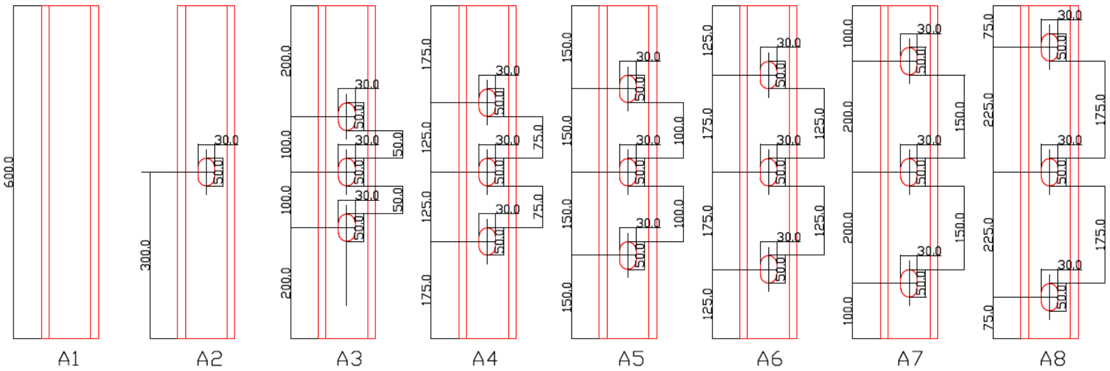

Figure 2: Perforation Positions

3.4Test Rig and Operation

The test rig used for the cold-formed steel column tests is shown in Figure 3. Thick steel end bearing plates with the thickness of 20 mm were welded to both ends of the col-umn specimens. The specimens are tested vertically under axial compressive load on a 1000 kN Universal Testing Machine. The columns are aligned to ensure the loads are applied at the centroid of the cross sections. The loads were applied at the lower end, while the upper end resists the developed reactions. Position of linear variable displacement transducers (LVDT) with magnetic base mount used to monitor the axial shortening as well as the lateral flange buckling displacement at mid-height of columns during loading condition.
The load was kept constant applied about 1–2 kN on the column. The intention of this method was to eliminate possible gap of the surface contact at the end bearing plates. Displacement control with a constant loading rate of 0.5 mm/min was used in the column tests. The axial compression load and the transducers readings were recorded at regular intervals by a data acquisition system.

Figure 3: Short column test set-up and instrumentation

4. Experimental Results

The parametric studies were used to investigate on the ultimate strength and the buckling behavior of the cold-formed steel columns with trapezoidal web stiffeners under the effect of perforation positions.

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4.1Axial Compressive Load

The maximum tested axial compressive load for each test series of all column specimens are provided in Table 1 and Figures4-5. The Σ-section columns show higher ultimate strength value compare to C-section columns with increment 0f 10-20 %. The effect of various perforation positions have influence on axial compressive, with the largest reduction being 11.46 % and 18.9 % for the SC103-1.2 and SE103-1.2 short columns respectively.

Table 1: Columns ultimate strength

Series	SC103-1.2 $P_{ult.}$(kN)	SE103-1.2 $P_{ult.}$(kN)
A1	41.0	48.3
A2	41.5	50.6
A3	41.1	45.3
A4	36.3	53.1
A5	41.4	50.0
A6	39.2	39.2
A7	41.5	47.3
A8	41.5	49.9

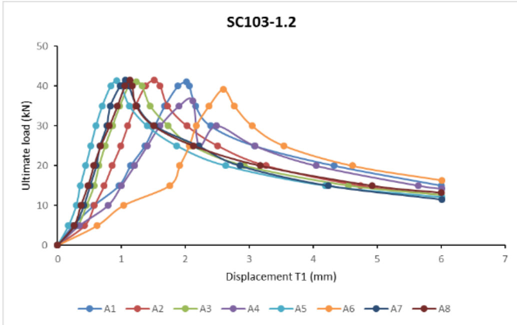


Figure 4: Load-displacement curve for columns SC103-1.2

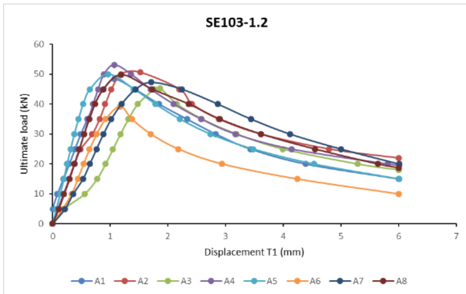
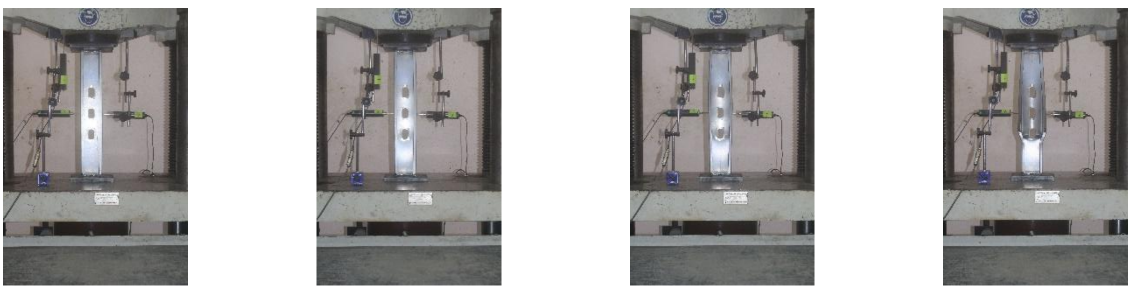


Figure 4: Load-displacement curve for columns SE103-1.2

4.2Buckling Behavior

The loading progression for both SC103-1.2-A3 and SE103-1.2-A3 columns is depicted in Figures 6 and 7 respectively. Both columns exhibit flange distortional and perforation local buckling (localized hole deformation). The C-section column shows that local web buckling occurred at flat web section starting from early initial buckling until post-peak condition. However, web stiffener within the Σ-section column prevent terminates web local buckling during initial buckling.

Web and flange local buckling | Flange warping | Local buckling at bottom perforation combines with distortional buckling



(a) P = 0 kN | (b) Initial buckling P = 22kN | (c) Peak Load P = 41.1 kN | (d) Post–Peak P = 12.7kN

Figure 6: Load-displacement progression for column SC103-1.2-A3

Flange local buckling and web stiffener terminates web local buckling

Local buckling at top perforation and near supports lip

Distortional at top perforation

(a) P = 0 kN

(b) Initial buckling P = 26kN

(c) Peak Load P = 45.3kN

(d) Post – Peak P = 18kN

Figure 7: Load-displacement progression for column SE103-1.2-A3

5. Conclusion

The laboratory experimental test was conducted to investigate the influence of elongated circle perforation with various numbers and positions on short cold-formed steel structural columns with edge and web stiffeners. The presences of perforations initiated only a minor reduction in the of the column's axial compressive strength, even though the post-peak remarks and column ductility were influenced by the presence of perforations and the cross section type. The post-peak response is studied in relation to the influence of perforations on the elastic local and distortion-al buckling behavior of the columns. For the SE103-1.2-A3 column, the web stiffener had a different influence, causing the deformations to remain in the local buck-ling mode through peak load. This provided a small boost in strength and ductility when compared to a similar column without web stiffener. Fix-ended thick steel end bearing plates were successfully employed to study local and distortional type failures of short columns only. Although, it still would not be satisfactory for the observation on all types of global buckling failures. The discussion and conclusions section should answer your research questions and explain what your results mean. In other words, the majority of the discussion and conclusions section should be an interpretation of your results.

Acknowledgements

The activity presented in the paper is part of the research grant from the Internal Research Grants, Universiti Malaysia Pahang (RDU1703174).

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