Assessment on the Behaviour of Cold-Formed Steel Built-up Beams

S. Vijayanand¹, a*, E. Gowshika²,b, P.K. Greevan²,c and P. Gunaseelan²,d

¹Assistant Professor, Department of Civil Engineering, Kongu Engineering College, Perundurai, Erode, Tamil Nadu, India
²UG Students, Department of Civil Engineering, Kongu Engineering College, Perundurai, Erode, Tamil Nadu, India

a*atmvijay.anand@gmail.com, bgowshika03@gmail.com, cgreevan1999@gmail.com, dgunaseelanp07@gmail.com

Keywords: Cold-Formed Steel, Built-Up Flexural Beams, Buckling, Eurocode and North American Specifications

Abstract. Cold-formed steel, thin-walled steel product finds a wide application in construction worldwide. It has many advantages such as flexibility, convenient handling and fabrication and so on. The CFS is commonly used in structures like bridges, railway coaches etc., as it is economical when compared with hot-rolled steel. It can be used as single or built-up flexural members. Generally, the open section beams are susceptible to failure by lateral-torsional buckling due to the position of its centre of shear and centroid of the cross-section. To overcome this issue, open doubly-symmetric built-up sections or built-up closed sections have been used by many researchers. The parametric studies were conducted by many researchers to find the accuracy of the design strength predictions of the built-up beams. In parametric study, Eurocode specifications, the direct strength method and effective width method based on the North American specifications were used. The study reveals that there are no proper design guidelines available in the current Eurocode and North American specifications. Therefore, the paper provides an outline of research works done on various CFS sections by the researchers and their proposed design recommendations to the codal specifications were also reviewed.

Introduction
Usage of CFS load bearing members has become more fashionable over the last few decades. CFS members are structural items that are prepared by shaping flat sheets of steel at room temperature in various forms that can be used to meet structural requirements and practical requirements [1]. On comparing hot rolled sections, using CFS section is one of the efficient ways to save construction material [2]. In construction, CFS beams are generally utilized as main eg. Structural elements, floor joist and as subsidiary eg. girders, rafter [3]. CFS has various advantages namely lightweight, flexibility, convenient handling, transportation, stacking, high specific strength and high stiffness to weight ratio, mass production, ease of prefabrication, uniform quality etc. The uncertainties in CFS beams include distortional buckling, local buckling, lateral-torsional buckling. CFS sections include single section such as C, I, R, Z, sigma, lipped channel, etc., and built up such as built-up open and built-up closed. Thus, the works of investigators on these sections are consolidated and presented in this paper.
Open built-up beams

Typical built-up open sections are shown in fig.1.

Open sections from I sections [1, 4-7], lipped channels [8-12], C sections [2, 13-16] are presented. Research works of an open section from I section were assembled by screws [4, 6, 7] and bolts [5]. Dar et al [1] investigated CFS beams with double trapezoidal corrugated webs and concluded that the strengthening schemes do not require new structural members and it is economic, time-saving, enhance load carrying capacity and reduce deflections. Laim et al [4], Meza et al [5], Anbarasu et al [6] and Yao et al [7] investigated built up I sections and inferred that good agreement between numerical and experimental results were achieved.

Wang and Young [8] investigated lipped channels with perforated web connected back to back using screws and on comparing with North American specification [17], DSM formulae are capable for calculating design strength. Wang and Young [9] investigation showed that design equations were progressive for lipped channels connecting back to back for design strength prediction. Dar et al [10] on doing a study using lipped channel assembled back to back with angle stiffeners found that design strength computed as per North American specification[17]and European Code are conservative. Manikandan and Thulasi [11]on investigating lipped channel stiffened at intermediate web revealed that the provision of intermediate web and edge stiffeners will improve the behaviour and increase the strength of the section. Muftah et al [12] investigated bolted built-up samples of two types as extended stiffener and outstand stiffener. Bolted built-up section with extended stiffener expressed a good outcome of flexural strength. Often, the flexural power of both beams depends on the space or position of the bolt only.

Ghannam [2] done on C section connected back to back in which DS(Direct strength) and EW(Effective width)gave a conservative result for bending moment capacity also more experimental works are required to compensate for the lack of data in this field study. Serror et al [13] experimented with C sections connected back to back and Hassan et al [16] done numerical prediction on C section, curve section and broken section connected back to back found that the C section is in need of stiffeners to enhance ductility. Wang and Young [14] investigated C sections connected back to back using screws with intermediate stiffeners and found that the numerical and experimental investigation are good in terms of ultimate moments, failure modes and the moment-curvature behaviour. Wang and Young [15] took two different configurations of two identical channel sections stiffened at intermediate back to back and face to face using self-tapping screws. Modified DSM equations are recommended.
Closed Built-up Beams

Typical built-up closed sections are shown in fig. 2

![Figure 2. Built-up closed sections](image)

R beams [4], plain channels [8], lipped channels [9], C sections [2, 14, 15], I sections [7] and sigma sections [18] were connected by screws [2, 4, 7-9, 14, 15] and spot welding [18] to form a closed section and investigations were carried out. Laim et al. [4] investigated R built-up close section and 2R connected together by U profile’s web and concluded that the 2R beam showed the best specific strength. Wang and Young [8] investigated plain channels with web perforations connected face to face. It was clear that DSM formulae in North American specification [17] are capable for the prediction of design strength. Wang and Young [14] investigated C section assembled face to face with intermediate stiffeners and inferred that numerical and experimental investigation are in good agreement. Wang and Young [15] investigated three configurations (two different closed sections with connection at flanges, closed section with connection at webs), in which two different closed sections with connection at flanges are unconservative, hence modified DSM (Direct strength method) equations are recommended. Wang and Young [9] investigation showed that design strength prediction. Ghannam [2] investigated a C section connected face to face in which DS and EW gave a conservative result for bending moment capacity also more experimental works are needed to fill the shortage of data in this field research. Selvaraj and Madhavan [18] tested built-up closed sigma sections with intermediate stiffeners interconnected by spot welding concluded that Modified design procedures and design equations are recommended. Yao et al. [7] investigated I section connected face to face and concluded that good agreement among numerical and experimental results was achieved.

Single Sections

Typical single sections are shown in fig. 3

![Figure3. Single sections](image)
Research works on Z sections [3, 19-22], C sections [3, 4, 20, 21, 23-27], I sections [28, 29], plain channel [30], lipped channel [30, 31] and super sigma section [31] were carried out. Put et al [19] and Put et al [23] investigated Z and C respectively and found that on comparing AS 4100 and AS 4600, AS 4600 design method produce high predictions. Yu and Schafer [20], on investigating Z and C sections found that AISI, S136 and the new NAS (North American Specification) design method provide adequate predictions. Chu et al [24] inferred that for C sections, modified DSM equations are recommended for a beam with boundary conditions other than simply supported. Schafer and Yu [3] tested Z and C beams and concluded that Eurocode is unconservative and recommended DSM equation. Yu and Schafer [21] investigation on Z and C section inferred that DSM is a reliable tool by using a suitable elastic buckling moment. Paczos and Wasilewicz [28] and Laim et al [4] investigation on I and C section respectively inferred that the analytical and numerical results are in good agreement. Nethercot and Haidarali [22] investigation on Z beams provides effective means of investigating various forms of buckling. Cheng et al [25] tested the C section and came up with the fact that the difference in temperature within the section has a major effect on the beam slenderness calculation.

Hadjipantelis et al [26] tested C section at prestressing and imposed loading stages. Hadjipantelis et al [27] worked on C sections in which a practical worked example is used to illustrate the implementation of the design recommendations. Abou-Rayan et al [29] found that for section Design code of European code (EN 1995) is conservative in terms of bending moment capacity. Gatheeshgar et al [31] tested out lipped channel (LCB), optimized LCB, super-sigma and folded-flange in which super-sigma was discovered to be an efficient section under shear, bending and web crippling.

Nie et al [32] investigated corroded CFS beams and inferred that Elastic modulus, yield strength and ultimate strength of the corroded specimens decreased greatly. Samuel et al [33] tested CFS beam with diagonal rebars in the web and concluded that use of beams with diagonal rebars can provide an alternate economic solution to construction industries. Sangeetha et al [34] investigated CFS hollow beams with web opening and came up with a fact that the stiffness of a rectangular hollow beam was higher than the square hollow beams.

**Single Section with Stiffeners**
Typical single sections with stiffeners are shown in fig.4

```
Figure 4. Single section with stiffeners
```

Single sections with stiffeners were investigated in [35-38]. Wang and Zhang [35] compared DSM equations with numerical results of C sections with inclined, upright and edge stiffeners. In lateral-torsional buckling, none of the specimens was failed and also each specimen possessed high bending strength. Haidarali and Nethercot [36] investigated Z sections stiffened at edge and
intermediate. The numerical investigation showed that distortional buckling occurred only at the edge stiffeners and concluded that only the design guidelines for lip/flange distortional buckling need to be considered in case of both intermediate and edge stiffeners in the Eurocode calculations. Pham and Hancock [37] on investigating C and Supacee sections with web stiffeners came up with an alternative proposal that instead of using yield moment (My), using plastic moment (Mp) provides good agreement with the results. Wang and Young [38] tested C sections with web stiffeners and found that DSM predictions are conservative, hence modified DSM equation was recommended.

**Single Sections with Perforations**
Typical Single section with Perforation is shown in fig.5

![Figure 5 single section with Perforation](image)

Investigation on C sections with web perforations was carried out in [39, 40] concluded that the critical moment PCFS beam decreases with the increase of hole size. Yuan et al [39] analytical analysis using EN1993-1-3. Nan-ting Yu et al [40] inferred that the effect of the stress gradient on distortional buckling gradually decreases as the length of the beam increases.

**Conclusion**
A clear summary of the research works in the CFS sections was given. All the sections investigated were different from each other in geometry. Usage of stiffeners seems to be more effective as it increases the stiffness of the beam for both single and built-up sections. The analysis also showed that the load bearing capacity of the beams was affected by a number of factors. Thus it is important to consider these factors viz., length of the beam, spacing between perforations etc while designing the beam sections. Many investigators came up with new provisions as the current codes are not good at predicting the strength of built-up beams. Although there were many research pieces, not many creative single sections were assembled to build a section that was built-up. There is also a broad opportunity to explore many creative built-up sections that may be economical. This paper will enable future researchers to know more about the various CFS sections investigated.

**References**

[1] M.A. Dar, N.Subramanian, A.Dar, M.Majid, M. Haseeb and M.Tahoor, Structural efficiency of various strengthening schemes for cold-formed steel beams: Effect of global imperfections, Steel and Composite Structures. 30 (2019) 393-403.

[2] M.Ghannam, Bending moment capacity of cold-formed steel built-up beams, International Journal of Steel Structures. 19 (2019) 660-71. https://doi.org/10.1007/s13296-018-0155-2

[3] C.Yu and B.W.Schafer, Distortional buckling tests on cold-formed steel beams, Journal of Structural Engineering. 132 (2006) 515-28.. https://doi.org/10.1061/(ASCE)0733-9445(2006)132:4(515)
[4] L.Laim, J.P.C.Rodrigues and L.S.da Silva, Experimental and numerical analysis on the structural behaviour of cold-formed steel beams, Thin-Walled Structures. 72 (2013) 1-13. https://doi.org/10.1016/j.tws.2013.06.008

[5] F.J.Meza, J.Becque and I.Hajirasouliha, Experimental study of cold-formed steel built-up beams, Journal of Structural Engineering. 146 (2020) 04020126. https://doi.org/10.1061/(ASCE)ST.1943-541X.0002677

[6] M.Anbarasu, A.Dar, A.I.Rather and M.A.Dar, Effect of external strengthening on the flexural capacity of cold-formed steel beams, Materials Today: Proceedings. 39 (2020) 1270-1274. https://doi.org/10.1016/j.matpr.2020.04.171

[7] X.Yao, X. Zhou, Y. Shi, Y. Guan and Y. Zou, Simplified calculation method for flexural moment capacity of cold-formed steel built-up section beams, Advances in Structural Engineering. 23 (2020) 3153-67. https://doi.org/10.1177/1369433220931208

[8] L.Wang and B.Young, Beam tests of cold-formed steel built-up sections with web perforations, Journal of Constructional Steel Research. 115 (2015) 18-33. https://doi.org/10.1016/j.jcsr.2015.08.001

[9] L.Wang and B.Young, Behaviour and design of cold-formed steel built-up section beams with different screw arrangements, Thin-Walled Structures. 131(2018) 16-32. https://doi.org/10.1016/j.tws.2018.06.022

[10] M.A. Dar, N.Subramanian, A.Dar, M.Anbarasu, J.B.Lim and M.Atif, Behaviour of partly stiffened cold-formed steel built-up beams: Experimental investigation and numerical validation, Advances in Structural Engineering. 22 (2019) 172-86. https://doi.org/10.1177/1369433218782767

[11] P.Manikandan and M.Thulasi, Investigation on cold-formed steel lipped channel built-up I beam with intermediate web stiffener, International Journal of Advanced Structural Engineering. 11 (2019) 97-107. https://doi.org/10.1007/s40091-019-0220-x

[12] F.Muftah, M.S.H.M.Sani and M.M.M.Kamal, Flexural strength behaviour of bolted built-up cold-formed steel beam with outstand and extended stiffener, International Journal of Steel Structures. 19 (2019) 719-32. https://doi.org/10.1007/s13296-018-0157-0

[13] M.H.Serror, E.M.Hassan and S.A.Mourad, Experimental study on the rotation capacity of cold-formed steel beams, Journal of Constructional Steel Research. 121 (2016) 216-28. https://doi.org/10.1016/j.jcsr.2016.02.005

[14] L.Wang and B.Woung, Behavior of cold-formed steel built-up sections with intermediate stiffeners under bending. I: Tests and numerical validation, Journal of Structural Engineering. 142 (2016) 04015150. https://doi.org/10.1061/(ASCE)ST.1943-541X.0001428

[15] L.Wang and B.Young, Behavior of cold-formed steel built-up sections with intermediate stiffeners under bending. II: Parametric study and design, Journal of Structural Engineering. 142 (2016) 04015151. https://doi.org/10.1061/(ASCE)ST.1943-541X.0001427

[16] E.M.Hassan, M.H.Serror and S.A.Mourad, Numerical prediction of available rotation capacity of cold-formed steel beams, Journal of Constructional Steel Research. 128 (2017) 84-98. https://doi.org/10.1016/j.jcsr.2016.08.010
[17] North American specification for the design of cold-formed steel structural members, American Iron and Steel Institute. (2001)

[18] S. Selvaraj and M. Madhavan, Structural design of cold-formed steel face-to-face connected built-up beams using direct strength method, Journal of Constructional Steel Research. 160 (2019) 613-28. https://doi.org/10.1016/j.jcsr.2019.05.053

[19] B.M. Put, Y-L. Pi and N. Trahair, Lateral buckling tests on cold-formed Z-beams, Journal of Structural Engineering. 125 (1999) 1277-83. https://doi.org/10.1061/(ASCE)0733-9445(1999)125:11(1277)

[20] C. Yu and B. W. Schafer, Local buckling tests on cold-formed steel beams, Journal of Structural Engineering. 129 (2003) 1596-606. https://doi.org/10.1061/(ASCE)0733-9445(2003)129:12(1596)

[21] C. Yu and B. W. Schafer, Simulation of cold-formed steel beams in local and distortional buckling with applications to the direct strength method, Journal of Constructional Steel Research. 63 (2007) 581-90. https://doi.org/10.1016/j.jcsr.2006.07.008

[22] M. R. Haidaral and D. A. Nethercot, Finite element modelling of cold-formed steel beams under local buckling or combined local/distortional buckling, Thin-Walled Structures. 49 (2011) 1554-62. https://doi.org/10.1016/j.tws.2011.08.003

[23] B. M. Put, Y-L. Pi and N. S. Trahair, Lateral buckling tests on cold-formed channel beams, Journal of Structural Engineering. 125 (1999) 532-9. https://doi.org/10.1061/(ASCE)0733-9445(1999)125:5(532)

[24] X-T. Chu, Z-M. Ye, R. Kettle and L-Y. Li, Buckling behaviour of cold-formed channel sections under uniformly distributed loads, Thin-Walled Structures. 43 (2005) 531-42. https://doi.org/10.1016/j.tws.2004.10.002

[25] S. Cheng, L-Y. Li and B. Kim, Buckling analysis of cold-formed steel channel-section beams at elevated temperatures, Journal of Constructional Steel Research. 104 (2015) 74-80. https://doi.org/10.1016/j.jcsr.2014.10.004

[26] N. Hadjipantelis, L. Gardner and M. A. Wadde, Prestressed cold-formed steel beams: Concept and mechanical behaviour, Engineering Structures. 172 (2018) 1057-72. https://doi.org/10.1016/j.engstruct.2018.06.027

[27] N. Hadjipantelis, L. Gardner and M. A. Wadde, Design of prestressed cold-formed steel beams, Thin-Walled Structures. 140 (2019) 565-78. https://doi.org/10.1016/j.tws.2019.02.029

[28] P. Paczos and P. Wasilewicz, Experimental investigations of buckling of lipped, cold-formed thin-walled beams with I-section, Thin-Walled Structures. 47 (2009) 1354-62. https://doi.org/10.1016/j.tws.2009.03.009

[29] A. M. Abou-Rayan, N. N. Khalil and A. A. Zaky, Experimental investigation on the flexural behavior of steel cold-formed I-beam with strengthened hollow tubular flanges, Thin-Walled Structures. 155 (2020) 106971. https://doi.org/10.1016/j.tws.2020.106971
[30] D. Dubina and V. Ungureanu, Effect of imperfections on numerical simulation of instability behaviour of cold-formed steel members, Thin-Walled Structures. 40 (2002) 239-62. https://doi.org/10.1016/S0263-8231(01)00046-5

[31] P. Gatheeshgar, K. Poologanathan, S. Gunalan, B. Nagaratnam, K.D. Tsavdaridis and J. Ye, Structural behaviour of optimized cold-formed steel beams, Steel Construction. 13 (2020) 294-304. https://doi.org/10.1002/stco.201900024

[32] B. Nie, S. Xu, Z. hang and R. Gu, Experimental investigation on corroded cold-formed steel beam-columns under compression and major axis bending, Journal of Constructional Steel Research. 169 (2020) 106026. https://doi.org/10.1002/stco.2020.106026

[33] J. Samuel, J. Pravin, R. Divahar, P. A. Raj and P. Joanna, Performance enhancement of built-up cold-formed steel beams with diagonal rebars in web, Materials Today: Proceedings. 169 (2020) 106026. https://doi.org/10.1016/j.matpr.2020.08.767

[34] P. Sangeetha, S. Revathi S, Sudhakar V, D. Swarnavarshini and S. Sweatha, Behaviour of cold-formed steel hollow beam with perforation under flexural loading, Materials Today: Proceedings. 38 (2020) 3103-3109. https://doi.org/10.1016/j.matpr.2020.09.492

[35] H. Wang and Y. Zhang, Experimental and numerical investigation on cold-formed steel C-section flexural members, Journal of Structural Engineering. 65 (2009) 1225-35. https://doi.org/10.1016/j.jcsr.2008.08.007

[36] M. R. Haidarali and D. A. Nethercot, Local and distortional buckling of cold-formed steel beams with both edge and intermediate stiffeners in their compression flanges, Thin-Walled Structures. 54 (2012) 106-12. https://doi.org/10.1016/j.tws.2012.02.013

[37] C. H. Pham and G. J. Hancock, 2013 Experimental investigation and direct strength design of high-strength, complex C-sections in pure bending, Journal of Structural Engineering. 139 (2013) 1842-52. https://doi.org/10.1061/(ASCE)ST.1943-541X.0000736

[38] L. Wang and B. Young, Design of cold-formed steel channels with stiffened webs subjected to bending, Thin-Walled Structures. 85 (2014) 81-92. https://doi.org/10.1016/j.tws.2014.08.002

[39] W.-B. Yuan, N.-T. Yu and L.-Y. Li, Distortional buckling of perforated cold-formed steel channel-section beams with circular holes in web, International Journal of Mechanical Sciences. 126 (2017) 255-60. https://doi.org/10.1016/j.ijmecsci.2017.04.001

[40] N.-T. Yu, B. Kim, L.-Y. Li, W.-J. Hong and W.-B. Yuan, Distortional buckling of perforated cold-formed steel beams subject to uniformly distributed transverse loads, Thin-Walled Structures. 148 (2020) 106569. https://doi.org/10.1016/j.tws.2019.106569