# INVESTIGATION ON COLD-FORMED STEEL BUILT-UP BEAMS

## A PROJECT REPORT

**Submitted by**

**MERLIN PRABHA.M 17CER096**

**PAARVENDHAN.I 17CEL230**

*in partial fulfillment of the requirements*

*for the award of the degree*

*of*

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**KONGU ENGINEERING COLLEGE**

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## BONAFIDE CERTIFICATE

This is to certify that this project report entitled **INVESTIGATION ON COLD-FORMED STEEL BUILT-UP COLUMNS** is the bonafide record of project work done by **M.MERLIN PRABHA (17CER058), I.PAARVENDHAN (17CEL230),** in partial fulfillment of the requirements for the award of the Degree of Bachelor of Engineering in **CIVIL ENGINEERING** of Kongu Engineering College of Perundurai, during the year 2020 - 2021.

**SUPERVISOR** **HEAD OF THE DEPARTMENT**

**Date :**

Submitted for the End Semester Viva Voce examination held on ______________

**EXAMINER I** **EXAMINER II**

**DEPARTMENT OF CIVIL ENGINEERING**

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**PERUNDURAI, ERODE – 638 060**

APRIL-2021

## DECLARATION

We affirm that the Project Report titled **INVESTIGATION ON COLD-FORMED STEEL BUILT-UP COLUMNS** being submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering is the original work carried out by us. It has not formed the part of any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

**Date:** **Signature of the Candidates**

**M.MERLIN PRABHA (17CER096)**

**I.PAARVENDHAN (17CEL230)**

I certify that the declaration made by the above candidates is true to the best of my knowledge.

**Date** : **Name and Signature of the Supervisor with seal**

# ABSTRACT

Cold-formed Steel (CFS), a sort of steel weighing lesser, suits to be a wise choice of material in the construction of steel structures. It has more benefits that indeed make CFS get famous. Effortless installation can be accomplished with the CFS. It also renders a factor that only a few materials show, that is, longevity. Corrosion does not affect the CFS. Employing under moderate loads, CFS finds to be economically feasible when compared with hot-rolled steel. It can be used as compression members comprising single or built-up members. Since a single member cannot sustain the heavy load, the built-up members can be utilized. Open and closed sections are the two sorts of built-up profiles and these profiles show diverse buckling characteristics. This paper lays out a clear outline of the research works done on providing design recommendations to the codes by employing diverse built-up sections. It is reviewed by categorizing the investigated research works based on the kind of CFS sections chosen by each researcher. It was evident from the study that after validation, many researchers have done parametric study on CFS built-up columns to assess the accuracy of the design strength prediction by codal specifications. Many codes failed to estimate the section's ultimate capacity accurately as there are no specific design equations.



**Keywords:** Cold-formed Steel, compression elements, built-up columns, open and closed sections.

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**TABLE OF CONTENTS**

# LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

## 1.1 ABOUT

CFS members are used in industries, office buildings (low-rise), houses with steel frames, etc., CFS single section's capacity to take large compressive loads is minimum. Connection of two or more single sections like the hat, C, Z, etc., give rise to built-up sections that show greater load carrying capacity than individuals. Lacings and battens are used to assemble them. The built-up members are made of two geometries i.e., open and closed. Higher torsional rigidity is shown by closed sections in contrary to open sections. These elements show unique behaviors of buckling. The demerit is that specific provisions in codes are not available for designing a built-up member. Thus, investigators on designing the built-up sections, have recommended new equations for the codes to calculate the bearing capacity of the columns. Their works are consolidated and presented in this paper.Cold formed steel structures are made through proper bending of flat sheets of steel generated at steel plants. Cold formed steel possess sharper edges which have more precise dimensions than the hot rolled sections. In general cold formed steel have greater mechanical properties than the hot rolled sections because the yield strength and tensile strength of cold formed steel will be higher than hot rolled, which makes cold formed steel less likely to fracture under pressure. When steel is formed by press-braking or cold rolled- forming, there is a change in the mechanical properties of the material by virtue of the cold working of the metal. When a steel section is cold-formed from flat sheet or strip, the yield strength and the ultimate strength is increased to a certain extent.

## 1.2 PROPERTIES OF COLD-FORMED STEEL

- Lightness in weight.
- High strength and stiffness.
- Ease of prefabrication and mass production.
- Fast and easy erection and installation.
- Substantial elimination of delays due to weather.
- More accurate detailing.
- Non shrinking and non creeping at ambient temperatures

- No formwork needed
- Termite-proof and rot proof
- Uniform quality
- Economy in transportation and handling
- Non combustibility
- Recyclable material
- Panels and decks can provide enclosed cells for conduits.

## 1.3. Closed built-up sections:

Fig.1.1 shows the typical built-up closed sections.

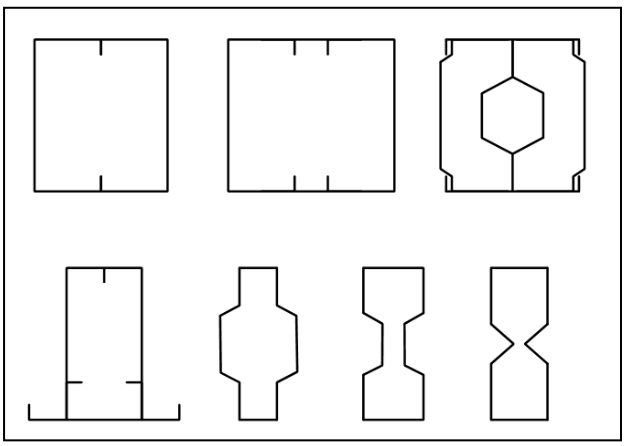

**Fig. 1.1 Built-up closed sections**

## 1.4 Usage of web stiffeners:

Research works employing stiffeners in the web of a section were presented in. Web stiffeners are generally said to give better resistance to local buckling. Young and Chen, on connecting two open profiles with screws (self-tapping) in their flange portion, formed a closed section. Inclination of 45º was made on the web. By testing the 17 fixed-ended columns under axial force, the Direct Strength Method (DSM) in North American Specification (NAS 2004) and Australian/New Zealand Standard (AS/NZS 2005) was checked for its aptness in calculating the ultimate strength of web stiffened built-up columns. There was a determination of unsuitability of the DSM. Later, Zhang and Young  done quality work on two different web-stiffened (inwardly and outwardly) built-up sections formed by connecting two open profiles with screws (self-tapping). The column ends were fixed and loaded axially. Here, the DSM was good for the sections having a nominal thickness at the area of contact. But, the same sections after validating by ABAQUS software in  and on doing an extensive study with 252 columns, modified DSM was seen to be a suitable one. On studying welded and screwed stub columns (made of plain and lipped channels), higher load carrying capacity was observed in the columns with stiffeners at webs .

## 1.5 Two lipped C-sections connected face-to-face:

Closed sections were assembled by welding in, screws in, battens in. There were only scanty research works in columns with welding connectivity. Whittle and Ramseyer tested 150 welded closed columns and came up with many conclusions regarding the appropriateness of the modified slenderness ratio approach. It was exceedingly conservative. Followingly, 48 seam welded closed sections were tested between the two support conditions - fixed or flexible. Ultimate strength was not reduced for all the columns except with maximum spacing of weld and so for those, it was concluded that there was no need to apply modified slenderness ratio in American Iron and Steel Institute (AISI S100-2007). Muftah et al., conducting investigations on the capacity of closed columns of various lengths with screw connection through tests and on comparing with Eurocode specifications (EC3), an 80% difference was observed. Kherbouche and Megnounif compared the numerical results (ANSYS) of closed columns with battens connectivity with theoretical results obtained from a new approach using DSM, AISI and EC3 specifications. It was evident from the study that the column’s strength was influenced by the ratio of channel spacing to the length of the web.

## 1.6 Open built-up sections:

Fig.1.2 shows the typical built-up open sections.

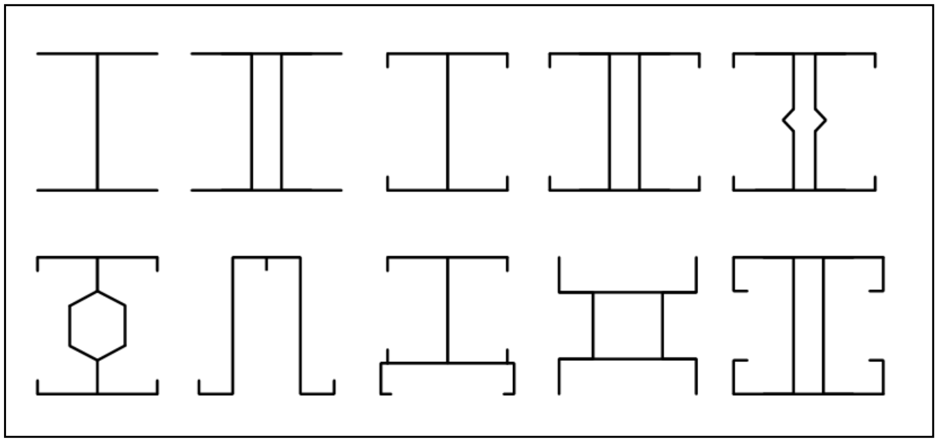

**Fig. 1.2 Built-up open sections**

**3.1 Lipped channels connected back-to-back:**

Investigations on back-to-back connectivity in lipped channels were carried out in. Thirty-two columns with screw connectivity were experimentally investigated in. Five stub columns were tested experimentally under axial compression in and numerically by LUSAS software in . With EWM, better results were obtained than DSM. Local buckling was the major type of failure seen in stub columns. Muftah et al. on conducting tests and comparing the results of open section columns with the EC3 approach, a 20% difference was seen. Then, Abu-Hamd et al. on doing a parametric study, found AISI's prediction was safe for medium and long but for not short columns. Roy et al. studied the thickness effect by using 204 models and as it was found that AISI and AS/NZS gave unsafe results for the columns undergoing local buckling, new rules of the design were given. Ting et al. studied the screw spacing effect on 144 columns. The strength of intermediate and short columns depended on screw numbers but not stub columns. Chen et al. found that holes (edge-stiffened) in the built-up open section rendered an increase in axial strength.

**3.2 Lipped channels connected back-to-back with gap:**

Using this section, researches were done in. Roy et al. found 53% appropriateness in AISI and AS/NZS strength predictions of columns with link-channels at intermediate. Kherbouche and Megnounif , with battened open columns, numerically studied and compared with the results of EC3, a new approach using DSM and AISI. Then, Vijayanand and Anbarasu on investigating the strength of columns with battens found DSM and EWM were appropriate only under specific buckling behavior. Further, 228 models were taken for parametric syudy and the adequacy of EC3 and AISI specicifications were checked. Followingly, Anbarasu and Adil Dar found the resistance to local buckling could be achieved by incorporating spacers in open built-up columns. Recently, Muthuraman et al. found safe predictions of DSM with the battened columns having a slenderness ratio less than 60.

**3.3 Plain channels connected back-to-back:**

Experimental work was done in cold-formed stainless steel columns without any interval inbetween in. Researches falling under the sections with intervals inbetween were presented in. NAS, AS/NZS and EC3 predictions were found unsafe for the battened columns that had locally buckled. Recently, two channels were connected by plates and an investigation was done in. It was revealed that the spacing of connectors and the component’s interaction with one another influenced the column’s ultimate capacity.

# CHAPTER 2

# REVIEW OF LITERATUTRES

## 2.1 GENERAL

The literatures were collected based on the investigations on Cold formed steel members which includes experimental investigations, finite element modeling & analysis and design methods. The collected literatures were reviewed and are discussed as follows.

## 2.2 LITERATURE REVIEW

**Young et al.(2008**) Research on cold-formed steel columns. Cold-formed steel open sections, such as plain and lipped channels, channels with simple and complex edge stiffeners as well as plain and lipped angles, unequal angles and built-up closed sections with intermediate stiffeners. Research on cold-formed steel columns. ABAQUS softaware. Tensile coupon test and column test. AISI and AS/NZS 4600. Axial compression. Summarises the design reccommendations for cold-formed steel columns. Summarises the design reccommendations for cold-formed steel columns.

**Anbarasu et al.(2015**) Investigation on the behaviour and strength of cold-formed steel web stiffened built-up battened columns.Numerical investigation on behaviour and design of cold-formed steel built-up column composed of lipped sigma channels. Cold-formed steel built-up closed section column composed of lipped sigma channels. Structural response and ultimate resuistance of cold-formed steel built-up columns. Current direct strength method in the North American Specification for cold-formed steel columns. It was shown that the FE model could reliably predict the compression resistance as well as the prior and post-ultimate load behaviour of CFS built-up columns and on evaluating the appropriateness of the current DSM and the modified DSM proposed by Zhang and Young (2018b) for CFS closed built-up section with web stiffener, the modified DSM provides overly conservative results for flexural buckling.

**Abbasi et al.(2018)**

Elastic buckling analysis of cold-formed steel built-up sections with discrete fasteners using the compound strip method.Four identical lipped angles connected by battens. Parametri study was conducted (96 models) varying global slenderness, section compactness and spacing of battens. AS/NZS and EC3 did not give reliable results and so new design rules proposed. On verifying the proposed numerical technique against FE solutions, it is found to be accurate and convergent and it is evident from the results that reducing the fastener spacing ratio enhances the buckling capacity of built-up sections, especially in the global and local buckling regions of built-up open sections and the global buckling region of built-up closed sections.

**Afshan et al.V(2013)** Strength enhancements in cold-formed structural sections-Part I: Material testing.Cold-formed structural sections - Square Hollow Sections (SHS), Rectangular Hollow Sections (RHS) and Circular Hollow Section (CHS), and materials-austenitic (EN 1.4301, 1.4571 and 1.4404), ferritic (EN 1.4509 and 1.4003), duplex (EN 1.4462) and lean duplex (EN 1.4162) stainless steel and grade S355J2H carbon steel. On combinig the results from the current test programme stress-strain data on cold-formed stainless steel sections from the literature, revised values for the model parameters and Young's modulus are obtained which were in accordance with the anticipated material response having the lowest value for the austenitic grades, the highest value for the ferritic grades and an intermediate value for the duplex grades which is not reflected in the current codified n values. It is recommended that a single Young's modulus value of 195,000 N/mm2 may be adopted for the stainless steel grades.

**Anbarasu et al.(2019)** Numerical investigation on behaviour and design of cold-formed steel built-up column composed of lipped sigma channels. Cold-formed structural sections - Square Hollow Sections (SHS), Rectangular Hollow Sections (RHS) and Circular Hollow Section (CHS), and materials-austenitic (EN 1.4301, 1.4571 and 1.4404), ferritic (EN 1.4509 and 1.4003), duplex (EN 1.4462) and lean duplex (EN 1.4162) stainless steel and grade S355J2H carbon steel. Strength enhancements in cold-formed structural sections. A series of tensile coupon test on material extracted from cold-formed tubular sections and full section tensile test. S/NZS 4673 (2001), SEI/ASCE-8(2002) and EN 1993-1-4 (2006). On combinig the results from the current test programme stress-strain data on cold-formed stainless steel sections from the literature, revised values for the model parameters and Young's modulus are obtained which were in accordance with the anticipated material response having the lowest value for the austenitic grades, the highest value for the ferritic grades and an intermediate value for the duplex grades which is not reflected in the current codified n values. It is recommended that a single Young's modulus value of 195,000 N/mm2 may be adopted for the stainless steel grades.

**Baldassino et al.(2019)** Evaluation of European approaches applied to design of TWCF steel members. Evaluation of European approaches applied to design of TWCF steel members. European approaches to design of TWCF steel members. EC3-1-3, EC3-GEM approach, EN1990 and EN 1993-1-3. On assessing the load carrying capacity sometimes significantly greater than the characteristic experimental one, suitable safety factors have been calibrated and proposed for each cross-section type, to be directly adopted in routine design to match the requirements associated with the limit state philosophy.

**Bedair(2009)** A cost-effective design procedure for cold-formed lipped channels under uniform compression. Cold-formed lipped channels. Formulation of a cost-effective design procedure for cold-formed lipped channels under uniform compression. Efficient automation procedure and existing AISI and CSA-S136-07 provisions. The paper highlighted the influence of flange and lip sizes on the buckling and post-buckling characteristics of the web which are not considered in existing AISI and CSA-S136-07 provisions. It is shown that the present procedure yields substantial material savings and guidelines to the cold-formed steel fabricators to determine the optimum section sizes that maximizes the buckling strength.

**Beregszaszi et al.(2011)** Application of the constrained finite strip method for the buckling design of cold-formed steel columns and beams via the direct strength method. Conventional and the constrained finite strip method. This paper discusses the applicability of the recently proposed constrained finite strip method in the calculation of moment capacity of beams and compression capacity of columns as it can completely eliminate the uncertainty of the prediction, and can ensure a fully automated calculation of the capacities.

**Buchanan et al.(2018)** Testing, simulation and design of cold-formed stainless steel CHS columns. Austenitic, duplex and ferritic stainless steel cold-formed CHS columns. To provide benchmark data to validate numerical models and underpin the development of revised buckling curves. The finite element (FE) analysis package Abaqus/CAE 2016. Material property test, stub column test and concentrically loaded long column test. EN 1993-1-4. Pure compression and pure bending and tensile load. The programme on testing, simulation have shown that the current European design approach can be unconservative. Existing non-iterative design proposals were then evaluated and were generally found to offer improved predictions of member level resistance.

**Cava et al.(2016)** Numerical investigation and direct strength design of cold-formed steel lipped channel columns experiencing local–distortional–global interaction. Cold-formed steel lipped channel columns. A numerical investigation concerning the relevance and Direct Strength Method prediction of the ultimate strength erosion caused by local-distortional-global interaction. ABAQUS shell finite element analyses. Generalised Beam Theory and DSM. Although the three DSM-based design approaches dealt with were shown to provide always safe failure load predictions, the currently codified design curve against local-global inter-active failures exhibits the best performance.

**Dar et al.(2018**) Behaviour of laced built-up cold-formed steel columns: Experimental investigation and numerical validation .Local-global buckling interaction procedures for the design of cold-formed columns: Effective width and direct method integrated approach. Cold-formed channel and Z-section columns. Local-global buckling interaction procedures for the design of cold-formed columns: Effective width and direct method integrated approach. Thomasson's test and Mulligan tests was used. EWM is seen unsafe compared to the experiments where the cross-section is more slender. The behaviour of built-up laced CFS columns is mainly affected by the chord width-to-thickness ratio as well as the lacing slenderness ratio (limited to nearly 80). The predicted axial strengths of FE models were also in good agreement with the test results. Both EC3 and NAS provisions were found to be inadequate for the prediction of design axial strengths of built-up laced CFS columns.

**Devi et al.(2019**) Cold-formed steel square hollow members with circular perforations subjected to torsion. Cold-formed YSt-310 steel square hollow section members. An experimental and numerical investigation on torsional behaviour of unperforated and perforated cold-formed steel hollow section members. ABAQUS software is used for analysis. Tensile test and member test is done. EN, DSM and Deformation Based Method. The introduction of perforation was found to adversely affect the stress distribution pattern. The increase in size of perforation as well as number of perforation was found to reduce torsional capacity. Position of perforation was found to have insignificant effect on the member torsional capacity.

**Muftah et al.(2015)** Mechanical behaviour of the cold-formed steel channel stub column under post elevated temperature. Cold-formed steel channel stub column. To determine the mechanical behaviour of the CFS channel stub column at post elevated temperature from normal to 10000C. The CFS channels are able to remain the strength after exposing to temperature up to 400 ºC. Beyond that, the capacity was reduced more than 40 % of the normal strength.

**Dinis et al.(2011)** Post-buckling behaviour and strength of cold-formed steel lipped channel columns experiencing distortional/global interaction. Cold-formed steel lipped channel columns. A numerical investigation concerning the elastic and elastic–plastic post-buckling behaviour of cold-formed steel lipped channel columns affected by distortional/global buckling mode interaction. Axial load is applied. The initial imperfection global amplitude has a relatively small impact on the column elastic post-buckling behaviour and ultimate strength – nevertheless, it is far more relevant than its distortional counterpart.

**Fang et al.(2018**) Structural performance of cold-formed high strength steel tubular columns.Cold-formed high strength steel tubular columns with square, rectangular and circular cross-section of steel grades S700, S900 and S1100. Numerical investigtaion into the structural performance cold formed column. European,Australian and AmericanStandards are refered. Comparing with the S700 columns, columns with steel grades of S900 and S1100 respectively showed higher normalised column strengths by 0.5-4.2 and1.0-7.4% since the reduction effec tof global geometric imperfetion and residual stress on the column strengths became less severe.

**Georgieva et al.(2012**) Composed columns from cold-formed steel Z-profiles: Experiments and code-based predictions of the overall compression capacity. Composed columns from cold-formed steel Z-profiles. Determination the overall compression capacity of double-Z columns. Full scale test was practiced. EN 1993-1-3:2006 and DSM. The new approach is appealing due to its simplicity and straightforwardness, on one hand, and because it yields a more precise prediction of the overall capacity of the built-up members, on the other.

**Gilbert et al. (2012)** Self-shape optimisation application: Optimisation of cold-formed steel columns. Singly-symmetric Cold-formed steel open columns. Optimisation of cold-formed steel open columns using the recently developed self-shape optimisation method. DSM, FSM and constrained FSM. Results show that the optimum cross-sections are found in a relatively low number of generations, and typically shape to non-conventional ‘‘bean’’, ‘‘oval’’ or rounded ‘‘S’’ sections.

**Gunalan et al.(2014**) Flexural-torsional buckling behaviour and design of cold-formed steel compression members at elevated temperatures. Cold-formed steel lipped channel columns. Investigation on the accuracy of using current ambient temperature design rules in Australia/New Zealand, American and European standards in deter- mining the flexural–torsional buckling capacities of cold-formed steel columns at uniform elevated temperatures. CUFSM and ABAQUS software. Elevated temperature test. AS/NZS 4600, AISI S100 and Eurocode 3 Part 1.3. Elevated temperature capacity predictions of AS/NZS 4600, AISI S100, DSM and Eurocode 3 Part 1.3 using reduced mechanical properties showed a good agreement and a better consistency for pinned ended columns subjected to flexural-torsional buckling. However, they were too conservative for fixed ended slender columns subject to flexural-torsional buckling.

**Martins et al.(2018)** On the distortional-global interaction in cold-formed steel columns: Relevance, post-buckling behaviour, strength and DSM design. Cold-formed steel plain lipped channel, web-stiffened lipped channel and zed-section columns. A numerical investigation on the post-buckling behaviour, strength and design of fixed-ended cold-formed steel columns. A numerical investigation on the post-buckling behaviour, strength and design of fixed-ended cold-formed steel columns. The initial geometrical imperfection shape plays an important role in the post-buckling (elastic or elastic-plastic) behaviour of columns undergoing D-G interaction, since it alters the global buckling nature.

**Abbasi et al.(2018)**

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**He et al.(2014)** Strength design curves and an effective width formula for cold-formed steel columns with distortional buckling, Cold-formed steel columns. Predicting the load-carrying capacity in the distortional mode. Current design methods, DSM and EWM which are incorporated in AISI-NAS: 2007, AS/NAS 4600: 200 and JGJ 227-201. The current design standards adopted Hancock's two strength design curves for the DSM and EWM, which have some differences at the partial extent. The proposed formula for dealing with these differences agrees better with the current DSM design formula than the current EWM.

**Imran et al.(2018)** Mechanical properties of cold-formed steel tubular sections at elevated temperatures. Cold-formed steel tubular SHS, RHS and CHS. Determination of mechanical properties Tensile coupon test. BS 5950 Part 8, EC3Part1.2, AS 4100 and ANSI/AISC 360-10. Suitable equations to predict the yield strength, stress at 2% strain, elastic modulus, and ultimate strength were proposed in this paper. Finally, a stress-strain model was developed to predict the elevated temperature stress-strain curves of cold-formed steel tubular sections.

**Kang et al.(2013)** Buckling modes of cold-formed steel columns. Cold-formed built-up C channel section columns (rectangular and I shaped). Determination of the buckling mode and maximum buckling capacity and evaluate the AISI-2001 Specification. Buckling test. AISI-2001. There are inconsistencies in the calculated values by AISI-2001 as compared to the maximum capacity loads determined from the buckling tests. The orientation of the column substantially impacts the maximum load of the column.

**Gilbert et al. (2012)** Self-shape optimisation application: Optimisation of cold-formed steel columns. Singly-symmetric Cold-formed steel open columns. Optimisation of cold-formed steel open columns using the recently developed self-shape optimisation method. DSM, FSM and constrained FSM. Results show that the optimum cross-sections are found in a relatively low number of generations, and typically shape to non-conventional ‘‘bean’’, ‘‘oval’’ or rounded ‘‘S’’ sections.

**Kesawan et al.(2018)** Post-fire mechanical properties of cold-formed steel hollow sections. Cold-formed steel hollow rectangular and square sections. An experimental investigation on post-fire mechanical properties. The proposed elastic modulus reduction factors were about the same with those proposed by others yet large differences were observed for the yield and ultimate strength reduction factors. This demonstrated that the proposed equations are only applicable to cold-formed steel hollow sections.

**Kulatunga et al.(2014)** Load capacity of cold-formed column members of lipped channel cross-section with perforations subjected to compression loading-Part I: FE simulation and test results. Cold-formed column members of lipped channel. An investigation was carried out into the influence of perforations of various shapes on the buckling behavior. ANSYS software. AISI Specification, British Standards (BS) and EU Standard. The design code predictions of load carrying capacity of cold-formed steel sections subjected to compression loading with perforations are inadequate and require further investigation.

**Landesmann et al.(2015)** DSM to predict distortional failures in cold-formed steel columns exposed to fire: Effect of the constitutive law temperature-dependence. Fixed-ended cold-formed steel lipped channel and rack-section columns. Performance of the current DSM provisions against distortional failure to estimate the ultimate strength. ANSYS shell finite element model. EC3:Part 1.2 and DSM. Axial load condition. DSM distortional strength curves were shown to predict fairly well the vast majority of the numerical and (few) experimental column distortional failure loads.

**Anbarasu et al.(2019**) Numerical investigation on behaviour and design of cold-formed steel built-up column composed of lipped sigma channels. Cold-formed steel built-up closed section column composed of lipped sigma channels. Structural response and ultimate resuistance of cold-formed steel built-up columns. Current direct strength method in the North American Specification for cold-formed steel columns. It was shown that the FE model could reliably predict the compression resistance as well as the prior and post-ultimate load behaviour of CFS built-up columns and on evaluating the appropriateness of the current DSM and the modified DSM proposed by Zhang and Young (2018b) for CFS closed built-up section with web stiffener, the modified DSM provides overly conservative results for flexural buckling.

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**Matsubara et al.(2019)** Lipped channel cold-formed steel columns under local-distortional buckling mode interaction. CFS lipped channel. Verifying design rules for cold-formed steel members under axial compression when local-distortional buckling modes is achieved. ANSYS shell finite element. The proposed solution follows the direct strength method concept, is easy to apply and accurate enough for the structural design of lipped CFS columns.

**Phan et al.(2019**) Flexural rigidity of cold-formed steel built-up members. Zinc-coated steel C-sections are connected back-to-back to form a double-web built-up I-section Experimental, numerical and analytical studies on the effect of fastener configurations on the flexural rigidity of built-up sections. ABAQUS software. The flexural rigidity of screw-fastened built-up sections increases with increasing number of fastener rows and when installing the fasteners further away from the mid-length location.

**Roy et al.(2018)** Nonlinear behaviour of back-to-back gapped built-up cold-formed steel channel sections under compression. Two-back-to-back gapped built-up CFS channel columns. Two-back-to-back gapped built-up CFS channel columns. ABAQUS software. Tensile coupon test. AISI and AS/NZS. Axial and tensile load. It is shown that design in accordance with AISI and AS/NZS can be conservative by as much as 53%..

**Sadovsky et al.(2018)** Influence of boundary conditions and load eccentricity on strength of cold-formed lipped channel columns. Cold-formed lipped channel columns. The ultimate buckling strength is investigated.The lowest capacities were significantly affected by boundary conditions. Releasing the cross-sectional rotations the lowest capacity decreased by 8.8%, while for free rotations of the loading platen the difference increased to 16.9%. On vast majority of positions the lowest values of buckling loads were obtained for eccentricity towards the web.

**Young et al.(2008**) Design of cold-formed steel built-up closed sections with intermediate stiffeners. Research on cold-formed steel columns. Cold-formed steel open sections, such as plain and lipped channels, channels with simple and complex edge stiffeners as well as plain and lipped angles, unequal angles and built-up closed sections with intermediate stiffeners. Research on cold-formed steel columns. ABAQUS softaware. Tensile coupon test and column test. AISI and AS/NZS 4600. Axial compression. Summarises the design reccommendations for cold-formed steel columns. Summarises the design reccommendations for cold-formed steel columns.

**Martins et al.(2018)** On the distortional-global interaction in cold-formed steel columns: Relevance, post-buckling behaviour, strength and DSM design. Cold-formed steel plain lipped channel, web-stiffened lipped channel and zed-section columns. A numerical investigation on the post-buckling behaviour, strength and design of fixed-ended cold-formed steel columns. A numerical investigation on the post-buckling behaviour, strength and design of fixed-ended cold-formed steel columns. The initial geometrical imperfection shape plays an important role in the post-buckling (elastic or elastic-plastic) behaviour of columns undergoing D-G interaction, since it alters the global buckling nature.

**Fang et al.(2018**) Structural performance of cold-formed high strength steel tubular columns.Cold-formed high strength steel tubular columns with square, rectangular and circular cross-section of steel grades S700, S900 and S1100. Numerical investigtaion into the structural performance cold formed column. European,Australian and AmericanStandards are refered. Comparing with the S700 columns, columns with steel grades of S900 and S1100 respectively showed higher normalised column strengths by 0.5-4.2 and1.0-7.4% since the reduction effec tof global geometric imperfetion and residual stress on the column strengths became less severe.

**Anbarasu et al.(2019**) Numerical investigation on behaviour and design of cold-formed steel built-up column composed of lipped sigma channels. Cold-formed steel built-up closed section column composed of lipped sigma channels. Structural response and ultimate resuistance of cold-formed steel built-up columns. Current direct strength method in the North American Specification for cold-formed steel columns. It was shown that the FE model could reliably predict the compression resistance as well as the prior and post-ultimate load behaviour of CFS built-up columns and on evaluating the appropriateness of the current DSM and the modified DSM proposed by Zhang and Young (2018b) for CFS closed built-up section with web stiffener, the modified DSM provides overly conservative results for flexural buckling.

**Roy et al.(2018)** Nonlinear behaviour of back-to-back gapped built-up cold-formed steel channel sections under compression. Two-back-to-back gapped built-up CFS channel columns. Two-back-to-back gapped built-up CFS channel columns. ABAQUS software. Tensile coupon test. AISI and AS/NZS. Axial and tensile load. It is shown that design in accordance with AISI and AS/NZS can be conservative by as much as 53%.

**Muftah et al.(2015)** Mechanical behaviour of the cold-formed steel channel stub column under post elevated temperature. Cold-formed steel channel stub column. To determine the mechanical behaviour of the CFS channel stub column at post elevated temperature from normal to 10000C. The CFS channels are able to remain the strength after exposing to temperature up to 400 ºC. Beyond that, the capacity was reduced more than 40 % of the normal strength.

**Cava et al.(2016)** Numerical investigation and direct strength design of cold-formed steel lipped channel columns experiencing local–distortional–global interaction. Cold-formed steel lipped channel columns. A numerical investigation concerning the relevance and

Direct Strength Method prediction of the ultimate strength erosion caused by local-distortional-global interaction. ABAQUS shell finite element analyses. Generalised Beam Theory and DSM. Although the three DSM-based design approaches dealt with were shown to provide always safe failure load predictions, the currently codified design curve against local-global inter-active failures exhibits the best performance.

**Phan et al.(2019**) Flexural rigidity of cold-formed steel built-up members. Zinc-coated steel C-sections are connected back-to-back to form a double-web built-up I-section Experimental, numerical and analytical studies on the effect of fastener configurations on the flexural rigidity of built-up sections. ABAQUS software. The flexural rigidity of screw-fastened built-up sections increases with increasing number of fastener rows and when installing the fasteners further away from the mid-length location.

**Landesmann et al.(2015)** DSM to predict distortional failures in cold-formed steel columns exposed to fire: Effect of the constitutive law temperature-dependence. Fixed-ended cold-formed steel lipped channel and rack-section columns. Performance of the current DSM provisions against distortional failure to estimate the ultimate strength. ANSYS shell finite element model. EC3:Part 1.2 and DSM. Axial load condition. DSM distortional strength curves were shown to predict fairly well the vast majority of the numerical and (few) experimental column distortional failure loads.

## SUMMARY

A clear sum up was given on the research works in CFS built-up sections. Each section was uniquely designed to carry the loads. Since the current design codes do not hold the provisions for the built-up sections, many investigators came up with new provisions to be adopted in those codes. Emerging software made their research works very easier. Though there were many pieces of research, not many innovative single sections were assembled to create a built-up section. Thus, there is a wide scope for investigating many innovative built-up sections that may serve to be economical. This paper may help the upcoming researchers to know more about the different CFS built-up sections investigated.

# REFERENCES

1. Young, B., *Research on cold-formed steel columns.* Thin-Walled Structures, 2008. **46**(7-9): p. 731-740.
2. Young, B. and J. Chen, *Design of cold-formed steel built-up closed sections with intermediate stiffeners.* Journal of Structural Engineering, 2008. **134**(5): p. 727-737.
3. Muftah, F., et al., *Ultimate load of built-up cold-formed steel column.* ARPN J. of Eng. and Appl.. Sciences, 2014. **9**(11): p. 2095-2101.
4. Zhang, J.-H. and B. Young, *Experimental investigation of cold-formed steel built-up closed section columns with web stiffeners.* Journal of Constructional Steel Research, 2018. **147**: p. 380-392.
5. Anbarasu, M., *Numerical investigation on behaviour and design of cold-formed steel built-up column composed of lipped sigma channels.* Advances in Structural Engineering, 2019. **22**(8): p. 1817-1829.
6. Vijayanand, S. and M. Anbarasu, *Effect of Spacers on Ultimate Strength and Behavior of Cold-Formed Steel Built-up Columns.* Procedia engineering, 2017. **173**: p. 1423-1430.
7. Vijayanand, S. and M. Anbarasu, *Strength and behavior of cold-formed steel built-up battened columns: tests and numerical validation.* Journal of Structural Engineering, 2019. **46**(2): p. 154-164.
8. Anbarasu, M., K. Kanagarasu, and S. Sukumar, *Investigation on the behaviour and strength of cold-formed steel web stiffened built-up battened columns.* Materials and Structures, 2015. **48**(12): p. 4029-4038.
9. Reyes, W. and A. Guzmán, *Evaluation of the slenderness ratio in built-up cold-formed box sections.* Journal of Constructional Steel Research, 2011. **67**(6): p. 929-935.
10. Georgieva, I., et al., *Design of built-up cold-formed steel columns according to the direct strength method.* Procedia Engineering, 2012. **40**: p. 119-124.
11. Anbarasu, M. and M.A. Dar, *Improved design procedure for battened cold-formed steel built-up columns composed of lipped angles.* Journal of Constructional Steel Research, 2020. **164**: p. 105781.
12. Zhang, J.-H. and B. Young, *Finite element analysis and design of cold-formed steel built-up closed section columns with web stiffeners.* Thin-walled Structures, 2018. **131**: p. 223-237.
13. Beulah Gnana Ananthi, G. and B. Ashvini, *Experimental theoretical and numerical studies on cold-formed steel stub channel columns with stiffeners.* Asian Journal of Civil Engineering, 2018. **20**(2): p. 171-185.
14. Aruna, G., S. Sukumar, and V. Karthika, *Behaviour of cold-formed steel built-up closed columns composed by angle profiles.* Asian Journal of Civil Engineering, 2019. **20**(7): p. 1037-1048.
15. Aruna, G., *Stub Column Tests of Cold-Formed Steel Built-Up Square Sections with Intermediate Stiffeners.* Strength of Materials, 2020. **52**(2): p. 281-290.
16. Whittle, J. and C. Ramseyer, *Buckling capacities of axially loaded, cold-formed, built-up C-channels.* Thin-Walled Structures, 2009. **47**(2): p. 190-201.
17. Kherbouche, S. and A. Megnounif, *Numerical study and design of thin walled cold formed steel built-up open and closed section columns.* Engineering Structures, 2019. **179**: p. 670-682.
18. El Aghoury, M., et al., *Strength of cold formed battened columns subjected to eccentric axial compressive force.* Journal of Constructional Steel Research, 2015. **113**: p. 58-70.
19. Anbarasu, M., *Behaviour of cold-formed steel built-up battened columns composed of four lipped angles: Tests and numerical validation.* Advances in Structural Engineering, 2020. **23**(1): p. 51-64.
20. El Aghoury, M.A., et al., *Ultimate capacity of battened columns composed of four equal slender angles.* Thin-Walled Structures, 2013. **63**: p. 175-185.

21. Dar, M.A., et al., *Behaviour of laced built-up cold-formed steel columns: Experimental investigation and numerical validation.* Thin-Walled Structures, 2018. **132**: p. 398-409.
22. Dar, M.A., D.R. Sahoo, and A.K. Jain, *Axial compression behavior of laced cold-formed steel built-up columns with unstiffened angle sections.* Journal of Constructional Steel Research, 2019. **162**: p. 105727.
23. Liao, F., et al., *Compression test and analysis of multi-limbs built-up cold-formed steel stub columns.* Journal of Constructional Steel Research, 2017. **128**: p. 405-415.
24. Meza, F.J., J. Becque, and I. Hajirasouliha, *Experimental study of the cross-sectional capacity of cold-formed steel built-up columns.* Thin-Walled Structures, 2020. **155**: p. 106958.
25. Meza, F.J., J. Becque, and I. Hajirasouliha, *Experimental study of cold-formed steel built-up columns.* Thin-Walled Structures, 2020. **149**: p. 106291.
26. Nie, S., et al., *Compressive behavior of built-up double-box columns consisting of four cold-formed steel channels.* Engineering Structures, 2020. **222**: p. 111133.
27. Nie, S.-F., et al., *Compressive behavior of built-up closed box section columns consisting of two cold-formed steel channels.* Thin-Walled Structures, 2020. **151**: p. 106762.
28. Yang, J., et al., *Experimental and numerical studies on axially restrained cold-formed steel built-up box columns at elevated temperatures.* Journal of Constructional Steel Research, 2020. **171**: p. 106143.
29. Yang, J., et al., *Experimental study on fire resistance of cold-formed steel built-up box columns.* Thin-Walled Structures, 2020. **147**: p. 106564.
30. Roy, K. and J.B. Lim. *Numerical investigation into the buckling behaviour of face-to-face built-up cold-formed stainless steel channel sections under axial compression*. in *Structures*. 2019. Elsevier.
31. Roy, K., C. Mohammadjani, and J.B. Lim, *Experimental and numerical investigation into the behaviour of face-to-face built-up cold-formed steel channel sections under compression.* Thin-Walled Structures, 2019. **134**: p. 291-309.
32. Stone, T.A. and R.A. LaBoube, *Behavior of cold-formed steel built-up I-sections.* Thin-Walled Structures, 2005. **43**(12): p. 1805-1817.
33. Abu-Hamd, M., M.M. Abdel-Ghaffar, and B.M. El-Samman, *Buckling strength of axially loaded cold formed built-up I-sections with and without stiffened web.* Ain Shams Engineering Journal, 2018. **9**(4): p. 3151-3167.
34. Fratamico, D.C., et al., *Experiments on the global buckling and collapse of built-up cold-formed steel columns.* Journal of Constructional Steel Research, 2018. **144**: p. 65-80.
35. Roy, K., et al. *Effect of thickness on the behaviour of axially loaded back-to-back cold-formed steel built-up channel sections-Experimental and numerical investigation*. in *Structures*. 2018. Elsevier.
36. Ting, T.C.H., et al., *Effect of screw spacing on behavior of axially loaded back-to-back cold-formed steel built-up channel sections.* Advances in Structural Engineering, 2018. **21**(3): p. 474-487.
37. Chen, B., et al., *Axial strength of back-to-back cold-formed steel channels with edge-stiffened holes, un-stiffened holes and plain webs.* Journal of Constructional Steel Research, 2020. **174**: p. 106313.
38. Kechidi, S., et al., *Simulation of screw connected built-up cold-formed steel back-to-back lipped channels under axial compression.* Engineering Structures, 2020. **206**: p. 110109.
39. Ting, C.H.T. and H.H. Lau. *Compression test on cold-formed steel built-up back-to-back channels stub columns*. in *Advanced Materials Research*. 2011. Trans Tech Publ.
40. Ting, T. and H.H. Lau, *A Numerical Investigation on Cold-Formed Steel Bulit-up Back-to-Back Channel Stub Columns.* Advances in Steel and Aluminum Structures, 2011: p. 443-449.
41. Roy, K., et al., *Nonlinear behaviour of back-to-back gapped built-up cold-formed steel channel sections under compression.* Journal of Constructional Steel Research, 2018. **147**: p. 257-276.
42. Anbarasu, M. and M. Adil Dar, *Axial capacity of CFS built-up columns comprising of lipped channels with spacers: Nonlinear response and design.* Engineering Structures, 2020. **213**: p. 110559.

43. Muthuraman, M., et al., *Numerical simulation and specification provisions for buckling characteristics of a built-up steel column section subjected to axial loading.* Engineering Structures, 2020. **207**: p. 110256.
44. Vijayanand, S. and M. Anbarasu, *Behavior of CFS built-up battened columns: Parametric study and design recommendations.* Structural Engineering and Mechanics,, 2020. **74**(3): p. 381-394.
45. Vijayanand, S. and M. Vignesh, *Numerical study on strength and behaviour of cold formed steel built-up battened columns.* International Journal of Intellectual Advancements and Research in Engineering Computations, 2019. **7**(2): p. 1634-1640.
46. Dobrić, J., et al., *Resistance of cold-formed built-up stainless steel columns–part I: experiment.* Journal of Constructional Steel Research, 2018. **145**: p. 552-572.
47. Dabaon, M., E. Ellobody, and K. Ramzy, *Nonlinear behaviour of built-up cold-formed steel section battened columns.* Journal of Constructional Steel Research, 2015. **110**: p. 16-28.
48. Dabaon, M., E. Ellobody, and K. Ramzy, *Experimental investigation of built-up cold-formed steel section battened columns.* Thin-Walled Structures, 2015. **92**: p. 137-145.
49. Zhang, J.-H. and B. Young, *Numerical investigation and design of cold-formed steel built-up open section columns with longitudinal stiffeners.* Thin-Walled Structures, 2015. **89**: p. 178-191.
50. Laím, L., et al., *Experimental analysis of cold-formed steel columns with intermediate and edge stiffeners in fire.* Thin-Walled Structures, 2020. **146**: p. 106481.
51. Deepak, M.S., G. Beulah Gnana Ananthi, and K. Mahendran, *Behaviour of thin-walled intermediate stiffened back-to-back columns under axial compression.* Materials Today: Proceedings, 2020.
52. Georgieva, I., L. Schueremans, and L. Pyl, *Composed columns from cold-formed steel Z-profiles: Experiments and code-based predictions of the overall compression capacity.* Engineering Structures, 2012. **37**: p. 125-134.
53. Liu, X. and T. Zhou, *Research on axial compression behavior of cold-formed triple-lambs built-up open T-section columns.* Journal of Constructional Steel Research, 2017. **134**: p. 102-113.
54. Anbarasu, M. and M. Venkatesan, *Behaviour of cold-formed steel built-up I-section columns composed of four U-profiles.* Advances in Structural Engineering, 2019. **22**(3): p. 613-625.