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# BUCKLING BEHAVIOR OF UNRESTRAINED STIFFENED COLD FORMED STEEL SINGLE BUILT SECTIONS - A REVIEW

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**Abstract: The aim of this report is to give a review of the progress in field of cold formed steel sections. Particular emphases are given to the finite element analysis of strength and behaviour of different cold formed steel single and built-up sections with flange or web stiffeners. Cold formed steel members can be plain in simple applications, but if provided with flange or web stiffeners, their performance and resistance to local, distortional, and lateral torsional buckling improves. The idea behind cold-formed steel members is to use shape rather than thickness to support load. Due to the relatively easy method of manufacturing, many different configurations can be produced to fit the demands of optimized design for both structural and economical purposes.**

**Keywords: Local, distortional, flexural buckling, stiffened elements, box sections.**

## I. INTRODUCTION

Cold-formed steel structures are steel structural products that are made by bending flat sheets of steel at ambient temperature into shapes which will support more than the flat sheets themselves. They have been produced for more than a century since the first flat sheets of steel were produced by the steel mills. However, in recent years, higher strength materials and a wider range of structural applications have caused a significant growth in cold-formed steel relative to the traditional heavier hot-rolled steel structural members. Cold-formed steel members have been widely used in building applications as the secondary cladding and purlin applications as well as the primary applications as beams and columns of industrial and housing systems. Consumption rate of cold-formed steel products is growing steadily. The reasons behind the growing popularity of these products include their ease of fabrication, high strength/weight ratio and suitability for a wide range of applications. These advantages can result in more cost-effective designs, as compared with hot-rolled steel, especially in short-span applications [1]. Cold-formed members can be produced in a wide variety of sectional profiles. The commonly used open cold formed sections are the "C" channels and, to a lesser extent, the "Z" sections shown in Fig. 1. While plain sections are finding applications as secondary members, the sections are usually enhanced with flange end stiffeners (e.g. the lipped channels) and/or web stiffeners in primary structural applications [2, 3]. With stiffeners, the members benefit from a larger cross-sectional effective area and are therefore expected to become better able to resist local and overall buckling.

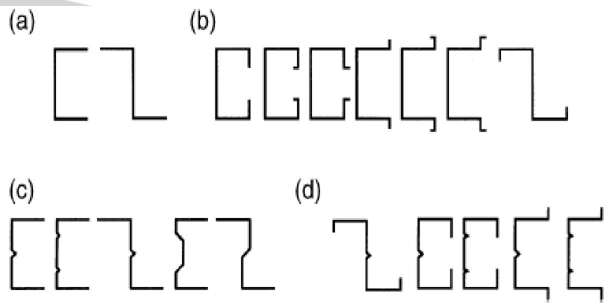


Fig.1. Channel and Z cold-formed sections (a) Plain sections; (b) Sections with flange stiffeners; (c) Sections with web stiffeners; (d) Sections with flange and web stiffeners

## II. COLD-FORMED STEEL STIFFENED SECTIONS

A wide parametric study to cast light onto the behavior of stiffened and unstiffened channel and zed members in various conditions of use has been carried out by El-Sheikh et. al., 2001 [1]; Kwon et. al., 2009 [4]; Yap and Hancock, 2011 [5] which shows that buckling strength was large with the smallest size web stiffener. The free edge of C or Z open cross-section members is of critical importance for their strength. Through providing small additional folds at the free edge an edge stiffener is formed; such a stiffener if formed properly will help preclude buckling at the free edge, and in doing so it will greatly enhance member strength, hence wide research has been carried out on various types of complex and simple inclined edge stiffeners by Schafer (2002) [6], Young and Hancock. (2003) [7] etc.

**Kwon Young B. (1992)** [8] performed a series of compression tests on lipped channel sections, with and without intermediate stiffeners in the web. The tests were carried out between fixed ends and investigated postbuckling in the distortional and mixed local-distortional modes. A

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significant postbuckling strength reserve in the distortional mode was observed, even when local and distortional buckling occurred simultaneously. There appeared to be no adverse interaction between local and distortional buckling for the case where local buckling occurred in the flange, which was deforming in a distortional mode. Two design equations have been proposed. The first is an extension of the earlier proposal by Lau and Hancock (1988) based on a column-buckling philosophy. The second is a modification of Winter's plate-strength curve and is based mainly on a plate-strength design approach as used for distortional buckling in the AISI specification (Specification 1986) when the lip is not adequate to fully support the flange.

**Schafer B W (1999) [9]** presented and verified new procedures for hand prediction of the buckling stress in the local and distortional mode of a laterally braced cold-formed steel flexural member with edge stiffened flanges (e.g., a C or Z section). Numerical investigations are employed to highlight postbuckling behavior unique to the distortional mode. Traditional design methods do not explicitly recognize distortional buckling, nor do they account for the observed phenomena in this mode. A new design method that integrates distortional buckling into the unified, effective width approach, currently used in most cold-formed steel design specifications, is presented. Comparison with experimental tests shows that the new approach is more consistent and reliable than existing design methods.

**El-Sheikh et. al. (2001) [1]** make attempts to cast light onto the behavior of stiffened and unstiffened channel members in various conditions of use. After discussing the section properties and how they change with the use of stiffeners, the section's structural performance is assessed according to British Standard specifications, BS5950 (1998). The work involves a wide parametric study in which channel members with various aspect ratios, stiffeners' sizes and slenderness ratios are analyzed. The results reveal how the members could be profiled to obtain the optimum performance in various applications, and for this reason, the results can be of significant value to future designs of cold-formed channel members.

**Young Ben et. al. (2004)** [10] performed the parametric study of cold-formed steel channel columns with complex stiffeners using finite element analysis. An accurate and reliable finite element model is used for the parametric study in which different sizes of complex stiffeners are investigated. Column strengths predicted by the finite element analysis are compared to the unfactored design column strengths calculated using the American Specification and the Australian/New Zealand Standard for cold-formed steel structures. It is shown that the design strengths obtained from the specification and standard are generally conservative for fixed-ended cold-formed steel channel columns with complex stiffeners for the slenderer sections having a plate thickness of 1 mm with the flat flange width to thickness ratio of 57, but unconservative for sections having a plate thickness of 2 mm with the flat flange width to thickness ratio of 27.

**Haiming Wang and Yaochun Zhang (2009)** [11] presented an experimental and numerical investigation on the bending strength and behavior of cold-formed steel C-section flexural members with upright, inclined, and complex edge stiffeners. The experimental results show that the edge stiffener and buckling mode have great influence on member's bending strength. Moment gradient effect has only a minor influence on local buckling, but has great influence on distortional buckling. The tests were simulated by finite element program of ANSYS and the simulated results show good agreement with the experimental results in terms of bending strength and buckling mode.

**Yap Derrick C Y and Hancock Gregory J (2011)** [12] described the design and testing of web-stiffened high strength steel cold-formed lipped channel columns. The effect of the different types of failure modes is also discussed. The experimental results are then compared with design methods in the existing design standards. It is shown that the existing standards are unconservative and new proposals for dealing with this are made.

**Liping Wang and Ben Young (2014)** [13] investigated the structural behaviour and evaluate the appropriateness of the current direct strength method on the design of cold-formed steel stiffened cross-sections subjected to bending. The stiffeners were employed to the web of plain channel and lipped channel sections to improve the flexural strength of cold-formed steel sections that are prone to local buckling and distortional buckling. An experimental investigation of simply supported beams with different stiffened channel sections has been conducted. The moment capacities and observed failure modes at ultimate loads were reported. A nonlinear finite element model was developed and verified against the test results in terms of strengths, failure modes and moment–curvature curves. The calibrated model was then adopted for an extensive parametric study to investigate the moment capacities and buckling modes of cold-formed steel beams with various geometries of stiffened sections. The strengths and failure modes of specimens obtained from experimental and numerical results were compared with design strengths predicted using the direct strength method specified in the North American Specification for cold-formed steel structures. The comparison shows that the design strengths predicted by the current direct strength method (DSM) are conservative for both local buckling and distortional buckling in this study.

## III. COLD FORMED STEEL BUILT UP SECTION

**K. A. Karthikeyan and Dr. G. Jaisankar (2016)** [16] investigated the buckling and post buckling strength of cold formed steel built-up beams both numerically and experimentally. A finite element model was developed in the

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finite element software and analyzed with simply supported end conditions and uniformly distributed load to find the buckling strength and mode of buckling. FEM is used to determine the mode of buckling and buckling strength of cold formed built-up beams. All built-up sections used in the analysis have low critical elastic local buckling moment compared to other modes like Lateral-Torsional Buckling, Distortional Buckling. Therefore, the built-up sections used in the analysis failed by local buckling. This denotes that sections are failed before reaching its yield limit to improve the capacities of beam stiffeners can be provided. The results obtained by theoretical analysis and finite element software analysis are compared and found that the results obtained by theoretical analysis gives lower buckling loads compared to software analysis.

**Jia-Lin Maa and Tak-Ming Chan (2017)** [17] worked on cold-formed high strength steel (HSS) tubular beams. In the complementary study (Ma JL, Chan TM, Young B. Experimental investigation of cold-formed high strength steel tubular beams.), experimental investigation on the beam specimens have been performed. Here, numerical modelling methodology for beams was first validated and parametric study on the cold-formed HSS tubular beams was conducted. A comprehensive numerical modeling program for cold-formed high strength steel tubular beams was performed. Upon validation of the finite element modeling methodology, parametric study was conducted to generate additional numerical data that covered a wide range of cross-section slenderness. The yield slenderness limits for SHS, RHS and CHS in different codes of practice were examined against the test and FEA results.

**Liping Wang and Ben Young (2018) [18]** investigated the cold-formed steel built-up beams with different screw arrangements. The built-up sections connected back-to-back at the web to form an open section or two plain channels connected face-to-face at the flanges to form a closed section, under four-point bending. Finite element (FE) models have been developed and validated against the test results for the built-up open section beams and built-up closed section beams, respectively. It is shown that the FE models can accurately predict the behaviour of cold-formed steel built-up beams with different screw arrangements. A parametric study on built-up beams with larger span and various screw spacing was further carried out using the verified FE models. The maximum longitudinal screw spacing for built-up closed section beams was also recommended for design practice. It is shown that the current DSM equations can predict the design strengths of built-up open section beams well, and different screw arrangements need not be considered.

**Jun Yea and Seyed Mohammad Mojtabaei (2018)** [19] developed a numerical model to investigate the flexural strength and failure modes of CFS back-to-back channel beams. The model incorporates non-linear stress-strain behavior. The developed Finite Element (FE) models are verified against six four-point bending tests on CFS back-to-back channel beams, where excellent agreement is found between the experimental results and the FE predictions. The model takes into account the non-linear stress–strain behaviour of CFS material, the strain hardening effects at the round corners due to the cold-working process, and the experimentally measured initial geometric imperfections. The numerical model was validated against an experimental program on a total of 6 lipped channel back-to-back beams.

## IV. FINITE ELEMENT METHOD

Finite Element Analysis is one of the reliable tools to get quite accurate results in a reasonable amount of time (Wang and Zang, 2009) [20]. Ren et. al. (2006) [21] verified nonlinear finite element models against experimental results of cold formed steel channels subjected to pure bending as well as combined bending and web crippling. A finite element method with the aid of effective width concept has been presented by Wang et. al. (1977) [22] to investigate the lateral torsional stability of locally buckled beams. Sivakumaiun (1989) [23] shown the good agreements of non-linear finite element predictions with experimental results in the analysis for web crippling behavior of thin-walled mono-symmetric (lipped channel section) cold-formed steel members. Wang and Zang (2009) [20] shown that FEA investigation on the bending strength and behavior of cold-formed steel C-section flexural members with upright, inclined, and complex edge stiffeners are generally in good agreement with the experimental buckling modes. Ashraf et. al. (2006) [24] described the development of the FE models, giving special emphasis to the appropriate guidelines for input parameters such as enhanced strength in the corner regions and the extent of this strength enhancement, initial geometric imperfections, and the significance of residual stresses. Silvestre and Camotim (2006) [25] validated GBT results concerning the local-plate and distortional elastic post buckling behaviors of cold-formed steel lipped channel columns with web and flange intermediate stiffeners by shell finite element analyses performed by means of the software ABAQUS. Maura and Kim (2006) [26] conducted finite-element research program on the distortional buckling of axially compressed, cold-formed stainless steel simple lipped channels. Macdonald et. al. (2010) [27] revealed that the nonlinear finite element models were best capable of closely simulating the web crippling failure behavior observed in the experiments for all ranges of displacement. Recently Tondini and Morbioli (2015) [28] performed and presented a numerical work employing multipurpose finite element software ANSYS inorder to develop a model to reproduce the experimental outcomes and used to expand the available findings over a wider slenderness range through parametric studies. Yu Chen et. al. (2015) [29] used finite element program ABAQUS to simulate cold-formed steel lipped channel beams under web crippling. Rodrigues and Silva (2013) [30]

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developed finite element models of cold formed steel beams with C, I, R and 2R-shaped cross-sections to compare with the experimental results and parametric study was undertaken in order to investigate the influence of the thickness, height and length of the beams on its structural behavior.

**Gotluru et. al. (2000) [31]** summarizes the research on the behavior of cold-formed steel beams subject to torsion and bending. A simple geometric nonlinear analysis method, based on satisfying equilibrium in the deformed configuration, is examined and used to predict the behavior of the beams. Simple geometric analyses, finite element analyses and finite strip analyses are performed and compared with experimental results.

**Pham and Hancock (2010)** [32] provided numerical nonlinear simulations, based on the finite element method (FEM) using the software package ABAQUS/Standard, of high strength C-section cold-formed steel purlins in shear and combined bending and shear. The simulations are compared with and calibrated against tests performed at the University of Sydney on a variety of section sizes and thicknesses. The accurate results of the numerical simulations show that finite element analysis can be used to predict the ultimate loads of thin-walled members including the postbuckling behavior of thin-walled sections in shear and combined bending and shear. It is demonstrated that finite element analysis can therefore be used to design and optimize thin-walled sections of high strength steel.

**Macdonald and Heiyantuduwa (2012)** [33] presented the details of finite element models and experimental investigations of research studies conducted with the aim of developing an alternative design rule to predict the web crippling strength of cold-formed steel lipped channel beams. Load-deformation curves were obtained from both the tests and FE models, and the FE models were validated using the test results. The validation showed a close agreement of FE results with the test results which provided the confidence of using the FE model for a parametric study beyond the limits of the experiments. Based on the results of the parametric study, a design rule was developed which is much more flexible to adapt for new types of sections and ranges of dimensions.

## V.CONSULSION

The development and complexity and of design of cold-formed sections has been increased as their use has been increased and this is likely to continue for the foreseeable future. This development has been a combination of improvements in technology and developments in applications. It has placed researchers under some demands to find adequate practical design procedures for increasingly complicated section shapes. Practical design models have been developed for the local and distortional buckling, and the interaction between them, for most of the sections of interest to the designers of building structures. For cold-formed steel columns and beams with the proportions typically used in practice, distortional buckling is often critical. Some design codes specify the need to use second order analysis under certain conditions. The direct strength method makes a more formal allowance for post-buckling and is evidently more appropriate when local buckling is significant. Developing a specification for the design of cold-formed steel, it became clear that the codes and standards would be at the frontline to eliminate the trade barrier and promote the usage in steel construction. Finite Element Analysis (FEA) is one of the reliable tools for obtaining quite accurate results in a reasonable amount of time. Perhaps this would be an opportune time to create a link between specifications and computer packages, with rigorous analysis using approved packages specified as complying with the design code.

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