Study on Strength and Behaviour of Cold-Formed Steel Built-up Columns

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Keywords: Cold-Formed Steel, Compression Elements, Built-Up Columns, Open and Closed Sections

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 code specifications. Many codes failed to estimate the section's ultimate capacity accurately as there are no specific design equations.

Introduction

CFS members are used in industries, office buildings (low-rise), houses with steel frames, etc., [1, 2]. 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 [3-5] that show greater load carrying capacity than individuals [6-8]. Lacings and battens are used to assemble them [9]. 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 [2, 5, 10-12]. These elements show unique behaviors of buckling. The demerit is that specific provisions in codes are not available for designing a built-up member [6]. 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.

Closed built-up sections

Fig.1 shows the typical built-up closed sections.

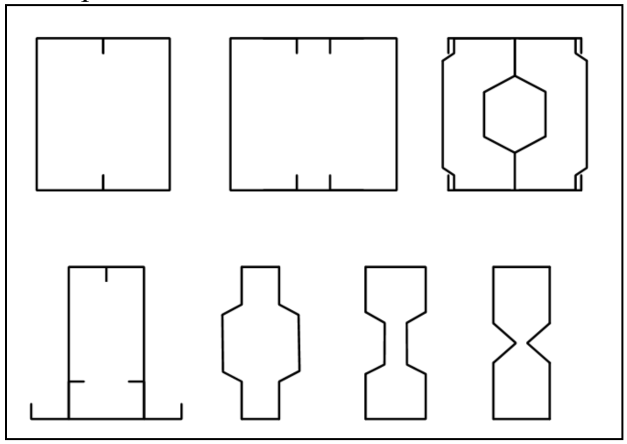

Figure 1. Built-up closed sections

Usage of web stiffeners

Research works employing stiffeners in the web of a section were presented in [2, 4, 13-16]. Web stiffeners are generally said to give better resistance to local buckling [1, 2]. Young and Chen [2], 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 [4] 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 [13] 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 [14].

Two lipped C-sections connected face-to-face

Closed sections were assembled by welding in [10, 17], screws in [3], battens in [18]. There were only scanty research works in columns with welding connectivity. Whittle and Ramseyer [17] 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. [3], conducting investigations on the capacity of closed columns of various lengths with screw connection through tests and on comparing with Eurocode specifications (EC3), observed an 80% difference in load values. Kherbouche and Megnounif [18] 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.

Assembling four angle sections
Four angle sections were connected by battens [19-21] and lacings [12, 22, 23] to form a closed section and investigations were carried out. Pin-ended laced columns with bolt connectivity were tested under monotonic axial loading experimentally. A parametric study was further carried out using ABAQUS software. Limitations on parameter varied were suggested and also as the effect of slenderness ratio of lacing was not included in codes, NAS and EC3 were not appropriate [22, 23]. Similarly, Anbarasu and Dar [12] investigated battened four lipped angle sections by varying the parameters like angle section's sectional compactness, global column slenderness and batten's spacing by ABAQUS. New design provisions were put forward as the current rules were not satisfactory. Yet another research on closed section with four lipped angles connected by battens was presented in [20]. It was clear that the capacity of the section increased with the lower slenderness of the chord. The design expressions proposed by EI Aghoury et al. (2013) gave safe results but not the provisions of NAS and EC3.

Connecting C and U-shaped elements
Single C and U-shaped sections were connected by screws and investigated in [24-30]. Various parameters on multi-limbs stub columns were analyzed by ANSYS. Reduction in the maximum width-thickness ratio increased the capacity of columns. Recently, single box [28] and double box [27] columns were investigated compressing concentrically and eccentrically by experimental, numerical and theoretical means. Some other recent research on box columns was to estimate the fire-resistant capacity [29, 30]. Findings on the effect of connector spacing were given in [25, 26].

Assemblage of single innovative sections
There were innovative columns investigated in [5, 11, 31, 32]. Georgieva et al. [11] compared DSM predictions with experimental buckling capacities of two sections formed by Σ, Z, channel and track profiles using CUFSM software. If the DSM was added with the global-distortional buckling interaction provision, DSM could be easily used. New design expression was provided in [5] to predict the CFS built-up lipped sigma channel's strength. Usually, local buckling stress and torsional rigidity were seen to get increased with closed sections formed by sigma shape.

Open built-up sections
Fig.2 shows the typical built-up open sections.

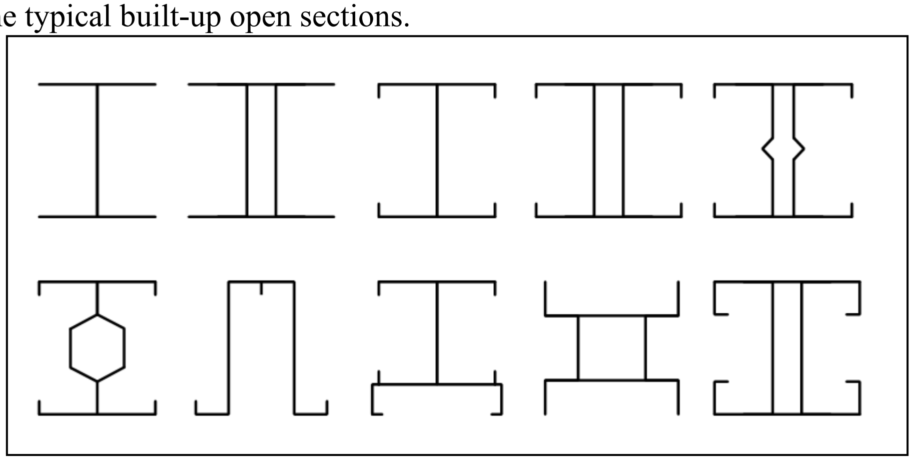

Figure 2. Built-up open sections

Lipped channels connected back-to-back

Investigations on back-to-back connectivity in lipped channels were carried out in [3, 33-41]. Thirty-two columns with screw connectivity were experimentally investigated in [33]. Five stub columns were tested experimentally under axial compression in [40] and numerically by LUSAS software in [41]. With EWM, better results were obtained than DSM. Local buckling was the major type of failure seen in stub columns. Muftah et al. [3] 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. [34] on doing a parametric study, found AISI's prediction was safe for medium and long but for not short columns. Roy et al. [36] 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. [37] 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. [38] found that holes (edge-stiffened) in the built-up open section rendered an increase in axial strength.

Lipped channels connected back-to-back with gap

Using this section, researches were done in [6, 7, 18, 42-46]. Roy et al. [42] found 53% appropriateness in AISI and AS/NZS strength predictions of columns with link-channels at intermediate. Kherbouche and Megnounif [18], with battened open columns, numerically studied and compared with the results of EC3, a new approach using DSM and AISI. Then, Vijayanand and Anbarasu [7] 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 study and the adequacy of EC3 and AISI specifications were checked [45]. Followingly, Anbarasu and Adil Dar [43] found that the resistance to local buckling could be achieved by incorporating spacers in open built-up columns. Recently, Muthuraman et al. [44] found safe predictions of DSM with the battened columns having a slenderness ratio less than 60.

Plain channels connected back-to-back

Experimental work was done in cold-formed stainless steel columns without any interval in between in [47]. Researches falling under the sections with intervals inbetween were presented in [25, 26, 48, 49]. NAS, AS/NZS and EC3 predictions were found unsafe for the battened columns that had locally buckled [48, 49]. Recently, two channels were connected by plates and an investigation was done in [25, 26]. It was revealed that the spacing of connectors and the component's interaction with one another influenced the column's ultimate capacity.

Employing stiffeners

Stiffeners were employed in built-up sections and investigated in [9, 14, 34, 50-52]. Anbarasu et al. [9] connected two lipped channels with web stiffeners using battens, studied 30 models and came up with the conclusion that there was no sight of local buckling due to stiffeners. A simple expression for the design was proposed then. In [50], with 40 hinged-hinged built-up sigma columns, a parametric study was conducted. AISI was found to give results conservatively of about 5% for long, medium and short columns. Beulah and Ashvini [14] found an increase in the axial capacity of the back-to-back connected channel column with stiffeners at both webs and flanges. Laim et al. [51] came up with the fact that the fire resistance for built-up sections was greater when compared to single sections. This was evident from the study on fire resistance behavior of edge and web stiffened sigma single and built-up open columns. There was also the incapability of existing methods to find the behavior of such columns under fire. Deepak et al. [52] found an increase in load carrying capacity of lipped back-to-back connected columns with stiffeners on comparing with seven other configurations.

Assemblage of single innovative sections

Innovative sections were investigated in [11, 25, 26, 53-55]. Georgieva et al. [11], comprising Σ, channel and track profiles formed a closed section and the suitability of DSM was assessed with the experimental results. Yet another research in this category was on bolted double Z members with rolled spacers in between [53]. Single Z profiles generally have low torsional rigidity and so the built up sections made of it could overcome this demerit. For such a section, there was a proposal of an approach based on DSM which seemed to be appealing. Liu and Zhou [54] tested 18 T-sections (long, intermediate and stub columns) formed by three lipped channels with screw connectivity and the study was conducted by varying parameters with 90 models. Anbarasu and Venkatesan [55] proposed an equation for accurate prediction of strength for an open section formed by four U-shaped sections. Recently, two different geometries formed by plain and lipped channels connected by screw were experimentally investigated [25, 26].

Conclusions

A clear sum up was given on the research works in CFS built-up sections. Each section was uniquely designed to carry the loads. Higher resistance to torsion was shown by CFS built-up closed sections. Stiffeners have shown good control against the local instabilities of the section. There was also an improvement of load carrying capacity with stiffeners. It was clear from the review that due importance should be given to various factors like connector spacing, number of connectors, slenderness of battens, etc., as they may affect the ultimate capacity of the column. 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.

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