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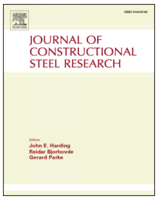

Resistance of cold-formed built-up stainless steel columns – Part I: Experiment

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ABSTRACT

Nowadays, the codified procedure for design of centrically compressed cold-formed stainless steel (CFSS) built-up members is absent in Europe. Besides, there are no published research information and experimental data in this structural area. This paper focuses on a comprehensive experimental investigation of closely spaced CFSS built-up columns and addresses their flexural buckling capacity about the minor principal axis. Two series with a total of 36 built-up members were assembled, each formed by two discontinuously and directly connected channel chords oriented back-to-back to form an I-section. The chords were press-braked from flat strips of austenitic stainless steel EN 1.4301 as non-slender channel sections. The chords were uniformly interconnected by bolts or by welds. To identify the effects of interconnection spacing on chords' composite action, the overall and chord slenderness ratios were varied. Material properties, cross-section response and initial imperfections were quantified before testing. As a result, the overall flexural buckling without any local-overall interactions was observed as the dominant failure mode. All findings were used in the accompanying paper [1] to establish qualitative data base through numerical simulations of flexural buckling tests. Additionally, a quantitative accuracy assessment of the design methods for carbon steel built-up columns provided in Eurocode and American Specification was reported on the basis of their ability to predict flexural buckling resistances of the tested columns. This enabled numerical parametric studies and proposing design rules for CFSS built-up columns with non-slender sections that capture interconnection shear stiffness, overall and chord slenderness ratio and strain hardening effects.

1. Introduction

Built-up members have a traditional application in civil engineering for compressed structural elements, mostly as columns and members of lattice structures. They are formed from two or more parallel chords discontinuously interconnected by bracing members: lacings or battens. The built-up members with chords in contact or closely spaced and connected through packing plates by bolts or welds represent the simplest structural solution for this element type. The chord members are usually channels or angles which may be differently positioned to form a built-up cross-section. Chords are always attached at the ends, and at equidistant spacing along the built-up members. The complex structural behaviour of a built-up column is strongly associated with the discreteness of its cross-section and absence of a solid web element. The relative interaction between the contact areas of the chords reduces the shear stiffness of the built-up column and leads to a decrease of its ultimate buckling resistance. The effects of shear on flexural deflection may significantly vary depending on the structural solution of interconnections and their number along the chords. In contrast to welded interconnections, the bolt-to-hole clearance in bolted interconnections usually results in a more substantial longitudinal slip between the chords and, consequently, causes additional flexibility of the built-up column. Thus, the longitudinal shear in built-up columns has to be evaluated and accounted for in the development of a design procedure. Additionally, the interconnections should be designed so as to provide composite action of individual chords, to resist shear forces which occur during buckling and slip between the contact areas of chords.

The existing European [2] and American standards [3,4] have distinctive analytical methods for the design of compressed carbon steel closely spaced built-up members. The European analytical method given in Clause 6.4 of EN 1993-1-1 [2] replaces the discrete structure of a built-up column with an equivalent continuous column, taking into account second order effects and smearing shear stiffness through properties of the bracing members. This method defines strict rules to restrict the influence of shear deformations between the connected chords: it may be applied only to uniform built-up compressed members with hinged ends providing that the number of regular spacing

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(modules) between restraints of chords is not smaller than three. In general, a closely spaced built-up column may be designed by using an analogy with a battened column. According to Clause 6.4.4 [2], this structural element can be alternatively designed against flexural buckling as a single integral member ignoring the effect of shear stiffness, if the limitations regarding the maximum spacing between interconnections are met. Maximum spacing between interconnections of closely spaced built-up columns formed by back-to-back channels is $15i_{\min}$, where $i_{\min}$ is the minimum radius of gyration of one chord member. These limitations are prescribed in order to avoid premature failure of individual chords. On the other hand, any explicit recommendation for the design of cold-formed steel (CFS) built-up columns is not stated in EN 1993-1-3 [5]. Conversely, both American specifications: AISI-S100-16 [3] for CFS structural members and ANSI/AISC 360-16 [4] for structural steel buildings, adopt modification of the general method for the design of axially compressed solid (single) columns by introducing empirical equations to define the equivalent overall slenderness ratio of built-up members, instead of the geometrical one. In addition, the following limitations should be satisfied: according to AISI-S100-16 [3] the chord slenderness ratio, based on the distance between interconnections and a minimum radius of gyration of individual chords, should not exceed 50% of the overall slenderness ratio of the built-up member; according to ANSI/AISC 360-16 [4] the chord slenderness ratio should not exceed 75% of the overall slenderness ratio of the built-up member. It should be noted that this approach assumes only flexural buckling in the prediction of column compressive capacity, and does not reflect the influence of the chord slenderness ratio or interconnection design solution on other stability modes including local buckling and cross-section distortion that are characteristic of CFS columns [6]. Unlike Eurocode [2], both American specifications [3,4] state additional requirements regarding the specific type of interconnections at the column's ends. The end interconnections should be welded having a length not less than the maximum dimension of the column's section or fastened where fasteners are at a longitudinal spacing of four diameters apart or less and for a distance equal to 1.5 times the maximum dimension of the column's section. ANSI/AISC 360-16 [4] notes that the end interconnections should be welded or connected by preloaded bolts. However, it can be emphasized that both European [2] and American specifications [3,4] are fundamentally based on the same analytical criterion proposed by Bleich [7].

The part of Eurocode 3 for the design of stainless steel structural elements EN 1993-1-4 [8] does not provide explicit rules for calculating the resistance of stainless steel closely spaced built-up members. In Clause 5.4.1 [8], it is stated that the design provisions for carbon steel columns given in EN 1993-1-1 [2] may be applied to stainless steels columns. However, the sharp distinctions between mechanical properties of these two metals require a modification of the carbon steel design rules for their use in stainless steel structural practice. Although numerous research of the behaviour of differently loaded stainless steel structural elements has been recently performed, none of them aimed at the flexural response of compressed built-up members. The majority of recent experimental tests were carried out on cold-formed stainless steel (CFSS) hollow sections with an emphasis on austenitic, ferritic and lean duplex alloys, while the available experimental data for columns with open cross-sections are fewer: Johnson and Winter [9]; Rhodes, Macdonald and McNiff [10]; Bredenkamp and Van den Berg [11]; Talja [12] and Stangenberg [13]; Lecce and Rasmussen [14]; Becque and Rasmussen [15,16]; Yang et al. [17,18]; Gardner et al. [19]. These researches provided a wealth of new reliable data and contributed to the improvement of existing codified methods for the design of compressed stainless steel members.

The theoretical and experimental findings gained on carbon steel built-up members represent important benchmarks for a better understanding of the structural behaviour of stainless steel built-up members. In the middle of the last century, Bleich [7] developed an analytical criterion to determine the modified slenderness ratio of pin-ended battened members. This criterion is based on the condition that the strain energy due to deflection is equal to the work done by the external axial compression load. The elastic strain energy of the deformed battened member consists of the energy due to overall bending of a built-up member and the energy due to the local bending of individual chords. Zandonini [20] experimentally tested two series of compressed closely spaced built-up members consisting of two back-to-back channels with welded and snug-tight bolted interconnections. The end connections of all specimens were constructed by means of preloaded bolts. Astaneh et al. [21] performed an experiment on two back-to-back angles with welded, snug-tight and preloaded bolted interconnections. Using the experimental data from the aforementioned investigations [20,21] as a basis, Zahn and Haaijer [22] recognized the impact of interconnection stiffness on the overall behaviour of closely spaced built-up columns and developed two different empirical formulations of the modified slenderness ratio for columns with snug-tight bolted interconnections and with welded or preloaded bolted interconnections. The developed empirical equations were introduced into the

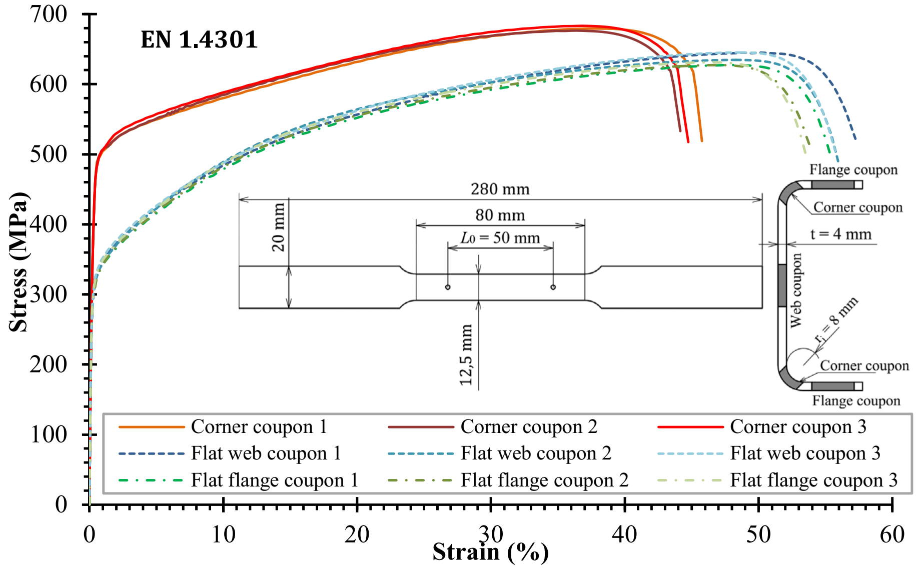

Fig. 1. Tensile test results: engineering stress-strain curves.