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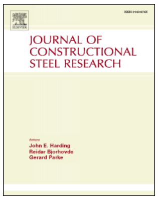

Experiments on the global buckling and collapse of built-up cold-formed steel columns

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ABSTRACT

This paper reports on experiments addressing the buckling and collapse behavior of back-to-back lipped channel built-up cold-formed steel (CFS) columns assembled using 16 different CFS lipped channel sizes. The lipped channel sections are connected at the web using a pair of self-drilling screw fasteners at a specified spacing along the column length of 1.83 m (6 ft). These experiments aim to quantify the effect of two web fastener layouts on composite action for each section size, study member end fixity, observe buckling and collapse behavior, and provide benchmarks for design that includes specific considerations for thin-walled member buckling. A total of 32 monotonic, displacement-controlled, concentric compression tests are completed with up to 17 position transducers monitoring displacements at key locations. All tests are conducted with the built-up member seated in CFS tracks, as would be found in practice. Local–global interaction is shown to be a prevalent failure mode, and the stud-to-track end condition is determined to be semi-rigid, but generally closer to a fixed condition. End rigidities are estimated using a Southwell approach. Rational design approaches extending the application of the Direct Strength Method (DSM) and employing current state-of-the-art numerical modeling techniques are proposed and validated with test data. In addition, the development of definitive design recommendations that help reduce the complexity of fastener designs and incorporates the DSM framework when predicting built-up member strength is underway.

1. Introduction

1.1. Background and current design

Cold-formed steel (CFS) framing provides a structural system that consists of repetitively placed columns (studs) or beams (joists) to frame out the building. When higher local rigidity, or axial or flexural capacity is required, such as in shear wall chords or around openings in headers or jambs, multiple members are connected together to form a built-up CFS member. The back-to-back lipped channel, or “I” section is the most traditional built-up CFS section as it is easy to assemble and produces a doubly symmetric cross section. Individual CFS studs are placed back-to-back and fastened together using self-drilling screws, welds, or bolts. Depending on the detail composite action can be developed via these inter-connections, giving axial or bending capacities for the built-up member that are ideally greater than the sum of the capacities of the individual sections, when global buckling controls.

Current design of built-up CFS columns is highly simplified. The maximum fastener spacing for the inter-connection between the webs is determined by ensuring that flexural buckling of the individual studs between fasteners will not occur prior to flexural buckling of the built-up section in both the Australia/New Zealand 4600 Standard [1] and in North America with AISI S100 [2]. In addition, AISI S100 Section I1.2 requires the calculation of axial capacity using a modified slenderness ratio approach, which was adopted from AISC 360 [3]. The principle is that the individual studs in a built-up section cannot be assumed to be fully connected such that shear forces are continuously transferred from one stud to another. The modified slenderness, which is a function of the slenderness of the fully built-up section and the fastener spacing, assumes a loss of total shear rigidity at the fasteners, but considers only minor-axis flexural buckling in the estimation of elastic buckling stress, which is calculated using the Euler buckling formula. This method increases the slenderness ratio of the built-up section to reduce its flexural buckling capacity. However, the modified slenderness approach cannot predict the effects of fastener layouts on torsional, flexural-torsional, local, or distortional buckling modes. As is typical in design, it is assumed that the back-to-back fasteners are always employed in pairs. In addition, AISI S100 also requires a

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prescriptive fastener grouping: an array of screw pairs that must be longitudinally spaced no more than 4 diameters apart and for a distance equal to 1.5 times the maximum width of the built-up section along the length, at either end of the column. This grouping is henceforth denoted as an end fastener group (EFG), and their function is to reduce the relative slip between two connected studs as they sustain flexural buckling; this reduction of slip boosts composite action and hence, the buckling load of a column. The impact of the EFG on the modified slenderness is not treated directly. For a complete column design, nominal strengths for modes other than minor-axis flexure are required to be determined using either the Effective Width Method (EWM) or the Direct Strength Method (DSM) on either the individual sections or the built-up cross section, although guidelines in the specifications [1, 2, 4, 5] are not clear.

Recent research on built-up CFS columns has worked to address limitations in current design specifications [1, 2, 5]. Tests on back-to-back lipped channels showed AISI's modified slenderness approach is conservative and the importance of end conditions were highlighted in Stone and LaBoube [6]. More complex CFS built-up columns including combinations of Zee, sigma, and track sections were tested, studied by numerical analyses, and a DSM design approach including bucking mode interaction was offered in Georgieva et al. [7–10]. Back-to-back built-up CFS sigma sections were tested and simplified models developed for predicting the partially composite buckling response in Zhang and Young [11]. Tests on back-to-back and toe-to-toe built-up sections compared to AISI [2] and Eurocode [5] were shown to agree best when fixed ends were assumed in the comparisons [12]. Tests on built-up CFS sections with intermediate stiffeners focusing on local and distortional buckling demonstrated that using only single section properties (hence, employing a non-composite assumption) were adequate for design [13]. Others have also explored modifications to DSM for built-up sections [14], although the effect of end conditions and fastener layouts were not explicitly addressed in the new design approach. Other testing has shown that if individual sections are longer relative to others within the same built-up section, the longer studs can attract load earlier and buckle before the other studs, reducing overall column capacity [15]. EFG are intended to attenuate this effect, but the authors do not comment on their effectiveness.

The experimental work and design method developments presented herein follow a previous phase of sheathed and bare built-up CFS column tests reported in Fratamico et al. [16]. The goal here is to experimentally assess whether current design methods are adequate for an all-steel design of non-perforated and un-braced built-up CFS columns buckling mostly in flexure. True end conditions are recreated in the lab by installing stud ends in tracks, thereby also allowing for a quantitative assessment of column end rigidities which heavily influence global buckling capacities. These tests are part of an ongoing effort to understand and quantify flexural, torsional, and shear rigidities of built-up CFS sections. The focus in this paper is to demonstrate the effects of column end rigidity, web fastener layout, and cross section size on the achievable composite action, interactive buckling modes, and collapse behavior of back-to-back CFS columns. Test results will also augment benchmarks for the assessment of appropriate design methods.

2. Design of experiments

2.1. Test setup

All 32 test specimens are composed of back-to-back lipped channel sections (henceforth referred to as studs) with screw pairs connecting the channels through the webs as shown in Fig. 1. Monotonic, displacement-controlled, concentric compression loading was applied to each column using a 445 kN (100 kip) MTS universal testing rig which has a servo-controlled hydraulic actuator. The load rate did not exceed 0.76 mm/min (0.03 in/min).

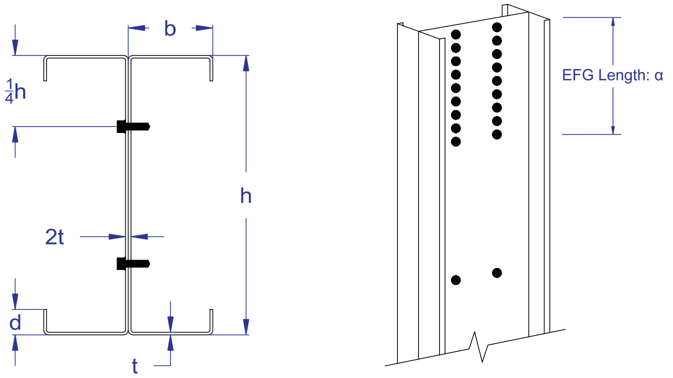

Fig. 1. The back-to-back section with web screws shown (left) and placement of EFGs (right).

Fig. 2 shows the MTS rig setup used for all tests. Studs were installed within tracks, with stud flanges screwed to track lips, and tracks were placed on fixed platens made of 12.7 mm (0.5 in.) thick low carbon steel. Studs were installed parallel to each other with a maximum relative inclination error of 0.05° from the horizontal. Fig. 2 (section B-B′) shows the placement of the specimens in the rig. Tracks were positioned and held in place on the platens using clamps prior to testing and in the absence of applied loads. Eccentricity and out-of-plumbness were recorded for each specimen, and maintained to be less than 0.64 mm (0.025 in.). A load cell installed at the top crosshead measured axial force and a built-in LVDT measured applied axial displacements. A LabVIEW program coordinated all data acquisition and National Instruments hardware was used to establish a control loop.

To track specimen deformations, 17 position transducers (PTs) were installed in the test setup. Lateral bi-planar displacements and rotation of the cross section at mid-height were tracked throughout the tests using 11 PTs at mid-height as shown in section A-A′ of Fig. 2. To monitor stud engagement to the track during the tests, a PT was installed between the column web and track web at the top and again at the bottom. In addition, 1 PT was installed on the top and bottom tracks to record out-of-plane deformations of the webs due to local buckling or localized failures at the column ends. Lastly, for some specimens with wider flange widths of 41.3 mm (1.625 in.), a PT was placed near the top and bottom of the column to monitor the relative slip of the channel webs seated in the track at the ends. The setup for these PTs is shown in Fig. 3. The PTs were firmly attached with magnets, but they did not disrupt cross section deformations during the tests.

2.2. Specimen selection and assembly

A total of 16 lipped channel section types were selected based on the capacity to include a wide range of global slenderness and cross section shapes commonly used for columns in CFS structures. These section types are listed in the test matrix in the following section and have a nominal steel thickness ranging from 0.84 mm (33 mil) to 1.72 mm (68 mil). Nominal web depths range from 63.5 mm (2.5 in.) to 152 mm (6 in.). Two nominal flange widths are chosen: 34.9 mm (1.375 in.) and 41.3 mm (1.625 in.), with lip lengths specified according to flange widths. All columns were unsheathed and tested at a length of 1.83 m (6 ft). Although this is shorter than the typical 2.44 m (8 ft) stud length in residential construction, the specimens are still long enough to mobilize the global buckling mode of failure.

The lipped channel sections were fastened together and to their corresponding track sections with Simpson #10 self-drilling screws for sections with plate thicknesses of 1.37 mm (54 mil) and 1.72 mm