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Experimental investigation of cold-formed steel built-up closed section columns with web stiffeners

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ABSTRACT

This paper presents an experimental investigation conducted on cold-formed steel built-up closed section columns with web stiffeners. To fabricate a built-up closed section, the single open sections were formed by brake press operation with high strength steel plate of thickness of 0.48 and 1.0 mm, then two identical sections were connected together face-to-face by self-tapping screws. After the measurements of material properties and the initial geometric imperfections were made, the built-up closed section specimens with inward or outward stiffeners at the web were tested between fixed-end boundary conditions with various column lengths ranging from 300 to 3200 mm. The tested specimens were failed by local buckling and interaction between local and flexural buckling. The ultimate strengths of the specimens were used to compare with the column strengths predicted using direct strength method, which is adopted in the North American Specification and Australian/New Zealand Standard for cold-formed steel structures. In addition, a reliability analysis was performed for this design method to access its reliability with cold-formed steel built-up closed section compression members. The results show that the direct strength method is applicable for the design calculation of cold-formed steel built-up closed section compression members with web stiffeners.

1. Introduction

Cold-formed steel members have a wide range of applications in building structures due to the high strength-to-weight ratio, recyclable nature and relatively high compatibility with other materials [1]. The structural members are normally formed by plain steel sheets using the manufacturing processes of cold-rolling or brake-pressing, which enable the steel sheets to achieve any desirable sections such as channel section, *Z*-section, hat section and other types of single open sections. Connecting two or more single sections together, referred to as a built-up section, is a favorable choice of compression member in cold-formed steel construction, where it is expected to achieve a higher loading capacity than a single section. This has led to a growing research interest in cross-sectional design of built-up sections, and subsequently the difficulties in design calculations caused by their complex configurations and connecting methods, such as self-tapping screws, bolts and welds. However, experimental studies of built-up sections are limited comparing with comprehensive research on cold-formed steel single section compression members [2–9].

Stone and LaBoube [10], Whittle and Ramseyer [11], Reyes and Guzman [12] and Lu et al. [13] studied the built-up sections fabricated with channel sections or lipped channel sections. Georgieva et al. [14] investigated the performance of bolt- connected built-up open sections formed by two identical lipped *Z*-shaped members, and the behaviour of built-up battened columns was explored experimental and theoretically by Dabaon et al. [15,16]. Experiments on multi-limb built-up sections were also conducted by Liao et al. [17] and Liu and Zhou [18]. Connecting two or more single sections is expected to obtain a high load bearing capacity, however a built-up section column may fail far before yielding; this can be attributed to the local and distortional buckling at the web and the flange caused by the high width-to-thickness ratios at the corresponding portion of the specimens. This early failure can be improved partly by the introduction of longitudinal stiffeners. Limited literature has reported the effect of web stiffeners, for example Young and Chen [19] for built-up closed sections and Zhang and Young [20] for built-up open sections. In addition, the direct strength method (DSM) has been an alternative design method for cold-formed steel members in the North American Specification (AISI S100) [21] and Australian/New Zealand Standard (AS/NZS 4600) [22], but the DSM is not applicable for built-up sections.

The purposes of this study were to provide test data to facilitate the design of cold-formed steel built-up closed sections and to evaluate the suitability of the direct strength method. A series of tests was conducted on cold-formed steel built-up closed sections compressed between fixed ends. The test program consisted of 26 fixed-end column

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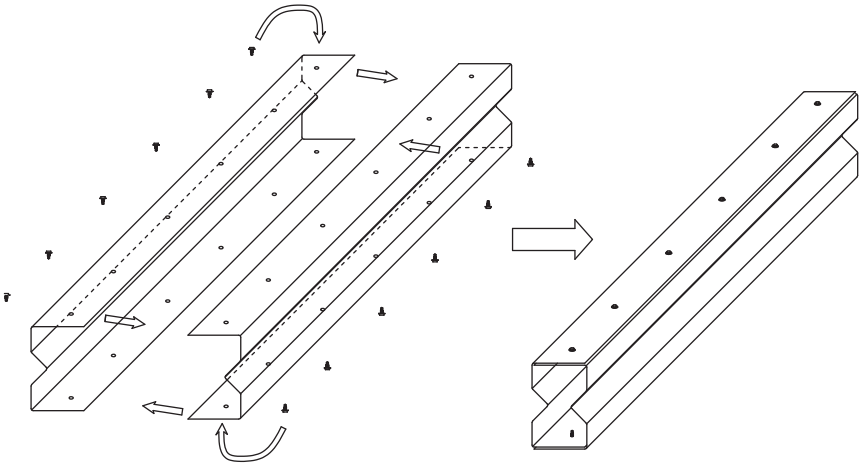
specimens, in which the lengths of the columns were 300, 800, 1400, 2000, 2600 and 3200 mm. A comparison was conducted between the ultimate strengths obtained from the tested specimens and the design strengths calculated using the direct strength method in the North American Specification (AISI S100) [21] and Australian/New Zealand Standard (AS/NZS 4600) [22]. Finally, design recommendations to cold-formed steel built-up closed section columns with web stiffeners are presented in this paper, and the reliability of the direct strength method for this kind of compression members is evaluated using reliability analysis.

2. Experimental investigation

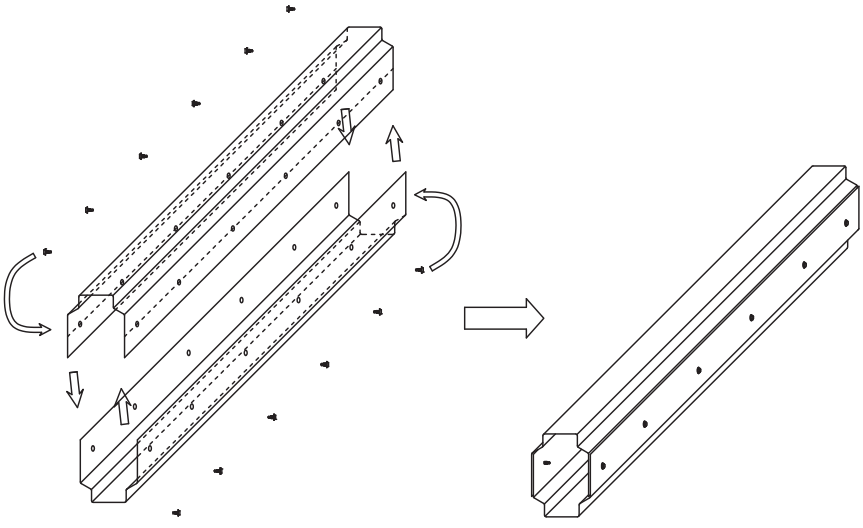
2.1. Test specimens

Two types of built-up closed sections, one with inward and the other with outward stiffeners at the web, were tested in this study. Before being connected with self-tapping screws, the single open sections were formed by using steel plate sheets with the brake press operation. In this test, the zinc-coated steel sheets were selected to fulfill the requirements of the Australian Standard AS 1397 [23]. The thicknesses of the pre-selected steel sheets were 0.48 and 1.0 mm, with nominal yield stresses of 550 and 500 MPa, respectively. Two single sections were assembly to form the built-up closed sections, as shown in Fig. 1. One of the fabricated built-up closed sections had inward stiffeners at the web and the other had outward stiffeners, as shown in Figs. 2 and 3, labelled as V-section and O-section, respectively. Each column specimen was cut to a pre-specified length and milled flat at both ends to be welded with 20 mm thick steel end plates. This step ensured the full contact between the steel end plates and the end bearings, thus a uniform axial load could be applied to the column specimen.

Two single sections were connected together along the longitudinal direction by self-tapping screws, and the nominal screw spacing was 100 mm. Smaller screw spacing was used near the ends of the test specimens to prevent any undesirable slip between the two components of a built-up section under axial compression load. For stub columns with length of 300 mm, the screws at both ends were 50 mm away from the steel end plate, whereas the corresponding distance for columns with lengths of 800, 1400, 2000, 2600 and 3200 mm was 20 mm. The screw arrangement is detailed in Fig. 4; the nominal diameter of the screw was 4.8 mm with screw length of 12.5 mm.



(a) V-section



(b) O-section

Fig. 1. Assembly of built-up closed sections.