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Numerical investigation and design of cold-formed steel built-up open section columns with longitudinal stiffeners

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A R T I C L E I N F O

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A B S T R A C T

A built-up I-section with longitudinal stiffeners is expected to have better performance to resist against local and distortional buckling compared to conventional built-up I-section by simply connecting two plain channels back-to-back. This paper presents a non-linear finite element analysis to investigate the behaviour of cold-formed steel built-up open section columns with edge and web stiffeners. A finite element model was firstly developed and verified against tests of cold-formed steel built-up compression members, in which the initial geometric imperfections and material properties of the test specimens were included. Secondly, the verified finite element model was used for an extensive parametric study of fixed-ended cold-formed steel built-up open section columns. The parametric study was designed to investigate the effect of edge and web stiffeners in the built-up open sections. The finite element results together with the test results were compared with the design predictions calculated from the current design rules in the North American Specification and the Australian/New Zealand Standard. Furthermore, design rules of the current direct strength method were modified. It is shown that the design strengths predicted by the modified direct strength method are generally in good agreement with the ultimate loads of the built-up open section columns. In addition, the current design rules and the modified direct strength method were evaluated by reliability analysis.

1. Introduction

Cold-formed steel built-up sections are being used as structural members in construction industry. Stone and LaBoube [1], Whittle and Ramseyer [2] and Reyes and Guzman [3] investigated the cold-formed steel built-up compression members. The investigations focused on typical built-up sections that were formed by lipped and plain channel sections without web stiffeners. Due to the high width-to-thickness ratio of the web, built-up compression members are easily failed by local buckling. A built-up section having edge and web stiffeners is expected to have better performance to resist against local and distortional buckling compared to sections without stiffeners. Young and Chen [4] investigated the cold-formed steel built-up closed sections with web stiffeners compression members and Zhang and Young [5] conducted a series of column tests on cold-formed steel built-up open sections with edge and web stiffeners. However, limited research has been reported on such kinds of structural members. Therefore, it is necessary to investigate the structural behaviour of cold-formed steel built-up compression members.

Finite element analysis (FEA) is a powerful tool for investigating the strength and complex behaviour of cold-formed steel structural members. Compared with an experimental investigation, a parametric study performed by FEA has the advantages of higher efficiency and lower cost. Finite element analysis has been used successfully for cold-formed steel open section columns by Yan and Young [6], Young [7] and Young and Ellobody [8]. The behaviour of lipped channel columns failed by interaction of local–distortional-overall buckling was numerically investigated by Dinis et al. [9]. It should be noted that an accurate and reliable finite element model (FEM) is the key of parametric studies, in which the geometric and material nonlinearities of the specimen should be included in the model. Therefore, a FEM was developed and verified against experimental results of cold-formed steel built-up open section compression members with longitudinal stiffeners in this study.

The purpose of this study is firstly to investigate the behaviour of cold-formed steel built-up open sections with edge and web stiffeners subjected to axial compression. An accurate and reliable FEM was developed and used for an extensive parametric study. Six series of built-up open section compression members, having different dimension of edge and web stiffeners, were performed in the parametric study to further examine the complex behaviour of built-up open section columns. The effect of edge and web stiffeners

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Notation

A_g	gross cross-sectional area
b_f	width of flange
b_l	width of lip
b_w	width of web
C_p	correction factor in reliability analysis
E	Young's modulus
e	axial shortening
F_m	mean value of fabrication factor
f_{od}	elastic distortional buckling stress of cross section
f_{ol}	elastic local buckling stress of cross section
f_y	yield stress is taken as the static 0.2% proof stress
K	effective length factor
L	length of column specimen
l^*	side length of artificial stiffener
M_m	mean value of material factor
P	axial load
P_{crd}	critical elastic distortional column buckling load
P_{cre}	critical elastic column buckling load in flexural buckling
P_{crl}	critical elastic local column buckling load
$P_{DSM\text{-}pro1}$	nominal axial strength calculated using the current direct strength method and rational design calculation for elastic buckling stress
$P_{DSM\text{-}pro2}$	nominal axial strength calculated using the modified direct strength method and rational design calculation for elastic buckling stress
$P_{DSM\text{-}s}$	nominal axial strength calculated using the direct strength method that assumes the built-up section as two independent single sections
$P_{DSM\text{-}2t}$	nominal axial strength calculated using the direct strength method that assumes the thickness of contact area to be 2t
P_{EXP}	ultimate load obtained by experiment
P_{FEA}	ultimate load obtained by finite element analysis
P_m	mean value of tested-to-predicted load ratios
P_n	nominal axial strength
P_{nd}	nominal axial strength for distortional buckling
P_{ne}	nominal axial strength for flexural buckling
P_{nl}	nominal axial strength for local buckling
P_u	column strength
P_y	yield strength
r	radius of gyration of full unreduced cross section about axis of buckling
r_i	inside corner radius at flanges of specimen
t	nominal plate thickness of specimen
V_F	coefficient of variation of fabrication factor
V_M	coefficient of variation of material factor
V_P	coefficient of variation of tested-to-predicted load ratios
w_1,w_2, w_3	dimensions of web stiffeners
β	reliability index (safety index)
β_1	reliability index determined using ϕ_{c1}
β_2	reliability index determined using ϕ_{c2}
ε	engineering strain
ε_f	elongation (tensile strain) after fracture
ε_{true}^{pl}	true plastic strain;
θ	angle between the inclined web stiffener and vertical axis
ϕ_c	resistance (capacity) factor for compression member
ϕ_{c1}	resistance (capacity) factor for prequalified columns in the current DSM
ϕ_{c2}	resistance (capacity) factor for other columns in the current DSM
λ_c, λ_d, λ_l	non-dimensional slenderness used in the direct strength method
σ	engineering stress
$\sigma_{0.2}$	static 0.2% tensile proof stress
σ_{true}	true stress
σ_u	static ultimate tensile strength

in the cold-formed steel built-up open sections was investigated. Secondly, the direct strength method was used for the design calculation of built-up open sections. Thirdly, the current direct strength method was modified for cold-formed steel built-up open section columns with longitudinal stiffeners. Finally, reliability analysis was conducted to evaluate the reliability of the current and modified design rules.

2. Summary of experimental investigation

2.1. General

The test programme on cold-formed steel built-up open section columns with edge and web stiffeners has been reported by Zhang and Young [5]. The columns were tested between fixed ends with different column lengths ranged from 300 to 3200 mm. Two identical lipped channel sections with web stiffeners were connected back-to-back to form a built-up open section by using self-tapping screws, as shown in Fig. 1. The nominal dimensions of the cross-section are listed in Table 1 and the measured cross-section dimensions are detailed in Zhang and Young [5]. The nominal screw spacing was 100 mm. The nominal plate thicknesses (t) of the specimens were 0.48, 1.0 and 1.2 mm. The test specimens were divided into three series and labelled as IT0.48, IT1.0 and IT1.2 accordingly. The specimens were labelled such that the plate thickness and the specimen length can be identified clearly from the label. For example, the label "IT1.0L2000R" defines the specimen as follows, the first letter indicates the cross-section shape where the letter "I" refers to built-up I-shaped section. The second letter "*T*" refers to the nominal plate thickness and follows by the digits showing the plate thickness of 1.0 mm. The third letter "*L*" refers to the nominal length of the specimen and follows by the digits showing the length of the column. If a specimen was repeated, the letter "*R*" is included at the end of the label. The

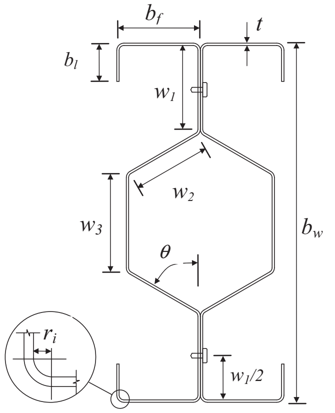

Fig. 1. Definition of symbols for built-up open sections.