Finite Element-Based Investigation on Performance of Intermediate Length Thin-Walled Columns with Lateral Stiffeners

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Abstract Distortional buckling of compression members usually comprises rotation and translation of each flange and lip about the flange-web juncture in opposite directions. The present study makes an attempt to possibly delay or prevent the distortional buckling mode by the introduction of lateral stiffeners. The stiffened channel section has been selected based on the elastic buckling analysis using CUFSM software to ensure the occurrence of distortional buckling. The test programme consisted of two pure axial compression tests under hinged–hinged end condition. A finite element model of the tested compression members was then developed and validated with the help of experimental results and also by the column test results conducted by Young and Yan (J Struct Eng 732:728–736, 2002). Geometric, material nonlinearities and initial geometric imperfection were included in the finite element model. An extensive series of parametric analyses was undertaken using the validated finite element model to investigate the effect of varying depth and many lateral stiffeners on the ultimate capacity of the columns. The details of the parametric study results are presented as charts. The lateral stiffeners effect on behaviour and strength is discussed.

Keywords Cold-formed steel · Column · Distortional buckling · Lateral stiffener · Thin-walled member

1 Introduction

Until recently, the hot-rolled steel members have been recognized as the most popular and widely used steel group, but in recent times, the use of cold-formed high strength steel members has rapidly increased. However, the structural behaviour of these thin-walled steel structures is characterized by a range of buckling modes such as local buckling, distortional buckling and global buckling. The behaviour of short compression member is well defined in the literature. The global buckling (flexural/flexural torsional) behaviour of cold-formed steel sections have been extensively studied in the past. Distortional buckling plays an important role in the use of open cold-formed steel columns. Distortional buckling occurs at intermediate length columns. Therefore, it is important to eliminate or delay these buckling problems with the introduction of lateral stiffeners intermediate length cold-formed steel column.
Takahashi [1] was the first researcher to publish a paper describing the distortional buckling mode. Hancock [2] presented a detailed study of a range of buckling modes (Local, distortional, and flexural-torsional) in a lipped-channel section. Lau and Hancock [3] provided simple analytical expressions to allow the distortional buckling stress to be calculated explicitly for any geometry of cross-section of thin-walled lipped-channel section columns. Kwon and Hancock [4] studied simple lipped channels and lipped channels with intermediate stiffener under fixed boundary conditions. They have chosen section geometry and yield strength of steel to ensure that a substantial post-buckling strength reserve occurs in a distortional mode for the test section. Davies and Jiang [5] used the generalized beam theory to analyse the individual buckling modes either separately or in selected combinations.

The distortional buckling strength of a few innovative and complex geometrical sections has been studied by Narayanan and Mahendran [9]. For intermediate length pallet rack columns, the distortional strength was studied by providing stiffeners to connect the flanges of upright sections by Talikoti and Bajoria [12]. Kut and Stachowicz [13] have experimentally and numerically studied the sheet metal forming procedure by blanking. The partly closed thin-walled steel columns were studied by Veljkovic and Johansson [14]. Kwon et. al [15] studied the buckling interaction of the channel columns. Shi et. al [16] conducted tests and finite element analysis on the local buckling of 420 MPa steel equal angle columns under axial compression. Theofanous and Gardner [17] studied the effect of element’s interaction and material nonlinearity on the ultimate capacity of stainless steel cross-sections. Anbarasu and Sukumar [18] studied the effect of stiffener ties in the intermediate length cold-formed steel (CFS) columns. Anbarasu and Sukumar [19] studied the connectors interaction on the behaviour and ultimate strength of stiffened channel columns.

The review of these papers suggests that buckling studies of cold-formed steel column with lateral stiffeners are limited. Therefore, a detailed parametric study based on finite element analyses was undertaken to fully understand the buckling behaviour of intermediate length cold-formed steel column with lateral stiffeners.

The aim of this paper was to investigate the behaviour and strength of intermediate length pin-ended column with lateral stiffeners using finite element analysis. The finite element programme ANSYS was used in the analysis. Lateral stiffeners are the transverse elements of CFS sheet used to connect the lips of the sections using self-drilling screw. For this work, stiffened channel-shaped section with lip was considered. The column length and cross-section dimensions were carefully selected to ensure distortional buckling using CUFSM [7] software. Totally, two columns have been tested under pinned end condition. The finite element model was validated by the experiments conducted and also by the column test results conducted by Ben Young and Jintang yan [8]. A parametric study was done to investigate the behaviour of intermediate length thin-walled columns with lateral stiffeners of varying the number and depth of stiffeners.

2 Test Programme

2.1 Test Specimens

The test programme considered two column specimens. The first section is fully opened, and the second section is with one lateral stiffener of 50 mm depth at the centre. The section was carefully selected to have distortional buckling using CUFSM software. CUFSM employs the semi-analytical finite strip method (FSM) to provide solutions for the cross-section stability of thin-walled members. A thin-walled cross-section is discretized into a series of longitudinal strips, or elements. The FSM is a variant of the finite element method that has been put to highly effective use in the study of the stability of thin-walled structures. For any thin-walled profile which may effectively be modelled as extruded FSM provides an inevitably powerful simplification to finite element method. The dimensions of the cross-section were chosen by keeping the plate slenderness ratio (b/t) within limits to eliminate local buckling. All specimens were tested in pure axial compression with pinned end conditions. The buckling plot for the selected section is shown in Fig. 1.

It can be observed that local buckling occurred at very short half wavelengths of approximately 60 mm and it can be noted that local buckling occurs in all plate elements. The distortional mode has a minimum at 1,067 mm in half wave length. From the buckling plot, intermediate length is chosen to investigate distortional buckling for column length as 1,200 mm to eliminate global buckling effects. The cross-section profile of the selected section is shown in Fig. 2.

The specimens are fabricated by press-braking operation. Lateral stiffeners are the transverse elements made up of the same material which is used for specimen, cut into required shape and connect the lips of the section using self-drilling screw. One screw of 6 mm in diameter is used at each interconnection. Table 1 shows the dimensions of the specimen.

2.2 Labelling

Figure 3 explains a typical specimen label for parametric study.

2.3 Tension Coupon Tests

The tensile coupon tests are carried out in accordance with IS 1608-2005 (Part-1) [11]. The stress–strain curves obtained