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Experimental investigation and finite element analysis of web-stiffened cold-formed lipped channel columns with batten sheets

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ABSTRACT

This paper presents an experimental investigation and a finite element analysis on web-stiffened cold-formed lipped channel columns with batten sheets connected between the column's two lips at reasonable space. Initially, the paper presents the static compressive test results on 18 specimens under pinned-end restraint conditions with different column length and load eccentricities considered. It is shown that the batten sheets exert significant influence on both the buckling modes and the ultimate strength of the specimens under positive eccentric loading and/or axial loading conditions, while they just have few impacts on that of the specimens under negative eccentric compression. Strengthened by the batten sheets, the columns performed obviously higher ultimate strength under axial and positive eccentric compression compared with the ones without batten sheets and the strengthening effect increase with the increase of column length. Furthermore, the tested specimens were also numerically investigated by finite element program of ANSYS. Geometric and material nonlinearities were both included in the finite element models and it is demonstrated that the numerical analysis can closely predict the ultimate strength and the buckling behavior of the tested columns. Finally, a parametric study was conducted by using program of ANSYS, in which effect of the increasing lip stiffener width and varying batten sheet space were all investigated and it is concluded that the contribution of the batten sheets to the columns' strength decreased notably with the increasing lip width or batten sheets' space for axial and/or positive compressed columns. The best choice of the distance between batten sheets ($d \leq \lambda/3$) for axial compressed lipped channel columns must also be a reasonable choice for positive compressed columns.

1. Introduction

As one of the most widely used sections of compression members in residential buildings and industrial constructions etc, cold-formed lipped channel columns may undergo local, distortional and overall buckling, and for the ones with longitudinal intermediate stiffener in the web, the distortional buckling stress may be lower than the local buckling and overall buckling stress under certain conditions, and thus it may control the design [1–5]. Research into the distortional mode of buckling has attracted considerable attentions in recent years, and on the basis of previous research work, design rules and formulas developed for distortional buckling have been incorporated into the relevant specifications or standards [6,7]. Since the buckling mode involves mainly a rigid body rotation of the lip-stiffened flange about the flange-web junction due to the edge stiffener's inadequacy to prevent its movement normal to the plane of the flange it supports, so it can be easy to find a countermeasure to improve the section's load-carrying capacity by connecting two lips of the section with horizontal batten sheets (flat bars) at reasonable spacing to postpone the rotation of the flange and lip combinations.

Some experiment works have been conducted by researchers to investigate the contribution of the batten sheets (flat bars) to the buckling modes and ultimate strength of axially-compressed members. Thomasson P firstly found in his test that flat bars connecting lip stiffeners could eliminate the distortional buckling mode of axially-loaded lipped channels [1]. In china, tests were also conducted by yuanqi LI and xiang LIU on high-strength cold-formed axially-loaded lipped channel columns with batten sheet set between two lips of the section [8], by dongping WU on axially-loaded hat section columns with batten sheets [9], and by Xiaotong YANG and Jian YAO on cold-formed C-section with different batten sheet space under axial and eccentric compression [10]. From what has been discussed above, it can be seen that few experimental data were available for the contributions of the batten sheets to the thin-walled eccentric compression members which

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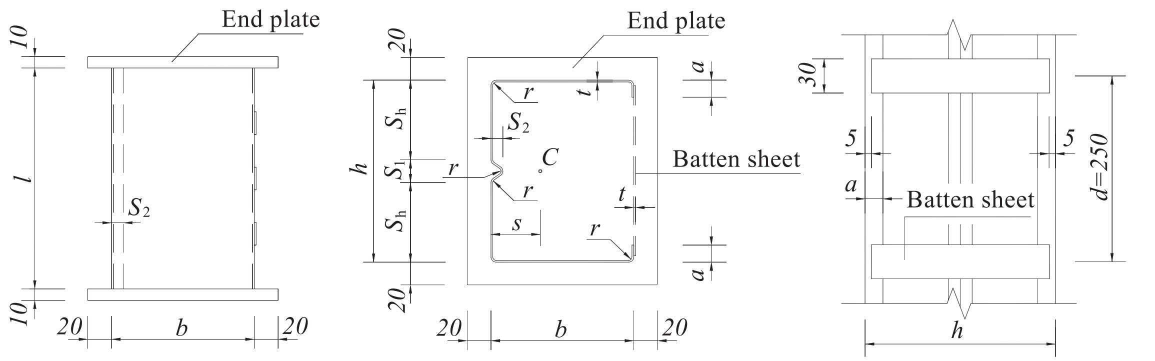

(a) lateral profile (b) cross-sectional geometry and definition of symbols (c) space and dimensions of batten sheets

Fig. 1. Specimen's geometries and definition of symbols.

have more extensive application in practical project and can be also eroded by distortional buckling [11,12].

The main purpose of this paper is to present experimental and numerical investigation on web-stiffened cold-formed lipped channel columns which were strengthened by the batten sheets. Influences of the batten sheets to the columns' buckling modes and ultimate strength under axial compression or one-way eccentric compression in the plane of symmetry are discussed. Moreover, validity of the finite element analysis (FEA), which is a powerful and economical supplement to experimental investigation, was also verified by the test results.

2. Experimental investigation

2.1. General

The column specimens were manufactured by press brake from mild zinc-coated structural steel sheets Q345-D with a nominal thickness of 1.5 mm. The specimens' geometries and definition of symbols are shown in Fig. 1. A total of 18 specimens were manufactured with the nominal lengths of the columns (l in Fig. 1(a)) chosen as 1000, 1500 and 2000 mm respectively, and the 6 specimens in each length were divided into three groups according the loading position for the convenience to compare with the test that detailed in literature [5]. An end plate of 10 mm thick was welded on each end of the specimen to facilitate the loading, so it can be considered that the warping of the end section is fully constrained. The plate's outlines in length and width both fell 20 mm out of the columns' section contour (see Fig. 1(a), (b)). The columns' cross-sectional geometries and definition of symbols are depicted in Fig. 1(b) and the nominal section dimensions are listed in Table 1. As illustrated in Fig. 1(c), the batten sheets, cut from the same batch of Q345-D steel sheets used to manufacture the specimens, were 30 mm in width, 150 mm in length, and were connected by spot welding between the two lips of the section at a space of 250 mm along the column length. The connection is detailed in Fig. 2.

Based on the test results and research work of Yuanqi LI and Xiaotong YANG [8,10], it can be noted that for the axially loaded columns, in order to prevent distortional buckling from happening by using batten sheets, the spacing of the batten sheets should not exceed λ/3, where λ is the half-wavelength of the column's distortional buckling mode. The λ values of about 870 mm can be got for all the

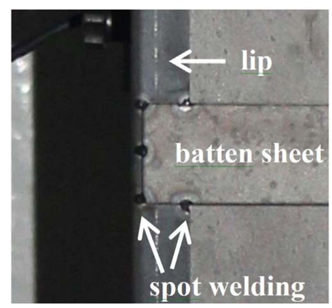

Fig. 2. Connection details between the batten sheet and the lip.

specimens by using a simplified formula for computing the λ of axially-loaded lipped-channel columns provided by Lau and Hancock [13]. Therefore, in the test, the space of the batten sheets was chosen as 250 mm.

The specimens were labeled such that the section type, column length and load eccentricity in the plane of symmetry can be identified.

For example, the labels "WSCb10e-20-1" and "WSCb10e20-2" define the models as follows:

"WSCb" indicates the section is a web-stiffened lipped channel with batten sheets connected between the two lips;
"10" means the nominal length of the column is 1000 mm;
"e20" or "e-20" indicates the load eccentricity value in the plane of symmetry is positive 20 mm or negative 20 mm, where positive means the loading position is between the centroid and the lips of the section while negative means the loading position is between the centroid and the web;
"−1" or "−2" represents the sequence member of the two specimens in the same group.

The actual cross sectional dimensions of the specimens were measured before test at the columns' each end and mid-height sections by a vernier caliper and the average of the measured values are summarized in Table 2, with the column lengths measured by a steel tape also included.

Table 1
Nominal dimensions of column specimens.

h (mm)	S_h (mm)	S_1 (mm)	S_2 (mm)	b (mm)	a (mm)	t (mm)	r (mm)	s(mm)
160	70	20	10	120	15	1.5	1.5	41.11