Thin-Walled Structures 114 (2017) 11–21

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

In-plane sway behaviour of slender cold-formed steel bolted frames

Yeong Huei Lee[a], Cher Siang Tan[b], Shahrin Mohammad[a,*]

[a] Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[b] Forensic Engineering Centre, Institute for Smart Infrastructure and Innovative Construction, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

ARTICLE INFO

Keywords:
Sway stiffness
Light steel frame
Joint flexibility
Cold-formed steel
Slender
Bolted connection

ABSTRACT

The use of light steel frames in rapid construction has grown significantly, especially concerning low and medium-rise buildings. However, there are limited resources available regarding the sway stiffness of light steel frames with flexible bolted joints. This paper presents a study on the lateral sway behaviour for light steel frames with bolted top-seat flange cleat connections comprising slender cold-formed steel sections. Two different sections, flexibility of beam-to-column joint and base conditions are the investigated variables. The result recorded showed that geometrics, joint flexibility and base conditions affect the sway stiffness of light steel frame. The increase rate is ranged from 29.2% to 47.5% for the identical tests for the effect of section depth. The ratio lies between 1.10 and 3.04 for the effect of connector thickness. In addition, beam-to-column bolted connections can contribute 34–88% of the overall frame elastic lateral stiffness for pinned bases and 17–33% for rigid base connections. Frame stability analysis with respect to global frame and column design were performed for the test specimens. Appropriate frame design analysis should be determined to provide a safe and reliable design for light steel frame considering bolted flexible joints and slender cold-formed steel sections.

1. Introduction

Light steel frame systems, a dry and rapid construction method that utilizes the light weight property of cold-formed steel, are gaining more attention in its uses in low- and medium-rise construction. The advantages of cold-formed steel were mentioned in previous paper [1]. In the past, the buckling problem of slender cold-formed steel sections raised concerns about its safety due to its thickness. Significant research has been carried out to understand and improve the structural performance of cold-formed steel [1–11] by providing intermediate stiffeners along the sections or prevent local buckling of the compressive flange through the use of a lip stiffener.

Cold-formed steel separate member designs for beams, columns and joints have been carried out aggressively since the last decade. Kotelko et. al. [2], Pastor and Roure [3], Maduliat et. al. [4], and Lee et. al. [5] studied the flexural behaviour of cold-formed steel beams. Cold-formed column behaviour has also been studied by Narayanan and Mahendran [6], Moen and Schafer [7] and Ting and Lau [8]. In addition, joint behaviour of light steel frame has been investigated by Wong and Chung [9], Lim and Nethercot [10] and Huei et. al. [11]. For frame design, a major concern is the stability of light steel frames that comprises slender steel sections, where it may vary from design with hot-rolled compact sections.

Nonlinear analysis for compact hot-rolled steel frames was carried out [12–15]. A pseudo spring method with various levels of stiffness, which was used to represent the gradual plasticity of the end of beam member, was investigated by Al-Mashary and Chen [12]. The modified stability function is applied into a simple incremental method in frame analysis. The proposed stiffness matrix formulation has the capacity to accommodate the effect of joint flexibilities as well. Kishi et. al. [13] estimates the second-order effects on the behaviour and strength of steel frames with semi-rigid connection. Frame analysis method has been proposed in a direct and practical manner by considering the characteristics of semi-rigid connections. Kishi's group extended their studies to derive equations by using the alignment chart approach and Shanley's inelastic column buckling theory [14]. Furthermore, the effect of non-linear moment-rotation behaviour on the *K*-factor for a one-bay two-storey frame and two flexibly jointed braced portals as examples were studied using the proposed simplified method. Barsan and Chiorean [15] studied the inelastic and large deflection analysis of flexibly jointed frames which is based on plastic zone analysis.

However, limited resources were found on the assembled frame analysis of non-compact or slender steel sections [16–18]. Avery and Mahendran [16,17] studied the plastic zone analysis of steel frame comprising non-compact sections. The proposed analytical procedure was validated with experimental results. Also relevant is the experimental testing of three-dimensional frames by Kim and Kang [18]. There were three specimens with the characteristic of two-storey,

* Corresponding author.
E-mail addresses: yhlee@civil.my (Y.H. Lee), tcsiang@utm.my (C.S. Tan), shahrin@utm.my (S. Mohammad).

http://dx.doi.org/10.1016/j.tws.2017.01.024
Received 31 January 2016; Received in revised form 18 January 2017; Accepted 18 January 2017

single-bay and sway allowed frames which were subjected to proportional vertical and horizontal loads. The AISC-LRFD method [19] was compared to the experimental results and found to be 13–21% conservative as it does not take into account the inelastic moment redistribution within the frame.

Stability has been studied for cold-formed steel portal frames [20]. Since the non-compact steel sections and joint flexibility should be focused in the frame analysis, these effects are essential for frame stability and reliable design. This paper presents a study of lateral sway stiffness for light steel frames with top-seat flange cleat connection that comprise slender cold-formed steel sections for different joint flexibility. Full-scale light steel planar frames are set up in order to investigate the sway behaviour with different geometrics, joint flexibility and base conditions. Frame stability was computed from global frame analysis with Eurocode design specifications and column design with effective length method. Appropriate design considerations have been suggested for light steel frames with bolted top-seat flange cleat connections.

2. Experimental program

A total of eight full scale frame tests were carried out. The objective of the testing was to investigate the structural performance of the frame in lateral sway conditions, while taking into account the joint flexibility. Each full-scale frame specimens consisted of two sets of 3000 mm length columns and one set of 4000 mm length beams. All were built-up by cold-formed steel double channel sections. The components of the frame were connected with bolted top-seat flange cleat connections. The experimental arrangement of the frame is shown in Fig. 1. Two types of cold-formed steel channel sections were applied in the investigation. The sections were 200 mm and 250 mm in depth, assembled back-to-back to form built-up I-section, namely DC200 and DC250. The thickness of the 2 mm and 6 mm flange cleats were used as connectors to differentiate the joint flexibility, whereas the 2 mm flange cleat connection was considered as a pinned joint and the 6 mm flange cleat connection was considered as a semi-rigid joint according to the joint classification analysis. Base connections of both the pinned and fixed joints were used to investigate the connection behaviour under lateral load in pinned conditions and actual behaviour under fixed-to-the-ground conditions. The frame load-deflection behaviour and joint rotational behaviour was determined in the presence of joint flexibility.

2.1. Test specimen

2.1.1. Member sizing

The test specimens and dimension details are summarised in Table 1. The specimens were divided into two categories: DC200 and DC250. For each category, four tests were carried out in order to understand the behaviour of the frame towards lateral actions. The four specimens included 2 mm flange cleat pinned beam-to-column connections with fixed-base connections and pinned-base connections. Also included was the 6 mm flange cleat semi-rigid beam-to-column connections.

Table 1
Specimen description of experimental study for frame test.

Test Specimen	Description		
	Sections Properties	Flange Cleat properties	Base Column Connection
H2002BP	D_s = 200 mm	L_{fc} = 60 mm t_{fc} = 2 mm Y_{fc} = 350 N/mm^2	Pinned
H2006BP	t_s = 2 mm L_{beam} = 4000 mm	L_{fc} = 60 mm t_{fc} = 6 mm Y_{fc} = 350 N/mm^2	Fixed
H2002BR	L_{column} = 3000 mm Y_s = 350 N/mm^2	L_{fc} = 60 mm t_{fc} = 2 mm Y_{fc} = 350 N/mm^2	Pinned
H2006BR		L_{fc} = 60 mm t_{fc} = 6 mm Y_{fc} = 350 N/mm^2	Fixed
H2502BP	D_s = 250 mm	L_{fc} = 60 mm t_{fc} = 2 mm Y_{fc} = 350 N/mm^2	Pinned
H2506BP	t_s = 2 mm L_{beam} = 4000 mm	L_{fc} = 60 mm t_{fc} = 6 mm Y_{fc} = 350 N/mm^2	Fixed
H2502BR	L_{column} = 3000 mm Y_s = 350 N/mm^2	L_{fc} = 60 mm t_{fc} = 2 mm Y_{fc} = 350 N/mm^2	Pinned
H2506BR		L_{fc} = 60 mm t_{fc} = 6 mm Y_{fc} = 350 N/mm^2	Fixed

Symbols:
D_s is the beam depth of the section.
t_s is the thickness of the section.
L_{beam} is the length of beam.
L_{column} is the length of column.
Y_s is the yield strength of the section.
L_{fc} is the length of flange cleat.
t_{fc} is the thickness of flange cleat.
Y_{fc} is the yield strength of flange cleat.

For steel sections, the requirements are stated in the BS EN1993-1-1 [21] for section classification under bending or compression or a combination of bending and compression. Cold-formed steel sections are usually considered as slender sections according to the BS EN1993-1-1 classification [21]. The beam and column were formed with double channels sections. Due to the presence of lip components, flange and web components were considered as internal parts of the investigated section during the section classification process. From Table 2, the DC200 and DC250 are classified as class 4 slender sections.

The steel grade for the cold-formed steel channel section is 350 N/mm^2. In order to clarify the steel grade, tensile tests were performed. A total of 12 tensile tests were carried out according to BS EN10002 [22]. The results indicated that the grade of 350 N/mm^2 was valid for the investigated cold-formed steel channel section.

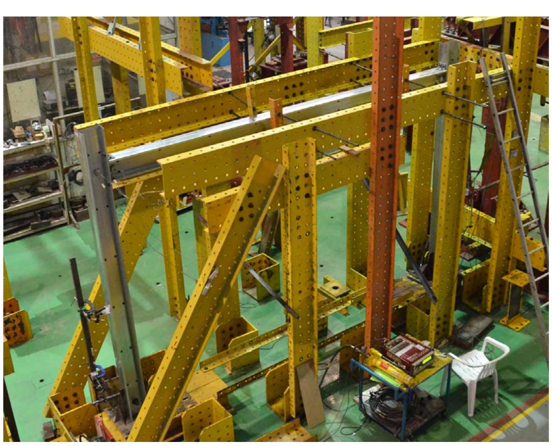

Fig. 1. Experimental investigation of lateral stability.

2.1.2. Frame geometry

Fig. 2 shows the reactions of a frame with uniform distributed load as an action. Both reactions, vertical (V) and horizontal (H), result from the action and its ratio is dependent on the span-to-height ratio. The relationship of these parameters is given as Eq. (1).

$$\frac{H}{V} = \frac{(L/h)^2}{4 + 6 \quad (L/h)} \tag{1}$$