Thin-Walled Structures 77 (2014) 17–25

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Behavior of steel plate shear walls with pre-compression from adjacent frame columns

Xuqiao Zhang *, Yanlin Guo

Department of Civil Engineering, Tsinghua University, Beijing 100084, PR China

ARTICLE INFO

Article history:
Received 29 June 2013
Received in revised form
30 October 2013
Accepted 21 November 2013
Available online 15 December 2013

Keywords:
Steel plate shear wall
Pre-compression
Frame columns
Reduction coefficient

ABSTRACT

This paper investigates the behavior of steel plate shear walls (SPSWs) with pre-compression from adjacent frame columns which is produced in the construction process. Firstly, some parameters used in analytical finite element models, such as the stiffness of frame beams and columns and the magnitude of the loads are discussed. Then, numbers of numerical examples are analyzed and show that the influence of pre-compression varies with the dimension of SPSWs. Also, the distribution and transferring of axial forces between frame columns and SPSWs during loading are discussed. Finally, a reduction coefficient of shear-carrying capacity of SPSW due to pre-compression is proposed.

1. Introduction

Steel plate shear walls (SPSWs) have been widely applied in high-rise structures as effective lateral load-resisting systems (Fig. 1). It has advantages such as light weight, high lateral stiffness, good ductility, high energy-dissipation capacity and also convenience of construction. Nippon Steel Building completed in 1970 in Japan is the first structure using SPSWs in the world. Other applications such as Olive View Hospital in the USA and Kobe office in Japan all performed exceedingly well during earthquakes [1].

The infill plates in SPSWs can be welded or bolted to surrounding frame columns and beams. In the practical construction process, the infill plates are mostly erected with adjacent frame columns simultaneously to reduce the construction period. Therefore, SPSWs need to bear axial forces due to compression of adjacent frame columns before the service period, which will reduce the shear-carrying capacity of SPSWs. Most national design codes consider SPSWs only bearing lateral forces from wind or earthquake without considering axial forces resulting from the construction process, which is unsafe for both SPSWs and frame columns.

There have been many literatures about SPSWs. Many researchers studied the post-buckling behavior of SPSWs. The most famous analytical model to simulate the behavior of thin unstiffened SPSWs considering post-buckling strength, known as the strip model, was developed by Thorburn et al. [2]. It was then refined by Timler and Kulak [3] and was verified by the experimental results achieved by Driver et al. [4]. Another analytical model was developed based on the strip model but incorporated strips in both directions to predict hysteretic behavior of thin SPSWS by Elgaaly [5]. Alinia et al. [6] demonstrated the nonlinearity in the post-buckling behavior of SPSWs. Furthermore, Bruneau and Bhagwagar [7] analyzed the effect of thin infill plates on seismically retrofit steel frames. Alinia and Dastfan [8] researched the influence of frame members on SPSWs. Habashi and Alinia [9] studied the interaction of the infill plates and frame columns in SPSWs.

However, little of former research considered the influence of pre-compression from adjacent frame columns. Gravity loads from columns were included in some experimental research. In the experiment conducted by Tromposch and Kulak [10], axial loads were applied to the columns prior to the lateral load by two pre-stressing rods at each column. The effect of axial compression was verified as the rods were removed before the last load step in the test and an increase of strength was observed. In the cyclic test of a four-story SPSW conducted by Driver et al. [11], axial loads of a magnitude representing gravity loads for a typical building at the lowest story were applied at the top of the columns before lateral loads, but no comparison was made between the behavior of SPSWs with and without axial compression. In the experimental research of thin SPSWs by Elgaaly and Yinbo Liu [12], the shear-carrying capacity of one specimen of specific dimension with and without pre-compression was compared by the finite element (FE) method. They obtained that the pre-compression affected little perhaps because the magnitude of compression in the analysis was small and the infill plate was quite thin. The conclusion could

* Corresponding author. Tel.: +86 10 62788124.
E-mail address: zhangxuqiao11@mails.tsinghua.edu.cn (X.Q. Zhang).

0263-8231/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tws.2013.11.011

Fig. 1. SPSWs in practical construction.

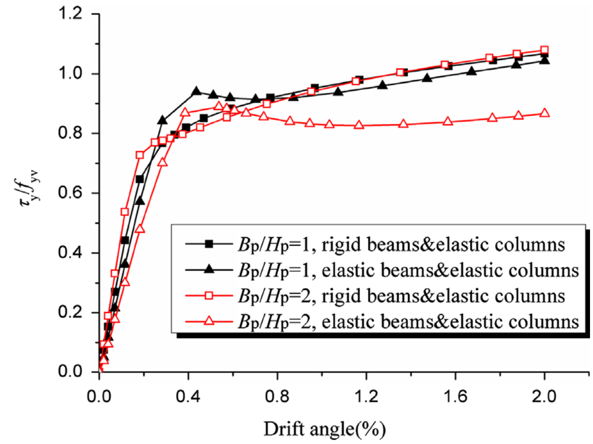

Fig. 2. Influence of beam stiffness considering pre-compression.

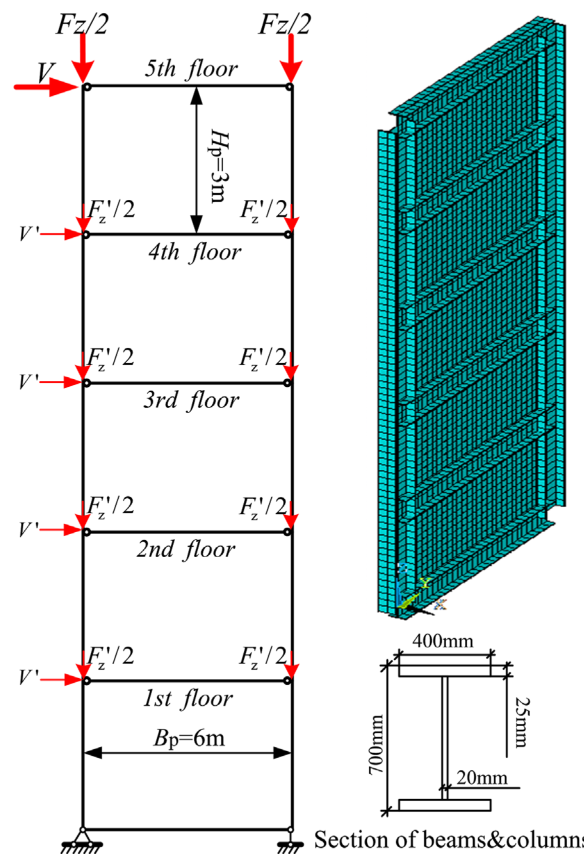

Fig. 3. Multi-storey SPSW model.

not be applied generally. Jian-Guo Nie et al. [13] measured the distribution of axial strain in the infill plates when frame columns were compressed in their experiments of stiffened SPSWs. Moreover, they observed the positive influence of vertical stiffeners in the test.

A related analytical research was conducted by Galambos [14]. He proposed an equation to calculate the elastic buckling strength of flat plate simply supported along all edges and subjected to pressure and shear, which is shown in Eq. (1) (where, σ and τ are critical pressure and shear; σ_{cr} is the buckling strength of simply supported plate under compression and τ_{cr} is the shear buckling strength of simply supported plate). Behbahanifared et al. [15] studied the effect of gravity loads and overturning moments on the behavior of SPSWs and found that these two loads reduced the elastic stiffness and strength of SPSWs. However, they did not propose a method to measure this reduction. Yan-Lin Guo and Ming Zhou [16] proposed a reduction coefficient of shear-carrying capacity due to pre-compression from frame columns by numerical analyses. But the influence of geometric parameters was not considered in the research.

$$\left(\frac{\sigma}{\sigma_{cr}}\right)+\left(\frac{\tau}{\tau_{cr}}\right)^2=1 \tag{1}$$

In this paper, the behavior of SPSWs with pre-compression from adjacent frame columns is studied. The elastic–plastic character of SPSWs of different dimensions under both axial and lateral forces is analyzed by modeling a frame-shear wall structure model and a reduction coefficient is proposed. Moreover, the distribution of axial forces in the loading process and the transfer of axial forces between the infill plate and the frame columns in post-buckling stage is researched specially.

2. Analytical model

In this paper, the commercial general-purpose finite element program ANSYS [17] is utilized for all numerical analyses. To reduce computation time, the single-storey SPSW model is usually used for numerical analyses. Parameters used in this FE model, such as stiffness of surrounding beams and columns and magnitude of loads, should be discussed before analysis.

2.1. Stiffness of beams

In previous studies, beams of SPSWs in the FE model are often built infinitely rigid, because they are constrained by tension fields formed in adjacent plate panels in middle floors [18]. But when taking axial forces from pre-compression of columns into account, the stiffness of beams matters much (Fig. 2, B_p and H_p are as shown in Fig. 3) and need to be studied more clearly.

To research the influence of the actual beam stiffness in a real structure, a five-storey model is built. The geometric dimension and the sketch of the model are depicted in Fig. 3. The infill plates are 10 mm thick and modeled by Shell181. Frame beams and columns are modeled by Beam 188. The material of frame members is defined elastic with E=206 GPa to avoid yielding before the infill plate. And for infill plates, the bilinear material model is selected, with initial stiffness of E_0=206 GPa, yield stress of σ_y=235 MPa, hardening stiffness of E=3% E_0. Poisson's ratio of both the materials is 0.3. The frame columns and beams are