Thin-Walled Structures 131 (2018) 816–826

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Shear resistance and post-buckling behavior of corrugated panels in steel plate shear walls

Chao Dou[a,b,*], Yong-Lin Pi[c], Wei Gao[c]

[a] School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, PR China
[b] Beijing's Key Laboratory of Structural Wind Engineering and Urban Wind Environment, Beijing 100044, PR China
[c] School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW 2052, Australia

ARTICLE INFO

Keywords:
Corrugated shear walls
Shear resistance
Reduction factor
Post-buckling
Load-displacement curve

ABSTRACT

Steel corrugated shear wall (SCSW) is an alternative to traditional shear walls with flat plates. However, shear resistance behavior and design of the infilled corrugated panels in SCSWs has not been well studies. This paper focuses on the shear resistance of sinusoidally corrugated panels in SCSWs under monotonic lateral shear force, via finite element analyses (FEA) considering both geometric nonlinearity and material elasto-plasticity. Firstly the effects of initial imperfections and geometric dimensions on shear resistance of corrugated panels are explored. Then based on extensive FEA, the maximum and the post-buckling strengths are investigated, and fitting equations to predict the shear resistant behavior of corrugated panels are proposed by introducing the normalized height-to-thickness ratio. It is found that, the maximum shear resistance of corrugated panels has a consistent relationship to the normalized height-to-thickness ratio, however variation of the post-buckling resistance is complex and geometric parameters have to be properly chosen to avoid significant strength drop after buckling. The equations proposed agree with the FEA results, and can be utilized in design of corrugated panels in SCSWs.

1. Introduction

Flat steel plate shear walls (SPSWs) have been utilized in practical engineering due to the effective lateral force-resisting capability, with design methods established based on extensive studies [1–8]. However, thin flat infilled plates are prone to buckling under small lateral loading, decreasing the lateral stiffness and inducing loud noise. In addition, the diagonal tension field after buckling brings large tension forces on the boundary frame and the hysteresis loop shows significant pinching. In recent years, steel corrugated shear walls (SCSWs) were proposed as an alternative. Due to corrugation, the out-of-plane rigidity and shear buckling load of the infilled panel are greatly improved. Meanwhile less demand for the frame stiffness, stable hysteresis loops and more seismic energy dissipation can be expected. Additionally, when the infilled corrugated panel is horizontally placed, the panel bears little vertical loads transmitted from the upper structures, thus it can be installed with the frames simultaneously.

A number of investigations have been done pertaining to inelastic lateral behavior of SCSWs [9–24]. Mo [9] conducted cyclic tests for FRP-strengthened concrete frames infilled with steel corrugated panels, and found that the thickness of the infilled panel was important to the structural ductility and energy dissipation. Cyclic tests for SCSWs were carried out by Berman et al. [10] where the corrugated panel was placed with an inclined 45° and connected to the frame with epoxy. Emami et al. [11,12] performed experimental and numerical studies on SCSWs with horizontally and vertically infilled corrugated plates, and revealed that material yielding was fully developed in the plate with plump hysteresis loops. Vigh et al. [13] investigated the cyclic behavior of SCSWs with profiled steel sheets, and proposed design recommendations based on FEMA P-695. Edalati et al. [14] conducted numerical analyses on SCSWs and concluded that trapezoidal corrugated panels had better structural behavior than the sinusoidal counterparts. Kalali et al. [15] explored the hysteretic behavior of SCSWs and showed that with proper selection of dimensions the corrugated shear walls exhibited better performance than the flat SPSWs. Zhao et al. [16] and Hosseinzadeh et al. [17] performed numerical and experimental studies on SCSWs. Bahrebar et al. [19,20] investigated the lateral resistant behavior of SPSWs with trapezoidal corrugations and centrally-placed square perforations. Tong [21,22] studied the shear resistance of stiffened corrugated panels under monotonic lateral loading.

To establish the design method for SCSWs, two key issues have to be

* Corresponding author at: School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, PR China.
E-mail addresses: douchao@bjtu.edu.cn (C. Dou), y.pi@unsw.edu.au (Y.-L. Pi), w.gao@unsw.edu.au (W. Gao).

https://doi.org/10.1016/j.tws.2018.07.039
Received 22 April 2018; Received in revised form 29 June 2018; Accepted 23 July 2018
Available online 23 August 2018

Nomenclature

C_a	corrugation depth of the infilled corrugated panel
C_l	corrugation length of the infilled corrugated panel
C_a/C_l	corrugation ratio of corrugated panels
E	modulus of elasticity
f_y	steel yield stress
G	steel shear modulus of elasticity
H	panel overall height
H_{co}	corrugation length along the panel height
H/C_l	corrugation repeating number of corrugated panels
L	panel overall width
L/H	aspect ratio of panels
S_c	developed length of the axis of one repeating corrugation
t	panel thickness
V	shear force
$V_{0.5}$	shear force corresponding to the storey drift $\Delta/(2\% H) = 0.5$
V_r	residual shear resistance
V_s	maximum shear resistance
V_y	full shear yield force
ν	Poisson ratio
Δ	storey drift of the corrugated panels under shear
Δ_s	storey drift corresponding to the maximum shear resistance or the shear yield storey drift
Δ_r	maximum storey drift
Δ/H	storey drift angle
φ	shear reduction factor
$\varphi_{0.5}$	half-storey drift reduction factor
φ_r	shear residual reduction factor of post-buckling resistance
φ_s	shear reduction factor of maximum shear resistance
λ_n	normalized height-to-thickness ratio of corrugated panels
τ_{cr}	buckling shear stress
τ_y	steel shear yield stress
τ_u	maximum shear stress

addressed. One is to evaluate the shear resistance of the frame-panel system, and the other is to reveal the interaction between the frame and the infilled panel. However, none of the issues is well studied so far. Most of the previous studies presented qualitative conclusions for the lateral resistant behavior of SCSWs, but no quantitative design methods or equations were proposed tackling the problems how to determine the shear resistance for the corrugated panel, or how to evaluate the interaction between the infilled panel and the frame.

As the first step into systematic investigations for SCSWs, this paper deals with the shear resistance and post-buckling behavior of infilled corrugated panels under pure shear force. Based on nonlinear inelastic finite element analyses, the effects of initial imperfections and geometric dimensions on lateral resistant behavior of corrugated panels under shear are firstly explored. Then on the basis of extensive numerical analysis results, the maximum shear resistance and the post-buckling strength of corrugated panels are calculated. By introducing the normalized height-to-thickness ratio, fitting equations are proposed for prediction of the lateral resistant behavior.

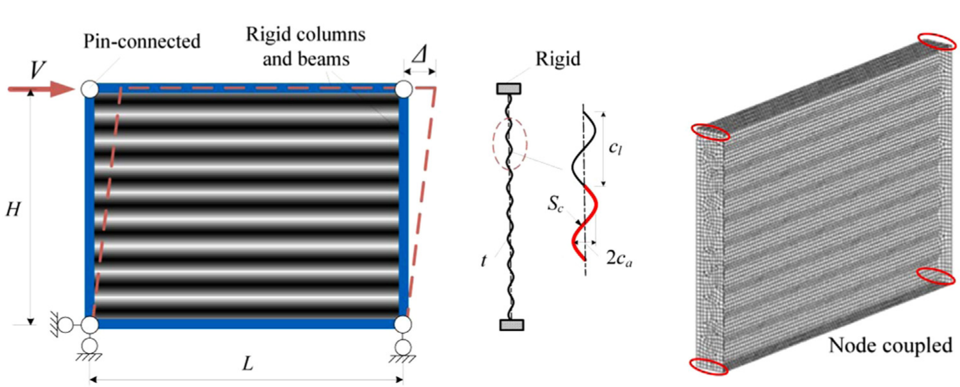
2. Scope and finite element model

In order to focus on the shear behavior of the infilled corrugated panel, in the analytical model the boundary beam and column are pin-connected and all assumed rigid as shown in Fig. 1a. Hence, the contribution of the boundary frame to lateral shear resistance of the system is eliminated, and the lateral force is only carried by the infilled corrugated panel under pure shear. The corrugated panel is horizontally placed with sinusoidal corrugations. Five parameters determine the geometric dimension of the model, namely the corrugation length C_l, the corrugation depth C_a, the panel thickness t, the panel height H and width L.

Finite element software ANSYS 16.1 [25] is used to conduct the non-linear lateral resistance analyses for corrugated panels. Shell element SHELL181 is used to simulate both the frame members and the infilled panel. The feasibility of analyses by ANSYS has been validated by several researches. In the studies of Bahrebar et al. [19,20], the numerical model of SCSWs was simulated by shell elements in ANSYS and compared with the cyclic test from Emami and Mofid [11,12]. Tong [21] conducted pushover and cyclic tests on double-corrugated shear walls, accompanied by numerical verification by ANSYS. Good agreement on hysteretic loops and failure modes proved the validity and accuracy of the numerical simulations [19–21].

2.1. Connections and boundary conditions

In the FE model, the frame beams and columns are set infinitely rigid. At the four beam-to-column joints, the nodes on the beam and the column are coupled to simulate the pinned connection as shown in Fig. 1b. In this way, the frame member elastic deformation and resistance contribution can be eliminated, and the infilled corrugated panels are under pure shear force equal to the lateral loading. The infilled panel is rigidly connected to the frame members by sharing nodes on the four sides to simulate the welded connection. The frame-plate system is simply supported at the column bottoms. The lateral loading was applied to the end of the top beam using a displacement control protocol, to a maximum drift angle $\Delta/H = 2.0\%$, according to Chinese



(a) Corrugated panel with pin-connected rigid frame (b) FE model

Fig. 1. Pure shear model of horizontal corrugated panels.