Thin-Walled Structures 127 (2018) 76–89

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Shear resistance of stiffened steel corrugated shear walls

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ARTICLE INFO

Keywords:
Steel corrugated shear wall
Stiffener
Shear resistance
Finite element analyses
Transition rigidity ratio
Shear buckling curve

ABSTRACT

In recent years, the steel corrugated shear walls (SCSWs) are widely used in building structures to serve as lateral force resistant members. For some practical engineering applications that the width of the infilled SCSWs in frame structure is much greater than its height, it is common to add vertical stiffening systems to the SCSWs, thus forming the stiffened SCSWs (SSCSWs), and the stiffening system is composed of a pair of vertical stiffeners installed on both sides of the corrugated plate and the connecting high-strength bolts. In this paper, the shear resistant behavior of the SSCSWs is investigated via FE analyses considering both the geometrical and material nonlinearities, and over 300 models are analyzed through elastoplastic numerical process. The comparison of the shear resistant behavior of SSCSWs with different stiffening rigidities is performed, which indicates that the stiffening system can effectively restrain the out-of-plane displacements of the corrugated wall, and can improve both shear resistance and ductility of the SSCSWs. Then a transition rigidity ratio of the stiffening system is proposed to reflect the critical value of the stiffening rigidity that the out-of-plane displacements of the corrugated plate are fully restrained at the bolted locations. Correspondingly, curve fitted formula of the transition rigidity ratio is provided to enable a conservative prediction. Finally, shear buckling formulas are fitted to reveal the relationship between the reduction factor and the normalized aspect ratio, and they are validated to be able to conservatively predict the ultimate shear stress of SSCSWs. Accordingly, some design recommendations are presented, which could provide valuable references for practical design of SSCSWs.

1. Introduction

The lateral force resistant ability of high-rise building is very essential in its design. The lateral force resistance of common frame structures could be significantly improved by adopting steel plate shear walls (SPSWs), and this technique has been utilized in practical engineering structures worldwide. Yet, some disadvantages exist in the frame structures with SPSWs as follows:

(1) Generally, out-of-plane bending rigidities of steel plates are quite small, especially for those with small thickness. Hence, when the SPSW is subjected to lateral forces induced by earthquake or wind effects, it easily buckles and its post-buckling strength would be produced through yielding of the diagonal tension field, leading to a loud noise.
(2) For the structure with its frame and SPSWs installed simultaneously, the vertical loads transmitted from upper structures would be applied to the SPSWs, thus producing pre-compression and influencing the shear resistance of the SPSWs [1].

With those considerations, the infilled steel plates could commonly be replaced by steel corrugated plates, forming the steel corrugated shear walls (SCSWs). Numerous investigations were conducted by researchers to perform the comparison of the shear resistance and hysteretic behavior between SPSWs and SCSWs [2–6]. Berman et al. [2,3] performed the comparison of hysteretic performances among SPSWs, ordinary concentrically braced frames (OCBFs) and SCSWs, in which the corrugations were set in a diagonal direction with an inclination angle of about 45°. Emami et al. [4,5] conducted hysteretic tests of SPSWs and SCSWs, in which the corrugations installed horizontally and vertically were respectively considered. Kalai et al. [6] conducted FE analyses of SPSWs and SCSWs under cyclic shear loads to perform comparison, in which the effect of corrugation shapes on the hysteretic performances of SCSWs was investigated. According to these researches, by utilizing SCSWs in frame structures, the shear buckling loads could be significantly promoted owing to the increase of bending rigidities of the steel corrugated plates. In addition, based on the investigations performed by Tong and Guo [7], the vertical pre-compression loads could be efficiently released for the SCSWs with their corrugations laid horizontally. Due to these advantages of SCSWs, they have been widely used in practical building structures as lateral force resistance systems in recent years, as shown in Fig. 1. Current

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https://doi.org/10.1016/j.tws.2018.01.036
Received 3 October 2017; Received in revised form 21 November 2017; Accepted 24 January 2018
0263-8231/

Nomenclature

a	amplitude of the corrugation
A_a	cross-sectional area of single steel angle stiffener
b	width of the steel corrugated shear wall
b_0	location of neutral axis of single steel angle stiffener
b_a	width of the steel angle stiffener
d_1,d_2	dimensions of the corrugation
D_x,D_y,D_{xy},H	rigidity constants of equivalent orthotropic plate
E	Young's modulus of steel
h	height of the steel corrugated shear wall
I_a	moment of inertia of single steel angle stiffener
I_s	Equivalent moment of inertia of the stiffening system
k	elastic buckling coefficient
k_1	elastic buckling coefficient of 1-side fixed, 3-side simply-supported orthotropic plate
k_2	elastic buckling coefficient of 2-side fixed, 2-side simply-supported orthotropic plate
q	arc length of one repeating corrugation
t	thickness of the steel corrugated shear wall
t_a	thickness of the steel angle stiffener
V	lateral shear load
β	converted aspect ratio of the steel corrugated shear wall
γ	angle of the incline segment in the corrugation
δ	lateral displacement of the steel corrugated shear wall
η	rigidity ratio of the stiffening system
$\eta_{0,e}$	transition rigidity ratios under elastic buckling analyses
$\eta_{0,p}$	transition rigidity ratios under elastoplastic analyses
θ	constant of equivalent orthotropic plate
λ	wave length of one repeating corrugation
λ_n	normalized aspect ratio of the stiffened steel corrugated shear wall
τ	shear stress
τ_{cr}	shear elastic buckling stress
τ_u	shear ultimate stress
τ_y	shear yield stress
υ	Poisson's ratio of steel
φ	reduction factor
φ_{lim}	upper limit of the reduction factor
Φ	intermediate variable of the reduction factor

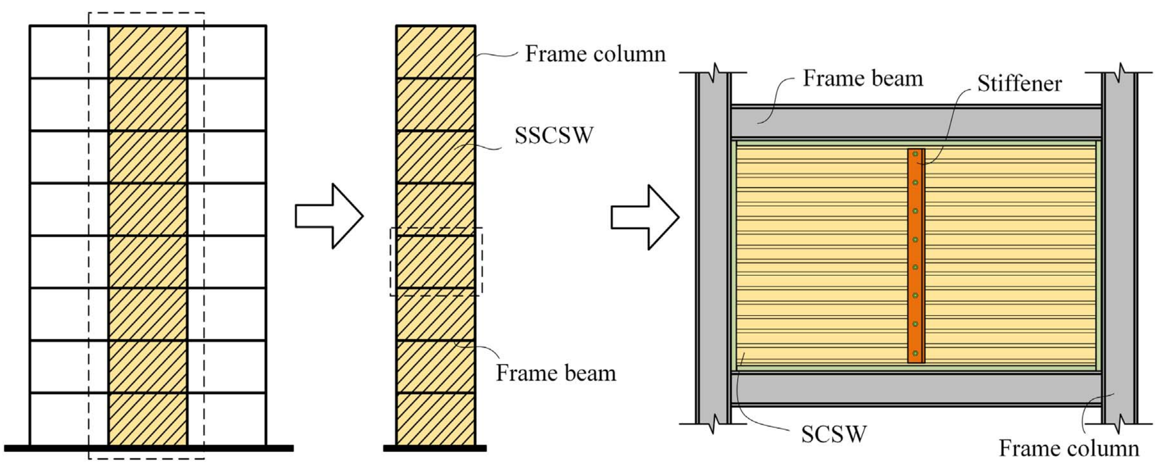

Fig. 1. SSCSWs in frame structures.

researches on SCSWs mainly focused on the shear resistance of SCSWs with small thickness (i.e. $t = 0.5 - 1.5$mm), and numerous experimental and numerical investigations have been published [8–16]. The SCSWs with small thickness are easily to be profiled into trapezoidal corrugations. However, they are only suitable for the applications in low-rise buildings since the thickness of SCSWs inevitably limits their upper bound of shear resistance. In order for the applications of corrugated plates with small thickness in high-rise buildings, multiple corrugated plates would be required to improve the ultimate resistance. Otherwise, SCSWs with large thickness (i.e. $t = 4 - 8$mm) should be adopted in high-rise buildings, which benefited from both the improvements of the steel ductile properties and the equipment for cold rolling. Correspondingly, the shear resistant behavior of SCSWs with large thickness is worth of investigation for high-rise structural applications.

In some practical structures, especially for long-span frame structure applications, the width of the SCSW is much greater than its height. In these situations, the shear resistance of the SCSW could be remarkably improved by adding a vertical stiffening system to it, thus forming the stiffened SCSWs (SSCSWs) as depicted in Fig. 1. For convenience of connections between the SCSW and stiffeners, the corrugations are usually chosen to be trapezoidal shapes, and the most commonly used types of corrugation shapes are depicted in Fig. 2. Among these shapes, the first type is the most adopted and it is therefore selected in the following discussions of this paper.

On the shear resistant behavior of SSCSW, little researches have been presented and the design method of shear resistance is of great concern of the engineers. The shear elastic buckling behavior of SSCSWs has been studied by the authors and formulas for shear elastic buckling loads were proposed [7]. On this basis, this paper would present the shear resistant behavior and corresponding design method of SSCSWs via FE nonlinear analyses.

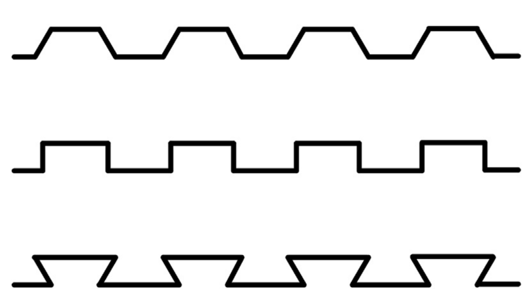

Fig. 2. Shapes of corrugations.