Thin-Walled Structures 130 (2018) 593–612

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Elastic buckling and load-resistant behaviors of double-corrugated-plate shear walls under pure in-plane shear loads

Jing-Zhong Tong*, Yan-Lin Guo, Jia-Qi Zuo

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

A R T I C L E I N F O

Keywords:
Double-corrugated-plate shear wall
Elastic buckling
Load-resistance
Pure in-plane shear load
Orthotropic plate model
Rigidity constants

A B S T R A C T

In this paper, a double-corrugated-plate shear wall (DCPSW) is proposed. It consists of two trapezoidally corrugated plates connected with high-strength bolts. It could be utilized in high-rise buildings as an alternative of the ordinary corrugated plate shear wall (CPSW) to resist lateral shear loads resulting from horizontal seismic or wind effects. In this paper, the elastic buckling behavior of DCPSWs subjected to pure in-plane shear loads is of major concern and is firstly investigated. The DCPSWs are equivalent into orthotropic plates, and accordingly, the rigidity constants, including flexural rigidity constants in the orthotropic directions (D_x and D_y) and the torsional rigidity constant (H), are defined and theoretically derived. By comparing the theoretical formulas of the rigidity constants with the results obtained from finite element (FE) eigenvalue buckling analyses, these theoretical formulas are validated to be accurate enough for practical engineering applications. Then, the shear elastic buckling formulas of the DCPSWs are provided by means of FE analyses and numerical fitting technique, and these formulas are validated to be able to conservatively predict the shear elastic buckling loads of DCPSWs with good accuracy. Finally, the shear-resistant behavior of the DCPSWs is investigated via a parametric study of FE models subjected to monotonic shear loads. It is concluded that the normalized aspect ratio could be regarded as a comprehensive design parameter which reflects the ultimate shear resistance of the DCPSW.

1. Introduction

The steel plate shear walls (SPSWs) have been widely utilized in high-rise buildings to resist lateral forces resulting from horizontal seismic effects. Generally, the SPSWs are infilled in the frames and welded with both the frame beams and columns. In practical engineering applications, the SPSWs easily buckle when subjected to laterally cyclic loads, especially for those with small thickness of the infilled plates. This is because the flexural rigidity of those flat plates is quite small, indicating that their shear buckling loads are quite small and the shear elastic buckling easily occurs. In addition, large noise would be produced when shear buckling occurs in SPSWs. In order to improve the stability of infilled shear walls when subjected to seismic loads, the corrugated plate shear wall (CPSW) was proposed as an alternative of the SPSW as seismic load resisting system. The CPSW is composed of corrugated plates infilled into frame structures [1,2], and commonly, the infilled plates are either of a trapezoidal or sinusoidal corrugated pattern [3,4]. Due to the existence of corrugations, the flexural rigidity of the infilled plates is significantly improved, leading to a larger elastic buckling load, and conveniences could be achieved during transportation and erection of the CPSWs. Moreover, during the construction process of building structures, the vertical pre-compression loads are inevitably introduced into SPSWs since the in-plane rigidity of the SPSWs is quite large. According to some previous researches [5,6], a reduction effect on the shear resistance of the SPSWs should be considered due to the pre-compression loads. In this consideration, another advantage of the CPSWs over SPSWs is realized by the engineers that the vertical pre-compression loads could be effectively released in CPSWs when their corrugations are laid horizontally [3]. In addition, a SPSW easily buckles under shear loads and its post-buckling shear resistance is achieved by forming the diagonal tension field, and the tension field directly anchors to the boundary elements, i.e. beams and columns of the SPSW. In order that the SPSW could achieve satisfactory post-buckling shear resistance, the flexural rigidities of the boundary elements should be restricted to be able to provide adequate lateral supports to the tension field, e.g., a minimum flexural rigidity of the frame in a SPSW is specified in AISC Seismic Provisions [7]. On the other hand, due to the existence of corrugations, it is considered that the formation of tension field rarely occurs in a CPSW. In this consideration, the flexural rigidity requirements of the boundary elements in a CPSW could be more easily satisfied compared with that of a SPSW, and this fact is also proved by the numerical simulation

* Corresponding author.
E-mail addresses: tongjingzhong13@tsinghua.org.cn (J.-Z. Tong), gyl@tsinghua.edu.cn (Y.-L. Guo), zuojq14@mails.tsinghua.edu.cn (J.-Q. Zuo).

https://doi.org/10.1016/j.tws.2018.06.021
Received 9 January 2018; Received in revised form 17 May 2018; Accepted 18 June 2018

Nomenclature

a	amplitude of the corrugation
b	width of the DCPSW
d_0,d_1,d_2,d_3	dimensions of the corrugation
d_b	horizontal distance between adjacent columns of bolts
D	flexural rigidity of flat plate
D_x,D_y,H	equivalent rigidity constants of the DCPSW
D_{x1},D_{y1},H_1	equivalent rigidity constants of the ordinary CPSW
E	Young's modulus of steel
f_{vy}	yield shear stress of steel
f_y	yield stress of steel
G	shear modulus of steel
h	height of the DCPSW
I_t	torsional moment of inertia of the DCPSW section
I_x	moment of inertia of the DCPSW section about the y-axis
k	shear elastic buckling coefficient of the DCPSW considering reduction effect
k_0	shear elastic buckling coefficient of the DCPSW without reduction
k_1	shear elastic buckling coefficient of the ordinary CPSW with single corrugated plate
m_x,m_y,m_{xy}	distributed moments applied on the boundaries of the orthotropic plate model
M_x,M_y,M_{xy}	moments applied on the boundaries of the orthotropic plate model
N	distributed shear load
N_{cr}	shear elastic buckling load
N_y	shear yield load
q	arc length of one repeating corrugation
t	thickness of the corrugated plate
w	out-of-plane deflection of the orthotropic plate
β	converted aspect ratio of the DCPSW
β_1	converted aspect ratio of the ordinary CPSW
γ	angle of the incline segment in the corrugation
δ	lateral displacement of the DCPSW
η	bolt distance factor of the DCPSW
θ	constant of equivalent orthotropic plate of the DCPSW
θ_1	constant of equivalent orthotropic plate of the ordinary CPSW
$\theta_x,\theta_y,\theta_{xy}$	average rotational angles in unit width of the orthotropic plate
λ	wave length of one repeating corrugation
λ_n	normalized aspect ratio of the DCPSW
υ	Poisson's ratio of steel
ω	reduction factor of elastic buckling coefficient considering discrete bolt connections

results provided in [8].

Numerous investigations on CPSWs have been conducted. The elastic buckling behavior of trapezoidal CPSWs was firstly investigated by Easley and Mcfarland [1,2] in early 1970s. In these researches, formulas were provided for prediction of the shear elastic buckling loads of CPSWs, which exhibit global elastic buckling. On this basis, Tong and Guo [3] investigated the elastic buckling behavior of CPSWs with vertical stiffeners, and elastic formulas were proposed. Dou et al. [4] investigated the elastic buckling behavior of sinusoidal CPSWs, in which the predictions of both the global and local buckling loads are involved. More recently, Hosseinzadeh et al. [9] investigated the elastic interactive buckling behavior of CPSWs under pure shear loads.

Apart from the shear elastic buckling behavior, the shear resistant behaviors of CPSWs under either monotonic or cyclic shear loads are also of major concern to the engineers. Correspondingly, a large number of experimental and numerical investigations were conducted. Berman et al. [10,11] performed cyclic tests of CPSWs, in which the corrugations of the infilled plates were laid diagonally with an inclination angle of about 45 degrees to the horizontal line; then, in this study, the cyclic test results of CPSWs were compared with the

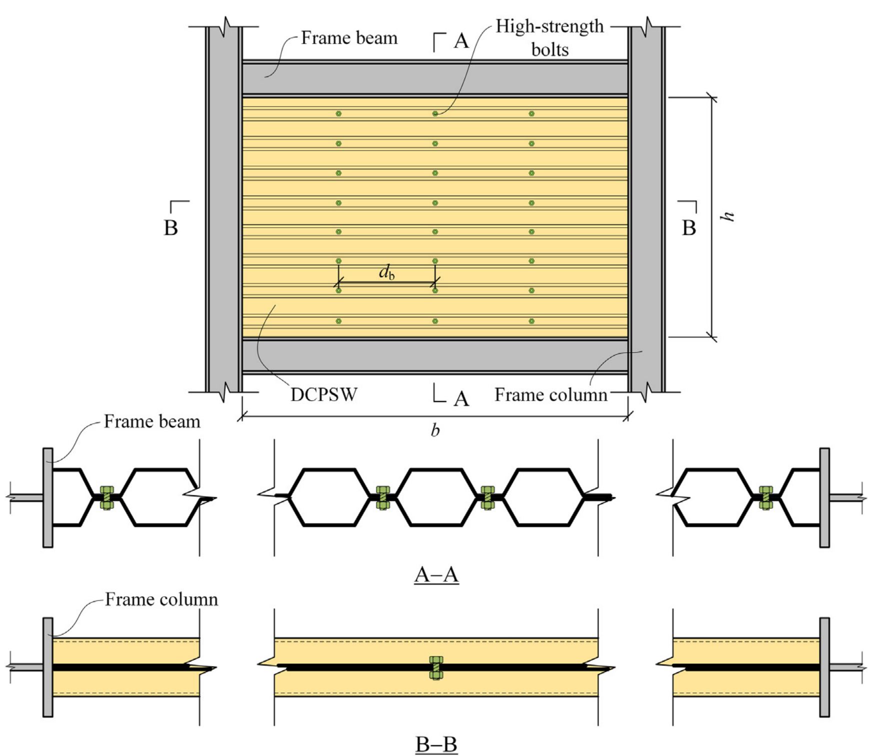

Fig. 1. Composition of the proposed DCPSW.