ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 18 (2018) 1547–1561

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Original Research Article

# Shear strength degradation of steel plate shear walls with optional located opening

*Mohammad Jalilzadeh Afshari* *, *Majid Gholhaki*

*Faculty of Civil Engineering, Semnan University, Semnan, Iran*

ARTICLE INFO

*Article history:*
Received 11 January 2018
Accepted 22 June 2018
Available online

*Keywords:*
Steel plate shear wall
Shear strength
Finite element
Tension field
Opening

ABSTRACT

Regarding high ductility and potential of steel plate shear walls in energy absorption, they are required to be very thin in thickness especially in upper floors of the building in order to resist lateral loads and sometimes it will reach to a fraction of millimeter in calculations. Since preparation of such thin steel plates is not simply possible, a thicker plate with an opening can be used to reduce stiffness. On the other hand, the existence of opening is inevitable due to architectural considerations such as lighting. In the present paper, shear strength of steel plate shear wall with openings in different zones has been studied by finite element method. As a result, an empirical simple dimensionless equation has been presented to estimate accurately the amount of decrease of shear strength of the wall with an arbitrary opening position in any zone of the plate. To validate the accuracy of suggested relation, numerous finite element models have been simulated with different geometric properties such as shape, diameter, location of opening, thickness and span to height ratio of plate. Comparing results with that of suggested relation and corresponding values of theoretic relations shows the accuracy of the proposed relation for applying in a wide range of steel plate shear walls with different geometric specifications.



## 1. Introduction

In recent years, many experimental researches have been conducted on steel plate shear walls under monotonic and cyclic loads and results show high stiffness, sufficient strength, excellent ductility, high energy absorption and dissipation of this seismic resisting system. Concerning that steel plate shear walls (SPSWs)[1] are used in seismic rehabilitation of the structures in addition to newly constructed structures, researchers have been interested in analytical study of steel plate shear walls.

Sabouri Ghomi and Robertz studied experimentally the effect of opening on behavior of steel shear panels with embedment of circular openings in the center of the plate under cyclic loads [1]. To construct any panel, the steel plate was bolted to boundary members and horizontal and vertical boundary elements were bound via simple connections. Cyclic

* *Corresponding author at*: Unit 5, No. 6, 9th East Aseman Ave., Sadaat Abad, Tehran, Iran.
E-mail addresses: jalilzadeh.afshari@semnam.ac.ir, m_jalilzadeh.afshari@yahoo.com (M.J. Afshari), mgholhaki@semnan.ac.ir (M. Gholhaki).

[1] Or steel plate walls (SPWs).

https://doi.org/10.1016/j.acme.2018.06.012

load was applied by diagonal corners via a 250 kN hydraulic jack. The panels were 300 mm deep, 300–450 mm wide and panel thickness was between 0.83 and 1.23 mm. Yield stresses of plates was considered equal to 219 and 152 MPa. Circular openings with 60, 105 and 150 mm diameters were tested at the center of plate. According to results, panel strength and stiffness are decreased due to the opening as follows [1].

$$\frac{V_{y\,Perf}}{V_{y\,Panel}} = \frac{K_{Perf}}{K_{Panel}} = \left(1 - \frac{D}{L}\right) \quad (1)$$

where $D$ is the opening diameter, $L$ is the panel width, $V_{y\,Perf}/V_{y\,Panel}$ and $K_{Perf}/K_{Panel}$ are ratios of strength and stiffness of panel with opening to the corresponding specimen without opening. They also stated that the suggested relation had the highest reducing effect for the opening at the plate center. Therefore, the use of Eq. (1) is very conservative for other opening locations. They also stated that $D$ parameter for the square and rectangular openings in Eq. (1) will be equal to diameter of circumscribed circle of the aforementioned openings [1,2]. They studied the strength and stiffness degradation of shear panel due to existence of a rectangular opening in stiffened and unstiffened panels and stated that strength and stiffness degradation due to the effect of opening are varied in panels with and without stiffener [3]. They also studied experimentally shear strength and stiffness of stiffened shear walls by making two symmetrical rectangular openings towards the plate center [4].

Bruneau and Purba modified Eq. (1) in perforated steel shear walls inside moment frame with reduced beam sections under a pattern of multiple regularly spaced circular openings throughout the infill plate using finite element method and numerical studies [5,6].

Alinia and Dastfan studied the effect of boundary members' rigidity on elastic shear buckling and post-buckling behavior of the panel via finite element method. As a result, torsional stiffness of boundary members had direct effect on increasing elastic buckling load but it was not effective on post-buckling strength. They also studied cyclic behavior, deformability and rigidity of stiffened SPSW [7–9]. Hosseinzadeh and Tehranizadeh studied via finite element methods the effect of great rectangular openings stiffened with local boundary elements on ductility, stiffness and shear strength of SPSW [10]. Valizadeh et al. studied experimentally the effect of opening sizes and slenderness ratio of steel plate on seismic behavior of steel plate shear walls under cyclic loads. Then, they studied amount of energy absorption of panels with openings using hysteresis curves resulted from specimens under study [11]. Similar experimental studies were conducted to investigate seismic behavior of stiffened and unstiffened shear walls with and without opening by Astaneh-Asl and the results were expressed in form of design codes based on seismic performance of steel shear walls [12]. Shekastehband et al. experimentally and numerically investigated the seismic behavior of high and low yield strength SPSWs with different circular opening ratios [13]. Sahebjam and Showkati experimentally studied the cyclic behavior of perforated carbon fiber reinforced polymer–steel composite shear walls in 2016 [14].

Seismic design of steel plate shear walls is based on very small thicknesses (in a fraction of mm) in upper floors of the building. Preparing such thin steel plates may be impossible in terms of availability. On the other hand, use of thicker plates increases shear capacity of the plate and subsequently ultimate load transferred to surrounding members. Thereupon, the demand for greater sections of adjacent beams and columns is increased. The simplest solution is to use a plate thicker than design demand and creation of opening for decreasing its stiffness. The present paper focuses on the effect of opening on decrease of shear strength of steel plate shear walls. As mentioned, theoretic relations are only valid for opening in the center of plate and their use for other areas

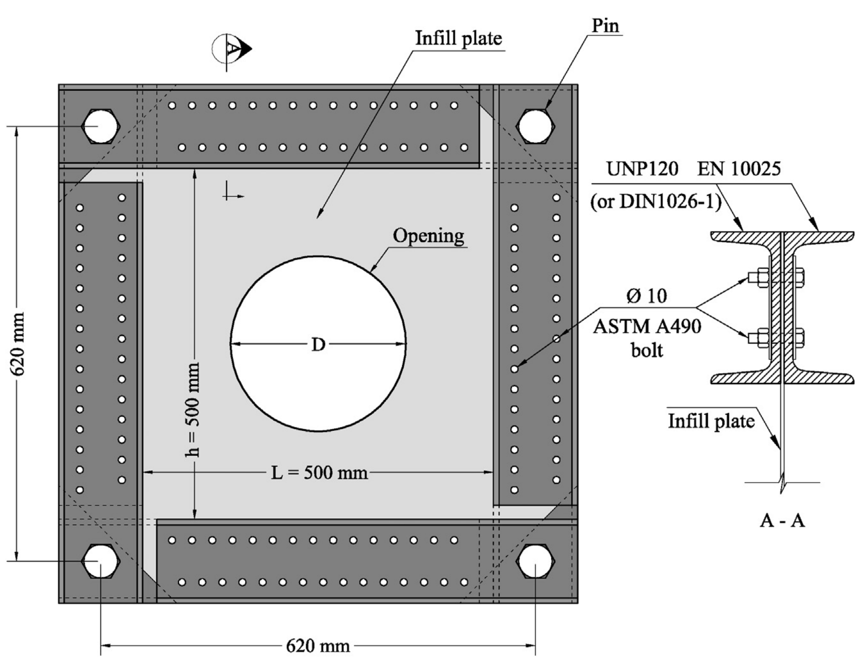


**Fig. 1 – Geometric specifications of experimental specimens.**