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Experimental study on the hysteretic behavior of steel plate shear wall with unequal length slits

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ABSTRACT

A steel plate shear wall with slits (SPSWS) is an effective anti-seismic component element, which owns good ductility and energy dissipation capacity. The infill steel plate is divided into flexural links by slits, which changes the path of conducting force. As a result, the SPSWSs obtain higher energy dissipation capacity and better ductility compared with conventional steel plate shear walls. However, both tests and finite element method (FEM) analysis have shown that the slits lower the ultimate bearing capacity and the lateral stiffness of the steel plate shear wall. In this case, two steel plate shear walls with unequal length slits (SPSWUS), i.e. papilionaceous SPSWUS and fusiform SPSWUS, are proposed and analyzed in this paper. Four 1/3-scaled test specimens are designed for the experimental study. Two of the specimens are SPSWUSs, and the other two are traditional SPSWSs. Testing of the systems were performed under cyclic lateral loading. Results show that SPSWUS has rather high energy dissipation capacity and good ductility as well as relatively high lateral stiffness and ultimate bearing capacity when compared with the traditional SPSWS. Experimental results correlate well with those from the finite element analysis, which validates the finite element model.

1. Introduction

Steel plate shear walls, as a new type of lateral resistant system, have been proven to exhibit high lateral stiffness and excellent ultimate bearing capacity in high rise buildings [1]. Ge et al. [2] conducted a shaking table test of a 1:3 scale semi-rigid steel frame with buckling-restrained steel plate shear wall to study the seismic performance of this type of structure. The results showed that the seismic resistance was adequate for survival in large seismic excitations. During the past 50 years, there is a large volume of published studies on steel plate shear walls with different design and detailing strategies. One approach employs heavily stiffened steel plate shear walls to ensure that the wall panel achieves its full plastic strength [3]. The employment of stiffened plates made of pure aluminium, with low yield strength and high ductility features [4], provides an effective dissipative capability to the whole structure, which can be controlled as a design parameter by choosing appropriate panel dimensions and varying the stiffeners arrangement [5]. Dissipative shear panel made of a low-strength material, namely the heath treated EN-AW-1050A aluminium alloy was further investigated and the obtained results signified that the buckling phenomena were mitigated compared with other more conventional shear panel typologies, characterized by the same geometry and material [6]. Tests of one story similar steel plate shear walls with and without stiffeners were carried out by Sabouri-Ghomi and Sajjadi. It was concluded that installation of stiffeners improved the behavior of the steel plate shear walls [7]. Natalia et al. [8] proposed a ring-shaped steel plate shear wall (RS-SPSW), consisting of a steel web plate cut with a pattern of holes leaving ring-shaped portions of steel connected by diagonal links. The ring shape resists out-of-plane buckling through the mechanics of a circular ring deforming into an ellipse. Eight 1:6 scaled test specimens, with two plate thicknesses and four different circular opening ratios at the center of the panel, were tested under the effects of cyclic hysteresis loading at the thin-walled structures research laboratory of Urmia University, Urmia, Iran. The obtained ductility of specimens shows the stable functioning of a system in the nonlinear range but existence of an opening at the center of the panel causes a noticeable decrease in energy absorption [9]. The hysteretic performance of steel perforated shear panels might be detrimentally influenced by pinching effects and softening. Therefore, a suitable analytical formulation for the prediction of the strength accounting for the influence of the detrimental effects and a useful predictive tool for defining the optimal perforation geometry to be adopted as a function of the expected shear demand were provided by De Matteis and Sarracco [10]. Otherwise, nonlinear seismic analysis was applied to design the perforated steel

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plate shear walls by predicting the design forces in the columns [11]. Astaneh-Asl [12] and Kulak et al. [13] summarized the multinational research on steel plate shear walls, including design models and procedures.

Inspired by the application of concrete shear walls with seams, traced to earlier studies by Omori et al. [14] and Mutoh et al. [15] who utilized slits to improve the earthquake resistance of concrete shear walls, a brand new type of earthquake-resisting element, steel plate shear walls with slits (SPSWS) was proposed. In recent years, there has been an increasing amount of literature on SPSWS. Hitaka and Matsui [16] studied the seismic design and inelastic behavior of SPSWS which relied on ductile flexural deformations provided by the numerous slits slotted in the panel. A total of 42 specimens were tested under monotonic and cyclic lateral loading to validate the performance of the shear wall. All specimens showed large ductility. Results supported the proposed equations for calculating the strength and stiffness of the wall panels. Ke and Chen [17] came up with a calculation equation aiming at estimating the energy dissipation capacity of SPSWS and then the equation was assured by results from FEM analysis. Width versus height ratio and width versus thickness ratio were considered as the influential factors of the energy dissipation capacity of SPSWS.

Cortés and Liu [18] performed a research on steel slit panel-frame system via an experimental program, mainly focusing on the fundamental characteristics of the steel slit panels, and the behavior of the steel slit panels within the frame. The research found that all the steel slit panels (SSPs) tested in the experimental program were capable of undergoing interstory drifts of at least 5% without causing reduction in load carrying capacity below 80% of its ultimate strength. The stiffness in the SSP is clearly affected by the flexural rigidity of the beams connected to the panels. Hebdon et al. [19] proposed some advices on designing slit walls in a frame that considers the benefits of the steel slit panel frame (SSPF) such as easing of fabrication and erection, function as replaceable fuse elements, and reduce cumulative story stiffness reduction due to the SSP-frame interaction.

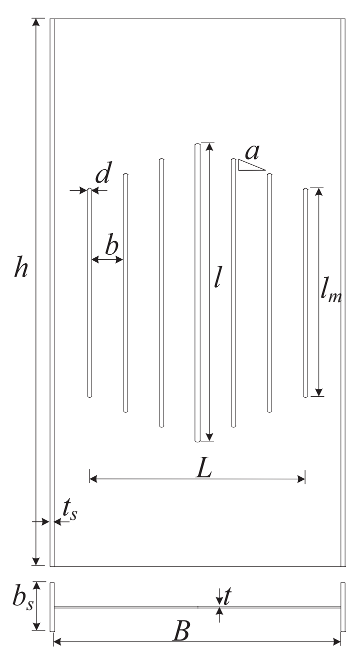
The steel slit damper (SSD), fabricated from a standard structural wide-flange section with a number of slits cut from the web, is an extension application of the SPSWS. Chan and Albermani [20] proposed steel slit dampers with weld-free design and analyzed its hysteretic behavior based on nine sets of tests. The results showed that the weld-free SSD yielded at a small lateral angle, which meant the large quantity of energy was absorbed in the early period of the earthquake. Jacobsen et al. [21] came up with a new passive damping device composed of steel plate with slits. Analysis demonstrated that it exhibited stable hysteretic performance with good ductility. Tests on slits dampers with frame were then carried out and results showed that this kind of system behaved excellent hysteretic performance and was recoverable after the earthquake.

Slits setting in the SPSW decreased the lateral stiffness and ultimate lateral loading capacity to some degree [22], which aroused concerns on satisfying the designing requirements for practical use. Approaches including employing diagonally stiffener [23] and adding concrete plate were adopted to ensure that the steel plate achieves the objective of excellent lateral stiffness, ultimate bearing capacity, and ductility.

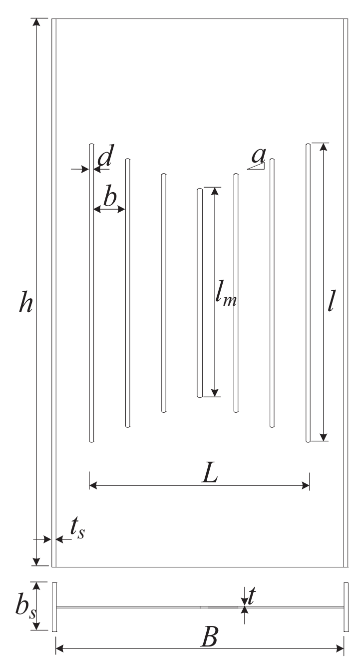
In this study, two types of SPSWUSs (the papilionaceous and the fusiform) are introduced and investigated systematically for the first time. This paper aims at putting up a simple approach to improve the stiffness and loading capacity with given designing parameters. Four 1/3-scaled test specimens are designed for the experimental study. Two of them are SPSWUSs, and the others are traditional SPSWSs. The main parameters studied in this paper were energy dissipation capacity, ultimate lateral loading capacity, lateral stiffness, ductility and failure modes. Results showed that SPSWUS had better energy dissipation capacity and ductility as well as relatively higher lateral stiffness and ultimate lateral loading capacity than conventional SPSWS. Results from experimental tests and finite element analysis were compared and good correlations were observed.

2. Concept of steel plate shear wall with unequal length slits

Two types of SPSWUSs, fusiform specimen (Fig. 1(a)) and papilionaceous specimen (Fig. 1(b)) are analyzed in this study. The two specimens have the same geometrical configurations including geometric dimension, slits spacing and stiffener dimensions. For papilionaceous specimen, the length of slits increases from the middle to edge. While for fusiform specimen, the length of slits decreases from the middle to



(a) Type A (fusiform specimen)



(b) Type B (papilionaceous specimen)

Fig. 1. Geometrical model of steel plate shear wall with unequal length slits.