Thin-Walled Structures 78 (2014) 57–69

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Experimental evaluation of dual frame structures with thin-walled steel panels

D. Dubina [a,b], F. Dinu [a,b,*]

[a] The Politehnica University, Timisoara, Romania
[b] Laboratory of Steel Structures, Romanian Academy, Timisoara Branch, Romania

ARTICLE INFO

Article history:
Received 5 July 2013
Received in revised form
31 December 2013
Accepted 1 January 2014
Available online 1 February 2014

Keywords:
Thin walled steel shear wall
Link beam
Semi-rigid connection
Energy dissipation
Behavior factor

ABSTRACT

Steel plate shear walls (SPSW) are efficient structural systems for resisting lateral loads owing to their high initial stiffness and stable cyclic behavior in the plastic range. The seismic response may be improved by connecting plate walls through link beams. Beam-to-column connections may range from simple connections to full rigid moment resisting connections. Given that initial stiffness is provided mainly by the plates′ rigidity, simple connections between horizontal and vertical boundary elements can be employed. Rigid, but expensive, connections may prove more beneficial than simple ones by increasing the frame capacity and also reducing residual drift after an earthquake. The more cost-effective semi-rigid connections between these members are also expected to increase capacity and reduce residual drift in comparison to simple connections. This study investigates the behavior of dual steel frames with thin walled steel shear walls and link beams. Four half-scale specimens were tested under monotonic and cyclic loading for characterizing energy dissipation and evaluating seismic behavior factors. The specimens exhibited good, stable behavior. The rigid beam-to-column connections, when compared to the semi-rigid ones, improved the ultimate capacity and dissipated energy. The experimental program provides a basis for validating a numerical model of slender SPSW.

1. Introduction

1.1. Structural system

Steel plate shear walls (SPSW) are efficient lateral load resisting systems and can act as an alternative to traditional systems. Depending on their slenderness, SPSW may yield under applied shear before they buckle or may buckle while almost elastic. Depending on the construction and design, the plate walls may be stiffened or unstiffened. Prior to 1980s, SPSW design was based on the concept of preventing the out of plane buckling of the infill panel by the use of heavily stiffened steel plates [1]. Such systems presented a good seismic behavior thanks to their dissipation capacity through the shear mechanism. However, when compared with reinforced concrete shear walls, the system was not very competitive, due to its higher cost. In order to make the SPSW more competitive, further studies focused more on slender systems, which utilize unstiffened thin walled steel panels and resist lateral forces mainly through post-buckling tension field action ([2–8]). Part of this research resulted in the development of first design guidelines for plate wall structures. Thus, the 2001 edition of the Canadian Steel Design Standard, CAN/CSA S16-01 [9] included design guidelines for SPSW structures, followed by the 2009 edition [10]. In the US, the 2005 edition of the AISC Seismic Provisions [11] incorporated first recommendations for the design of SPSW systems, followed by the 2010 edition [12].

The main advantages of slender SPSW consist of economy in steel weight due to thinner walls, fast construction time and easier retrofit [13]. Furthermore, with appropriate design and detailing, SPSW systems may be classified as ductile systems. Code designed SPSW are also capable of meeting drift limitations when subjected to ground motions that approximate the design shaking [14]. However, there are some concerns regarding the seismic response of slender steel plate shear wall systems because they buckle during the early stages of lateral loading and therefore the response of the system is characterized by a pinched cyclic behavior. The pinching effect decreases the area of the hysteresis loops and, as a result, decreases the energy absorption of SPSW. In order to reduce pinching and increase energy absorption, plate walls may be combined with frames that have rigid moment connections between boundary elements. The resulting frame action provides some stiffness around zero storey drift [8]. Another method is either to use a thicker plate, which is uneconomical, or to use stiffeners [15]. Too much stiffening leads to a loss of structural deformability and therefore, an optimum amount of stiffeners should be used to achieve both sufficient rigidity and deformability.

Two issues have recently raised interest for seismic applications of SPSW. The first issue is related to the potential

* Corresponding author.
E-mail address: florea.dinu@ct.upt.ro (F. Dinu).

0263-8231/$ - see front matter
http://dx.doi.org/10.1016/j.tws.2014.01.001

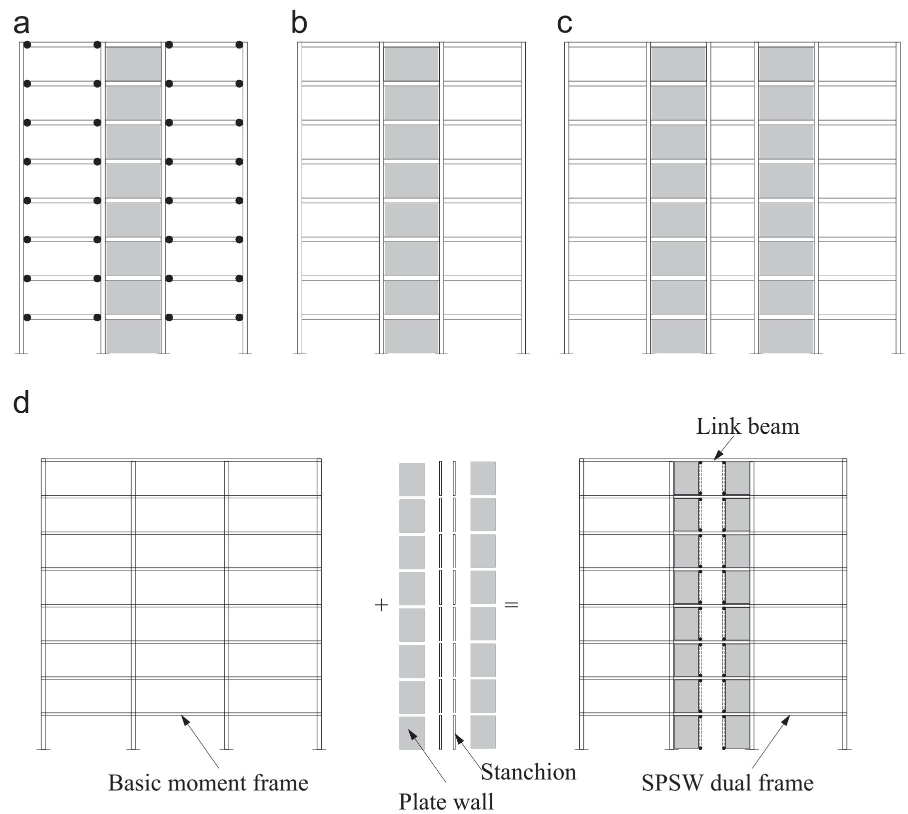

Fig. 1. SPSW frame systems: (a) singular shear wall inside gravity frame; (b) dual system with shear wall and moment frames; (c) dual system with shear wall and coupling beams; (d) dual system with link beam.

of improving the seismic behavior by linking two or more plate walls. Thus, typical SPSW systems include either singular SPSW (Fig. 1(a)), where the shear wall is the only element resisting storey shear, or dual SPSW systems with parallel moment frames (Fig. 1(b)). A coupled shear wall system is a specific dual system, whereby a coupling beam connects two shear wall bays (Fig. 1(c)). A particular system, which consists of inserting plate walls inside moment frames, aiming at providing additional lateral rigidity, has been proposed and studied by the authors (Fig. 1(d)). The plate wall is bordered by additional vertical elements (stanchions) having simple connections at their ends to the beams. The beam outside the plate wall acts as a short, intermediate or long link, depending on the relative length of the plate walls and bay width. Such systems may be applied for new constructions and also for upgrading the lateral resistance of existing constructions. For large bays, the shear wall inside the moment frame (Fig. 1(b)) results in a large length to height ratio (L/h) that can make the shear panel to be excessively flexible. Therefore, the system with plate walls and link beam (Fig. 1(d)) may be used instead. In comparison with the systems based on singular shear walls inside gravity frames, the dual systems shown in Fig. 1(b–d) have better seismic response, higher dissipation capacity, and smaller residual drifts. Their use may also improve the overturning stiffness and reduce the axial force demand on vertical boundary elements [5]. Despite the potential benefits of such systems, there is limited research available, while current code provisions contain limited guidance for their design [16,17].

The second issue is related to the reduction of residual displacements after an earthquake so as to reduce the cost of intervention. Residual or permanent displacements are considered harmful because they suggest structural damage. Repairing damaged structural elements can be technically tasking if not impossible; nevertheless, the process is expensive. If the damage is localized in easily replaceable members, repairing is easier and costs less. In addition, structure recentering allows for easy replacement of damaged or "sacrificial" members. The particular behavior of SPSW makes them appropriate for such applications [18]. The results of our previous study [19] also showed that dual structural configurations composed of a rigid subsystem with removable ductile elements and a more flexible subsystem, designed to remain elastic, are appropriate for demonstrating the "removable dissipative element" concept. The use of simple connections between boundary beams and columns reduces the recentering force; thus, rigid moment connections may prove more beneficial. When a shear wall is placed inside a moment frame, the corners of the shear wall plate act as gusset plates above and below the moment connection and impose considerably less rotation demand on rigid connections. This particular behavior suggests that connections with lower stiffness (i.e., semi-rigid connections) can be used instead of rigid ones. Moreover, semi-rigid connections reduce costs and enhance constructability. Frames of the type shown in Fig. 1(b–d) may be designed to prevent plastic deformation in the frame members for low-to-moderate seismic action, and thus to recover their initial position after the damaged panels are replaced.

This study focused on the seismic performance of thin walled SPSW with link beams. Rigid and semi-rigid moment connections between horizontal boundary elements (HBE) and vertical boundary elements (VBE) have been employed. We evaluated the influence of HBE–VBE connections on overall system behavior, and the behavior factor. For addressing the abovementioned issues, a research program including experimental testing and numerical analyses was developed within the Department of Steel Structures and Structural Mechanics at the Politehnica University, Timisoara [20]. Structures were tested under monotonic and cyclic loadings. This paper presents the results of the experimental program.