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Experimental study of cross stiffened steel plate shear wall with semi-rigid connected frame

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ABSTRACT

There is complex interaction between the infill steel plate and frame edges in the steel plate shear wall structure. The bearing capacity and stiffness of SPSW structure not only depends on the section sizes of frame and wall, but also relates to the stiffness of joint connection. The beam-to-column connection is easy to construct using semi-rigid joints which enhances the deformation and energy dissipation capacities of SPSW structure and effectively avoids the brittle failure of traditional welded joint. Based on the pseudo static test of cross stiffened SPSW structure with semi-rigid connected frame, this paper analyzes the failure mode and energy dissipation mechanism of the structure, discusses the influence of joint connecting forms and arrangement of stiffeners on the seismic performance of the structure. According to the results, the effect of the beam-to-column connection stiffness on the bearing capacity of SPSW structure is small and the differences among the ultimate bearing capacities are less than 5%. When the inter-story displacement angle is 1/50, the ductility factor is between 3.69 and 4.4, which indicates that SPSW structure is good in plastic deformation capacity. The cross stiffeners divide the thin steel plate into small cell plates. By setting the cross stiffeners, the thin steel plate is divide into small cell plates, and mainly pattern of local buckling.

1. Introduction

The steel plate shear wall (SPSW) was put into use in 70's of the last century. Compared with the traditional concrete shear wall structure, the SPSW structure has obvious advantages in thickness, light in self-weight, and fast to construct. With stable hysteretic behavior and good energy dissipation capacity, the SPSW structure is widely applied in high-rise buildings in high-intensity seismic regions and the maintenance and reinforcement of post-seismic buildings [1–2]. The infill steel plate can be either constructed with or without stiffeners. The unstiffened SPSW, which takes advantage of the post-buckling strength of steel plate under strong earthquake, has excellent ductility and energy dissipation capacity. Stiffened SPSW can restrain the out-of-plane buckling of steel plate and increase the buckling bearing capacity and lateral displacement stiffness of the structure.

Caccese et al. [3], Driver et al. [4], and Lubell et al. [5] carried out many experimental researches on the unstiffened thin steel plate wall. According to the experimental results, local buckling would appear when the thin steel plate wall was under small horizontal load. Tension band forms in the diagonal direction of wall. The energy dissipates through the deformation caused by the buckling of thin steel plate. Due to the tension band relaxation and plastic residual deformation, the stiffness of steel plate softening and the hysteretic loop "shrinks". Thorburn and Timler [6–7] presented a strip model after using thin steel plate buckling strength. The analytic outcome of this method has been compared with experimental results, and several methods like modification of stress-strain curves [8] and correction in angle of strips [9] have been recommended for modification of the strip model. Berman and Bruneau developed equations for determining the shear strength of steel plate shear walls by using plastic analysis [10–11] of the strip model together with considering surrounding frame. Plate-Frame interaction theory (PFI) was presented for predicting the linear and nonlinear behavior of different steel plate shear walls configurations including thin or thick steel plates, with or without stiffeners and opening by Sabouri Ghomi, Aliniaand Ventura [12–16]. Based on some of these research studies, CAN/CSA 16-01 [17] provided mandatory design clauses to allow SPSWs to buckle and develop diagonal tension fields. Thereafter, several aspects of SPSW design requirements were introduced in AISC 341 [18] and AISC Design Guide 20 [19].

To retard the buckling of thin steel plate, increase the bearing

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Table 1
Specifications of experimental specimens.

Item	HAC	HEC	HBC
Middle beam (mm)	HN200 × 100 × 5.5 × 8	HN200 × 100 × 5.5 × 8	HN200 × 100 × 5.5 × 8
Top beam (mm)	HN300 × 150 × 6.5 × 9	HN300 × 150 × 6.5 × 9	HN300 × 150 × 6.5 × 9
Column (mm)	HW150 × 150 × 7 × 10	HW150 × 150 × 7 × 10	HW150 × 150 × 7 × 10
Stiffener form	Cross stiffener	Cross stiffener	Cross stiffener
Joint connection style	Top and seat angles with double web angles	End plate	Welded bolted
Top and seat angle (mm)	L140 × 90 × 8	–	–
Web angles (mm)	L70 × 8	–	–
End plate thickness (mm)	–	10	–
Stiffener thickness (mm)	–	– 40 × 4	– 40 × 4
Infill steel plate thickness (mm)	4	4	4

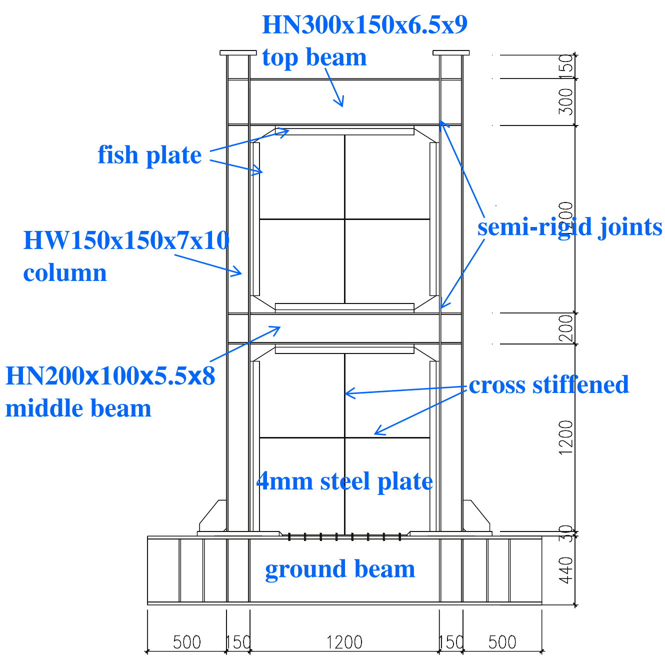


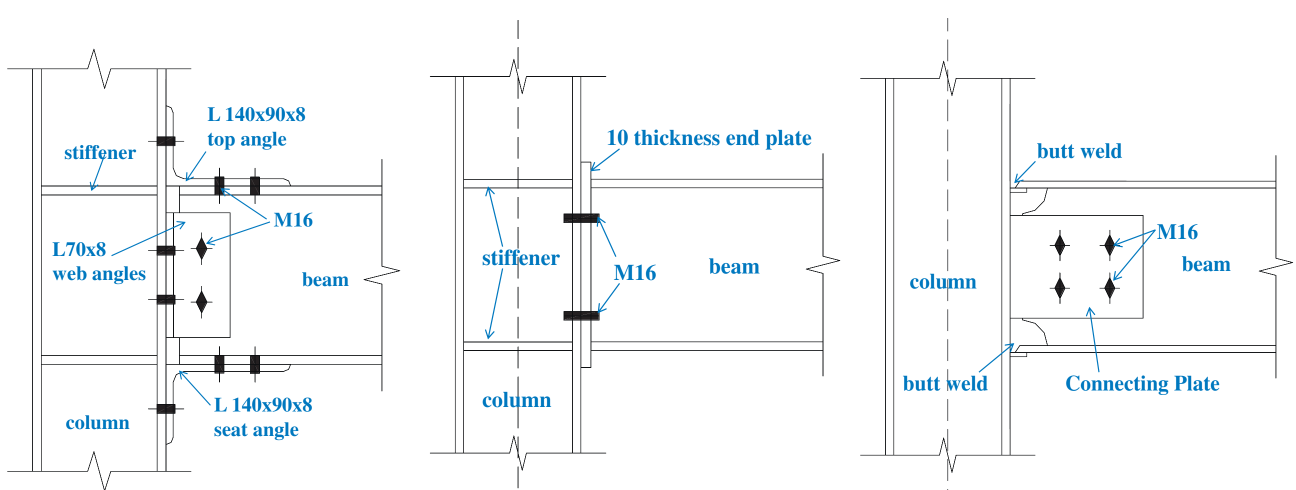
Fig. 1. Design of specimen.

capacity and stiffness of wall, and reduce the consumption of steel, reasonable arrangement of stiffeners, which can increase the stiffness of thin steel plate and avoid the "shrinkage" of hysteretic loop, is needed.

Table 2
Material properties.

Item	Yield stress f_y (MPa)	Ultimate stress f_u (MPa)	Elastic modulus E (10^5MPa)	Tensile elongation δ(%)
HW150 × 150 × 7 × 10	292.87	437.3	1.99	45.0
HN200 × 100 × 5.5 × 8	312.90	463.3	2.01	41.0
HN300 × 150 × 6.5 × 9	285.61	451.0	2.01	41.0
L140 × 90 × 8	297.48	429.0	2.10	43.3
L70 × 8	353.31	461.6	2.10	40.0
4 Thickness panel	301.18	467.9	2.01	36.0

Hughes et al. [20] developed some improved for elastic local plate buckling and overall panel buckling of uniaxially compressed stiffened panels. Byklum et al. [21] provided a tool for the buckling assessment of stiffened panels by deriving a computational model for global buckling and post buckling analysis of stiffened plates subjected to biaxial in-plane compression or tension, shear and lateral pressure. Alinia et al. have been investigating the various aspects of stiffened and unstiffened shear panels [22–24]. The optimization of transverse stiffeners in plate girders was discussed in [23]. Deformability and rigidity of stiffened shear panels under cyclic loading were evaluated in [24]. In recent years, Sabouri and Sajjadi [25] tested 4 one story one span SPSWs with a central stiffened rectangular. Hosseinzadeh [26] investigated the behavior of SPSWs with and without stiffened large rectangular openings. Nateghi [27] investigations to that the diagonal stiffeners increase shear strength and improve cyclic behavior of a thin SPSW. Alavi [28] experimentally developed a formula and verified it for the estimation of shear strength of a perforated and diagonally



(a) top and seat angles with double web angles connection (b) end plate connection (c) Welded bolted connection

Fig. 2. Details of the semi-rigid connection.