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Cyclic behavior of low yield point steel shear walls

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Abstract

This paper presents the research works on the cyclic behavior of low yield point (LYP) steel shear wall. In the LYP steel shear wall system, the LYP steel plate is used for steel panel and conventional structural steel is used for boundary frame. A series of experimental studies were carried out to examine the stiffness, strength, deformation capacity, and energy dissipation capacity of the LYP steel shear wall under cyclic load. The effect of width-to-thickness ratio of steel plate, continuity of shear wall, and the design of beam-to-column connections on the boundary frame was examined. Good energy dissipation capacities were obtained for all specimens studied. Excellent deformation capacities were obtained from both rigid frame–shear wall system and simple frame–shear wall system. The LYP steel shear wall is able to maintain stable up to 3–6% of story drift angle. A two-force strip model was also proposed to simulate the elastic and inelastic behavior of shear wall system. Good correlations were found between experimental and analytical studies. Based on these research findings, suggestions are made for the design of LYP steel shear wall systems.

Keywords: Elastic buckling; Energy dissipation; Low yield point steel; Steel shear wall; Inelastic buckling; Two-force strip model

1. Introduction

Steel structures have been widely used in the construction of buildings in seismic active area due to its superior strength and ductility. Steel buildings are usually designed as the moment resisting frames or braced frames. There are pros and cons for both systems. For example, the stiffness of braced frame is usually larger than that of moment frames. However, the ductility of moment frame is usually superior to that of braced frame. Besides, the construction of braced frame is more complicated and its cost is usually higher than that of moment frame. The steel shear wall is another possible option for seismic resistance. The steel plate can be welded or bolted to the boundary frame. Research works have been carried out on the thin steel plate shear walls. Experimental works of the thin steel plate shear walls under cyclic load have been reported [1–3]. Analytical studies on the shear buckling behavior and the behavior of multi-story thin steel wall system have been conducted [4–7]. The fundamental behavior of steel shear wall is similar to that of reinforced concrete shear wall. However, the strength of steel is much larger than that of concrete. The shear buckling of thin steel plate usually governed the ultimate strength of the steel plate shear wall. Elastic and inelastic shear buckling behavior of the steel plate is the major concerns of thin steel plate shear wall. Although the buckling failure of the shear panel can be deferred by adding stiffeners, this will increase the construction cost. Besides, the pinching of thin steel plate under cyclic load may reduce the energy dissipation capacity of steel shear wall. Adding concrete covering on the steel panel can increase its in-plane stiffness and enhance its buckling performance [8].

In recent years, the advance of steel production has made the new structural steel available. The Low-Yield-Point Steel (LYP steel) possesses extremely low yield strength and high elongation properties. The yield stress of this type steel can be as low as 100 MPa, which is about one-third of the convention structural steel such as ASTM A36 steel. Yet, its elongation properties can exceed 40% which is more than two times of the conventional structural steel. The LYP steel also possesses low yield ratio (the ratio between yield stress to ultimate stress) which is only 0.34.

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With low yield ratio, the structure is able to redistribute the plastic stress and provide a larger inelastic zone. The LYP steel has been used in the steel dampers to dissipate earthquake energy [9,10]. The LYP steel can be used for the steel wall system. With proper design, the LYP steel shear wall is able to yield at predetermined force level and dissipate the seismic energy via plastic deformation, and at the same time possessing ample post-yield stiffness till reaching its ultimate strength. The low yield strength also provides better strength ratio between the shear wall and the surrounding frame with good arrangement of capacities. With lower yielding strength of steel shear wall, it is easier to design the system to let the shear wall yield prior to that of the surrounding frame and to ensure that the frame would not collapse before the wall reaches its ultimate strength. This reported research is aimed at examining the basic behavior of LYP steel shear walls. A series of experimental and analytical studies are conducted to examine the elastic and inelastic behavior of LYP steel shear walls at recursion of cyclic load. Recommendations for the design of this type of LYP steel shear wall are also proposed.

2. Experimental study of LYP steel shear wall

Five specimens are designed to examine the behavior of LYP steel shear wall under cyclic load that simulate the recursion of seismic excitation. The low yield point steel plate LYP100 is used for the shear panel, and conventional steel is selected for the boundary beams and columns. The dimensions of LYP steel plates of specimen nos. 1 and 2 are 1250 × 1250 mm with plate thickness of 8 mm. The dimensions of LYP steel plates of specimen nos. 3 and 4 are 1250 × 870 mm with plate thickness of 6 mm. The mechanical properties of steel used in this study are listed in Table 1. The typical stress–strain relationships of conventional steel and LYP-100 steel used is shown in Fig. 1.

Table 1
Mechanical properties

Specimen	Material	F_y (MPa)	F_u (MPa)	F_y/F_u
No.1	7 mm plate	444.85	555.81	0.80
	9 mm plate	335.84	453.49	0.74
No.2	11 mm plate	438.95	540.49	0.81
	14 mm plate	317.19	442.19	0.72
No.3	9 mm plate	381.25	487.89	0.78
No.4	14 mm plate	375.08	472.57	0.79
No.5	9 mm plate	425.21	550.45	0.77
	14 mm plate	419.31	535.13	0.78
LYP steel	6 mm plate	93.77	274.96	0.34
	8 mm plate	92.84	272.15	0.34

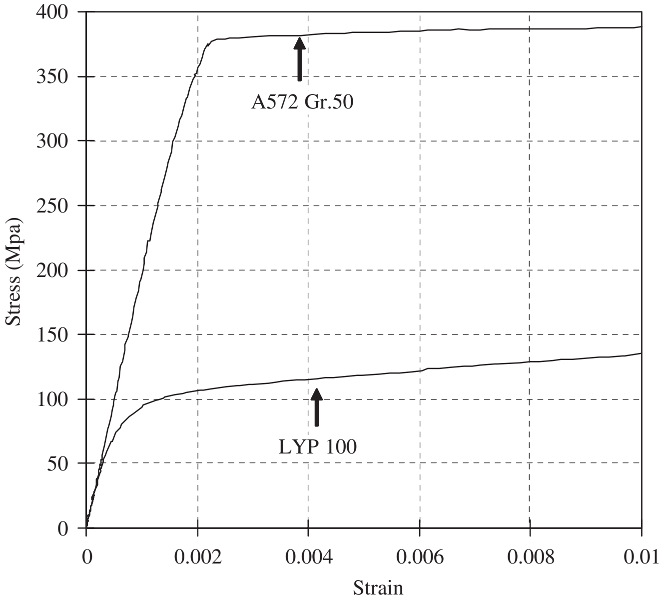

Fig. 1. Typical stress–strain curve of steel used.

Specimen no. 1 is aimed at studying the fundamental behavior of unstiffened steel shear wall made of LYP steel surrounded with beams and columns as its boundary members. The LYP steel plate is of square type with width-to-thickness ratio of 156. Specimen no. 2 is similar to specimen no. 1, except an extension of 15 cm steel plate is added to the bottom of the boundary beam. This is to simulate the continuity of shear wall from the lower part. Specimen nos. 3 and 4 are aimed at examining the behavior of the mid-story shear wall system with continuous shear panels on its top and bottom. Specimen no. 3 adopted an unstiffened LYP steel plate with width-to-thickness ratio of 200, and height-to-thickness of 146. The design of specimen no. 4 is same as specimen no. 3, except a horizontal and a vertical stiffener are added so that the width-to-thickness ratio becomes 100 while the height-to-thickness ratio is 73. These values are only half of that of specimen no. 3. This is to examine the effect of width-to-thickness (height-to-thickness) ratio on the seismic behavior of steel plate wall. The design of specimen no. 5 is the same as specimen no. 4, except simple connections are adopted for the beam-to-column connections of boundary frames. This is to examine the effect of rigid or simple beam-to-column connection of the boundary frame. Fig. 2 shows the relative locations of the specimens studied in a steel shear wall building system. Figs. 3 and 4 show the design of the specimens. Table 2 shows the summary of the design of specimens.

The test setups are shown in Fig. 5. The loading protocol is shown in Table 3. Following the loading protocol, the specimens are subjected to cyclic load with increasing load or displacement amplitudes. The variations of stiffness, energy dissipation capacity, and the ultimate strength are the major characteristics that affect the seismic performance of the steel shear wall system. The loading tests were stopped when the load has passed its peak value and decayed to the load less than 80% of its ultimate value. The hysteresis behaviors of the specimens tested are shown in Fig. 6. Fig. 7 shows the typical deformation pattern after