Engineering Structures 160 (2018) 281–292

Contents lists available at ScienceDirect

Engineering Structures

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

Experimental study on seismic behavior of steel plate reinforced concrete composite shear wall

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ARTICLE INFO

Keywords:
Steel plate reinforced concrete composite shear wall
Composite shear wall
Cyclic loading tests
Seismic behavior
Hysteretic model

ABSTRACT

Steel plate reinforced concrete composite shear wall (abbreviated as SPRW) is a novel type of composite shear wall which consists of a steel plate incased in the middle of a reinforced concrete shear wall. This arrangement aims at improving the performance of the wall, as steel plate can effectively increase the seismic behavior and concrete can protect steel plate from bulking and corrosion. In this paper, a total of 16 SPRW specimens and 3 traditional reinforced concrete (RC) walls are designed for the cyclic loading test to study the seismic performances, including failure phenomena, failure mechanism, load carrying capacity, ductility and energy dissipation characteristics, etc. Based on the extensive experimental results, the influences on the seismic behavior of SPRW are analyzed through varying parameters, e.g. aspect ratio, thickness of the wall and the steel plate, structural detailing. Finally, the hysteretic curve model and shearing capacity are generalized based on massive test data, and the design formula of shearing capacity is also proposed based on current design codes.

1. Introduction

Earthquake is an unexpected natural disaster threatening human's lives and properties. Many seismic measures have been proposed to reduce its destructive results. One way is to install dampers in the specific part of structure for controlling the dynamic response [1–6]. Another way is to optimize the current structural members to dissipate energy through the structure itself. The traditional reinforced concrete (RC) shear wall tends to develop tension cracks in the tension zones and crush in the localized compression areas during large cyclic excursions. Such cracks and crushing failures result in splitting and spalling failure of the wall with serious deterioration of stiffness and reduction in strength. Therefore, it is necessary to optimize the traditional RC shear wall for better seismic performances. On the other hand, examples of very good behavior of traditional RC wall (when properly designed) under severe input ground motions are available in literature. A couple of examples are reported in [7,8]. With the development of urbanization, the need of high-rises leads to some other directions of optimization.

Experimental results and numerical analysis indicate that the composition of steel and concrete has theoretical value and practical significance in bearing shear force [9–13], hence the composite shear wall with steel plate and concrete is proposed. To be classified by the position of the steel plate, the composite shear wall has two categories, as shown in Fig. 1. Fig. 1(a) and (b) shows composite walls whose steel plates are outside the concrete panel unilateral or bilateral. Researchers have carried out experiments on these kinds of walls and found that reinforced concrete shear walls with steel plate unilateral or bilateral both have excellent strength and ductility [14–19]. However, they have drawbacks of easier buckling of steel plates, the construction difficulty of connection between wall and floor and the erosion of steel plates.

To meet the needs of high-rise structures, steel plates can also be encased in the concrete, as shown in Fig. 1(c) and (d). The composite shear wall in Fig. 1(c) is a kind of precast shear wall. The steel frame and the steel plate are installed at the beginning, while the concrete panels are installed by bolts at the last phase of the construction [20]. In this kind of structure, the concrete panels are used only as the out-of-plane restraint, hence their material properties are not fully used. Moreover, their bolts and steel exposed in the air are easily destroyed because of fire or erosion.

The composite shear wall shown in Fig. 1(d) is a kind of cast-in-place shear wall whose reinforcements, steel channels and steel plate are arranged in order before casting. This kind of composite shear wall is the research object in this paper, which named as steel plate reinforced concrete composite shear wall (SPRW). Such structural component makes full use of steel plates and concrete and it has low

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https://doi.org/10.1016/j.engstruct.2018.01.050
Received 1 September 2017; Received in revised form 14 January 2018; Accepted 17 January 2018

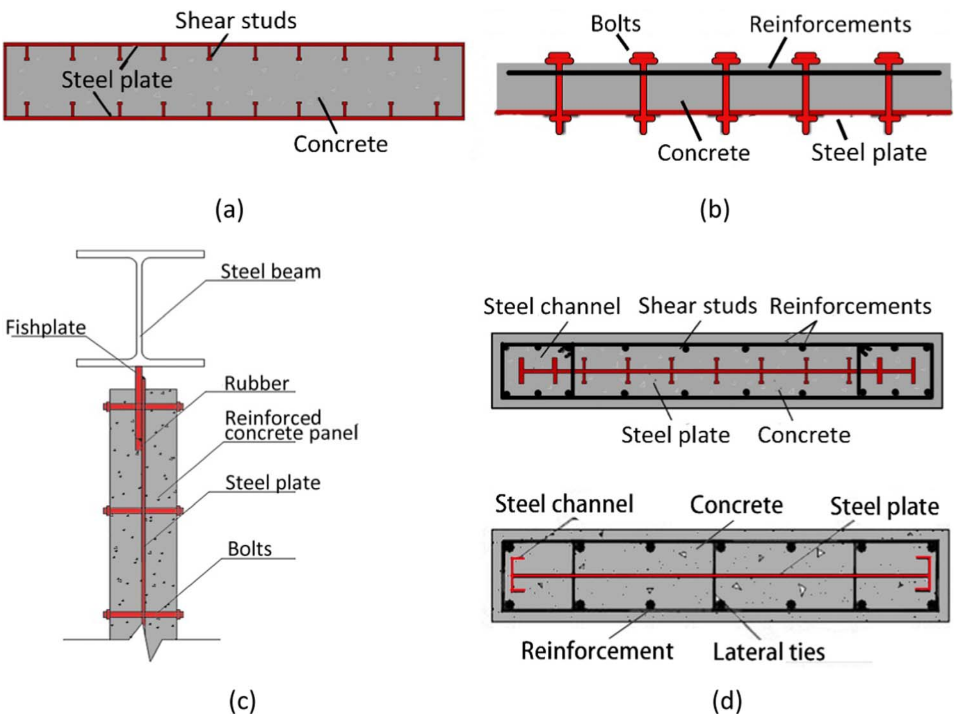

Fig. 1. Schematic diagram for steel-concrete composite shear wall. (a) Double skin steel-concrete composite wall; (b) Single skin steel-concrete composite wall; (c) Infill-plate concrete shear wall; (d) Steel plate reinforced concrete shear wall (SPRW).

requirements of fire resistance and durability.

However, there is limited understanding of such structural member no matter in practical engineering field or in theoretical research field. Wang et al. [21] simulated the steel plate reinforced concrete walls whose primary parameters varied in the axial load ratio, the ratio of steel plate and the ratio of web reinforcement in RC shear wall. However, the influence of some key parameters, such as thickness of the steel plate, thickness of the wall, aspect ratio and detailing between concrete and steel plate, on the seismic behavior of SPRWs is still short of systematic research, especially for the corresponding experimental study, which will certainly restrain the application of such structural member.

Consequently, a total of 16 SPRW specimens and 3 traditional RC walls with various parameters are tested. Their seismic performances, including failure phenomena, failure mechanism, load carrying capacity, ductility and energy dissipation characteristics are investigated. The key influence of some important parameters is also analyzed for the understanding of the seismic mechanism. Finally, the design formula of shearing capacity is also proposed based on current design codes. This paper systematically investigates the seismic behavior of SPRW, from extensive experiments, parametric study and practical design formula, which will provide reference for engineering design and promote its applications in future building constructions.

2. Experimental design

2.1. Specimen design

A total of 16 SPRW specimens are designed at the scale of 1:2. The properties are listed in Table 1, and the details are shown in Fig. 2. Another three parallel specimens of traditional RC walls equivalent in dimensions are also designed as a control group. To study the seismic behaviors of SPRWs, a cyclic quasi-static test is carried out at the State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University. The test setup consists of vertical and horizontal loading devices. Axial load is applied by four ball-bearing hydraulic jacks whose oil pump is manually controlled to ensure that the axial load remains constant. Lateral cyclic load is applied by the horizontal actuator with one end fixed on the reaction wall and the other on the loading beam. The test setup is shown in Fig. 3.

Seven linear variable displacement transducers (LVDTs) are horizontally placed on the model at the level of mid-height, top and bottom of the specimen. LVDT at the top level aims at measuring top movement of the SPRW for drawing its hysteretic curve, while LVDT at the bottom level is used to monitor whether the specimen slide during the test. Another four LVDTs are fixed on two sides and the diagonal directions of the specimen to observe whether the wall distorts.

The force and displacement-controlled loading history is adopted in this test. Before the specimen yields, force-controlled multi-stage loading is applied. The initial load is 25% of the estimated yield load, and it has an increase of 10 kN or 20 kN per level (according to the aspect ratio of the specimen). The difference between the levels should be reduced when it is close to the estimated cracking or yield load. For each level, one cycle is performed. After the specimen yields, displacement-controlled multi-stage loading is applied, whose level difference is 2 mm. For each displacement level, three cycles are performed. The horizontal forces are applied under controlled cyclic displacements until the strength of the specimens decreases to 85% of the peak horizontal load. The method to determine yield point of the specimen is the same as introduced in literatures [14,16], which is mainly evaluated by its definition. When the hysteretic curve abruptly changes, the specimen is considered to be yielded. The loading history is illustrated in Fig. 4.

2.2. Material properties

In the specimens, the steel plates are made of Grade Q235 steel. Tension tests have been performed on steel plates and steel bars, whose results are shown in Table 2. There are two kinds of concrete, C30 and C50. The test cubes and the specimens are fabricated, casted and cured simultaneously. The size of the test cube is 150 mm × 150 mm × 150 mm. The cube compressive strength test is performed on test cubes after 28 days' natural maintenance and on the same day of the test respectively. The results can be seen in Table 3.