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Seismic performance of a repaired thin steel plate shear wall structure

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ABSTRACT

A multi-ribbed grid of channels can effectively restrain the deformation of an embedded steel plate shear wall, improving the elastic stiffness of the overall structure while enhancing its energy dissipation capacity. Aone-bay, two-story specimen was tested under low cycle reversed loading in two stages. After being damaged in Stage I, the structure was repaired by anchoring the multi-ribbed channel grid. The structure was then loaded to destruction. To investigate the changes in performance of the structure due to reinforcement, comparison and analysis of the structure were conducted for the two stages. The results indicate that in the elastic stage, when the repaired structure is in its normal service state, the deformation of the steel plate is effectively restrained, and the elastic stiffness and energy dissipation capacity is improved. In the elastic-plastic stage, the failure mode of the structure is reasonable, and the hysteresis loop is full as the multi-ribbed channel grid effectively restrains the pinching phenomenon. Based on the results of the experiment, finite element models were established. According to the finite element analysis, the yield load, initial stiffness, and maximum lateral force bearing capacity of the repaired structure improved significantly.

1. Introduction

The reinforcement of damaged structures represents a remarkable interest topic in the field of Seismic Engineering [1,2]. The steel plate shear wall structure is mainly composed of steel frames and embedded steel plates. The steel frame bears the vertical load while the embedded steel plate bears most of the horizontal load [3–4]. According to the "strong frame, weak wallboard" design concept, the embedded steel plate yields firstly and the frame yields secondly under an earthquake. [5–6]. This disaster prevention design concept makes the steel plate shear wall a repairable structure [7].

To determine the performance characteristics of a repaired steel plate shear wall, Qu etal. conducted a two-stagepseudo-dynamic test on a full-scaletwo-story steel plate shear wall specimen [8]. Between the two stages of the test, the damaged steel plate shear wall structure was repaired by replacing the embedded steel plates. The test results indicated that the repaired structure behaved similarly to the original one, demonstrating that it is feasible to repair damaged post-earthquake shear wall structures by replacing the embedded steel plates. However, significant labor is required to replace the embedded steel plates in practical applications. Therefore, it remains necessary to develop an easier repair method.

To address the difficulties of repairing or replacing embedded steel plate shear walls, the anchoring of a multi-ribbed channel grid to the shear wall to repair a damaged steel plate shear wall is proposed in this paper. To verify the performance of this proposed system, a single-span, two-story shear wall specimen was tested under two stages of low-cycle reversed loading. In Stage I, earthquake damage was applied to the specimen. Then the damaged structure was repaired using the multi-ribbed grid. In Stage II, the repaired structure was again loaded to the point of damage. The mechanical behavior of the frame in the elastic phase of each stage was then analyzed and compared. The failure mode and hysteretic behavior of the repaired structure was also studied.

2. Experiment details

2.1. Specimen design

In order to study the seismic performance of a steel frame-thin plate shear wall structure before and after repair, a one-bay, two-story specimen was designed for a pseudo-static test based on typical building details. To accommodate the available test conditions, the geometric similarity ratio of the specimen was set to 1:3. The clear height of each story in the specimen was 1200 mm, making the total height of the specimen 3670 mm, and the center-to-center spacing of the columns was 1380 mm. The beam-to-column joints were welded without inner diaphragms.

To ensure that the frame effectively anchored the embedded steel plates so that the post-buckling strength of the steel plates could be fully utilized, 100 × 8 mm splice plates were butt welded to the frame and fillet welded to the embedded steel plate. To simulate the requirements of building infrastructure, which often must pass pipes through

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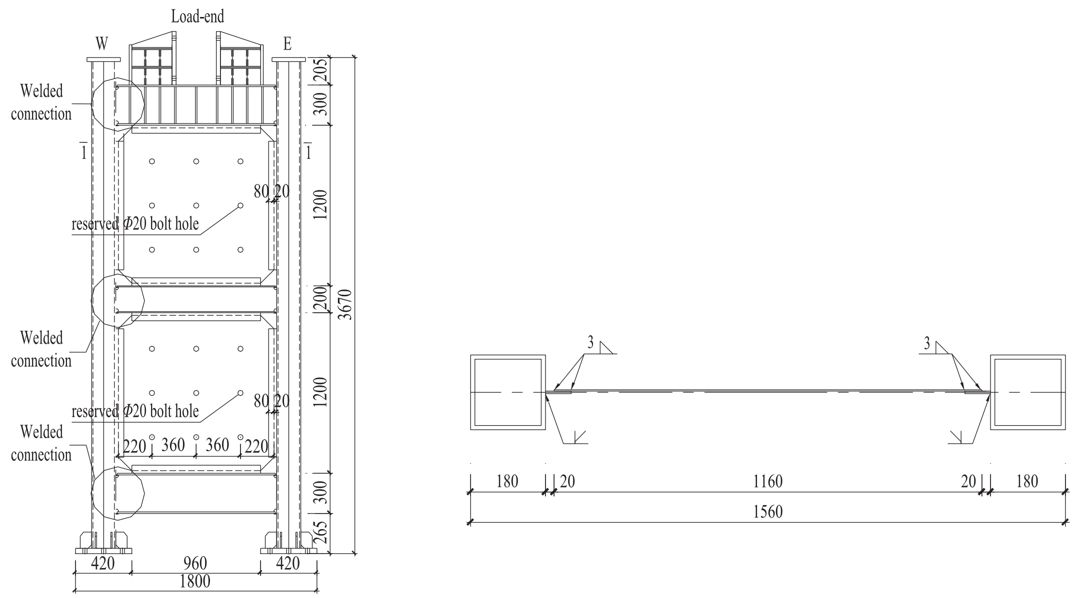

(a) Dimensional drawing (b) Section 1-1

Fig. 1. Dimensions of specimen (mm).

a shear wall, 100 mm was cut off of each corner of the embedded steel plate. Large 20-mm diameter bolt holes were included on the embedded steel plates to provide convenient installation of the multi-ribbed grid. The geometry of the specimen is shown in Fig. 1.

Following the conclusion of Stage I, the multi-ribbed channel grid was anchored to the embedded steel plates with friction-type high strength bolts to reinforce the specimen. In this application, the relatively high stiffness of the multi-ribbed channel grid eliminates the residual deformation of the embedded steel plate once installed. Details of the multi-ribbed channel grid are shown in Fig. 2.

According to the ANSI/AISC 341-16 standard, "Seismic Provisions for Structural Steel Buildings", the frame should remain elastic before the plastic properties of the embedded steel plate are fully engaged [9]. To meet this requirement, Q345 steel was selected as the column material and Q235 steel was selected for the remaining components, based on the results of a finite element analysis of the frame. To ensure the stability of the steel frame-thin plate shear wall structure in the out-of-plane direction, square steel tubes were selected as the column sections. The sections of each component are shown in Table 1.

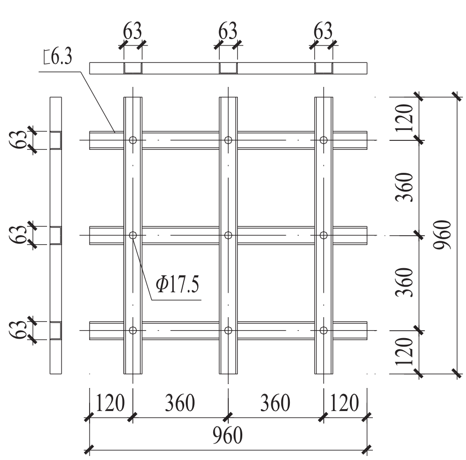

Fig. 2. Details of multi-ribbed channel grid (mm).

2.2. Test setup

Based on the test requirements, the lateral deformation and overall displacement of the specimen were monitored. To measure the horizontal displacement at each story of the specimen, displacement gauges were placed on the east and west sides of each beam. To measure the deformation of the columns, displacement gauges were placed on the columns in the middle of each story in the in-plane direction. To monitor the overall displacement of the rigid body, displacement gauges were placed at the column bases and the ground beam. Strain gauges were placed at the column bases, beam-column joints, and diagonally on the embedded steel plate [10] to monitor the changes in the stress during loading.

The experimental setup is shown in Fig. 3. The specimen was fixed to the ground beam by high-strength bolts. The ground beam was in turn thoroughly fixed to the ground by two support beams. Vertical loads were applied to the steel columns by two hydraulic jacks mounted on sliding bearings. The horizontal load was applied by two 1000-kNMTS hydraulic servo actuators with a stroke of ±250 mm to the top beam through a loading beam. Lateral braces were placed on both sides of the middle beam and the top beam, and they were connected to the specimen by wheels to reduce the influence of friction on the horizontal bearing capacity of the frame.

2.3. Material properties

The steel frame and embedded steel plates were sampled and tested according to [11–13]. The results are shown in Table 2.

Table 1
Sections of specimen.

Component	Section(mm)	Component	Section (mm)
Column	180 × 180 × 10	Splice plate	−100 × 8
Top and bottom beams	HN300 × 150 × 6.5 × 9	Embeddedsteel plate	−3
Middle beam	HN200 × 100 × 5.5 × 8	Channelstiffener	6.3