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Seismic behavior of steel coupling beam with different buckling constraint materials

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HIGHLIGHTS

- The buckling constraint steel coupling beam with shear yielding failure mode was proposed.
- Eight buckling constraint steel coupling beams were tested under quasi-static load.
- The seismic behavior of buckling constraint steel coupling beams was studied.

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ABSTRACT

With constrained plates on both sides of steel coupling beam web, the continuous strengthening can be achieved in steel coupling beam subject to cyclic shear loading with web shear yielding failure. Compared to traditional steel coupling beam which sets stiffeners on the web, the local buckling of the new type of steel coupling beam with shear yielding will not occur, before the steel web reaches its ultimate shear strain, resulting in excellent energy dissipation capacity. Eight quasi-static tests on buckling constraint steel coupling beams with shear yielding had been carried out to study the impact of various constraint manners on seismic behavior of this type of steel coupling beam. Tests results showed that all the test specimens realized shear yielding and strengthening of bearing capacity, and major failure mode included weld joint fracture between flange and endplate and failure of constrained plate. Average over strength factor of the test specimens was 1.38, above 1.1, the minimum requirement of *Code for Seismic Design of Building Structures*. Among them, the over strength factor of test specimens which used 50 mm-thick reinforced concrete constrained plates and 25 mm-thick wooden constrained plates exceeded 1.5. Test specimens with different constraint methods showed similar yield shear strain. While test specimens without constrained plates showed the minimum ultimate shear strain, test specimens with 25 mm-thick wooden constrained plates showed the maximum, approaching the ultimate shear strain of the web's steel in material property test.

0. Introduction

Coupling beam is often employed as an essential dissipative component of the coupled shear wall structure system under earthquake, and its strength, stiffness and energy dissipation capacity have a great impact on the seismic behavior of the system [1–4]. Under the earthquake load, it is the first defense of ductile shear wall structure system against seismic failure [5,6]. Hysteresis loop shows obvious "pinch" effect since energy dissipation capacity of reinforced concrete is relatively poor under cyclic loading [7,8]. Researchers in Canada, America and other countries have looking for the resolution by replacing reinforced concrete with steel coupling beam since the 1990s. Fortney proposed a kind of replaceable coupling beam with weakened section [9,10], which ensures central part of the web first yield in the earthquake by weakening the thickness of the area, thus protecting other parts of steel coupling beam. In 2009, Chung et al. put friction damper in the central area of web to strengthen the energy dissipation of coupling beam [11]. In 2014, Ji et al. proposed coupled shear wall of replaceable steel coupling beam on the basis of damage control thoughts [12]. All research results have shown that compared to the coupling beam of reinforced concrete, steel coupling beam is an ideal energy dissipation component with better ductility and energy dissipation capacity [13]. However, the local buckling of web of steel coupling beam always occur after the web yielding, which reduces the energy dissipation of the steel coupling beam.

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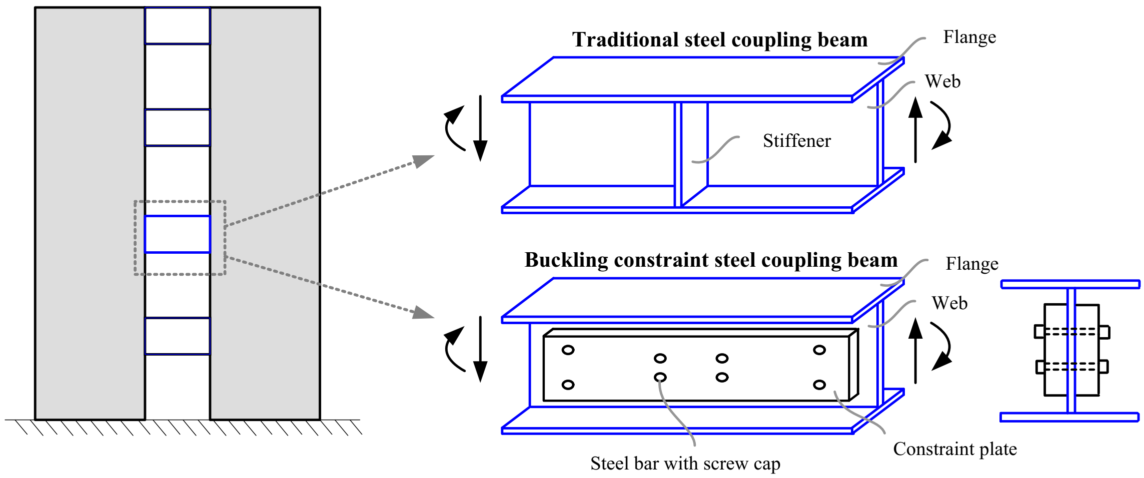

Fig. 1. Buckling constraint steel coupling beam with shear yielding failure mode.

With basic idea and techniques of buckling-resistance of steel structure [14–18], a new style buckling constraint steel coupling beam with shear yielding failure mode was developed, as shown in Fig. 1, to resolve the energy dissipation reduction of steel coupling beam since the beam tends to occur local buckling after shear yielding. With constrained plates on both sides of steel coupling beam web, the continuously strengthens of shear bearing capacity of web after shear yielding can be achieved under cyclic shear loading. Compared to traditional method which sets stiffeners on web, the local buckling of the web of buckling constraint steel coupling beam will not occur before the steel web reaches its ultimate shear strain, thus having excellent energy dissipation capacity. The impact of various constraint manners on seismic behavior of steel coupling beam was studied in this paper and the beams' energy dissipation capacity and strengthening characteristics of their shear bearing capacity were investigated by carrying out quasi-static loading tests on eight buckling constraint steel coupling beams with shear yielding.

1. Test study

1.1. Design of test specimens

On the basis of the coupling beam in an actual shear wall structures, the test specimens of coupling beam were designed with a reduced scale of 3:8. While the cross section of the coupling beam was a welded I-beam H290 × 200 × 6 × 10 (height of section × width of flange × thickness web × depth of flange, units: mm), the length of all the coupling beams was 660 mm. The dimensions of the test specimens are shown in Fig. 2. The flakiness ratio of the flange of steel coupling beam was 9.7 and the ratio of height to thickness of web was 45.0, which satisfied the requirements *Code for Seismic Design of Building*. The stiffeners of web adopted 6 mm-thickness steel plate and the design strength grade of the concrete of the reinforced concrete plate was C35. The wooden plate was made of pinewood and 20 mm-thick endplate were set on the both sides of the coupling beam. Variable parameter of the test specimens included thickness of constrained plates, material of constrained plates and the position of cross screw. Totally, there were eight test specimens, of which the specific parameters are shown in Table 1.

In order to ensure complete yielding of the web of steel coupling beam under shear loading, the flange of test specimen adopted Q345 steel and its web was made of Q235 steel. Tables 2 and 3 show the property test results of the steel and wooden materials. According to the results, the average compressive strength f_{cu} of the concrete was 42.6 MPa, as shown in Table 4. The flanges, webs and endplates of the test specimens were all connected by twin weld joints, of which the weld height satisfied the requirements of *Code for Design of Steel Structure*.

1.2. Parameter design of test specimens

I-section steel coupling beam often used web stiffeners in order to prevent the web local buckling after shear yielding. This specimen LS, of which the web had stiffeners, and specimen L0, of which the web had no stiffeners were designed to investigate the constrained effects of stiffeners on web local buckling after shear yielding. In addition, two types of reinforced concrete constrained plates, 25 mm-thick and 50 mm-thick, were designed to study the influence of thickness of plate on the constrained effects of steel coupling beams. With advantages of light weight, high strength and easy to process, wood is a common material used in composite structures. Therefore, this test designed specimen LW25-8 and LW50-8 with wood constraint plates, to investigate the constrained effects of wooden plates on the web of steel coupling beams.

Fig. 3 shows elastic buckling modes of pure steel coupling beams under shear loading. The software used was ABAQUS which is advanced in general nonlinear finite element analysis. 4 node reduced integral quadrilateral shell element S4R was used to simulate steel plate. It was found that most of out-of-plane buckling deformation of the web of steel coupling beams appeared in the central area. In order to investigate the influence of out-of-plate buckling constraint methods of steel coupling beams under shear loading on the constrained effect, the specimen LC25-4 and LC50-4 were set with cross screw only at their corners, while the specimen LC25-8 and LC50-8 were set with another four cross screw in the center area of their webs, in addition to the four at their corners, thus strengthening the constrained effect of out-of-plane deformation of steel coupling beam's central part.

1.3. Loading device and systems

The test was employed in the conventional test area of shaking table laboratory in Chongqing University, which adopted self-designed detachable loading device of coupling beams shear tests, as shown in Fig. 4. The placement of test specimen was in vertical