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Seismic performance of high-strength steel fabricated eccentrically braced frame with vertical shear link

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ABSTRACT

In high-strength steel fabricated eccentrically braced frame with vertical shear link (HSSEBF-VSL), the vertical shear links use conventional steel while beam and column use high-strength steel (HSS). Using HSS for beams and columns in HSSEBF-VSL can reduce steel weight and increased economic efficiency. In this paper, static tests for two 1:2 length scaled HSSEBF-VSL specimens with one-bay and one-story were carried out, including one static pushover test and one cyclic loading test. The failure mode, load-bearing, ductility and energy dissipation capacities of the specimens were studied through the two static tests. Shake table test of a 1:2 length scaled three-story HSSEBF-VSL specimen was used to study its dynamic responses and dynamic strain responses of the vertical shear links. In addition, the finite element models of several HSSEBF-VSL and conventional EBF with vertical shear link (EBF-VSL) buildings were established for seismic effects. Nonlinear pushover and dynamic analyses were conducted to compare their seismic performance and economy. The test results indicated that the specimen with one-bay and one story had reliable lateral stiffness, ductility and energy dissipation capacity. The three-story specimen had good lateral stiffness and there was no dangerous of collapse for the specimen during the severe earthquakes. Under the same design conditions, the seismic performance of HSSEBF-VSL was slightly lower than that of EBF-VSL if it was designed to match the member section strength of EBF-VSL, but it used less steel than that of EBF-VSL, which could reduce the usage amount of steel in HSSEBF-VSL.

1. Introduction

Eccentrically braced frames (EBF) is known for its attractive combination of high elastic stiffness and superior inelastic performance characteristics. In EBF system, link dissipates the energy induced by earthquake loads through its inelastic deformation. Major contributions to the understanding of inelastic deformation of link in EBF for resisting earthquake motion were primarily made during the 1980s [1–4]. Currently, the seismic performance and design method of EBF has been wildly studied [5–10]. Moreover, improvements in the mechanical properties and weldability of high-strength steel (HSS) had made HSS an economical alternative to conventional steel in the constructions [11–14]. As HSS has a higher strength than conventional steel, the structural members made of HSS can have smaller cross-sections than those of structural members made of conventional steel under the same design conditions. This can reduce the usage amount of steel in the structure and improves economy through reduced material costs.

In high-strength steel fabricated eccentrically braced frame with vertical shear link (HSSEBF-VSL), the shear link is made of conventional steel, braces are made of conventional steel or HSS, and other structural members are made of HSS. As a point of reference, "conventional steel" is defined as steel with a specified nominal yield stress of up to 345 MPa. "HSS" is defined as steel with a specified nominal yield stress above 345 MPa. In HSSEBF-VSL, the shear links dissipate the energy through the inelastic deformation during the severe earthquakes, the columns and beams remain in elastic or experience only a slight plastification because that the HSS has higher yielding strength than that of conventional steel. In addition, considering the properties of HSS, HSSEBF-VSL will have smaller member cross-sections relative to the conventional EBF with vertical shear link (EBF-VSL), which is designed under the same conditions. Furthermore, the strength of HSS columns can have higher strength than that of the conventional steel columns of equal length and cross-section when compared on a nondimensional basis [15,16]. Using HSS columns and beams can reduce the member sections and decrease the structural total weight, which can reduce the damage of the earthquakes to structures [17].

In order to study the seismic performance of HSSEBF-VSL, static and dynamic tests were carried out. Static pushover and cyclic loading tests

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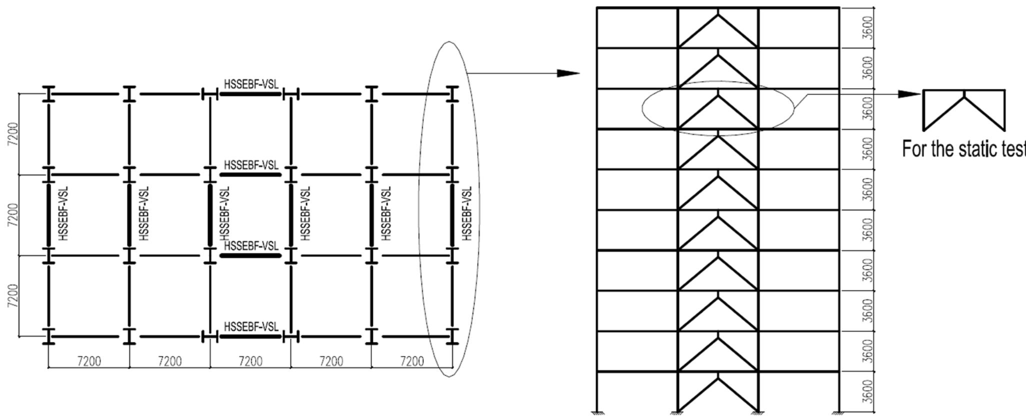

Fig. 1. Prototype structure for static tests.

were used to observe the seismic behaviors of 1:2 length scaled HSSEBF-VSL specimens with one-bay and one-story, including the load-bearing capacity, lateral stiffness, ductility and energy dissipation capacity. Shake table test was considered to study the dynamic responses of a three-story HSSEBF-VSL specimen, including the dynamic properties, displacement responses and strain responses of shear links. Finally, the finite element models (FEMs) of several HSSEBF-VSL and EBF-VSL buildings were established for the seismic performance and steel usage amount comparison by nonlinear pushover and dynamic analyses.

2. Static test

2.1. Test specimen

A ten-story HSSEBF-VSL building was designed as the prototype structure for the static test specimens and it was designed through the design codes of GB50011-2010 [18] and JGJ99-98 [19]. The prototype structure is shown in Fig. 1. The prototype was characterized using the peak ground acceleration for an exceeding probability of 10% exceedance probability a in 50-year period, equal to 0.2 g, and moderately firm ground conditions. And then the HSSEBF-SLV in the eighth story of the prototype structure was selected (refer to Fig. 1) and its 1:2 scaled specimens were manufactured for the static tests.

The static tests in this study included a static pushover test and a cyclic loading test. One specimen was used for the static pushover test and one specimen was used for the cyclic loading test. In order to compare the performance of these specimens under the different lateral loads, the specimens in these two tests were same. In these specimens, the story height and span were 1.8 and 3.6 m, respectively. The shear link length in the specimens was 500 mm ($eV_p / M_p = 1.46$; where e, V_p, and M_p are the link length, plastic shear capacity and plastic moment capacity, respectively). Moreover, the shear links were made of Q345 steel (the nominal yield strength is 345 MPa), while other members were made of Q460 steel (the nominal yield strength is 460 MPa), including beams, columns and braces. Table 1 shows the member sections and the mechanical properties of the steel. The connection details of the specimens are shown in Fig. 2.

2.2. Test setup

Fig. 3 shows the setup of the static tests. In this test setup, the lateral load of the actuator was applied to the load beam to have two identical lateral loads in both sides of the specimen, so the load beam had much higher stiffness than that of the beam. However, if the lateral loads were applied to the beam-end instead of the load beam, it might result in the axial compression deformation occurred at the beam, which would affect the performance of the specimen. Thus, using load beam could avoid the axial compression deformation of the beam. In order to consider the influence of the vertical load transferred from the upper layers and P-delta effects to the performance of the specimens, a constant axial load of 400 kN was applied, and using an oil jack pushing against the top of the column. The lateral loading condition was generated using an actuator that was connected to the specimen. In the tests, displacement meters and strain gauges were used to obtain the deformation and strain responses of the specimen. Fig. 4 shows the displacement meter and strain gauge distributions on the specimen.

Table 1
Structural member dimensions and design properties in specimens.

Structural member	Links	Braces	Beams	Columns
Steel grade designation	Q345	Q460	Q460	Q460
Section[a]	H225 × 125 × 6 × 10	H125 × 120 × 6 × 10	H225 × 125 × 6 × 10	H150 × 150 × 6 × 10
Link web thickness, t_w	6	6	6	6
Link flange thickness, t_f	10	10	10	10
Material nominal yield f_y, MPa	345	460	460	460
Material measured yield of web f_{yaw}, MPa	427.40	496.90	496.90	496.90
Material measured yield of flange f_{yaf}	383.33	468.77	468.77	468.77
Material measured strength of web f_{uaw}, MPa	571.10	658.57	658.57	658.57
Material measured strength of flange f_{uaf}, MPa	554.40	627.97	627.97	627.97
Material elongation web, %	26.53	29.73	29.73	29.73
Material elongation flange, %	31.01	35.88	35.88	35.88

[a] "H" refers to the welded H-shaped section, the following numbers are the section depth (h), flange width (b_f), web thickness (t_w), and flange thickness (t_f), with unit of mm.