Journal of Constructional Steel Research 101 (2014) 242–253

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental and numerical study on steel reinforced high-strength concrete short-leg shear walls

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ARTICLE INFO

Article history:
Received 31 July 2013
Accepted 26 May 2014
Available online 18 June 2014

Keywords:
Short-leg shear wall
Steel reinforcement
High strength concrete
Finite element analysis
ABAQUS

ABSTRACT

Reinforced concrete (RC) short-leg shear wall structure is a new type of mid-rise residential structure system. It has been widely used in China. In order to expand its scope of application to higher high-rises, studies have been focused on novel approaches improving the seismic behavior of this structure system. The present experimental and numerical study was performed to investigate the bearing capacity and seismic behavior of steel reinforced high-strength concrete (SRHC) short-leg shear walls. Results indicate that the tested SRHC short-leg shear walls have shown a bending failure mode, with the crushing of the compressed concrete and the yielding of the tensioned steel. The loading capacity of SRHC short-leg shear walls was greatly improved. The ductility coefficient of the specimens was between 3.62 and 4.35, which was equivalent to that of common RC short-leg shear walls. The specimens with steel-plate skeleton are more ductile in terms of displacement ductility and energy dissipation than the specimens with steel-truss skeleton. The results also indicate that decreasing the compressive ratio improves ductility. The bearing capacity of SRHC short-leg shear wall can be considerably improved by using high strength concrete, while the ductility decreases with the increase of the concrete strength due to the inherent brittleness of high-strength concrete.

1. Introduction

Short-leg shear walls refer to specific reinforced concrete walls with the ratio of limb length to thickness between 5 and 8 [1]. The short-leg shear walls are designed according to the architecture function and locations, and various section shapes such as T, L, cross, ∏ and − are commonly adopted in practice. Structure system consisting of short-leg shear walls has been popular in China for about twenty years, as it has few extruding edges or corners that not only ensures the building function tidy and perfect but also helps in architectural layout [2]. Although a large number of buildings have been built using this approach in China, the seismic design methods of the short-leg shear wall are rarely considered in the existing codes.

The mechanical properties of short-leg shear walls are intervenient between special-shaped columns and common long shear walls [2]. On the one hand, short-leg shear wall has the characteristic of frame flexible in spatial arrangement; on the other hand, comparing with ordinary long shear walls, it is considered to be insufficient in side rigidity, seismic behavior and bearing capacity due to its relative short limb [3–5]. For this reason, the Chinese seismic codes [6] specify more severe restriction to short-leg shear walls than ordinary shear wall both in the anti-seismic class and the limits of axial force ratio. At present the application of this structure system has been confined to tier dwellings and high-rises of 10–25 stories. Therefore, it is important to break through the limitation of short-leg shear wall structure and expand its scope of application.

During the last decades, numerous studies have been focused on novel approaches improving the seismic behavior and bearing capacity of this structure system. Wu [7] and Yang [8] performed tests on concrete short-leg shear walls with encased profiled steel in the extremities under cyclic loadings. The results showed good ductility and high lateral strength of the specimens. Cao [9] conducted experimental programs on short-leg shear walls with concealed bracings. It was found that the concealed bracings embedded in concrete offer a higher strength and deformation capacity than the ordinary reinforced specimen.

Steel reinforced high-strength concrete (SRHC) short-leg shear walls are high-strength concrete short-leg shear walls with encased structural steel. The bearing capacity of short-leg shear wall can be considerably improved by using high strength concrete, meanwhile the encased steel profile offers a better seismic behavior to the structure. Miao [10] conducted experimental programs on SRHC short-leg shear walls with a concrete strength class of C80. The result indicated that the bearing capacity of SRHC short-leg shear wall has been greatly improved, but the ductility was worse than that of the steel reinforced elements with

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http://dx.doi.org/10.1016/j.jcsr.2014.05.015
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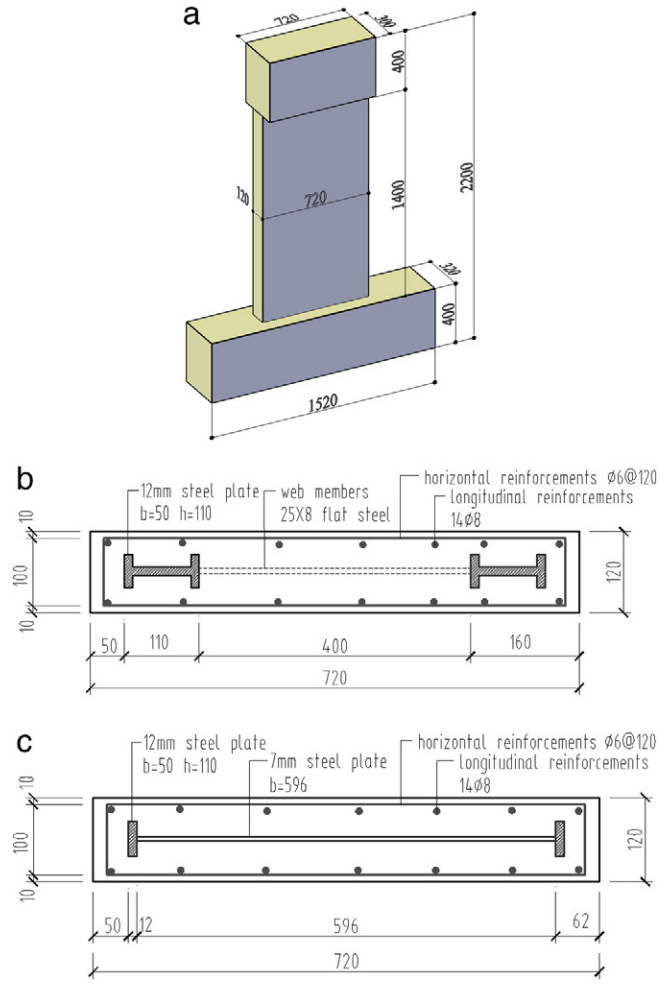

Fig. 1. Schematic diagram of cross section of specimens. (a) Shape of the specimens. (b) Specimens with steel-truss skeleton (STW). (c) Specimens with steel-plate skeleton (SPW).

common concrete. As a new type of element, further studies are needed to extend the range of test data and to investigate the unknown aspect.

In this paper, two parallel studies of numerical and experimental models were performed to evaluate the mechanical behavior of SRHC short-leg shear walls. First 4 models of SRHC short-leg shear walls embedded with steel skeletons were manufactured and tested experimentally under cyclic loading condition. Then numerical models of SRHC short-leg shear walls were built allowing nonlinear behavior for the material. The research reported herein elucidates many new aspects of the mechanic behavior of the SRHC short-leg shear wall, including the failure pattern, strength, ductility, stiffness deterioration, energy dissipation and the local stress and strain distributed on the steel skeleton. This research also quantifies the relationship between the seismic behavior of the structure and several related parameters, such as the compressive ratio and the concrete strength.

2. Experimental program

To study the behavior of SRHC shot-leg shear walls, a theoretical and experimental program was developed in the Civil Engineering Department at the Guangxi University of Guangxi, China.

2.1. Design of experimental specimens

The experimental program consists of four 1:2 scale specimens with "-" shape sections. The specimens are divided into two groups according to the types of embedded steel skeletons and each group was tested and conceived to investigate the effects of the axial load ratios into the behavior of the SRHC short-leg shear walls. The steel skeleton were designed in accordance with the Chinese Code (JGJ138-2010) [11], and with reference to existing literatures on steel reinforced special-shaped columns [12–14] and SRHC short-leg shear walls [10,15]. The design details of the SRHC short-leg shear walls and the steel skeletons are separately shown in Figs. 1 and 2. The specimens are named according to the steel reinforcement type and the value of compressive ratio. The length to thickness ratio of all the tested specimens was 6. All the specimens had the same amount of vertical reinforcement and stirrup. The parameters of the specimens are presented in Table 1.

2.2. Material properties

The designed concrete quality was C60 class, the reinforcement steel was HRB355 and the structural steel was Fe360. The steel skeletons were manufactured by welding the steel plates. Tensile tests on steel samples were done to determine the yield strength (f_y) and the ultimate strength (f_u). The formulas used for determining the material parameters for the constitutive model of concrete are taken from the Chinese

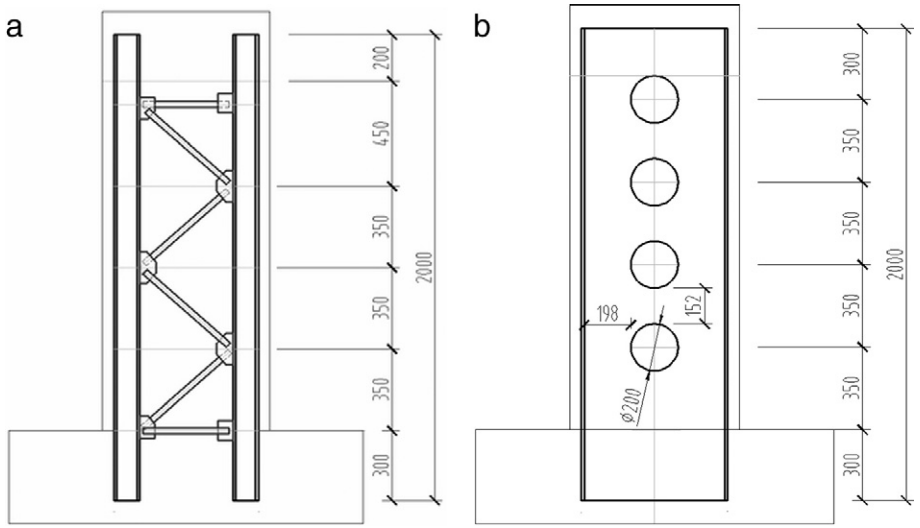

Fig. 2. Elevation of the steel skeletons. (a) Steel truss. (b) Steel plate.