Engineering Structures 82 (2015) 214–225

Contents lists available at ScienceDirect

Engineering Structures

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

Experimental study of reinforced concrete and hybrid coupled shear wall systems

Min-Yuan Cheng *, Rijalul Fikri, Cheng-Cheng Chen

Department of Construction Engineering, National Taiwan University of Science and Technology, No. 43, Sec. 4, Keelung Rd., Taipei, Taiwan

ARTICLE INFO

Article history:
Received 3 May 2014
Revised 15 October 2014
Accepted 17 October 2014
Available online 14 November 2014

Keywords:
Coupling beam
Coupling ratio
Low yield point steel
Diagonal reinforcement

ABSTRACT

Two approximately half-scale four-story coupled shear wall specimens were tested under both gravity and lateral displacement reversals. Specimen CW-RC, featuring traditional reinforced concrete (RC) shear walls and RC coupling beams, sustained ductile hysteretic response up to 3.00% drift. Specimen CW-S, featuring RC shear walls and steel coupling beam with low yield point steel (LYP) web, failed after completion of 2.00% drift cycles. The proposed connection detailing between the steel coupling beam and RC shear wall worked well in Specimen CW-S. Research results indicate that a ductile coupling beam design does not guarantee a ductile behavior of a coupled shear wall system. RC shear walls should be proportioned for axial and shear based on the provided coupling beam capacities. Design recommendations are provided.

1. Introduction

A reinforced concrete shear wall is often selected as the major lateral-force-resistant system due to its large in-plane stiffness. In practice, openings in a shear wall are often inevitable because of architectural or practical needs. These openings are generally provided along the story height in a regular pattern and divide the original shear wall into two or more slender walls which are interconnected by beams. These interconnecting beams are referred to as coupling beams while the whole system is referred to as a coupled shear wall system.

The coupled shear wall system provides several advantages in seismic response. First, the moment demand of each individual wall can be reduced due to coupled action. Second, the seismic energy can be dissipated through coupling beams over entire stories. Last but not least, the coupled shear wall system has a lateral stiffness that is significantly greater than the sum of its component wall piers [1]. To maintain designed lateral-resisting mechanism of the coupled shear wall system, both shear walls and coupling beams must be sufficiently ductile when subjected to earthquake-type loadings.

For RC coupling beams with height to length ratio less than two and shear stress demand greater than $0.33\sqrt{f'_c}$ MPa ($4\sqrt{f'_c}$ psi), a special diagonal reinforcement layout is necessary in addition to the confinement requirements according to the current ACI Building Code [2]. In which, f'_c is the specified concrete strength. Although effective, this reinforcement layout creates significant construction challenges.

One of the alternatives is the use of a hybrid coupled shear wall system with steel coupling beams and reinforced concrete shear walls [3–7]. A comprehensive review of relevant research is well documented elsewhere [1]. The existing research indicates that steel coupling beams governed by shear are generally more ductile than those governed by flexure. Also, the performance of steel coupling beam under cyclic loading is significantly affected by the connection between the steel coupling beam and the reinforced concrete shear wall.

Low yield point (LYP) steel, with specified yield strength around 100 MPa (15 ksi), has been recently studied in shear dominated structural component by Chen and Jhang [8]. The inherent stress–strain characteristics of LYP steel such as (1) large fracture strain, (2) large peak to yield stress ratio, (3) low width to thickness ratio and large value of its limit to prevent local buckling, make this material ideal to develop better ductility and energy dissipation on the structural components. In this research, the potential of using LYP steel as the web panel in the central part of steel coupling beam is evaluated. A test program consisting of two approximately half-scale four-story coupled shear wall systems was conducted. The first specimen, labeled as Specimen CW-RC, represents the control specimen using diagonally RC coupling beams and RC shear walls. The second specimen, labeled as CW-S, features the proposed hybrid coupled shear wall system with LYP steel web coupling beams and RC shear walls.

* Corresponding author. Tel.: +886 2 2737 6564.
E-mail address: minyuancheng@mail.ntust.edu.tw (M.-Y. Cheng).

http://dx.doi.org/10.1016/j.engstruct.2014.10.039
0141-0296/

The objectives of this research aim to (1) investigate the cyclic behaviors of RC and hybrid coupled shear wall systems that features diagonally reinforced and LYP steel coupling beam, respectively; and (2) evaluate the proposed detailing used for force transfer between the steel coupling beams and wall piers.

2. Research significance

This study investigates the cyclic behaviors of RC and hybrid coupled shear wall systems. Two large-scaled coupled shear wall systems were tested. Design specifications of the current ACI Building Code [2] for the RC coupled shear wall system are evaluated. Test results provide valuable information of RC/Hybrid coupled shear wall systems subjected to cyclic displacement reversals and may be used to improve the relevant building code provisions in the future.

3. Test specimens

Coupling ratio (CR), defined as the proportion of the overturning moment resisted by the coupling action, is generally taken as an index to measure the efficiency of the coupled shear wall system. For a system having a coupling ratio equal to 0%, it means that the coupling beams develop no end moment. For a system having a coupling ratio equal to 100%, the wall piers behave as a single pier. Based on finite element analysis of a 12-storied hybrid coupled shear wall system, El-Tawil et al. [9] recommended a CR range between 30% and 45% as an efficient structural design. For RC coupled shear wall systems, the typical coupling ratio varies between 20% and 55% [10]. A low CR results in inefficient lateral resistance and a high CR leads to reduction of deformation capacity of a coupled shear wall system.

Considering the maximum test capacity of the Architecture and Building Research Institute (ABRI) laboratory in Taiwan, test specimens were designed to represent a half-scale four-story coupled shear wall system. Two external loads, 294 kN (66 kips) and 588 kN (132 kips) applied at the 3rd floor and the roof floor, respectively, are taken as the ultimate design forces for both specimens. The clear length to height ratio, also known as aspect ratio, of the RC and the LYP steel coupling beams is 1.5. The specimen was designed to achieve the mechanism in which yielding is assumed to develop over the coupling beams and at bases of the walls. A moderate CR of 35% is selected for the test specimens. As a result, design forces of the shear walls and the coupling beams can be determined, as shown in Fig. 1. The average shear demand of each RC shear wall and coupling beam is 445 kN (100 kips) equivalent to $0.33\sqrt{f'_c}$ MPa ($4\sqrt{f'_c}$ psi) and 214 kN (48 kips) equivalent to $0.75\sqrt{f'_c}$ MPa ($9\sqrt{f'_c}$ psi) shear stress, respectively. In which, the specified concrete strength (f'_c) is 4 ksi (28 MPa) for both shear walls and coupling beams.

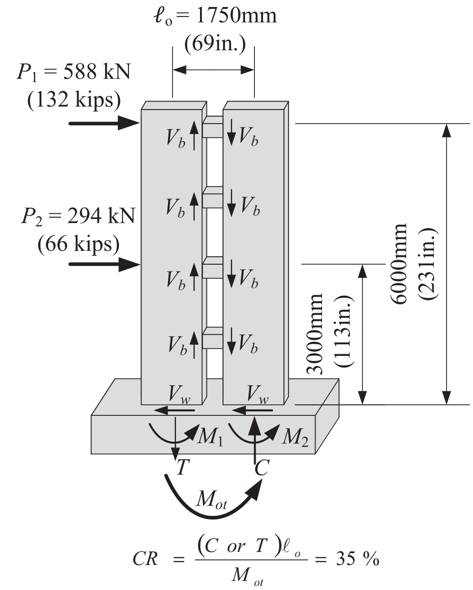

Fig. 1. Design forces of the test specimen.

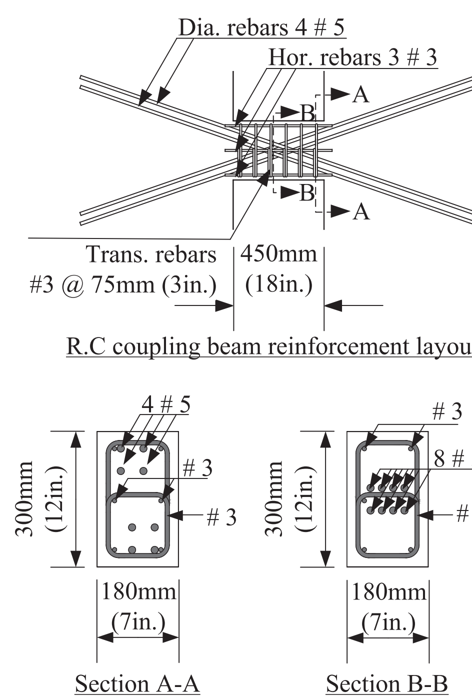

Fig. 2. Detailed reinforcement layout of the RC coupling beams.

3.1. RC coupling beam

The RC coupling beam is 450 mm (18 in.) long, 300 mm (12 in.) high and 180 mm (7 in.) wide. Two groups of four No. 5 (diameter = 15.9 mm/0.63 in.) Grade 60 diagonal rebars are provided with an angle of approximately 19 deg. The detailed reinforcement layout of the RC coupling beam is presented in Fig. 2. Based on Eq. (1) per the ACI Building Code [2], the ultimate shear capacity of the RC coupling beam is approximately 214 kN (48 kips). In which, A_s is the area of diagonal rebars, f_y is the specified yield strength of the diagonal reinforcing rebar and α is the angle of diagonal rebar with respect to the horizontal plane. Confinement of the RC coupling beam is provided per Section 21.6.4 of the Code [2]. The specified f_y of the reinforcing rebar is 420 MPa (60 ksi).

$$V_{n,cb} = 2A_s f_y \sin\alpha \tag{1}$$

3.2. LYP steel coupling beam

The LYP steel coupling beam is a built-up section consisting of three regions: the mid-span region and the two end regions. A 300 mm (12 in.) square LYP steel panel is used in the mid-span region of the steel coupling beam with thickness of 12 mm