FRPRCS-14, Belfast - June 2019

Seismic Upgrading of RC Coupled Shear Walls Designed According to Codes Prior to the 1970s Using FRP Composites

Honarparast, S.[1], El-Saikaly, G.[1], Chaallal, O.[1]

[1] *Department of Construction Engineering, École de technologie supérieure, University of Quebec, Montreal, Canada*

Abstract

This paper presents a new strengthening method for existing reinforced concrete (RC) coupling beams (CBs) of coupled shear walls (CSWs) designed according to codes prior to the 1970s, using externally bonded (EB) carbon fiber reinforced polymer (CFRP) composites. Two RC CSW specimens, one control and one retrofitted with EB-CFRP, were tested under reversed cyclic loading. Results show that the proposed EB-CFRP retrofit method substantially enhanced the load carrying capacity and energy dissipation capability of the CBs. In addition, the EB-CFRP upgrading technique transformed the deficient pinched hysteresis behavior in the control CB specimen into more stable hysteretic curves with less pinching. In addition, the new upgrading technique resulted in a higher ductility and reduced strength and stiffness degradations compared to control specimen.

Keywords: reinforced concrete, coupled shear wall, coupling beam, strengthening, CFRP composite, externally bonded, seismic performance, cyclic loading

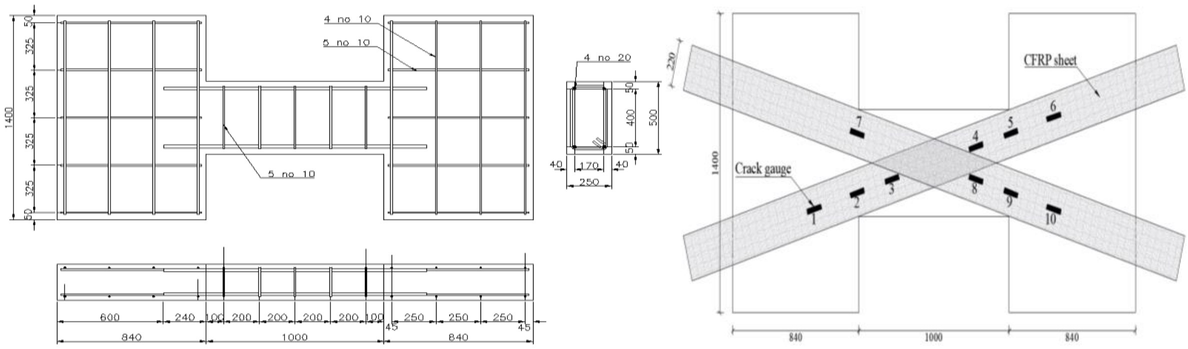
Corresponding author's email: sara.honarparast.1@ens.etsmtl.ca

Introduction

As a seismic resistance system, a properly designed coupled shear wall (CSW) should ensure that plastic hinging occurs in the coupling beams (CBs) before the walls, meaning that the CBs should function as the primary energy dissipation elements. To that end, the CBs should have stable hysteretic behavior without significant pinching and feature no strength nor stiffness degradations. However, the CSWs designed according to the codes prior to the 1970s are not able to offer all these crucial features. Therefore, they are at risk of suffering severe damage under moderate to severe earthquakes and need to be strengthened. A comprehensive review of retrofit methods for CBs along with their advantages and drawbacks can be found in [1]. In the last few years, the use of externally bonded (EB) fiber reinforced polymer (FRP) composites has proven to be a reliable and a cost effective retrofit method for basic reinforced concrete (RC) structures such as slabs, beams, and columns. However, the use of FRP composites for seismic strengthening of CBs in CSWs is rather limited. This paper aims to investigate the efficiency of EB-FRP sheets in enhancing the seismic performance of old existing CBs through experimental tests.

Experimental study

Two identical RC CSW specimens with conventionally reinforced CB (Figure 1a) were designed and constructed according to the National building Code of Canada (NBCC) 1941 [2]. The CB of the first specimen, labelled CB1, was considered as a control specimen and the second one, named CB2, was retrofitted with carbon FRP (CFRP) sheets using a diagonal configuration and designed based on the concept of the diagonally RC CBs according to modern standards [3]. Therefore, considering the properties of selected CFRP sheets (Table 1), one layer of 220-mm-wide CFRP strip was applied on both sides of the specimen (Figure 1b) and extended to the edges of the wall.
The test setup is shown in Figure 2. The left wall segment was fixed to the strong floor of the laboratory, and the load was applied vertically to the right wall through the loading beam on top, such that the centroids of the walls remained parallel. A comprehensive number of strain gauges were installed on the longitudinal and transverse steel reinforcements and CFRP strips and linear variable-displacement transducers (L1-L4) were installed in different zones to monitor strains and yielding of the steel reinforcement as well as displacements of the walls during the test (see Fig.2). The specimens were tested under reverse cyclic loading in displacement-control condition. Two load cycles were applied at a rate of 3 mm/min at each displacement amplitude up to failure.



(a) (b)

Figure 1: a) Geometry and reinforcement details of specimens, b) CFRP configuration of retrofitted specimen, CB2

Table 1: Properties of CFRP sheet

Tensile strength (MPa)	Tensile modulus (GPa)	Tensile elongation (%)	Thickness (mm)
4240	240	1.75	1.3

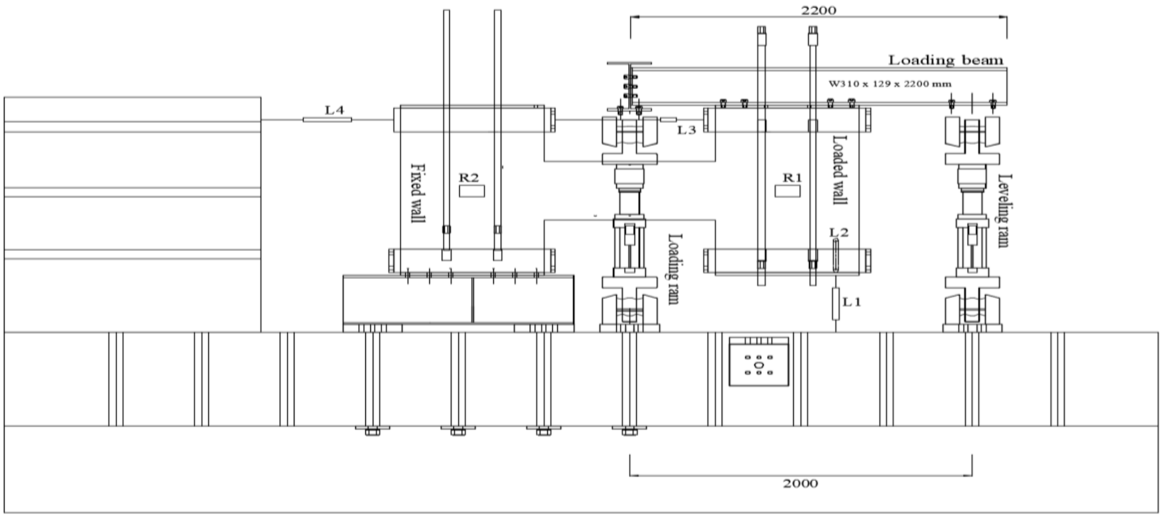


Figure 2: Experimental test setup

Tests results

The performance of the specimens under reverse cyclic loading is discussed in terms of hysteretic behavior, ductility, strength and stiffness degradations, as presented below.

Hysteresis behavior

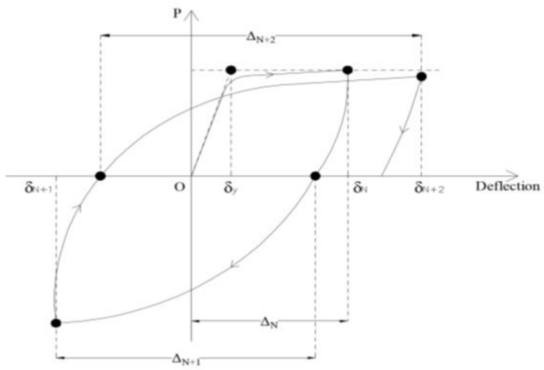
The hysteresis behavior of specimen CB1 (Figure 3a) indicates that a maximum load of 152.36 kN was achieved at a displacement amplitude of 12 mm. Thereafter, the load-carrying capacity of the specimen decreased significantly due to the pinching effects caused by wide shear cracks at the beam-wall joints. Therefore, as illustrated in Figure 3b, the specimen exhibited sliding shear failure and slippage of the longitudinal reinforcement due to insufficient embedment length. The retrofitted specimen CB2 reached a maximum load of 308.28 kN at a displacement of 60 mm, indicating that the EB-CFRP retrofit increased the maximum load-carrying capacity by 2.02 times, compared to the control specimen. Unlike the control specimen CB1, CB2 did not show any significant pinching and the efficiency of EB-CFRP composites resulted in greater and more stable hysteresis loops (Figure 3a). Therefore, a significant increase was obtained in the energy dissipation capacity of the retrofitted specimen due to larger area of hysteretic loops compared to the control specimen. However, CFRP partial debonding occurred at the coupling beam-wall joints and expanded to the wall and the CB during the applied displacement increment. Finally, delamination of CFRP strips and propagation of inclined cracks resulted in rupture of the CFRP strips (Figure 3c) and a sudden drop in the load carrying capacity of the specimen.

Displacement ductility

Displacement ductility (μ) is an important indicator of the seismic performance of CBs. In this study, the ductility factor of the specimens was computed according to the method proposed by [4] (Figure 4a). Figure 4b indicates the displacement ductility of both specimens at each loading cycle. The specimen CB1 reached a ductility factor of 2.77 at the 7th cycle when the failure of specimen occurred. In contrast, CB2 exhibited a maximum ductility factor of 7.2 just before rupture of CFRP strips.

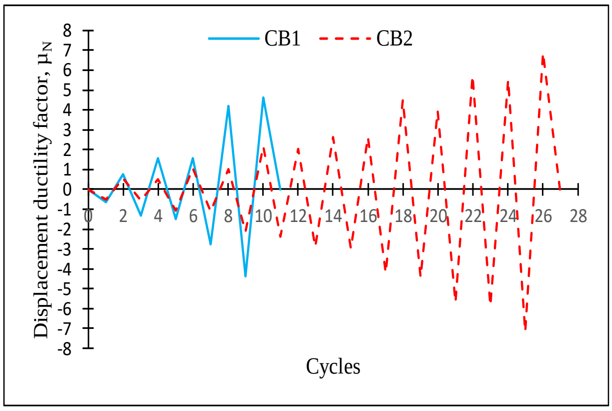
(a) (b) (c)

Figure 3: a) Hysteretic behavior b) Specimen CB1 at failure, c) Specimen CB2 at failure



$$\mu_N = \frac{\Delta_N}{\delta_y}, \mu_{N+1} = \frac{\Delta_{N+1}}{\delta_y}, \mu_{N+2} = \frac{\Delta_{N+2}}{\delta_y}$$

(a)



(b)

Figure 4: a) Method used to compute ductility factor, b) Ductility of specimens

Strength and stiffness degradation

Figure 5a indicates the percentage of strength reduction at each applied displacement. It is found that the control specimen, CB1, featured a significant strength reduction of 71% at a 24-mm displacement amplitude that led to failure of the specimen. This contrasts with the retrofitted specimen CB2, where the CFRP strips prevented any substantial drop of strength during the early stages of applied loading. It is clear that applying EB-CFRP strips diagonally resulted in a much less strength degradation of the retrofitted specimen, compared to control one.

Figure 5b indicates the percentage of stiffness degradation at each applied displacement with respect to the previous one. It was found that the stiffness of the both specimens degraded with the increase of applied displacement. However, due to the confining effect of the CFRP wrap, a lower rate of stiffness degradation was observed for the EB-CFRP retrofitted specimen compared to the control one.

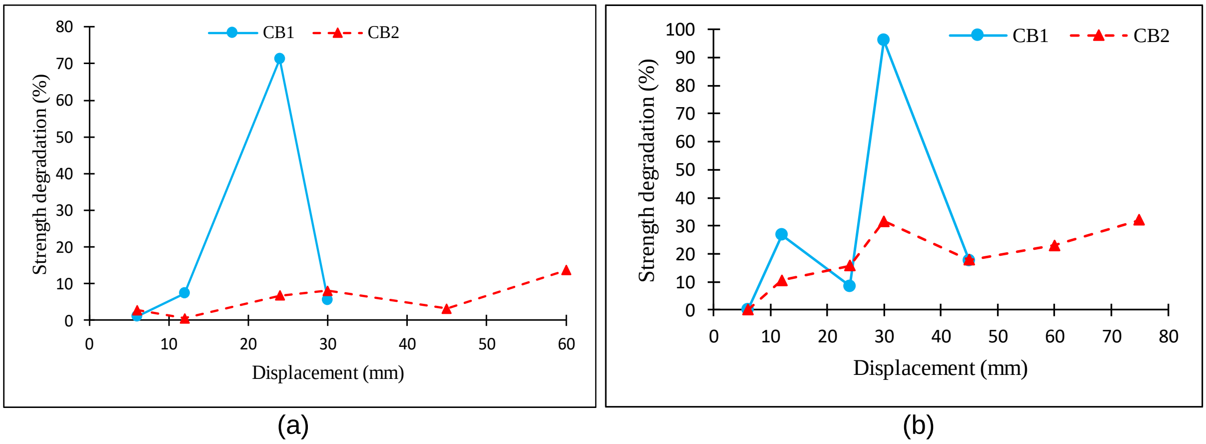


Figure 5: a) Strength degradation percentage, b) Stiffness degradation percentage

Conclusions

This paper investigated the seismic performance of two RC CBs designed according to old codes in which one of them was retrofitted using diagonally applied EB-CFRP composites. Both specimens were tested under reverse cyclic loading up to failure. The experimental results indicated that the proposed CFRP retrofit method resulted in a substantial enhancement of the load carrying capacity and ductility. Diagonal EB-CFRP strips also resulted in more stable and greater hysteretic loops and hence a greater energy dissipation capability. Finally, the strengthened specimen exhibited less strength and stiffness degradations, compared to the control specimen.

References

[1] Honarparast, S., and Chaallal, O., 2015, "Seismic upgrading of RC coupled shear walls: State of the art and research needs," Global J. Adv. Eng. Technol. Sci., 2(12), 1–19.

[2] National Building Code of Canada (NBCC), 1941, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario.

[3] Canadian Standards Association (CSA), 2014, "Design of Concrete Structures for Buildings," Standard CAN-A23.3-14, CSA, Rexdale, Ontario, Canada.

[4] Santhakumar, AR., 1974, "The Ductility of Coupled Shear Walls," PhD thesis, University of Canterbury, New Zealand.