Retrofitting Earthquake-Damaged RC Structural Walls with Openings by Externally Bonded FRP Strips and Sheets

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Abstract: The majority of research studies on the behavior of reinforced concrete members with externally bonded fiber reinforced polymer (FRP) sheets have been focused on beams, columns, and beam-column joints. However, limited experimental studies have been conducted to investigate the performance of structural walls retrofitted by wrapping FRP strips or sheets, especially on structural walls with openings. The validated retrofitting schemes for strengthening damaged walls without openings may not be suitable for walls with openings. Therefore, a series of experimental studies were carried out at Nanyang Technological University, Singapore, to study the effectiveness of the proposed repair and strengthening schemes in recovering the seismic performance of the damaged walls with irregular or regularly distributed openings. The strut-and-tie approach was utilized to design the repair schemes. The repaired walls managed to recover their strength, dissipated energy, and stiffness reasonably, indicating that the strut-and-tie approach can be a good design tool for FRP-strengthening of structural walls with openings. Moreover, the shear and sliding capacities of repaired walls were enhanced by using fiber anchors. The repaired walls failed primarily because of debonding of the fiber reinforced polymer at the base of the walls. DOI: 10.1061/(ASCE)CC.1943-5614.0000336. © 2013 American Society of Civil Engineers.

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Introduction

RC structural walls play a very important role in carrying lateral loading and resisting drift in tall buildings. Piercing a wall with openings may significantly influence its behaviors, such as changing its force transfer mechanism, deducing its strength and stiffness, and decreasing its ductility level. Although walls with openings have been studied by some researchers (Yanez et al. 1992; Ali and Wight 1991; Marti 1985), the effects of the regular and irregular openings on the seismic performance of RC walls are still not fully understood. Thus, two 3-story reinforced concrete model walls, scaled to one-third, were tested under reversed cyclic lateral load. Sassemblies W1 and W2 were designed with similar dimensions and details as Yanez et al. (1992) and Marti (1985), respectively. Moreover, for detailed results of these two control specimens refer to Wu (2005) and Zhao (2004), respectively. The goal of this paper is to investigate whether the damaged walls with openings could restore their seismic performances after proposed retrofitting. Fiber reinforced polymers (FRP) were utilized in this study because of their high strength-to-weight ratios, corrosion resistance, ease of application, and tailorability. In addition, the orientation of the fiber in each ply can be adjusted to meet specific strengthening objectives (Engindeniz et al. 2005).

Although numerous research studies had been conducted to strengthen or repair the structural components, such as beams, columns, and beam-column joints (Lam and Teng 2001; Teng and Lam 2002; Pampanin et al. 2007; Teng et al. 2009; Li and Chua 2009; Li and Kai 2011; El-Maadawy and Chekfeh 2012), there are limited experimental studies that were conducted to investigate the effectiveness of FRP retrofitting the damaged RC structural walls, especially for walls with openings.

Neale et al. (1997) have tested wall-like columns that were strengthened using FRP, including wall-like columns with different arrangements of externally bonded FRP reinforcements subjected to uniaxial compression only. Lombard et al. (2000) performed rehabilitation of structural walls using carbon fiber reinforced polymer (CFRP) externally bonded to the two faces of the wall to increase its flexural strength. The use of unidirectional carbon fibers with the fibers aligned in the vertical direction increased the flexural capacity and precracked stiffness and the secant stiffness at yield. Several nonductile failure modes of the wall were attributed to the loss of anchorage or tearing of the fibers. Antoniades et al. (2003) tested squat RC walls up to failure and then repaired them using high-strength mortar and lap-welding of fractured reinforcement. The walls were subsequently strengthened by externally bonded FRP sheets as well as by adding FRP strips to the wall edges. FRP increased the strength of the repaired walls by approximately 30% compared with traditionally repaired walls. However, the energy dissipation capacity of the control walls could not be restored completely. Li and Lim (2010) restated four seismically damaged structural walls (two low-rise walls and two medium-rise walls) after conventionally repaired and strengthened by wrapping with FRP sheets. It was reported that the repaired and strengthened walls were able to restore the performance of the damaged RC walls. This repair method is relatively easy.