Tests on Seismically Damaged Reinforced Concrete Structural Walls Repaired Using Fiber-Reinforced Polymers

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Abstract: This paper presents the results of an experimental study on the seismic performance of axially loaded reinforced concrete (RC) walls with boundary elements confined by limited transverse reinforcement. These specimens were initially subjected to axial compression loading and cyclic lateral loading to failure, and subsequently repaired and subjected to loading again. The test specimens include two low-rise walls of aspect ratio 1.125 and two medium-rise walls of aspect ratio 1.625. Results show that significant drift capacities were achieved from the strengthened walls. The performance of the repaired walls was similar to the original walls before repair in terms of the flexural behavior, shear strength, and ductility capacities. While the fiber-reinforced polymer (FRP) anchorage may undergo premature failure, it however failed only after the peak lateral strength of the repaired wall was attained. This paper demonstrates that repair of damaged RC walls using FRP is able to restore the performance of damaged RC walls while also serving as repair method of relative ease.

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Introduction

Reinforced concrete (RC) structural walls are often used in buildings to resist winds and earthquakes. According to a research, buildings containing shear walls exhibit fair earthquake performance (Fintel 1991). Due to their intrinsic ability to resist lateral load, RC structural walls can serve as an important earthquake resistance mechanism in the RC structures. However, earlier seismic design provisions may not have addressed the demands induced on RC walls, as a result, major earthquakes have caused extensive damage to older shear walls which have insufficient in-plane stiffness, flexural and shear strengths, and/or ductility.

One repair and strengthening method involves the application of shotcrete, the filling of openings in walls with RC and masonry in-fills, followed by epoxy injection and possible addition of steel bracing elements. More recently, the use of fiber-reinforced polymers (FRPs) for strengthening existing buildings has increased, because of its low weight-strength ratio, short installation periods, and low intervention on the structure (Alcaino and Santa-Maria 2008).

Research on the behavior of reinforced concrete members with externally bonded FRP jackets has mainly focused on columns or piers where its use is more common (Priestley et al. 1996; Penelis and Kappos 1997; Triantafillou 2001). Bonding of FRP sheets on RC walls using epoxy has proven to be the most cost effective alternative in repairing buildings within a short time (Ehsani and Saadatmanesh 1997). Experimental studies involving RC walls strengthened by FRP include wall-like columns with different arrangements of externally bonded FRP reinforcement subjected to uniaxial compression (Neale et al. 1997). A separate research was carried out on four series of half-sale RC walls (Lombard et al. 2000). Two tests involved strengthened RC walls which include the following categories: (1) wall strengthened by one vertical layer of carbon-fiber-reinforced polymer (CFRP) sheets on both sides of the wall and (2) wall strengthened by one horizontal and two vertical layers of CFRP sheets on both sides of the wall. The walls strengthened by the CFRP sheets were found to have an improved load-carrying capacity and ductility. The anchorage system between the CFRP sheets and the wall footing was shown to play a major role. Inadequate anchorage system may not allow proper load transfer from the sheets to the adjacent elements, which can lead to premature failure such as delamination of the fiber sheets from the surface of the walls. More recently, cyclical load tests on six RC cantilevered wall specimens, which were repaired and subsequently strengthened by FRP sheets and strips, were carried out (Antoniades et al. 2003). Test results showed that the flexural and shear strength of the repaired specimens were significantly larger than the original walls before repair. The anchorage system, which involved a combination of metal plates and FRP strips, appeared to be effective. Other related studies include the following: (1) RC columns with small elongated members extending from the column (Iso et al. 2000) and (2) RC walls strengthened by FRP sheets bonded on one or both of the wall faces (Triantafillou 2001).

The present study is an addition to works carried out in Nanyang Technological University, Singapore (Li and Xiang 2006). The study was motivated by the effect of low to moderate seismicity in regions such as Singapore on RC walls. The lower ductility demands within low to moderate seismicity regions imply that the required amount of reinforcement, especially the transverse reinforcement in web and boundary element, would be relatively small. As such, these walls would have limited transverse reinforcements. In the earlier study, the seismic performance of