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Strengthening of RC walls using externally bonding of steel strips

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ABSTRACT

The purpose of this experimental study is to investigate the hysteretic behavior of shear deficient reinforced concrete (RC) shear walls that are strengthened by bonding of steel strips. Four, 1/2 scale shear wall test specimens were constructed and tested under cyclic lateral loading. The slenderness ratio of the wall (h/l, where h = wall height, l = wall length) was 1.5. For this experimental research three wall specimens were strengthened with different steel strips configurations. The different configurations of steel strips were considered the diagonal strip, lateral strip and the combination of both lateral and vertical strips. All steel strip configurations are arranged on both sides of the shear wall symmetrically. The research focused on the effect of using bonding steel strips enhancing strength and increasing ductility of the non-seismic detailed shear walls. Test results showed that all the steel strip configurations improved the lateral strength, energy dissipation capacity and deformation capacity of the shear deficient RC wall significantly. Strengthened specimens developed the nominal flexural strength, and hence, the observed maximum base shear was controlled by flexure. Steel strips limited the opening of shear cracks and improved the lateral displacement capacity.

1. Introduction

In earthquake resistant design, shear walls are common lateral load resisting systems found in many reinforced concrete (RC) structures. In older buildings, use of reinforced concrete shear walls is limited. In some cases, members having cross sections with relatively bigger slenderness ratios, which resemble elongated rectangular columns rather than a shear wall, can be observed. Even in these buildings, poorly designed and detailed shear resisting members may develop diagonal shear cracks wide enough to suggest some yielding of the reinforcement, but survived the earthquake, and saved the structure from collapse. There were other shear wall buildings also with older and significantly lower quality concrete. The shear walls of numerous existing buildings have a number of design, construction detailing and material deficiencies, including poor or no confinement of boundary element reinforcement, poor or no anchorage of the transverse reinforcement, insufficient shear strength to develop hinging and poor concrete quality. Consequently, strengthening the shear capacity of RC walls becomes more of a concern in the area of seismic design of RC structures [1–3]. Strengthening of the shear deficient reinforced concrete walls, may provide an important contribution to the improvement of seismic structural behavior.

Slenderness ratio is one of the critical parameters affecting the behavior of the wall. For slenderness ratio values over 2.0, wall behavior is dominated by flexure and for values smaller than 1.0, shear is dominant. Between these limits, a combined behavior develops, and neither flexure nor shear is distinct [4–7]. Low reinforcement ratios, slenderness ratio less than 2.0, and inadequate seismic detailing characterize such walls. According to widely held views, RC walls with low reinforcement ratios are susceptible to brittle shear failure, restricting deformation capacity. Thus, poor seismic performance is expected.

In order to improve the seismic behavior of RC members, strengthening with externally bonded steel members is an effective technique. Strengthening of reinforced concrete columns and beams with bonding steel technique is an effective and convenient method to improve member strength and ductility [8–20]. But despite their effectiveness, studies on shear strengthening of RC walls is limited in the literature. The first study on the shear strengthening of walls was conducted by Sharpe and Ugrte [18] in 1988. In this study, the walls of an elevator shaft of an existing building were strengthened by adding steel plates. For shear strength intervention Elnashai and Salarna [19] bonded lateral steel plates at predetermined spacing up the height of the wall section. They suggested that this intervention could be performed on walls that exhibit a shear dominated inelastic mechanism. They aimed to increase the shear strength so that a flexural mechanism forms. Taghdi et al. [20] concluded from their experiments that the steel

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Nomenclature

A_{cv}	area of reinforced concrete wall section	V_s	shear force carried by steel straps
b	width of adhesion surface	$V_{u.calc.}$	calculated shear capacity
E_c	modulus of elasticity, concrete	V_w	the total shear strength carried by concrete and by steel reinforcement
E_s	modulus of elasticity, steel	$V_{flex.}$	shear strength that corresponds to the analytically calculated flexural strength
f_c	compressive strength of concrete	x	coordinate
f_y	specified yield strength of reinforcement	α_c	coefficient defining the relative contribution of concrete strength to nominal wall shear strength
G	modulus of shear	ρ_t	ratio of area distributed transverse reinforcement to gross concrete area perpendicular to that reinforcement
h	wall height	τ	shear stress
h_{cp}	height of concrete prism	ω	a constant
l	wall length		
l_{as}	length of adhesion surface		
P	load		
s	thickness of adhesive layer		
t	thickness of steel strip		

strip system, proposed to retrofit low-rise masonry and concrete walls, is effective in significantly increasing their in-plane strength, ductility, and energy dissipation capacity.

The main focus of the present study is an experimental research on finding out an effective steel strip configuration in order to improve the hysteretic behavior of shear deficient RC walls under lateral load. The goal of the retrofit is to improve the diagonal tension shear strength, ductility and energy absorption of the poorly detailed RC walls. In this study, shear deficient RC walls were strengthened using three different steel strip configurations and then tested under cyclic lateral load. The different configurations of steel members considered were the diagonal shaped (X-shaped), lateral and combination of lateral and vertical strips. The measured and observed cyclic response of RC shear walls is discussed in this paper. The study focused on the lateral load–displacement behavior of specimens strengthened using steel strips. Characteristics such as lateral strength, ductility and failure mode of wall specimens were measured and are presented herein.

2. Experimental study

2.1. Test specimens and materials

The test specimens represent lower part of a shear wall of an older existing building. Four half scaled, four shear deficient RC wall specimens were constructed and tested at Gazi University to investigate the influence of shear strengthening using different externally bonded steel strip configurations on the hysteretic response of structural walls. Slenderness ratio of the wall was 1.5. Dimensions and reinforcement details of the test specimens are given in Fig. 1. The specimen consists of three parts: the head beam through which the lateral load is transferred into the wall, the panel which models a shear wall and the footing used for anchoring the specimen on the rigid floor. Uplift of the footing was prevented by post-tensioned high strength anchor rods. The head beam was 300×300 mm and reinforced longitudinally by eight deformed bars having 12 mm diameter and reinforced transversely by ties with a diameter of 10 mm deformed bars spaced at 100 mm. The base beam section was 400×500 mm. As longitudinal reinforcement, 16 mm diameter deformed bars were used in the base. Deformed bars with a diameter of 10 mm spaced at 100 mm were used as double ties in the base beam. Wall had a uniform section of 1000×100 mm, through the wall height of 1500 mm. The lateral and vertical reinforcement in the wall consisted of two layers. As vertical reinforcement of the wall 6 mm diameter bars at 250 mm spacing was chosen. The transverse reinforcement consists of 6 mm diameter bars at 400 mm spacing, and was chosen to provide a shear critical wall specimen. Longitudinal and lateral reinforcement ratios were 0.0183 and 0.0014 respectively. In order to simulate the poor seismic details in the existing structures, each of the transverse reinforcement in the wall was anchored by 90° hooks and walls had no boundary members at either side. The concentrated vertical reinforcement at each side of the wall consists of four 16 mm diameter deformed bars, providing high flexural capacity, thus, increasing shear strength demands to be satisfied with strengthening.

Properties of test specimens are summarized in Table 1. Specimen 1 was the reference specimen that was tested without strengthening. Remaining three specimens were tested after strengthening by bonding steel strips with epoxy adhesive on the surface of the wall. Steel strip configurations are presented in Fig. 2. Specimen 2 was strengthened by bonding steel strips having dimensions of $1560 \times 200 \times 2.5$ mm through the diagonals of the wall symmetrically. Specimen 3 was strengthened by horizontally placed, 280 mm distant, steel strips having dimensions of $1000 \times 100 \times 2.5$ mm. Specimen 4 was strengthened with lateral and vertical steel strips having dimensions of $1000 \times 100 \times 2.5$ mm and $1500 \times 100 \times 2.5$ mm respectively. Lateral steel strips bonded in Specimen 4 were similar to Specimen 3 and unlike any of the strengthened specimens a total of three, equally spaced at 450 mm, vertical strips were bonded on the wall sides. Steel strips were symmetrically bonded on the both faces of the strengthened specimens. Strips on each face of the wall connected to each other by the edges and intersecting zones with 10 mm diameter and 140 mm length threaded rods. The two edges of the rods were fastened with nuts after passing through 12 mm diameter holes drilled on the concrete wall and steel strip. In this way steel strips braced the RC wall, debonding of the steel strips from the concrete surface was delayed and premature buckling of steel strips were prevented. Fig. 2 shows the locations of the rods on steel strips and rod connection detail is given in Fig. 3.

All specimens were casted in a horizontal position in the laboratory. Specimens were fabricated in two stages. In the first stage, RC shear wall was casted and cured for 28 days. In the second stage, specimens were strengthened with steel members. To this purpose, first of all steel strip and anchor locations were marked on the specimen. Then, at predetermined anchor locations 12 mm diameter holes were drilled and the areas where steel strips will be bonded were roughened by mechanical grinding machine until the aggregate was exposed. Later wall surface was brushed and vacuum cleaned to remove loose particles and dust. The bonding faces of the steel plates were also finely roughened by a mechanical grinding machine and cleaned thoroughly with acetone. Then the epoxy was spread all over the surface of wall