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SEISMIC RETROFITTING OF REINFORCED CONCRETE SHEAR WALL USING CARBON FIBER REINFORCED POLYMERS (CFRP)

Shahzad Khan[1], Samiullah Qazi[2], Ali Siddique[3], Muhammad Rizwan[4], Muhammad Saqib[5]

[1] Lecturer, Civil Technology Department, Government College of Technology, Swat, Pakistan

[2] Assistant Professor, Civil Engineering Department, University of Engineering and Technology, Peshawar, Pakistan

[3] Civil Engineering Department, COMSATS University Islamabad, Punjab, Pakistan

[4] Lecturer, Civil Engineering Department, University of Engineering and Technology, Peshawar, Pakistan

[5] Lecturer, Civil Engineering Department, Iqra national university Hayatabad, Peshawar, Pakistan

Email: [1]shahzadkhan@uetpeshawar.edu.pk, [2]Samiullah.qazi@uetpeshawar.edu.pk, [3]ali_cui@citwah.edu.pk, [4]Mrizwan@uetpeshawar.edu.pk, [5]Muhammadsaqibkhan@inu.edu.pk

Corresponding Author: **Shahzad Khan**

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Abstract

In this paper, the experimental results of a partially retrofitted non-compliant with code concrete shear wall using uni-directional carbon fibre reinforced polymer (CFRP) are introduced. The common deficiencies in the wall were insufficient reinforcement, un-confinement at the boundary zone, the lake of in-plane stiffness, and ductility. The adopted retrofitting technique consists of the CFRP strips bonded to both wall face with mesh anchors installed in the wall panel and foundation to avoid debonding. The wall was tested before and after retrofitting under a constant axial load, and the displacement control lateral cyclic load was applied to the head beam level. The retrofitted wall showed satisfactory results in terms of drift and shear strength. The test results include the failure pattern, load-displacement behaviours, and deflected shape.

Keywords: Reinforced concrete, Deficient wall, partial retrofit, CFRP fabric, cyclic loading

I. Introduction

The shear walls are considered an integral part of building constructed in high to moderate seismic region, because of its influence in improving the structure performance against lateral loading in terms of strength and stiffness [XIII]. However, in developing countries, due to cost-saving techniques adopted by owners and contractors, the structural members are not fabricated according to seismic design code provision. Likewise, findings were made on the field survey conducted in Pakistan twin cities (Islamabad and Rawalpindi). The shear walls provided in the building did not fulfill the seismic code provision, i.e., UBC 97 [XV], ACI 318-05 [I], and BCP 07 [III] . The primary defects observed were: design, flaws in construction materials, insufficient reinforcement (vertical and transverse), the lake of a seismic hook in confinement, and non-confinement of boundary elements. Therefore to improve their seismic performance strengthening these structural members is the need of the day.

Researchers around the world have used/proposed numerous techniques of techniques to strengthen deficient structure members. These include concrete replacement and concrete jacketing [II], the addition of steel section [VII], steel bracing [XIV], and through-thickness rods [VIII]. However, the proposed technique disadvantage is its high weight to strength ratio. Therefore it is also can alter the structure behaviour to increase load mass. To counter this phenomenon, researchers have used fibre-reinforced polymers [IX] and Shape Memory alloys [VI] to strengthen weak structural members. Among these, the FRP strengthening technique is well adapted for the strengthening of beams and columns in this region [XI], [XII]. Therefore the same technique is adopted in this research.

The objective of this research work is first to gauge the seismic performance of theses existing non-compliant RC walls and then proposed a strengthening/retrofitting CFRP configuration based on the observed failure mode. This paper presents the results of a quasi-static cyclic test conducted on a non-compliant RC wall, fabricated a 1:3 scale. The test result of the control specimen and FRP retrofitted RC wall are discussed in detail. It includes the load-displacement curve, failure modes, and stiffness.

II. Experimental study

Material properties

During the shear wall fabrication, three cylinders were cast to conform to the ordinary concrete compressive strength of the shear wall. While in the same manner, three cylinders of Engineered cementitious concrete (ECC) [X] were cast. All the cylinders were cured for 28 days and afterward tested in the universal testing machine (UTM). The calculated ultimate strength of the concrete and ECC are 2637 psi and 3500 psi, respectively. Fig. 1 indicates the average stress-strain curves for the shear wall and Engineered cementitious concrete (ECC), respectively.

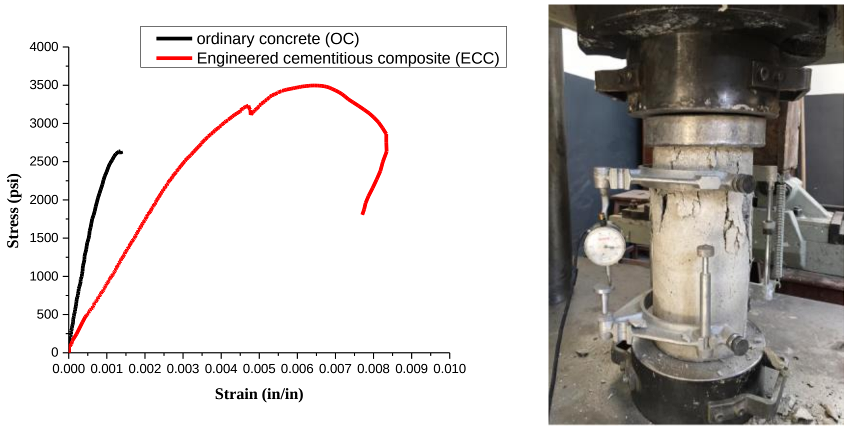

Fig. 1: The stress-strain curve of the concrete cylinders

The steel bar of size #3 and #4 was used as reinforcement in the shear wall to match with the non-compliant RC wall reinforcement ratio. Table 1 illustrates the properties of the steel used in the shear wall.

Table 1: Steel rebar strength

Steel Reinforcement properties		
Bar Size (#)	**Yield Strength (psi)**	**Ultimate Strength (psi)**
3	65992	80061
4	71939	87168

The Uni-directional carbon fibre fabric (CJ200T) was used as a reinforcement material for retrofitting with Sikadur (330) resin material. Sikadur (330) is a two-mixed, thixotropic epoxy-based saturated adhesive matrix consisting of Part A) having white colour and Part (B) of grey colour that is the hardener. The standard mixing ratio for both A & B is 1:4 by weight with at least 3 minutes of mixing with a 600rpm electric spindle machine. Table 2 presents the properties of the CJ200T composite dry fibre system and Sikadur (330) epoxy.

Table 2: Properties of composite materials and Epoxy

Parameter	(a) Typical dry fibre	(b) Sikadur-330 Epoxy(2-Part epoxy impregnation resin)
Tensile Strength (psi)	495304	4352
Elongation at break (%)	1.7	0.9 (7days at +23°C)
Tensile Modulus (psi)	34809057	652670
Fibre Fabric Thickness (mm)	0.111	NA
Fibre Specification	12K	NA
Width (mm)	100	NA

Specimen detail

The 1:3 scale down slender shear wall specimen having a slenderness ratio (H/L) of 2.4 was detailed to have similar properties and dimensions of the non-compliant with code structures. Fig. 2 shows the dimensions and reinforcing details of the shear wall. Table 3 shows the percentage of steel reinforcement.

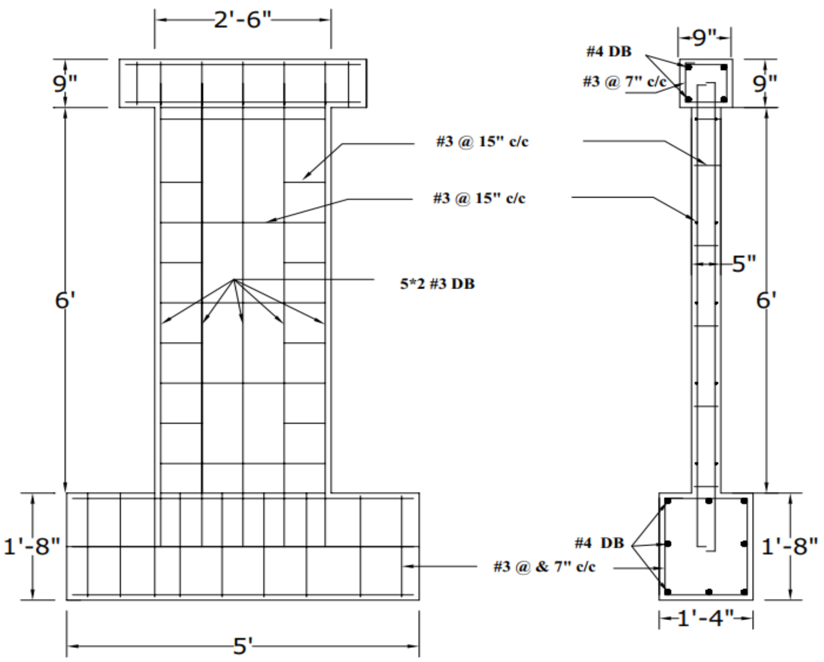

Fig. 2: RC shear wall structural detailings

Table 3: Reinforcement details of shear wall

Aspect ratio	Vertical steel bars ratio (web) (%)	Horizontal steel bars ratio (%)	Confinement in boundary element (%)
2.4	0.73	0.33	0.33

III. Methodology

Control wall failure mode

The original wall was tested up to the failure and damaged heavily in the critical regions. Concrete splitting at the wall edge, buckling of reinforcement at the toe, flat crack at the wall foundation joint, flexural, and diagonal cracks was the observed mode of failure, as shown in Fig. 3.

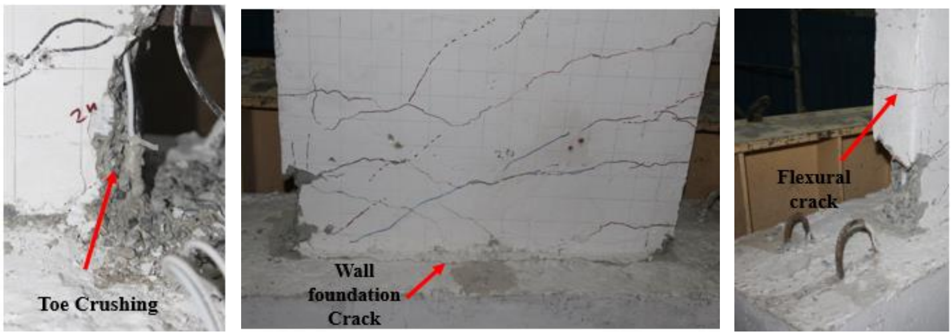

Fig. 3: Cracks propagation of wall

FRP retrofitting

The retrofitting strategies were based on crack propagation in the control wall. Therefore, the observed cracks within the wall panel were up to half of the wall height, with no crack observed above the mid-height of the wall. The methodology adopted to restore the flexural capacity of the wall include the repair of a damaged specimen before the application of CFRP. For this purpose, a superior mix design of the Engineered Cementitious concrete (ECC) was used to replace the damaged concrete at the wall toe, as shown in Fig. 4. Hydrophilic Polymer Fibers (HPF), polymer thickeners, and Superplasticizer (SP430) were used in the preparation of ECC. The high strength of concrete within a minimum time was achieved with ECC. The repair locations were cured for seven days.

a b c

Fig. 4: Repair Techniques (a) Engineer Cementitious Concrete preparation, (b) Removal of Crush Concrete (c) Replace of damaged concrete with ECC

The roughness and unevenness of the wall surface were removed by using an electric grinder. The wall was cleaned with an air compressor with a pressure of 200 psi, as shown in Fig. 5. The CFRP strips along with mesh anchors are installed in the foundation and wall panel with the aim to limit the debonding of CFRP and to transfer the load safely from the wall panel to the foundation block. A drilled hole was made at each intersection point within the wall panel and foundation (up to 6 inches depth), and each anchor is embedded into the hole. The extra length of each anchor was expanded on the surface for the proper bond between horizontal and vertical stripes, as shown in Fig. 6. All dimensions and details of the anchors are listed in Table 4.

Fig. 5: Smooth ground surface for CFRP and holes drilling for CFRP anchorages in foundation and wall panel

Table 4: CFRP reinforcement and anchors details

	CFRP Strip		Anchor fibre tows (Number)		Anchor number	
Specimen	**Type**	**Width(mm)**	**Wall foundation**	**Wall Panel**	**Wall foundation**	**Wall Panel**
Control wall	-	-	-	-	-	-
Retrofitted wall	Unidirectional	100	26	6	3 (each block)	9

Fig. 6: Retrofitting methodology

IV. Test Setup

The response of the specimen subjected to displacement control lateral cyclic loading test was monitored by using two actuators (vertical and horizontal) and linear variable displacement transducers (LVDTs) at different locations, as shown in Fig. 7. A constant vertical load of 90 KN was maintained with a control mechanism of hydraulic pressure gauge and applied directly to the surface of two steel plates kept at the head beam level. Between the steel plates, three steel roller was positioned not to interrupt the lateral cyclic loading.

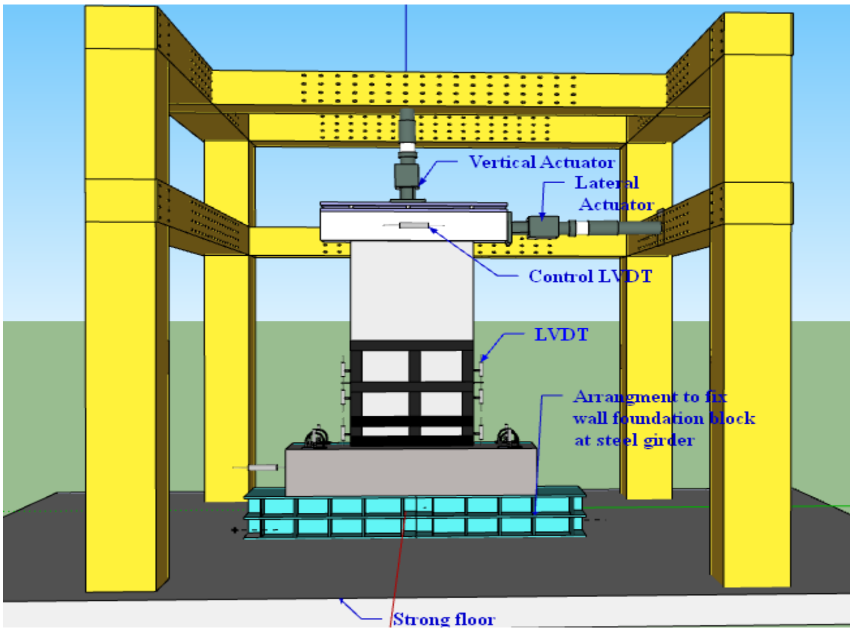

Fig. 7: Test Setup

V. Results and Discussion

Retrofitted wall failure

The CFRP with mesh anchor limited the pre-existing cracks in the wall panel and shifted the load demand to the wall foundation joint. The failure mode of the retrofitted wall (SW2) was cracking beneath CFRP strips just at free ends, 12 mm pull out of foundation anchors near to wall ends, Rupture of CFRP at 150 mm height above the base of the wall, and ECC concrete chunk split at the wall toe. The applied CFRP strips restricted the old cracks within the wall panel, and no damages were noted except the old cracks were widened. The failure mode of the retrofitted wall is shown in Fig. 8.

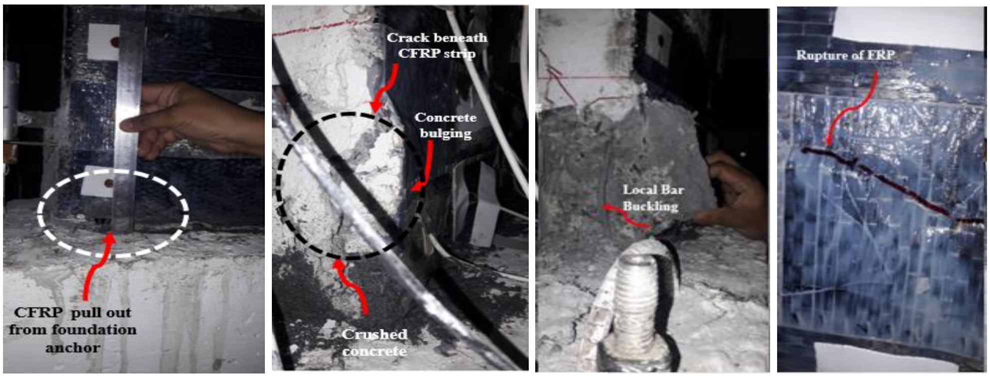

Fig. 8: Failure modes of the tested wall

The response of retrofitted wall

The retrofitted wall was retested under the same loading conditions as that of the control wall. The drifts were [0.25. 0.5, 0.1, 0.75 ….1.7%]. At 0.8% drift, the debonding of FRP was observed due to extreme concrete cracking at the toes of the wall concrete crushes at the compression zone. At a lateral displacement of 20 mm (1.1% drift), FRP initial anchor debonding was observed. CFRP anchors debonding were only noted at the wall foundation where concrete was broken and crushed, but no proof of complete pull out of the anchors in the wall panel was found. At 20 mm lateral displacement, the strength of the wall was consistently degraded, and the FRP fracture was marked on the vertical strips near the edges of the wall due to cracks propagated beneath the FRP strips resulting in the debonding of the CFRP strips from the concrete surface. The average ultimate load of the repair wall, RSW2 in both push and pull direction, is 81 KN with a maximum drift of 1.7% and ductility of 5. The external CFRP reinforcement gained its initial stiffness with a 29 % increase in ultimate strength in the push direction. The hysteretic curves of the tested specimen are shown in Fig. 9. The figure showed an increase in stiffness, strength, and ductility of the wall compared to the control wall specimen. However, the CFRP performed its role and limited the pre-existing crack propagation.

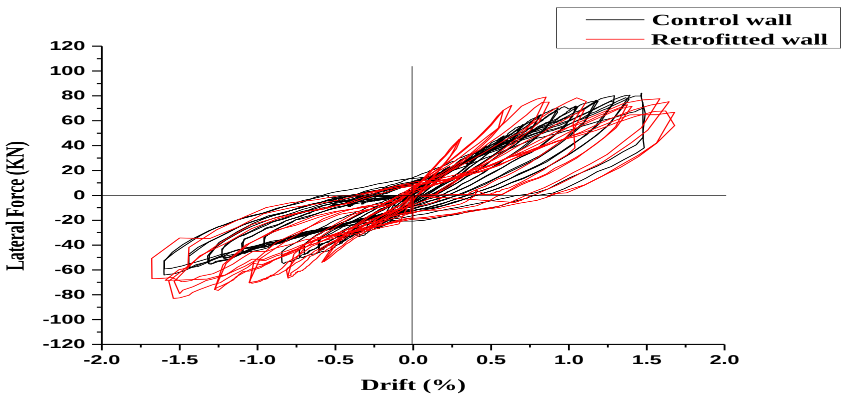

Fig. 9: Hysteresis curves

Lateral load-displacement relationship

Fig. 10 shows the comparison in terms of envelope curves. Table 5 highlighted all the measured quantities recorded during the test. The control specimen showed non-linear behavior with an average flexural capacity of 64 KN (in push) and 76.61 KN (in pull) direction at the induced lateral drift of 1.6 % and 1.17 %. The post-peak curve of the specimen is not shown because, at this stage, the test was stopped for the safety concern where severe concrete falling at the location of the wall toe end was observed. Specimen RSW2 showed an increase of 30 % strength (82.96 KN) in pull and 3% strength (79.13 KN) in the push direction at the induced lateral drift of 1.54 % and 0.85 %, respectively. The yield load of the retrofitted specimen (RSW2) was 26% higher than that of the control wall SW2. The sudden drop in the post-peak curve is due to the rupture and pull out of CFRP and toe crushing in the last few cycles. Fig.11 the load-displacement behavior of the before and after retrofitting.

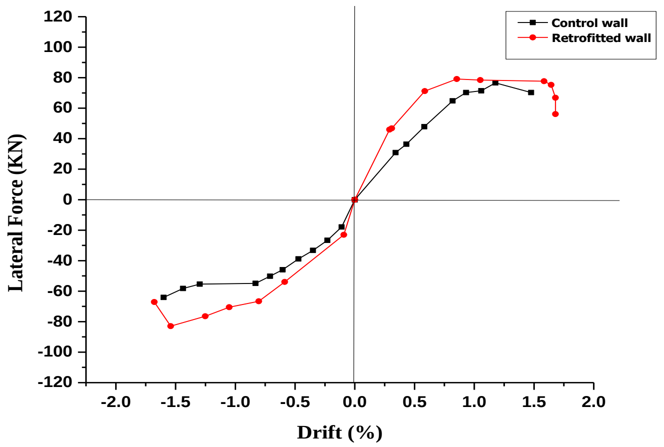

Fig. 10: Load displacement envelopes of original and retrofitted wall

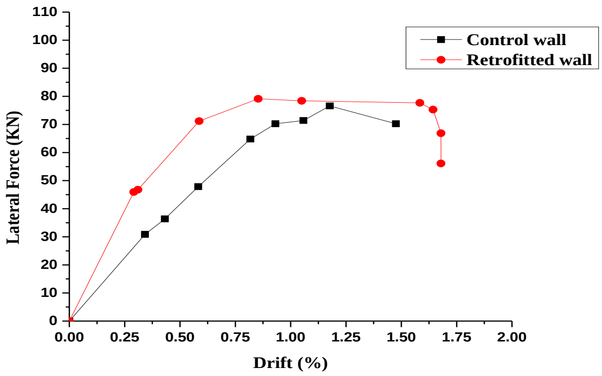

Fig. 11: Load comparison of control and retrofitted wall

Table 5: Maximum and Minimum displacement measured during tests

Name	Fu⁻	[%]	Δ u⁻	[%]	Fu+	[%]	Δ u+	[%]
	[KN]		[mm]		[KN]		[mm]	
Control wall	64.11		27.64		76.61		20.32	
Retrofitted Wall	82.96	29%	26.61	-4%	79.13	3%	14.74	-27%

Xu+ : maximum value in push, Xu⁻ : maximum value in pull

V. Conclusions

The research examined the significance of the partial retrofitting technique using CFRP strips on the behaviour of non-compliant with code concrete shear wall structure. The method improved the ultimate strength, stiffness, and ductility of the pre-damaged shear wall. The CFRP mesh anchors have transferred the load from the strips to the foundation block, limited the pre-existent cracks, and delayed the debonding of CFRP strips. No complete pull out being reported during the test. Besides, the ECC played its role and delayed the concrete crushing and falling at both wall edges. It is presumed that rather than fully wrapping the wall, the partial retrofitting technique adopted to retrofit the wall proved to be successful.

Conflict of Interest :

No conflict of interest regarding this article

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