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Retrofitting of Reinforced Concrete Shear Walls Using Carbon Fiber Reinforced Polymer Wrap

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Abstract-- *This research work is an experimental program which includes retrofitting of Reinforced Concrete (RC) shear walls. Two identical full scale shear walls (5'x10'x8") were tested under quasi static tests and the pattern of cracks was observed before retrofitting. The walls were then repaired and retrofitted using Carbon Fiber Reinforced Polymer (CFRP) wrap on either sides of walls. Study of failure mechanism before and after retrofitting was carried out. The envelope curves and bilinear idealization curves were obtained from the observed back bone data. Performance levels against the story drifts were determined, using ASCE/SEI-41-06 approach. From this study it was concluded that the performance of the retrofitted walls has greatly improved.*

Key words: *Retrofitting; RC Shear Walls; CFRP wrap; Ductility.*

I. INTRODUCTION

Recently the design of reinforced concrete shear wallshave got significant importance in the new construction based on seismic and capacity design philosophies[1].To encounter the requirements for modern seismic design it is necessary to enhance the seismic capacity of the shear walls which is possible only by retrofitting of shear walls to raise their capability at positions of greaterearthquake demands which could more possibly occur at the foundation of wall in a plastic hinge zone, or may occur due to higher modes of vibrationatupper stories [2]

Several retrofitting techniques are used which aims to increasestrength, ductility,stiffness, ora combination of these for RC shear walls. Due to some special characteristics of fiber reinforced polymer(FRP) which are high strength, light weight, ease of application and resistant to corrosion, these materials have got special attention in the past few decades [3]. Some time it is not possible to relocate or disturb the use building and it is necessary to retrofit it, in such cases the FRP composite deals a faster and easier alternative [4].

The FRP materials are used to improve the flexural capacity of shear walls by treating the extremities of the cross sections and modifying the fibers parallel to the axis of the wall [5]. Shear strength of reinforced concrete shear walls may also be increased by crossing the potential cracks by orienting the FRP fiber normal to the axis of the shear wall which will produce displacement ductility about 57% higher than the control shear walls and the energy will be dissipated three times higher than the control shear wall [6].

The flexural and shear capacities of the retrofitted shear walls may be enhanced by applying the diagonal strips of FRP in both directions. This has resulted the increase in lateral load capacity by 40 and 57% of 1st and 2nd wall respectively and the displacement ductility was increased three to four times[7]

A recent research in which, usage of shear wall is mandatory in multi-story buildings as these walls reduce the displacement in the structure along with safety against failure so it reflecting the concept that the storey without shear wall will be vulnerable during earthquake and it will not be rigid [8].

Performance-based retrofit and repair of older RC structures can lead to a cost effectiveapproach where demolishing and reconstruction is not applicable or economical. There are large numbers of existing RC structures designed according to pre 1970's standards which are vulnerable to seismichazards [9].

Fiber reinforced polymer (FRP) materials are continuing to show great promise for use in strengthening reinforced concrete (RC) structures. These materials are an excellent option for use as external reinforcing because of their light weight, resistance to corrosion, and high strength. Externally bonded FRP sheets have been used to increase moment capacity of flexural members and to improve confinement in compression members. The moment capacity of flexural members has been enhanced by fiber reinforced polymer (FRP) and the confinement of compression members has also been done by using this material due to its distinct qualities in the form of light weight, resistant to corrosion etc.[10].

In this research the samples are prepared in the Laboratory and tested for finding different parameters like ductility, strength and then to investigate the effect of CFRP wrap, as a technique of retrofitting of RC shear walls.

II. MATERIAL PROPERTIES AND SAMPLE PREPARATION

2.1 Material Description

The material used for the construction of shear walls is concrete and steel rebar, while for retrofitting CFRP wrap and Epoxy were used. The properties of these materials are presented below:

2.1.1 Concrete

To measure the compressive strength of concrete, standard cylinders of size 6-in dia and 12-in length were made as per ASTM [11]. The average compressive strength of the concrete test cylinders is reported as 2991Psi, shown in Table 1.

Table 2.1: Compressive Strength of Concrete

Sample	1st	2nd	3rd	4th	Average
fc (psi)	2855	3100	2798	3210	2991

2.1.2 Steel Rebar

The steel rebar of size #3 has been used in the research work. The reinforcement was obtained from the same source of ASTM standard A706 [12].Threesamples were checked in lab, and the average yield strength, ultimate strength was noted to be 82323 psi and 99484 psi respectively. (Shown in Table 2.2.)

Table 2.2: Steel Rebar Strength

Bar #	Yield Strength(psi)	Ultimate Strength (psi)	Percent Elongation (%)	Effective Dia (in)	Weight (lbs/ft.)	Bend Test
No.3	82339	99523	9.4	0.375	0.376	OK
No.3	82509	99319	9.3	0.375	0.376	OK
No.3	82121	99610	9.5	0.375	0.376	OK

2.1.3 Epoxy

In the market this epoxy is known by the name"**Chemdur 300"**; Impregnation Epoxy. The properties of Epoxy are given in Table 2.3.

Table 2.3: Properties of Epoxy [13]

Technical Data	
Components	Chemdur 300
Color	Comp. A White, Comp. B Grey
Mix ratio	A comp : B Comp= 4:1 by weight
Physical data	
Density (20C°)	1.31 kg/Lit. (Comp. A + B mixed)
Viscosity	Pasty does not flow.
Application Temperature	Substrate & ambient Temp. :+15 C° to 35 C°.
Tensile Strength (DIN 53452)	Curing : 7 days, 23 C° : 30 N/mm²
Shelf life	At least 18 months from date of production if stored in unopened original containers at temperatures between + 5 C°and 25 C°
Packing	5/10 kg units(A+B)

III. SAMPLE PREPARATION

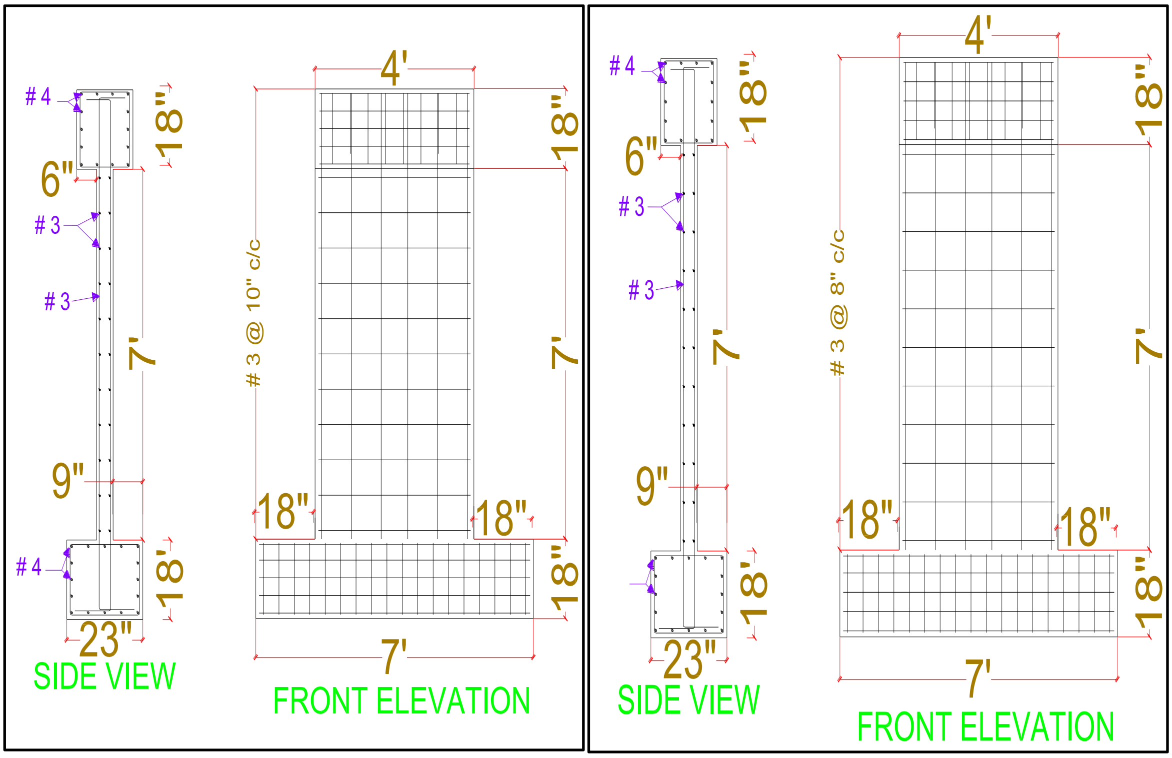
Two identical RC shear walls were prepared and tested [8] under quasi static loading up to ultimate strength. The walls were then repaired and retrofitted by CFRP wrapping as shown in Figure-1

Figure 1: Construction of RC shear wall 1& 2 in progress

3.1 Walls Geometry and Details

Both the walls were of same geometry. However, reinforcement ratio was the changing factor as shown in Figure-2.

The design i.e. Dimensions and Reinforcement details of Reinforced Concrete Shear Walls were already finalized. [8]



Wall – 1 Wall – 2

Figure 2: Nominal Dimension of test specimens

IV. METHODOLOGY FOR TESTING

The shear walls were initially tested [8] as shown in Figure 3. The damage pattern observed was limited to lower third portion of the shear walls, therefore the repair & retrofitting scheme was applied to that area only. The repairing technique includes (a) removal of damaged concrete from the tested walls (Figure-4), (b)surface treatment (i.e. surface was made rough through chisel before filling of fresh concrete) for a mechanical bonding of new concrete with the old one (Figure-5). The freshly applied concrete was cured for about 28 days. In order to apply CFRP wrap over the repaired walls a diamond dick was used to smoothen the surface of concrete. (c) Epoxy resin (Chemdur-300) was applied on the surface before wrapping CFRP so that the composite action of concrete and CFRP wrap ensure the maximum strength of the assembly. The application of epoxy and CFRP wrap single layer is shown in Figure-6. The assembly was prepared and kept for curing to prevent deboning of the wrap from the concrete.

The assembly was then tested according to ASTM[14]

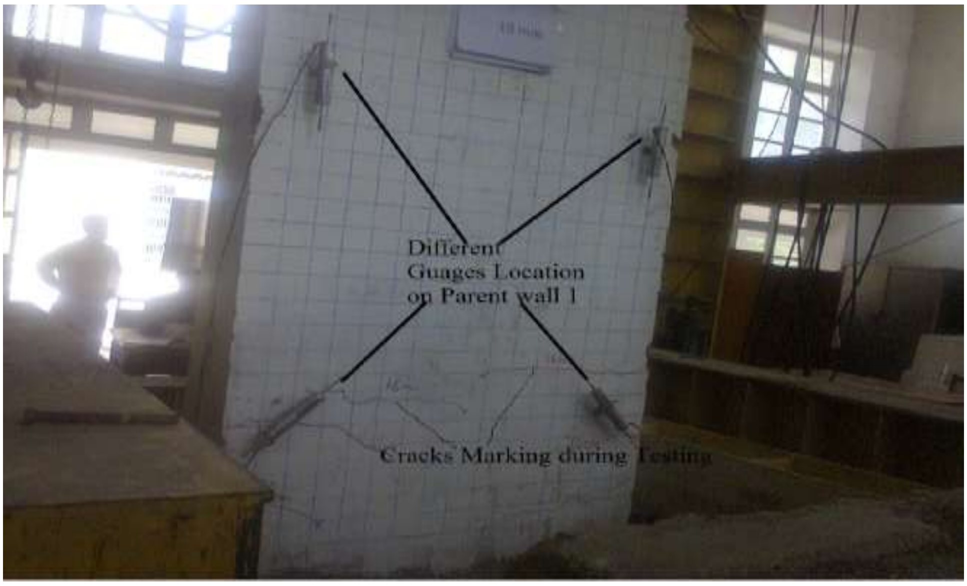


Figure 3: Testing of Parent Wall 1 [8]

Figure 4: Removal of loose concrete from the damaged portion of the wall after phase 1 Testing

(a) (b)

Figure 5 : Repairing of the damaged shear wall and Preparation of surfaces of RC Shear wall for CFRP Wrapping

(a) (b)

Figure 6: Application of Epoxy before application of CFRP Wrap

4.1 Experimental test setup

Shear walls were made under the testing assembly in the laboratory. The footing of the walls was fixed with the strong floor via 4 (1-in threaded) bolts. For applying racking load on the top of the Shear walls, a hydraulic actuator of capacity 500KN or 50 tons was fixed to horizontal beam attached to the steel columns of steel testing assemblage. The actuator was pushed forward for about 5-6 inches to reach so that the end plate touches the shear wall. Figure-7 shows these arrangements. To find the top displacement of the shear walls two calibrated Linear Displacement Transducers (LDT) of gauge length of 2 inches were connected near the swivel and its opposite side. A wire was tighten with gauge and attached with the nail in the mid of top beam from both gauges. Similarly to find out diagonal compression or tension in the panel during the application of the load four (04) Nos LDT of gauge length of 2 inches were fitted at each bottom corners of the shear wall. For fixing of Linear Displacement Sensors [LDS], holes were made with the help of drill machine.

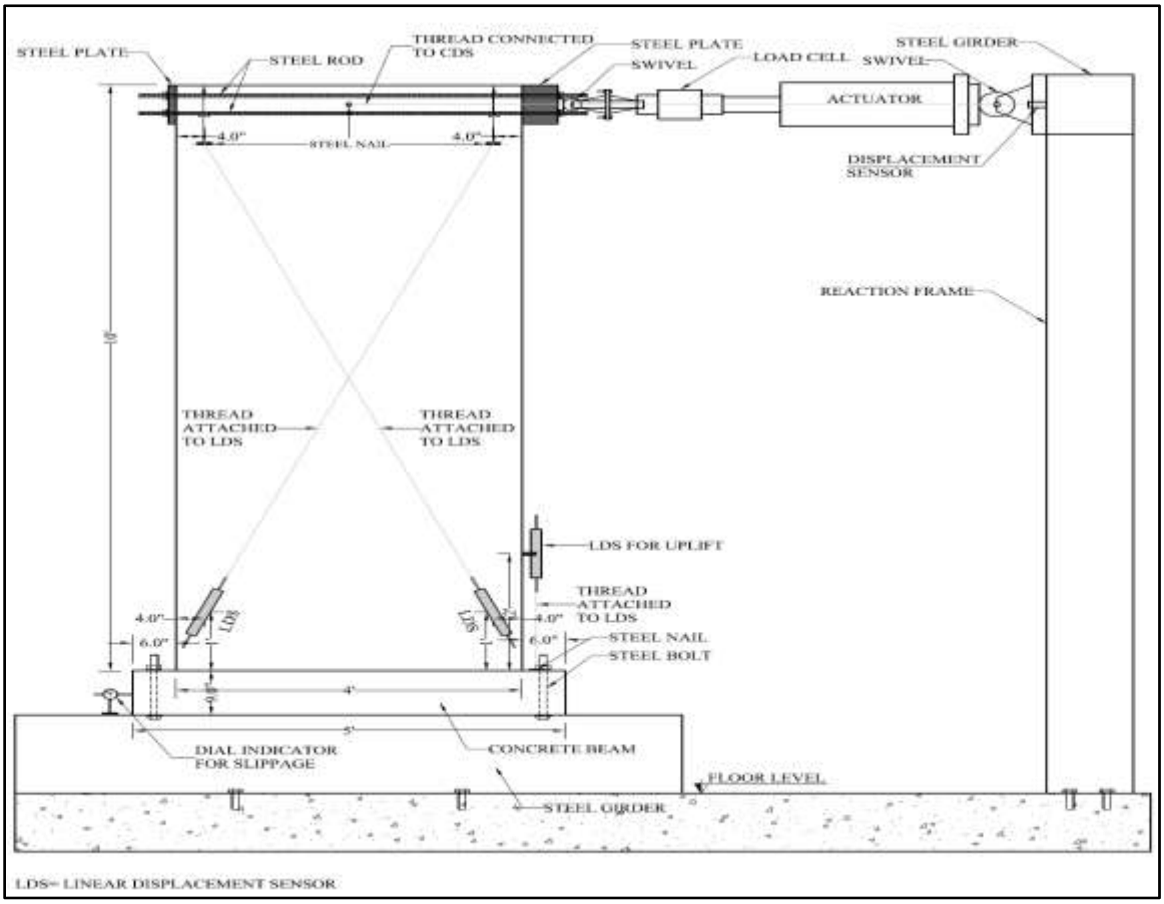


Figure 7: Detailed Experimental Setup for cyclic shear load test

4.2 Failure Modes and Crack Pattern of RC Shear Walls after Retrofitting

The first crack observed in Wall-1 after retrofitting was at 0.4% drift with a load of 100KN. After 0.4% drift the separation of wall from the foundation was observed. At 0.8% drift with a load of 116 kN, bulging of concrete started in CFRP wrap as shown in Figure8. This bulging of concrete continued in the subsequent cycles, therefore no further cracks appeared on the face of the wall. Plastic hinge formation was observed at peak load of 118 kN for wall-1 and 137.5kN for wall-2 at storey drifts of 1.4% and 1.5% respectively. The CFRP wrap remained safe even after the crushing of concrete and yielding of steel.

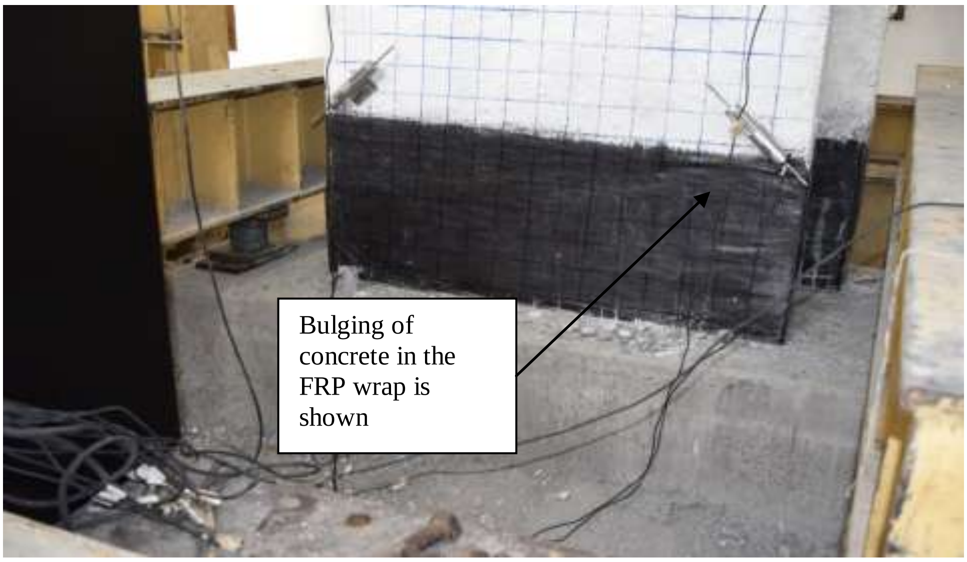
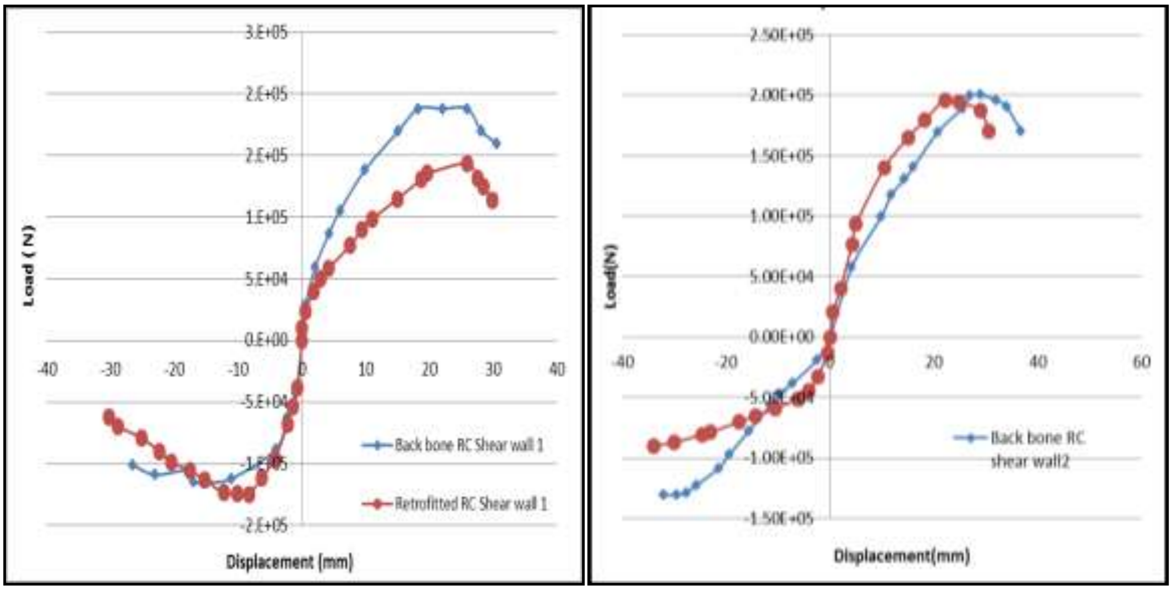


Figure 8: Bulging of Concrete in CFRP Wrap

V. TEST RESULTS COMPARISON OF CONTROL RC SHEAR WALLS & RETROFITTED RC SHEAR WALLS

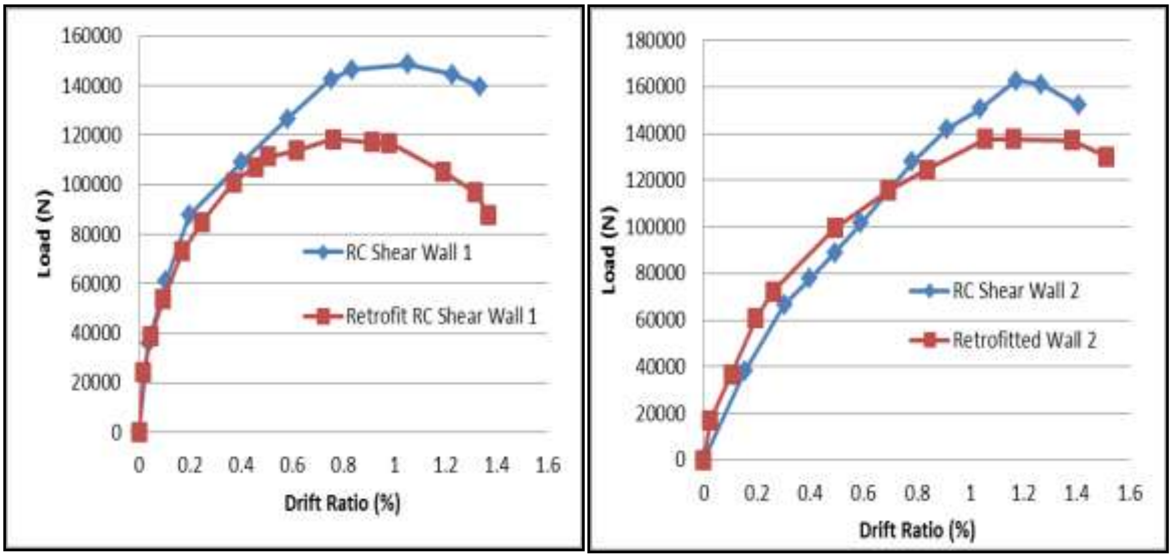
In order to compare the results of RC shear walls, before and after retrofitting and the back bone curves have been plotted as shown in Figure 9.



(a) (b)

Figure 09: Comparison of Back bone curve of Original and Retrofitted RC shear wall-1& 2

The average positive and negative values of each initial cycle has been plotted for both shear walls before and after retrofitting as shown in Figure 10. These graphs show the maximum load taken by each shear wall.



(a) (b)

Figure 10: Load Comparison of Control and Retrofitted RC shear wall-1& 2

5.1 Force-Deformation Parameters (ASTM E-2126)

The bilinear curve consists of the average force deformation both in positive and negative directions.Magenese and Calvi (1997) who proposed a procedure which is based on equal energy principals for elasto- plastic curve.Table-5.1 shows the force deformation parameters for control walls and retrofitted walls.

Newmark and Hall formula for intermediate Periods (0.2<T<0.5 seconds) for calculation of response modification factor(R) and displacement amplification factor (Cd) is given by

$$R = \sqrt{2\mu - 1} \qquad C_d = \frac{\mu}{\sqrt{2\mu-1}}$$

Table 5.1: Comparison of Force-deformation Parameters

Ductility Factors	Shear Wall-1		Shear Wall-2	
	Before Retrofitting	After Retrofitting	Before Retrofitting	After Retrofitting
Ductility Ratio ((μd)	8.91	14.60	2.38	7.72
Response modification Factor (R)	4.10	5.31	1.94	3.8
Displacement Amplification Factor (Cd)	2.2	2.75	1.28	2.03

Based on the above force deformation parameters of the structure before and after retrofitting, significant increase in the ductility of the retrofitted structure was noticed. This is mainly due to improvement of materials properties of RC Shear Wall with CFRP Wrap.

5.1.1 Ductility

The ductility ratio for wall-1 is computed to be 8.91 before retrofitting while a high ductility ratio of 14.6 after retrofitting shown in table 5.1. The ductility ratio for wall-2 is computed to be 2.38 before retrofitting while a high ductility ratio of 7.72 after retrofitting. This shows that the CFRP wrap brings an efficient ductility in the structure which dissipates the energy and prevents it from the sudden collapse. Formula for the determination of Ductility Ratio

$$\mu = \frac{\Delta_u}{\Delta_y}$$

Where Δu is the lateral deflection at the end of the post-elastic range, and Δy is the lateral deflection when yield is first reached.

VI. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

On the basis of the research work, the following conclusions were drawn

1. CFRP proved to be about 80-90% effective mean for retrofitting of RC shear walls.
2. The increment in capacity to resist lateral load was significant after retrofitting.
3. From the bilinear curve, it can be seen that the ductility of the shear walls after retrofitting has been increased significantly. This means that with increase in ductility the life safety during an earthquake is ensured.

6.2. Recommendations

4. It is suggested that CFRP wrap may be used for retrofitting as it is effective in improving the seismic performance of existing shear walls and80% to 85 % of the strength was restored by this technique.
5. The results obtained from the research work were local and may develop a confidence in using CFRP Wrap as a quick retrofitting/strengthening technique without evacuating the structure.

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