Seismic Strengthening of Deficient RC Frame using FRP Laminates

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ABSTRACT: *Effectiveness of FRP warping in improving the seismic evauation of a 4-story RC frame building is presented in this paper. In order to assess the effects of FRP warping, two different categories of RC frame buildings are designed, seismically deficient and seismic resistance RC frame. Seismic resistance RC frame is designed considering dead load(DL), live load(LL) and earthquake forces, whereas the seismically deficient RC frame is designed only for dead load and live load. Seismically deficient RC frame is strengthen by applying FRP confinement to beams and of deficient RC frame as per the provisions of ACI 440.2R-08. Seismic evaluation of seismically deficient as well as strengthen RC frame with FRP wrapping is carried out using nonlinear static pushover analysis. The response reduction factors of the FRP strengthen RC frame is also evaluated. The results of study confirm considerable increase in ductility and reliability of reinforced concrete (RC) frames applied to lateral seismic forces(EQ) due to FRP strengthening.*

Key Words: *FRP-strengthening, RC-frame, pushover analysis, 'R'-factor.*

Introduction

In past years many different buildings in different parts of the world have been designed based on older codes, in which the earthquake load (EQ) were taken a lower emphasis comparing to today's practice while gravity loads(dead load) were considered as the major design loads. Consequently, these structures have become vulnerable to earthquakes as is evident in the past earthquake events such as Bhuj 2001 and Chi-Chi 1999. To reduce the seismic damage of these deficient structures, Fibre reinforced polymer (FRP) at lower costs provides one of the best economical solutions to increase seismic strength of deficient buildings.

Cao et al. (2014) identified the the effect of FRP on 8-storey seismically deficient RC frame subjected to different seismic(eq) loadings. They performed time history analyses with damage analyses for the seismically deficient RC frame and its FRP retrofit RC frame. Eslami et al. (2012) had outlined FRP wrapping of critical regions of the columns is the main technique, the evaluation of code-compliant building shows the effect of increase in the beam ductility after seismic evaluation of a structure. Ronagh et al. (2012) presented design case studies of the medium-rise structures. The slight intervention in the lateral displacement-ductility and provision of the strong-column weak-beam design philosophy is considered. the strengthening design strategy is aimed at increasing the lateral resistance. the nonlinear results confirm CFRP improvement was as much as twice of the GFRP. However, the latter provides higher ductility.

Design Methodology

In this study, symmetric RC -frame building having 4 storey , which typically represent short period structures are selected. seismic assessment of 4 storey RC Frames are performed as per provisions of IS: 456-2000 and IS:1893 (Part1-2016).Design of two different Categories of RC Frame building is carried out as [**I**] Design of seismic deficient RC Frame building (Combinations of DL & LL) [**II**] Design of building as per seismic load consideration (Combinations of DL, LL & EQ). The considered RC -frame buildings have four numbers of bays of 5 m each in both directions as shown in Figure 1. Typical story height is taken as 3.75 m. The thickness of the interior and exterior masonry wall is assumed as 115 mm and 230 mm respectively. The slab thickness is taken as 150 mm. The live load (LL) of 4 kN/m^2 and floor finish (FF) of 1 kN/m^2 is assumed on slabs. The study buildings are assumed on medium soil and is located in zone- **I**V of IS 1893, which is the seismically intensive zone (as described in table-1) covering a large part of the India.

Table1

Seismic parameters	Value
Z (Zone Factor as per IS1893)	0.24
I (Importance Factor as per IS1893)	1.2
R (Response Reduction Factor as per IS1893)	3
T (Natural Time Period as per IS1893)	0.3018
S_a/g (Spectral Acceleration as per IS1893)	2.5

The RC -frame buildins are designed with grade of concrete as M20 and grade of steel as Fe415 respectively. The lateral load distribution is conducted as per table-2.The reinforcement detailing for the seismic deficient and strengthen RC Frame is shown in table-3. A typical plan of study RC frame buildings is shown in figure 1.FRP Strengthening of seismic deficient RC Frame building as per provisions of ACI: 440.2R-08 is done. Seismic assessment of FRP Strengthen RC Frame and deficient RC frame by using Non linear static (push over) analysis.

Table2

Lateral Load Distribution

Floor	Wi	Hi	$Wi.Hi^2$	Qi	Vi
4	1127.14	15	253606.5	239.76	239.76
3	1289.28	11.25	163174.5	154.26	344.02
2	1289.28	7.5	72522.2	68.56	462.56
1	1289.28	3.75	18130.5	17.14	479.72

Table3

Reinforcement detail of 4- storey RC frame

Frame	Members	Width (mm)	Depth (mm)	Reinforcement Details
4-Storey	Beam (top)	300	500	4-nos- 20mm dia.
(DL+LL)	Beam(bottom) Column	300 525	500 525	4-nos- 20mm dia. 8-nos- 20mm dia.+ 4-nos- 25mm dia.
4-Storey	Beam(top)	300	600	4-nos- 25mm dia.
(DL+LL+EQ)	Beam(bottom) Column	300 650	600 650	4-nos- 25mm dia. 12-nos- 25mm dia.

FRP strengthening

Flexural strengthening Using FRP laminates

FRP materials are light in weight, non-corrosive, and gives high tensile strength to the member.

Step-1 Calculation of the FRP system design material properties

$$f_{fu} = \ ?_e f_{fu}^*$$

$$\varepsilon_{fu} = \ ?_e \varepsilon_{fu}^*$$

Step-2 Preliminary calculations

$$\beta_1 = 1.05 - \ ).05\times f_c^{'}/6.9)]$$

$$E_c = 4700\times \sqrt{f_c^{'}]}$$

$$A_f = \ t_f w_f$$

Step-3 Calculation of the existing strain on the soffit(beam)

$$\varepsilon_{bi} = \frac{M_{DL}(d_f - \quad d)}{I_{cr}E_c}$$

Step-4 Calculation of the FRP design strain

$$\varepsilon_{fd} = \sqrt{\frac{f_c'}{nE_f t_f}} \leq \ ).9\varepsilon_{fu}$$

Step-5 Estimation of the depth c,

$$c = \ ).20\times \ l$$

Step-6 Calculation of the strain in the FRP with reinforcement

$$\varepsilon_{fe} \ = \ ).003\times \ \frac{d_f - \ }{c}) - \ _{bi} \leq \ _{fd}$$

Step-7 Evaluation of the existing reinforcement strain level

$$\varepsilon_s = \ \varepsilon_{fe} + \ _{bi})(\frac{d - \ }{d_f - \ })$$

Step-8 Evaluation of the stress in the reinforcement and FRP

$$f_s = E_s \times \ _s \leq \ _y$$

$$f_{fe} = E_f \times \ _{fe}$$

Step-9 Internal force resultants and equilibrium

$$\beta_1 = \frac{4\varepsilon_c' - \ _c}{6\varepsilon_c' - 2\varepsilon_c}$$

$$\alpha_1 = \frac{3\varepsilon_c'\varepsilon_c - \ _c^2}{3\beta_1\varepsilon_c'^2}$$

$$\varepsilon_c' = \ .7f_c'/E_c$$

Step-10 Adjustment of c until force equilibrium is satisfied

$$c = \frac{A_s f_s + A_f f_{fe}}{\alpha_1 f_c' \beta_1 b}$$

Step-11 Calculate flexural strength components

$$M_{ns} = A_s f_s (d - \frac{\beta_1 c}{2})$$

$$M_{nf} = A_f f_{fe} (d_f - \frac{\beta_1 c}{2})$$

Step-12 Calculation of design flexural strength of the section

$$\varphi M_n = \ [M_{ns} + \ _f M_{nf}]$$

The number of FRP laminates required for the Flexural strengthening of an interior reinforced concrete beam is six as per table- 4;

Table 4
Configuration of CFRP for the Flexural strengthening of an interior reinforced concrete beam

	Value
Modulus of elasticity	37 GPa
Tensile strength	621 MPa
Rupture strain	0.015 mm/mm
Thickness per ply	1.02 mm

The number of FRP laminates required for the axial strengthening of an concrete column for axial load increment is two as per table -5;

Table 5
Configuration of CFRP for the axial strengthening of an noncircular concrete column

	Value
Modulus of elasticity	227527 MPa
Tensile strength	3792 MPa
Rupture strain	0.0167mm/mm
Thickness per ply	0.033 mm

Non linear Static Pushover Analysis

- In order to calculate the seismic performance of the structures, the nonlinear static (pushover) analysis was evaluated. A finite element analysis program, seismo-struct was used to run the pushover analysis of seismic deficient as well as for strengthen RC frames are performed. The commonly choosen confined concrete model recommended by Mander was used and uniaxial steel model proposed by Menegotto and Pinto [1973] is used for the modelling. figure -2 and 3 shows the pushover curve of seismic deficient RC Frame and strengthen RC frame respectively. The response reduction(R) factor is a function of ductility factor, strength factor, damping factor and redundancy factor. It's calculation is described in table -6.

$$R = R_S R_\mu R_\xi R_R$$

Where, R_S= strength factor, R_μ= ductility factor, R_ξ= damping factor,

R_R= redundancy factor. $R_S = \frac{V_u}{V_d}$

Where, Vu = ultimate base shear and Vd = design base shear

- The ductility factor (Rμ) is measure as per (Newmark and Hall, 1982) ,the (Rμ) is obtained by,

$$R_\mu = \sqrt{2\mu} \quad -$$

Where, $\mu = \frac{\Delta}{\Delta}$, Δ = displacement corresponding to maximum base shear and Δ = yield displacement.

Table6
Pushover parameter and component of 'R' factor for 4-story RC Frame

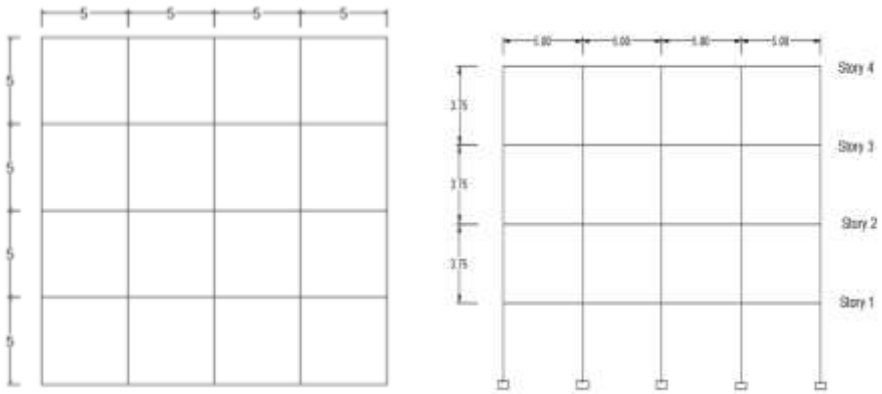
Frame	V_d	V_u(kN)	μ	R_s	R_μ	R_R	R
4-Storey (Without FRP)	479.74	786.75	2.73	1.63	2.11	1	3.44
(With FRP)	479.74	869.43	3.01	1.81	2.24	1	4.05

Conclusion

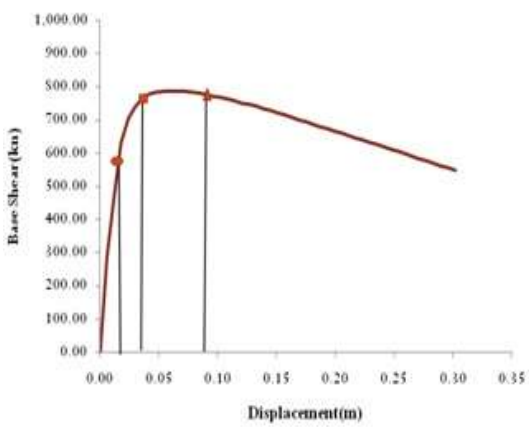
- Base shear capacity for RC-frame evaluated using FRP is increasing approximately 10% than that deficient RC frame.
- FRP increases flexural strength of beam up to 2.27 times than the seismic deficient RC-frame building for similar structures.
- FRP increases Axial strength of column up 1.07 times than the seismic deficient RC-frame

building for similar structures.

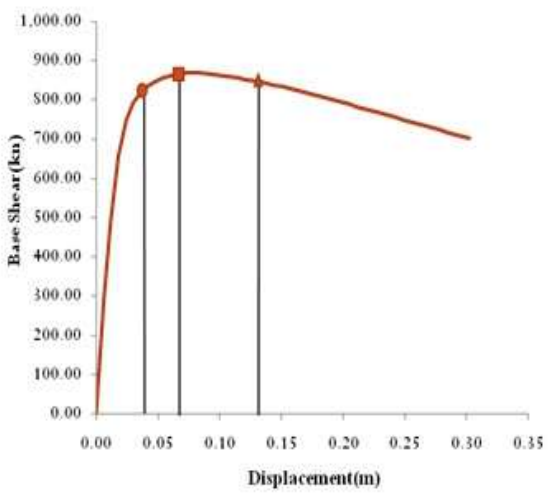
- The response reduction [R] factor of the FRP retrofitted RC frame is increases around 20% than the seismic deficient RC-frame .
- Ductility ration also increases approximately 20% after application of FRP.



(Fig -1-plan and elevation of 4- storey RC Frame)



(Fig -2 - Pushover Curve of 4- storey Frame)



(Fig -3- Pushover Curve of 4- storey FRP Retrofitted Frame)

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