Research Article

Investigation of Retrofitting Reinforced Concrete Structures in Near-Fault Regions

Seyed Nima Naghibi Iravani[a], Ph.D. Rasoul Sabet Ahd[b]

[a] M.Sc. Civil Engineer, Structural Engineer
Islamic Azad University, Sofian Branch
Email: niravani22@gmail.com
[b] Supervisor
Islamic Azad University, Sofian Branch
Email: Sabetahd.r@sofianiau.ac.ir

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Abstract: Generally, existing reinforced concrete structures are retrofitted to withstand applied loads and to increase the structural ductility using appropriate materials and proper executive guidelines. The use of FRP has gained much attention for its low weight, ease of implementation, and high strength as it involves no architectural restrictions, especially in concrete-made buildings. This research used the finite element method and the ABAQUS software to examine the effects of FRP on stress, strain as well as bending deformation parameters from a nonlinear static analysis of concrete, reinforced concrete, and FRP-reinforced concrete. The maximum stress and strain values on the lower and upper surfaces of the models as well as the maximum values in the middle of each beam span were obtained for three models. The findings suggested that an FRP plate of 1.4 mm thick significantly reduced bending in the middle of the span. On average, the maximum stress caused in the reinforced concrete beam model was found to be 23% lower than that in the non-reinforced concrete beam, indicating the application of reinforcement in the model. However, the average maximum stress caused in the FRP-reinforced concrete beam model was 54% lower than that of the reinforced concrete beams, again indicating a significant efficiency of FRP in retrofitting structures.

Keywords: Concrete beam, FRP fibers, bending deformation, stress, strain

1. Introduction

Low-rise buildings constitute over 95% of buildings in Iran. In this connection, it is critical to investigate the vulnerability and retrofitting of reinforced concrete buildings due to existing special complexities. Today, building reinforcement in Iran is becoming increasingly popular considering the new edition of Iran Earthquake Regulations (standard 2800).

On the one hand, one would suggest that Iran's location on one of the three earthquake-prone regions of the world (Himalayan-Alpine belt) and the utilization of unsafe buildings constructed back in 30 years ago are seen the gravest problems facing the country, as cities across the country have proved to be vulnerable to quakes. As suggested by past earthquake studies and the situation of the building in the country, a large number of existing buildings are likely to be damaged by quakes, and vulnerability-based studies have confirmed this; since it is impossible to prevent an earthquake, it is of paramount significance to address such issues as reinforcing vulnerable structures against earthquakes as well as retrofitting damaged facilities. This clearly shows the importance of selecting appropriate techniques to strengthen buildings against seismic behaviors. If a structure is damaged under specific conditions (earthquake, digging, etc.) or if changes are made to a building use or the number of floors are increased, the existing structure will no longer be safe to withstand the loads applied and reinforcement and retrofitting

techniques will be required. Over the past two decades, more emphasis has been laid on retrofitting and reinforcing structures around the world, as infrastructures are aging and more work should be done to strengthen the buildings. On the other hand, it is highly important to strengthen the structures, especially in earthquake-prone areas [1].

In this connection, reinforcing shear walls in general and retrofitting building parts in particular as well as reinforcing connections in a building to increase the overall performance of the building are critical steps [2]. Adding shear walls and braces are thought of as the best structural reinforcement strategies as they are characterized by high stiffness and strength against lateral forces [3]. It should be pointed out that the shear wall serves as an infilled frame for being inside the frame [3]. Also, using steel braces is one of the most applicable reinforcement methods, especially in steel-framed structures. These types of braces, known as reinforced systems, meet the common architectural needs through the different shapes they have [4].

On the other hand, shear walls have, in recent years, been increasingly used in new buildings reinforcement procedures. These systems are characterized by suitable stiffness to control the structural deformation; they also have high energy dissipation and ductile failure mechanism while meeting design criteria [3]. To restrain the end of the bending plates, a steel angle section adjacent to the wall support on which it is fastened by a screw, or a shear FRP plate perpendicular to a bending FRP layer at the end of the layer can be used [5]. In most cases, relatively thin FRP profiles are well implemented [6].

Reinforcement-based FRP systems functioning as an outer coating should not be used as a boosting pressure. The FRP layers collapse can include transversal tensile collapse, fiber local buckling, or shear failure. This type of collapse depends on the type of fiber, its amount, and the type of resin used. The FRP system compressive strength with glass, carbon, and aramid fibers account for about 55, 78, and 20% of their tensile strength, respectively. Generally speaking, the greater the tensile strength, the greater its compressive strength, except for the aramid where fibers have a non-linear behavior at low compressive stress levels. The compressive modulus of elasticity of the FRP is usually lower than its tensile modulus of elasticity. For example, the compressive modulus of elasticity of FRP systems with glass, carbon, and aramid fibers constitutes about 80, 85, and 100% of their tensile modulus of elasticity, respectively [5-7-8].

In general, existing concrete structures are being reinforced to withstand the applied loads, strengthen the failures caused by erosion and increase structural ductility using appropriate materials and proper implementation procedures. Using fiber-made composites in polymer resin media as fiber-reinforced polymers, or FRP for short is increasingly becoming popular to replace traditional materials. To create a FRP system, fibers and resins are used to make multi-layer composites, with the resins (epoxy resins) used to bind multi-layer composite to the lower concrete surface, and coatings to protect materials. FRPs have received much consideration for their low weight, ease of implementation, high strength, and no architectural restrictions, especially in concrete buildings. Thus, this study aimed to investigate methods and procedures to retrofit and reinforce already-reinforced concrete structures in near-fault regions.

2. Materials and procedures

The materials used in modeling the samples, i.e., concrete, steel, and FRP, are listed in the following tables.

Table 1: Material properties

Materials	**Material properties**			
	υ	σ_y (MPa)	E(GPa)	M.D (Kg/m^3)
Steel	0.3	400	210	7850
Concrete	0.19	25	$15100\sqrt{f_c}$	2400
FRP	-	3400	72.5	2570

M.D= Mass density

σ_y= Yield stress

E= Modulus of elasticity

υ = Poisson's Ratio

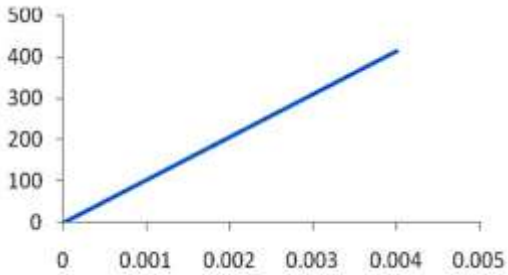

Figure 1: Linear stress-strain curve of steel

The stiffness parameter in composite materials was used instead of using Poisson's ratio parameter in the software. The table describing stiffness properties of the integrated FRP model as consisted of the commercial modeling specifications is as follows:

Table 2: Stiffness properties of the integrated FRP model

K(stiffness)	
Knn=9.285	Kns=6.785
Kss=11.0714	Knt=6.785
Ktt = 11.0714	Kst =6.785

The geometric dimensions of the concrete beam modeled by the ABAQUS software have been suggested by studies. In terms of boundary conditions, a simple type beam (pin-ended) was selected. This is because, in this type of beam, the maximum flexural moment is seen in the middle of the span with the moment-curvature being simple. Also, because this research intended to use the FRP for the bending reinforcement of the beam, attempts were made to provide research conditions by creating pure bending in the span range of the beam. Figure (2) illustrates a schematic of the intended model.

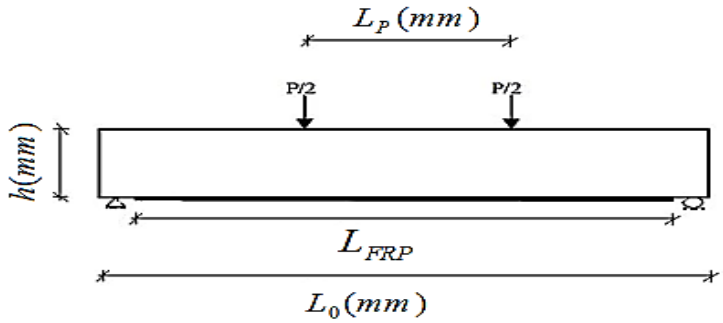

Figure 2: Schematic view of the geometric conditions and loading of FRP-reinforced concrete beams

Table 3: Geometric dimensions of the concrete beam model

Rectangular concrete beam			
Beam span length $L_0(mm)$	**Distance between two individual loads** $L_P\,(mm)$	**Section width** $b(mm)$	**Section height** $h(mm)$
1500	450	100	200

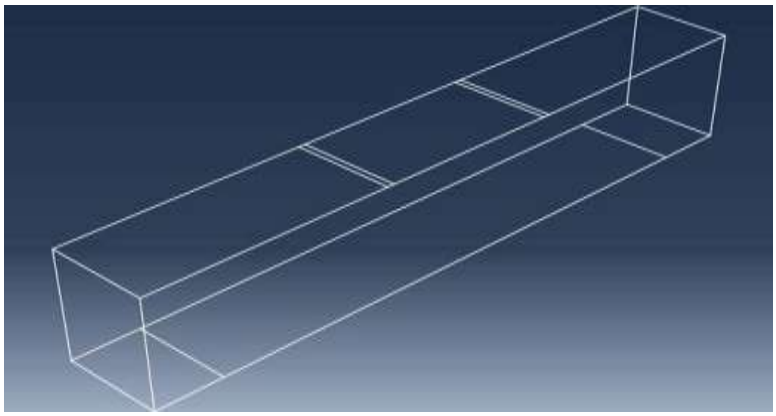

Figure 3: Concrete beam modeling

Table 4: Reinforcement specifications of the concrete beam model

Reinforcement specifications of rectangular concrete beam			
Type of reinforcement	**Reinforcement score** $\phi(mm)$	**No. in each row** **N**	**Distance** $C/C\,(mm)$

Longitudinal (Tensile)	16	2	-
Longitudinal (Compressive)	10	2	-
Transversal (stirrup)	8	-	75

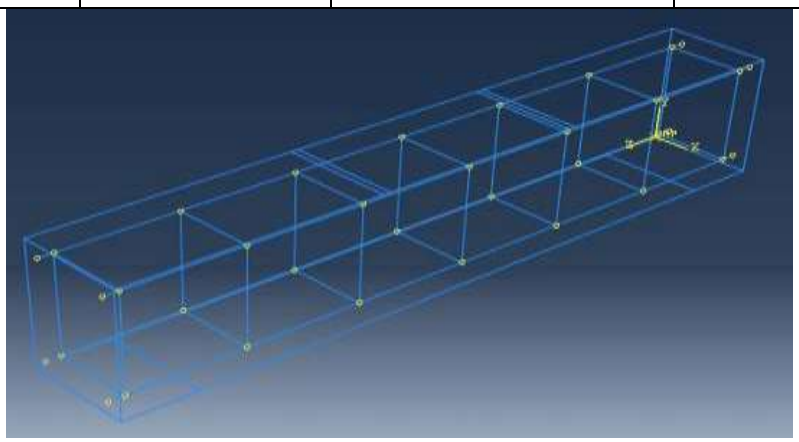

Figure 4: Concrete beam model reinforcement modeling

Table 5: FRP specifications in concrete beam model

FRP specifications in rectangular concrete beam			
Materials	**Plate length** $L_{FRP}(mm)$	**Plate width** $w_{FRP}(mm)$	**Plate thickness** $t_{FRP}(mm)$
FRP	1100	50	1.4

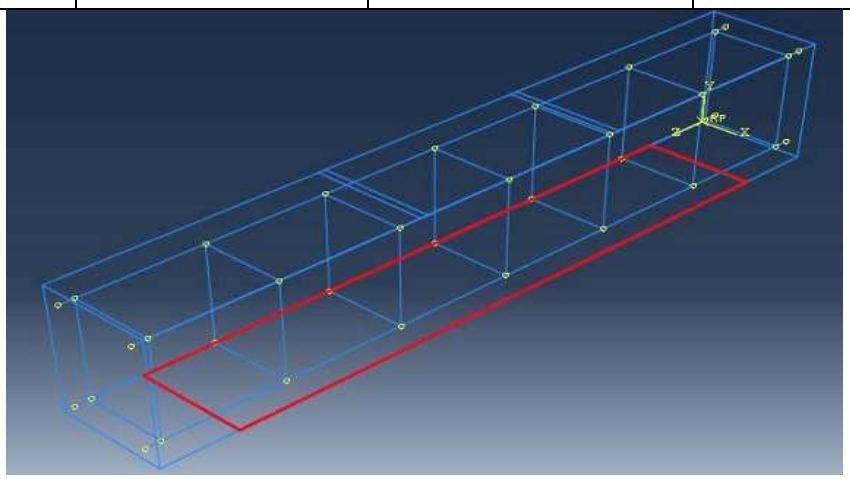

Figure 5: FRP plate modeling in concrete beam model

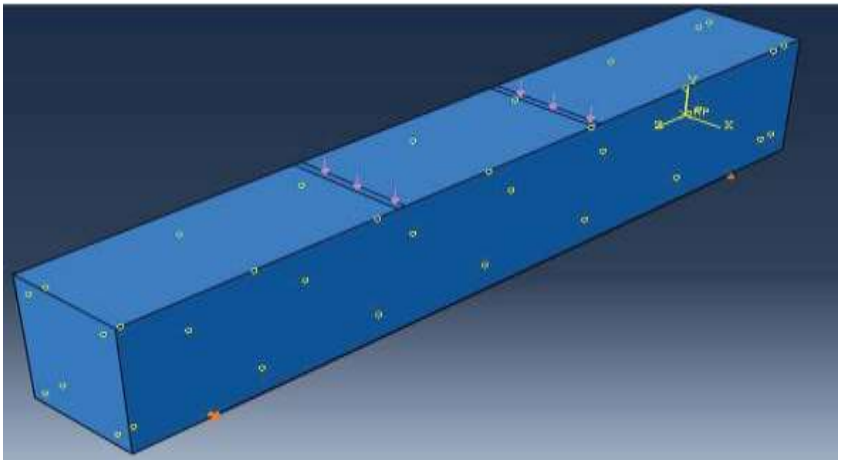

Figure 6: Applying boundary conditions and loading in the FRP-plate reinforced concrete beam model

3. Findings

The present study was aimed at examining the stress, strain, and bending deformation parameters. The maximum strain values of the lower and upper surfaces of the models along with the maximum bending values in the middle of each beam span for all three models were obtained. Tables (6), (7), and (8) provide analysis results of PCB-RCB-RCBF models.

Table 6: Analysis results of PCB model

Loading (KN)	**Upper stress** (N/mm^2)	**Upper strain** $(\times 10^{-4})$	**Lower stress** (N/mm^2)	**Lower strain** $(\times 10^{-4})$	**Bending** (mm)
0	0	0	0	0	0
10	3.214	1.025	2.545	0.878	0.08421
20	5.947	2	4.587	1.517	0.1684
30	7.989	2.729	6.554	2.32	0.2526
40	11	3.642	9.4	3.5	0.3368
50	13.5	4.74	12.34	4.231	0.4210

Table 7: Analysis results of RCB model

Loading (KN)	**Upper stress** (N/mm^2)	**Upper strain** $(\times 10^{-4})$	**Upper strain** (N/mm^2)	**Lower strain** $(\times 10^{-4})$	**Bending** (mm)
0	0	0	0	0	0
10	2.31	0.878	2.2	0.8775	0.07334
20	3.98	1.517	4.1	1.517	0.1467

30	6.102	2.32	6.125	2.319	0.22
40	7.5	3.102	8.35	3.3	0.2934
50	11.024	3.865	10.24	3.865	0.366

Table 8: Analysis results of RCBF model

Loading (KN)	**Upper stress** (N/mm^2)	**Upper strain** $(\times 10^{-4})$	**Upper strain** (N/mm^2)	**Lower strain** $(\times 10^{-4})$	**Bending** (mm)
0	0	0	0	0	0
10	1.465	0.775	1.454	0.7714	0.0213
20	3.012	1.407	3.168	1.407	0.0365
30	4.425	2.012	4.785	2.1	0.0498
40	6.785	2.828	6.674	2.828	0.0615
50	7.895	3.123	8.012	3.3	0.0703

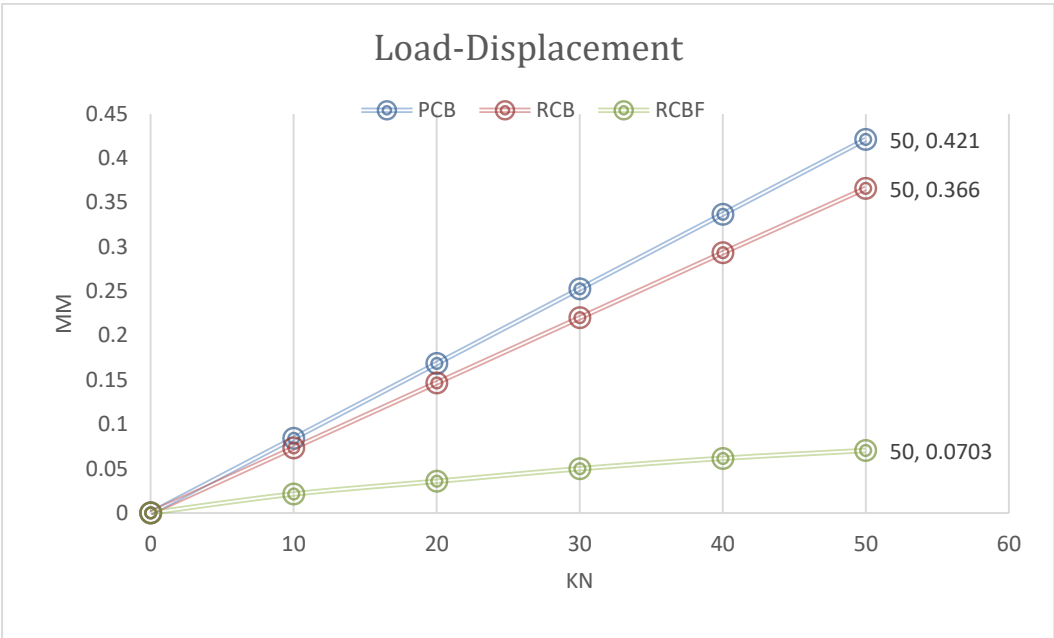

Figure 7: Load-displacement curve of models

The findings suggested that FRP-reinforced bending significantly reduced the bending deformation value. This study found that the FRP had reduced the bending by 80%.

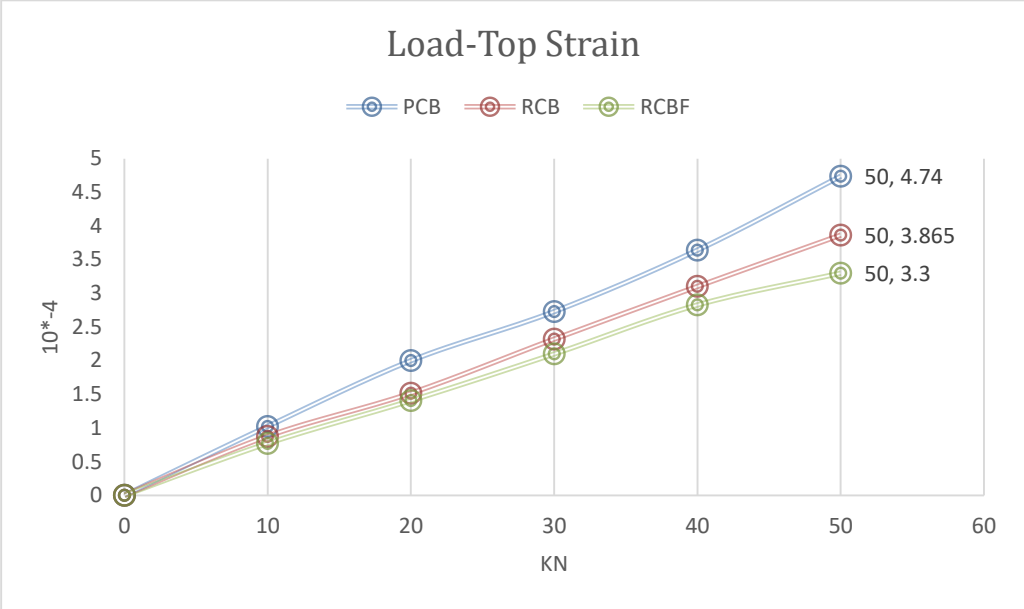

Figure 8: Load-change curve of model upper strain

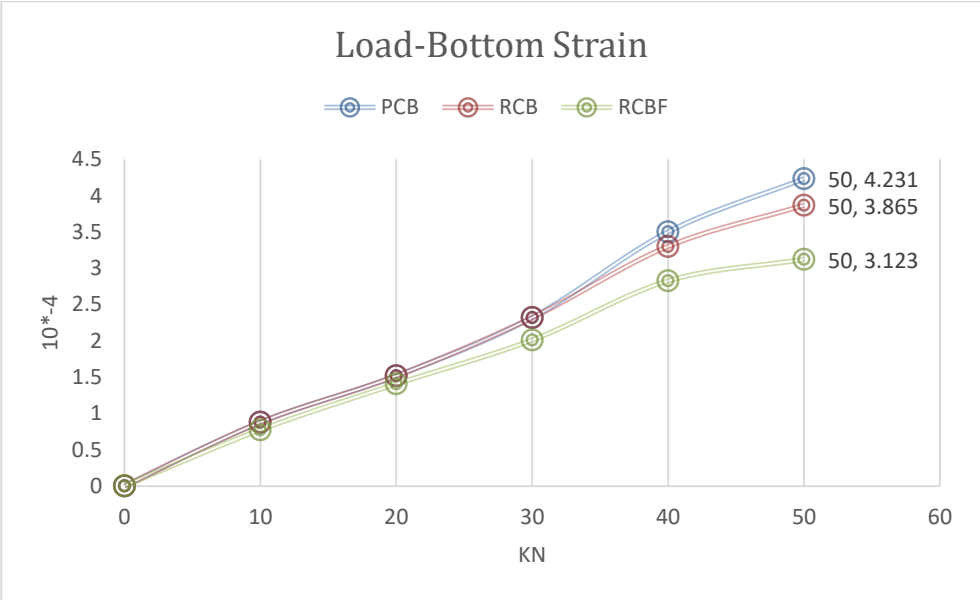

Figure 9: Load-change curve of a model lower strain

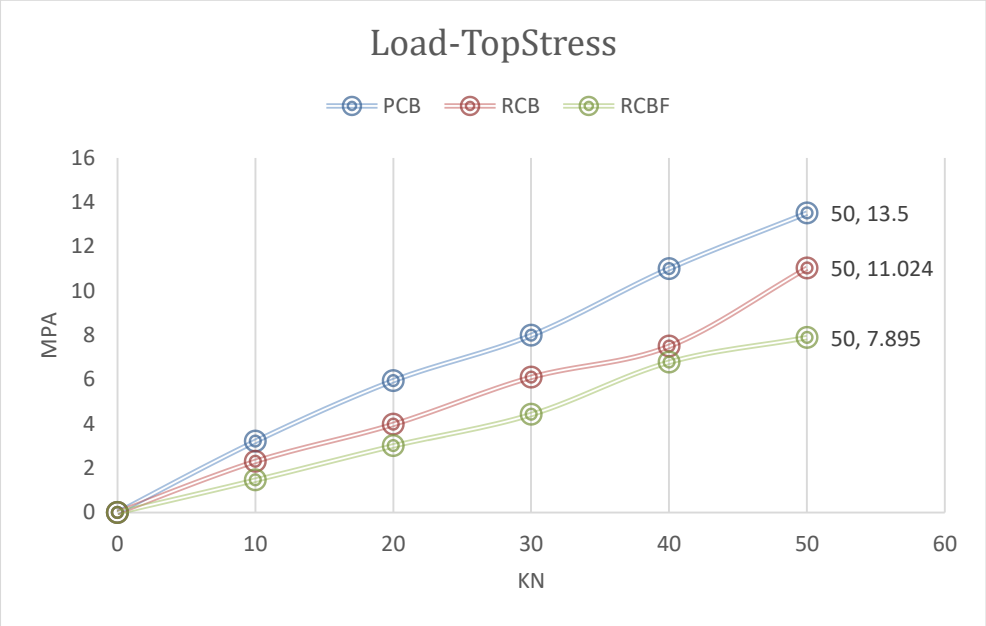

Figure 10: Load-change curve of a model upper stress

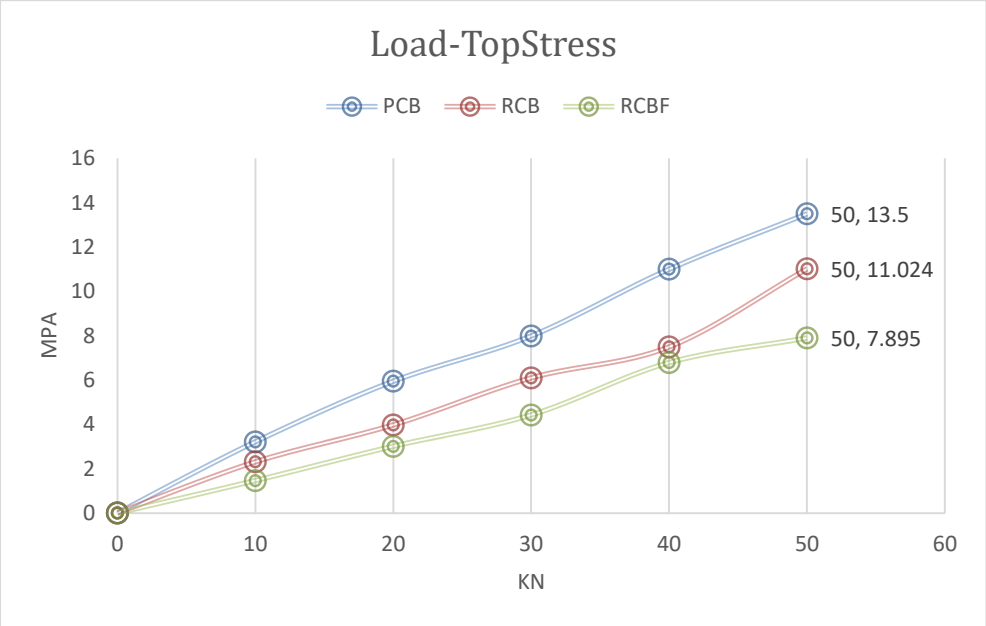

Figure 11: Load-change curve of a model lower stress

This study, carried out by the force control method, suggested that the effect of FRP on stresses, strains, and bending deformations is clear which caused the above values to decrease. The findings suggested that an FRP plate of 1.4 mm thick significantly reduced bending in the middle of the span. On average, the maximum stress caused in the reinforced concrete beam model was found to be 23% lower than that in the non-reinforced concrete beam, indicating the application of reinforcement in the model. However, the average maximum stress caused in the FRP-reinforced concrete beam model was 54% lower than that of the non-reinforced concrete beams, again indicating a significant efficiency of FRP in retrofitting structures.

4. Conclusion

This study reviewed the effects of FRP on stress, strain, and bending deformation parameters from nonlinear static analysis of concrete, reinforced concrete, and FRP fibers-reinforced concrete. The data obtained were classified, and finally, the effect of FRP was examined. The maximum stress and strain values of the upper and lower surfaces of the models as well as the maximum bending values in the middle of each beam span were obtained for all three models. The findings suggested that an FRP plate of 1.4 mm thick significantly reduced bending in the middle of the span. On average, the maximum stress caused in the reinforced concrete beam model was found to be 23% lower than that in the non-reinforced concrete beam, indicating the application of reinforcement in the model. However, the average maximum stress caused in the FRP-reinforced concrete beam model was 54% lower than that of the non-reinforced concrete beams, again indicating a significant efficiency of FRP in retrofitting structures. Because Iran is located on the earthquake belt and most aging existing residential buildings are vulnerable to earthquakes and because earthquake design regulations are not completely complied with (e.g., Iranian 2800 regulations), it is imperative to employ appropriate and systematic procedures to strengthen these existing structures against earthquakes. The fact that most Iranian facilities are vulnerable is due to the fledgling engineering knowledge in the world, especially in Iran, and non-compliance with engineering procedures, as most structures have been designed and built using non-scientific and empirical procedures. Thus, the goal is to take necessary measures to reinforce the structures to withstand seismic pressures. In sum, strengthening vulnerable structures against earthquakes as well as retrofitting structures damaged by earthquakes are key. This elucidates the significance of selecting appropriate techniques to strengthen and retrofit the buildings. In the end, it is recommended that the issue of bending beam reinforcement under dynamic loads and dynamic analysis be further examined.

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