Examining Strain and Bending Deformation Parameters From Nonlinear Static Analysis of Concrete, Reinforced Concrete, and Fiber-Reinforced (FRP) Concrete Samples

Seyed Nima Naghibi Iravani[a], Ph.D. RasoulSabetAhd[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: Fiber-made composite materials as fiber-reinforced polymers (FRPs) in polymer resin media are today replacing traditional materials and existing procedures. Thus, the present study was aimed at examining the strain and bending deformation parameters from nonlinear static analysis of concrete, reinforced concrete and fibers-based reinforced concrete samples. In this research, FRP effects on strain and bending deformation parameters from nonlinear static analysis of concrete, reinforced concrete, and fibers-based reinforced concrete samples were examined using the finite element method and ABAQUS software. This study, carried out by the force control method, yielded 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. 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%, as the use of an FRP plate of 1.4 mm thick significantly reduced the middle of the span bending.
Keywords: FRP-based fiber reinforced concrete, Strain parameters, Bending deformation

1. Introduction

Building reinforcement, although carried out in the past and involved various reinforcement procedures, has now received more consideration in Iran following the Manjil and Bam earthquakes and measures taken by the people and authorities.

To strengthen the structures, common and new types of braces including concentric braced frame (CBF), eccentric braced frame (EBF), buckling-restrained braced frame (BRBF), and various types of braced dampers can be used [1]. A concentric braced frame is one of the most applicable reinforcement procedures, especially in steel-framed facilities. These types of braces, known as hard reinforcing systems meet common architectural needs through different forms [2]. two important points need to be pointed out when using braced frames to reinforce steel and concrete frames. First, braces should be used in the spans and floors in a way not to cause torsional irregularities. Second, on the first floors of the building, using braces of the existing frames increase the uplift force at the foot of the columns, with the foundations controlled at the site where the braces are added. K-shaped braces cannot be used to strengthen the frames [1].

Eccentric braced frames (EBFs), although being less hard than concentric braced frames (CBFs), show a more ductile behavior. buckling-restrained braced frames (BRBFs) are a new type of bracing system with energy dissipation that uses details to strengthen concentric braced frames [3]. One of the common reinforcement procedures against earthquakes is to use different types of walls including concrete shear walls, building materials-filled walls, prefabricated concrete panels, metal shear walls, compound shear walls, and building and reinforced infilled frames [4].

To compensate for the bending weakness of the wall, FRP plates are vertically installed on the wall along with their height equal to the longitudinal reinforcement [5].

The findings suggest that the FRP plate-reinforced wall bending increases resistance against cracks, yield strength, secondary stiffening during yield, and the final strength of the wall. The failure is of bending ductility type which occurs in the form of the wall toe crushing under pressure. To constitute an FRP system, fibers and resins are used to fabricate several composite layers, with the resins used to bond several composite layers to the lower concrete surface, and the coatings to protect the composite materials [6]. The FRP compressive modulus of elasticity is usually less than its tensile modulus of elasticity. For example, the compressive modulus of elasticity of FRP systems along with glass, carbon, and aramid fibers is about 80, 85, and 100% of its tensile modulus of elasticity, respectively [5-7-8].

Following exposure to environmental factors such as temperature, humidity, and chemical conditions, a majority of FRP systems have their mechanical properties reduced [9-10]. The results indicate that the FRP system-reinforced concrete member increases its resistance against fire by using special resins or fire-proof coatings [11-12]. In multi-span beams, which support the column, a simple option for bracing is to raise the FRP strip or plate from over the beam to a part of the column surface and to bind it together; however, studies have indicated that this bracing procedure is ineffective because stresses in the FRP strip can be directed into the holes already created in the column [13-14-15]. As stated, this study aimed to investigate the strain and bending deformation parameters from nonlinear static analysis of concrete samples, reinforced concrete, and reinforced concrete with FRP fibers.

2. Materials and procedures

This study aimed to investigate the strain and bending deformation parameters from nonlinear static analysis of concrete samples, reinforced concrete, and reinforced concrete with FRP fibers. The materials used in modeling the samples, including concrete, steel, and FRP, are introduced according to the following tables.

Table 1: Material properties

Materials	Materials 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 = density

σy = yield stress

E=modulus of elasticity

υ =Poisson's ratio

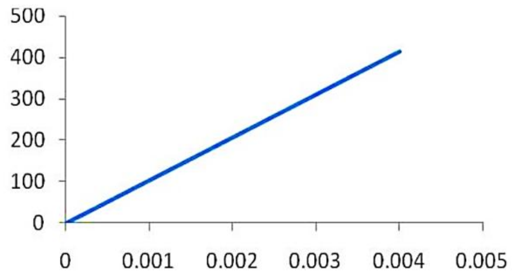

Figure 1: Linear steel stress-strain curve

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

Table 2: Stiffness properties of the FRP-integrated 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, 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.

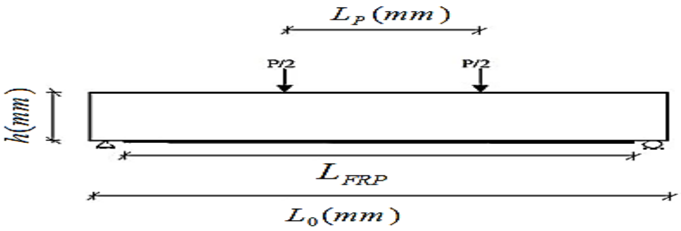

Figure 2: Schematic view of the geometric conditions and loading of FRP-reinforced concrete beams

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

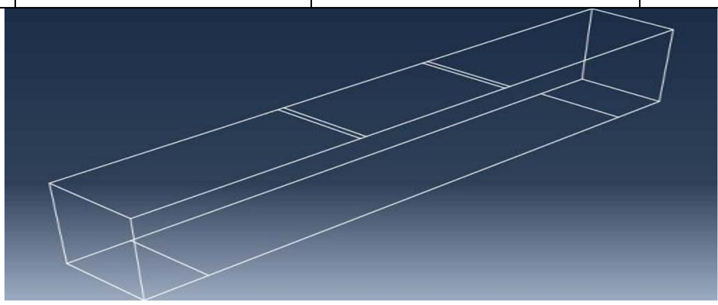

Figure 3: Concrete beam modeling

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	-
Transverse (stirrup)	8	-	75

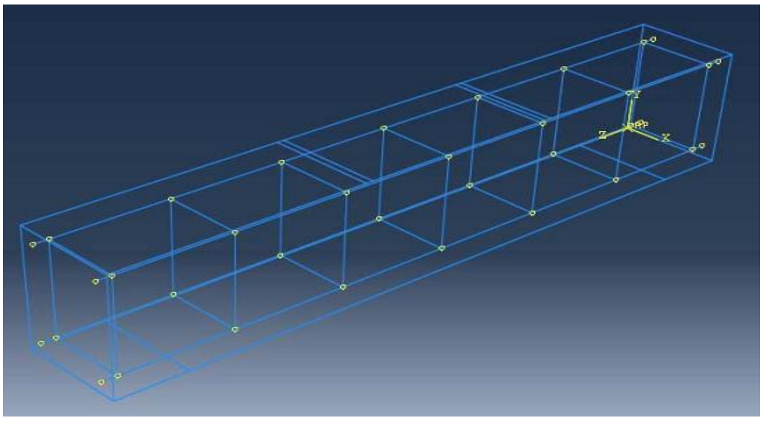

Figure 4: Concrete beam model reinforcement modeling

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

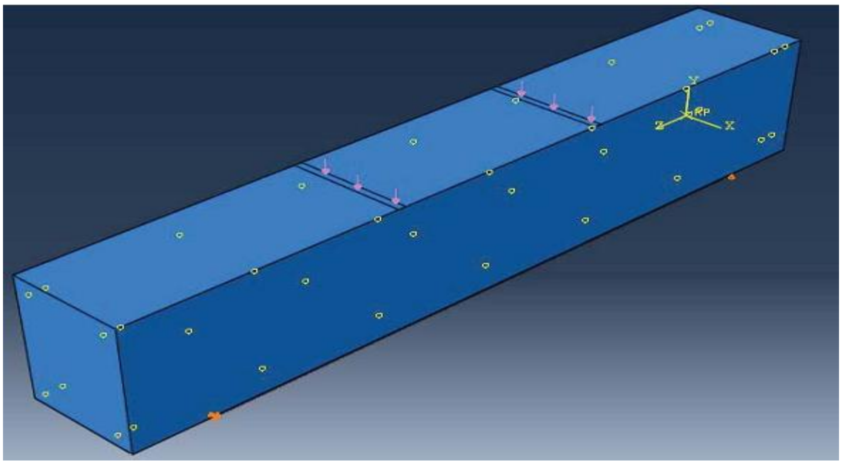

Figure 5: FRP plate modeling in concrete beam model

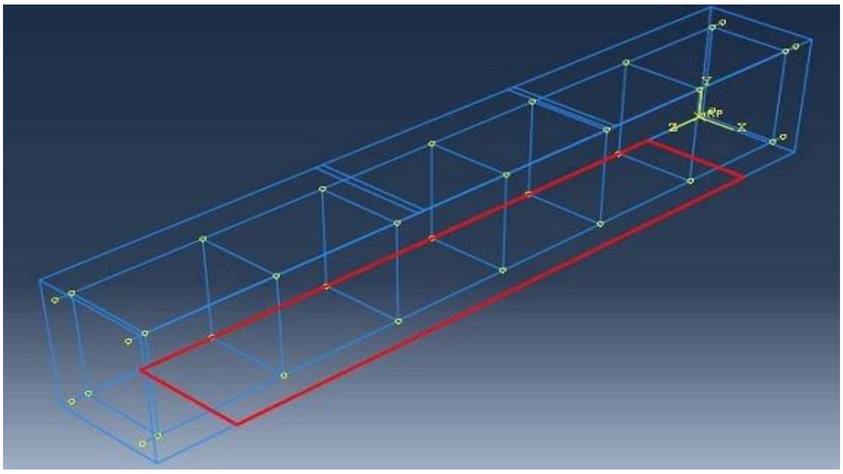

Figure 6: Applying boundary conditions and loading in the FRP-plate reinforced concrete beam model

The element used to mesh FRP plate on the concrete beam surface is (*T3D3*) in Abacus software [16].

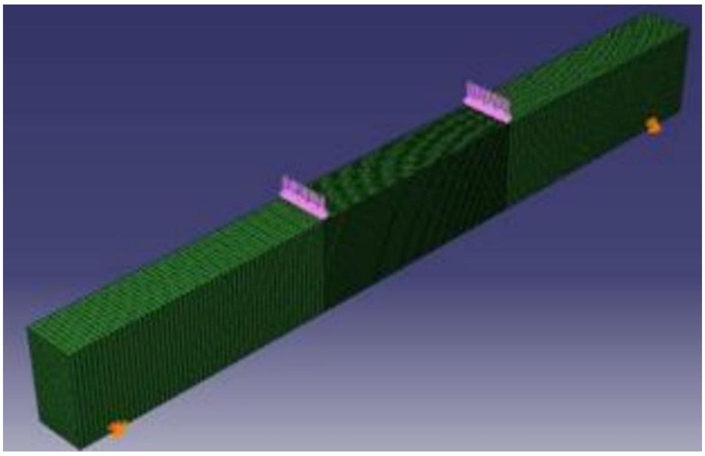

Figure 7: Meshing in complete sample modeling

In this study, three beam models underwent nonlinear static analysis. In all models, boundary and geometric conditions were the same. The plain cement concrete beam (PCB) model, i.e., the concrete beam without reinforcement and FRP plate was the first model to be regarded as a base model for comparison and analysis. The reinforced concrete beam (RCB) model, i.e., the longitudinal and transverse-reinforced concrete beam consistent with specifications provided, was the second model to be compared and analyzed with the base model. Reinforced concrete beam with FPR (RCBF) model, i.e., longitudinal and transverse-reinforced and FRP plate concrete which is installed externally with epoxy adhesive and serves as flexural reinforcement in the tensile zone of the beam was considered as the third model to be compared and analyzed with other models. Loading on samples was applied in the form of two local loads and terms of (KN). Therefore, the force exerted on the models was applied in five stages at 10-20-30-40-50 kN.

3. Findings

The present study was aimed at examining the strain and bending deformation parameters from nonlinear static analysis of concrete, reinforced concrete and FRP fibers-based reinforced concrete samples. 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.

Table 6: Analysis results of PCB model

Loading (KN)	**Upper strain** $(\times 10^{-4})$	**Lower strain** $(\times 10^{-4})$	**Bending** (mm)
0	0	0	0

10	1.025	0.878	0.08421
20	2	1.517	0.1684
30	2.729	2.32	0.2526
40	3.642	3.5	0.3368
50	4.74	4.231	0.4210

Table 7: Analysis results of RCB model

Loading (KN)	**Upper strain** $(\times 10^{-4})$	**Lower strain** $(\times 10^{-4})$	**Bending** (mm)
0	0	0	0
10	0.878	0.8775	0.07334
20	1.517	1.517	0.1467
30	2.32	2.319	0.22
40	3.102	3.3	0.2934
50	3.865	3.865	0.366

Table 8: Analysis results of RCBF model

Loading (KN)	**Upper strain** $(\times 10^{-4})$	**Lower strain** $(\times 10^{-4})$	**Bending** (mm)
0	0	0	0
10	0.775	0.7714	0.0213
20	1.407	1.407	0.0356
30	2.012	2.1	0.0498
40	2.828	2.828	0.0615
50	3.123	3.3	0.0703

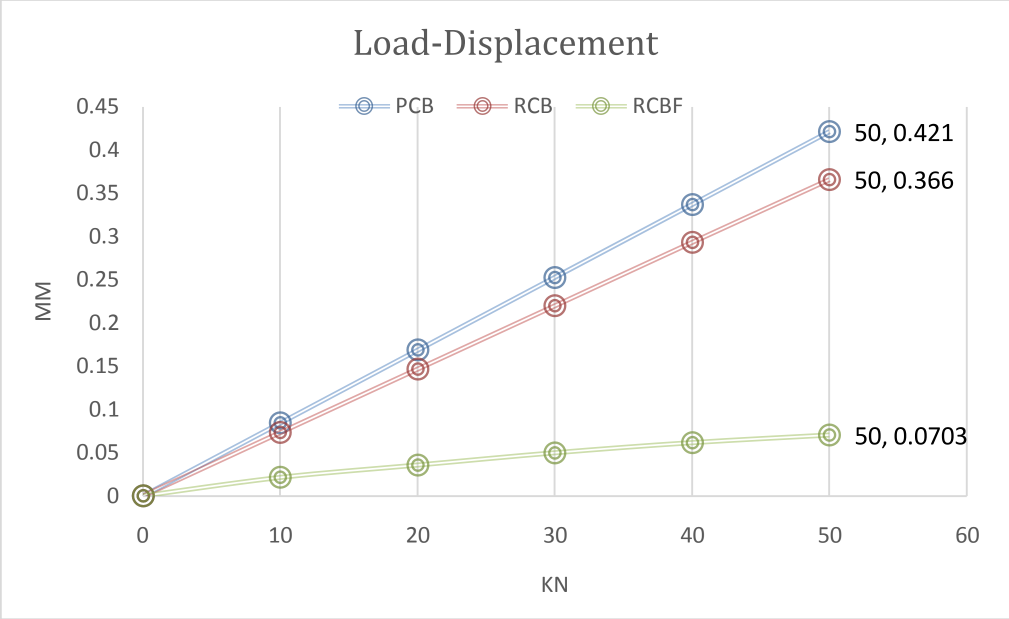

Figure 8: Load-displacement curve of models

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%.

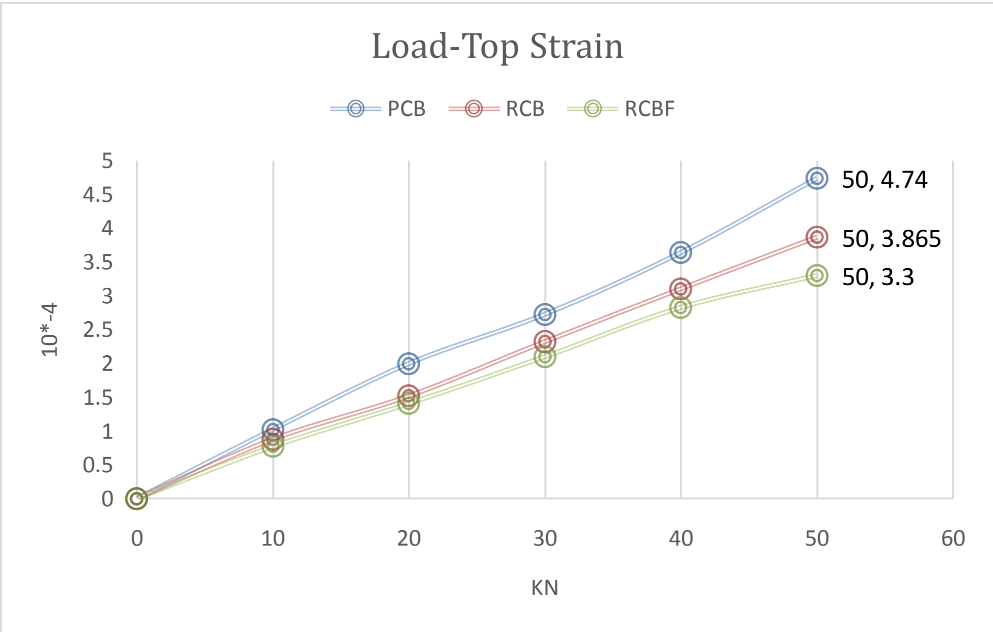

Figure 9: Load-change curve of model upper strain

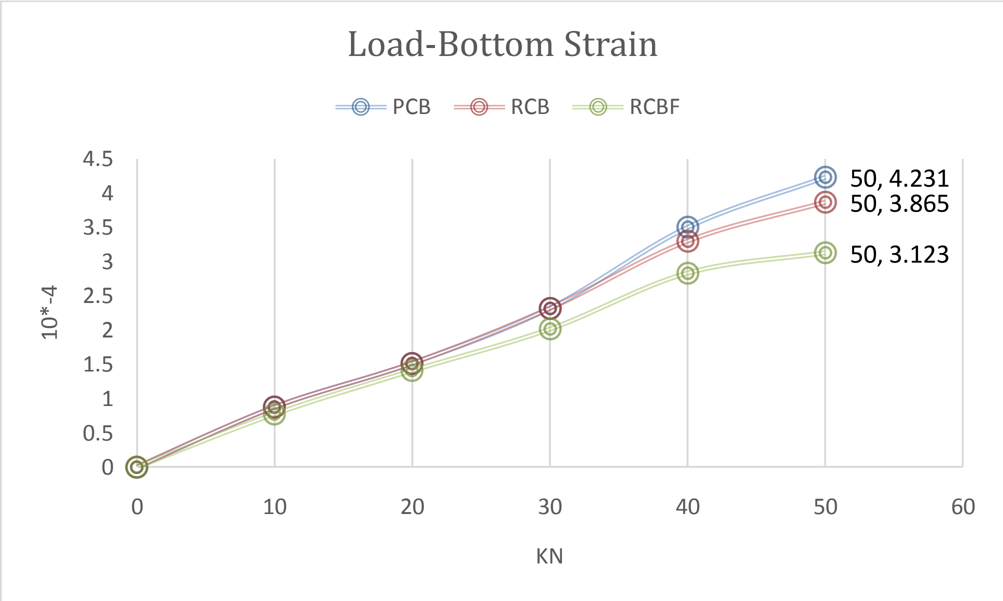

Figure 10: Load-change curve of a model lower strain

4. Conclusion

Generally speaking, it is required to reinforce the existing concrete structures to withstand the applied loads, improve the failures from erosion, and increase structure ductility; to do this, using appropriate materials and proper execution procedures are warranted. Fiber-made composite materials as fiber-reinforced polymers (FRP) in polymer resin media are today replacing traditional materials and existing procedures.

Connecting FRP materials to the tensile concrete areas with its fibers aligned in a longitudinal direction of the flexural member increases its flexural strength. Accordingly, the present study was aimed at examining the strain and bending deformation parameters from nonlinear static analysis of concrete, reinforced concrete and fibers-based reinforced concrete samples.

This study, carried out by the force control method, yielded 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. 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%. Put it simply, the research parameters were compared to review the effects of FRP of the same values as regards the forces applied to the beams. The effect of FRP on strains and bending deformation helped reduce parameter values. The use of an FRP plate 1.4 mm thick reduced the bending in the middle of the span.

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