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Finite Element Analysis of Reinforced RC Bracket Using CFRP Plates

A. Rafati [1], S.V. Razavi [2,*]

[1]Department of Civil, Dezful Branch, Islamic Azad university, Dezful, Iran
[2]Department of Civil Engineering, Jundi-shapor University of Technology, Dezful, Iran

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ABSTRACT

CFRP composites have unique application qualities such as high resistance and durability to environmental conditions, having relatively low weight and easy to install in strengthening concrete structure elements. The brackets should be strengthen sufficiently if they are not calculated and implemented well. Application of the CFRP is one of the methods for such purposes. The study involves using five different configurations of CFRP sheets as a means of strengthening bracket, using finite element and non-linear dynamic analysis method within the ABAQUS software. Comparative analysis results of non-strengthened bracket model, show a 24.06% increase in the load-carrying capacity of strengthened models using the CFRP compared with the initial model (without CFRP). Results further show an increase of 24.96% of energy absorption in the strengthened models compared with the non-strengthened model.

Keywords : Bracket; Load carrying capacity;Energy absorption; CFRP;ABAQUS.

1 INTRODUCTION

REINFORCED brackets are important parts of concrete columns applied in pre-fabricated concrete structures. They are used to support beams and are in two forms of bracket and corbel. There are cases of bracket failure due to various design and implementation problems, inappropriate shortage of bars, low quality materials; unsuitable concrete quality. Shear fracture in column, yielding of main tensile bars, compression fracture in edges and external edges of bracket, local fracture in free end are among cases of bracket fractures that can be reinforced in order to increase the structural stability and safety. application of polymer composite is an effective method by which to enhance the material strength of brackets. Polymer composites that are reinforced with CFRP are structurally and qualitatively more superior compared to other fibers for strengthening . This is attributed to their lighter weight, more desirable strength to weight ratio, elasticity module rate to high weight, higher resistance to fatigue and corrosion, and lower electric conductivity [1].

Application of polymer composites consisting of CFRP is proposed by Abou Elez [2] and Norris [3] as a method of strengthening concrete structures. Curry and Dolan [4] studied the strengthening of brackets with CFRP sheets under experimental condition, the results of which was an increased in shear and flexural capacity of Corbel ranging from 50 to 75% [4]. Abdel Rahman et al [5] used carbon fibers to investigate the behavior of reinforced brackets, the results of which show an increase in the stiffness of material using the CFRP, compared to non-strengthened model [5]. Elgwady et al [6] investigated the strengthening of corbels using CFRP without removing load from Corbel. They performed various regulations of CFRP on corbel under experimental conditions and found that CFRP sheets

*Corresponding author. Tel.: +98 61 424 28000.
E-mail address: *vrazavi@jsu.ac.ir* (S.V.Razavi).

increases the load-carrying capacity of corbels. The increase in load-carrying in the final load ranged between 8 to 70% compared to the control specimen (without CFRP) [6].

Soket Ozden and Meydanli Atalay [7], evaluated the number of CFRP sheets and direction of carbon fibers to strengthen concrete corbels, which in their case led to an increase in the load-carrying capacity and resistance of up to 73% [7]. Yao, L., Wan, [8] study also showed a similar results showing an increase in the corbel shear capacity that ranged between 50 to 80% [8].

One of the important parameters in structures design is the investigation of load-displacement chart which showed a significant change in the chart using CFRP [9]. In this study, load-deflection chart of brackets strengthened by various CFRP configurations is evaluated and is compared with bracket without CFRP. Finite element within the ABAQUS software is used for the purpose and the results of which are validated by the experimental results [5].

2 THE SELECTION OF THE FEATURES OF MATERIALS IN SOFTWARW

For modeling in ABAQUS software, we should consider suitable behavioral models for materials. The selection of behavioral models has great impact on the outcomes and the conditions should be considered as the model reaches reality. The hypotheses of applied materials in ABAQUS software are defined as follows.

2.1 Concrete characteristics

Concrete, by its virtue, is a material having complex non-linear behaviors even at low-level stresses. The underlying causes of the concrete's non-linear responses of the concrete are not only linked to its material characteristics , but arise from the environmental factors, cracking, bi-axial stiffness and softening of strains [10]. Two principal theories of plasticity and damage mechanism are highly consistent with real behavior of concrete, although each of which often predicts reinforced concrete behavior, some cases of which nonetheless, does not explain the realities with high accuracy. The plausible way in simulating concrete behavior is a synthesis of the plasticity and damage models. Such model combines the isotropic behavior of elastic damage with the plastic isotropic behavior under compression and tensile conditions.

ABAQUS software uses suitable parameters to simulate the damage mechanics for tensile and compression effects within the Concrete Damaged Plasticity (CDP) analytical framework [1], [10]. Numerical values of five plastic parameter and specific parameters of concrete behavior in tensile and compression are used in the ABAQUS software to simulate full behavior of concrete, besides elastic parameters (elasticity module and Poisson coefficient). The first parameter introduced in concrete plastic features is dilation angle. Internal dilation angle is volume strain ratio to shear strain of materials. Internal dilation angle that is considered here ranges between 20 to 40 degree for concrete with considerable impact on materials ductility. By increasing the angle, ductility value is correspondingly increased. This angle is 25 degree in this study [11].

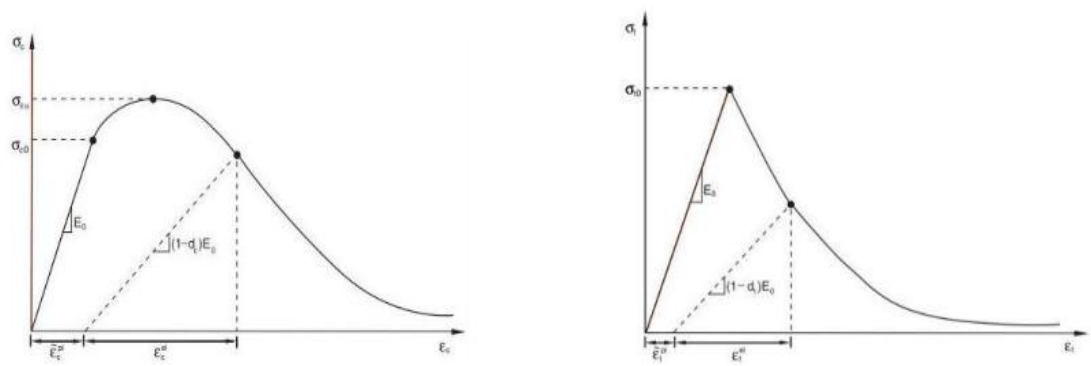
Second parameter is eccentricity, which is a small positive value that expresses the rate of approach of the plastic potential hyperbola to its asymptote. The higher this value, the higher flexure in low potentials. This parameter is considered as 0.1 in software as default value. The third in CDP model is fbo/fbc parameter, the two-surface yield stress to compressive one-surface yield stress as obtained 1.1 to 1.16 in tests [10]. The value of dimension-less parameter in Abaqus parameter is 1.16 , which is taken as a criterion in this study. The fourth parameter in plasticity definition of CDP model is parameter K defining the form of yield surface which ranges between 0.5 to 1. K value in ABAQUS software is 0.667 and is suitable for concrete modeling based on references [12]. The last parameter of CDP model in plasticity parameters is viscosity parameter (μ) showing visco-plastic resting time. Some of the convergence problems can be eliminated by standardization and regulation of visco-plastic equations. Thus, the stresses can exit yield level. The elasticity module parameter in this study is 23.49 *GPa* and Poisson coefficient is 0.2. Table 1. is based on behavioral model of Mander and Park for confined concrete, to introduce concrete behavior in compression phase. Table 2. is therefore, used to introduce concrete behavior in tensile phase [13]. The numerical values of equivalent compressive plastic strain and equivalent tensile plastic strain are used to show damage extension. As can be seen in Fig.1, equivalent plastic strains can be attained by compressive or tensile strain and stress values, damage parameters and elasticity elastic module.

Table 1
Concrete compressive behavior for modeling in Abaqus software [13].

7	35.0	34.2	33.4	32.5	31.7	29.0	26.4	23.6	21.7	18.8	15.7	13.6	Yield stress(*Mpa*)	Compressive behavior
11	3.6	3.4	3.3	3.1	3	2.5	2.0	1.5	1.2	0.7	0.2	0	Non-elastic strain (*mm*)	

Table 2
Tensile behavior of concrete for modeling in Abaqus software [13].

Tensile behavior	
Yield stress (Mpa)	Cracking strain (m)
3.4	0
0.034	0.001



(a) (b)

Fig.1
Plastic strain and non-elastic strain in concrete response curve to uni-axial load (a) Compressive and (b) Tensile [11].

2.2 Steel characteristic

Steel behavior is idealized and the tensile and compressive behavior of this matter is equal without having specific effect on the results. Two-linear ideal curve is used for modeling in order to reduce analysis time and avoid the problems of non-convergence of elastic-fully plastic models. The behavior curve of steel materials (rebar) is bi-linear with slope 0.01 and elasticity module in stiffening region is similar to those in Fig. 2. The volume mass for steel materials is 7850 kg/m3, elasticity model is 200 Gpa, Poisson coefficient is 0.3 and yield stress is 360 *Mpa* [11].

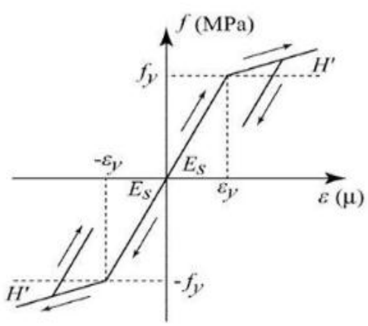


Fig.2
Bi-linear curve of steel materials behavior [11].

2.3 CFRP characteristics

CFRP mechanical features are different in various directions and carbon fibers form a CFRP sheets as multi-layer with Epoxy resin. As CFRP is a brittle material, there is no need to define damage evolution and just need to define Hashin Damage. The features polymer composite sheets reinforced with carbon fibers (CFRP) are introduced in accordance with the extracted features of lab specimen to Abaqus software. The mechanical and strength features of CFRP sheets are shown in Tables 3, 4.

Table 3
Strength features of CFRP sheets [5].

Transverse shear strength (*Mpa*)	Longitudinal shear strength (*Mpa*)	Transverse compressive strength (*Mpa*)	Transverse tensile strength (*Mpa*)	Longitudinal compressive strength (*Mpa*)	Longitudinal tensile strength (*Mpa*)
3	3	2300	3100	2300	3100

Table 4
The mechanical specifications of CFRP sheets [5].

G23(*Mpa*)	G13(*Mpa*)	G12(*Mpa*)	Nu12	E2(*Mpa*)	E1(*Mpa*)	P(*kg/m3*)
2038	2038	1019	0.3	82500	165000	1800

3 MODELING IN ABAQUS

3.1 Materials interaction

As in modeling we have different materials, to show the boundary between the materials and correct performance of analysis, we should define interaction. Among the terms in ABAQUS software, Embedded region is used as interaction between steel (rebar) and concrete. To define interaction between CFRP and concrete surface, there is a difference between defining interaction between rebar and concrete and we can use Tie to define interaction between concrete and CFRP. Resin is also defined among them and to reduce analysis time, Tie is used in this study.

3.2 Dividing the model to finite elements (Meshing)

Different elements of various parts are selected based on elements performance. For concrete modeling, C3D8R element of solid type with eight nodes and three degrees of freedom in each node are applied. This element can apply plastic deflections and big deflections and can model cracking in three orthogonal directions in all eight integrating points. To model rebars inside bracket and concrete column, T3D2 element of beam elements with two end nodes is used. This element is a 3-D first order linear element. To model composite coverage CFRP, shell element S4R with four nodes and six degree of freedom in each node (three translational degrees of freedom and three rotational degrees of freedom). The above shell element can have one-layer isotropic section and single-layer or multi-layer orthotropic with various angular configurations of layers.

Mesh sensitivity analysis is applied to achieve suitable mesh for analysis and achieving exact answer. Based on required outputs, meshing dimensions are reduced as the output parameter changes are ignored in two meshing. partitioning operation is used in order to apply regular meshing on models, in connection site of bracket to column .

3.3 Definition of boundary conditions and loading

Possible to create joint support, by creating reference point in two ends of column, joint support is dedicated to these points.

An axial force Nu (horizontal force) and a shear force Vu (vertical force) are applied on concrete bracket. As the beam is placed directly on bracket, beam support is provided as the horizontal movement of beam is free. Thus, Nu=0 and based on specimen test method (bracket) in lab, vertical force Vu is imposed as extended to bracket loading plane. Two ways can be considered for applying load on bracket. Loading can either be done as force control or by displacement control on bracket. All models are loaded based on controlling maximum displacement 1cm.

3.4 Analysis type

Because of the non-linear features of concrete, any analysis should therefore be done within the non-linear theoretical framework. The method has static nature and as some static issues are encountered with non-convergence, non-linear dynamic analysis is used to explain the realities. Application of dynamic analysis instead of static analysis is likely to yield more realistic results under circumstances where the ALLKE ratio (kinetic energy) to ALLIE (internal energy) in each time of loading is less than 0.1 [11].

4 CFRP CONFIGURATIONS AND NAMING MODELS

In this study, the features of analyzed models are defined as in Table 5. The distance of CFRP sheets from each other and CFRP position on bracket are selected based on experimental specimen.

Table 5
Naming models and CFRP configuration for strengthening.

Configuration type	Sheet characteristics		Model
	Width (*mm*)	Thickness (*mm*)	
Non-strengthened model-initial model	-	-	C0
Two horizontal strips around bracket and three aspects of column	6	1	C1
Two horizontal and two vertical strips around bracket	6	1	C2
Two horizontal strips on bracket and column and two vertical strips on bracket and using vertical patches on column	6	1	C3
Two horizontal strips around bracket and column and using vertical patches on bracket	6	1	C4
A horizontal strip around column and bracket	35	1	C5

As shown, five strengthening models as C1, C2, C3, C4 and C5 are used and the results are evaluated with non-strengthening specimen C0. The type of CFRP configurations is shown in Fig. 3. CFRP configurations in C1, C5 models are used to increase shear capacity and CFRP configurations in C2, C3, C4 models to increase shear and flexural capacity of section.

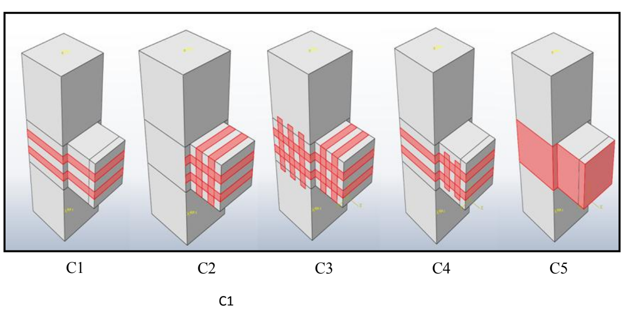


Fig.3
CFRP configurations and study models:1-C1 model, 2-C2 model, 3-C3 model, 4-C4 model, 5-C5 model.

5 THE RESULTS OF SOFTWARE ANALYSIS

5.1 Load-Deflection chart

Results are evaluated by Experimental study of Abdelrarhman et al., and the modeling validity as substantiated by [5]. Chart 1 shows the comparison of load-deflection charts of initial software and experiment models. The analysis show a close proximity between the two sets of results.

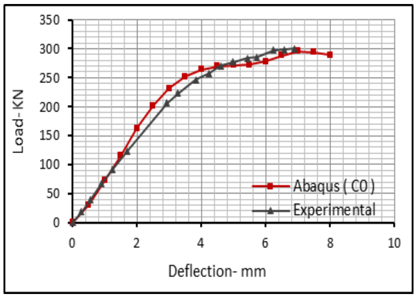


Chart.1
The comparison of load-deflection charts of initial designed models in Abaqus software and lab [5].

The charts 2, 3, 4, 5, 6 are load-deflection charts of models reinforced with CFRP as compared with the load-deflection chart of initial model. The vertical axle of chart indicates the load in KN and horizontal axle indicates deflection in mm. All these charts are obtained based on maximum vertical displacement 1cm. The results of these charts are shown in Table 6. The ultimate load and vertical deflection of ultimate load of all models are shown.

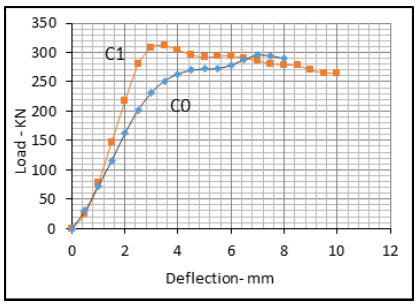


Chart.2
The comparison of load-deflection charts of C1,C0.

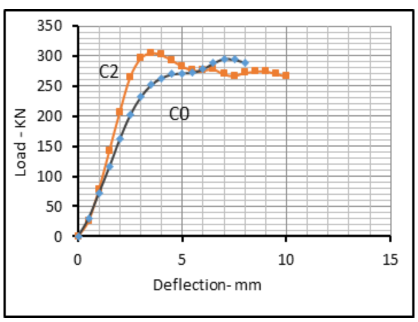


Chart.3
The comparison of load-deflection charts of C2,C0.

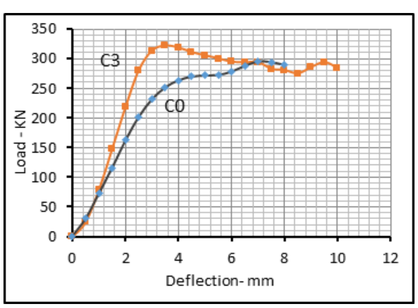


Chart.4
The comparison of load-deflection charts of C3,C0.

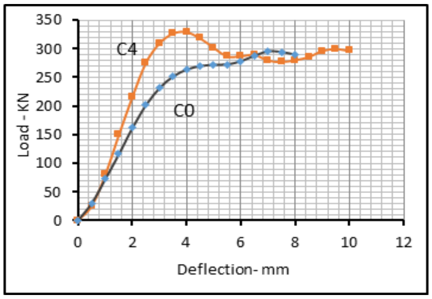


Chart.5
The comparison of load-deflection charts of C4,C0.

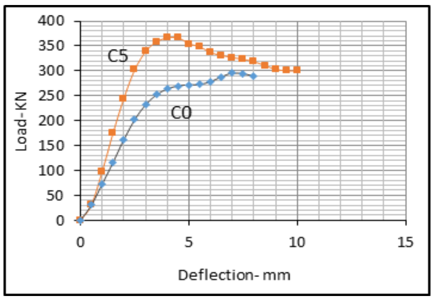


Chart.6
The comparison of load-deflection charts of C5,C0.

Table 6
Ultimate load and ultimate deflection of all models.

C5	C4	C3	C2	C1	C0	Model
366	329	321	305	311	295	ultimate load (Vu)-KN
4.5	4	3.5	3.5	3.5	7	ultimate deflection-mm

Based on load-deflection charts of models strengthened with CFRP, the slope of charts is increased compared to the slope of C0 model and this shows the increasing stiffness due to using CFRP sheets. Table 7. shows the increase of load carrying capacity of models strengthened compared to initial model for maximum displacement 1cm. It can therefore, be deducted that increasing load-carrying capacity of C1, C2, C3, C4, C5 models compared to C0 model is 5.42, 3.38, 8.81, 11.52 and 24.06%, respectively. The configuration in C5 model shows a high load-carrying capacity relative to other models.

Table 7
The increase of load carrying capacity of models strengthened compared to C0 model.

C5	C4	C3	C2	C1	C0	Model
24.06	11.52	8.81	3.38	5.42	0	Increasing load carrying capacity (%)

5.2 Internal energy chart

Charts 7, 8, 9, 10, 11 are energy-time charts strengthened with CFRP as compared with energy-time chart of initial model (without CFRP). The vertical axle indicates energy in *J* and horizontal axle is time in seconds. Energy absorption or maximum energy the bracket specimen can store for maximum vertical displacement 1cm is shown in Table 8.

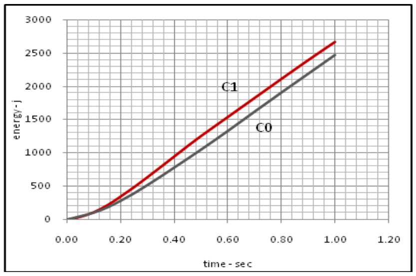


Chart.7
The comparison of load-deflection charts of C1,C0.

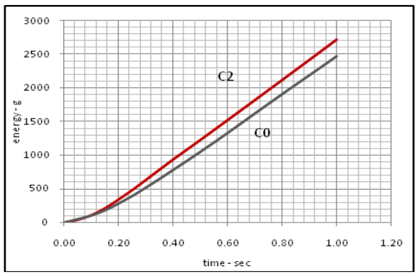


Chart.8
The comparison of load-deflection charts of C2,C0.

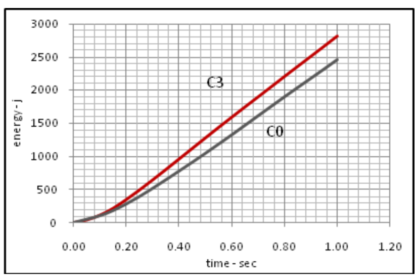


Chart.9
Comparison of load-deflection charts of C3,C0.

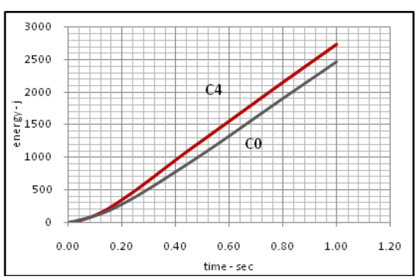


Chart.10
Comparison of load-deflection charts of C4,C0.

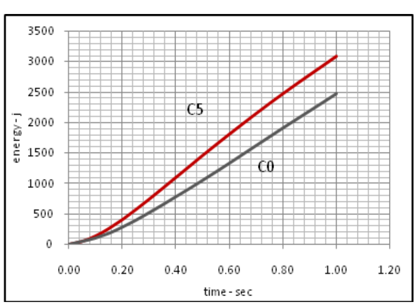


Chart.11
Comparison of load-deflection charts of C5,C0.

Table 8
The internal energy values of all models.

C5	C4	C3	C2	C1	C0	Model
3083	2733	2816	2721	2664	2467	Internal energy-J

Based on energy-time charts of models strengthened with CFRP, internal energy of models strengthened with CFRP is increased compared to initial model. Table 9 shows an increase in the internal energy of models strengthened compared to initial model for maximum displacement 1cm. The increase of internal energy for C1, C2, C3, C4 and C5 models is 7.98, 10.29, 14.14, 10.78 and 24.96 %, respectively. The configuration applied in C5 model shows a more increase in the internal energy than other specimen. If absorbed energy in a structural system is of great importance under seismic load, internal energy can be studied as a good output. Tosonos et al., have elaborated on these parameters in more details[14].

Table 9
The increase of internal energy of models strengthened compared to C0 model.

C5	C4	C3	C2	C1	C0	Model
24.96	10.78	14.14	10.29	7.98	0	Increasing internal energy (%)

6 CONCLUSIONS

In this study, five different configurations of CFRP sheets, namely, C1, C2, C3, C4 and C5 are analyzed by Abaqus software and compared with the no strengthening specimen C0. The results of which are showed as follows:

1. Load carrying capacity is increased by different models strengthened with CFRP, compared to non-strengthened specimen as 5.42, 3.38, 8.81, 11.52, 24.06%, respectively for C1, C2, C3, C4 and C5 models.
2. Internal energy is increased compared to non-strengthened sample by different models strengthened with CFRP, as 7.98, 10.29, 14.14, 10.78 and 24.96%, respectively for C1, C2, C3, C4, C5 models. To evaluate the absorbed energy value in a structural system under seismic load, we can study internal energy as a good output.

Among applied configurations, checked configuration of Model C5 increases the load carrying capacity compared to initial model at most as 24.06% and configuration in C5 also increases the internal energy compared to initial model at most as 24.96%.

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