

Effect of the Distance between Points Load on the Behavior of Strengthened Reinforced Concrete Beams

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Abstract

The general behavior of the reinforced concrete beams depends on many variables, including what is the quality of the concrete and strength and including those on reinforcement type and quantity of reinforcement in the beam. But there is an important variable which nature of loads application on the beam and type of load is it point or distributed. Sometimes the distance between points load is variable such as vehicle wheel load because each vehicle as different distance between wheels.

In this research, the effect of changing the distance between the points load were studied and compared with model carrying a single point load at mid span, as well as studying the effect of the use of carbon fiber with a length equal to the distance between the points load.

Theoretical results consists of eight models were compared in this study with the results of the previous experimental results. The study contains a discussion of the general behavior of the beam in addition to the study of the failure carrying load, cracking load, ductility and the relationship between the stages of load application and the deflection of concrete beams with and without carbon fiber sheets.

Key words: Ansys, strengthening, ductility, carbon fiber.

1. Introduction

Concrete structural components require the understanding into the responses of these components to a variety of loadings application.

A simply-supported reinforced concrete beam may fail primarily- either in flexure or in shear. Failure in flexure will occur if the ultimate flexural moment capacity is exceeded at any section of the beam before the conditions for shear failure have been satisfied at any section. Failure in shear will occur when the limiting shear-moment capacity is reached at some section of the beam at which inclined cracks have developed sufficiently to reduce the available compressive area.

Whether a given beam will fail in flexure or in shear will depend on the relative magnitudes of the ultimate flexural moment (Mf), the limiting shear-moment (Ms) and the critical shear(V) at various locations along the span and on the actual values of moment and shear at these locations. The relationship between mode of failure and properties of the beam cross-section and loading arrangement is illustrated most simply by considering the hypothetical behavior of a simply-supported beam as illustrated in Fig.(1).

The beam shown in Figure (l) is simply-supported at its end span is assumed to carry two concentrated loads arranged symmetrically about mid span. Only half of the span is shown in the Figure, The distance from the support to the load is called the "shear-span" and is designated by the symbol (a). For the particular type of loading shown, the maximum moment and the maximum shear both occur at the location of the load and their ratio is $M/V = a$.

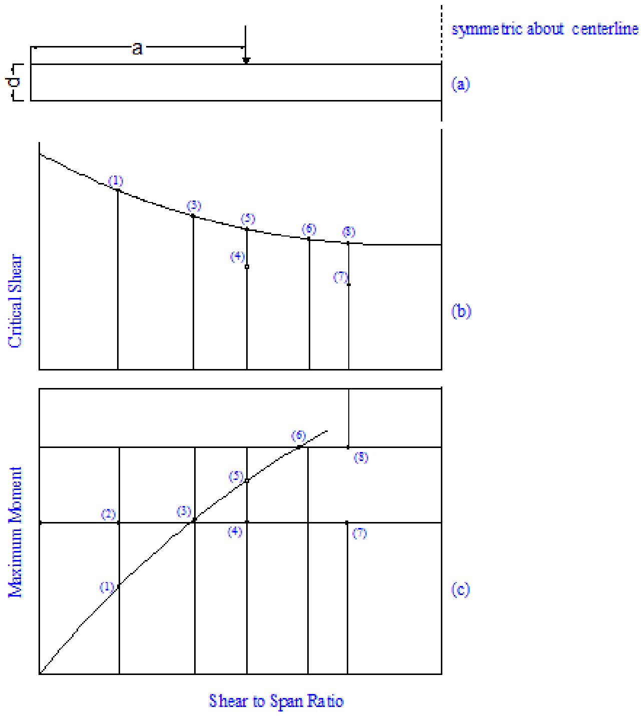

Figure (1) Effect of moment-shear ratioon failure mode

2. Carbon Fiber

Carbon fiber is defined as a fiber containing at least 92 wt % carbon, while the fiber containing at least 99 wt % carbon is usually called a graphite fiber. Carbon fibers generally have excellent tensile properties, low densities, high thermal and chemical stabilities in the absence of oxidizing agents, good thermal and electrical conductivities, and excellent creep resistance. They have been extensively used in composites in the form of woven textiles, prepregs, continuous fibers/rovings, and chopped fibers. The composite parts can be produced through filament winding, tape winding, pultrusion, compression molding, vacuum bagging, liquid molding, and injection molding.

In terms of final mechanical properties, carbon fibers can be roughly classified into ultra-high modulus (>500 GPa), high modulus (>300 GPa), intermediate modulus (>200 GPa), low modulus (100 GPa), and high strength (>4 GPa)[(1)].

Ehsan Ahmed et al[(2)]. studied the flexural behavior of reinforced concrete beams strengthened with carbon fiber through an experimental and theoretical study includes six models, one without carbon fiber and the others with different number of layers of carbon fiber. They concluded that there is an increase in member stiffness in addition to improvement in yield and ultimate load. Another group of researchers (tom Norris et al.)[(3)] used in their research different ways to paste carbon fiber to concrete beams to see what is the proper way to use carbon fiber for strengthening the concrete beams, All ways showed that there is a clear improvement in carrying capacity of beams in addition to the improvement in ductility and yield load.

3. Test Program

The experimental work program conducted by Mohammad Z.Y[(4)] was selected to validate the simulations presented in this paper. In his study, two experimental programs were carried out to investigate the behavior of reinforced concrete (RC) beams strengthened with CFRP fabrics between points load using a wet layup method. The aim of the research was to study the failure characteristics, deflection behavior and general performance. A total of six reinforced concrete beams were tested under two points bending with different distances between points of loading. In this test program, The variables of the beams were the distance between points load, CFRP bond length (equal to the distance between points load). To simulate the behavior under service, the beam named as (B) was selected. The geometrical properties and reinforcement details are illustrated in Table(1) and Figure (2).

Table (1) Experimental Work Variables

Beam No.	Distance Between Point Load	Length of Carbon Fiber
B1	0	0
B2	20	20
B3	40	40
B4	60	60

In this study, the main flexural and shear steel reinforcements in the finite element models were assumed to be an isotropic linear elastic material until the yield point. The ultimate and yield stresses are summarized in Table (2). The Poisson's ratio of steel was taken as 0.3.Concrete properties are selected as (fc'=52.88, fr =4.75 and the Poisson's ratio of steel was taken as 0.2).
The dimensions of beams was selected (100x150)mm with 2ϕ4mm at the top ,2ϕ10 at the bottom and ϕ4@150mm shear reinforcement along the beam.

Table (2) Steel Properties

Bar type	Modulus of elasticity (kN/m^2)	Yield strength (fy) (MPa)	Ultimate strength (fu) (MPa)
Main Reinforcement	200000	484	719
Shear Reinforcement	200000	383	620

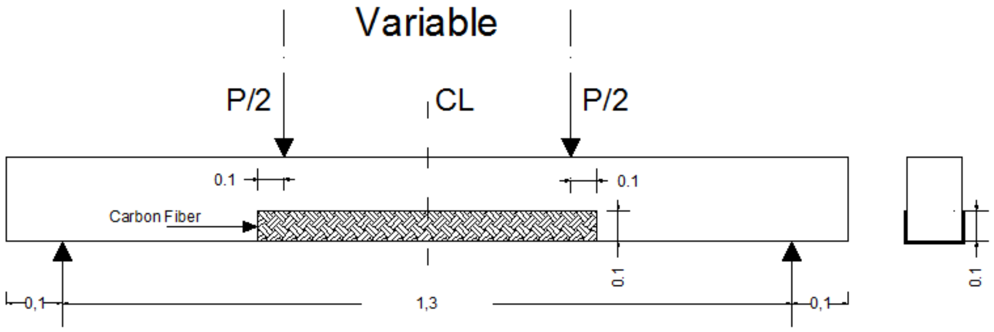

Figure (2) Reinforced Concrete Beam With Loading

4. Finite Element Analysis

ANSYS computer program has been used for the finite element modeling. Four beams that have been studied were of a simply supported beamslengthof1.5mand an area100X150mm and loaded with two symmetrically placed concentrated vertical loads with Variable distances between point load, see Figure (3) below and Table (3). Table (3) shows the distances between the points load and length of carbon fiber sheets for each model.
Model includes linear relationship to the properties concrete, a linear bond-slip relation and bilinear steel properties. The method of load application was applied incrementally each 2 kN. See Plate below which represents position of load application and position of supports. In ANSYS program symmetry properties were applied for the purpose of representation models.

Figure (3) FEM Discretization for a Half of the Beam

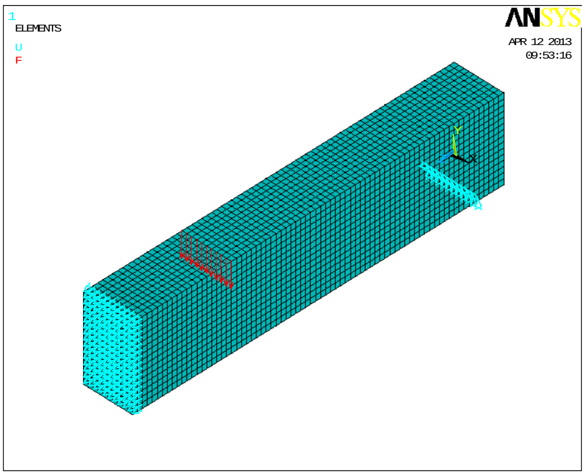

Table (3) Distance Between Points Load

Model Number	Description	Distance Between Point Load (mm)	Length of Carbon Fiber Sheet
B1	Without carbon fiber one point load	One point load	-------
B2	With carbon fiber two point load	200	200
B3	With carbon fiber two point load	400	400
B4	With carbon fiber two point load	600	600
B1W	Without carbon fiber one point load	One point load	-------
B2W	Without carbon fiber two point load	200	200
B3W	Without carbon fiber two point load	400	400
B4W	Without carbon fiber two point load	600	600

5. Material Modeling

SOLID65 isotropic element is used to represent the concrete material, since it has a capability of both cracking in tension and crushing in compression. SOLID65 element is defined by 8 nodes with three degrees of freedom at each node; translations in the nodal x, y, and z directions, see Figure below.

LINK8 element (It is a uniaxial tension-compression member) is used to represent the reinforcing steel (main and stirrups steel material). LINK8 element is defined by two nodes with three degree of freedom at each node; translations in the nodal x, y, and z directions, see Figure below.

SHELL41 element is used to represent the carbon fiber sheets. SHELL41 element is defined by four nodes with three degree of freedom at each node.it is a 3-D element having membrane (in-plane) stiffness but no bending (out of plane) stiffness. See Figure below.

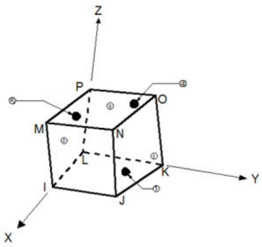

Figure (4) Solid 65

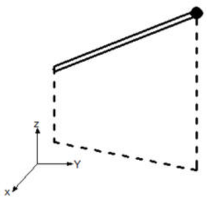
Figure (5) Link 8

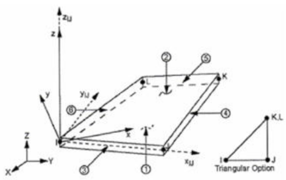
Figure (6) Shell41

5.1 Real Constants

The real constants for this model are shown in Table below

Table (4) Real Constant

Real constant set	Element type	Constant			
1	SOLID65 concrete		Real constant for Rebar 1	Real constant for Rebar2	Real constant for Rebar 3
		Material number	0	0	0
		Volume ratio	0	0	0
		Orientation angle	0	0	0
2	LINK8 Reinforce-ment	Steel Bar Diameter	$(\phi\, 10\ mm)$		
		Cross-sectional area (mm^2)	78.54		
		Initial strain (mm/mm)	0		
3	LINK8 Reinforce-ment	Steel Bar Diameter	$(\phi\, 4\ mm)$		
		Cross-sectional area (mm^2)	12.566		
		Initial strain (mm/mm)	0		
3	SHELL41 CFRP	CFRP type	Fabric		
		Shell thickness at node I (mm)	0.1		
		Shell thickness at node J (mm)	0.1		
		Shell thickness at node K (mm)	0.1		
		Shell thickness at node L (mm)	0.1		
		Element x- axis rotation	0		
		Elastic foundation stiffness	0		
		Added mass/unit area	0		

5.2 Material Properties

The material properties for this model are shown in Table below:

Table (5) Materials Properties

Material model number	Element type	Material properties		
1	SOLID65	Linear Isotropic		
		EX	34178	
		PRXY	0.2	
		Multilinear Isotropic		
			Strain	Stress
		Point 1	0.000464	15.864
		Point 2	0.001	30.94
		Point 3	0.00158	42.83
		Point 4	0.0018	45.96
		Point 5	0.003	52.88
		Concrete		
		ShrCf-Op	0.2	
		ShrCf-CI	0.3	
		UnTensSt	3.64	
		UnCompSt	-1	
		BiCompSt	0	
		HydroPrs	0	
		BiCompSt	0	
		UnTensSt	0	
		TenCrFac	0	
Material model number	Element type	Material properties		
2	LINK8	Linear Isotropic		
		EX	200000	
		PRXY	0.3	
		Bilinear Isotropic		
		Yield Stress	484	
		Tang Mod.	0	
3	LINK8	Bilinear Isotropic		
		Yield Stress	383	
		Tang Mod.	0	
		Linear Isotropic		
		EX	200000	
		PRXY	0.3	
4	SHELL41	Linear Orthotropic		
		Ex	234000	
		Ey	1	
		Ez	1	
		PRXY	0.3	
		PRYZ	0	
		PRXZ	0	
		Gxy, Gyz, Gxz	1	

6. Theoretical Results

6.1 Failure Load

After the data was analyzed and carefully considered, it can be said that the collected data of the failure load obtained from the theoretical solution for all beams is approximately equal experimental load and all the beams failed by flexure. The final loads for the ANSYS finite element method are the last applied load step before the solution diverges due to numerous cracks and large deflections.

Through an extensive comparison between the unsupported specimens with carbon fiber and other supported specimens, it can be concluded that the specimens with carbon fiber have failure load more than other specimens without carbon fiber. This can be explained that the carbon fibers connecting both sides of the crack together and delay extension more during the concrete section (increase in tensile cracking strength of concrete due to confinement).

Also, the increasing Length of the carbon causes an increase in the amount of carrying capacity to bending stresses, because the increase in length means cover as much as possible the bending area and are controlled more cracks generated during download stages.

The moment generated in the mid length of the beam is the result of multiplying the reaction by the distance between the reaction and applied force (couple). When the distance between the two points load increased this leads to decrease of the distance between the applied force and the reaction, this leads naturally to a decrease in couple as a result of decrease in the distance between them, for the above reasons we can say that the increasing in the distance between the loading points provides to some extent an increase in carrying capacity for specimens.

6.2 Behavior at First Cracking

The analysis of reinforced concrete beams in the linear region depends mainly on the appearance of cracks in that region where maximum bending stresses are concentrated. As was expected through a comparison between the different beams (different distances between the points of loading), the greater distance between points load delayed appearance of first cracks in the beams the reason for that is as stated previously that the increase in distance between point loads means decrease the applied moment on beam for same value of load if compared with the other models with less distance.

A comparison of values obtained from the FE model and experimental can be seen in Table (6). The results in Table (6) indicate that the FE analysis of the beam prior to cracking is acceptable.

The first cracks for the beams without carbon fiber (B1W, B2W, B3W and B4W) were observed at (27.27%, 25%, 26.6% and 26.3%) of the ultimate load respectively where for carbon fiber reinforced beam the first crack load was found to be between (13.63% to 15%) the ultimate load. There is a 11.5% to 12.8% increase in ultimate load for carbon fiber reinforced concrete beams when compared with beams without carbon fiber reinforcement. Thus the experimental results show that there is increase in the ultimate load and the first crack load for the fiber reinforced concrete beams.

Table (7) Cracking and Ultimate Load Deflection

Model	Load at First Cracking (kN)		Centerline Deflection (mm)		Ultimate load (kN)		$P_{cr}/p_{ultimate}$ %	
	Exper.	Theo.	Exper.	Theo.	Exper.	Theo.	Exper.	Theo.
B1	6.5	6	0.5	0.33	36	38	18	15.8
B1W		6		0.332		22		27.27
B2	7	6	0.255	0.3175	44	44	15.9	13.63
B2W		6		0.321		24		25
B3	9	8	0.54	0.386	54	58	16.6	13.79
B3W		8		0.392		30		26.6
B4	10.5	10	0.52	0.414	70	68	15	14.7
B4W		10		0.42		38		26.3

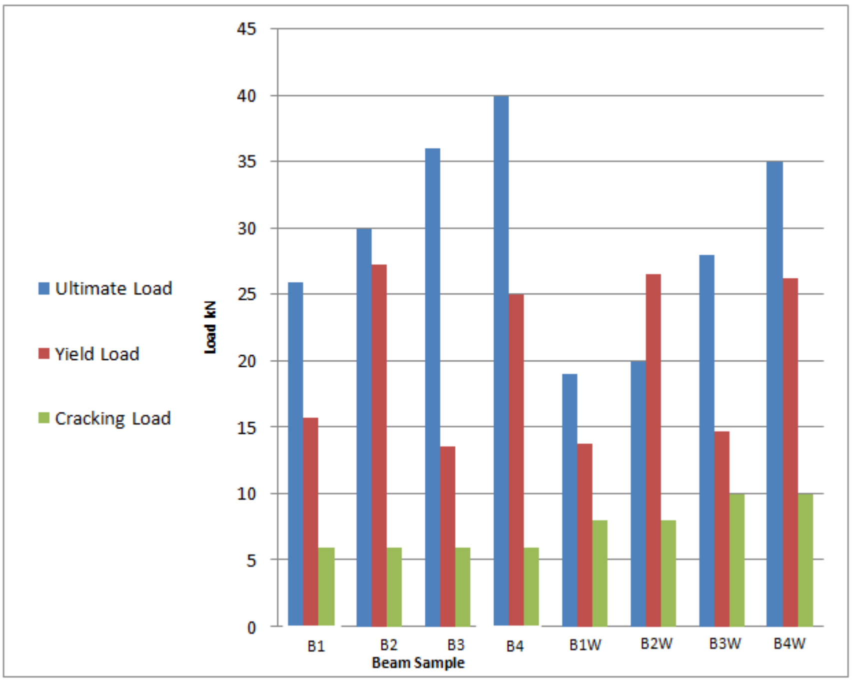

Figure (7)Comparison Between Theoretical Cracking, Yielding and Ultimate load.

6.3 Load-Deflection Relationship

The theoretical results for all specimens are displayed and compared with experimental results. Figures below contain a load-deflection curves predicted by ANSYS and the test results for all specimens Examined by Mohammad Z.Y.. The results of ANSYS converge with the non-strengthened specimens more than other strengthened specimens with carbon fiber because of not taking the slip between the concrete and the carbon fiber into account in the theoretical study.

In general, the beams strengthened with carbon fiber were stiffer and more ductile than the control specimens with a higher ultimate load see Figure (7). In every stage of loading application, the deflections are reduced significantly thereby increasing the stiffness for the strengthened beams.

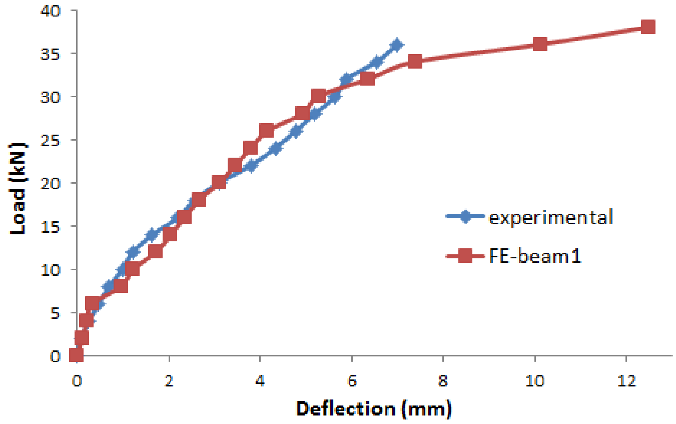

Figure (8) Experimental and Theoretical Load Deflection Curve for Beam (B1)

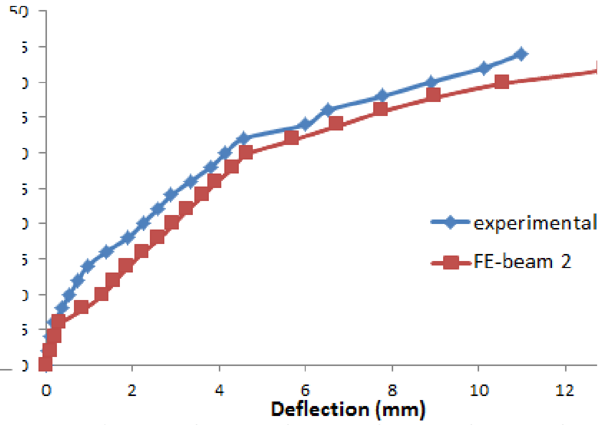

Figure (9) Experimental and Theoretical Load Deflection Curve for Beam (B2)

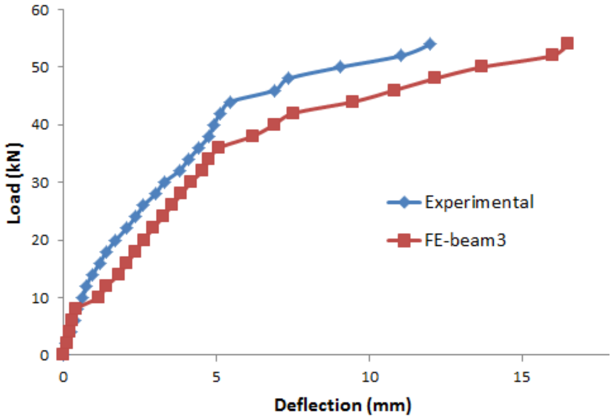

Figure (10) Experimental and Theoretical Load Deflection Curve for Beam (B3)

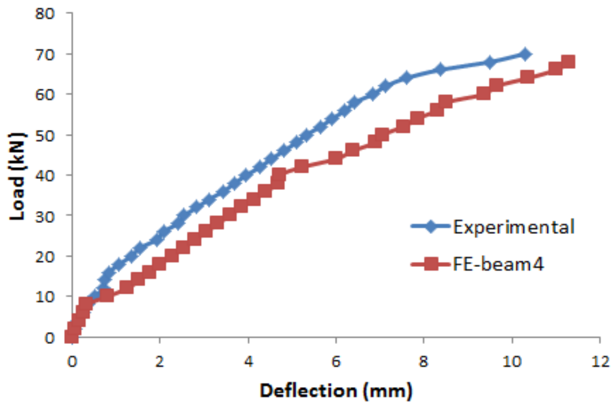

Figure (11) Experimental and Theoretical Load Deflection Curve for Beam (B4)

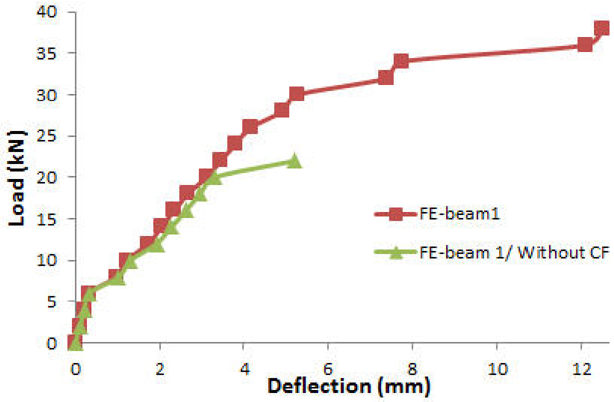

Figure (12) Theoretical Load Deflection Curve for Beam (B1) and (B1W)

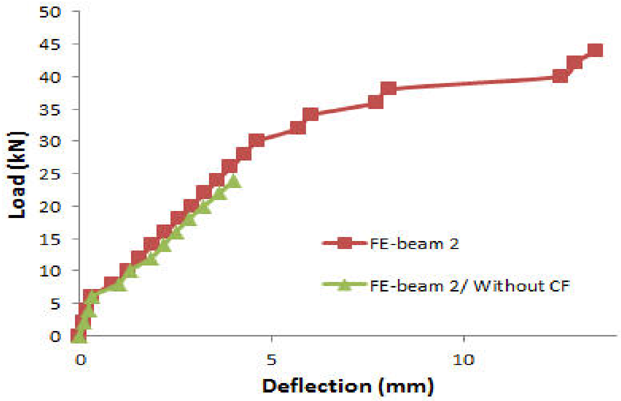

Figure (13) Theoretical Load Deflection Curve for Beam (B2) and (B2W)

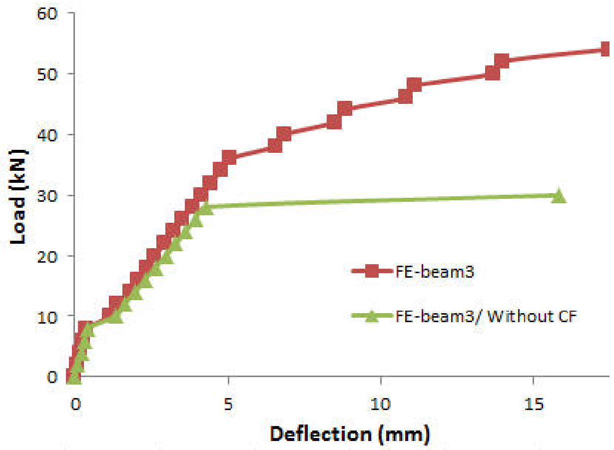

Figure (14) Theoretical Load Deflection Curve for Beam (B3) and (B3W)

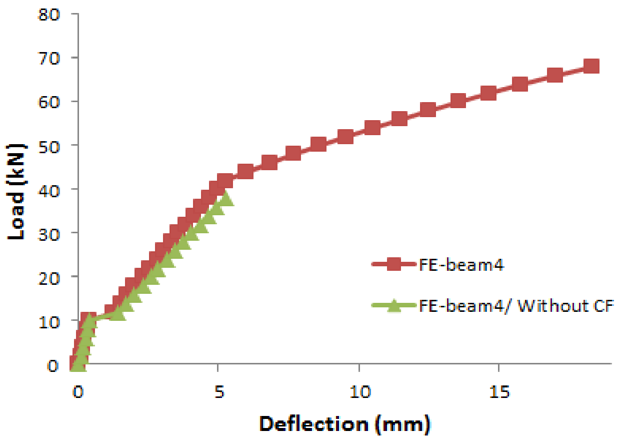

Figure (15) Theoretical Load Deflection Curve for Beam (B4) and (B4W)

6.4 Ductility

Ratio of curvature at crushing of concrete to that at yielding of steel gives the numerical value of ductility, known as ductility index.

It can be seen that for a given dimension and strength, the load versus displacement curves for both specimens with carbon fiber and other specimens without carbon fiber appear similar. In addition, as can be seen in Table (8) the deflection at yielding and ultimate strength for beams without carbon fiber appear lower than those of beams with carbon fiber. It has been known that the deflection ductility, $\mu\Delta$, in terms of ultimate deflection to yielding displacement, is highly correlated to the length of the carbon fiber sheet. As can be seen in Table (8),

the ductility of both types of concrete beams exhibit a extrusive length effect, i.e., ductility increase with the increase of carbon fiber sheets, namely, a strengthened beam performs more ductile.
The effect of increasing the distance between the points load seemed clear as when you increase this distance increases the ductility due to decrease moments that cause for ultimate deflection in the beam at failure.

Table (8) Ductility of tested beams

Beam No.	Deflection at Yield (mm)	Deflection at Failure (mm)	Ductility Index
B1	4.16	12.5045	3
B2	4.64	13.4386	2.896
B3	5.09	18.357	3.606
B4	4.97	18.3	3.682
B1W	3.1	5.22	1.683
B2W	3.6	4.01	1.113
B3W	4.3	15.822	3.679
B4W	4.7	4.917	1.046

7 .Conclusions

Based on the results obtained from theoretical analysis and comparison with the experimental work, the following conclusions are drawn:

1. At any given load level, the deflections are reduced significantly thereby increasing the stiffness for the strengthened beams.
2. All the beams strengthened with carbon fiber experience flexural failures. None of the beams exhibit brittle failure.
3. The failure load of specimens with carbon fiber more than other specimens without carbon fiber.
4. The bending stresses are reduced when length of the carbon was increased.
5. The increasing in the distance between the loading points provides an increase in carrying capacity for specimens.
6. In this study, the appearance of the first crack mainly depends on the distance between the points load, higher distance between the mount points load lead to the delay in appearance of the cracks.
7. Through the adoption of the distance between the point load as a variable show that increasing the distance between the points load result a decreasing in moment in the mid span of the beam, this means an increase in carrying capacity for specimens.
8. Through a comparison theoretical results with the experimental, showing that there is a convergence between the two results.
9. It is very clear the development in ductility as a result of increasing the length of carbon fiber sheets and increase the distance between the points load.

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