Finite Element Behavior of Reinforced Concrete Beams by Using Glass Fiber

Walaa Mahmoud Shaaban[1]

1 Department of Civil Eng., the Higher Institute of Engineering, El Sherouk City, Cairo, Egypt

Abstract.

Due to the high steel prices in recent years. And it also limited ore could be carried out at any time. Therefore become composite materials such as glass fiber reinforced polymers and carbon fiber center of attention in the field of structural engineering to be used as an alternative to steel reinforcement in the structural elements to reduce cost. This research study on the behavior of reinforced concrete beams in flexure and shear using locally produced glass fiber reinforced polymer GFRP bars and stirrups depend on the finite element analysis by using ANSYS program. Thirty beams analyzed using finite element program ANSYS V12. Sixteen beams prepared to investigate flexure behavior compared with experimental beams had been done by Amr Hilal [1]. All beams had a T- cross section of 120 mm wide, 300 mm total depth, and 480 mm flange wide and 60 mm slab thickness. The beam effective depth was set to 266 mm. The clear span of the tested beams was fixed for all beams to be 1800 mm but the total length of beams was 2200 mm. And fourteen beams prepared to investigate shear behavior compared with experimental beams had been done by Tamer Magdy [5]. All beams had a rectangular cross section of 150 mm wide and 300 mm total depth. The beam effective depth was set to 266 mm. The clear span of the tested beams was fixed for all beams to be 1000 mm but the total length of beams was 1100 mm. All beams were tested under two-point load.

Keywords: Finite Element, Reinforced concrete beams, Ultimate Load, Economic Studies.

1. Introduction

Deterioration of concrete structures throughout the world and the cost of their repair and rehabilitation have become a major concern in recent years. In some cases the repair costs can be twice as high as the original cost. In Canada, it is estimated that the cost of repair of parking garages is in the range of 6 billion dollars, and over 74 billion dollars for all concrete structures. The estimated repair cost for existing highway bridges in the USA is over 50 billion dollars, and 1-3 trillion dollars for all concrete structures. In Europe, steel corrosion has been estimated to cost about 3 billion dollars year. Excessive corrosion problem also exist in Arabian Gulf countries (Benmokrane et al., 1998).

Organizations, private industry and university researchers are seeking ways to avoid the corrosion problem and thereby eliminate, partially or totally, burden of never ending repair costs. One preferred solution, which has assumed the status of cutting edge research in many industrialized countries, is the use of fiber reinforced polymer (FRP) rebars in concrete.

FRP reinforcement has an advantage over steel in that it has high corrosion resistance and a high strength to weight ratio, thus for structures built in or close to seawater or at similar corrosive environment. They are also non-conductive for electricity and non-magnetic.

FRP reinforcement has widely been used as internal reinforcement in the new construction of civil structures or as NSM concrete reinforcement for increasing flexural and shear strength of deficient reinforced concrete member. This has made it necessary to create a comprehensive overview needed to justify their safe an economic use.

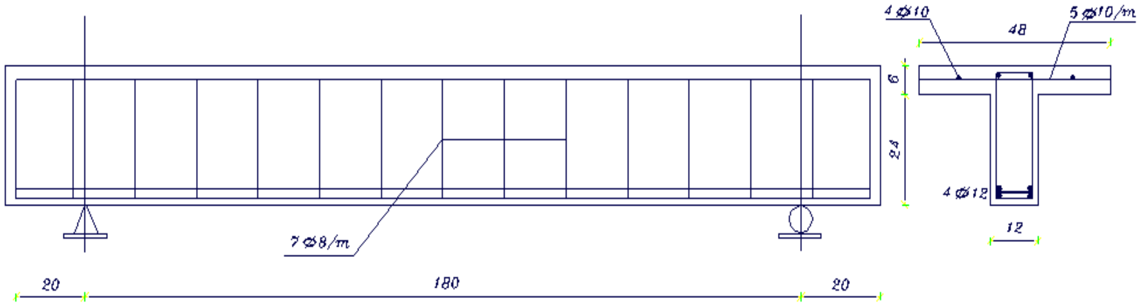
2. Non-linear Finite element Analysis

2.1 Geometry

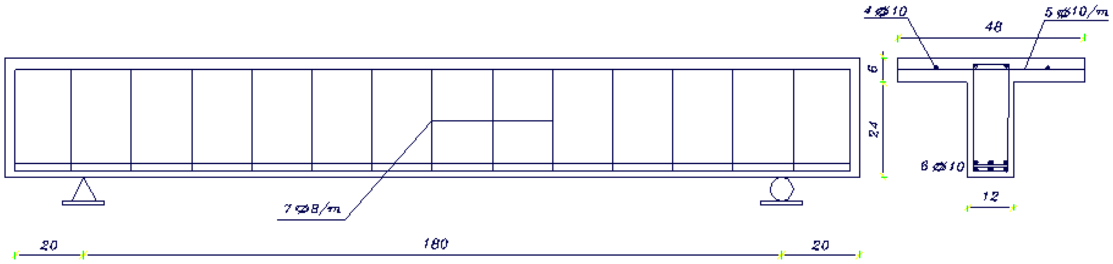
The numerical analysis carried out on sixteen beams prepared to investigate flexure behavior. All beams had a T- cross section of 120 mm wide, 300 mm total depth, and 480 mm flange wide and 60 mm slab thickness. The beam effective depth was set to 266 mm. The clear span of the tested beams was fixed for all beams to be 1800 mm but the total length of beams was 2200 mm. The ultimate compressive strength of concrete was 0.025 KN/mm2. Another fourteen beams prepared to investigate shear behavior. All beams had a rectangular cross section of 150 mm wide and 300 mm total depth. The beam effective depth was set to 266 mm. The clear span of the tested beams was fixed for all beams to be 1000 mm but the total length of beams was 1100 mm. The ultimate compressive strength of concrete was 0.0285 KN/mm2. All beams were tested under two-point load. The samples codes are illustrated in Table1and Table2 while the beam dimensions and reinforcement indicated in Fig. 1and Fig. 2

***Table 1**. Details of Tested Flexure beams*

Group No.	Spec. symbol	Bar material	Main RFT		Sec. RFT	Stirrups
			Straight			
1	B1	Steel	4 ϕ12		2 ϕ10 (Steel)	7ϕ 8\ m (Steel)
2	BBS1	GFRP	4 ϕ12		2 ϕ10 (Steel)	7ϕ 8\ m (Steel)
	BBS2	GFRP	6 ϕ10		2 ϕ10 (Steel)	7ϕ 8\ m (Steel)
	BBS3	GFRP	2 ϕ16		2 ϕ10 (Steel)	7ϕ 8\ m (Steel)
3	BDL2	GFRP	4 ϕ12	Ld = 0	2 ϕ10 (Steel)	7ϕ 8\ m (Steel)
	BDL3	GFRP	4 ϕ12	Ld=10	2 ϕ10 (Steel)	7ϕ 8\ m (Steel)
4	BD2	GFRP	2 ϕ12		2 ϕ10 (Steel)	7ϕ 8\ m (Steel)
	BD3	GFRP	10ϕ12		2 ϕ10 (Steel)	7ϕ 8\ m (Steel)
5	BBS1F	GFRP	4 ϕ12		2 ϕ10 (GFRP)	7ϕ 8\ m (GFRP)
	BBS2F	GFRP	6 ϕ10		2 ϕ10 (GFRP)	7ϕ 8\ m (GFRP)
	BBS3F	GFRP	2 ϕ16		2 ϕ10 (GFRP)	7ϕ 8\ m (GFRP)
6	BDL2F	GFRP	4 ϕ12	Ld = 0	2 ϕ10 (GFRP)	7ϕ 8\ m (GFRP)
	BDL3F	GFRP	4 ϕ12	Ld=10	2 ϕ10 (GFRP)	7ϕ 8\ m (GFRP)
7	BD2F	GFRP	2 ϕ12		2 ϕ10 (GFRP)	7ϕ 8\ m (GFRP)
	BD3F	GFRP	10ϕ12		2 ϕ10 (GFRP)	7ϕ 8\ m (GFRP)



Specimen Details for Beam B1, BBS1

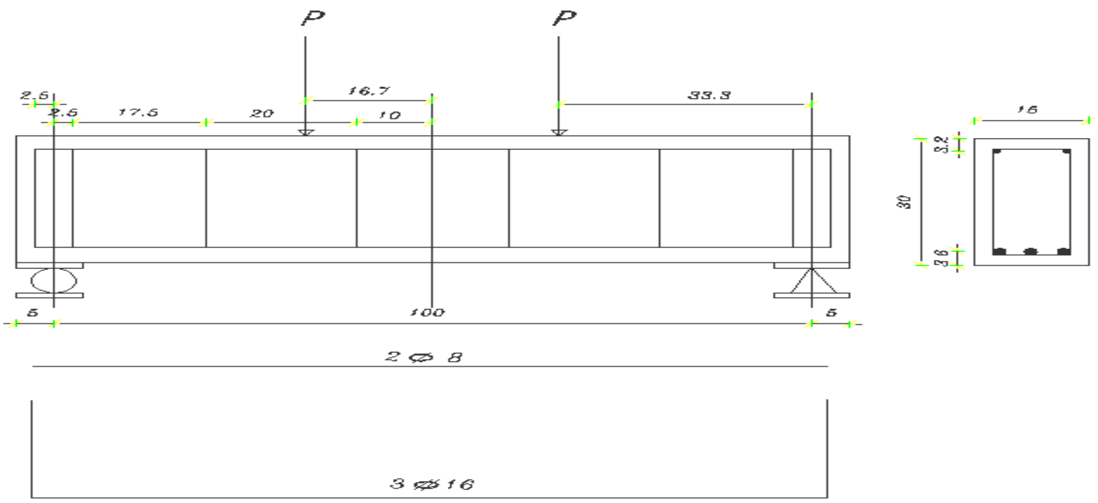


Specimen Details for Beam BBS2

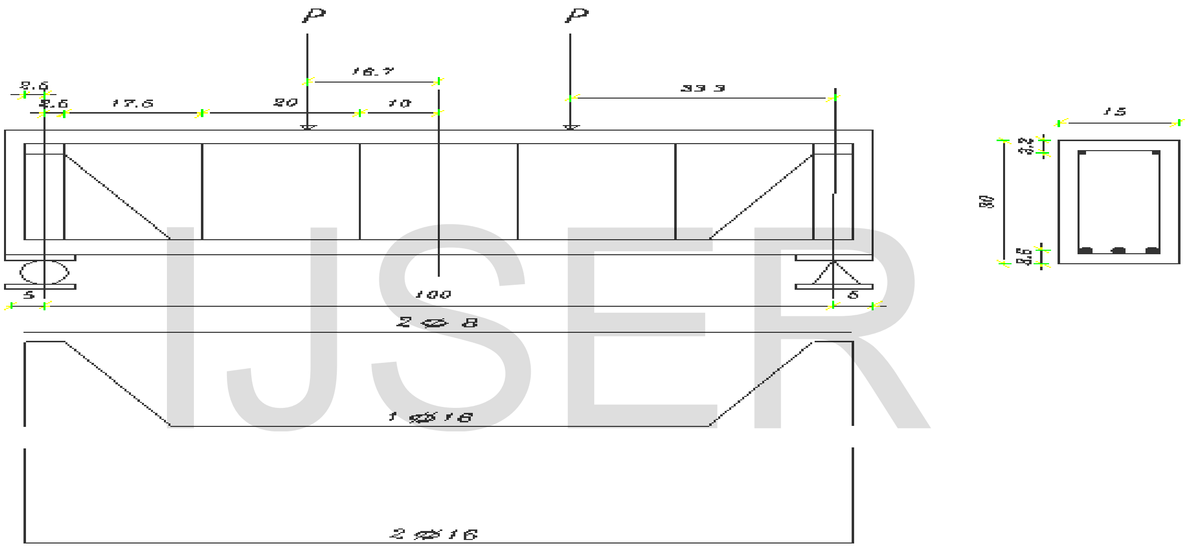
Fig. 1*: Beams Reinforcement Details*

Table 2*. Details of Tested Shear beams*

Group No.	*Spec. symbol*	*Bar material*	*Vf %*	*Main RFT*		*Reinf ratio*	*Sec. RFT*	*stirrups spacing*
				Straight	*Bent*			
1	*BC1*	*Steel*		*3ϕ16*		*1.51%*	*2ϕ8 (Steel)*	*20*
	BC2	*Steel*		*2ϕ16*	*1ϕ16*	*1.51%*	*2ϕ8 (Steel)*	*20*
2	*B1SQ*	*GFRP*	*48*	*3ǂ14*		*1.47%*	*2ǂ7 (GFRP)*	*20*
	B2SQ	*GFRP*	*48*	*3ǂ14*		*1.47%*	*2ǂ7 (GFRP)*	*15*
	B3SQ	*GFRP*	*48*	*3ǂ14*		*1.47%*	*2ǂ7 (GFRP)*	*10*
3	*B4SQ*	*GFRP*	*58*	*3ǂ14*		*1.47%*	*2ǂ7 (GFRP)*	*20*
	B5SQ	*GFRP*	*58*	*3ǂ14*		*1.47%*	*2ǂ7 (GFRP)*	*15*
	B6SQ	*GFRP*	*58*	*3ǂ14*		*1.47%*	*2ǂ7 (GFRP)*	*10*
4	*B7SQ*	*GFRP*	*68*	*3ǂ14*		*1.47%*	*2ǂ7 (GFRP)*	*20*
	B8SQ	*GFRP*	*68*	*3ǂ14*		*1.47%*	*2ǂ7 (GFRP)*	*15*
	B9SQ	*GFRP*	*68*	*3ǂ14*		*1.47%*	*2ǂ7 (GFRP)*	*10*
5	*B10SQ*	*GFRP*	*48*	*2ǂ14*	*1ǂ14*	*1.47%*	*2ǂ7 (GFRP)*	*20*
	B11SQ	*GFRP*	*58*	*2ǂ14*	*1ǂ14*	*1.47%*	*2ǂ7 (GFRP)*	*20*
	B12SQ	*GFRP*	*68*	*2ǂ14*	*1ǂ14*	*1.47%*	*2ǂ7 (GFRP)*	*20*



Specimen Details for Beam BC1



Specimen Details for Beam BC2

Fig. 2: Beams Reinforcement Details

2.2 Modelling

A three dimensional finite-element program 'ANSYS' was used for the numerical analysis of the thirty beams. In the analysis, appropriate material models were employed to represent the behavior of concrete, the steel reinforcement, the steel plates, GFRP bars. They are described in detail in the ANSYS manual set in addition to model the bond behavior interface element.

A solid element, SOLID65, is used to model the concrete in ANSYS. The solid element has eight nodes with three transitional degrees of freedom at each node. In addition, the element is capable of simulating plastic deformation, cracking in three orthogonal directions, and crushing. The steel plates at the supports for the beams are modeled using Solid45 elements. This element has eight nodes with three degrees of freedom at each node – translations in the x, y, and z directions. in order to obtain the internal strains in the reinforcement bars and keep them in their right positions, the discrete technique using the 3D spar Link8 element is *followed.*

This element has two nodes with three degrees of freedom translations in the x, y, and z directions. This element is also capable of plastic deformation.

In this study the all beams were tested under two-point load.

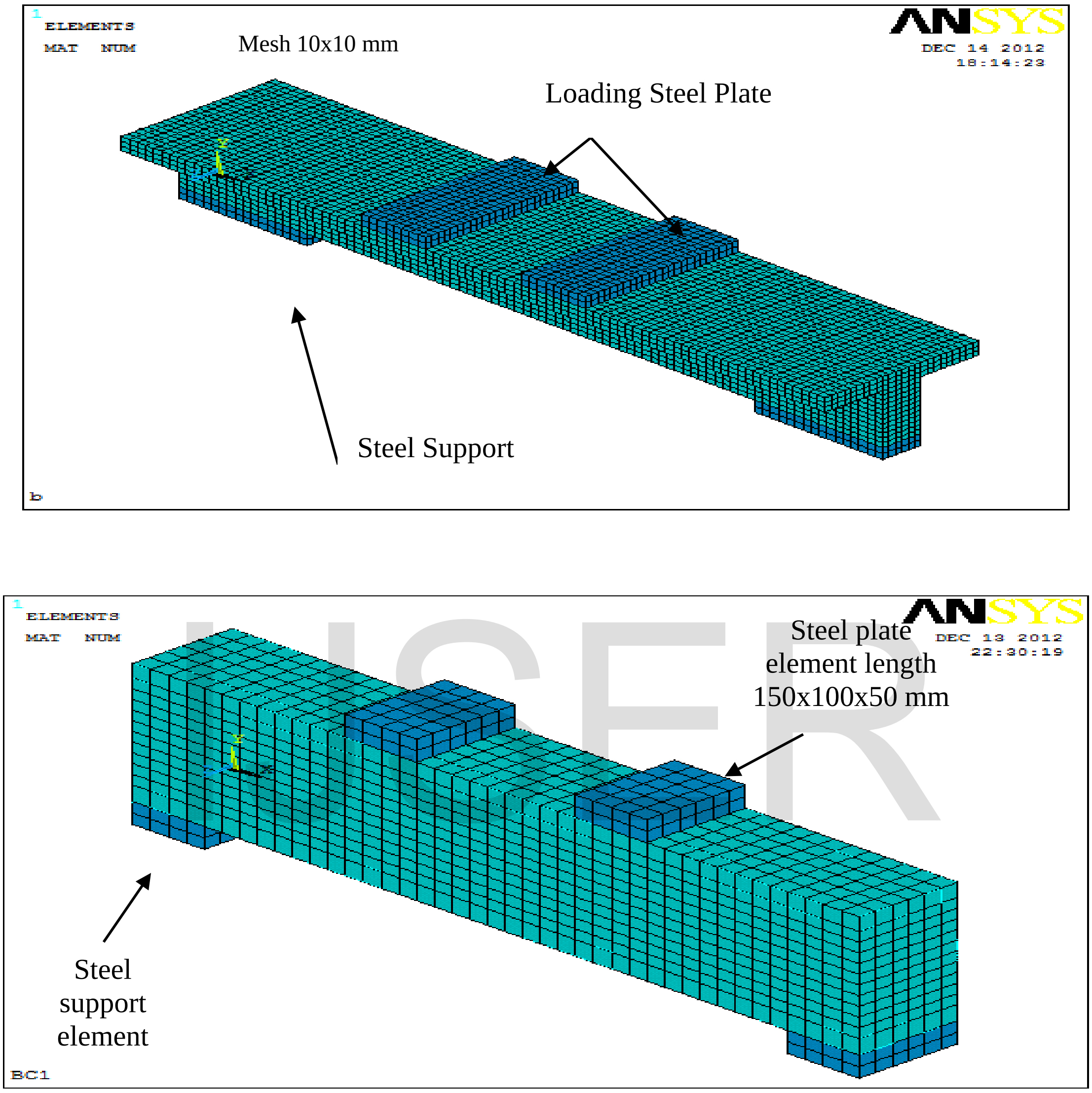


Fig. 3: Mesh

3. Results and Discussion

3.1 Reinforced Concrete Beam in Flexure.

3.1.1 Failure Load.

Figure 4 show the change of bar diameter resulting in change the failure load, the beam reinforced with steel bars (B1) gives a higher failure load more than the similar beam reinforced with GFRP bars (BBS1).

Fig. 5 The change of development length had very little effect on the failure load. The beams with shorter development lengths showed a lower failure load than the beams with full development lengths.

Fig. 6 shows the effect of changing the reinforcement ratio on the failure load. The beams with low reinforcement ratio (BD2 with μ= 0.7%) showed a very low failure load in comparison to the beam with a very *high reinforcement ratio (BD3 with μ= 3.5%) and with beam BBS1 (μ= 1.4%) that its lies in between the two beams.*

Fig. 7 shows the effect of fiber stirrups and volume fraction on the failure load. The failure loads were directly proportional to the fiber stirrups spacing. It can be noticed decreasing the fiber stirrups spacing from 200 to 150 mm for beams reinforced with GFRP stirrups with volume fraction (Vf) 48% has small effect on the ultimate load , but increased the ultimate load by about 44.86% for stirrups volume fraction (Vf) = 58% , and about 14.3% for stirrups volume fraction (Vf) = 68%.While decreasing the stirrups spacing from 200 to 100 mm has increased the ultimate load by about 10.4% for stirrups volume fraction (Vf) = 48%, increased the ultimate load by about 53.06% for stirrups volume fraction (Vf) = 58%, and about 17.03% for stirrups volume fraction (Vf) = 68%.

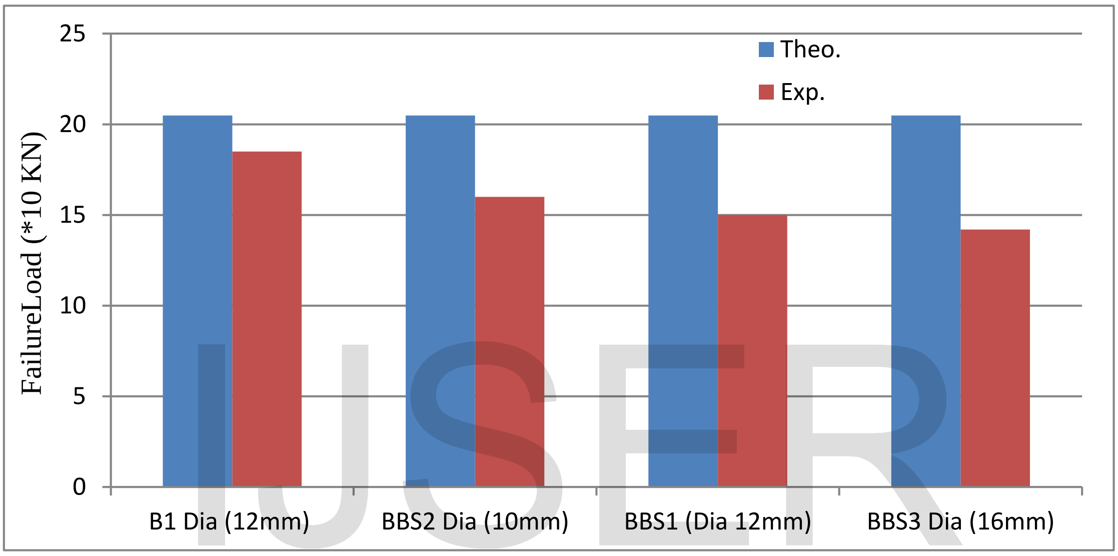


***Fig. 4**: Effect of Bar Diameter on the Failure Load with Compression with Experimental Result*

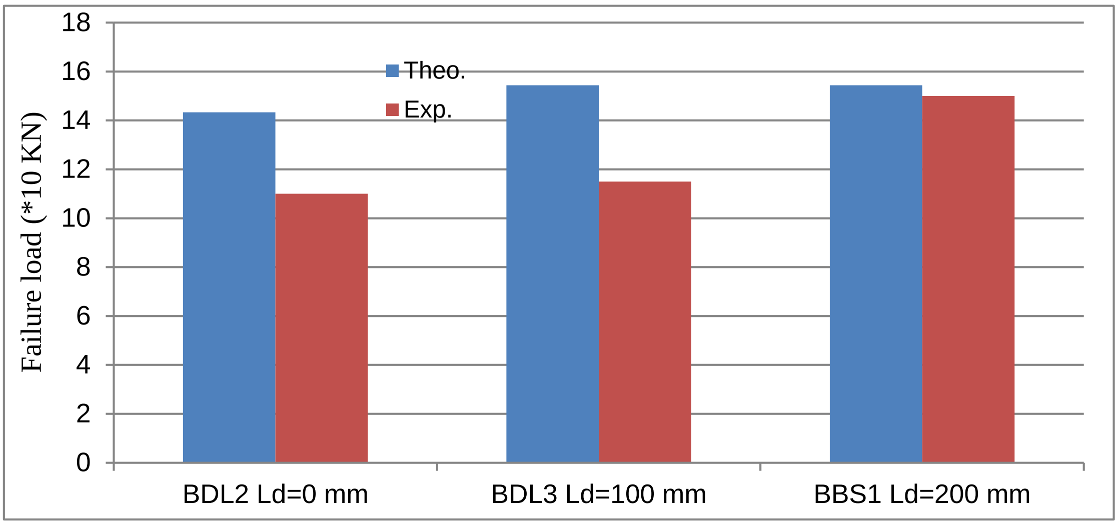


***Fig. 5**: Effect of Development Length on the Failure Load with Compression with Experimental Result*

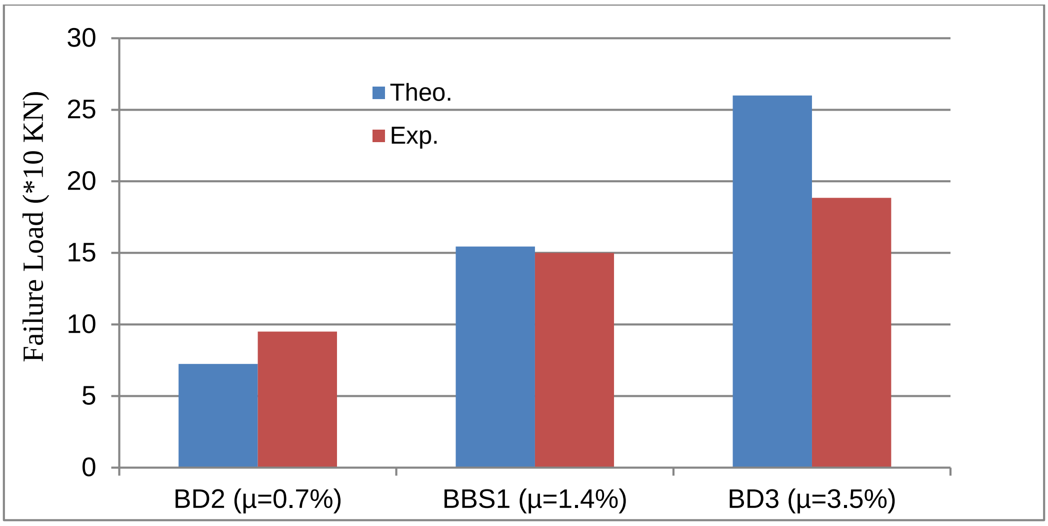


Fig. 6: *Effect of Reinforcement Ratio on the Failure Load with Compression with Experimental Result*

3.1.2 Load Deflection Relationship

Referring to Table 3 and Table 4 verify the experimental beams by Amr Hilal [1] and Tarek Magdy [2] with the analyzed beams

Table 3*: Verification of Finite Element Model with Experimental Beams done by Amr Hilal [1]*

Group No.	**Spec. symbol**	**Pu Exp. (KN)**	**Pu Theo. (KN)**	**Mid-span deflection (mm) Exp.**		**Mid-span deflection (mm) Theo.**	
				δ_{cr}	δ_{ul}	δ_{cr}	δ_{ul}
1	**B1**	185	204.9	1.00	17.66	0.91	12.12
2	**BBS1**	150	154.40	1.01	11.50	0.29	20.04
	BBS2	165	166.20	0.98	12.20	0.29	19.24
	BBS3	142	129.50	1.40	15.20	0.29	18.40
3	**BDL2**	110	143.3	0.50	12.86	0.29	16.62
	BDL3	115	154.4	0.50	11.86	0.29	19.68
4	**BD2**	95	72.40	0.52	12.00	0.30	17.00
	BD3	188.5	26.00	0.72	10.20	0.184	18.16
5	**BBS1F**	-	154.9	-	-	0.30	19.96
	BBS2F	-	167.0	-	-	0.30	19.68
	BBS3F	-	129.5	-	-	0.30	17.66
6	**BDL2F**	-	143.5	-	-	0.30	17.42
	BDL3F	-	151.2	-	-	0.30	20.65
7	**BD2F**	-	71.00	-	-	0.30	15.50
	BD3F	-	238.0	-	-	0.28	15.66

3.1.2.1 Effect of Bar Diameter on the Load- Deflection Relationship

Fig. 7 shows relation between failure load and mid-span of the concrete beams reinforced by GFRP bars with different bar diameter. The change of bar diameter between BBS1, BBS2, and BBS3 resulted in small difference in load – deflection relationship

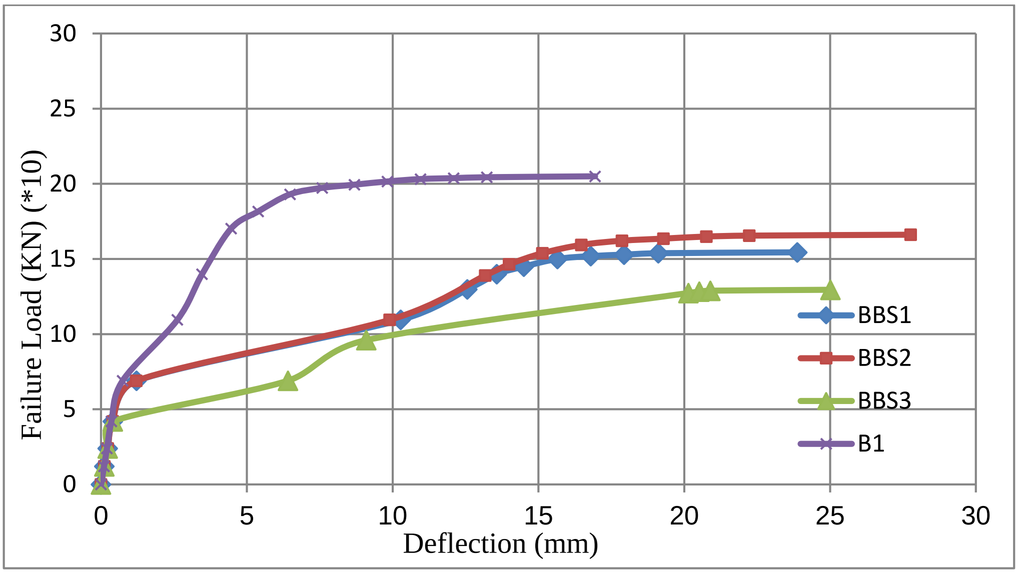


Fig. 7: Bar Diameter Effect on Failure Load- Deflection Relationship

3.1.2.2 Effect of Development Length on the Load- Deflection Relationship

Fig. 8 show the load mid-span deflection curve of the concrete beams reinforced by GFRP bars with different development length.

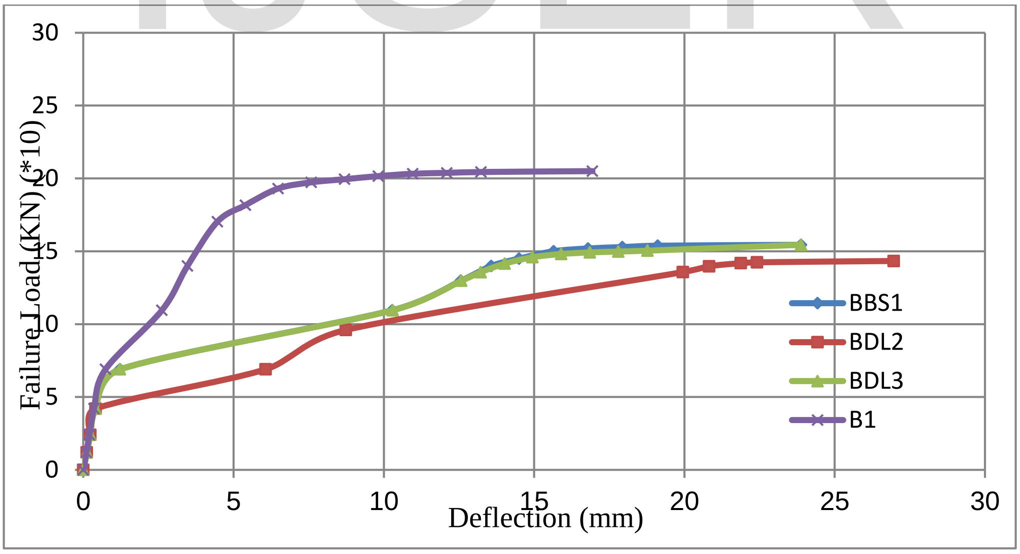


Fig. 8: Development Length Effect on Failure Load- Deflection Relationship

3.1.2.3 Effect of Reinforcement Ratio on the Load- Deflection Relationship

Fig. 9 shows the load mid-span deflection curve of the concrete beams reinforced by GFRP bars with reinforcement ratio.

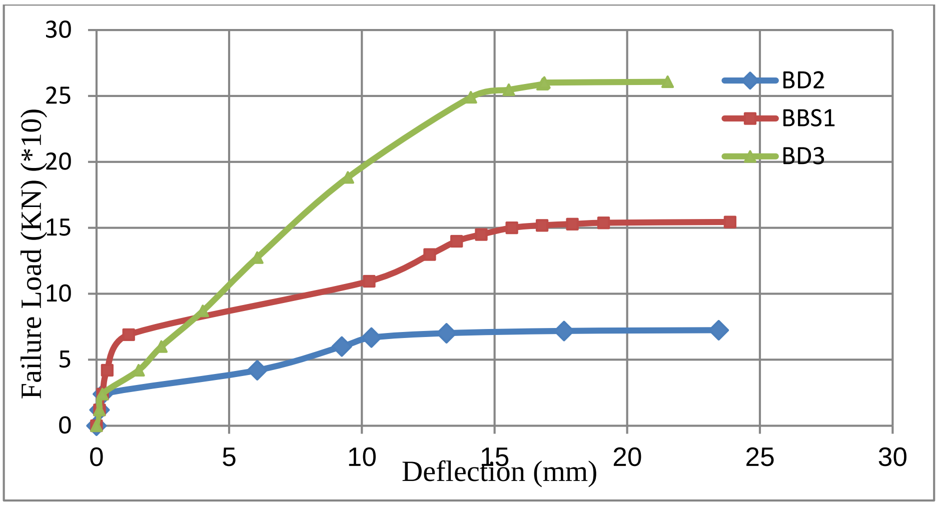


Fig. 9: Reinforcement Ratio Effect on Failure Load- Deflection Relationship

3.2 Reinforced Concrete Beam in shear.

3.2.1 Effect of Stirrups Fiber Volume Fraction on the Specimens Failure Load

The change of stirrups fiber volume fraction (Vf) had very big effect on the beams failure loads, where the failure loads were directly proportional to the stirrups fiber volume fraction.

In Figs. 10, 11 it can be noticed when increasing the stirrups volume fraction from 48% to 58% to 68% the ultimate load increased.

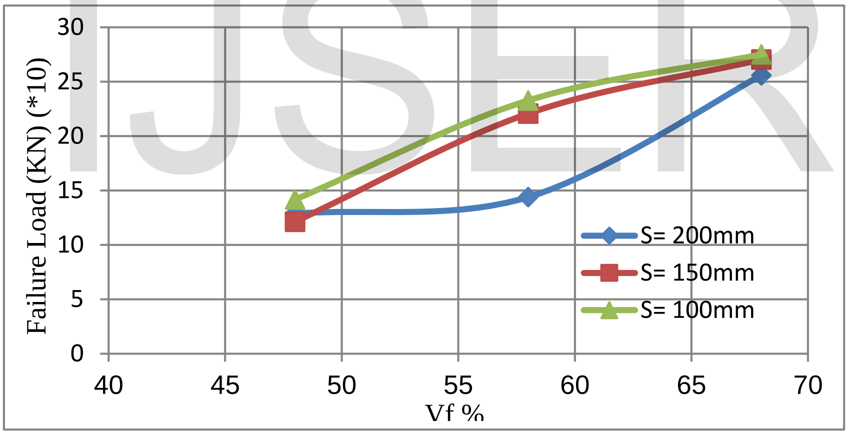


***Fig. 10**: Effect of Stirrups Fiber Volume Fraction on the Failure Load without Bent Bar*

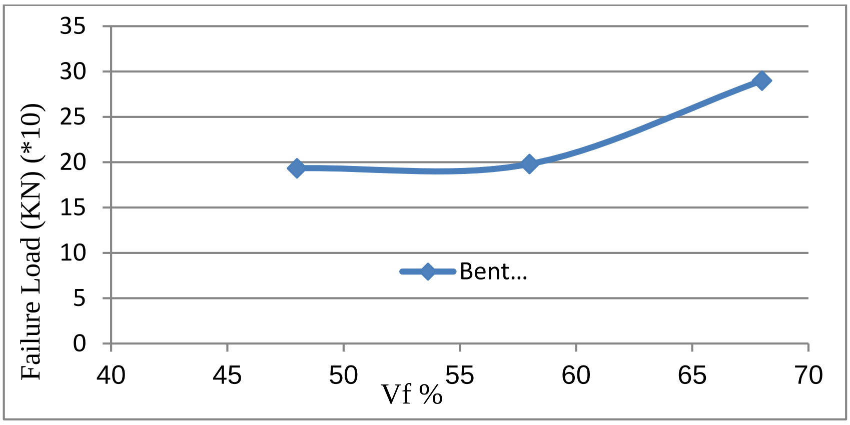


***Fig. 11**: Effect of Stirrups Fiber Volume Fraction on the Failure Load with Bent Bar*

3.2.2 Effect of Fiber Stirrups Spacing on the Specimens Failure Load

The failure loads were inversely proportional to the stirrups fiber stirrups spacing. In fig. 12 can be noticed decreasing the fiber stirrups spacing from 200 to 150 mm for beams reinforced with GFRP stirrups with volume fraction (Vf) 48% has small effect on the ultimate load , but increased the ultimate load by about 54% for stirrups volume fraction (Vf) = 58% , and about 7% for stirrups volume fraction (Vf) = 68%.

While decreasing the stirrups spacing from 200 to 100 mm has increased the ultimate load by about 10% for stirrups volume fraction (Vf) = 48%, increased the ultimate load by about 61.7% for stirrups volume fraction (Vf) = 58%, and about 7.5% for stirrups volume fraction (Vf) = 68%.

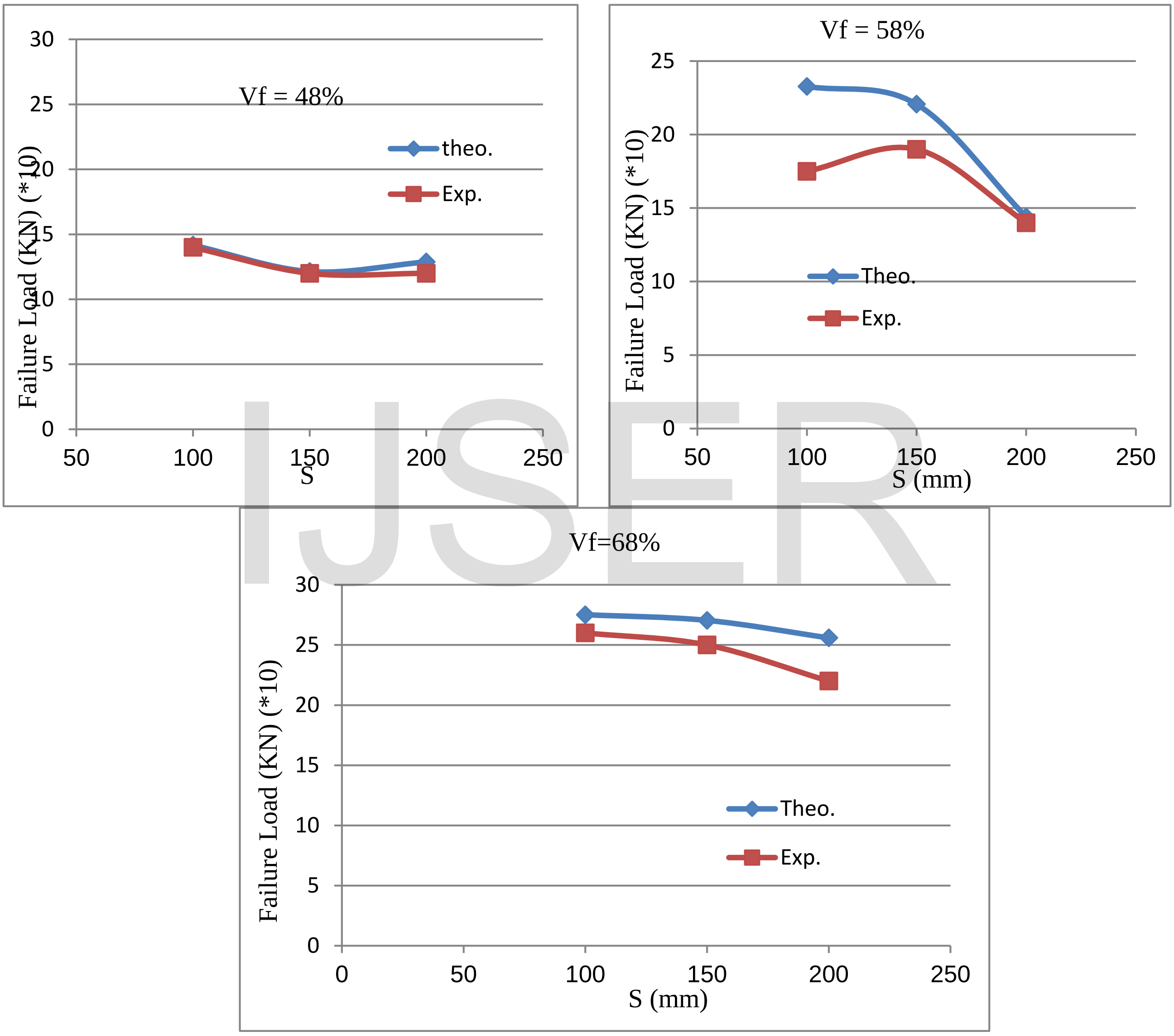


Fig. 12: *Effect of Fiber Stirrups Spacing on the Failure Load of Concrete Beam Reinforced by GFRP Stirrups in Comparison between Exp. and Theo. Result*

3.2.3 Load Deflection Relationship

***Table 4**: Verification of Finite Element Model with Experimental Beams done by Tamer Magdy [2]*

Group No.	*Spec. Symbol*	***Vf %***	***Pu Exp. KN***	***Pu Theo. KN***	***Mid-span Deflection (mm) Exp.***		***Mid-span Deflection (mm) Theo.***	
					δ_{cr}	δ_{ul}	δ_{cr}	δ_{ul}
1	*BC1*	*-*	*230.0*	*223.1*	*5.81*	*10.52*	*0.282*	*1.30*
	BC2	*-*	*270.0*	*289.5*	*2.12*	*6.40*	*0.286*	*2.39*
2	*B1SQ*	*48*	*120.0*	*128.8*	*1.72*	*4.70*	*0.124*	*1.13*
	B2SQ	*48*	*120.0*	*121.3*	*1.8*	*5.80*	*0.129*	*1.65*
	B3SQ	*48*	*140.0*	*141.7*	*1.37*	*5.24*	*0.168*	*1.83*
3	*B4SQ*	*58*	*140.0*	*143.9*	*2.33*	*7.00*	*0.124*	*2.60*
	B5SQ	*58*	*190.0*	*220.7*	*2.20*	*8.00*	*0.129*	*5.40*
	B6SQ	*58*	*175.5*	*232.8*	*1.82*	*8.00*	*0.130*	*5.80*
4	*B7SQ*	*68*	*220.0*	*255.9*	*1.72*	*7.70*	*0.124*	*6.36*
	B8SQ	*68*	*250.0*	*270.4*	*1.79*	*10.01*	*0.129*	*6.88*
	B9SQ	*68*	*260.0*	*275.1*	*1.47*	*10.50*	*0.130*	*8.36*
5	*B10SQ*	*48*	*180.0*	*193.3*	*1.67*	*6.24*	*0.285*	*10.00*
	B11SQ	*58*	*185.0*	*198.0*	*2.24*	*7.35*	*0.293*	*10.68*
	B12SQ	*68*	*250.0*	*290.0*	*1.52*	*9.16*	*0.179*	*14.61*

Notes: δ_{cr} = *Mid-span deflection at first cracking load.*

δ_{ul} = *Mid-span deflection at ultimate load.*

3.2.3.1 Load Deflection Relationship

Fig. 13 to 16 show the load mid-span deflection curve of the concrete beams reinforced by GFRP stirrups with deferent fiber volume fraction 48%, 58%, and 68%.

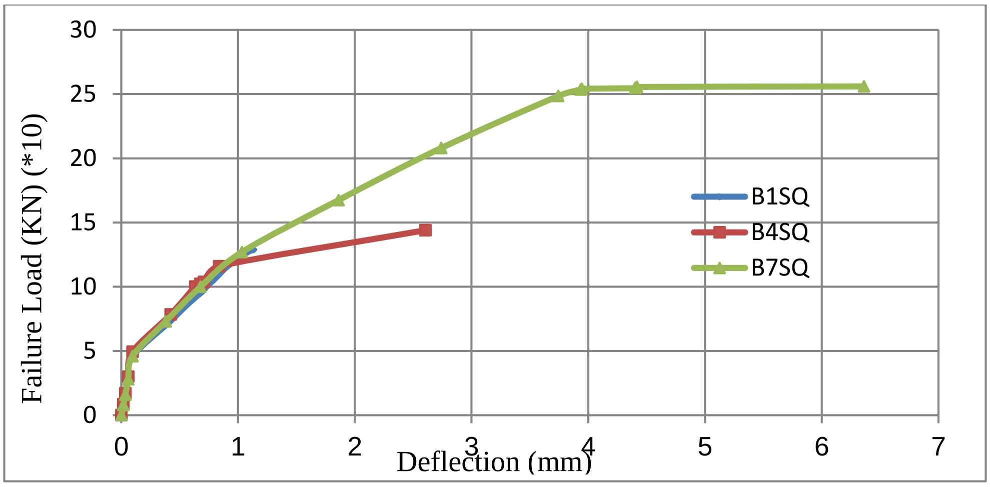


Fig. 13: Failure Load Mid- Span Deflection Curve for Beams Reinforced with GFRP Stirrups Spacing = 20 cm

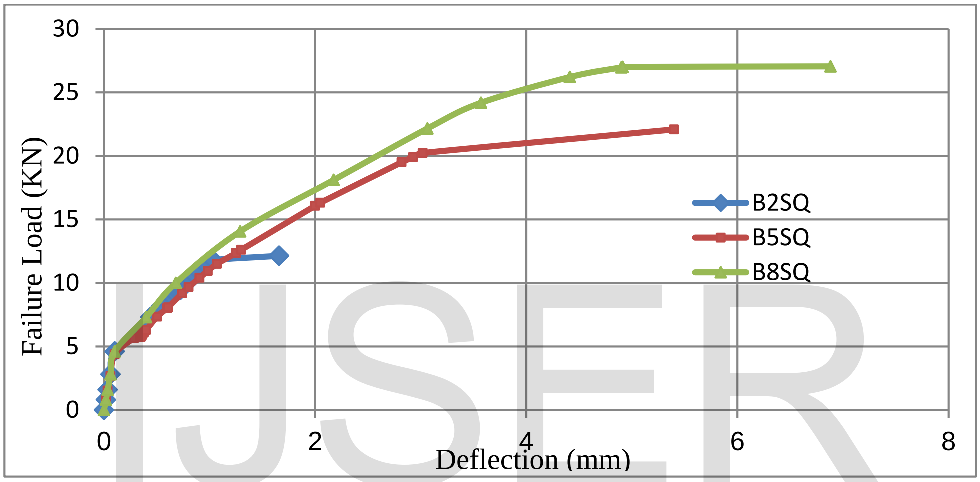


Fig. 14: Failure Load mid- Span Deflection Curve for Beams Reinforced with GFRP Stirrups Spacing = 15 cm

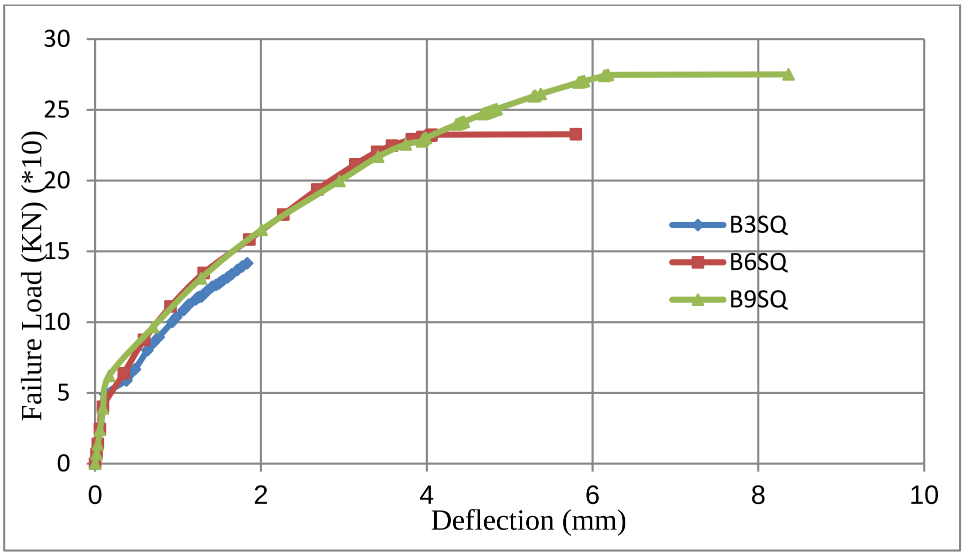


Fig. 15; Failure Load mid- Span Deflection Curve for Beams Reinforced with GFRP Stirrups Spacing = 10 cm

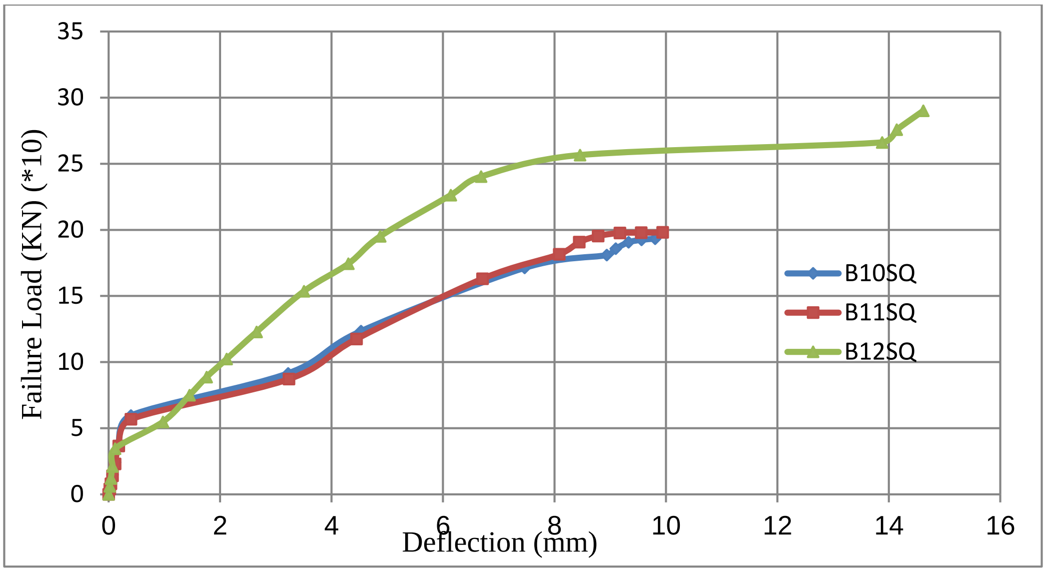


Fig. 16; *Failure Load mid- Span Deflection Curve for Beams Reinforced with GFRP Stirrups and Bent Bar Spacing = 20 cm*

3.2.3.2 Effect of Stirrups Spacing on the Specimens Load Mid – Span Deflection Relationship

Figs. 17 to 19 show the load mid-span deflection curve of the concrete beams reinforced by GFRP stirrups with deferent stirrups spacing 100, 150, 200 mm.

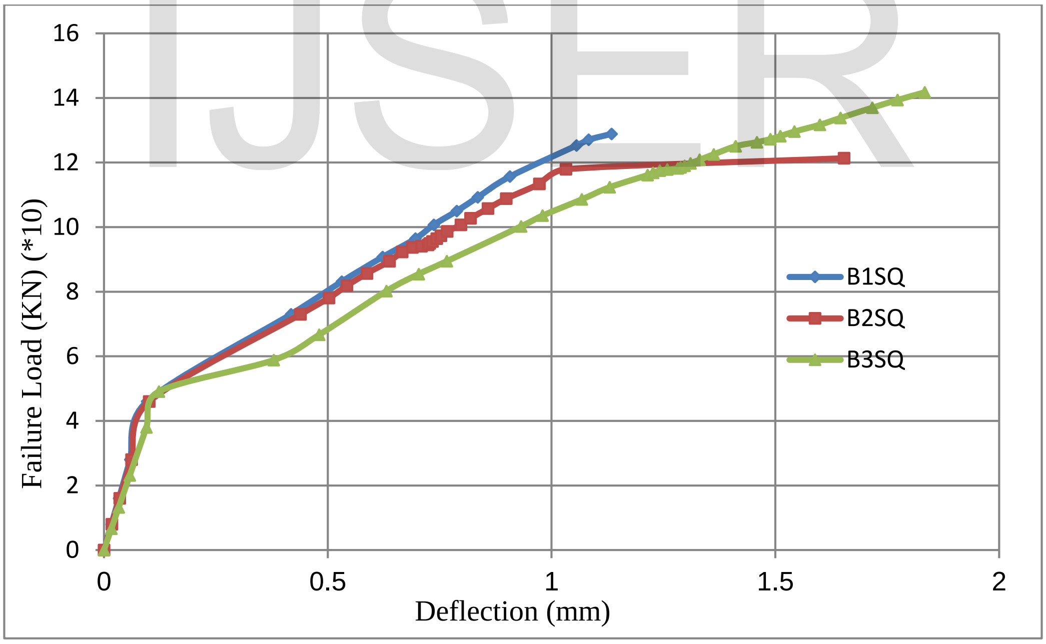


Fig. 17: *Failure Load mid- Span Deflection Curve for Beams Reinforced with GFRP Stirrups of Vf = 48%*

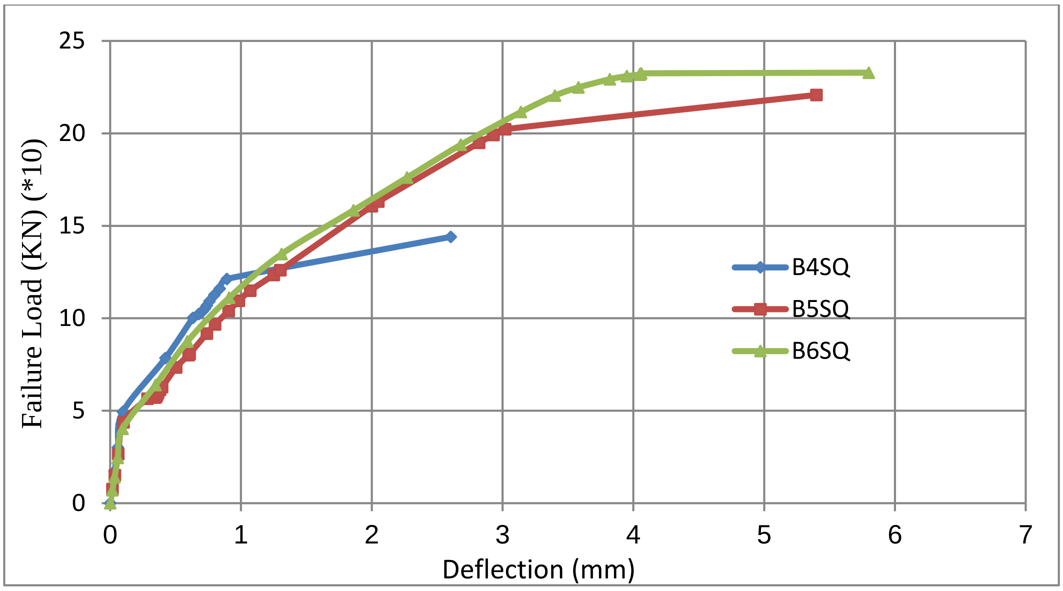


Fig. 18*: Failure Load Mid- Span Deflection Curve for Beams Reinforced with GFRP Stirrups of Vf = 58%*

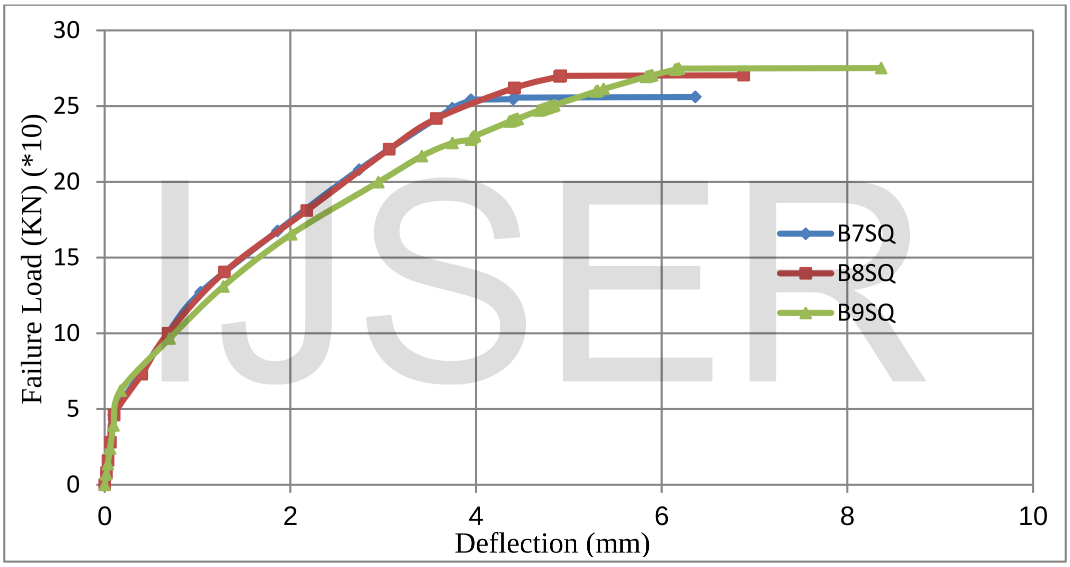


Fig. 19: *Failure Load mid- Span Deflection Curve for Beams Reinforced with GFRP Stirrups of Vf = 68%*

5. CONCLUSIONS

5.1 Regarding Reinforced concrete beams in flexure:

1. The analytical results obtained by using ANSYS program shown a good agreement with the comparative experimental results.

2. Behavior of concrete beams reinforced with GFRP bars was linearly before cracking and then a softer linear part from cracking to failure.

3. Comparing the failure loads of the beams reinforced with the same cross sectional area of steel bars, there was only 25% increase in the failure load of steel reinforced beams. This increase was due to lack of dowel action of GFRP bars and low elastic modulus of GFRP bars in comparison to steel bars.

4. Comparing the cracking loads of the beams reinforced with the same cross sectional area of steel bars, there was only 57% increase in the cracking load of steel reinforced beams. This increase was due to great different stiffness between the GFRP bars and steel bars.

5. Deflections of beams reinforced with GFRP bars are significantly larger than beams reinforced with conventional steel bars. This due to the low elastic modulus of GFRP bars in comparison to steel bars.

6. The change of bar diameter resulting in change the failure load and small difference in deflections. This due to the change in the surface area of reinforcement.

7. The change of development length of GFRP bars had very little effect on failure load and deflections.

8. The GFRP beams with low reinforcement ratio (μ = 0.7%) showed low failure and cracking load in comparison to the beam with very high reinforcement ratio (μ = 3.5%).

5.2 Regarding Reinforced concrete beams in shear:

9. All beams with shear reinforcement failed in shear mode.

10. Increasing the fiber volume fraction of the stirrups increasing the failure load of the beams.

11. Increasing the stirrups spacing for the beams decreasing the failure load and decreasing deflection of the beams at the same fiber volume fraction of the stirrups.

12. Deflections of beams reinforced with GFRP bars are significantly larger than beams reinforced with conventional steel bars. This due to the low elastic modulus of GFRP bars in comparison to steel bars.

13. Comparing the failure loads and cracking load of the beams reinforced with GFRP bars with stirrups only or reinforced with GFRP bars using stirrups and one bent bar as shear reinforcement with the same cross sectional area of steel bars, there was increase in the failure and cracking load of steel reinforced beam .

6. REFERENCES

1- ANSYS, ANSYS User's Manual.

2- Amr Hilal Riad, "Flexural Behavior of Concrete Beams Reinforcement with Local GFRP-Rebars", MSc. Structural Engineering (1999), University of Calgary, Alberta, Canada.

3- Benmokrane; Ehab El-Salakawy; Amr El-Ragaby; Thomas Lackey (1998), "Designing and Testing of Concrete Bridge Deck Reinforced with Glass FRP Bars", Journal of Bridge Engineering, Vol. 11, No. 2 March 1, 2006. ©ASCE, ISSN 1084-0702/2006/2-217–229/$25.00

4- Egyptian code of design and execution specifications for using fiber reinforced polymers in construction field's No. 208 / 2005.

5- Tamer Magdy Tawfik Gobran(2010), "Behaviour of Square GFRP Bars as Shear Reinforcement", M. Sc. Thesis, Faculty of Engineering, Civil Department, Helwan University.