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Shear Strengthening of Reinforced Concrete Deep Beams Using Glass Fiber Sheet

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Abstract:
This study examines the shear strength characteristics of deep reinforced concrete beams without shear reinforcment strengthened with glass fiber sheets. Tests were performed to determine whether an externally bonded RC deep beam with GFRP sheets would fail. The Four-point static loading approach was applied for the experiment. In order to investigate the effects of the factors (glass fiber sheets and shear span to depth ratio (a/h)), six reinforced concrete deep beams were tested. Deep beams were strengthened using GFRP sheets. The GFRP type used was Chopped Strand Mat glass fiber sheet (CSM). The test result indicated that the increase of a/h lead to decrease the ultimate shear capacity, while the ultimate shear capacity increases with strengthening the deep beams with glass fiber sheets polymer. The chopped strand mat (CSM) GFRP increased the shear capacity of the deep beams compared to control beam in group (I, II and III), the increase in strength was (81%, 67% and 62%) respectively, therefore, it is recommended to use (CSM) sheets in deep beam strengthening.
Keywords: *Deep Beams; Shear Capacity; Shear Span; Glass Fiber Sheets; CSM.*

1. Introduction

Reinforced concrete deep beams are structural members with depths that are significantly more than slender beams in relation to their spans, whereas the thickness perpendicular to these dimensions is significantly less [1]. These structural components are used for a variety of purposes, including water tanks, foundations, bunkers, offshore structures, shear walls, girders used in multistory buildings.

Deep beams are members with a length of clear span (Ln) measured face to face of supports (Ln < 4h) that does not exceed four times depth (h), or a region of beams with concentrated loads within a distance (a) of two times full depth (h) measured from the support (a < 2h), which is loaded on one face and supported on the other face, according to the ACI code Provisions for Shear ACI 318M-2019, [2]. Deep beams often have shear rather than flexural strength control because of their proportions. However, compared to what formulas created for slender beams suggest, its shear strength is substantially higher [3].

Because it is a structural component for transferring loads, the deep beam has a deeper depth and is typically utilized to transfer substantial loads from above to supports below. Deep beams are typically employed as transfer girders in high-rise structure construction. In the construction of load bridges, concrete shear walls, bunker walls, and transfer girders for offshore structures and foundations, reinforced concrete deep beams are frequently employed.

The current member's structural capacity is significantly impacted by these requirements. A strengthening substance, like a glass fiber reinforced polymer (GFRP), is used to reinforce the beams externally to deal with such circumstances.

Codes and design guidelines have also been created for FRP sheet applications based on the results of earlier research. The American Concrete Institute's most recent code for the use of FRP materials to improve concrete structures is ACI 440.2R-17,[4]. ACI 440.2R-17 states that several wrapping strategies and fiber orientations can be used to reinforce shear using FRP sheets, as shown in Fig. 1.

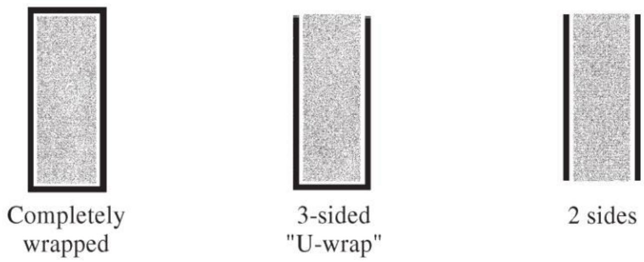


Figure 1: Typical FRP sheet wrapping techniques for shear strengthening

Given all of the aforementioned reasons, this study presents the results of shear strengthening carried out using GFRP sheets, conducted according to the beam models. This research contributes to a) better understanding of the GFRP sheets to strengthen concrete deep beams as a safeguard from sudden failure; and b) providing an information for the definition of future glass fiber sheets, and its role in increasing the shear strength.

1.2 Research Significant

This study investigates the shear span to depth ratios (a/h) and the shear capacity of reinforced concrete deep beams strenghtened with GFRP sheet. More specifically, shear span to depth ratio (a/h) and GFRP sheet strength and ductility of deep beams are examined.

2. Literature Review

The demand for unique, cutting-edge materials is rising as a result of the building industry's rapid expansion were examined. Deep reinforced concrete beams were particularly useful for towering buildings, foundations, and offshore projects. In civil engineering projects, deep beams are widely used for structural purposes. As foundation walls, folded plates, and transfer girders, they are generally used as load-transfer elements. Deep beams are those with a span-to-depth ratio of less than 2.0 and less than 2.5, respectively, for simply supported beams and continuous beams. The use of fiber-reinforced plastic wraps and sheets to strengthen and repair RC members is currently the subject of extensive research. Applying FRP to a structure that has been structurally weakened over time can reinforce and repair it extremely successfully. The flexural and shear behavior of continuous GFRP sheets-enhanced RC deep beams is being studied experimentally. On RC deep beams with externally and epoxy-bonded GFRP sheets, failure testing was done. The test was run using two static loading points. they constructed two sets of beams and subjected them to stringent testing. The three beams that were strengthened in flexure and cast in SET I consisted of one controlled beam and two beams that were strengthened using continuous glass fiber reinforced polymer (GFRP) sheets. For SET II, three shear-strengthened beams were cast, one of which was controlled. Continuous GFRP sheets were used to strengthen the shear of the other two beams, [5].

Using a four-point bending loading system and varying the shear span-to-depth ratio (a/d) and clear span-to-depth ratio (l/d), tested 12 steel-RC deep beams. According to the report, specimens with a/d = 0.3 showed evidence of web compression mode of failure, while specimens with a/d = 0.65 and a/d = 1.0 showed evidence of flexural failure by crushing concrete between the two loading points as a result of an increase in compressive stresses in the horizontal strut. Additionally, it was determined that, in contrast to the l/d, which had a negligible impact on the ultimate capacity, decreasing a/d significantly increased the ultimate capacity as a result of the shift in the mechanism of failure. In other words, for examples with the same a/d, the extent of the arch action reduced with increasing l/d, [6].

The examination of how GFRP sheeting could be used to reinforce RC beams in shear. The experimental study's goal was to determine how well her GFRP composites reinforced concrete beams that were only partially supported and did not have adequate shear resistance. Successive layers of fiberglass cloth were placed closely together along the shear span to improve shear strength and stop catastrophic premature failure mechanisms. Using the results of a control beam with closed stirrups as web reinforcement, a reinforced beam without web reinforcement was constructed to evaluate the efficacy of the recommended reinforcement method. Regarding the effects of various shear reinforcement systems and varying longitudinal reinforcement ratios on structural behavior, the test results for 18 separate beams were analyzed. The findings demonstrated that beams with insufficient shear capacity can significantly improve their overall structural behavior and shear strength with the proper application of GFRP wraps. Under the pressure of its own weight, the layer is known to slightly expand [7].

The study examines beams covered with GFRP (glass fiber reinforced polymer) panels. He created and tested eight rectangular beams measuring (150 x 150) mm in section and 700 mm in span. Two important factors including strength, ductility, degree of damage. examined a beam that showed a slight bend. In the first set of four, under the R.C.C. reinforcement bar, his remaining two bars served as controls. Two of these beams that were reinforced with a single layer of GFRP plates and submitted through destructive static load testing were from stress planes parallel to the axis of the beam. Two of the four weak beams in the second set were reinforced with GFRP plates and tested to failure. His other two speicmens acted as controls. they compared the two sets of results [8].

RC beams reinforced with externally bonded carbon fiber reinforced polymer (CFRP) skins were experimentally tested for shear performance and failure reasons. There were 27 full-size RC carriers tested as part of the test program. The edge anchor (U-Wrap with and without anchor), a/d ratio of 3 to 4, shear span to depth ratio, amount and distribution of CFRP, bonded surface area (side vs. U-wrap), fiber orientation (90°/0° fiber combination vs. 90° direction), and amount and distribution of CFRP are among the variables examined in this research study. A research program looked into how effectively CFRP reinforcement increased the shear capacity of his RC beams in negative and positive moment zones, as well as beams with rectangular and T sections. The shear strength was greatly and dependently increased by the CFRP that was externally attached, according to experimental data. According to the findings, the shear strength of all beams improved by 22-145%. [9].

The study of 19 simply supporting selnder beams with two-point loading. The cross-section of each beam was either 9 inches or 7 inches, and the length was always 24 inches. This study investigates the behavior of deep beams with respect to many factors, including the length-to-depth ratio, web reinforcement ratio, concrete strength, longitudinal reinforcement ratio, and the manner of web reinforcement (vertical or inclined stirrups). Adding more longitudinal steel bars mentioned the beam's ultimate stress, which moved the failure mechanism from flexural failure to shear failure, according to experimental results. The higher concrete strength had no effect on the ultimate strength of the non-bendable beams. Additionally, the development of vertical cracks and the ultimate strength of the beams were not significantly affected by web reinforcing [10].

In this study, shear span-to-depth ratios (a/d) and various GFRP sheet types have been used to strengthening deep reinforced concrete beams in order to better withstand shear loads.the strength and ductility of deep beams are investigated for three distinct GFRP sheet types and shear span to depth ratios (a/d), with respect to load-deflection behavior and fracture patterns. To choose the strengthening technique that, in light of earlier studies, is the most successful among all the strengthening techniques. Because there is low researches on the strengthening of deep beams using GFRP, the current study provided to prove the ability of GFRP in enhancing the capacity of deep beam. For this reason the type of chopped strand mat GFRP used. As this type of strengthening is the lowest cost than other FRP.

3. Methodology

The following methodology was developed to achieve the objectives listed below:

1. Examine the available literature and the American Concrete Institute's (318-19) guidelines for developing deep beams.
2. Using a concrete mix design made of C39/C39M-14 grade to build the deep beams.
3. A total of twelve beams, with three cubes per beam, were cast.
4. Unstrengthened and strengthened beams are tested under two-point loading after 74 days and 28 days of curing, as well as the cubes after 28 days, to determine the compressive strength of concrete.

3.1 Specimen Details and Materials

Six deep beams constructed from reinforced concrete were tested with Four-point static loading. Each beam had a 1900 mm long overall length and a 150 x 350 mm overall cross-section. Simply supported throughout a span of 1200 mm, all test specimens. The main steel reinforcement ratio (ρ_w) was 0.0174, while all beams were tested without shear reinforcement only 4 stirrups provided at each end to hold the top reinforcement and to assist in development length. The beams tested were divided into three groups. Table 1 and Figure.2 shows the details and properties of tested specimens, all test specimens were designed to fail in shear. The two beams in group I (control beam (CB1), beam strengthened with chopped strand mat glass fiber (SB1M). The two beams in group I were tested with span to depth ratio a/h=1. The two beams in group II (CB2 and SB2M) were tested with shear span to depth ratio a/h=1.285. The two beams in group III (CB3 and SB3M) were tested with span to depth ratio a/h=1.428. The length of glass fiber sheet used to strengthen the beams were selected to cover the shear span area in each strengthen specimen.

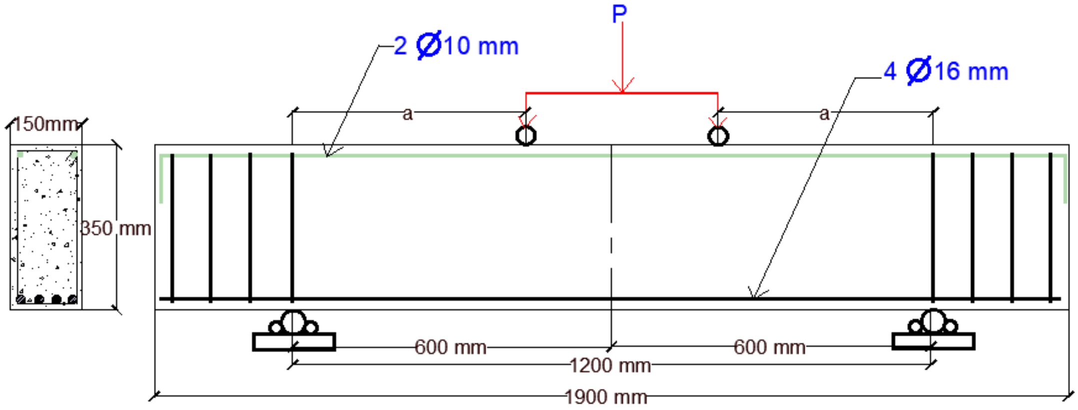


Figure 2: Details of Tested Specimens

The properties of the used materials GFRP and steel are represented in Table 1. The average cylindrical compressive strength of 30MPa was used.

Figure 3: Surface texture of the used GFRP sheets (CSM)

Table 1: The mechanical properties of GFRP sheets, and steel bars

Material	Density (kg/m3)	Thickness (mm)	Yield Tensile Strength (MPa)	Elongation %	Modulus of Elasticity (GPa)
CSM	2540	0.8	126	1.8	6.7
STEEL	7850	16mm (diameter)	530	16.44	200

The longitudinal rebar is comprised of four 16 mm diameter rebars at the bottom and two 10 mm diameter rebars at the top of the beam. Testing was performed according to ASTM A615/A615M-22. Table 1 shows the properties and results of the steel bars [12]. A glass fiber GFRP type (Chopped strand mat glass fiber polymer) and an epoxy-based impregnated resin type (Sikadur -330) were applied to the reinforced concrete deep beams outside the shear span.

3.2 Casting

The concrete required for casting was prepared using a ready mixer of 1.2 m3. In response to a request from 4Bridges Company for one batch of ready-mix concrete, the RC beams were cast following the necessary specifications and qualities. The concrete compressive strength was evaluated using the ASTM C39/C39M-14 standard test for the cylindrical compressive strength of specimens [11]. A concrete cylinder test 28 days after casting revealed an average concrete compressive strength of 31.72 MPa.

Figure 4: Steel reinforcement case of the beam specimens

3.3 Fabrication of GFRP

After 28 days of casting, the GFRP sheets were glued to the specimens. Before applying the epoxy resin, the concrete surface was cleaned and smoothed to provide strong adhesion between the epoxy glue and the concrete surface (Sikadur - 330). Manual mixing and application of the epoxy resulted in a thickness of around 1 mm. Even though it was considered that the epoxy coating was complete, additional epoxy had to be put out along the sheet's borders where the bond was precisely controlled.

Figure 5: The installation process of GFRP sheets

3.4 Testing

Two symmetrical point loads were applied to the specimens during testing (using a universal testing machine, type OZKAN PRES, with a maximum capacity of 2500 kN, in Turkey). Loads and responses were applied by bearing rollers to allow the end supports to freely rotate and move horizontally. A dial gauge with a maximum travel of 30mm and accuracy of 0.01mm was used to measure deflections at the span's center.

To have a constant amount of each beam's performance, an incremental stage loading was used. At each load step, the deflection was recorded, and cracks and their extensions were looked for. After recording the cracking load, the loading was continued until failure.

To investigate the effects of the GFRP (CSM) and the shear span to depth ratio on the ultimate shear capacity and behavior of such beams, test results of six concrete deep beams and their crack patterns are presented.

Figure 6: Loading frame

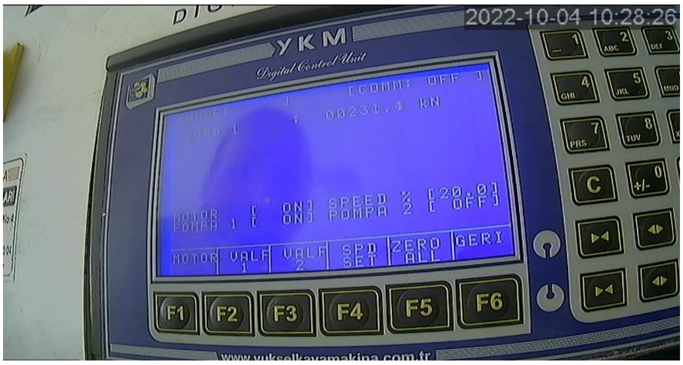


Figure 7: Digital control unit for testing deep beams

4. Analysis Method

4.1 Shear Capacity

4.1.1 ACI Code Provision for Shear

The nominal shear strength (V_n) of a RC beam can be determined by adding the nominal shear strength of the concrete (V_c) and the shear strength of steel reinforcement (V_s). This is presented in ACI 318M-19 as follows [14]:

(1) $$Vn = Vc + Vs \;;\; Vs=0$$

The ACI 318M-19 permits the use of the following equation for computing the nominal shear strength obtained by concrete and tension reinforcement bars for each of the specimens:

(2) $$Vc = [0.66\lambda\ \lambda s\ (\rho w)1/3 \sqrt{\mathbf{f'c}} + \frac{\mathbf{Nu}}{\mathbf{6Ag}}]\ bwd$$

(3) $$\lambda s= \sqrt{\frac{\mathbf{2}}{\mathbf{1+0.004}\boldsymbol{d}}} \leq 1$$

Where λs is the factor for considering the component height; λ is the standard light weight concrete factor; ρ_w is the tension longitudinal bar ratio; $f'c$ is the cylindrical concrete compressive strength; Ag is the area of cross section; N_u is the design axial force; b_w is the beam width and d is the beam effective depth.

4.1.2 Capacity of a GFRP Strengthened Section in Shear

The capacity of strengthened beam in shear by externally bonded FRP strips, may be computed by simply adding the third term to take into consideration the contribution from FRP composites to shear capacity (Vf) an adopted from ACI 440.2R-17 [2]:

(4) $$\Phi Vn = \Phi\ (Vc + Vs + \Psi_f\ V_f)$$

(5) $$V_f = A_{fv}\ f_{fe}\ (\sin\alpha + \cos\alpha\ )\ d_{fv} s_f$$

(6) $$A_{fv} = 2\ n\ t_f\ w_f$$

(7) $$f_{fe} = \epsilon_{fe}\ E_f$$

For two –side strips:

(8) $$\epsilon_{fe} = kv\ \epsilon_{fu} \leq 0.004$$

(9) $$kv = (k_1\ k_2\ Le)/(11900\ \epsilon_{fu}) \leq 0.75$$

(10) $$k_1=(f'c27)2/3$$

(11) $$k_2 = d_{fv}–2\ Le\ d_{fv}$$

(12) $$Le=23300(\text{n}\ t_f\ E_f)0.58$$

Where Φ is the shear strength reduction factor; Ψ_f is a reduction factor, a value of 0.85 for two-opposite side schemes; A_{fv} is the FRP shear reinforcement area; s_f is the spacing of FRP strips center-to-center; f_{fe} is FRP effective stress; d_{fv} is the effective depth of FRPs; α is the orientation of FRP reinforcement application; n is the number of plies in the FRP strips; t_f is the FRP strip thickness ; w_f is the width of FRP strip; ϵ_{fe} is the effective strain level in FRPs achieved at failure; E_f is the tensile modulus of elasticity of FRP; kv is the coefficient bond-reduction; k_1 & k_2 are the modification factors and Le is the active bond length.

Table 2: Deep beam details and capacities

Specimen		A shear span (mm)	a/h	Shear strengthening (GFRP)				ACI 318-19	ACI 440.2R-17		Exp. Shear Strength Vu (kN)	First cracking load (kN)	Failure mode
				t_f (mm)	w_f (mm)	A_{fv} (mm2)	d_{fv} (mm)	Vc (kN)	V_f (kN)	ϕ Vn (kN)			
Group I	CB1	350	1	-	-	-	-	43.13	-	32.34	147.5	70	DTF
	SB1M	350	1	0.8	350	560	350		12.39	41.64	209.5	210	DTF
Group II	CB2	450	1.285	-	-	-	-		-	32.34	130	120	DTF
	SB2M	450	1.285	0.8	450	720	450		15.39	44.29	170	113	DTF
Group III	CB3	500	1.428	-	-	-	-		-	32.34	55	92	DTF
	SB3M	500	1.428	0.8	500	800	500		17.70	45.62	142.5	81	DTF

DTF= Diagonal tension failure

5. Results and Discussion

For each of the tested beams, the load vs. mid-span deflection curves are shown in Figures 8 through 12. As expected, the formation of diagonal shear cracks in the shear span zone causes the sudden collapse of all control beams. Equation (3) predicts that the GFRP sheets' shear strength contribution will be.

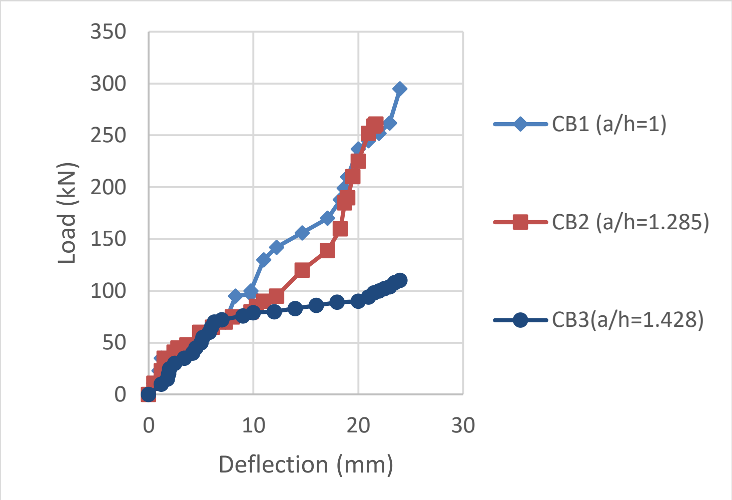


Figure 8: Load- Deflection curve for control beams

Figure 8 shows the effect of shear span to depth ratio (a/h) on the shear strength,. The control beam (CB1) failed at load 300 kN with maximum deflection 24 mm, and control beams (CB2 and CB3) failed at load (260 and 110) kN and maximum deflection (21.7 and 23.6) mm respectively.

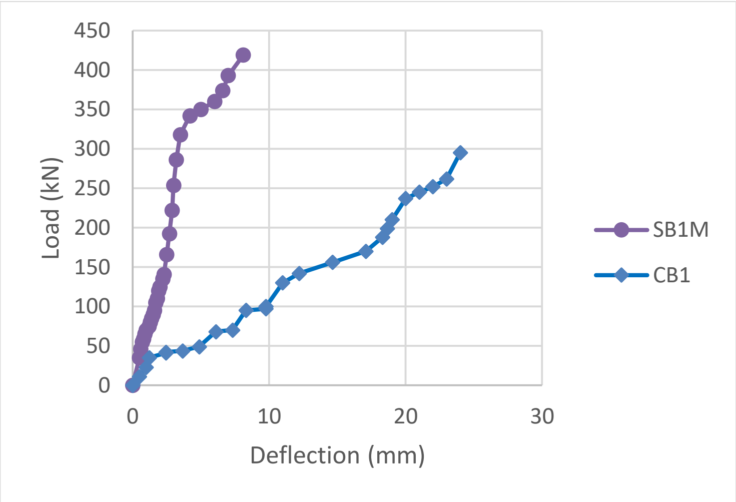


Figure 9: Load- Deflection curve for group I

Figure 9 shows the effect of using GFRP, the use of GFRP increased the ultimate loads for tested beams. The deep beam strengthened with (SB1M) failed at load 419 kN with maximum deflection 8.1 mm. compared to the beam CB1 which failed at load 300 kN with maximum deflection 24 mm.

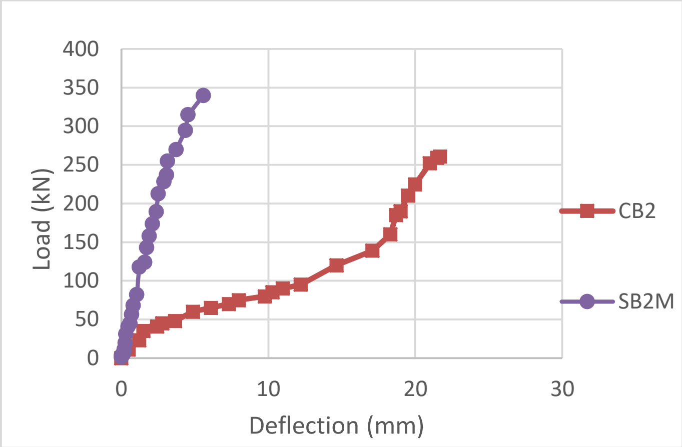


Figure 10: Load- Deflection curve for group II

Figure 10 shows the deep beam strengthened with (SB2M) failed at 340 kN with maximum deflection 6.3 mm. compared to the beam CB2 which failed at load of 260 kN with maximum deflection 21.7 mm.

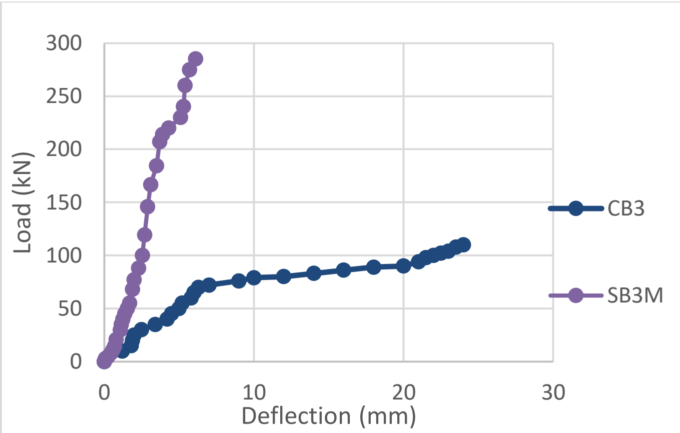


Figure 11: Load- Deflection curve for group I

Figure 11 shows the deep beam strengthens with (SB3M) failed with 285 kN with maximum deflection 6.1 mm. compared to the beam CB3 which failed at load of 110 kN with maximum deflection 23.6 mm.

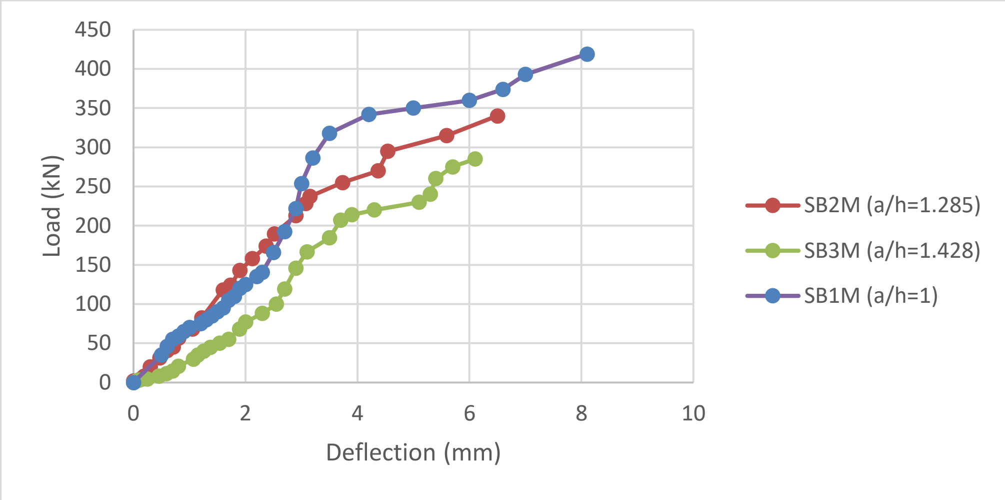


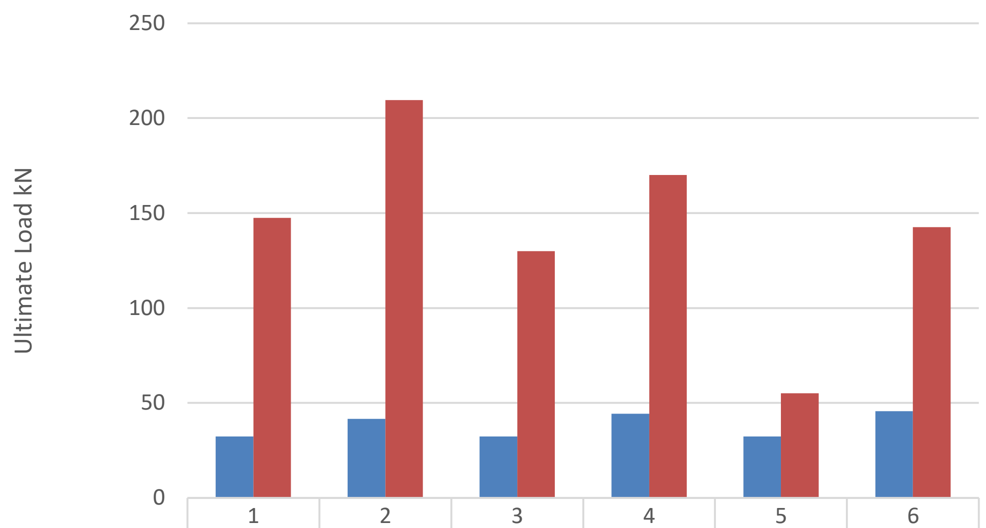
Figure 12: Load- Deflection curve for group I

Figure 12 shows the effect of using (CSM) GFRP with different span to depth ratio. The use of GFRP increased the ultimate loads for tested beams. The deep beam strengthened with (SB1M) failed at 419 kN with maximum deflection 8.1 mm, which is higher than (SB2M and SB3M), where failed at (340kN and 285kN) and maximum deflection (6.3mm and 6.1 mm) respectively.

Table 3: Comparison between experimental and theoretical results

Specimen		a shear span (mm)	a/d	Experimental Result (kN)	ACI 440.2R-17 ϕ Vn (kN)
Group I	CB1	350	1	147.5	32.34
	SB1M	350	1	209.5	41.64
Group II	CB2	450	1.285	130	32.34
	SB2M	450	1.285	170	44.29
Group III	CB3	500	1.428	55	32.34
	SB3M	500	1.428	142.5	45.62

As presented in table 3 that the use of CSM sheets to strengthing the deep beam specimens the amount of increase in group I was 81%, group II 67% and in group III 62% in the cpapcity of the strenghted beam.



	1	2	3	4	5	6
Theotical	32.34	41.64	32.34	44.29	32.34	45.62
Experimental	147.5	209.5	130	170	55	142.5

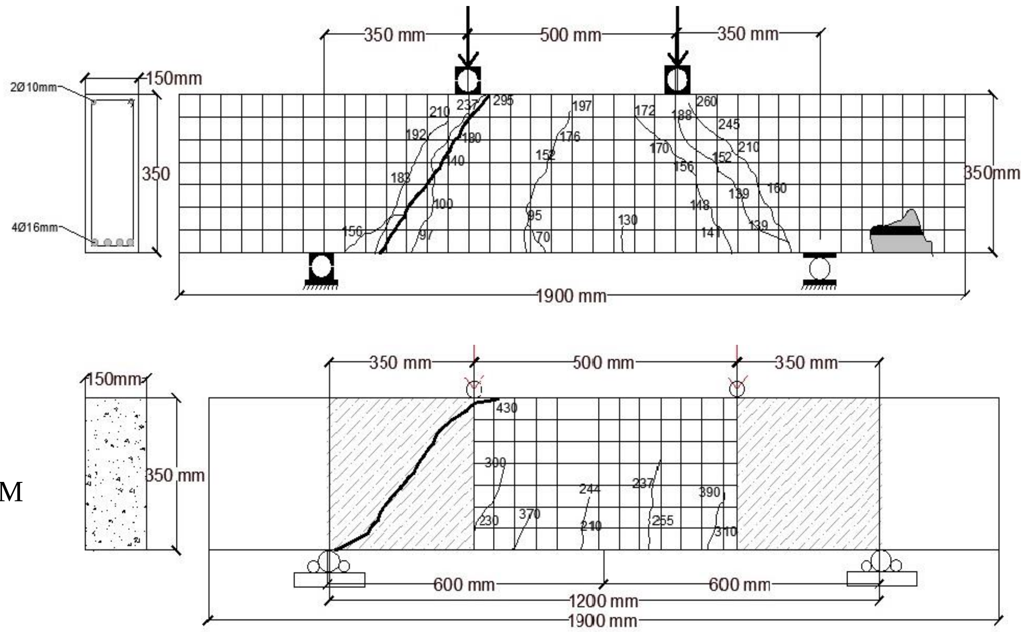
Figure 13: Theoritical and Experimental result of ultimate load

5.1 Crack Patterns

Fig. 13 displays the crack patterns of the tested RC deep beams. Typically, the first flexural fracture always occurred at the region of constant moment close to the mid-span. The control beam shear failure was caused by diagonal shear cracks in the shear span zone. In the meantime, the placement of GFRP sheets in the shear span zone has a major impact on the patterns of cracking, causing cracks to appear at the zone of maximum moment. For the tested beams, diagonal shear failure was the mode of shear failure. In the shear span zone at the loading support. But as Figure illustrates, the GFRP sheets application resulted in beams with more cracks.

(a) CB1

(b) SB1M



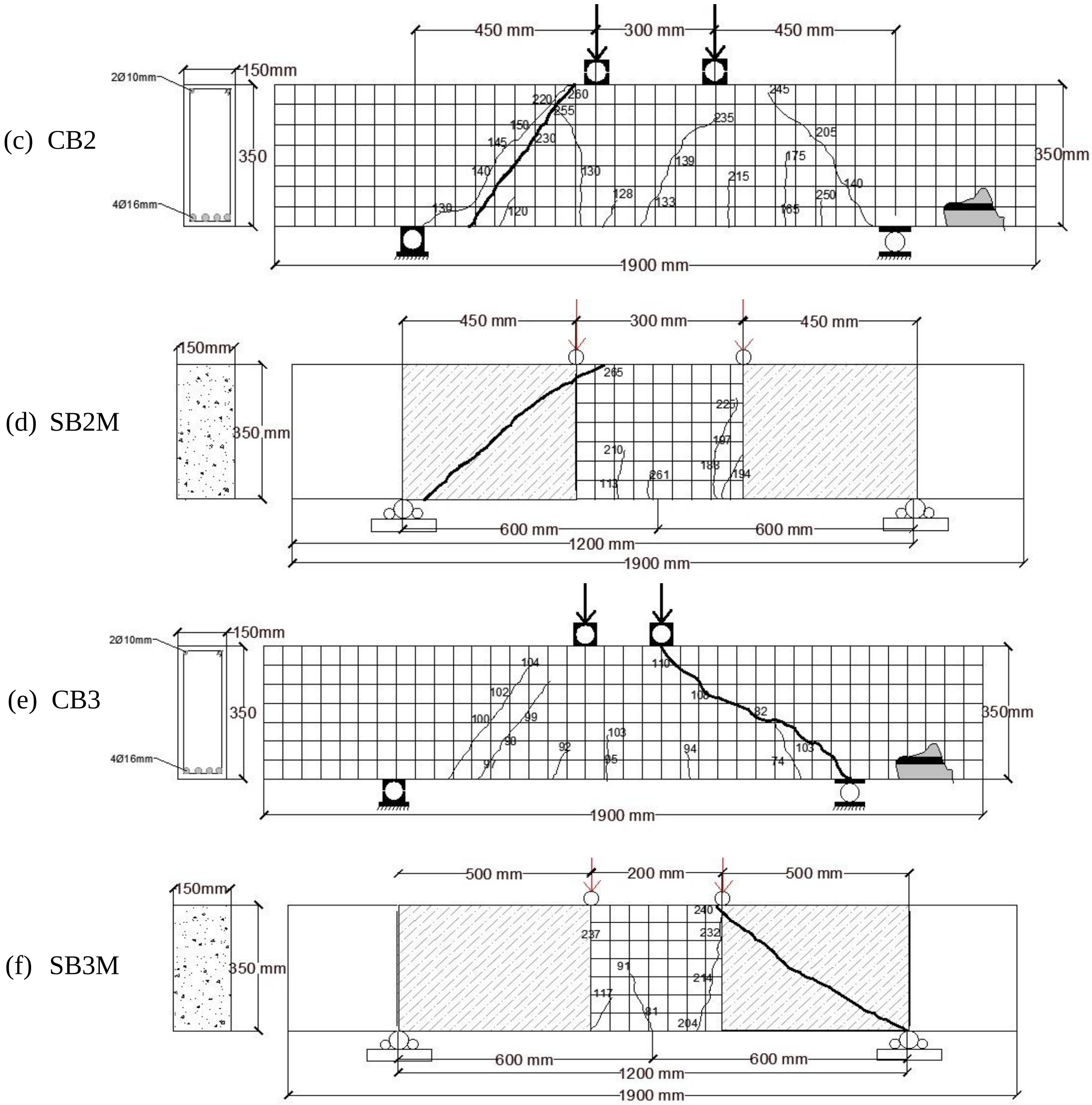


Figure 14: RC deep beam failure modes and cracking patterns

6. Conclusion

From the results, the following conclusion are drawn:

1. In all groups of beams, the mode of failure was diagonal tension.
2. The strengthened beams show behavior and capacity better than the unstrengthen beam. When compared to the control beam in group I, the shear capacity of the deep beams enhanced by (CSM) rose by 81%.
3. As the shear span increase the shear strength of the deep beams strengthened by (CSM) compared to control beam in group (I, II and III) increased by (81%, 67% and 62%) Respectively.
4. The chopped strand mat (CSM) GFRP exhibit good behavior in strengthening deep beams. Therefore, it is recommended to use chopped strand mat (CSM) in deep beam strengthening.

5. In general, strengthening deep beams resulted in first cracking of flexure type at midspan, and lead to more cracks in the beam.

7. Conflict of Interest

I hereby certify that the paper Shear Strengthening of Reinforced Concrete Deep Beams Using Glass Fiber Sheet is my original work, and I further declare that, except where appropriate citation is made in the text, all work presented in this paper is original to me and was not previously submitted for consideration for any other degree at any institution.

8. Acknowledgemnt

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