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EVALUATION OF REINFORCED CONCRETE BEAMS STRENGTHENED EXTERNALLY BY A TWO-LAYER OF CARBON FIBER REINFORCED POLYMER

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Abstract

This paper investigates reinforced concrete (RC) beams strengthened externally with a two-layer carbon fiber reinforced polymer (CFRP). The CFRP fabric strips were cut to the required size and were bonded to the RC beam by Sikadur(R)-31 epoxy resin. After the epoxy glue Sikadur(R)-31 was mixed, it was scraped into the concrete surface to the desired thickness. Four (4) out of nine (9) beam samples were strengthened with two-layer of 200 g/m^2 and another set of four beams was strengthened with two-layer of 300 g/m^2 CFRP fabric of 100 mm width and 1100 mm length with a 2, 4, 6, and 8 mm bond thicknesses on the first layer and another 2 mm bond thickness on the second layer applied at the tension face as a model of the prototype. The remaining beam was not strengthened and was taken as a control beam. Before loading, the structural epoxy resin was cured for at least seven days at room temperature. The beams were tested on a 20-ton (196.3 kN) loading frame to examine the load-carrying capacity and load-deformation response. One-third point load application was used. The study showed the possibility of using two-layer epoxy-bonded CFRP fabrics to enhance the load resistance in the flexure and shear of RC beams. However, doubling the CFRP layer does not result in further increments in load resistance. Carbon fiber-reinforced polymer is useful in upgrading existing RC beams externally. However, it reduces the capacity of the beam to resist deformation under external load. The serviceability of the reinforced concrete beam member is usually evaluated through deformation and crack width. The deformation of an RC member strengthened with two-layer epoxy-bonded CFRP fabric was observed to be higher at failure relative to a concrete beam without epoxy-bonded CFRP fabric. The two-layer bonded CFRP fabric increased the bending strength by up to 55% as long as the suitable strengthening configurations and the appropriate bond thickness were used.

Keywords: CFRP, Two-layer, flexure, load, deflection, ductility, concrete, beam

1. INTRODUCTION

The increasing number of dilapidated structures in the nation has become a subject of concern to the construction industry. The dilapidation is mostly the outcome of insufficient internal reinforcement, internal reinforcement corrosion, poor quality control during construction, or a change in design purpose [1, 2]. Furthermore, modifications in design guides may cause a good number of existing buildings to defy present requirements [3, 4]. In such cases, there are primarily two options: demolish and reconstruct or strengthen. The decision between these two options is based on a number of crucial factors, such as manpower and cost implications, and interruption of electrical facilities [5]. Based on the financial implications, upgrading deficient infrastructures to withstand more effects in current design documents, strengthening is regarded as a more desirable alternative to demolishing and rebuilding. The word 'upgrading', which entails structural members' strengthening after construction, secures three procedures, that is; repairing, strengthening, and retrofitting [6, 7].

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Various practices have been established to rehabilitate a variety of structurally deficient members. Among them are: the near-surface mounted (NSM) system; introducing additional columns; adding more internal steel; consequently, eliminating and casting concrete; and epoxy bonded system.

Structural rehabilitation may be required when the elements are unable to resist the anticipated load. There are two (2) main procedures that have been described in papers for rehabilitation, such as near-surface mounting and externally bonded steel or CFRP Sheet [8]. An externally bonded technique comprises bonding steel or CFRP to the tensile surface of the structural element using epoxy with suitable properties. It is observed that most of the early research [9, 10, 11], adopted an externally bonded approach for steel plate retrofitting of concrete structural members because of the straightforwardness of its application. With the near-surface mounted technique, the CFRP or steel plate is usually installed in an already grooved channel to the required surface through the use of suitable epoxy glue. In recent investigations, this approach has been used to solve some of the failure mechanisms in externally bonded techniques [12]. The technique offers a better look at the member being rehabilitated as the CFRP or steel plate could be glued to entirely, even with the face of the member. Another advantage is that the plate can be grouted to shield it against environmental attacks [13]. On the other hand, the usefulness of this approach relies on the availability of acceptable cover for the internal reinforcement; otherwise, creating a groove of the required depth may be difficult. The near-surface mounting process is an efficient cement or adhesive grout coating method. It improves the load-resisting strength and member stiffness of the rehabilitated member in bending [14, 15].

CFRP or steel plate is commonly used in strengthening the shear and flexure of structural concrete members. This is normally accomplished by bonding CFRP or steel plate to the RC surface using structural glue. Epoxy glues or adhesives give the capability to bond with various substrates and their variations to accomplish the needed properties. The epoxy resin comprises epoxide rings containing a 3-element ring each, with 2-carbon atoms independently glued to an atom of oxygen [16]. The other part is the curing agent, called the hardener, which when combined with the resin yields a cross-linked polymer [17].

As infrastructures in a nation approach their limited state, one main problem to face in the construction industry is the increase in structural failure, which results in the collapse of civil engineering structures [18, 19]. The necessity for increased maintenance is unavoidable. Since demolishing and rebuilding is liable to turn out to be a rising economic burden, it is undoubtedly a waste of public funds if demolishing and rebuilding is a feasible substitute. Buildings may collapse due to failure to adapt to new uses, aging, changes in design purpose, or poor construction methods. Strengthening with an externally bonded steel plate or CFRP technique can be an effective means to restore and/or improve the strength and serviceability of a structural member. An externally bonded CFRP technique in these instances is the only alternative to demolition and rebuilding. According to John *et al* [20] and Amadise *et al* [21], the use of CFRP for strengthening applications had a positive effect on the structural element, which can improve its bending and shear strengths. This paper intends to evaluate RC beams strengthened externally by a two-layer of carbon fiber-reinforced polymer fabric glued to the bottom face.

2. MATERIALS AND METHOD

2.1 MATERIALS

2.1.1 Carbon Fiber Reinforced Polymer (CFRP)

Unidirectional CFRP fabrics from Shanghai Horse Construction Technology Co., Ltd., were used in this investigation. There were two types of CFRP. One was 200 g/m^2, and the other was 300 g/m^2. The CFRP fabric properties are given in Table 1. The structural epoxy resin (Sikadur$^{(R)}$-31), a two-part epoxy adhesive and strengthened mortar, was used for bonding the CFP fabrics to the RC beam. The properties are also given in Table 1. The function of the adhesive is to bond the CFRP and RC beam together, ensuring that full composite behavior is achieved by the transfer of stress through the adhesive layer. Adhesive thicknesses of 2 mm, 4 mm, 6 mm, and 8.0 mm were used

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Table 1: Properties of CFRP fabrics and epoxy adhesive

Material	Thickness (mm)	Tensile Strength (MPa)	Tensile Modulus of Elasticity (MPa)	Elongation at Break (%)	Bending Strength (MPa)
200g/m^2	0.111	3964	2.3 x 10^5	1.74	744
300g/m^2	0.167	3964	2.3 x 10^5	1.74	744
Epoxy resin	-	15 – 20	3300	4.3	30 – 40

2.2 Method

All the beams were designed as prototypes and modeled with a 2.5 scale ratio according to ACI [22]. A model is a demonstration of an actual size that may be studied to predict the behavior of the actual size in some required detail. A model scale of 1:2.5 means that all prototype geometric values must be 2.5 times those of the model. Based on the 2.5 scale ratio, beams were reinforced internally with 2Φ10 mm bars used as the flexural reinforcement. 2Φ8 mm was used as hanger rebar. The internal shear rebar for the beam samples was R6 and spaced at 220 mm.

2.2.1 Production of Beam Sample

Nine (9) model RC beams with a length of 1100 mm and a cross-sectional of 100 x 150 mm were produced at Niger Delta University's concrete laboratory. One batch of 1:2:4 was used to produce the beam samples. Beams were cured by water bath for a minimum of 28 days prior to the investigation. The choice of beam dimensions was based on the shear span-effective depth ratio of 2.5. The sides of the RC beams to be bonded were scarified till the coating of cement paste was removed prior to strengthening. The surface of the RC beams was cleaned with compressed air to eliminate any loose particles.

2.2.2 Bonding of CFRP Fabrics Strips

The CFRP fabric strips were cut to size and then properly cleaned. The CFRP strips were glued to the RC beam with Sikadur(R)-31 epoxy glue. After the epoxy glue Sikadur(R)-31 was mixed, it was scraped into the concrete surface to the desired thickness. Four (4) out of nine (9) beam samples were strengthened with two-layer of 200 g/m^2 and another four beams were strengthened with two-layer of 300 g/m^2 CFRP fabric of 100 mm width and 1100 mm length with a 2, 4, 6, and 8 mm bond thicknesses on the first layer and another 2 mm bond thickness on the second layer applied at the tension face as a model of the prototype. The remaining beam was not strengthened and used taken as a reference. The structural epoxy resin was cured for at least seven days at room temperature before testing. The descriptions of the sample in Table 2 are as follows: F-flexural strengthening, 0, 2, 4, 6, and 8-adhesive layer thicknesses, A, B, and D-sample groups.

Table 2: Beam configuration

Sample Type	Beam Section		CFRP Fabric g/m^2	First adhesive layer thickness (mm)	Second adhesive layer thickness (mm)
	b (mm)	h (mm)			
FA-0	100	150	-	-	-
FB-2/2	100	150	200	2	2
FB-4/2	100	150	200	4	2
FB-6/2	100	150	200	6	2
FB-8/2	100	150	200	8	2
FD-2/2	100	150	300	2	2
FD-4/2	100	150	300	4	2
FD-6/2	100	150	300	6	2
FD-8/2	100	150	300	8	2

2.2.5 Instrumentation and Test Procedure

The beams were tested on a 20-ton (196.3 kN) loading frame to examine the load-carrying capacity and load-deformation response as presented in Figure 4. One-third point load application was used. A dial gauge was attached to the bottom side of the beam specimens, and two steel rollers were employed as supports beneath both ends of the test specimen. The load was applied with a hydraulic jack, and it was measured with a load cell.

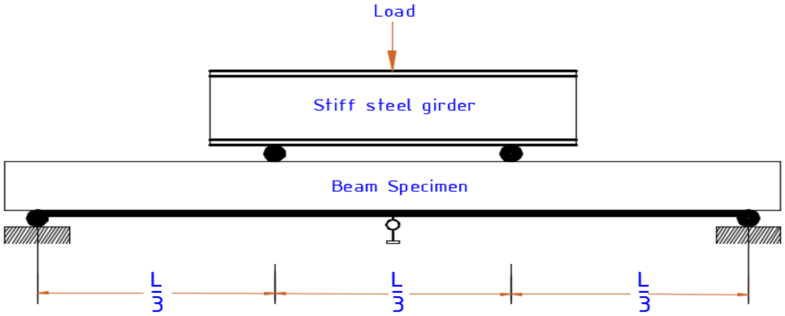


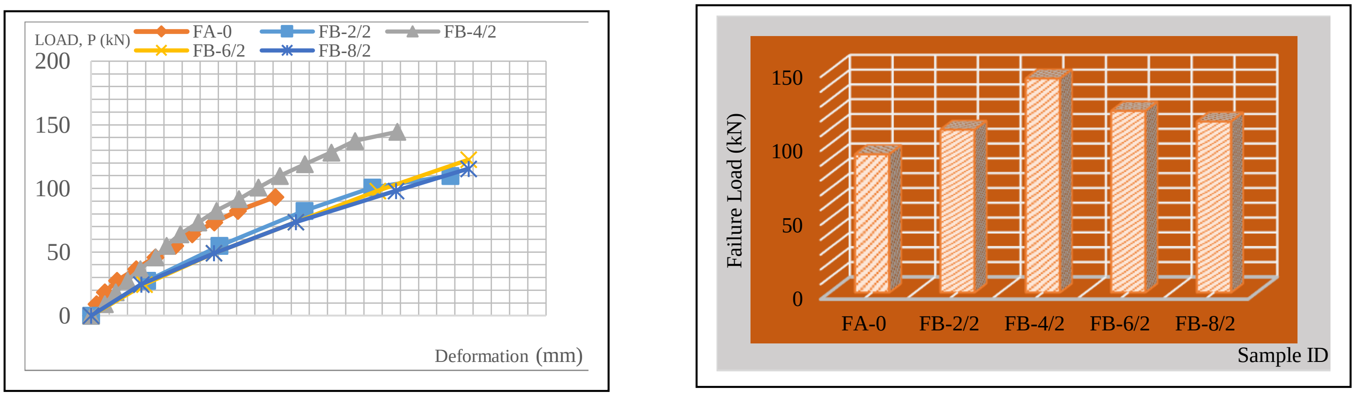
Figure 1: Schematic of Test Setup

3. RESULTS AND DISCUSSION

Results, as presented and discussed, are those of prototype beam FB-2/2, FB-4/2, FB-6/2, FB-8/2, FD-2/2, FD-4/2, FD-6/2, and FD-8/2. Results are presented in Figures 2, 3, and Table 3 and were studied to examine the actual behavior of the RC beams strengthened with a two-layer of CFRP. Each beam type under this group was examined and compared with the reference beam. This strengthening configuration was trying to simulate the conventional two-layer longitudinal reinforcement in beams. The load-deformation and failure load against sample type are shown in Figures 2 (a) and (b), respectively.

Table 3: Test Results for Beam Samples

Sample Type	Yield Load (kN)	Deformation at Yield load (mm)	Failure Load (kN)	Deformation at Failure load(mm)	Mode of Failure
FA-0	71.85	9.625	93.325	10.13	Flexure
FB-2/2	100.08	15.05	109.90	19.75	Shear
FB-4/2	119.08	10.38	144.55	16.83	Shear
FB-6/2	98.10	15.75	122.63	20.75	Shear
FB-8/2	70.65	15.75	115.45	18.75	Shear
FD-2/2	71.13	6.85	110.38	17.20	Shear
FD-4/2	79.45	16.15	130.00	21.98	Shear
FD-6/2	73.75	17.3	122.63	20.75	Shear
FD-8/2	71.2	17.05	103.00	25.38	Shear



(a) (b)

Figure 2: (a) Load vs Deformation (b) Failure Load vs Sample type

3.1 Ultimate Load Capacity

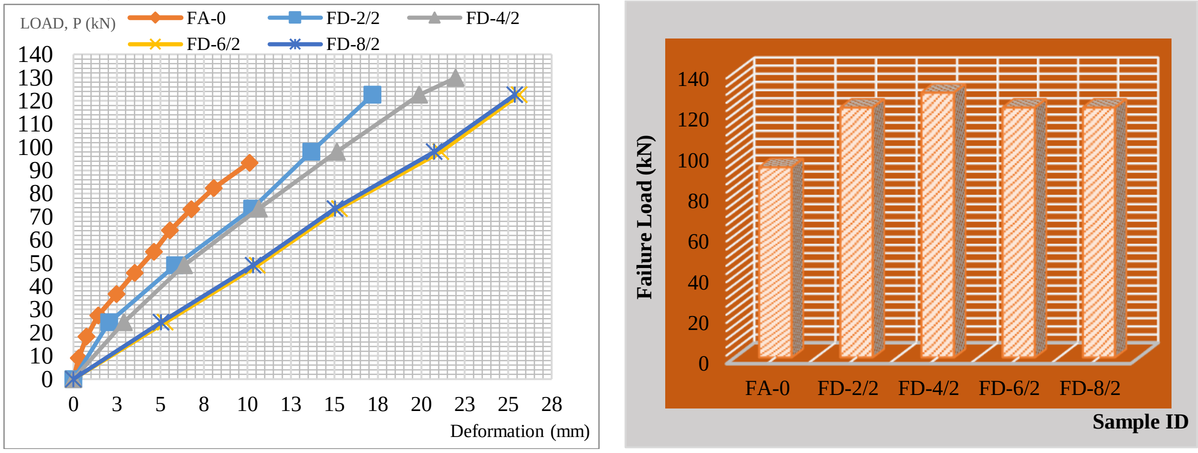
The beam FB-2/2 showed no yielding of the CFRP fabric and had a sudden failure at 109.9 kN due to shear-tension failure at the end of the CFRP. Notwithstanding, an increase in load-carrying capacity of 18% was obtained. The failure was bristle. The sample FB-4/2 failed in shear at an ultimate load of 144.55 kN, which is 55% greater than the failure load of reference beam FA-0, and exhibited brittle behavior. The beam FB-6/2 finally failed at a load of 122.63 kN, which is 31% greater than the failure load of reference beam FA-0. The test results show that the reference beam had less load-carrying capacity when compared to that of the beam FB-6/2 using CFRP fabrics. The FB-6/2 beam failed by shearing off the concrete. As the applied load on FB-8/2 increased, the cracks became more visible and wider, and the beam eventually failed with an ultimate load-carrying capacity of 115.45 kN, as shown in Figures 5(a) and (b). Beam FD-2/2, FD-4/2, FD-6/2, and FD-8/2. According to Figures 3(a) and (b), Beam FD-2/2 had a maximum load-carrying capacity recorded at the failure of 110.38 kN, which is 18% greater than FA-0. The sample FD-4/2 yielded at a load of 79.45 kN and failed by shear at a load of 130.0 kN, as presented in Figure 3 (b), which is 39% greater than the failure load of reference beam FA-0. The beam FD-6/2 failed by shear, followed by the crushing of concrete at the compression zone at an ultimate load of 122.63 kN, which is 31.4% higher than the failure load of reference beam FA-0. As a result of failure in the shear region, the FD-8/2 beam finally failed due to shear at a load of 103.0 kN with a maximum deformation of 25.38 mm. Comparing these results with those of John *et al* [20] showed that an additional CFRP layer did not lead to any further load increment, which is similar to Sharif *et al* [23].

Table 4: CFRP Contribution to Bending Capacity

Sample ID	Failure Load (kN)	Bending Capacity $M_{exp,}$ (kNm)	FRP Contribution to Bending Capacity $M_{f,\ exp,}$ (kNm)
FA-0	93.33	17.11	-
FB-2/2	109.90	20.15	3.04
FB-4/2	144.55	26.50	9.39
FB-6/2	122.63	22.48	5.37
FB-8/2	115.45	21.17	4.06
FD-2/2	110.38	20.24	3.13
FD-4/2	130.00	23.83	6.72
FD-6/2	122.63	22.48	5.37
FD-8/2	103.00	18.88	1.77

3.2 Bending Capacity

Table 4 shows that the bending capacity for FB-2/2, FB-4/2, FB-6/2, FB-8/2, FD-2/2, FD-4/2, FD-6/2, and FD-8/2 improved significantly and recorded a contribution of 3.04 kNm, 9.39 kNm, 5.37 kNm, 4.06 kNm, 3.13 kNm, 6.72 kNm, 5.37 kNm, and 1.77 kNm (about 18, 55, 31, 24, 18, 39, 31.4, and 9 % contribution) by CFRP to bending capacity, respectively.



(a) (b)

Figure. 3: (a) Load vs Deformation (b) Failure Load vs sample types

4. CONCLUSION

The evaluation of two-layer CFRP fabric-strengthened reinforced concrete beams have been studied and concluded as fellow:

i. Study showed the possibility of using epoxy-bonded CFRP fabrics and steel plate schemes to enhance the load resistance in flexure and shear of RC beams. However, doubling the CFRP layer does not result in further increments in load resistance.

ii. Carbon fiber reinforced polymer is useful in upgrading existing RC beams externally. However, it reduces the capacity of the beam to resist deformation under external load.

iii. The serviceability of the reinforced concrete beam member is usually evaluated through deformation and crack width. The deformation of an RC member strengthened with epoxy-bonded CFRP fabric was observed to be higher at failure relative to a concrete beam without epoxy-bonded CFRP fabric.

iv. The bonded CFRP fabric increased the bending strength by up to 55% as long as the suitable strengthening configurations and the appropriate bond thickness were used.

REFERENCES

[1] Nanni, A., Loreto, G., Babaeidarabad, S., (2014)', Flexural Strengthening of RC Beams with an Externally Bonded Fabric-Reinforced Cementitious Matrix. *Journal of Composites for Construction*, 18(5), pp. 234-244.

[2] Akinropo M. O. and Morgan D. (2014). ‘Methods for flexural strengthening of reinforced concrete elements using steel plates’ *Construction Materials and Structures S.O. Ekolu et al. (Eds.) IOS Press*

[3] Ashraf A. Alfeehan, (2014) Strengthening of R.C Beams by External Steel Plate Using Mechanical Connection Technique. Journal of Engineering and Development, 18(2), pp 202-215.

[4] Anandhi. L., Ramamoorthy. S, and Dhanasekar, K. (2018) ‘Strengthening of RC Beam with Steel Plate as Shear Reinforcement’. *International Journal of Engineering Research and Technology (IJERT),* 6(2), pp. 103-109.

[5] Saqaan, E., Rasheed, H., Hawileh, R., (2013) ‘An efficient design procedure for flexural strengthening of RC beams based on ACI 440.2R-08’, *Composites Part B: Engineering, Elsevier*, 49, pp. 71-79.

[6] Seible, F. (2001) ‘Designing with FRP composites in the civil structural environment, FRP Composites in Civil Engineering’, *Proceedings of the International Conference on FRP Composites in Civil Engineering, Hong Kong, China, edited by J. G. Teng*, pp. 73-84.

[7] Khattab S. A., Hayder, I. A., and Mais M. A. (2017) ‘A New Strengthening Technique for Deep Beam Openings Using Steel Plates’ *International Journal of Applied Engineering Research*, 12(24), pp. 15935-15947

[8] Lu, X. Z., Teng, J. G., Ye, L. P., and Jiang, J. J. (2005). Bond slip models for FRP sheets/plates bonded to concrete. *Engineering Structures*, 27(6), pp. 920–937.

[9] Jones, R., Swamy, R. N., and Ang, T. H. (1982), ‘Under- and Over-reinforced Concrete Beams with Glued Steel Plates’, *The International Journal of Cement Composites and Lightweight Concrete*, 4(1), pp. 19-32
and EBROG methods on debonding of FRP sheets used for shear strengthening of RC beams. *Composites Part B: Engineering,* 45(1), pp. 1704–1713.

[10] Jansze, W., Den, J., and Walraven, J. (1996) ‘Anchorage of Externally Bonded Steel Plates", Proceedings of Concrete in the Service of Mankind Congress, 'Concrete Repair, Rehabilitation and Protection', *R. K. Dhir and M. R. Jones (eds.), E. & F. N. Spon, University of Dundee, Dundee, Scotland*, pp 591-598.

[11] Hollaway L. C. (1993) ‘Polymer Composites for Civil and Structural Engineering’, *Glasgow, Blackie Academic, and Professional*.

[12] Mithaq A. L., Husain K. J., and Bayda M. H. (2013) ‘Load-deflection behavior of reinforced concrete beams strengthened with CFRP sheets’, *Journal of engineering and development,* 17(4), pp. 14 – 26.

[13] Xiang L. Xianglin G., Zeng Z., and Weiping Z., (2006) ‘Study on Steel Reinforced Concrete Composite Beams Strengthened with Steel Plates or CFRP Sheets, Structural Analysis of Historical Constructions’, *New Delhi P.B. Lourenço, P. Roca, C. Modena, S. Agrawal (Eds.)*

[14] Mostofinejad, D. and Tabatabaei K.A. (2013). Experimental study on the effect of EBR

[15] Alaa A. B. (2013). ‘Experiments on Flexural Strengthening of Reinforced Concrete Beams Using Valid Strengthening Techniques’. *Acta Technica Napocensis: Civil Engineering and Architecture 56(1)*, pp. 275-293.

[16] Kelly, P.L., Brainerd, M. L. and Vatovec, M. (1997) ‘Sika Carbo Dur and Sika wrap Design Guideline’, *Sika corporation, Lyndhurst, NJ*.

[17] Da Silva, L.F.M., Adams R.D., and Gibbs M., (2004). Effect of Adhesive Type and Thickness on the Lap Shear Strength, *The Journal of Adhesion*. 24(1): p. 69-83

[18] Denton, S. R., Shave, J. D., and Porter, A. D. (2004) ‘Shear Strengthening of Reinforced Concrete Structures using FRP Composites’, *Proceedings, International Conference on Advanced Polymer composites for Structural applications in Constructions, Cambridge,* UK, pp. 134-143.

[19] Kamal, G. S., Hassan, A. M., and Moaz M. M., (2019) ‘Strengthening of RC Beams Exposed to Shear and Flexure Stresses by Different Methods’, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* 21(3), pp. 6-16

[20] John A. T., Osuji S. O*., Nwankwo E. (2022) ‘Characterized Indices of Bond Thickness Variation on RC Beams Strengthened Externally by Bonded Carbon FRP’ NIPES Journal of Science and Technology Research, 4(4) 164–171*

[21] Amadise S. O., John A. T., Enyeru U. D. (2021) ‘Shear Strengthening of Reinforced Concrete Beams with Different Glass Fiber Fabric Strip Width and Adhesive Thickness’ Journal of Multidisciplinary Engineering Science Studies,7(2), pp. 3663 - 3668

[22] ACI Committee 444 (1993) ‘Models of Concrete Structures, *American Concrete Institute, Detroit, MI, Publication SP- 24*

[23] Sharif, A., Al-Sulaimani, G. J., Basunbul, I. A., Baluch, M. H., and Ghaleb, B. N. (1994) ‘Strengthening of Initially Loaded Reinforced Concrete Beams Using FRP Plates’, *ACI Structural Journal*, 91(2), pp. 160-168.