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Shear Strengthening of Concrete with FRP Reinforcement

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***Abstract*:Reinforced concrete is one of the commonly used building materials all over the world in various structures like bridges, chimney, flyover, residential building, marine structure, industrial building etc. Reinforced Concrete is a highly used building material in the world. It's being damaged due to various reasons such as aging, weather condition, exposure to atmosphere, continuous increase in volume of concrete, corrosion of reinforcement, salt water interaction, temperature effect etc. Many times is not feasible to replace such damaged structure with new structure as it require lots of investment of time and money every times. In such cases strengthen of damaged structure becomes best possible option. In this study, reinforced concrete beams were casted. M20 grade of concrete mix is used for beams. Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) were used for strengthening the beam which were procured from Forsook Constructive solution. CFRP were applied in different configuration in flexure and shear on that beam using epoxy primer and saturate. The main objective of this paper is to present the optimized technique for strengthening the Reinforced with suitable pattern of wrapping the beam. To enable guidelines for future design recommendation. Analytical analysis carried out in ABAQUS software.**

Keywords: Shear, Flexure, Strengthening,Fiber Reinforced Polymer (FRP)

I. INTRODUCTION

The use of externally bonded fiber reinforced polymer (FRP) reinforcement to strengthen RC structures is becoming an increasingly popular retrofit technique. The light weight and formability of FRP reinforcement bmake these systems easy to install. And since the materials second-hand in these system are non-corrosive, non-magnetic, and generally resistant to chemicals, they are an brilliant option for external reinforcement. FRP is a composite material generally consisting of carbon, aramid, or glass fibers in a polymeric matrixAmong many options, this reinforcement may be in the appearance of preformed laminates or flexible sheets. The laminates are stiff plates or shells that come pre-cured and are installed by bonding the cover to the concrete surface with epoxy. The sheets are either dry or pre-impregnated with resin (pre-preg) and cure after installation onto the concrete surface. This installation technique is known as wet lay-up. The use of externally bonded fiber reinforced polymer (FRP) reinforcement to strengthen RC structure is becoming an increasingly popular retrofit technique. The light weight and formability of FRP reinforcement make these systems easy to install. And since the materials used in these systems are non-corrosive, non-magnetic, and normally resistant to chemicals, they are an excellent option for external reinforcement.

1.1 Fibre Reinforced Concrete

Fiber Reinforced Concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers. Fiber reinforced concrete is of different types in addition to properties with many advantages. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibers. Fiber is a small piece of reinforcing material possessing certain characteristics properties. They be capable of be circular or flat. The fiber is often described by a convenient parameter called “aspect ratio”. The aspect ratio of the fiber is the relative amount of its length to its diameter. Typical aspect ratio ranges from 30 to 150. Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed in addition to randomly oriented. Fibers include steel fibers, glass fibers, and synthetic fibers in addition to natural fibers. Within these dissimilar fibers that character of fiber reinforced concrete changes with varying concretes, fiber resources, geometries, distribution, orientation and densities.

1.2 Research Methodology

This methodology is an attempt to study the effect of CFRP strengthened RC beams under four point loading test. Two categories of beams are casted such as normal beam and second and strengthened beam. Each category of the beams is designed to measure the effect of CFRP on flexural strengthening. Failure prototype of the beams are also shown and compared with available models. CFRP sheets are applied at the bottom of the beams for various techniques such as end plate type, vertical, debonding type of FRP sheet assuming minimum exposure of the structural member. At the end, it is found effect of strengthening beam and ultimate strength significantly.

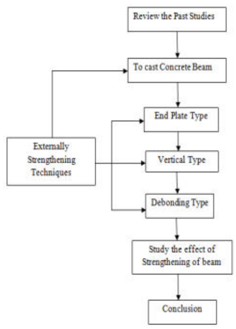

Fig.1: Flowchart Of Methodology

II. LITERATURE REVIEW

- **FRP Retrofitted RC Beam Suffering From IC Debonding, Apr 2019.**

Fiber reinforced plastic (FRP) also called fiber reinforced polymer. It is a composite material made of polymer matrix reinforced with fibers. The fibers are usually glass, carbon, agamid, and basalt. FRP are commonly used in the aerospace, automotive, marine and construction industries. Fiber Reinforced Polymer (FRP) plates can be bonded to the tension face of a reinforced concrete beam to increase its flexural capacity. Many studies have been done and found that premature failure by deboning of the FRP plate occur before reaching the ultimate flexural capacity of the plated section and the most commonly reported deboning failure mode is commonly referred to as intermediate crack induced due to interfacial deboning or simply intermediate crack (IC) deboning.

- **Size Effect on the Shear Failure of High-Strength Concrete Beams, 2019.**

Six large-scale high-strength concrete beams reinforced with basalt fiber reinforced polymer (BFRP) bars and stirrups and three corresponding beams without stirrups were constructed and tested for shear failure under four-point bending. The main parameters considered were the beam effective depth (300, 500, and 700 mm) and the stirrup spacing. The test results indicated that the size effect on shear failure could not be eliminated completely, as the initial shear crack, shear crack width, shear resistant components analysis, strain in the BFRP stirrups, and normalized shear strength were still related to the beam depth. The ACI 440-15 strain limit of 4000 ms could be relaxed with the condition that the serviceability requirement is satisfied. Furthermore, based on a collected database from the literature, an accurate and conservative equation was proposed to predict the FRP stirrup strain limit. The proposed equation includes the effects of all influencing parameters, which is more reasonable than the constant strain limit used by most design codes.

- **Double Shear Test on Bonding Mechanical Properties of Sprayed FRP and Concrete Substrate, 2019.**

To study the bonding mechanical properties of the interface between sprayed FRP and concrete substrate, seven double shear specimens were made to do the double shear tests. The failure mode, load and deformation, shear strength and deformation, distribution of strain and stress were studied. Furthermore, the influence of three main factors including fiber volume ratio, thickness of sprayed FRP and bonding length were analyzed in the paper as well. The results show that the thickness of sprayed FRP and bonding length have great influence on the bonding mechanical properties, while fiber volume ratio has little. The bonding interface that participate in bearing shear load can only develop to a certain length and then move from loading end to the other end with the development of debonding. The study can provide reference to the further research on sprayed FRP material used in concrete structure reinforcement.

III. METHODOLOGY

1) Externally Bonded FRP to Shear Capacity of Flexural Members

The behavior of externally bonded FRP sheets used to increase the moment capacity of flexural members. One limit to increasing the moment capacity is that eventually the shear capacity of the member is exceeded. In these situations, it has been shown that externally bonded FRP sheets may be used to increase the shear capacity as well. However, few studies have specifically addressed shear strengthening and design algorithms for computing the shear contribution of FRP sheets are not yet clear. One of the difficulties with defining the shear contribution of FRP sheets is the wide variety of possible FRP shear reinforcement configurations.

- **Shear Strength of RC Beams Strengthened with FRP Reinforcement**

The nominal shear strength of a RC beam may be computed by the basic design equation presented in ACI 318-95 and given below as Equation (1).

$$V_n = V_c + V_s \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

Vn = Nominal shear strength

Vs = Nominal shear strength provided by steel shear reinforcement

Vc = Nominal shear strength provided by concrete

In this equation the nominal shear strength is the sum of the shear strength of the concrete (which for a cracked section is attributable to aggregate interlock, dowel action of the longitudinal reinforcement, and the diagonal tensile strength of the uncracked portion of concrete) and the strength of the steel shear reinforcement. In the case of beams strengthened with externally bonded FRP sheets, the nominal shear strength may be computed by the addition of a third term to account for the contribution of the FRP sheet to the shear strength. This is expressed in Equation (2).

$$V_n = V_c + V_s + V_f \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where,
Vn = nominal shear strength
Vs = nominal shear strength provided by steel shear reinforcement
Vc = nominal shear strength provided by concrete
Vf = nominal shear strength provided by FRP shear reinforcement

- **The Contribution of FRP Reinforcement to Shear Capacity (Vf)**

In order to compute the nominal shear strength as given in Equation (2), it is necessary to quantify the contribution of CFRP reinforcement to the shear capacity (Vf). The contribution of CFRP depends on several parameters including the stiffness of the CFRP sheet, the quality of the epoxy resin, the compressive strength of the concrete, the number of layers of CFRP sheet, the wrapping scheme, and the fiber orientation angle. It has been difficult to establish one formula to computeVf because the parameters are numerous and there is a lack of adequate experimental results. This study presents two equations that may be used to obtain Vf and suggests taking the lower of the two results as the shear strength contribution of the CFRP reinforcement. These two equations represent two possible failure modes.

- **Design Approach Based on the Effective FRP Stress**

The design approach based on fracture of the CFRP sheet is quite similar to the approach used to compute the contribution of steel shear reinforcement. The stress in the sheet at ultimate must be calculated in the vertical direction and multiplied by the area of sheet that crosses a potential shear crack. However, instead of the ultimate condition being governed by a yield point, as with steel, the rupture point of the CFRP sheet must be considered. Triantafillou (Oct 1997) noted that CFRP sheets used for shear strengthening rupture at stress levels below their ultimate strength due to stress concentrations in the sheet. If the level of strain at rupture is considered as the effective strain, εfe, the contribution of externally bonded FRP sheets to the shear capacity of an RC beam may be computed from Equation (3).

$$V_f = \rho_f E_f \varepsilon_{fe} b_w \, 0.9d(1+\cos\beta)\sin\beta \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,
Vf = nominal shear strength provided by FRP shear reinforcement
εfe = the effective FRP strain
bw = width of the beam cross section
Ef = elastic modulus of FRP (GPa)
ρf = FRP shear reinforcement ratio = (2tf / bw) (wf / sf)

This equation, as presented by Triantafillou, is in the Eurocode format. The shear reinforcement ratio, ρf, is the FRP shear reinforcement ratio as defined in the appendix, and the angle β is the angle between the orientation of the principal fibers in the sheet and the longitudinal axis of the beam. This equation may be rewritten in ACI code format as Equation (4).

$$V_f = \frac{A_f f_{fe}(\sin\beta+\cos\beta)d_f}{s_f} \quad \ldots\ldots\ (4)$$

Where,
Af = area of CFRP shear reinforcement = 2 tfwf
ffe = effective tensile stress in the FRP sheet in the direction of the principal fibers
df = effective depth of the CFRP shear reinforcement (usually equal to d for rectangular sections and d-ts for T-sections)
sf = spacing of FRP strips

- **Determination of the Effective Strain**

A relationship between effective strain and axial rigidity was found and is given in Equation (5-a) and (5-b).

$$\varepsilon_{fe} = 0.0119 - 0.0205\,(\rho_f E_f) + 0.0104(\rho_f E_f)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (5\text{-}a)$$

For $0 \le \rho_f E_f \le 1$ Gpa

$$\varepsilon_{fe} = 0.00245 - 0.00065\,(\rho_f E_f) \quad \ldots\ldots\ldots\ldots\ldots\ldots (5\text{-}b)$$

for$\rho_f E_f \le 1$ Gpa

- **Modifications to the Effective Strain Model**

As originally suggested, the effective strain is determined by equating the experimentally determined shear strength to Equation (3) and back calculating εfe. To eliminate the effects of various types of FRP sheet, the ratio of effective strain to ultimate strain, R = εfe / εfu, is plotted versus axial rigidity. This plot is shown in Figure 3. A polynomial is used as a best fit to the data in the case of ρfEf< 1.1 GPa. This polynomial is given in Equation (6).

$$R = 0.5662\,(\rho_f E_f)^2 - 1.2188\,(\rho_f E_f) + 0.778 \le 0.50 \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

The upper limit on R of 0.50 has the effect of limiting the strain in the FRP sheet to an order of 400 με to 500 με. This limit is suggested to maintain the shear integrity of the concrete. At higher levels of strain the shear crack widths would be such that aggregate interlock would be lost and the shear capacity of the concrete dramatically reduced.

The ratio of effective strain to ultimate strain, R, may be used as a reduction factor on the ultimate strain. Thus, the effective strain for use in Equation (3) may be computed from Equation (7).

$$\varepsilon_{fe} = R\varepsilon_{fu} \qquad \ldots\ldots\ldots\ldots\ldots(7)$$

Where,

εfu = Ultimate tensile elongation of the fiber material in the FRP composite

εfe = The effective FRP strain

R = Ratio of effective stress or strain in the FRP sheet to its ultimate strength or elongation

Thus the computational procedure for design would involve finding the reduction factor, R, from Equation (6); finding the effective stress, ffe, by Equation (8); and determining the shear contribution of the CFRP, Vf, from Equation (4).

IV. VALIDATION OF SOFTWARE

Paper- strengthening in Flexure shear of RC beam with hybrid FRP systems: experiments and numerical modeling. In this research paper present an experimental and numerical investing of reinforced concrete beams strengthening by means of different combinations of externally bonded hybrid fabrics-reinforced polymer composite analyzed in ABAQUS software.

- **Material**

Concrete mixtures - In this study, RC beam with 150mm width, 200mm height, and 1000mm length were used. Compressive and flexural tensile strengths of concrete at 28 days are 22MPa and 3.6 MPa, respectively.Steel bars. The beams were reinforced with two HA10 bars as tensile reinforcement and two HA8 bars as top reinforcement. The steel type in longitudinal direction is S400. The value of Young's modulus is 210 GPa, the stress at the elastic limit is 450 MPa, and the Poissonratio is 0.3. The value of Young's modulus is 210 GPa, the stress at the elastic limit is 250MPa and the Poisson ratio is 0.3.FRP composites - For strengthening RC beams, three types of composite materials have been selected: A bidirectional GFRP, a unidirectional CFRP, and a bidirectional JFRP, with a weight of 262 g/m2, 183 g/ m2, and 135 g/m2, respectively.

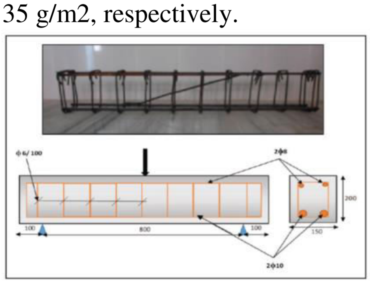

Fig.2: RCC Beam Dimension

Table 1: Mechanical Properties Of FRPS Samples

Properties	CERP	GFRP	JFRP
Tensile Strength (MPa)	184	124.5	29.6
Elastic Modulus in Tension (GPa)	25.5	5.8	2.8
Ultimate elongation in tensile (%)	0.66	2.66	1.24

- **Results**

Table 2: Load Carrying Capacity of Research Paper

Sr. No	Beam Code	Djeddi et. al Results	Abaqus Load Carrying Capacity	Percentage Error
1	CB	77	76	1.3
2	BRCC	119	116	2.5
3	BRGG	92	101	8.9
4	BRJJ	94	102	13.0
5	BRCG	114	125	12.3
6	BRCJ	127	119	6.3
7	BRGC	94	102	13.0
8	BRGJ	101	103	1.9
9	BRJC	97	100	3.0
10	BRJG	94	95	1.1

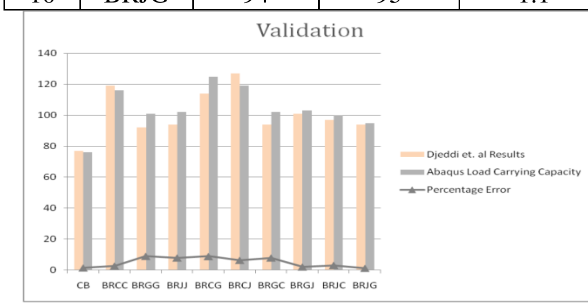

Fig.3: Load Carrying Capacity of Research Paper

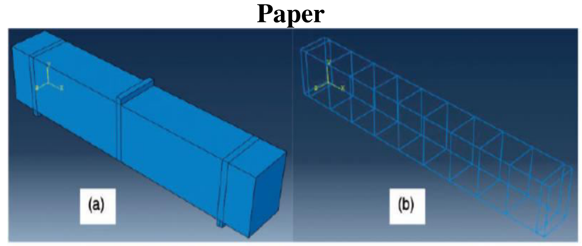

Fig.4: Reinforcement Of Model

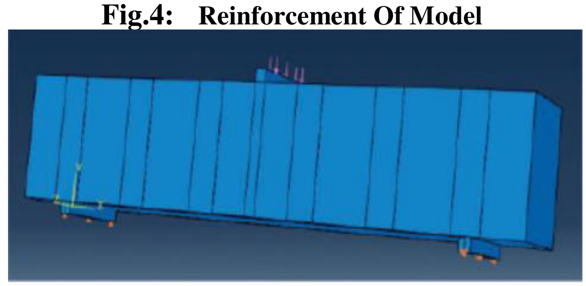

Fig.5: Loading Of Model

V. RESULT AND DISCUSSION

1. Load Deflection Analysis

Table 3: Application of End Plate Type of FRP Strip At Both End Of Beam

Sr. No	Load KN	Nil mm	25 mm	30 mm	35 mm	40 mm	45 mm	50 mm	55 mm	60 mm	65 mm	70 mm
1	2	0	0	0	0	0	0	0	0	0	0	0
2	4	0	0	0	0.3	0	0.4	0.3	0.8	0	0.2	0
3	6	0.62	0.6	0.36	0.4	0.4	0.56	0.8	0.87	0.3	0.3	1
4	8	0.98	0.78	0.45	0.5	0.8	0.87	1.1	1.5	0.9	0.5	0.35
5	10	1.1	1.5	0.65	0.89	1	1.4	1.3	2.13	1.1	0.6	0.8
6	12	1.5	1.78	1.04	1.05	1.1	1.9	2.4	2.76	1.3	1.1	1.04
7	14	2.8	2.01	1.6	2.21	1	2.06	3.5	3.39	1.5	1.9	1.8
8	16	3	2.29	2.16	3.37	1.7	3.5	4.6	4.02	1.7	2.7	2.06
9	18	3.6	3.2	2.72	3.53	2.01	3.2	3.7	4.65	1.9	3.6	2.08
10	20	4.5	3.5	3.28	5.69	2.32	3.2	4.89	5.28	2	4.4	3.1
11	22		3.8	4.35	5.85	1.63	3.5	5.87	5.91	2.2	5.3	4.12
12	24			5.42	6.01	2.94	3.89	6.2	6.54	2.7	5.4	5.14
13	26				6.17		4.89	6.8	7.17	3.2	6.9	6.16
14	28							7.025	7.8	3.8	7.8	6.18
15	30								8.43	4.8	8.6	7.2
16	32											10.22
17	34											11.24

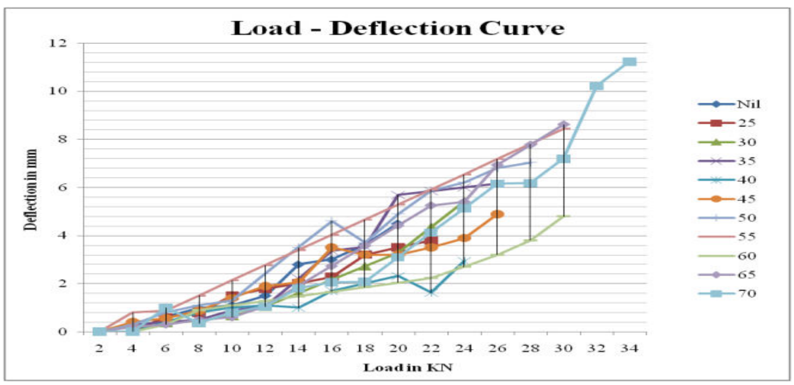

Fig.6: Load deflection curve for End Plate Type of FRP Strip at Both End of Beam

Table 1: Application of Vertical Type of FRP Strip At Both Sides Of Beam

Sr. No	Load KN	25 mm	30 mm	35 mm	40 mm	45 mm	50 mm	55 mm	60 mm	65 mm
1	2	0	0	0	0	0	0	0	0	0
2	4	1	0	0	2	1	0.9	0	1.5	0
3	6	1.5	0	1.1	2.5	1.2	1.3	1.1	2.5	0
4	8	1.8	1.8	1.3	3	1.8	1.7	2.1	3.5	1.3
5	10	2.1	2.01	1.8	3.4	2	2.1	3.1	2.5	2.4
6	12	2.4	2.3	2.3	3.8	2.5	2.5	4.1	3.5	3.5
7	14	2.7	2.5	2.8	4	3	2.9	5.1	4.5	4.6
8	16	3	3.2	3.5	4.5	3.5	3.3	6.1	5.5	5.7
9	18	3.3	3.8	3.8	3.5	4	3.7	7.1	6.5	6.8
10	20	3.6	3.5	4.2	4.2	4.5	4.1	8.1	7.5	7.9
11	22	3.9	5.2	4.8	4.6	5	4.5	9.1	8.5	9
12	24	3.95	5.5	5.3	5	5.5	4.9	10.1	9.5	10.1
13	26	4.2	5.9	6.5	5.4	6	5.3	11.1	10.5	11.2
14	28		6.5	7.2	5.8	6.5	5.7	12.1	11.5	12.3
15	30			7	6.02	6.8	6.5	13.1	12.5	13.4

16	32					6.2	7.8	14.1	13.5	12.5
17	34						9.1	15.1	14.5	13.6
18	36						10.4	16.1	15.5	14.7
19	38							17.1	16.5	15.8
20	40							18.1	19.5	16.9
21	42									19.1
22	44									20.2

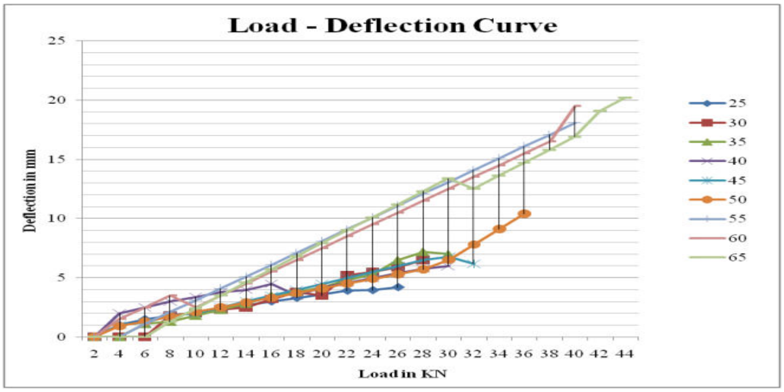

Fig.7: Load deflection curve for Vertical Type of FRP Strip At Both Sides Of Beam

Table 2: Application of Debonding Type of FRP Strip At Bottom Of Beam

Sr. No	Load	2	3	4	5	6	7	8	9	10
	KN	mm	mm	mm	mm	mm	mm	mm	mm	mm
1	2	0	0	0	0	0	0	0	0	0
2	4	0	0	0	0.3	0	0.5	0	0	0
3	6	0.62	0	0.2	0.4	0.75	0.3	0	0.87	0.65
4	8	0.98	0.78	0.3	0.44	0.95	0.65	0	1.2	0.9
5	10	0.99	0.89	0.6	0.55	1.15	1.1	1.3	1.53	1.15
6	12	1.2	1.2	0.9	1.05	1.35	1.55	2.4	1.86	1.4
7	14	1.41	1.51	1.3	1.8	1.55	2	3.5	2.19	1.65
8	16	1.62	1.82	1.7	2.2	1.05	2.45	4.6	2.52	1.9
9	18	1.83	2.13	2.1	2.6	1.95	2.9	3.7	3.85	2.15
10	20	2.04	2.44	2.5	3	2.3	3.35	4.89	5.18	2.4
11	22	2.3	2.75	2.9	3.8	2.65	3.8	5.87	6.51	2.65
12	24			3.3	4.3	3	4.25	6.2	7.84	2.9
13	26					3.35	4.7	6.5	9.17	3.15
14	28									3.4

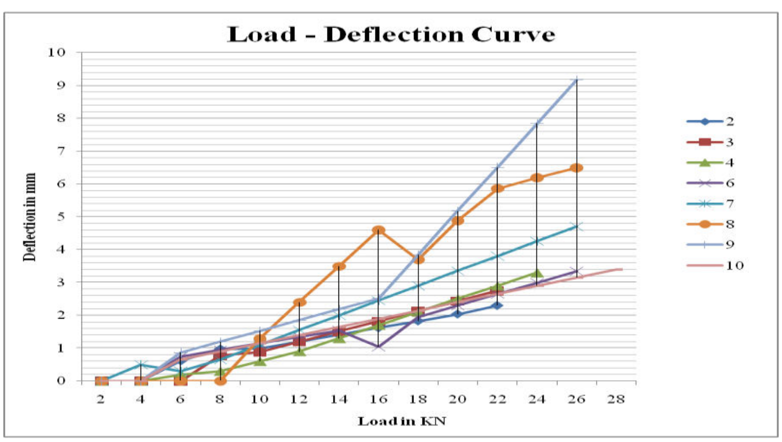

Fig.8: Load deflection curve for Debonding Type of FRP Strip At Bottom Of Beam

VI. CONCLUSION

The CFRP application led to an increase of the beam strength and stiffness. Although all specimens were reinforced with identical layers of CFRP, it was observed in literature that different resin and anchorage systems significantly influenced the resulting strength and stiffness of the specimens.

Based on the results presented herein, the following conclusions can be drawn:

- The analytical results giving load carrying capacities of strengthening of beam provided loading, is found to be almost similar to that of the result obtained in the research paper using software and a percentage variation in load carrying capacity is found to be below 10% approximately. Hence, it can be concluded that the results of ABQUS are validated with the results obtained by using software in research paper.
- In end plate type of beam maximum deflection for 70 mm width of strip is 11.24 mm and minimum for 40 mm width of FRP strip is 2.94 mm
- In vertical type of strip beam maximum deflection for 65 mm width of strip is 20.2 mm and minimum for 25 mm width is 4.2 mm
- In debonding type of beam maximum deflection for 9 mm width of strip is 9.17 mm and minimum for 2 mm width of FRP strip is 2.3 mm

VII. REFERENCES

1. Aswathi T, Manju P. M, “Numerical Study on FRP Retrofitted RC Beam Suffering From IC Debonding”, International Research Journal of Engineering and Technology (IRJET), Vol. 06 Issue: 04, Apr 2019..
2. Ghazi BahrozJumaa, Ali Ramadhan Yousif, “Size Effect on the Shear Failure of High-Strength Concrete Beams Reinforced with Basalt FRP Bars and Stirrups”, Construction and Building Materials, Vol. 209, Pp. 77–94, 2019Ashraf F. Ashour, IlkerFatih Kara, “Size Effect on Shear Strength of FRP Reinforced Concrete Beams”, Composites: Part B, Vol. 60, Pp. 612–620, 2014.
3. Zhao Yang, Jiajia Li, “Double Shear Test on Bonding Mechanical Properties of Sprayed FRP and Concrete Substrate”, Composites Part B, Vol. 162, Pp. 388–39
4. F. Matta & A. Nanni, T. M. Hernandez, et.al, “Scaling of Strength of FRP Reinforced Concrete Beams without Shear Reinforcement”, Fourth International Conference on FRP Composites in Civil Engineering, July 2008.
5. G.M. Chen, S.W. Li et.al., “Full-Range FRP Failure Behaviour in RC Beams Shear-Strengthened with FRP Wraps”, International Journal of Solids and Structures, Vol. 125, Pp. 1–21, 2017.
6. .
7. Ibrahim M. Metwally, “Prediction of punching shear capacities of two-way concrete slabs reinforced with FRP bars”, Housing and Building National Research Center Journal, Vol. 9, Pp. 125–133, 2013.
8. Martin Noel, Khaled Soudki, “Estimation of the Crack Width and Deformation of FRP-Reinforced Concrete Flexural Members with and without Transverse Shear Reinforcement”, Engineering Structures, Vol. 59, Pp. 393–398, 2014.
9. RalejsTepfers, “Compatibility Related Problems for FRP and FRP Reinforced Concrete”, Composites in Construction: A Reality, 2001.
10. Ahmed Khalifa, William J. Gold, et.al., “Contribution of Externally Bonded FRP to Shear Capacity of Flexural Members”, ASCE-Journal of Composites for Construction, Vol. 2, No. 4, Pp. 195- 203, 1998.
11. Antonio Marí, Antoni Cladera, et. al, “Shear Design of FRP Reinforced Concrete Beams without Transverse Reinforcement”, Composites: Part B, Vol. 57, Pp. 228–241, 2014.
12. Barbieri, G., Biolzi, L., Bocciarelli, M., Cattaneo, S., Size and Shape Effect in the Pull-Out of FRP Reinforcement from Concrete, Composite Structures, 2016.