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Behavior of R.C.C. Beam with Rectangular Opening at Shear Zone and Bending Zone Strengthened by Three Types of GFRP Sheets

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ABSTRACT

In the construction of high rise buildings, the openings in beams are provided for pipes and utility ducts, electric lines. Provision of opening in beam develops cracks inside and around the opening due to stress concentration. In this paper the behavior of R.C.C. beam with rectangular opening strengthened by three different types of GFRP sheets at shear zone and bending zone were studied with single layer bonding technique.

Keywords: R.C.C. beam, GFRP, Rectangular opening, wrapping, Experimental and Numerical Analysis

I. INTRODUCTION

Ducts are necessary in order to accommodate essential services such as water supply, electricity, telephone, and computer network. These pipes and ducts are usually placed underneath the soffit of the beam and for aesthetic reasons, are covered by a suspended ceiling, thus creating a dead space. In each floor, the height of this dead space adds to the overall height of the building depending on the number and depth of ducts. Therefore, the web openings enable the designer to reduce the height of the structure, especially when considering tall building construction, thus leading to a highly economical design.

The presence of openings will transform simple beam behaviour into a more complex behaviour, as they induce a sudden change in the dimension of the beam's cross section. However, the failure plane always passes through the opening, since the opening represents a source of weakness. The ultimate strength, shear strength, crack width and stiffness may also be seriously affected. Beam openings may be of different shapes, sizes and are generally located close to the supports where shear is dominant.

The presence of an opening in the reinforced concrete beam leads to many problems in the beam behaviour such as excessive cracking, deflection, reduction in the beam stiffness and reduction in the beam strength. In this paper behaviour of beams with opening in shear zone and bending zone under single layer strengthening technique using 3 different types of GFRP Sheets is carried out. 18 beams are casted; 16 beams are with rectangular pre-planned opening during casting (In both zones) .12 beams are strengthened with 3 types of GFRP sheets (MESH GFRP, WOVEN ROVINGS [W.R], CHOPPED STRAND MAT[CSM]) in which each beam is strengthened with these 3 available GFRP sheets by single layer process in both bending and shear zones. 2 beams are casted in each zone using each type of sheet, thus making 12 beams. 2 beams have no opening and 4 are with opening (without wrapping in both zones) These beams are tested under two-point loading in the loading frame the ultimate failure load of the beam and deflection have been recorded, crack pattern is analysed both experimentally and Numerically (ANSYS Work bench 16.1) and results were compared with the control beam without opening and control beams with rectangular opening.

The organization of this document is as follows. Section 2 (**Preliminary investigation of materials),** Section 3 (**Methodology and Material properties**), I'll give the details and method of the project I've done and the properties of GFRP I used, section 4 (**Beam opening dimensions and reinforcement details),** In Section 5 (**Experimental Investigation),** I'll explain the experiment that I've conducted, In Section 6 (**Numerical Analysis)**, I've done the same problem Numerically in Ansys Workbench 16.1. In Section 7 (**Result and Discussion**), I present my research findings and analysis of those findings. Section 8 is **Conclusion**.

II. PRELIMINARY INVESTIGATION OF MATERIALS

Portland pozzolana cement of 43 grade is used and has been tested for various properties as per IS: 4031-1988 and found to be confirming to various specifications of IS: 12269-1987.

Table 1: - Test results of cement

Test conducted	Result
Specific gravity	3.02
Standard Consistency, %	38
Initial setting time, min	35
Fineness, %	2

River Sand as fine aggregate and coarse aggregate of 20mm size is used. Laboratory tests were conducted to determine the physical properties of aggregates as per IS: 2386 (Part III) -1963.
Both the aggregates were tested for their gradation.

Table 2: - Test results of aggregates

Test conducted	Result
Specific Gravity of Fine Aggregate	2.60
Specific Gravity of coarse Aggregate	2.70

A mix M20 grade was designed as per IS 10262:2009 and the same was used to prepare the test specimens. The design mix proportion is shown in Table 3.

Table 3: - Mix proportion for M20

Cement	Fine aggregate	Coarse aggregate	Water Cement ratio
1	1.66	3.41	0.50

Compressive strength test on concrete cubes of 150mmx150mmx150mm size were conducted. Slump obtained was 110 mm after conducting slump tests. The compressive strength of hardened concrete was found to be 24.4 N/mm^2.

Table 4: - Test results on hardened concrete

Seven-day strength	17.48 MPa
Twenty eight-day strength	24.4 MPa

III. METHODOLOGY AND MATERIAL PROPERTIES

1. Review of existing literature and codal provision for openings in beams.
2. Design M20 mix
3. Determine compressive strength, tensile strength.
4. Cast conventional beam, beam with and without opening(rectangular) and beam with openings strengthened by layer of GFRP sheet.
5. Determine flexural property and crack pattern of conventional beam, beam with and without opening and beam with openings strengthened by layer of GFRP sheet.
6. Determine the ultimate load carrying capacity of conventional beam, beam with and without opening (rectangular) and beam with openings strengthened by layers of GFRP sheet of same thickness.
7. Determine the suitable type that can be provided in a beam.
8. Analysis of beam using ANSYS Workbench 16.1. and comparing it with experimental results.

Table 5-: Material Property of GFRP Composite

Type of GFRP used	Elastic modulus MPa	Poisson's ratio	Tensile strength MPa	Shear modulus MPa
GFRP Rovings (WR 0.4mm thick)	Ex =22000	Vxy =0.21	600	Gxy =3300
	Ey =16100	Vxz =0.18		Gxz =3300
	Ez =16100	Vyz =0.18		Gyz =3700
Chopped GFRP (CSM 0.3mm thick)	Ex =21000	Vxy =0.17	490	Gxy =2880
	Ey =7000	Vxz =0.16		Gxz =2880
	Ez =7000	Vyz =016		Gyz =3080
GFRP MESH (5X5) 0.2mm thick	Ex =8900	Vxy =0.15	310	Gxy =2050
	Ey =7300	Vxz =0.13		Gxz =2050
	Ez =7300	Vyz =0.13		Gyz =2145

1. Various types of opening are as follows:

1) Rectangular
2) Square
3) Circular
4) Hexagonal
5) Octagonal
6) Diamond
7) Irregular shapes

An opening creates discontinuity in the normal flow of stresses, thus leading to stress concentration at edges of the opening and leading to early cracking of concrete. To avoid this special reinforcement enclosing the opening should be provided in the form of external or internal reinforcement. Internal reinforcements are steel bars provided along with the main reinforcements during casting. External reinforcements are applied externally around opening in the form of jacketing of composite materials like glass fiber or carbon fiber reinforced polymer called GFRP or CFRP

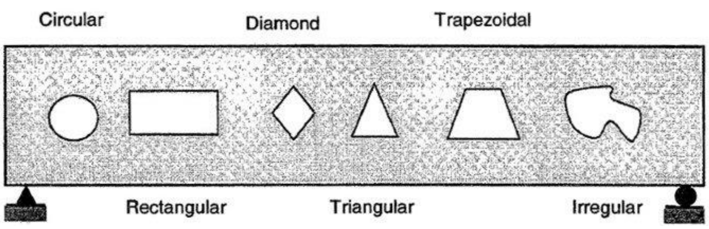


Fig. 1: - Types Openings

2. FRP as Strengthening material

Fiber-reinforced polymer (FRP) is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, aramid or carbon fiber, while the polymer is usually an epoxy. FRP sheets are used for the repair and strengthening of structural concrete members. FRP composite materials is an excellent option for external reinforcement when compared to other repairing material because of their superior properties such as high specific stiffness and specific strength, ease of installation, possibility of application without disturbing the existing functionality of the structure, non-corrosive and nonmagnetic nature of the materials along with its resistance to chemicals.

IV. BEAM OPENING DIMENSIONS AND REINFORCEMENT DETAILS

1. Beam dimensions adopted are as follows:

Length (L) = 0.75 m

Width (b) = 0.15 m

Depth (D) = 0.15 m

Effective span (l) = 0.73 m

2. Opening Dimensions:

Openings are provided as per SP 34.
Rectangular opening (L,D)

Single rectangle = 120x60(mm)

Figures below show the reinforcement details of beams used

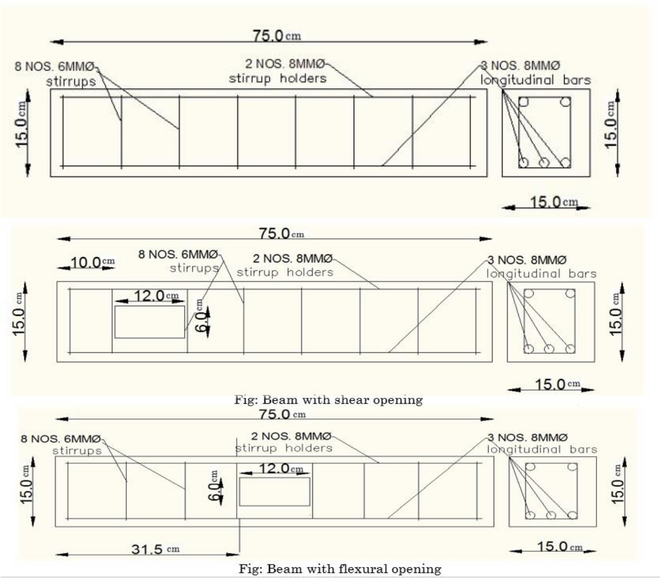
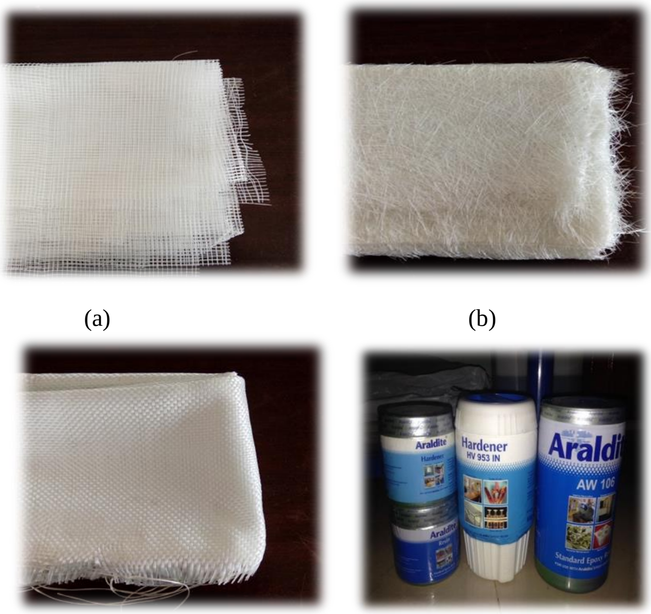


Fig 2: - Reinforcement details of beams

V. EXPERIMENTAL INVESTIGATION

The experimental study consists of casting of eighteen rectangular reinforced concrete beams including beams with and without opening. All the beams casted are tested to failure. The beams are indicated by the label BG1, BG2, GFOS1, GFOS2, GFOF1, GFOF2, GFOS3, GFOS4, GFOF3, GFOF4, GFOS5, GFOS6, GFOF5, GFOF6, BGOF1, BGOF2, BGOS1, BGOS2. Each having same longitudinal and transverse steel reinforcement. All beams had the same geometrical dimensions. The behaviour of beams with rectangular opening (keeping area constant) under strengthening using GFRP is carried out. In this paper, behaviour of beams with opening in shear zone and bending zone using different types of GFRP Sheets is carried out. eighteen beams were casted; 16 beams were with rectangular pre-planned opening during casting, in which Twelve beams are strengthened with GFRP sheets by single layer process (In shear and flexural region). Two beams have no opening and four are with opening (without wrapping at shear and flexural area). These beams are tested under two-point loading in the loading frame, the ultimate failure load of the beam and deflection have been recorded and results were compared with the control beam without opening and control beam with rectangular opening.



(a) (b)

(c) (d)

Fig 3: - Different types of GFRP used, (a) Mesh (b) CSM (c) WR

Fig 4: - Wrapping of GFRP inside and around opening

Fig 5: - opening wrapped using W.R, CSM and Mesh

A. Test setup

All the specimens were tested for flexural strength under two point loading. Conventional beam, beams with rectangular and circular openings and beams with strengthened openings were tested in universal testing machine having capacity 600 kN .Testing procedure for the all the specimen is same. First the beams are cured for a period of 28 days then its surface is cleaned with the help of steel plate and then the surface is cleaned to make the cracks clearly visible after testing. Two-point loading arrangement is used for testing of beams. The load is transmitted through a load cell and spherical seating directly at the midpoint of the beam. The specimens placed over the two steel rollers placed at the ends of the beam. The specimens were arranged with simply supported conditions, cantered over bearing blocks adjusted over an effective span of 600 mm. The load was applied at midpoint of the beam specimen, increased at a uniform rate till the ultimate failure. Deflection of the beam was measured by LVDT placed one at mid span. For each load increment, the deflection and crack were observed and tabulated. The test setup of for the flexural test is shown in figure 5.

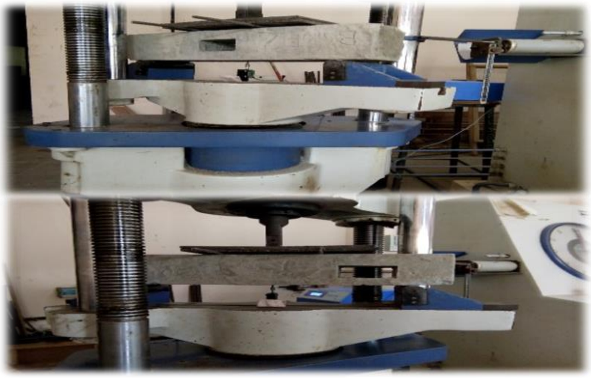


Fig 6: - Test setup for control beams with opening

Fig 7: - Test setup for beams with opening wrapped using W.R

Fig 8: -Test setup for beams with opening wrapped using C.S.M

Fig 9: - Test setup for beams with opening wrapped using Mesh

VI. NUMERICAL ANALYSIS

B. Modeling

RCC beams with and without openings and openings strengthened with GFRP under two point loading case was taken for analysis. Size of the reinforced concrete beam – 150mm × 150 mm × 750mm.Steel reinforcement details: 3 rebars of 8 mm diameter at bottom and 2 rebars of 8 mm diameter at top as stirrups holders, stirrups of 6 mm diameter at 90 mm c/c. Material property table is given below.

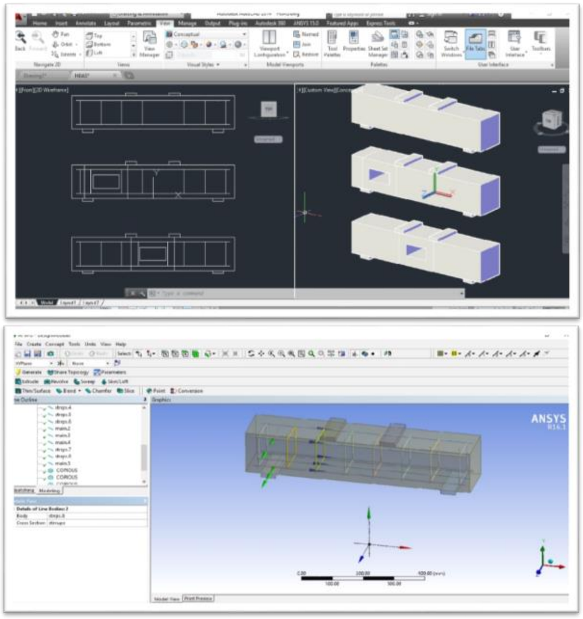
Table 6:- Material properties

Material (MPa)	Young's modulus (MPa)	Poisson's ratio (MPa)	Tensile/Compressive strength (MPa)
Concrete	24698	0.16	24.4
Steel	200000	0.30	500

Loads and Boundary Conditions

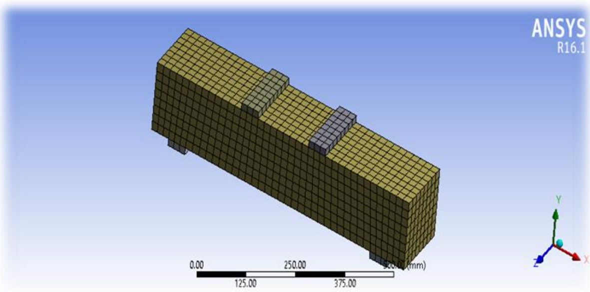
Displacement boundary conditions are needed to constrain the model to get a unique solution. The support was modelled in such a way that a roller was created. A single line of nodes on the plate were given constraint in the *UY*- and *UX* directions, applied as constant values of 0. By doing this, the beam will be allowed to rotate at the support. The force, *P*, applied at the steel plate is applied across the entire Centre line of the plate.

Modeling was done in two stages. First of all, the three models were drawn in AutoCAD 2013 as line body. Then all were imported into workbench 16.1 interface and generated the completed model by applying Reinforcement cross section and scale factor. Fig.(a) shows the modeling.

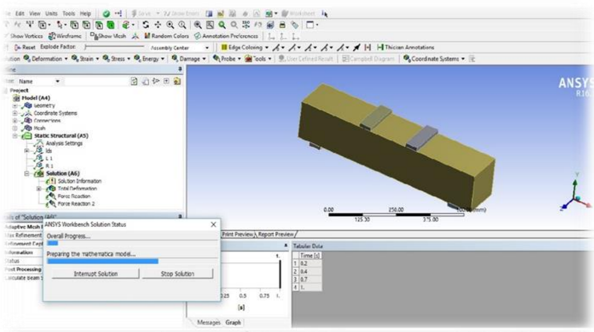


(a)

After completing the beam modeling, rebars are bonded with concrete around it. Load bearing plates and supports are not bonded. Then selecting appropriate mesh size, mesh generation has carried out followed by solving the model. Fig. 7.2 shows the mesh generated model and fig.7.3shows the solution of problem.



(b)



(c)

Fig 10: - (a) Modeling, (b)&(c) Meshing, Analysing

VII. RESULTS AND DISCUSSION

C. Experimental Part

Table 7: -Value of ultimate load and maximum deflection

Type of GFRP used	Average Load (kN)	Average Deflection (mm)	Initial visible crack(kN)
control beam w/o opening	118	4.0055	33.7
control flexural opening	67.8	3.452	26.5
control shear opening	31.5	2.985	19
GFRP ROVINGS(Shear)	54.25	3.83	30.5
GFRP ROVINGS(Flexure)	103.5	7.124	35.5
CHOPPED GFRP(Shear)	41	4.771	25.5
CHOPPED GFRP(Flexure)	97.5	4.4445	32
GFRP MESH(Shear)	37.25	4.4125	21
GFRP MESH(Flexure)	83.5	3.737	28

Based on the above observations, following figure 11 has been plotted which shows the ultimate load carrying capacity of the wrapped beams as well as control beams. This classification is made by comparing the ultimate load carrying capacity of the control beams with the beam which is strengthened by using the wrapping technique

Table 8: - Energy absorption data

Type of GFRP used	Specimen 1 (kNmm)	Specimen 2 (kNmm)	Average (kNmm)
control beam w/o opening	369.719	478.0505	423.88475
control flexural opening	214.2007	232.625	223.41285
control shear opening	79.5225	43.9275	61.725
GFRP ROVINGS(Shear)	170.5415	153.0225	161.782
GFRP ROVINGS(Flexure)	638.746	737.77325	688.25963
CHOPPED GFRP(Shear)	187.7895	100.7095	144.2495
CHOPPED GFRP(Flexure)	343.865	390.685	367.275
GFRP MESH(Shear)	95.476	184.685	140.0805
GFRP MESH(Flexure)	260.6685	225.74425	243.20638

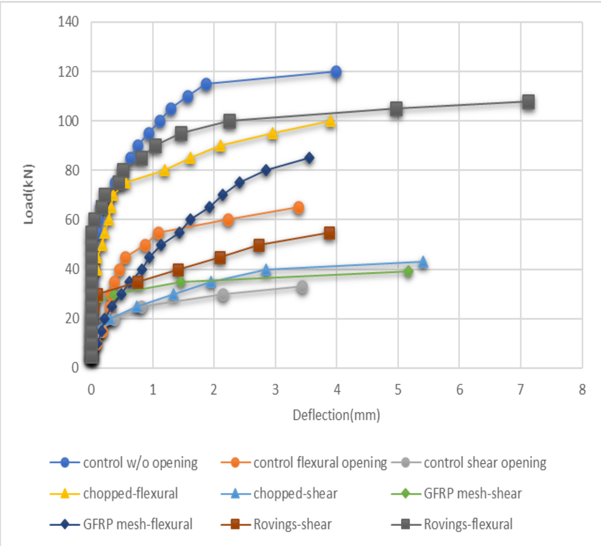


Fig 11: -Load -Deflection plot (all beams)

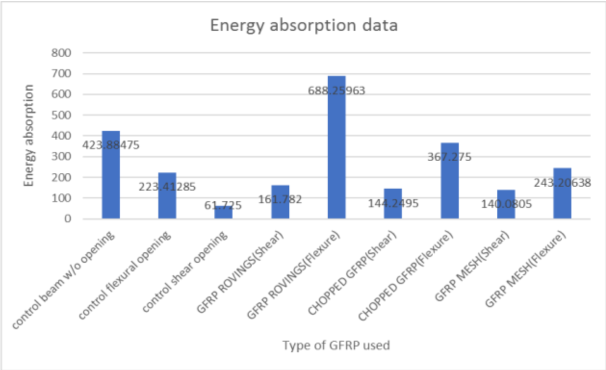
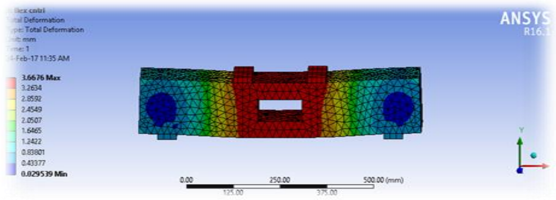


Fig 12: - Energy absorption data (in kNmm)

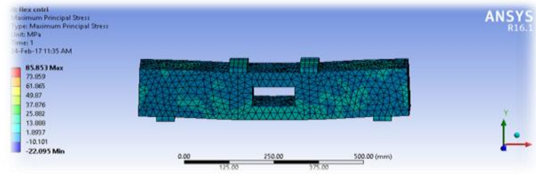
The average energy absorption capacity of control beam with flexural opening and control beam with shear opening was found to be less than the absorption capacity of all other beams wrapped with different types of GFRP sheets.

D. Numerical part

The Total Deformation Diagram (a) and the Maximum Principal stress diagram (b) obtained from Numerical analysis using Ansys Workbench 16.1 are shown in the following figures

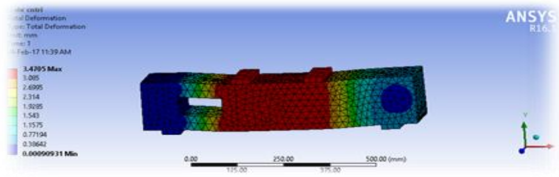


(a)



(b)

Fig 13 :- (a) control beam with Flexural opening



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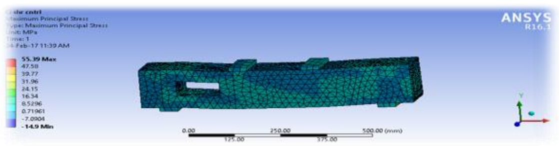
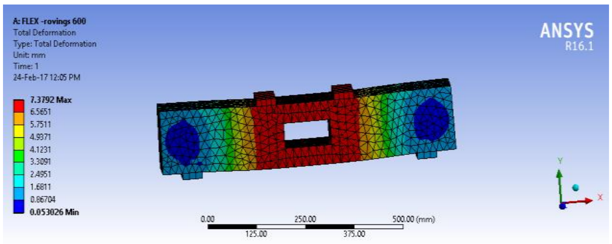


(b)

Fig 14:- control beam with Shear opening



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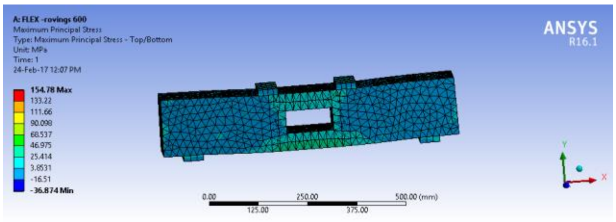
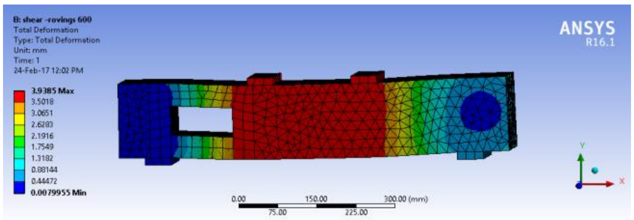


(b)

Fig 15:- Opening wrapped with W.R. GFRP in flexure



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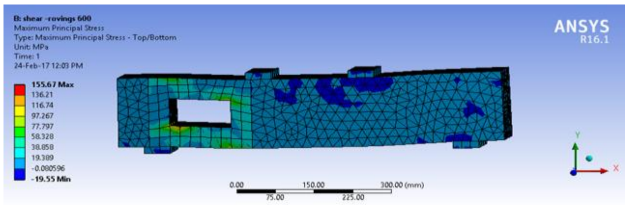
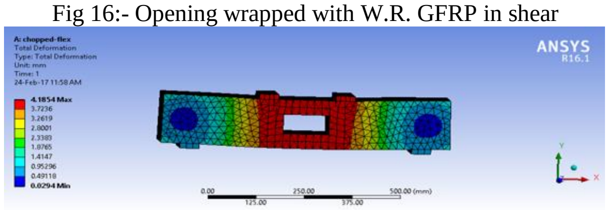


(b)

Fig 16:- Opening wrapped with W.R. GFRP in shear



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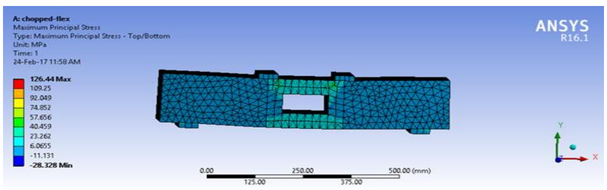
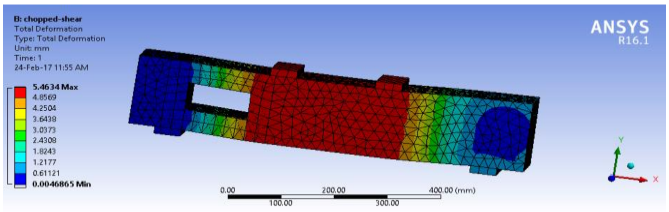


(b)

Fig 17:- Opening Wrapped with GFRP CSM in Flexure



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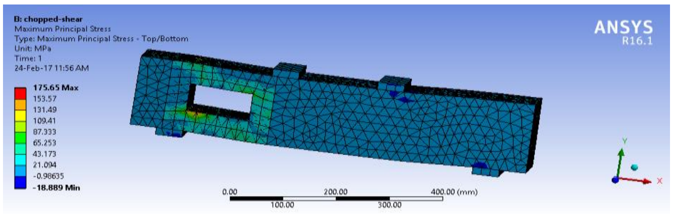
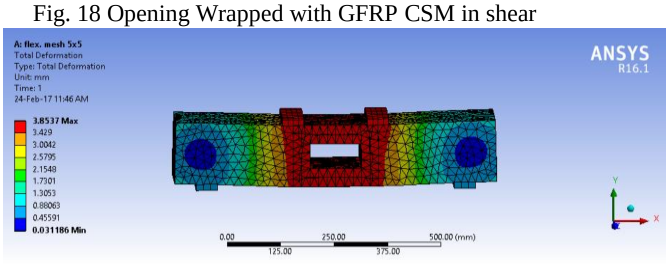


(b)

Fig. 18 Opening Wrapped with GFRP CSM in shear



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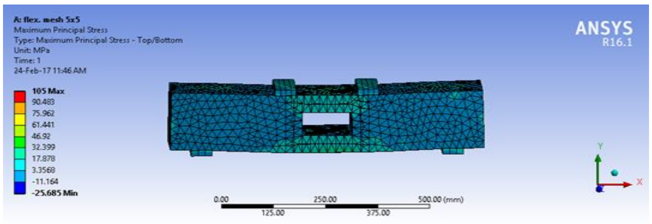
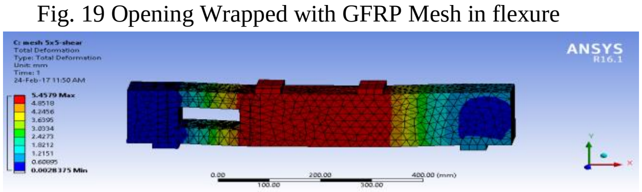


(b)

Fig. 19 Opening Wrapped with GFRP Mesh in flexure



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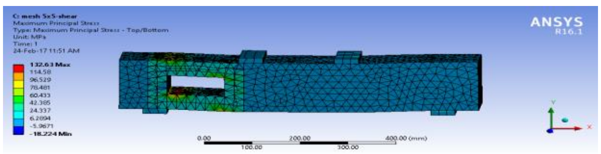

(b)

Fig. 20 Opening Wrapped with GFRP Mesh in shear

The stress concentration in the Maximum Principal stress diagram gives the crack forming areas.

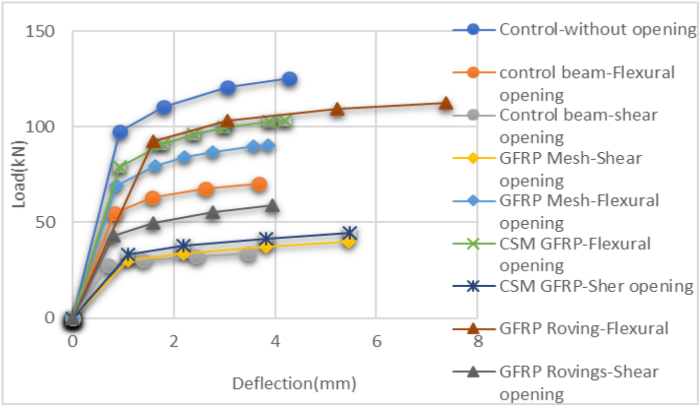

Fig 21:- Load-Deflection graph from Ansys 16.1

Table 9:- Load-Deflection data from Ansys 16.1

Type of GFRP used	Ultimate load(kN)	Maximum deflection(mm)
control beam w/o opening	125.532	4.2776
Control flexural opening	70.365	3.6676
control shear opening	33.6458	3.4705
GFRP ROVINGS(Shear)	58.784	3.9385
GFRP ROVINGS(Flexure)	112.282	7.3792
CHOPPED GFRP(Shear)	44.527	5.4634
CHOPPED GFRP(Flexure)	103.306	4.1854
GFRP MESH(Shear)	39.678	5.4579
GFRP MESH(Flexure)	90.32	3.8537

Among the three different types of GFRP sheets, GFRP Rovings can carry more load (688.25kNmm and 161.78 kNmm) than Chopped mat GFRP (367.27 kNmm and 144.24 kNmm) and GFRP Mesh (243.20 kNmm and 140.08 kNmm).

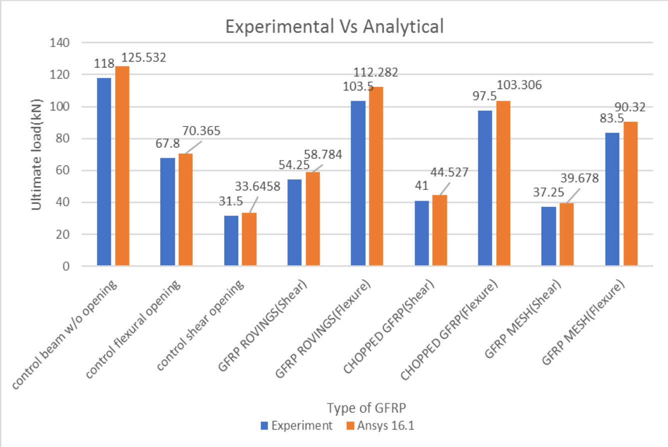

Fig 22:- Load-Deflection graph from Experiment and Ansys 16.1

VIII. CONCLUSION

Based on the experimental investigation and analytical study of strengthening of RC beams with openings using externally bonded GFRP composites, I reached into the following conclusions.

1. The initial visible cracks in the strengthened beams are formed at a higher load compared to the ones in the control beams
2. Formation of crack gets delayed due to the use of GFRP sheets.
3. The load carrying capacity of the strengthened beams is found to be greater than that of the control beams, thus the externally bonded GFRP composites enhances the load carrying capacity.
4. Among the two types of failure (shear failure and flexural failure) in beams, shear failure was observed during experimental testing
5. The results obtained from experiment and numerical study is comparable.
6. Among different types GFRP wrapping around openings, WR GFRP wrapping is found to be more effective than CSM&Mesh
7. From the overall study, it can be concluded that the strengthening with GFRP around and inside rectangular opening having WR GFRP wrapping is more efficient, but costlier than CSM&Mesh.
8. CSM Wrapping is also good since it has sufficient load carrying capacity as well as it is economical.
9. The average energy absorption capacity of control beam with flexural opening was found to be 223.4128 Which is less than the absorption capacity of all other beams with flexural opening wrapped by different types of GFRP sheets
10. The average energy absorption capacity of control beam with shear opening was found to be 61.725 Which is less than the absorption capacity of all other beams with shear opening wrapped by different types of GFRP sheets

IX. ACKNOWLEDGEMENT

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