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NUMERICAL STUDY ON BEHAVIOUR OF FRP STRENGTHENED RC BEAMS WITH SHEAR AND FLEXURAL OPENING

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ABSTRACT

Abstract: In the construction of multi-storey buildings the opening in beams are provided for utility ducts and pipes. Providing an opening in beam develops cracks around the opening due to stress concentration. In this paper the behaviour of R.C.C. beam with rectangular opening strengthened by CFRP and GFRP sheets were studied. This paper presents the behaviour of R.C.C. beam with rectangular opening strengthened by CFRP and GFRP sheets with different techniques. In this analytical study total nine beams were modelled ,one beam without opening (i.e. solid beam) and one beam with rectangular shear opening and one with flexural opening. These three considered as a control beams for comparison. The remaining six beams were externally strengthened by Carbon fibre reinforced polymer (CFRP) and Glass fibre reinforced polymer (GFRP) sheets with different strengthening techniques i.e. around the opening, inside the opening, inside and around the opening and double layer around the opening. These beams were analysed using ANSYS 14.5 . The effect of CFRP and GFRP sheets with different strengthening schemes on such beams were studied in terms of initial crack load, ultimate failure load, cracking pattern and deflection, From the analytical results it is concluded that the ultimate load carrying capacity of the R.C.C. beam with opening strengthened with GFRP sheets of different schemes were increased in the range of 3.74 % to 37.41% and beams strengthened with CFRP sheets increased in the range of 9.35% to 50.50%. Among all these techniques, the strengthening with CFRP around and inside the opening was found more effective in improving the ultimate load carrying capacity of beam. This investigation helps the practicing engineers to provide an opening in the beams without reducing its load carrying capacity.

Keywords: Reinforced concrete beams, Beams with rectangular opening, CFRP, GFRP, Strengthening schemes, Ultimate load carrying capacity.

I. INTRODUCTION

Beam openings may be of different shapes, sizes and are generally located close to the supports where shear is dominant. In practical life it is quite often use to provide convenient passage of environmental services which reduce the story heights of buildings and weight of concrete beams as it improves the demand on the supporting frame both under gravity loading and seismic excitation which results in major cost saving. Openings should be positioned on the concrete beams to provide chords with sufficient concrete area for developing ultimate compression block in flexure and adequate depth for providing effective shear reinforcement [1]. Hanson (1969) tested a typical joist floor i.e. a series of longitudinally RC T-beams representing square and circular openings in the web and found that an opening located adjacent to the centre stub (support) produced no reduction in strength [2]. The test data reported by Somes and Corley (1974) indicated that when a small opening (0.25 times the depth of the beam) is introduced in the web of a beam which is unreinforced in shear, the mode of failure remains essentially the same as that of a solid beam [3]. Salam (1977) investigated perforated beams of rectangular cross section under two symmetrical point loads [4]. Siao and Yap (1990) stated that the beams fail prematurely by sudden formation of a diagonal crack in the compression chord when no additional reinforcement is provided in the members near the opening (chord members) [5]. Mansur et al. (1991) tested eight RC continuous beams, each containing a large transverse opening and found an increase in depth of opening led to a reduction in collapse load. Mansur (1998) discussed about the effects of transverse opening on the behavior and strength of RC beams under predominant shear and stated that opening represents a source of weakness and the failure plane always passes through the opening, except when the opening is very close to the support so as to bypass the potential inclined failure plane. Abdalla et al. (2003) used fibre reinforced polymer (FRP) sheets to strengthen the opening region in his experiment [6].

The studies are limited due to the problems in providing the materials and the proper conditions to conduct the experiments and scarcity of usage of materials which are constituted according to certain size and number of elements. Modeling of all these Processes unlimitedly in computer is dependent on the capacity of the computer being used. While modeling on the computer, properties and limit conditions of materials should be defined properly and completely [12].

Finite element method is a numeric method which can solve complex and difficult physical problems) with acceptable approximation. As concrete is a material showing nonlinear behavior during loading, it is modeled in such a way that it will show a nonlinear behavior with (Ansys) finite element program which is the most advanced comprehensive reputable finite element analysis and design software package available for Structural Engineering Projects. The System combines the state of the art general propose structural analysis features of ANSYS with the high and civil engineering specific structural analysis capabilities of making it a unique and powerful tool for a wide range of civil engineering projects [7].

The openings are usually provided in such beams to have an access for utility ducts like air conditioning, electricity or a computer network without further increases in ceiling head room.

II.MODELING AND ANALYSIS PROCESS BY ANSYS

2.1 General Information

2.1.1 Dimension (Fig. 1)

Reinforced concrete beam: 150 x 1200 x 250

Post rectangular opening : 200x100x150

2.1.2 Steel Reinforcement (Fig. 1)

Top rebar: 2ø10mm

Bottom rebar: 3ø10mm ,Stirrup: 2 legged ø8 mm @ 100 mm c/c

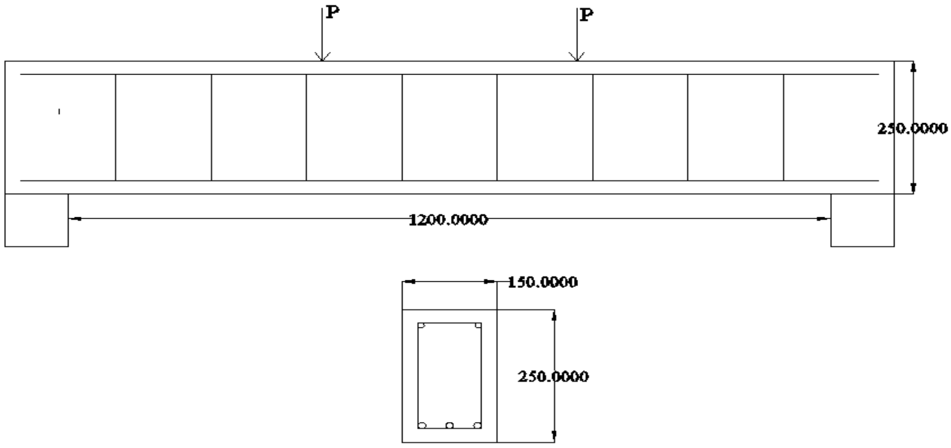

Fig 1: Dimension of beam

2.2 Element Types and Material Properties

2.2.1 Concrete

SOLID65 is used for the 3-D modeling of concrete. The element is defined by eight nodes having three degrees of freedom at each node i.e. translations in the nodal x, y and z directions. The most important aspect of this element is the treatment of nonlinear material properties [7]. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation and creep. Concrete was assumed to be both linear elastic and multilinear inelastic material. Compressive strength of concrete was 25 MPa and tensile strength was assumed 9% of concrete compressive strength. Poisson's ratio of 0.2 was used.

2.2.2 Reinforcing Bar

LINK8 is defined by two nodes which has used for the modeling of reinforcing bar. The 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y and z directions. As in a pin-jointed structure, no bending of the element is considered. Plasticity, creep, swelling, stress stiffening and large deflection capabilities are included [7]. Reinforcing bars was assumed to be both linear elastic and bilinear inelastic material. Yield strength of longitudinal reinforcements and stirrups were 415 Mpa. Poisson's ratio of 0.3 was used.

2.3 Loading and Boundary Condition

To ensure that the model behave the same way as the experimental beam boundary conditions were needed to be applied at nodes in the supports. The supports were modeled to create fixed supports. The force P was applied on all nodes through the entire centre line of two points in top fibre of the beam at equal distance from the mid span.

2.4 Meshing

In this research a convergence study was carried out to determine an appropriate mesh density. Various mesh sizes were examined in ANSYS. It was observed that the obtained ultimate load for mesh size 25 mm (77021 N) is nearest to the ultimate load of experimental beam (80000 N) [6]. For this reason, the mesh size equal to 25 mm was chosen for this study.

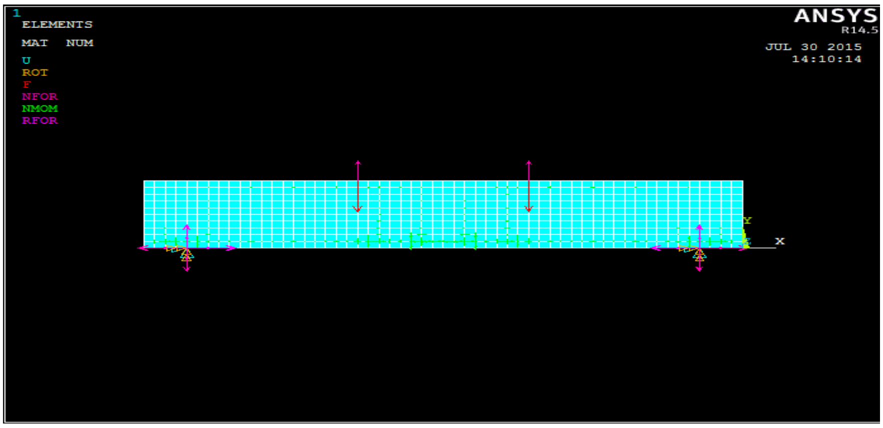

Fig. 2: Loads,Supports & Meshing Done on Model

III. RESULTS AND DISCUSSION

3.1 General

Here a total of nine beam models were analysed and the results were discussed. This section is divided into three parts. The first part comprises of result and discussion about control beam. The second part comprises of result and discussion of beam with GFRP wrapping in the opening. The third part comprises of the result and discussion of beam with CFRP wrapping at the opening.

3.2 Control Beam-Analysis

Here a total of three beams were modelled and analysed. i.e a normal beam without opening, beam with flexural opening , beam with shear zone opening. The Fig (3-15) shows model, deflection,stress distribution, crack pattern of all type of beam without the fibre polymer wrapping.

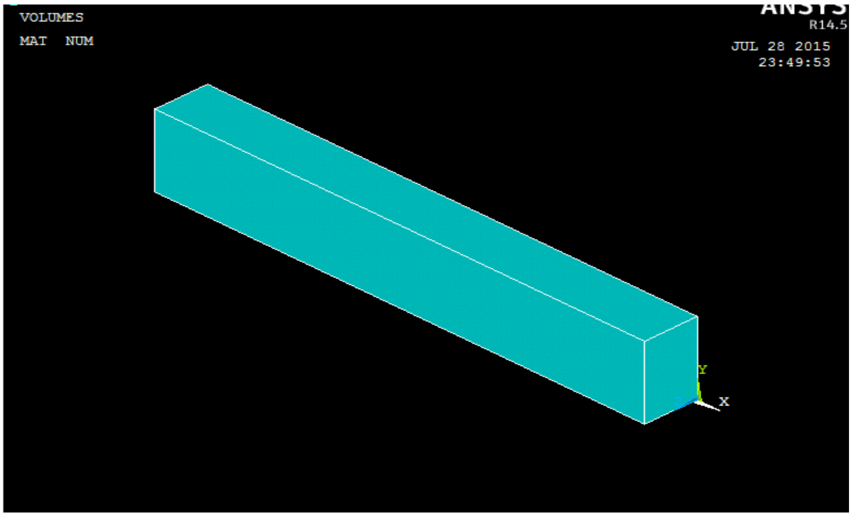

Fig. 3: Model Of Normal R.C Beam

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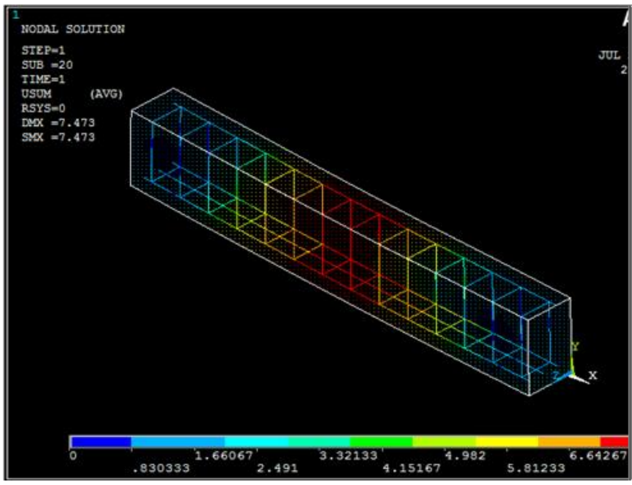

Fig. 4: Deflection Of R.C Beam

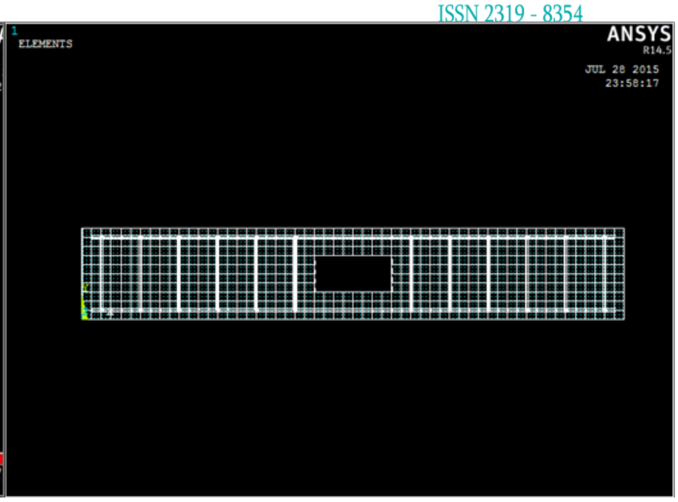

Fig. 7: Model Of Flexural Opening Beam

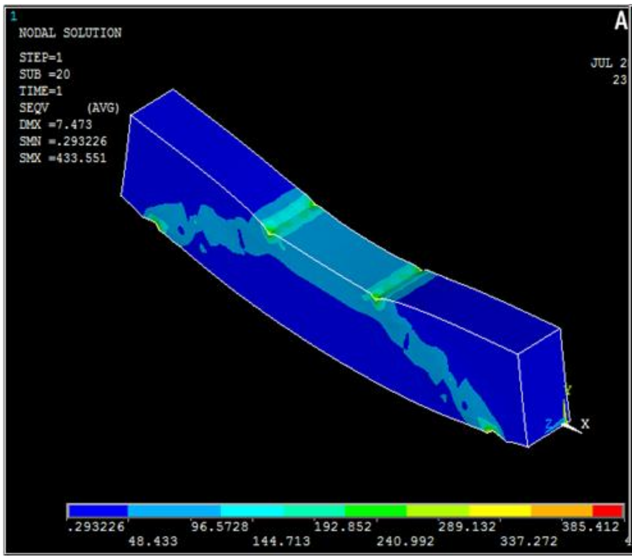

Fig. 5: Stress Distribution In R.C Beam

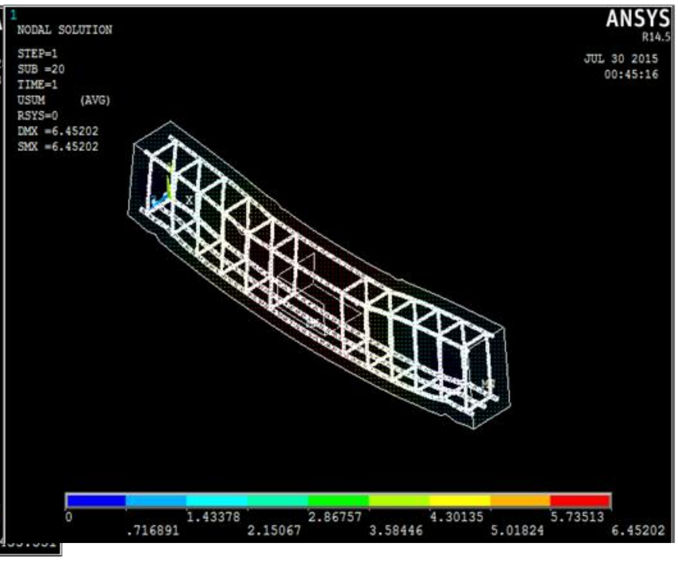

Fig. 8: Deflection Of Flexural Opened Beam

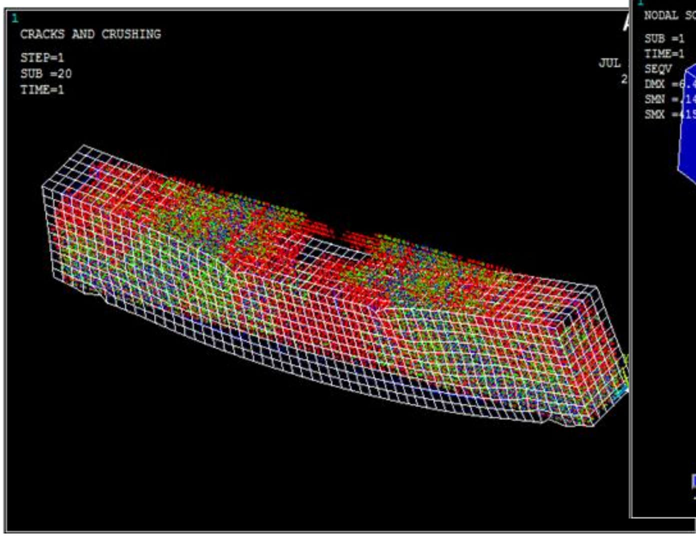

Fig. 6: Crack Pattern

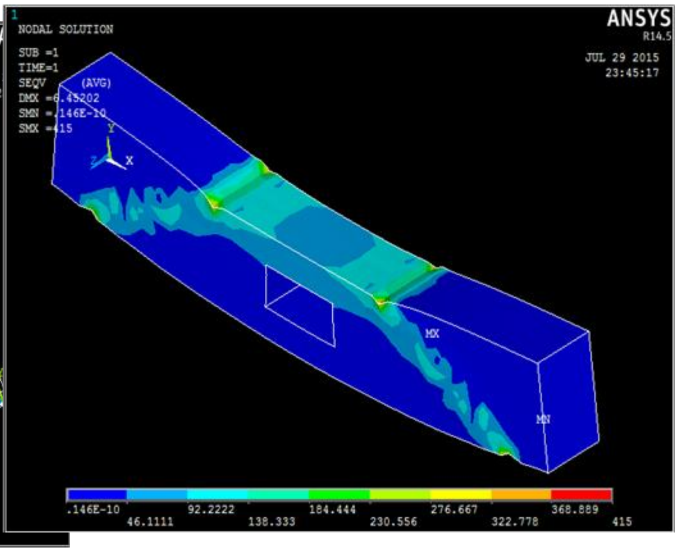

Fig. 9: Stress Distribution Of Flexural Opened Beam

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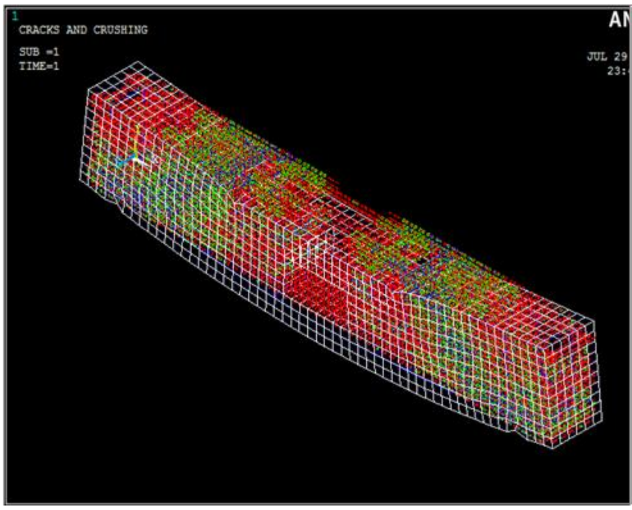


Fig. 10: Crack Pattern Of Flexural Opened Beam

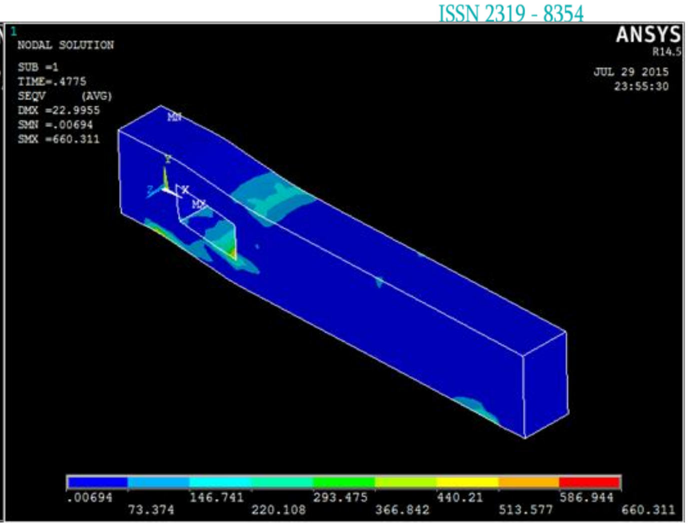


Fig. 13: Stress Distribution Of Shear Opening

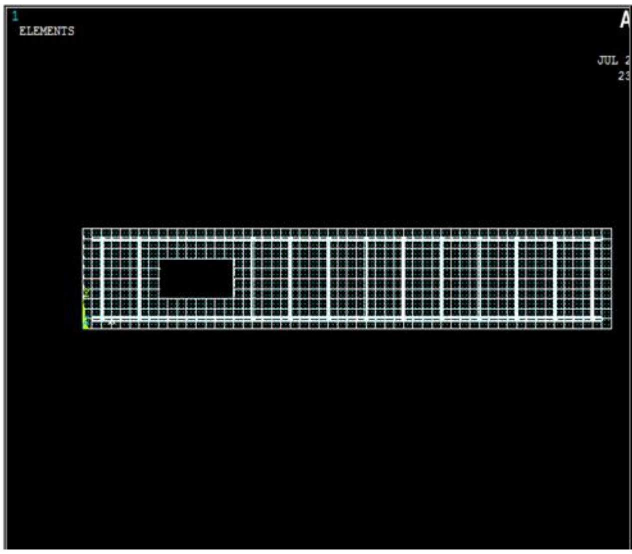


Fig. 11: Model Of Shear Zone Opening

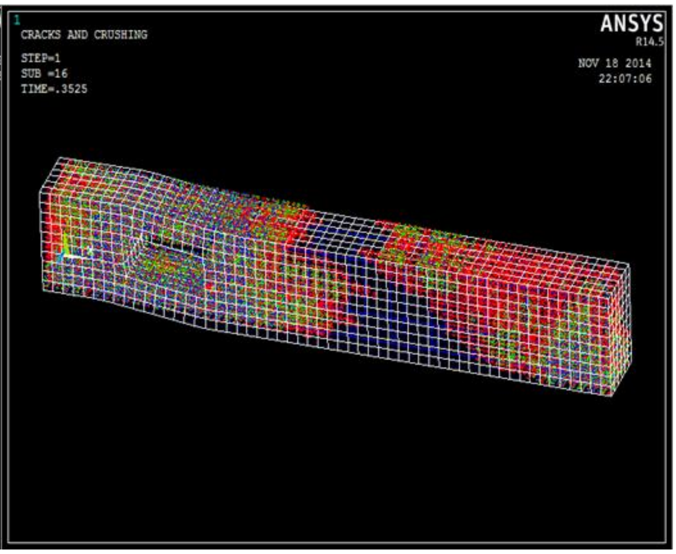


Fig. 14: Crack Pattern Of Shear Zone Opening

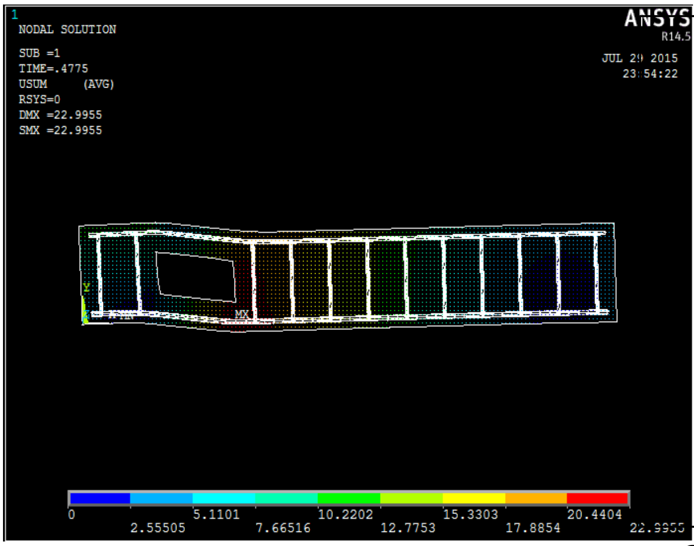
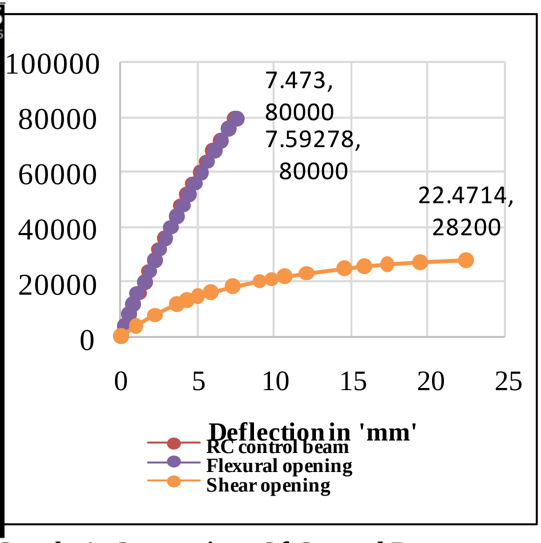


Fig. 12: Deflection Of Shear Opening



Graph. 1: Comparison Of Control Beams

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3.2.1 Discussion of the Control Beam

From the test results, it could be concluded that the ultimate load carrying capacity of the RC beam at shear zone with opening was maximum reduction but at flexure zone, it showed minimum reduction.The location of openings has a large effect, where this effect is the largest when openings location is at shear zone and a small effect when openings location is at flexure zone, so the best place for the location of opening in these beams is in middle of a beam. Also from the Gaph 1 the beam with shear opening shows the maximum deflection, thus the progress of the project was based on the improvement of the shear zone opening.

3.3 Shear Zone Strengthened By Gfrp Sheet

A numerical study is done on the shear behavior ofreinforced concrete beam containing openingsstrengthened by GFRP sheets.Three reinforcedconcrete (RC) beams containing openings weak in shear having same reinforcement detailing are modeled and tested under two point loading.The Fig (15-26) shows the various GFRp wrapping technique and its analysis.

Table 1: Material Property Of GFRP

FRP Composite	Elastic modulus MPa	Major Poisson's ratio	Tensile strength MPa	Shear modulus MPa	Thickness of laminate mm
GFRP	Ex=21000	Vxy=0.26	600	Gxy=1520	1.3
	Ey=7000	Vxz=0.26		Gxz=1520	
	Ez=7000	Vyz=0.30		Gyz=2650	

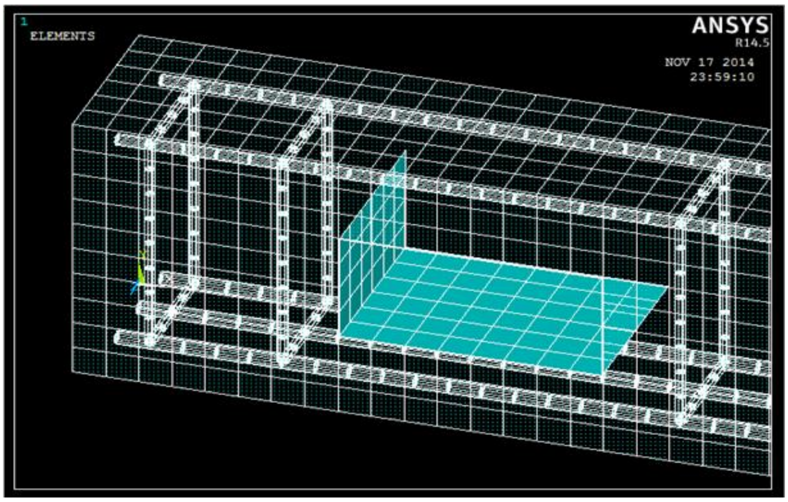

Fig. 15: Model Of GFRP Wrapped Inside The Opening

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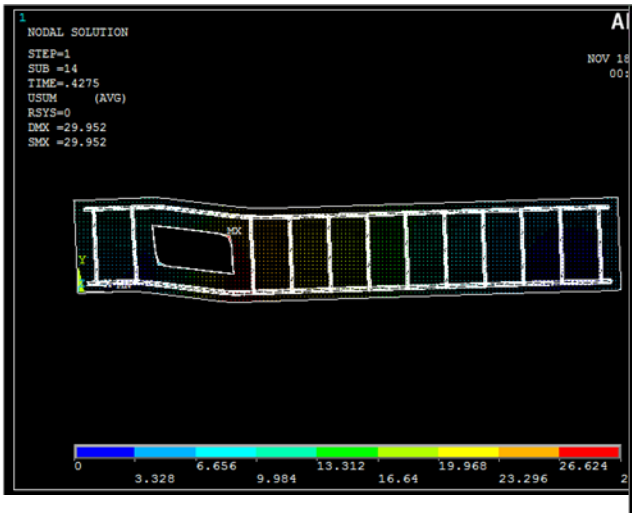

Fig. 16: Deflection Of GFRP Wrapped Inside The Opening

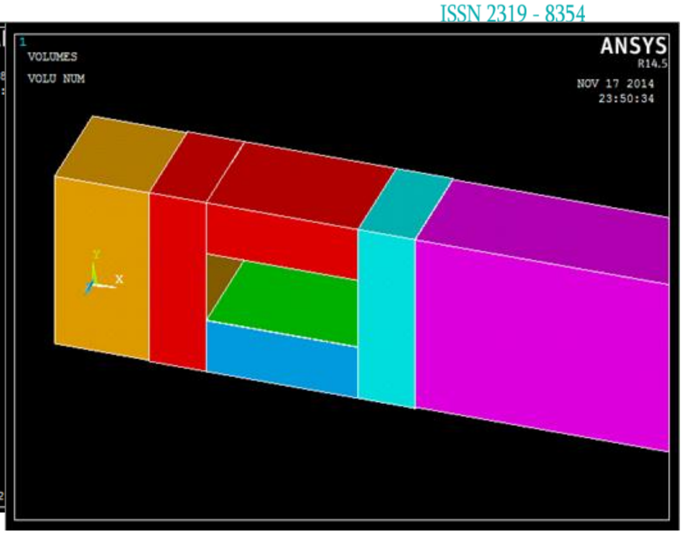

Fig. 19: Model Of GFRP Wrapped Around The Opening

Fig. 17: Stress Distribution Of GFRP Wrapped Inside The Opening

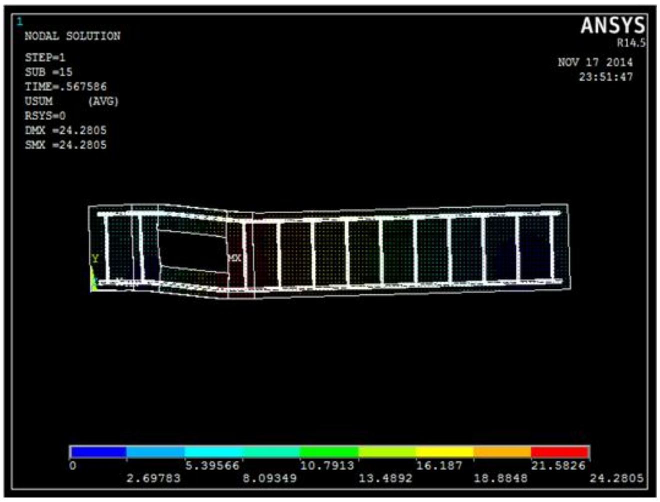

Fig. 20: Deflection Of GFRP Wrapped Around The Opening

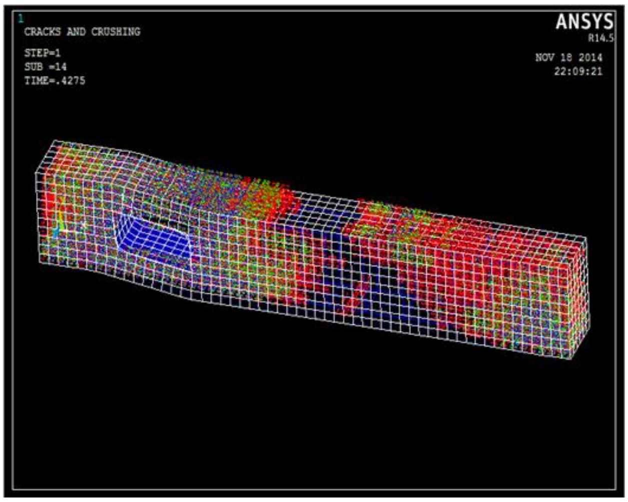

Fig. 18:Crack Pattern Of GFRP Wrapped Inside The Opening

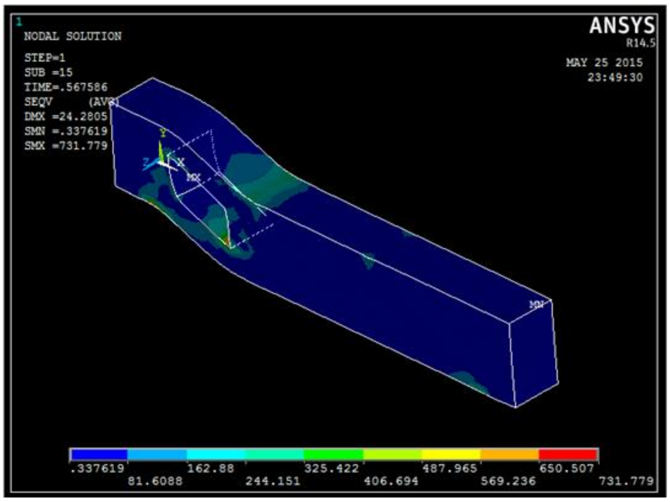

Fig. 21:Stress Distribution Of GFRP Wrapped Around The Opening

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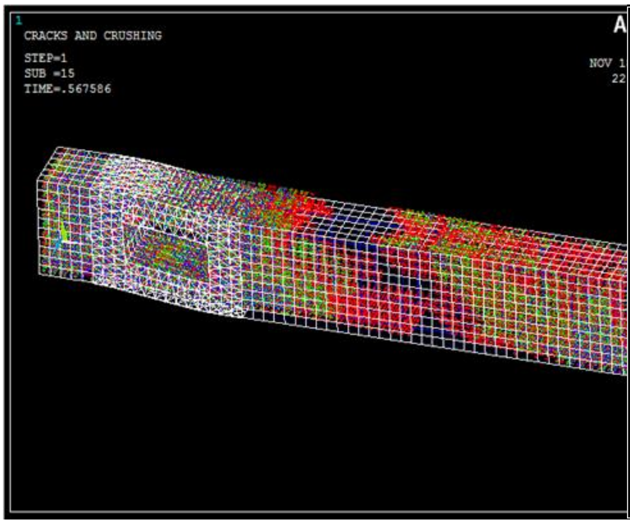

Fig. 22: Crack Pattern Of GFRP Wrapped Around The Opening

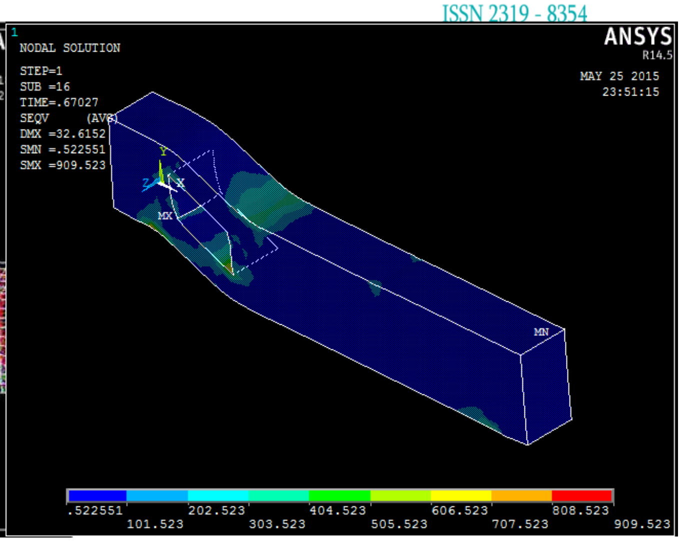

Fig. 25: Stress Distribution Of GFRP Wrapped Inside And Around The Opening

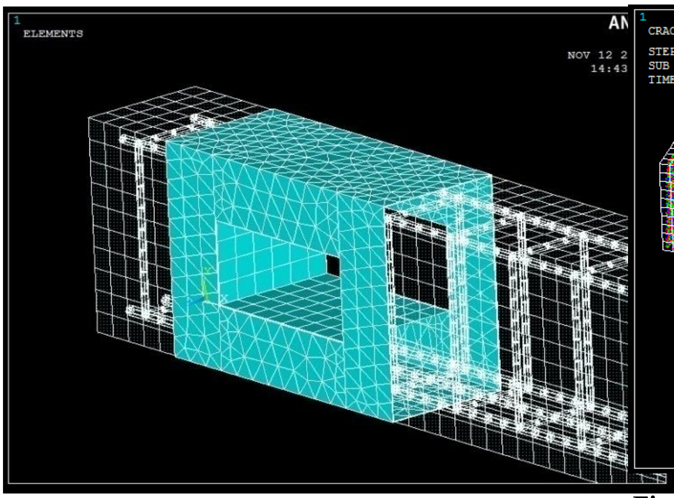

Fig. 23: Model Of GFRP Wrapped Inside And Around The Opening

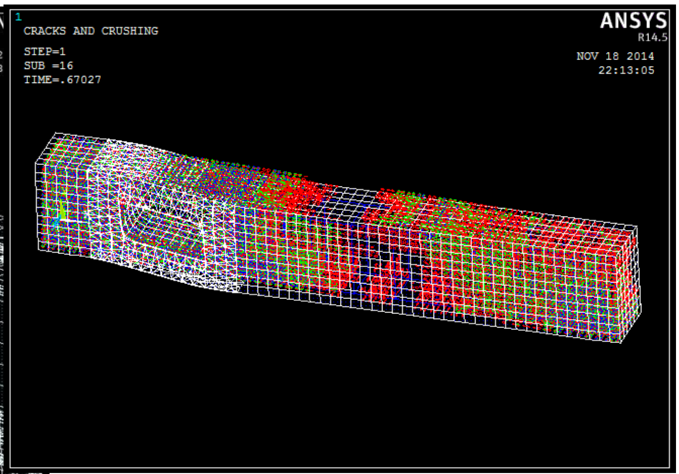

Fig. 26: Crack Pattern Of GFRP Wrapped Inside And Around The Opening

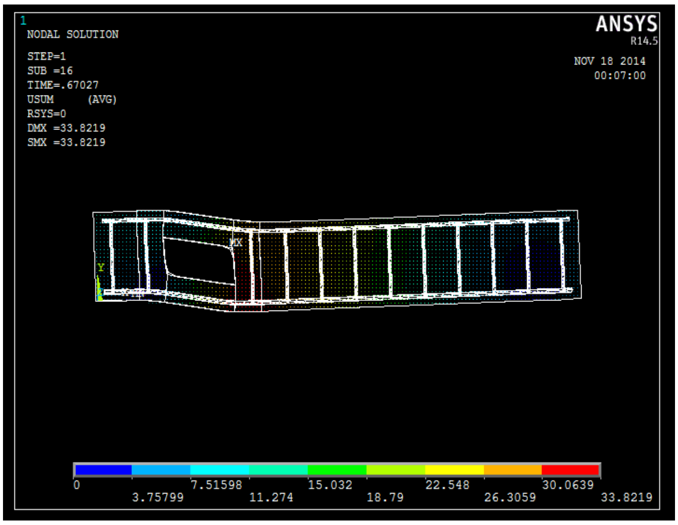

Fig 24:Deflection Of GFRP Wrapped Inside And Around The Opening

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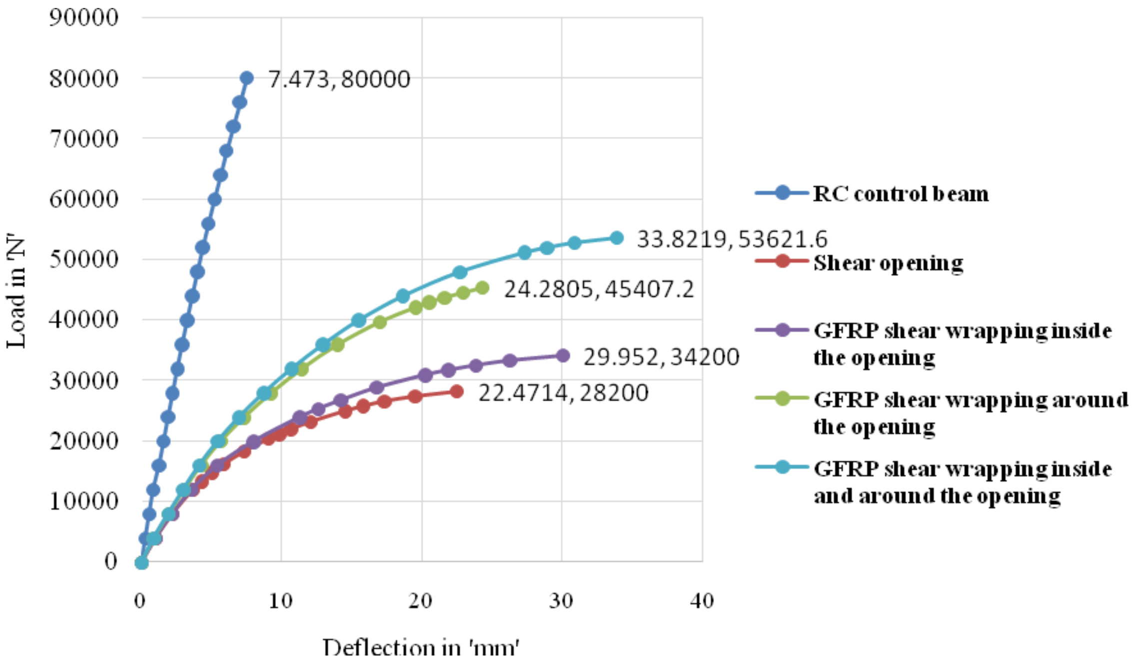

Graph 2: Comparison Of GFRP Wrapping Technique

3.3.1.Discussion Of The Beam Wrapped With Gfrp

The numerical results presented in graph it is clear that the presence of an opening not only reduced the load carrying capacity of the beam but also reduce the stiffness of the beam.The percentage of increase in load carrying capacity for the beams strengthened with GFRP(B4) sheet inside the opening was 15.49% and the beams strengthened with GFRP (B5) sheet around the opening was 36.35%. The percentage of increase in load carrying capacity for the beams strengthened with GFRP (B6) sheet inside and around the opening was 46.10% respectively as compared to non-strengthened beam B3 (RC beam with rectangular post opening).

3.4 Shear Zone Strengthened By Cfrp Sheet

An numerical study is done on the shear behavior of reinforced concrete beam containing openings strengthened by CFRP sheets.Three reinforced concrete (RC) beams containing openings weak in shear having same reinforcement detailing are modeled and tested under two point loading. The similar way of procedure done in GFRP wrapping technique is followed in case of CFRP wrapping. The CFRP strengthened beams are analysed in the similar way as done for GFRP wrapping, so only the graphical representation is shown here in **Graph 3.**

Table 2: Material Property Of CFRP

FRP Composite	Elastic modulus MPa	Major Poisson's ratio	Tensile strength MPa	Shear modulus MPa	Thickness of laminates
CFRP	Ex=2.3e5	Vxy=0.22	3.5e3	Gxy=1.179e4	1 mm
	Ey=1.79e4	Vxz=0.22		Gxz=1.179e4	

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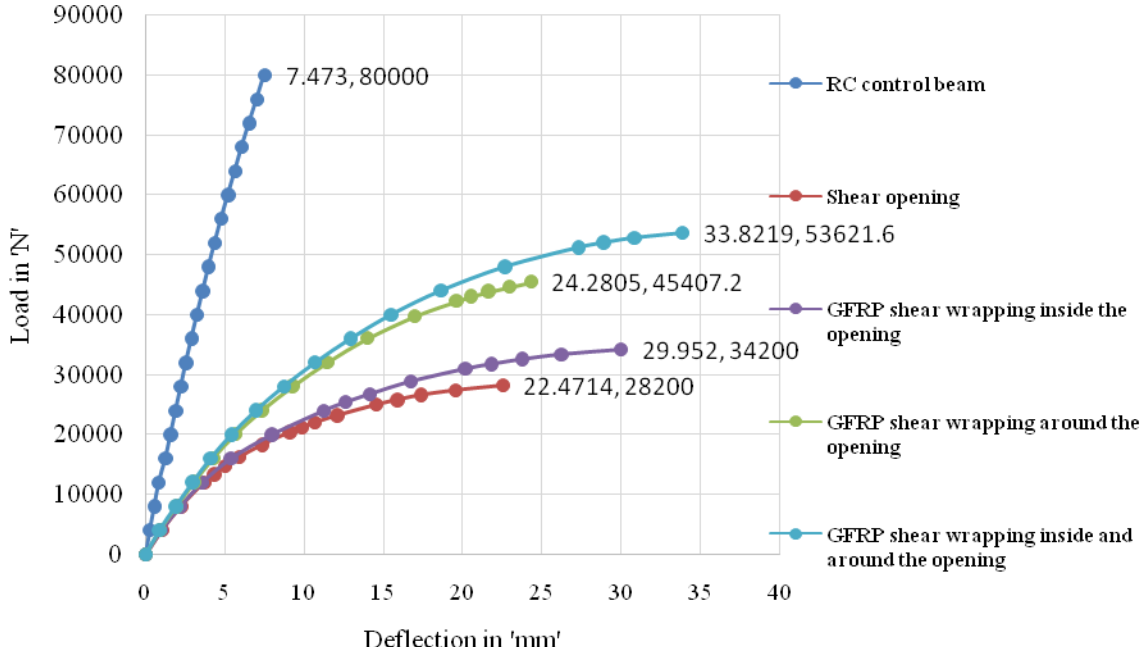
	Ez=1.79e4	Vyz=0.30		Gyz=6.88e3	



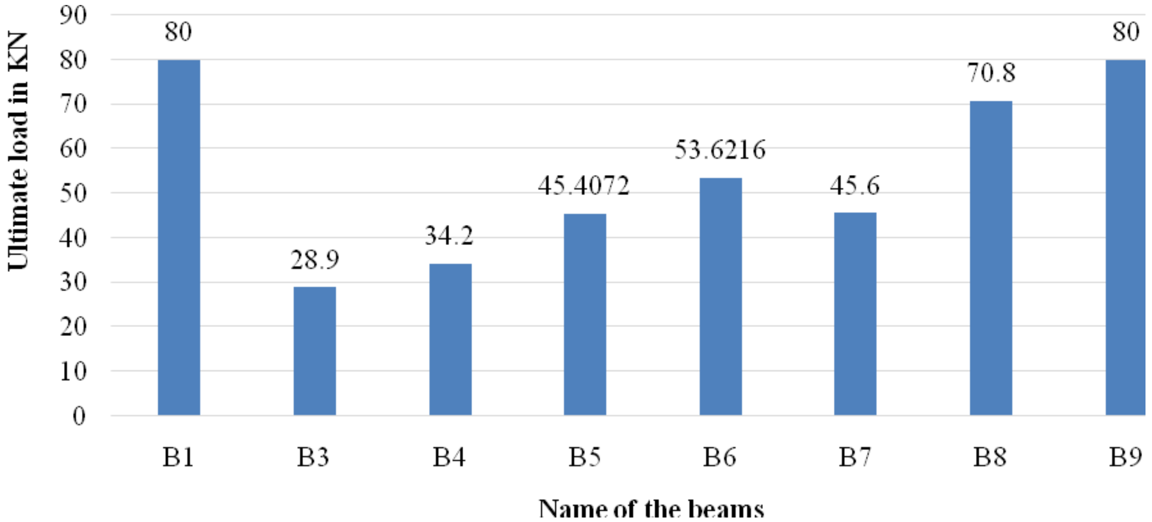
Graph 3: Comparison Of CFRP Wrapped Inside And Around The Opening

3.4.1 .Discussion of The Beam Wrapped With Cfrp

The numerical results presented in graph , it is clear that the presence of an opening not only reduced the load carrying capacity of the beam but also reduce the stiffness of the beam.The percentage of increase in load carrying capacity for the beams strengthened with CFRP (B7) sheet inside the opening was 36.62% and the beams strengthened with CFRP(B8) sheet around the opening was 59.18%. The percentage of increase in load carrying capacity for the beams strengthened with CFRP (B9) sheet inside and around the opening was 63.87% respectively as compared to non-strengthened beam B3 (RC beam with rectangular post opening). All the designation of the beam , mode failure, deflection etc.. are shown in **TABLE 3.**

3.5 Comparison of Gfrp and Cfrp Wrapping Technique

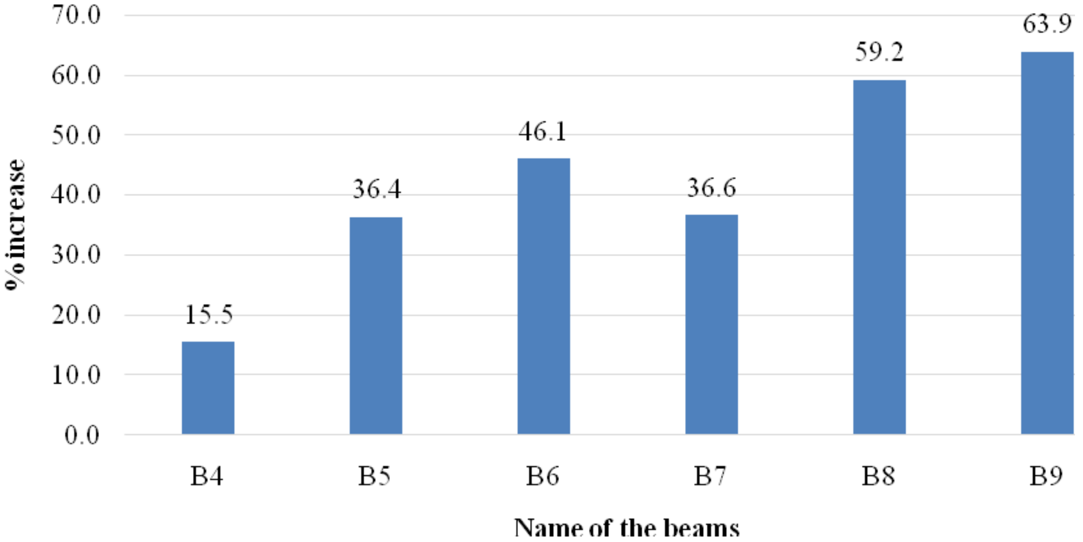
In this section both the wrapping technique has been compared and based on the comparison of the result obtained for GFRP and CFRP wrapping the conclusion have been made. The following figures and graphs shows the difference in the ultimate load carring capacity and percentage of increase in the loading carring capacity.



Graph 4: Ultimate Load Carring Capacity Of Both GFRP And CFRP Strengthened Beams With Opening At Shear Zone

Table 3: Designation And Details Of The Modelled Beam

Designation on Beam	Type of strengthened	Ultimate failure Load in KN	Increase in load carrying capacity in %	Mode of Failure
B1	Control beam	80.0	-	Flexure
B3	Non strengthened control beam (post opening)	28.9	-	Shear
B4	GFRP wrapping inside the opening	34.200	15.49	Shear
B5	GFRP wrapping around the opening	45.4072	36.35	Shear
B6	GFRP wrapping inside and around the opening	53.6216	46.10	Flexure
B7	CFRP wrapping inside the opening	45.600	36.62	Shear
B8	CFRP wrapping around the opening	70.800	59.18	Shear
B9	CFRP wrapping inside and around the opening	80.0	63.87	Flexure



Graph 5: Percentage Of Increase In The Ultimate Load Carring Capacity Of Both GFRP And CFRP Strengthened Beams With Opening At Shear Zone

IV.CONCLUSIONS

In this study an effort was taken to compare the strength obtained by the beams with post opening, when it is subjected to CFRP and GFRP wrapping technique.Following are the conclusions obtained from the graphs by comparing the both technique.

1. The present numerical study is done on the shear behavior of reinforced concrete beams containing openings strengthened by GFRP and CFRP sheets.
2. By an inclusion of rectangular post opening in the beam the load carrying capacity of the beam decreases by28.9% as compared to solid beam i.e. control beam due to decrease its stiffness. The diagonal cracks were developed due to stress concentration around the opening edges.
3. Strengthening of the beam opening with CFRP and GFRP sheets around the opening is more efficient than strengthening of the beam opening with CFRP and GFRP sheets inside the opening.
4. Strengthening of the beam opening by using CFRP and GFRP sheets both inside and around the opening increases the load carrying capacity significantly and in case of CFRP sheets percentage of increase in load carrying capacity is 63.87%, where as in case of GFRP sheets percentage of increase in load carrying capacity is 46.1%.
5. From the overall study, it can be concluded that the strengthening with CFRP around and inside the opening is more efficient and is considered as best strengthening scheme.
6. These techniques help the practicing engineers to strengthen the openings provided in existing building

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