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Comparative and Numerical Study of Open Webbed RC Beams with Different FRP's using ANSYS

Puneet Shetty
PG Student, Department of Civil Engineering, Global Academy of Technology, Bengaluru, India

***Abstract*: In the construction of modern building structures, reinforced concrete (RC) deep beams are often used as primary load transferring elements, such as transfer girders in offshore structures and foundation. Transverse openings in reinforced concrete deep beam are provided for the purpose to accommodate ducts and pipes. The existence of web opening interrupts the natural load path and reduces the stiffness and load carrying capacity of structural element. Even the location of opening for beam is a major factor to be kept in mind while designing. The objective of this study is to enhance the stiffness of the beam by providing a coat of FRP composite near the opening and in same time compare it with thee stiffness of control beam with opening. In this study a beam model of size (230 X 450 X 1700) mm is modelled in ANSYS and an opening of size (300 X 150) mm is provided at 150mm from both the ends of the support and in case of beam coated with FRPs a 5mm coat of different FRP composites wherein the opening size in such beams is reduced to (290 X140) mm. The fibers used are Aramid Fiber, Basalt Fiber, Carbon Fiber, Glass Fiber and Polypropylene Fiber. A total of 6 models are analysed. The deformation in FRP coated beam is less compared to that of Control beam.**

***Keywords*: Deep beams, strengthening, aramid fiber, basalt fiber, carbon fiber, glass fiber, polypropylene fiber, openings, deformation.**

1. INTRODUCTION

A beam is a basic structural element which is used to bear the loads coming on it. In the modernisation of presentday structures, various channels and conduit are essential to be considered for major provisions like water supply, sewage, cooling, electricity, telephone, and PC framework.

At each level of the building, this dead space will require some height to accommodate these ducts and pipes. This height will particularly depend on the number of channels and conduits needed per floor which then will be added to the height of the building which may go up-to increase in half a metre to the normal height especially in case of tall structures.

Openings with different shapes are possible, but the round and rectangular shape openings are most preferred ones. Circle-shaped openings at times can be too clumsy to accommodate the water-pipes and the electrical supply lines along with the AC ducts and channels whereas in case of rectangle shape opening all of these can be properly adjusted. In case, if in the rectangular shaped openings if these conduits are compactly fitted or if more space is needed to accommodate more pipes then the corners can be varied accordingly which cannot be done in case of circle shaped openings.

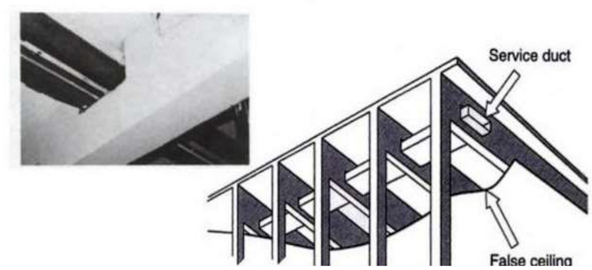

Fig. 1. Typical Layout of Service Duct and Pipes

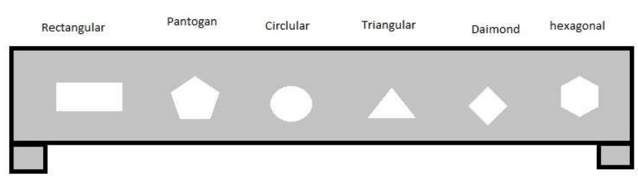

Fig. 2. Openings of different shapes

Types of fibers used:

A. Aramid Fiber

Aramid fibers are man-made high-performance fibers, with particles that are categorised by comparatively unyielding polymer links. These particles are connected by powerful hydrogen links that transmits mechanical stress very effectively, making it likely to use chains of comparatively lower molecular mass.

The term "Aramid" is derived from "Aromatic Polyamide". These fibers belong to class of resisting heat fibers and highly resistant to high temperature. They were first used commercially in 1960's. There are 2 most widely used aramid fibers namely Nomex and Kevlar, both invented by Du Pont Ltd USA. Nomex fibers are meta-paramid fibers manufactured by polymerization of *m*-phenylene diamine and dichloride of *m*-

isopthalic chloride It is well-known for its combination of heating defiance and strength. Moreover, meta-aramid fibers are fire resistant and does not dissolve or leak. They are generally used in making of fire-proof dresses, space-suits, Foundry worker's clothing etc.

Kevlar Fibers are para-aramid fibers. These fibers have high tensile strength, high tensile modulus and high heat resistance because of the highly adjusted solid molecular configuration. Kevlar is about five times lighter than steel in terms of the same tensile strength. Para aramids generally have high glass transition temperatures nearing 370°C and do not soften or burn easily. Kevlar is used where its *high strength and modulus* are required especially in radial tyres, high-power transmission belts and for composites as a reinforcing component.

Fig. 3. Aramid Fiber Sheet

B. *Basalt Fiber*

It is a kind of igneous-rock fashioned through quick freezing of magma molten rock at exteriors of the globe. The manufacture of such fibers and the glass-grains remains alike. Compacted basalt rock is the lone crude material required for engineering the fibre. These fibers are continuous fibre formed during melting of igneous basalt rock at a temperature nearing 1500°C. Fibers like Basalt are moderately a new arrival to fibre reinforced polymers and structural amalgams. Carrying a comparable chemical arrangement similar to glass fibers and improved strength features, it is very much impervious to alkaline, acidic and salt assault, which is building it a good contender for concrete, bridge and coastline structures.

The value of fibers prepared from basalt is complex than those made of E-glass, but less than S-glass or carbon fibre and as universal fabrication increases, its cost of creation is much reduced. Basalt fibers possess high ability along with receiving a lot of consideration because of its pitching temperature and abrasion opposition. Related to fiber composites made from carbon, glass and polypropylene fibre, its consumption in the construction organisation marketplace is very less.

Fig. 4. Basalt Fiber Sheet

C. *Carbon fiber*

Carbon fibre comprises of 3 kinds of polymers polyacrylonitrile(PAN) fibre, rayon fibre and pitch. They have a undeviating stress-strain curve till the point of break. Regardless of the fact that there are several carbon fibres accessible at the open marketplace. Carbon fibres have thermal development coefficients lower than the glass. A anisotropic material with the transverse modulus less than the longitudinal modulus in terms of size. It is resistant to weakness and creep. Its elastic modulus ranges between 200-800 GPa. The final elongation has a range of 0.3 to 2.5%, lower the elongation higher is the toughness and vice-versa. They don't absorb water and they are resistant against many chemical actions. Carbon fibre is electrically semi-conducting and, thus, may provide galvanic decay in direct contact with metal.

Due to the fact that its ductile behaviour decreases as modulus increases, its stress at break will be very less. Due to the fibers fragility at greater modulus, becomes vital near junction and assembly, which could devour extreme strain applications. Hence CFRP coats are extra effective with adhesive linking than motorized fasteners.

Fig. 5. Carbon Fiber Sheet

D. *Glass Fiber*

The glass elements are split into 3 castes - E-glass, S-glass and C-glass. E-glass is allocated for electrical utilization and the S-glass for high-level. C-glass is intended for extreme erosion safety and significant for the structural building usage. Out of all these strands, E-glass stands most established reinforcement material employed on behalf of ordinary structures. They are produced from lime, alumina, borosilicate, that easily grows from riches of unpolished materials as sand. These filaments are extracted to small fibers with diameters ranging from 2 - 13 X 10 - 6 m. The glass fibre power and modulus can degrade with inflating temperature.

Irrespective of the reality that the glass material creeps under a persistent load, it is proposed in such a way that it performs suitably ok. The fiber itself is viewed as an isotropic material and has a shorter thermal widening coefficient than that of steel. It has notably less priced than carbon and other fibres. Hence glass fiber combinations have transformed out to be well known in various applications. The moduli of fibres range between 70-85 GPa and critical elongation of 2 to 5 % depending upon quality. Glass fibres are soft to stresses; there is decomposition of fibres at high stress planes. Glass fibres are fragile to dampness, yet with the right decision of matrix the fibres are secured.

Fig. 6. Glass Fiber Sheet

E. Polypropylene Fiber

Polypropylene's raw material is extracted from monomeric C3H6 which is a hydrocarbon. Its a technique meant for polymerization, its extreme nuclear mass and the method by which it is set up as filaments to offer polypropylene strands an extraordinarily supportive property. As a result of normal structure, it is known as isotactic polypropylene. Strands are impervious to the greater part of the synthetic compounds due to probable invention and whichever the substance that not outbreaks the solid has no effect on the filaments either. Solid will breakdown first if on contact with the stronger synthetic substances. The hydrophobic surface does not get wet because of bond glue which helps the filaments from balling impact during merging. In the event that the strands are orientated sidelong way then the filaments are powerless which may prompt fibrillations.

The fibers can be created by the drawing cable system with round cross segment or by expelling the plastic flick with quadrangular cross-segment. The fibrillated polypropylene strands remain molded through augmentation of a plastic flick, which is then split into strips and a short time later opening. The fiber bunches are reduced into demonstrated measurements and fibrillated. In monofilament strands, the haul out load is expanded by including the catches at the finishes of the fiber and by turning activity of filaments achieves the most extreme load and stress exchange.

Fig. 7. Polypropylene Fibers

2. Objectives of Study

This paper focuses mainly on the following objectives:

1. Control beam was analysed for total deformation, normal stresses, shear stresses, maximum principal stresses using Ansys Workbench software.
2. Analysis of beam strengthened with FRP sheets of Basalt, Carbon, Glass, Aramid and polypropylene fibers around openings was individually carried out and similarly the deformation and stresses were studied.
3. A comparative study was made between the control beam and the beam reinforced with different fibers and its load carrying capacity was compared.

3. Scope of study

A RC beam with opening is selected to study the stress patterns and the deformations.

Table 1
Dimensions

Beam Size	230mm X 450mm X 1700mm
Young's Modulus for Concrete	25491.17 N/mm^2
Unit wt. of Concrete	$25KN/m^3$
Concrete Grade	M20
Poisson's Ratio	0.20
Grade of Steel used in Concrete	Fe 500
Size of opening provided in Beam	300mm X 150 mm
Concrete Density	2300 Kg/m^3
Steel Density	7850 Kg/m^3

Table 2
FRP Properties

Parameter	Density (Kg/m^3)	Poisson's Ratio	Elastic Modulus (MPa)	Tensile Strength (MPa)
CFRP	1950	0.3	230000	2679.7
PPFRP	900.9	0.28	350000	760
GFRP	2530	0.31	89000	4600
BFRP	2700	0.32	90000	4000
AFRP	1440	0.36	124000	3600

4. Modelling

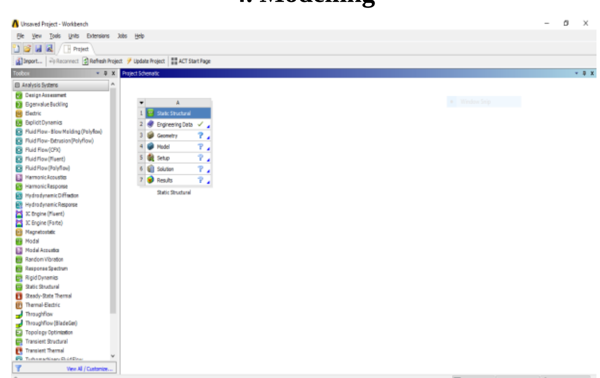

Fig. 8. Ansys Software Interface

This section deals about the modelling of the reinforced concrete open-webbed beams in ANSYS 18.2 software. Modelling materializes to be adding of significant material needed for the study, describing the reinforced concrete open-webbed beam according to the sizes of both beam and the

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opening, initiating the contacts, meshing of the arrangement, support cases, loading pattern and adding the needed output parameters.

In the Engineered data section, the properties of the materials such as Concrete, Steel and as in my case properties of FRP's required for the analysis are entered.

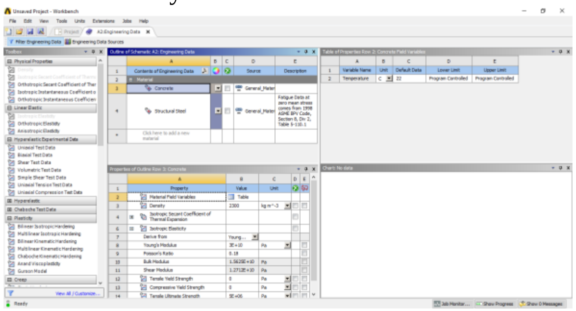

Fig. 9. Considering element types and material properties

Open static structural GUI to draw the model as required for the analysis.

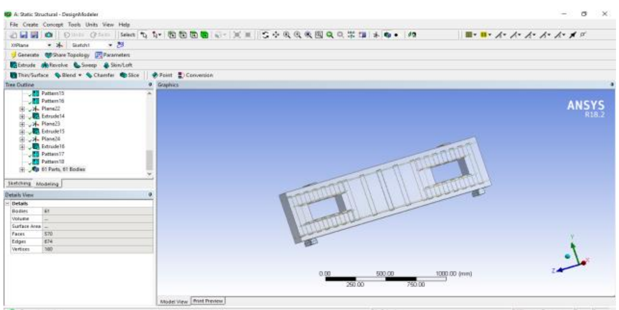

Fig. 10. Static Structural Model

A. *Creating named selection*

Firstly, all the main bars, shear reinforcement bars, laminates and supports shall be named separately by selecting the required elements in the geometry. So that it becomes easy for us while developing manual contacts.

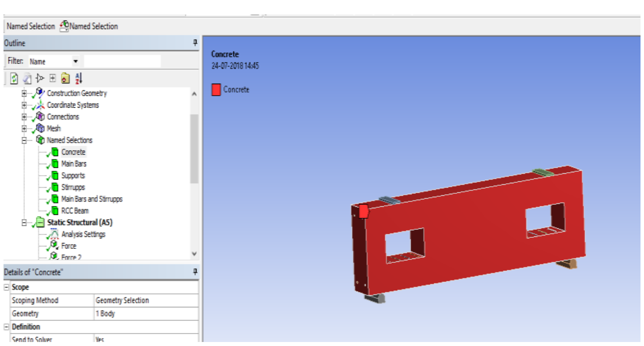

Fig. 11. Named selection

B. *Contacts*

Elements were manually made to contact i.e. manual contact option was used and individually manual contacts were developed instead of automatic contact option. Firstly, as we had created named selection using those we developed a manual contact between stirrups and main bars.

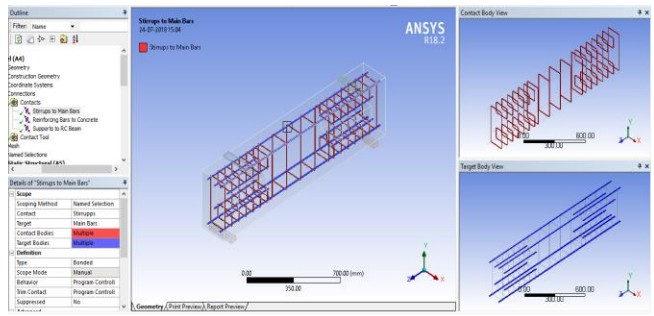

Fig. 12. Stirrups to Main bar Contact

Similarly, second manual contact region was generated using main bars and stirrups in named selection as contact bodies to concrete as target bodies.

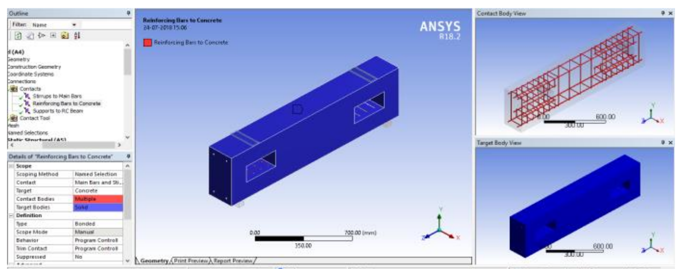

Fig. 13. Main Bar to Concrete Contact

Third manual contact region was made between whole of RC Beam to supports.

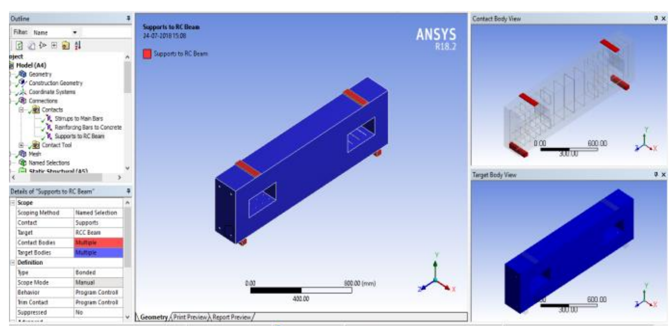

Fig. 14. Concrete to Supports Contact

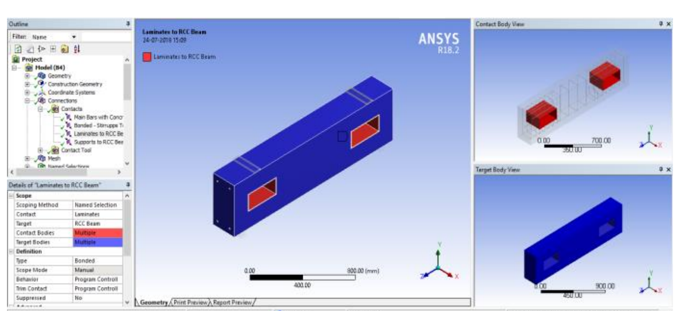

Fig. 15. Laminates to RC Beam Contact

In case of FRP coated sheets, we developed a manual contact between the RC Beam as the target bodies and the contact body as the laminate sheets.

C. Meshing

The model is meshed to smaller units. Meshing size of 25 mm is used to study the control beam with respect to deflection and stresses. It is important in the finite element method that nodes of different bodies match with one another. Tetrahedron meshing is adopted for the concrete along with reinforcing bars and Hex-Dominant meshing for the supports is used to create the mesh. Method sizing option is used for sizing to the bodies. Meshing helps to get the results precisely in the finite element method.

And even for composite laminates tetrahedron meshing is adopted with mesh sizing of 50mm for the whole FRP model.

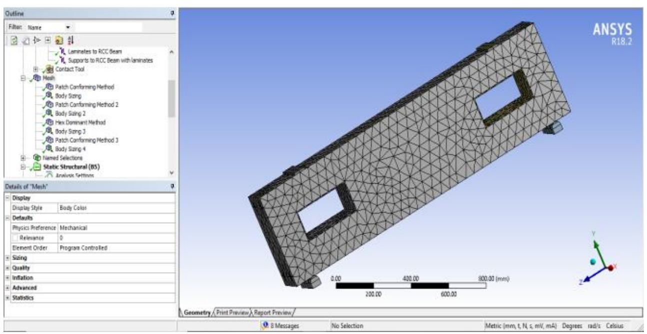

Fig. 16. Meshing of FRP model

D. Supports

As it is one of the most important aspects of any structure as it specifies how the forces within the structure are transferred to the ground. Different support conditions being fixed support, pinned support, roller support and simply support.

Fixed support being the most rigid type of support connection. Hinged or Pinned support being the most common type of support condition as it allows rotation to occur but no translation. Roller support is the one which resists vertical force. Simply supports aren't widely used as they are quite similar to roller supports and used in the worst case.

In this project simply support condition is adopted for both control beam as well as FRP coated beam so that its behaviour could be studied for the worst boundary condition.

E. Loading condition

IS and ASCE Code suggests two types of loads on any structure: Vertical loads and Horizontal loads. Vertical loads being dead loads, live loads, snow loads etc. Horizontal loads being earthquake loads, wind loads etc.

In case of beam element based on action of the forces the loads can be classified into 3 types: Point Load, UDL and UVL. *Point Load:* When the load acts concentrated at a definite point then it is named as concentrated or point load.
Uniformly Distributed Load(UDL): A distributed load is a load which is spread on some length of a beam.
Uniformly Varying Load (UVL): When the load distributed along the length of the beam varies in intensity uniformly, according to the law. 2-point loading is assigned for my study.

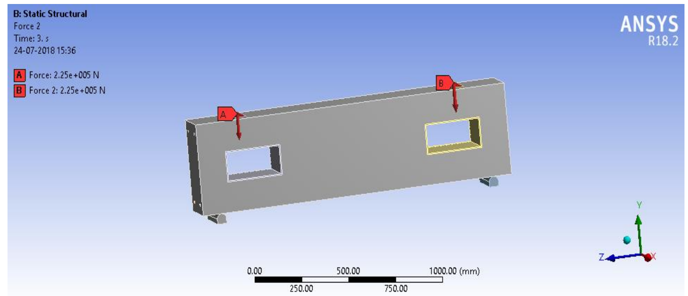

Fig. 17. Load condition for Beam

F. Selection of output parameter

In this project, the parameters considered for analysis are total deformation, principal stresses and strain, equivalent stresses and strain, shear stresses and strain, linearized stresses.

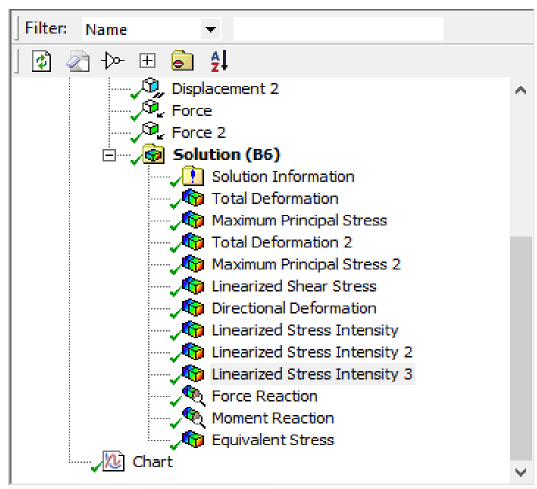

Fig. 18. Solution Output Parameter

G. Geometry

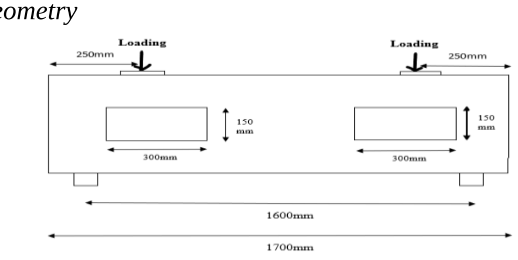

Fig. 19. Beam Dimension

The beam of size (230 X 450 X 1700) mm is used with an opening of size (300 X 150) mm and an 5mm thick FRP coated beam around openings is also studied. This is modelled in ANSYS 18.2 software in the geometry option. In this tab, the required geometry was drawn and extruded. Pattern option is used for creating the reinforcement at 150 mm centres. FRP laminates of 5mm is coated around the openings in the rectangle configuration. Total of 6 beam specimens are designed. One

Table 3
Load vs. Deformation for all the beams

Force [N]	Total Deformation [mm]					
	CB	AFRP	BFRP	CFRP	GFRP	PPFRP
5000	3.0176	7.46E-02	8.8E-02	2.9889	0.33478	8.31E-02
25000						
50000	3.263	0.17291	0.23931	3.0541	0.42717	0.61362
75000	3.0691	0.35041	0.26458	2.7502	0.35305	0.5623
1.00E+05	3.277	0.4421	0.49718	2.9293	0.5254	0.55652
1.25E+05	2.7699	0.35428	0.48953	3.0649	0.43821	0.45018
1.50E+05	2.7137	0.42348	0.50856	3.1732	1.6725	0.63947
1.75E+05	2.811	0.41135	0.59958	2.8917	1.4083	0.74338
2.00E+05	3.2637	0.462	0.55986	2.5819	1.3824	0.61964
2.25E+05	3.4093	0.52475	1.1167	2.6938	2.0901	1.3406
2.50E+05	3.52	1.1107	1.0745	2.6453	2.2478	1.2127

control beam, 5 beams strengthened with FRP Laminates individually i.e Basalt, Carbon, Polypropylene, Aramid, Glass fibers.

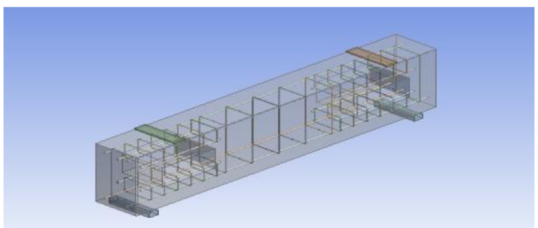

Fig. 20. Control Beam Reinforcement

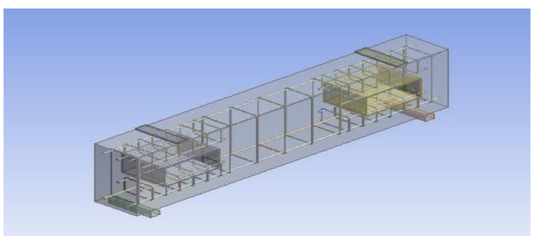

Fig. 21. Beam Reinforcement with FRP Coating

5. Results

Results of comparative study of all the fiber reinforced beam and the control beam for load vs deformation.

A. Load versus deformation for all beams

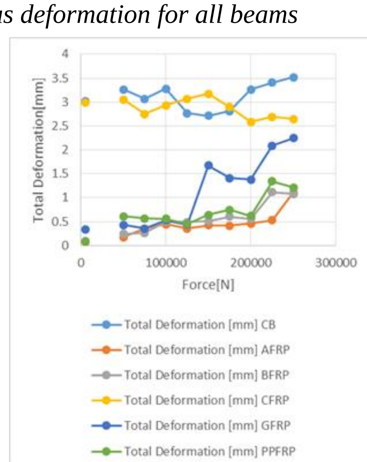

Fig. 22. Load vs. Deformation for all the beams

The graph in Fig. 22, is a plot between load vs. deformation for the control beam as well as fiber reinforced beams wherein we can see the deformation value is found to be in maximum in control beam and the beam reinforced with CFRP the deformation value for a certain value of load increases and then decreases and is found to be less than the control beam. In the case of other FRPs reinforced beam the deformation value is found to be minimum compared to the control beam.

6. Conclusion

This section sums up the finish of the dissertation work carried out on the analytical and comparative study of RC open-webbed beams strengthened with different fiber coats surrounding the opening. The following outcomes were interpreted total deflection, Equivalent Stress-Strain, Normal Stress-Strain, Maximum Principal Stress-Strain values using a Finite Element Modelling software called ANSYS WORKBENCH 18.2.

A. Conclusions

- The deflection rate seen in control beam was higher compared to those in beams braced with FRP sheets near opening as my main study dealt with how to reduce the deflection rate.
- The load carrying capacity of open-webbed RC beams with FRP's has been increased.
- The Stress distribution contours due to varying load were obtained and the stress-strain graphs were seen to be linearly increasing in control beam as well as fiber reinforced beam.
- Among the various fibers properties considered the Basalt fiber was considered to be the most effective one with increasing load carrying capacity with aramid fibers standing the next best fiber.
- As the stress-strain values for the beams is usually maximum at centre and minimum near supports it's better to provide openings near the supports.
- If by any means the length of opening needs to be increased then it's better to extend in the area where the stresses are minimum.

B. Scope for future studies

1. The work may be carried out with different support conditions like fixed support conditions on both the ends.
2. Different FRP composites can also be used and analysed for the same.
3. Openings of different shape can be checked for consistency.
4. The same work can be carried out experimentally and can be compared for the same.
5. The present analysis can be analysed for multiple loading like two-point load with UDL, Concentrated load with UDL and with different shapes of opening throughout the length of beam or for partial length.
6. Crack Pattern, size of crack formation, crack width can also be studied.

Different parameters such as directional deformation along the length, across the opening can be found out.

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