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Dynamic analysis of RC beam with opening strengthened by GFRP using ANSYS

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Abstract— In present day construction, conduits and ducts are provided to facilitate services like water supply, sewage, electrical, communication cables, ventilation and air conditioning. These essential services are usually provided in bottom portion of the beam. To improve the aesthetic view, these are generally concealed either by suspended ceiling or false ceiling. To tackle this problem engineers have come up with a solution, to provide transverse openings in the beam. Due to the provision of opening in the beam, there may be a reduction in structural behaviour of the beam. An efficient method for strengthening of RCC beam using GFRP is proposed in this project. In most of the cases, the opening introduced in the beam are mostly pre-planned or post planned. The behaviour of RCC beam with rectangular, rounded-rectangular and elliptical opening strengthened with GFRP under dynamic loading is studied. A total of seven beams were analysed of which one is solid beam (without opening), three are rectangular, rounded-rectangular, elliptical opening and rest three beams are sheathed with a layer of GFRP inside rectangular, rounded-rectangular, elliptical openings. All these beams are simply supported and analysed under harmonic loading using ANSYS. The frequency response of the beams are studied and analysed in detail. An increase in the performance of the RCC beam strengthened with GFRP is found to be more effective.

Keywords—Beam with opening, GFRP, Frequency& mode shapes, Dynamic analysis, Frequency response curves

I. Introduction

In present day construction, conduits and ducts are provided to facilitate services like water supply, sewage, electrical, communication cables, ventilation and air conditioning. These essential services are usually provided in bottom portion of the beam. To improve the aesthetic view, these are generally concealed either by suspended ceiling or false ceiling. This arrangement along with false ceiling makes dead space and reduces the clear space between the floors. To tackle this problem engineers have come up with a solution, to provide transverse openings.

Presence of opening reduces the performance of beam under load (static and dynamic) when compared to beam without opening. To improve the performance of the beam, strengthening is vital. Providing additional reinforcement around the opening or sheathing of fibrous material is generally done. Fibres like Carbon fibre reinforced polymer (CFRP), Glass fibre reinforced polymer (GFRP), Aramid fibre reinforced polymer (AFRP) etc are used generally. No building codes have a provision for this, so special care should be taken during design and construction of these beams.

Categorization of opening: Transverse openings in beam can be categorized on many criteria, one such criterion is shape and other is its size. The shape may be circle, rectangle, triangle, trapezoid, diamond or any irregular shape. For services like electrical and plumbing, beams with circular shaped opening is generally preferred, and for air-conditioning ducts rectangle shaped opening is preferred. The edges of rectangular opening are trimmed to reduce the stress concentration around the corners to enhance the performance of the beam by reduction in crack formation.

II. MODELING

The height and width of beam considered for analysis was 300 mm and 200 mm having a length of 1600 mm. 2#10 mm steel reinforcement was given in tension zone and 2#8 mm bars were used in compression zone. 8 mm stirrups were used at 250 mm spacing. GFRP of thickness 3 mm was used to sheath the opening.

Material properties and element properties:

Material	Density in kg/m^3	Elastic modulus in Mpa	Poisson's ratio
Concrete	2500	24834.83	0.2
Steel reinforcement	7850	200000	0.3
Glass fibre reinforced polymer	1800	95000	0.3

Table 1: Different material with their engineering properties

Material Type	Element type
Concrete	Solid 65
Steel	Link 180
GFRP	Shell 180

Table 2: Element type used in ANSYS

Geometrical Modeling:

The concrete beam of size is modelled by sketching a 2D model of size 200*300 mm and extruding for length 1600 mm to get the complete 3D model. The reinforcement is modelled by drawing a 2D sketch and then extruding using slice material option. Pattern option is used to create similar elements like stirrups and rebar at known distance. The support plates and loading plate is modelled similarly**.**The concrete beam without opening is abbreviated as SB.

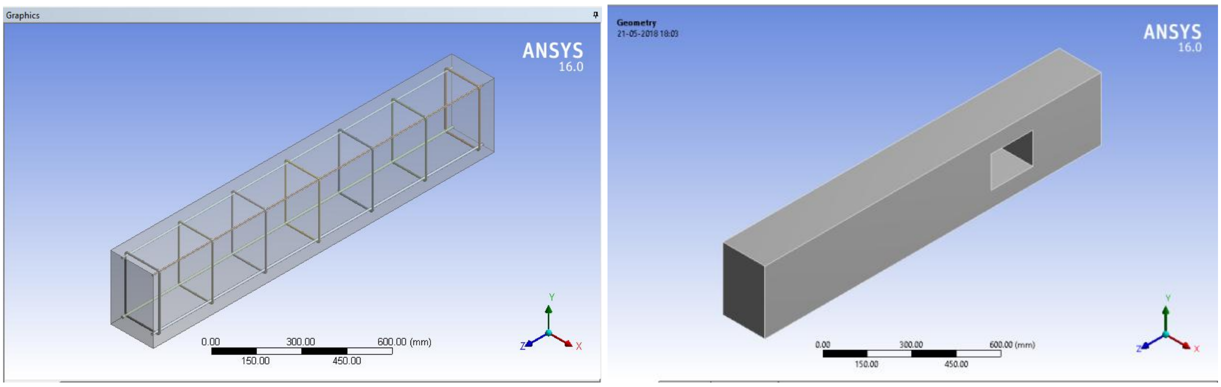

Fig. 1(a) Model of concrete beam with reinforcement (b) Model of Rectangular beam with opening

Meshing:

The accuracy of solution depends upon the size and shape of mesh considered for analysis. Finite element mesh of tetrahedron shape and size 15 mm was used. It has to be noted that nodes of different elements must sync together to act as single body.

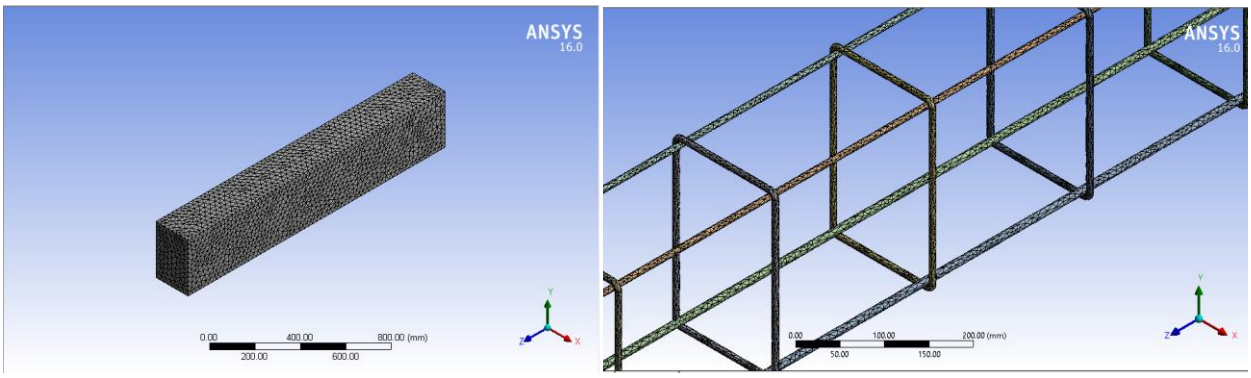

Fig.2: (a) Meshed model of concrete beam (b)Meshed model of steel reinforcement

Contacts:

Manual contacts were established between different types of elements. Grouping of elements was done using named selection option as rebar, stirrups, concrete and GFRP. First the contact between rebar and stirrup was established, then reinforcement was given contact with concrete. In static analysis contact was established between plates (loading & support) with concrete. Lastly the contact between GFRP and concrete was established.

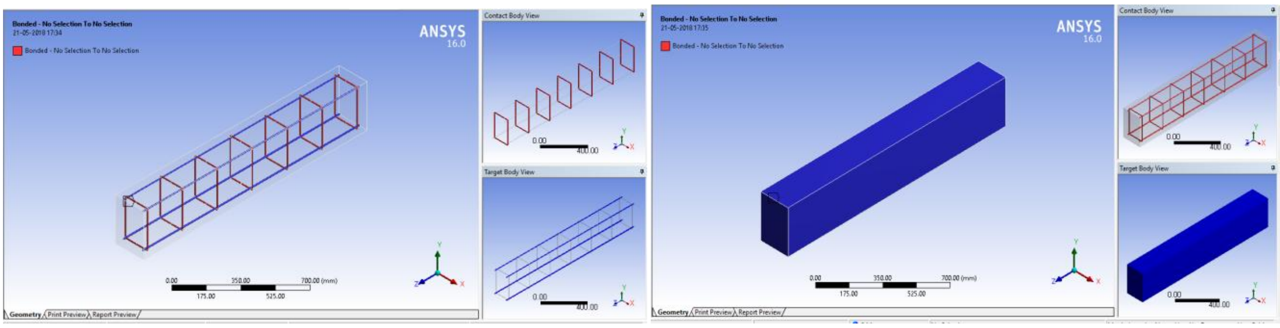

Fig.3: (a) Contact between stirrups and main bars **(b) Contact between reinforcement and concrete**

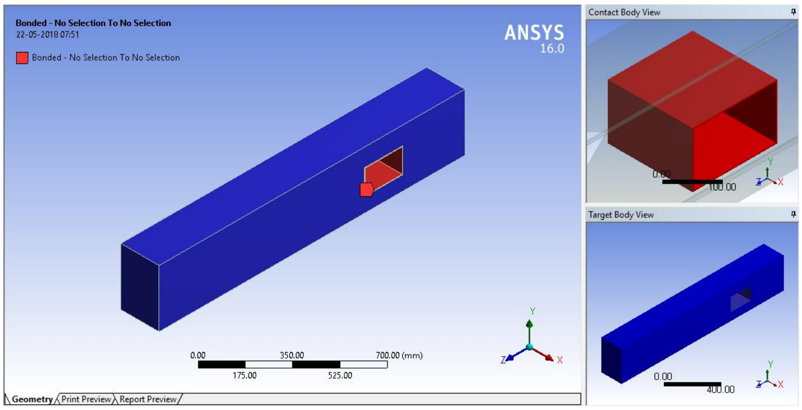

Fig.3: (c) Contact between GFRP and Concrete

Boundary conditions & Loading conditions:

For analysis simply supported conditions were adopted. One edge is given as hinge support & other edge as roller support to simulate simply supported conditions.

For harmonic analysis amplitude of 100kN was considered.

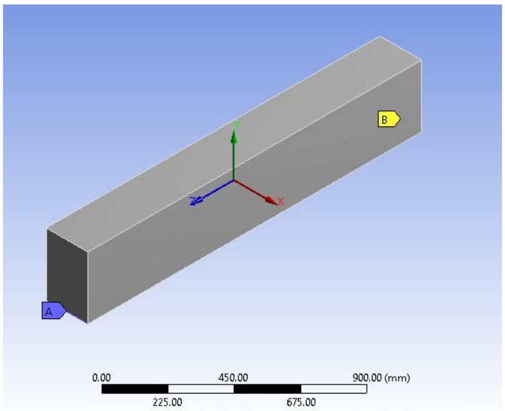

Fig.4: Boundary conditions applied

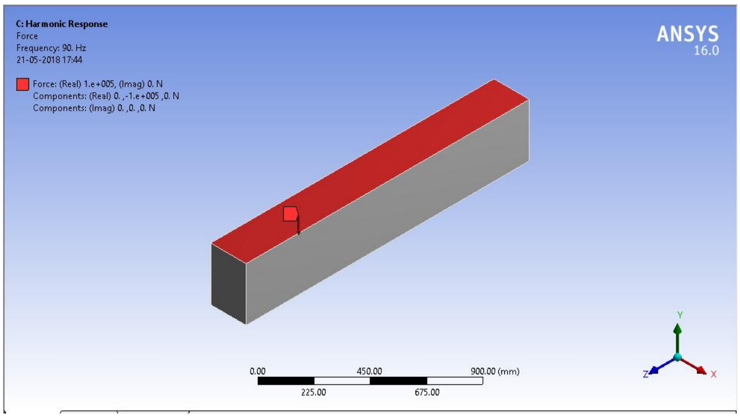

Fig 5: Harmonic load applied on beam

Beams with opening:

Three types of opening namely rectangular (RO), elliptical (EO) & rounded rectangular (RRO) having opening dimension of 200*150 mm was considered. The opening was situated at a distance of 500 mm from right end.

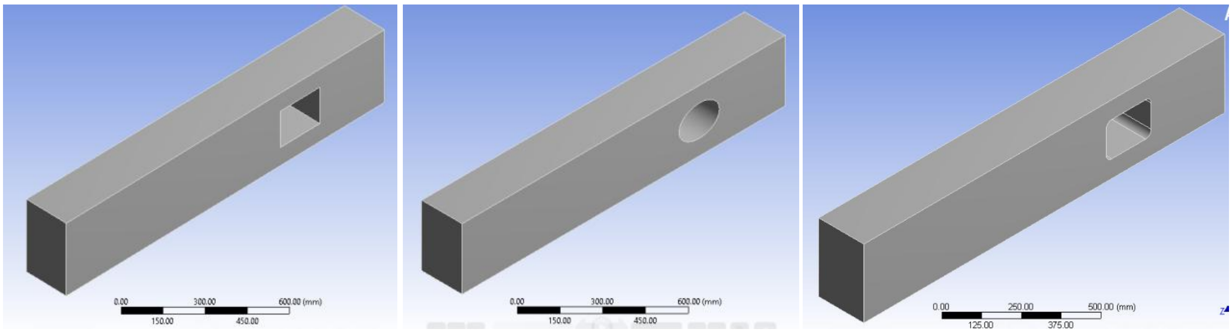

Fig.6: Model of (a) Rectangular opening (b) Elliptical opening (c) Rounded rectangular opening

Beams with opening sheathed by GFRP:

The types of opening namely rectangular(ROG), elliptical(EOG) & rounded rectangular(RROG) having opening dimension of 200*150 mm was sheathed by GFRP of thickness 3mm.

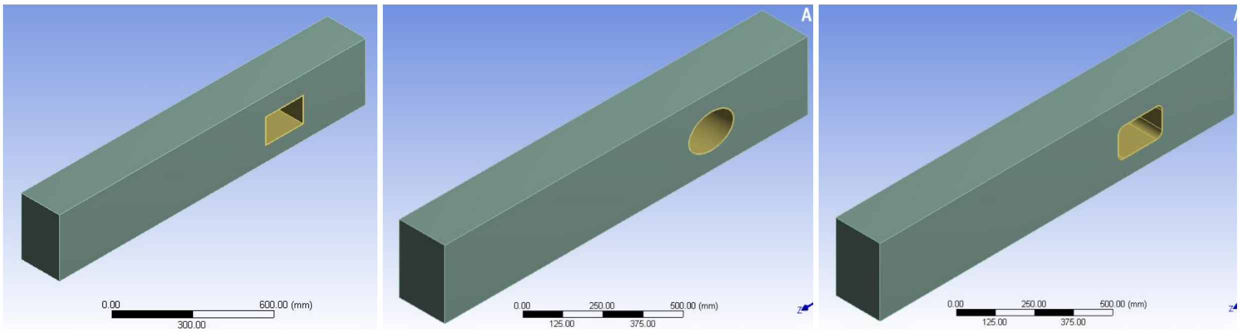

Fig.7: Model of beam sheathed by GFRP having (a) Rectangular opening (b) Elliptical opening (c) Rounded rectangular opening

III. RESULTS AND DISCUSSION

The static analysis i.e, two point loading was done to know ultimate strength of all seven beams. The solid beam/ control beam have an ultimate strength of 120.67 kN, presence of opening decreased the load carrying capacity of beam. GFRP sheathing has improved the performance of beam with opening.

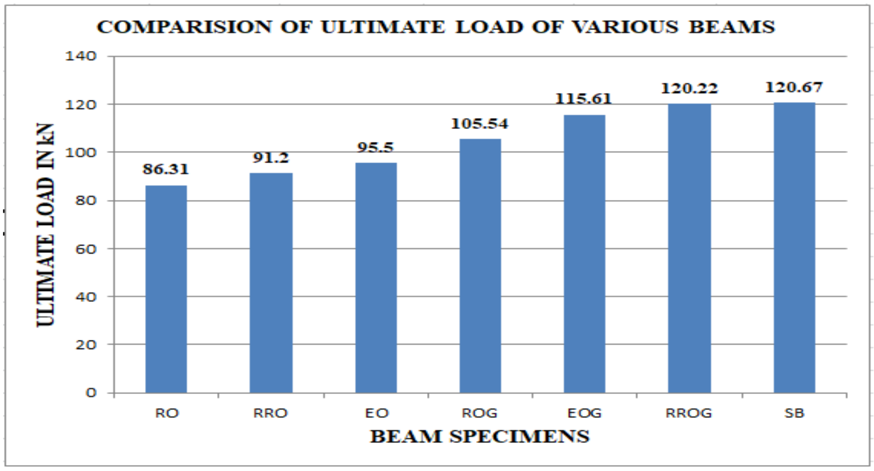

Fig 8: Comparison of ultimate load of all seven beams

For all the seven beams modal analysis was performed to get the natural frequency and mode shapes. First six mode shapes were considered in all seven beams.

Mode	Frequency of SB in Hz	Frequency of RO in Hz	Frequency of EO in Hz	Frequency of RRO in Hz	Frequency of ROG in Hz	Frequency of EOG in Hz	Frequency of RROG in Hz
1	101.58	99.651	100.5	99.834	101.46	101.42	101.66
2	117.92	117.52	117.88	117.64	117.86	117.96	117.91
3	125.68	125.49	125.61	125.52	125.61	125.63	125.63
4	126.33	126.33	126.33	126.32	126.33	126.33	126.33
5	137.01	135.26	137.44	135.95	137.31	137.94	137.63
6	138.89	138.87	139.03	138.9	139.04	139.21	139.1

Table 3: Modal Frequency of all beam types

Harmonic analysis with amplitude 100 kN was performed on all seven beams and its frequency response was obtained for each case. After that the results were interpreted and a single graph was drawn.

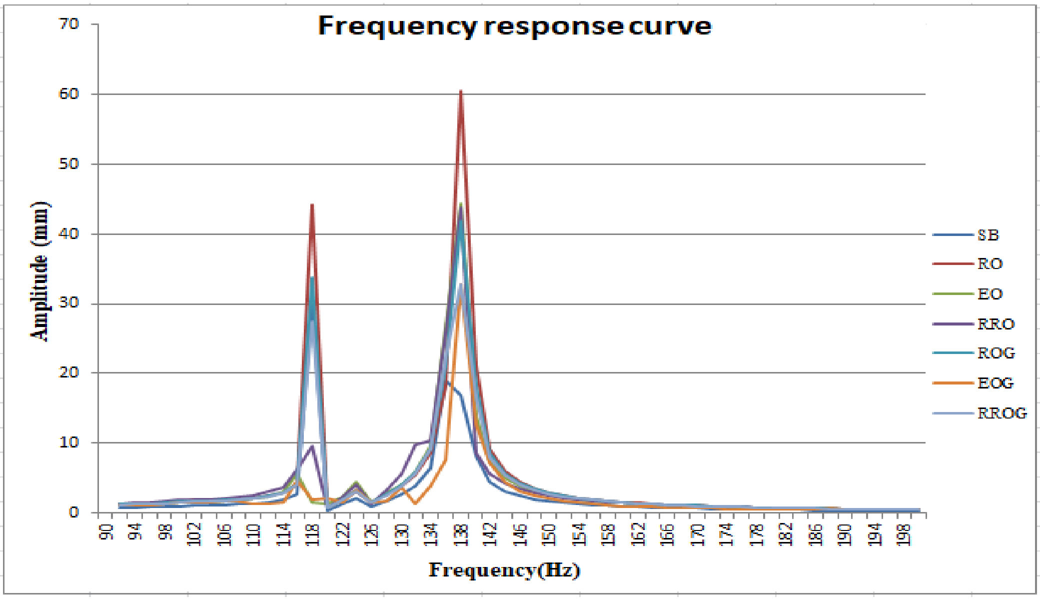

Fig 9: Comparison of frequency response curves of all seven beams

IV. Conclusions

Following conclusions were made from the study,

- Beam with rectangular opening have least load carrying capacity 86.31kN and beam with elliptical opening has highest load carrying capacity of 95.5 kN under static load for beams with opening not sheathed by GFRP.
- From ultimate load values, it can be noted that performance of beams with opening is similar to that performance of solid beam under static load when it was sheathed by GFRP.
- For beams with sheathed GFRP laminates, rounded rectangular opening has highest load carrying capacity of 120.22 kN compared to other shapes of opening under static load.
- Presence of opening reduces the stiffness of the beam, if the size of opening is small (volume is less than 5 %) not much change in stiffness value occurs but if the opening is of sufficient size stiffness will be reduced to much extent.
- The natural mode shape values of all seven beams are similar since the volume of opening is 5 % of the total volume.

- The presence of opening reduces the performance of beam drastically under harmonic load having increased deflection values of 60.492 mm,43.852 mm, 44.34 mm for rectangular, elliptical & rounded rectangular opening compared to 29.714 of solid beam.
- Beams with sheathed opening have similar behaviour to that of solid beam under static and harmonic loading.
- Addition of GFRP has reduced the deflection values of rectangular opening by 30.9 %, elliptical opening by 25.33 % & rounded rectangular by 26 %.

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