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ANALYTICAL INVESTIGATION OF ENCASED COMPOSITE BEAMS UNDER FLEXURE AND TORSION

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Abstract — *Research on composite members is popular as they have major role in high rise buildings and bridges with aesthetically pleasing complex designs. In this study, steel encased composite beams are considered in which structural steel I section is embedded within the reinforced concrete. A non linear structural analysis of encased composite beams incorporating the material non linearity and geometric non linearity is conducted to evaluate the flexural behavior and torsional behavior of composite beams. The primary goal of the research is to conduct an analytical investigation on fully encased composite beams with various I section of similar cross section area under flexure and torsion. Unlike other steel encased composite beams, in this study, the longitudinal reinforcement bars are completely excluded. Therefore, behavior and failure mode of beams are greatly affected by the steel beam core. ie. even in the absence of longitudinal bars, the steel section can provide the flexural strength for the beam. This research is focused on the comparison of flexural–torsional behavior of steel-encased composite members with conventional reinforced beams using five set of I section namely ISHB 150, ISMB 225, ISWB 200, ISLB 250 and ISHB 200. The load-deflection behavior is plotted. From the above studies, ISHB 200 has shown a better performance under flexure. Moreover, the depth of section is reduced compared to conventional reinforced beams. In this way the dead load of the structure is been reduced. But the reduction of depth is limited by incorporating the flexural rigidity of the section. The torsional actions on beams are studied with ISHB 200 using lateral stirrups of various spacing. Maximum shear strength is attained with lower spacing of lateral stirrups. Application of frictional surface on the top and bottom flanges of I sections to avoid the slippage of concrete from steel suface showed a positive effects on the structure.*

Keywords- *encased composite beams; flexure; torsion; non linear analysis; precast reinforced continuous beam; optimum depth*

I. INTRODUCTION

Structural members that are made up of two or more different materials are known as composite elements. The main benefit of such elements is that the properties of each material can be combined to form a single unit that performs better overall than its separate constituent parts. The composite members are used in construction from the necessity of protecting the steel member from fire and corrosion. The benefits brought to the columns yield and stability by using concrete to encase the steel profile haven't been took account of until the 50's. More recently, with the advent of modern composite frame construction in high rise buildings, engineers developed new methods to take advantage of the stiffening and strengthening effects of concrete and reinforcing bars on the bearing capacity of steel-concrete composite member. The developments related to high-strength concrete and seismic design motivate the review of composite column behaviour and current design provisions. Using the composite leading to larger openings, reducing the height levels and provides a better lateral stiffness. The steel core acts as a back-up system in providing the shear strength and the required ductility to prevent brittle failure modes. In the last few decades a number of research works have been carried out to understand the behavior of structures under flexure as well as torsion. The main aim of this project is to study the flexural-torsional behavior of concrete encased composite beams without using longitudinal reinforcement bars and comparing the same with that of a conventional reinforcement beam. The beam elements are manufactured as precast structures but not as pre-stressed members. This is because; the pre-stressed members involve pre-stressing losses during the process of post tensioning or pre-tensioning. The finite element software Ansys Workbench 16.0 is used for modeling and performing the non linear structural analysis of encased composite beams incorporating the material non linearity and geometric non linearity.

II. OBJECTIVES

From the literature review conducted, a gap is found in the area of analysis of encased composite beams under flexure and also under torsion. So the objectives of the project concentrate on this area.

- To carry out analytical investigation on encased composite beams to study:

- structural behavior of precast reinforced continuous beam under flexure
- structural behavior of precast reinforced continuous beam under combined action of flexure and torsion
- the flexural behavior of composite beams strengthened with various I beam section and lateral stirrups excluding longitudinal bars
- the torsional behavior of composite beams strengthened with lateral stirrups
- the load-deflection behavior of encased composite beams strengthened with I Section.
- To determine the optimum depth of section required for better load carrying capacity using various I Section.
- Comparison of flexural–torsional behavior of steel-encased composite members with conventional reinforced beams using five set of I section namely ISHB 150, ISMB 225, ISWB 200, ISLB 250 and ISHB 200
- To conduct the parametric studies under flexural-torsional behavior using various I section of similar steel area.

III. PRECAST REINFORCED CONTINUOUS BEAM UNDER FLEXURE

The relative stiffness of the individual components influences the internal actions in a continuous beam. Due consideration has to be given in the structural analysis to geometric compatibility besides the condition of equilibrium. Maximum bending moments and maximum deflections in a continuous member are substantially minimized in accordance with hogging moment. The increase in stiffness and reduced requirement of strength allow a lighter section for any serviceability requirement. Even if the beams are precast, they are not pre-stressed because it involves various losses of pre-stressing during post tensioning or pre-tensioning.

3.1 Material Properties

3.1.1 Concrete

- Density - 2400 kg/m^3
- Young's modulus – 31623 MPa
- Poisson's ratio - 0.18
- Tensile ultimate strength - 5 MPa
- Compressive ultimate strength - 44.17 MPa

3.1.2 Reinforcement steel

- Density - 7850 kg/m^3
- Young's modulus – 2e5 MPa
- Poisson's ratio - 0.3
- Tensile yield strength - 250 MPa
- Tensile ultimate strength - 500 MPa

3.2 Design aspects of continuous beam

The dimension of the beam created was 300 x 550mm with a span of 7.5m under rigid boundary condition considering the functional aspect. As per IS 875, maximum imposed load of 45 kN/m is considered along with dead load. Standard concrete of grade M40 and rebars of Fe 415 has been used. An effective cover of 50mm is provided with reference to IS 456. Longitudinal reinforcement being provided with 6 no. of 20mm dia. bars at tension and 2 no. of 20mm dia. bars at compression side. Lateral stirrups of 10 mm dia. at 300mm c/c being used.

3.3 Failure criteria

The model generates the critical output parameters which are used to check against predefined failure criteria. The different failure limit states incorporated under IS 456 are as follows:

- Maximum deflection of the beam does not exceed L/26
- Maximum principle strain in compression fibre under flexure does not exceed 0.0035
- Maximum principle strain in tensile fibre under flexure does not exceed 0.002 + (0.87/fy)

3.4 Non linear analysis of precast continuous beam under flexure

A finite element modeling and non linear analytical investigation of continuous beam is done under static structural analysis. The required depth of section and reinforcement can be found out based on the failure criteria. By applying the incremental load to the beam, the stress and deflection can be obtained after the analysis.

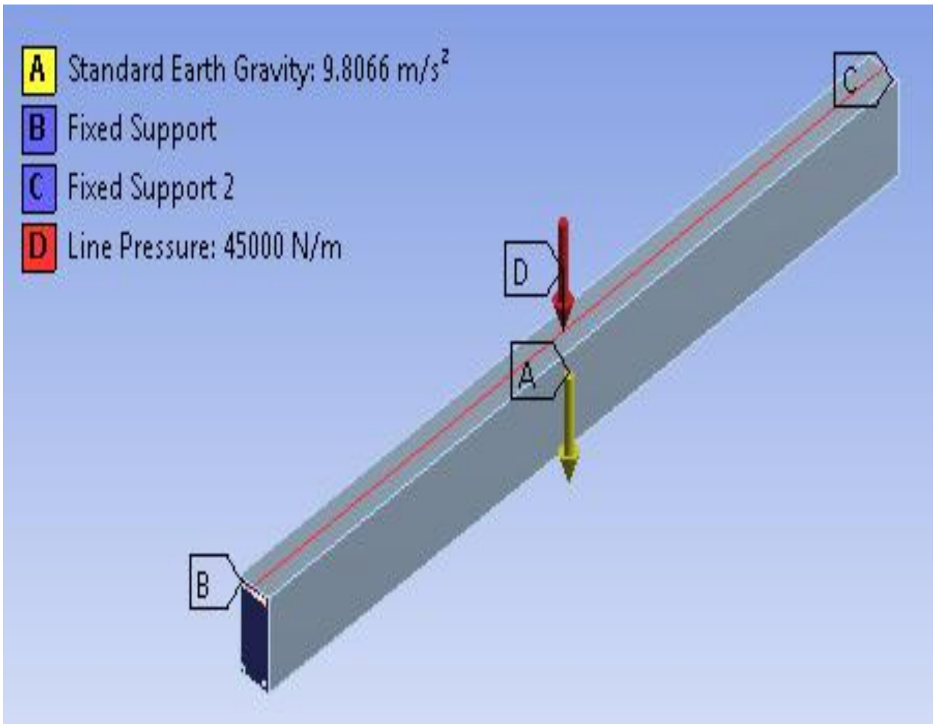


Fig. 1 Loading diagram of reinforced beam under flexure

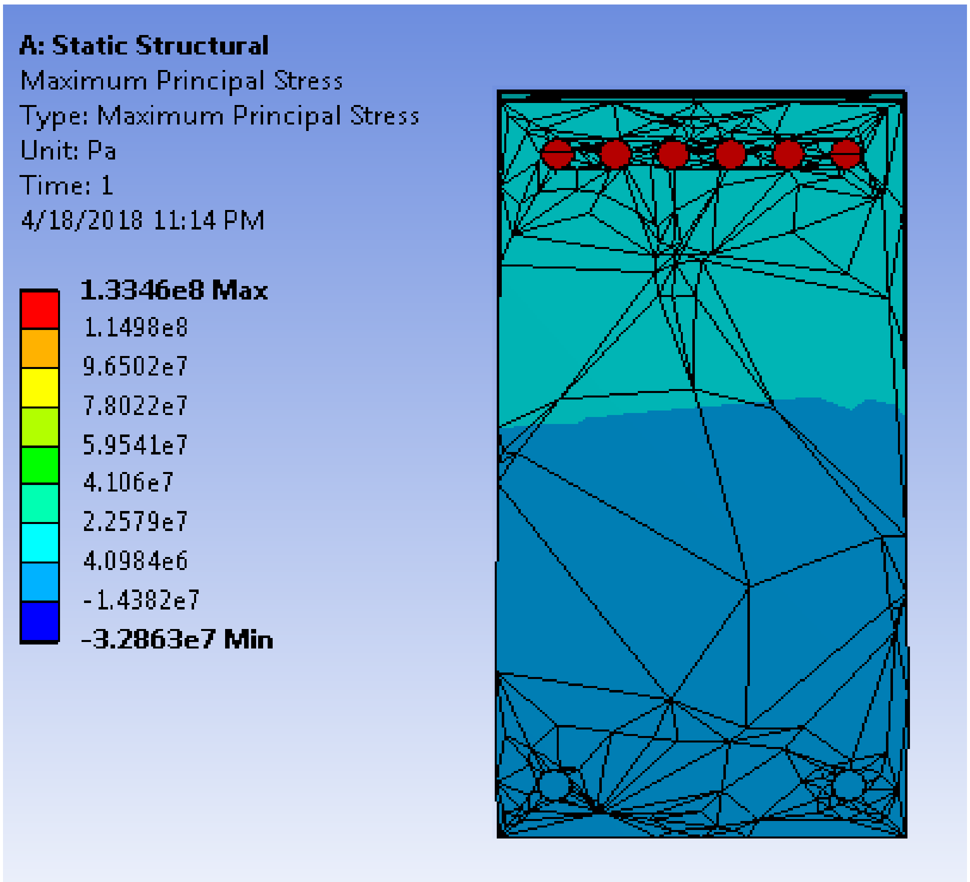


Fig. 2 Maximum principle stress profile of reinforced beam at suppots

Being an under reinforced section, the steel at tension zone reaches yield strain at loads lower than the load at which concrete reaches the failure strain in the considered continuous beam. With the influence of hogging moment at intermediate supports, the tension zone exist at top fibres of beam section.

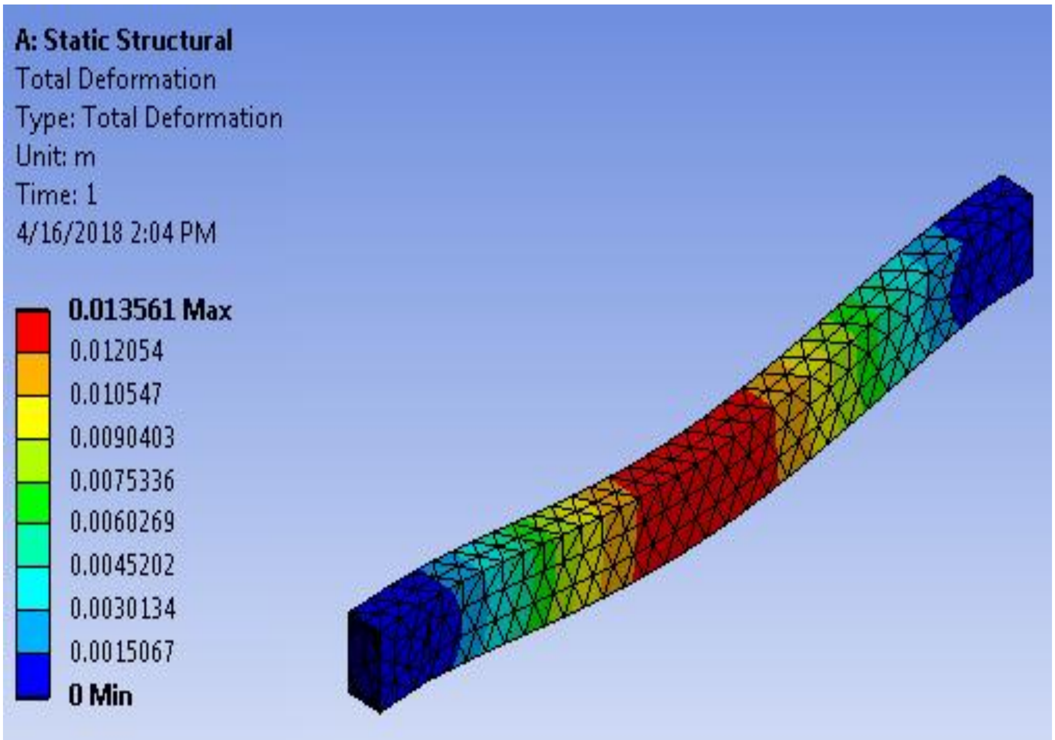


Fig. 3 Deformation diagram of reinforced continuous beam under flexure

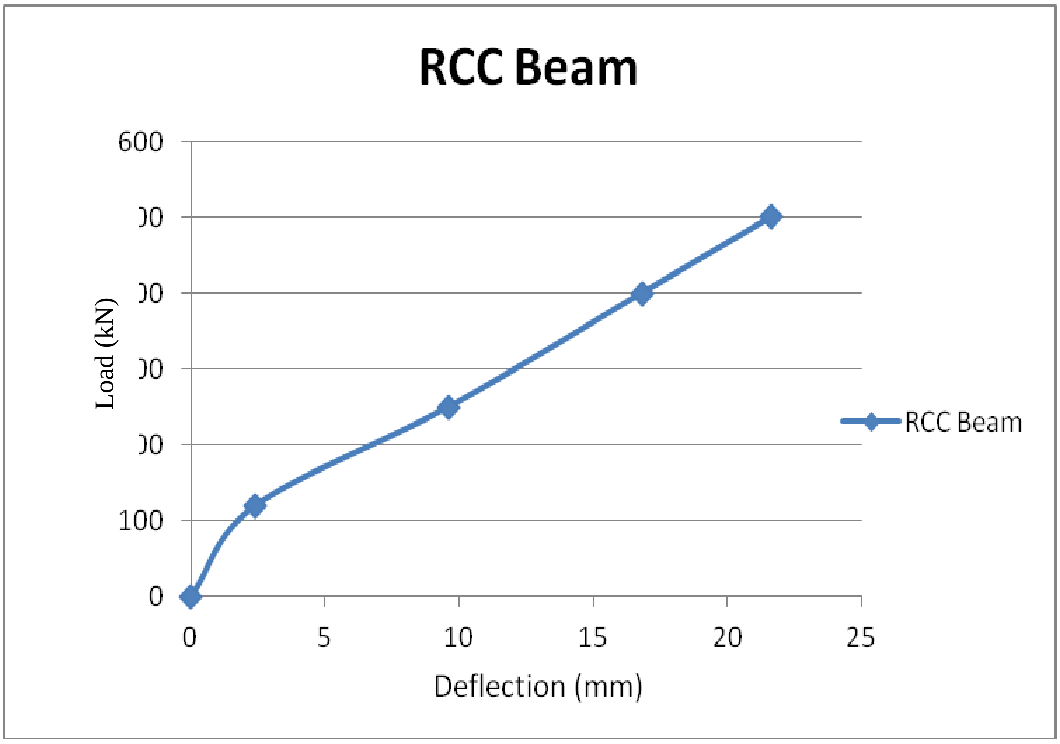


Fig. 4 Load deflection diagram of continuous reinforced beam under flexure

IV. PRECAST ENCASED COMPOSITE BEAMS UNDER FLEXURE

In this study, a combination of reinforced concrete and structural steel is considered to form a composite material. Structural steel is used in the form of I Sections as per IS 800. In order to model composite structures, the design should be done based on the codal provisions in IS 11384. In this study a set of 5 beams has been analyzed under flexure with a span of 7.5m under rigid boundary condition. The longitudinal bars are excluded and substituted with I sections and lateral stirrups of 10mm dia. at 300 mm c/c spacing being used as shear reinforcement. The beams were kept with similar steel area. Standard concrete of grade M40 and rebars of Fe 415 has been used.

4.1 Sectional Properties

Table 1. Sectional properties of encased composite beams with various I sections

Specimen	Beam size	I Section						
		Area (mm^2)	Depth (mm)	Flange width (mm)	Web thickness (mm)	Flange thickness (mm)	I_{xx} (mm^4)	I_{yy} (mm^4)
Beam with ISHB 150	200 x 250	4410	150	150	8.4	9	1640 x 10^4	460 x 10^4
Beam with ISHB 200	250 x 300	4550	200	200	6.1	9	3600 x 10^4	967 x 10^4
Beam with ISMB 225	200 x 350	3970	225	110	6.5	11.8	3440 x 10^4	218 x10^4
Beam with ISLB 250	200 x 350	3550	250	125	6.1	8.2	3720 x 10^4	193 x 10^4
Beam with ISWB 200	220 x 330	3670	200	140	6.1	9	2620 x 10^4	329 x 10^4

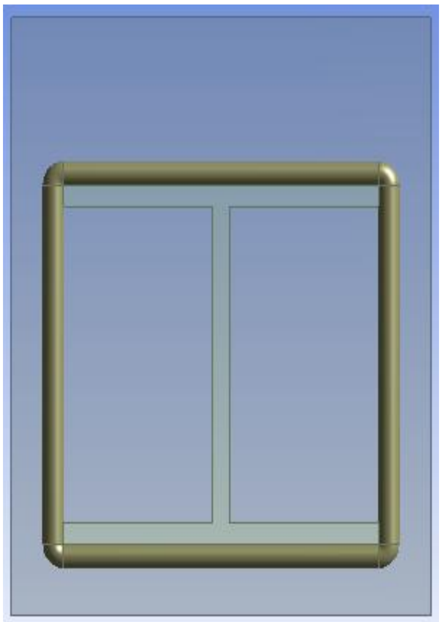
4.2 Failure Criteria

The model generates the critical output parameters which are used to check against predefined failure criteria. According to IS 11384:1985 different failure limit states incorporated are as follows:

- The deflection should not exceed the value for steel structures as L/325
- The total elastic stress considering the different stages of construction in the steel beam should not exceed 0.87fy and nor the stress in concrete exceed one-third of the characteristic strength

4.3 Non linear analysis of precast encased composite beams under flexure

In the serviceability aspect, boundary conditions are suspected to be simply supported and as well as in functional aspect, rigid boundary conditions are suspected to maintain the continuity of beams. With the existence of hogging moments at the rigid boundaries, the maximum bending moment will be reduced compared to simply supported beams. With respect to IS 875, an imposed load of 65 kN/m was applied on the beam surface along with dead load.



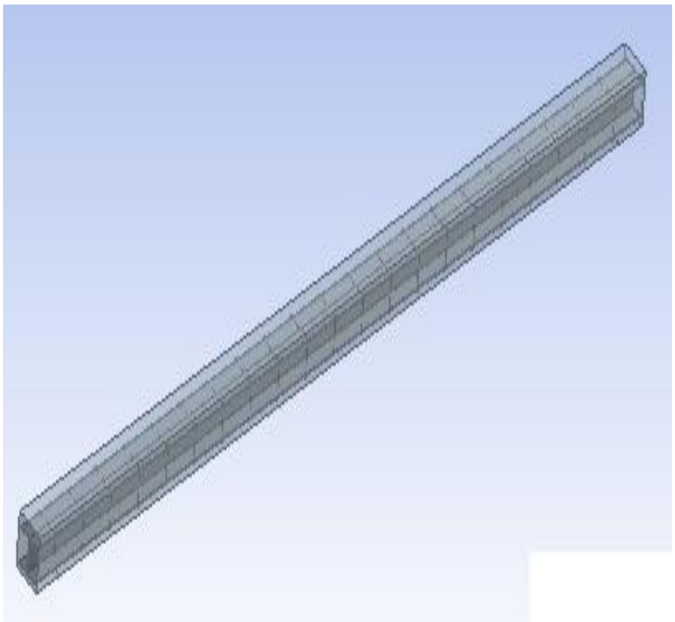


Fig. 5 Geometry and modelling of precast encased composite beams with I section

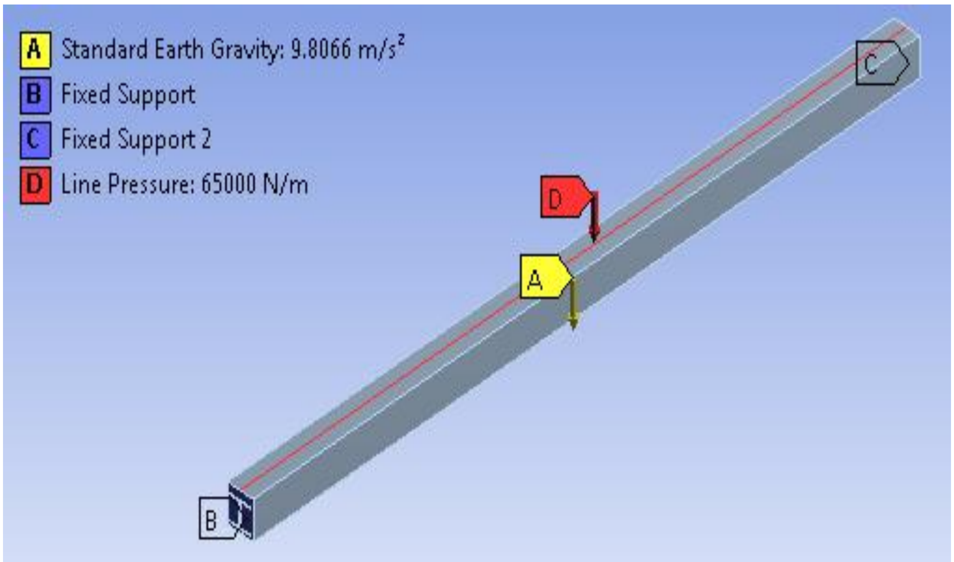


Fig.6 Loading diagram of encased composite beamb with ISHB 200 under flexure

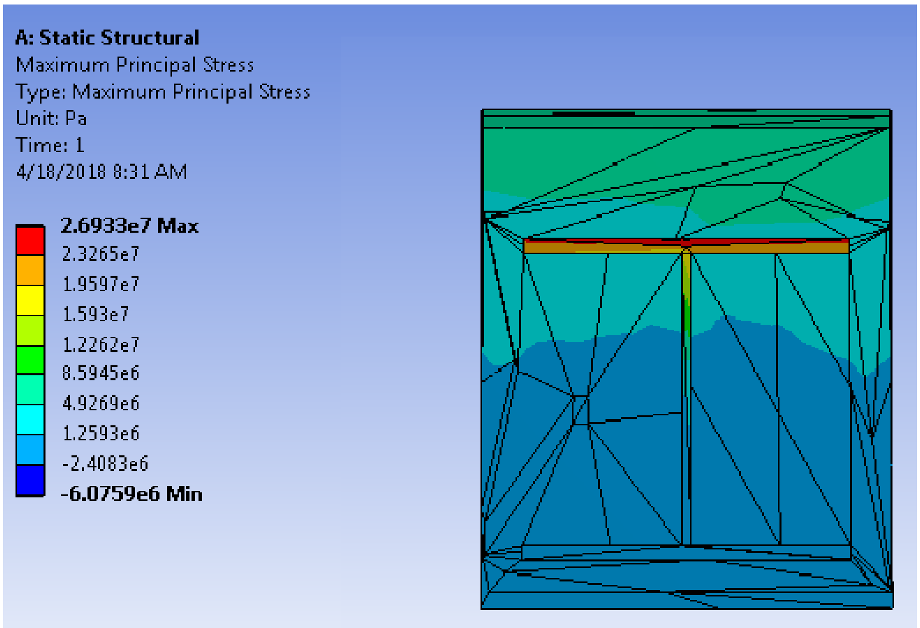


Fig. 7 Maximum principle stress profile of encased composite beamb with ISHB 200 beam at suppots

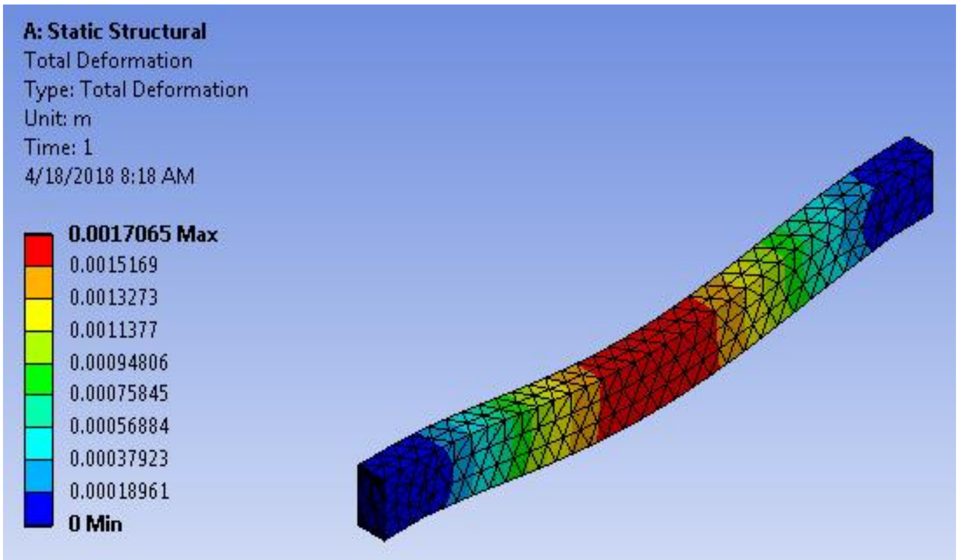


Fig.8 Deformation diagram of encased composite beam with ISHB 200 beam under flexure

V. COMPARISON OF RCC BEAM WITH ENCASED COMPOSITE BEAMS UNDER FLEXURE

In this section, the performances of five encased composite beams are evaluated and compared with reinforced concrete beam. From the stress profile, it is observed that the stress handled by longitudinal bars in RCC beam is safely adapted by the top and bottom flanges of I section in encased composite beams at a reduced stress intensity. When reinforced beam undergoes yielding beyond a loading of 350 kN, encased composite beams can withstand higher load of about 500 kN under small deflections. With an optimum flange thickness and depth of section, beam with ISHB 200 has shown a better load carrying capacity under reduced deformation and stress intensity. It is also observed that too much reduction in depth can also adversely affect the load carrying capacity of section as the flexural rigidity of the section is lost.

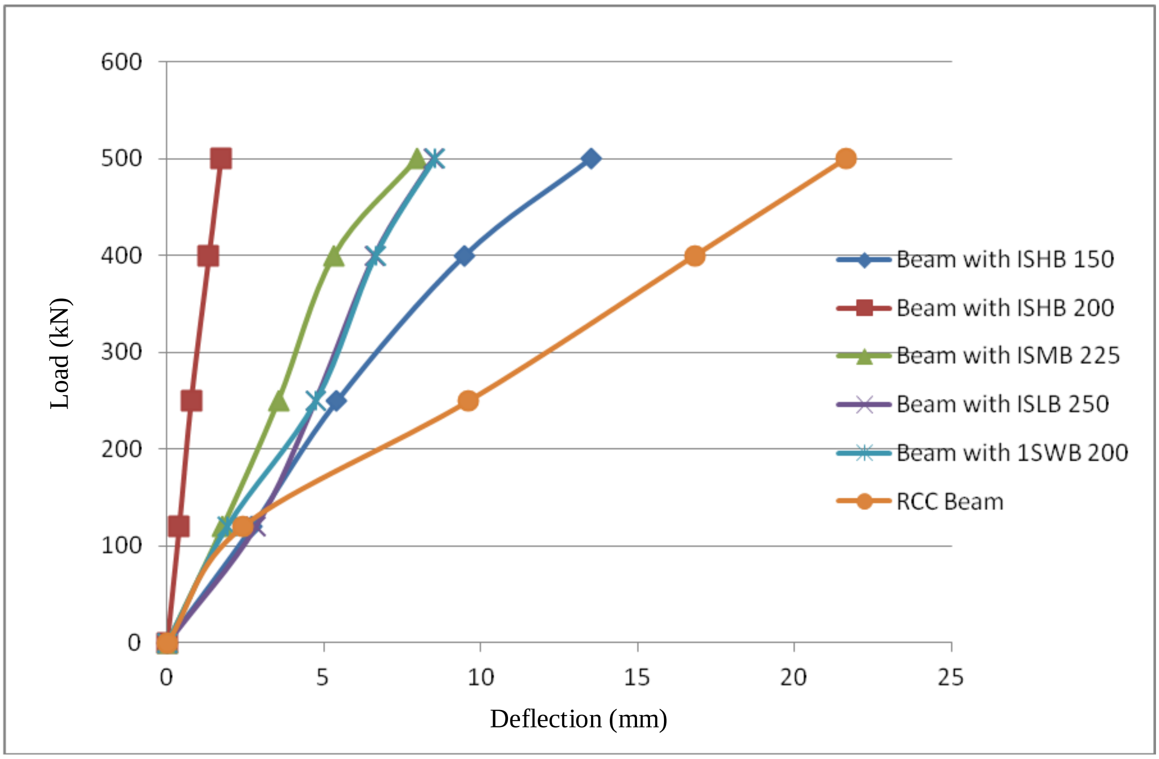


Fig. 9 Comparison of load deflection diagram of various encased composite beams with conventional reiforced beam

5.1 Parametric Studies

The parameters that are used for studying the variation in encased composite beams are depth variation and various I sections. Longitudinal bars are excluded from the beam sections. Five set of encased composite beams were used under investigation in addition to conventional RCC beam.

With increased steel area and depth of section, the flexural capacity is improved. With reduced depth of composite section, the dead load of section is significantly reduced. Composite beams with ISHB 200 showed better load carrying capacity compared to all other sections. It is also observed that too much reduction in depth can also adversely affect the load carrying capacity of section as the flexural rigidity of the section is lost. Optimum width of flanges of I section also plays an important role under flexure. In case of ISHB 200, flange width is equal in magnitude with its depth which helps in improving load carrying capacity.

VI. PRECAST REINFORCED CONTINUOUS BEAM UNDER COMBINED FLEXURE AND TORSION

The reinforced concrete structural elements such as the peripheral beams in each floor of multi-storied buildings, ring beams at the bottom of circular tanks, edge beams of shell roofs, the beams supporting canopy slabs and the helical staircases are subjected to significant torsional loading in addition to flexure and shear. In reinforced concrete design, depending on the load transfer mechanism the torsion is classified as 'equilibrium torsion' and 'compatibility torsion'. Equilibrium torsion is induced in beams supporting lateral overhanging projections, and is caused by the eccentricity in the loading. In compatibility torsion, torsion is induced in a structural member by rotations (twists) applied at one or more points along the length of the member. The twisting moments induced are generally statically indeterminate and their analysis necessarily involves compatibility conditions. Hence it is named 'compatibility torsion'. In this study, compatibility torsion is considered along with flexure for a continuous beam.

6.1 Design aspects of continuous beam

The dimension of the beam created was 300 x 600mm with a span of 3m under rigid boundary condition. The imposed load of 340.7 kPa is considered along with dead load. In addition, a maximum torque of 100 kNm is applied about its longitudinal axis. Standard concrete of grade M40 and rebars of Fe 415 has been used. An effective cover of 50mm is provided. Longitudinal reinforcement being provided with 4 no. of 20mm dia. bars at tension and 2 no. of 20mm dia. bars at compression side. Lateral stirrups of 10mm dia. at 150 mm c/c being used.

6.2 Failure Criteria

The model generates the critical output parameters which are used to check against predefined failure criteria. The different failure limit states incorporated are as follows:

- Maximum shear stress $= [(M^2 + T^2)/z]^{1/2}$

M = Bending moment due to dead load and imposed load

T = Torque applied

Z = Section moduls

6.3 Non linear analysis of precast continuous beam under combined flexure and torsion

A finite element modeling and non linear analytical investigation of continuous beam is done under static structural analysis. The required depth of section and reinforcement can be found out based on the failure criteria. By applying the incremental load to the beam, the stress and deflection can be obtained after the analysis.

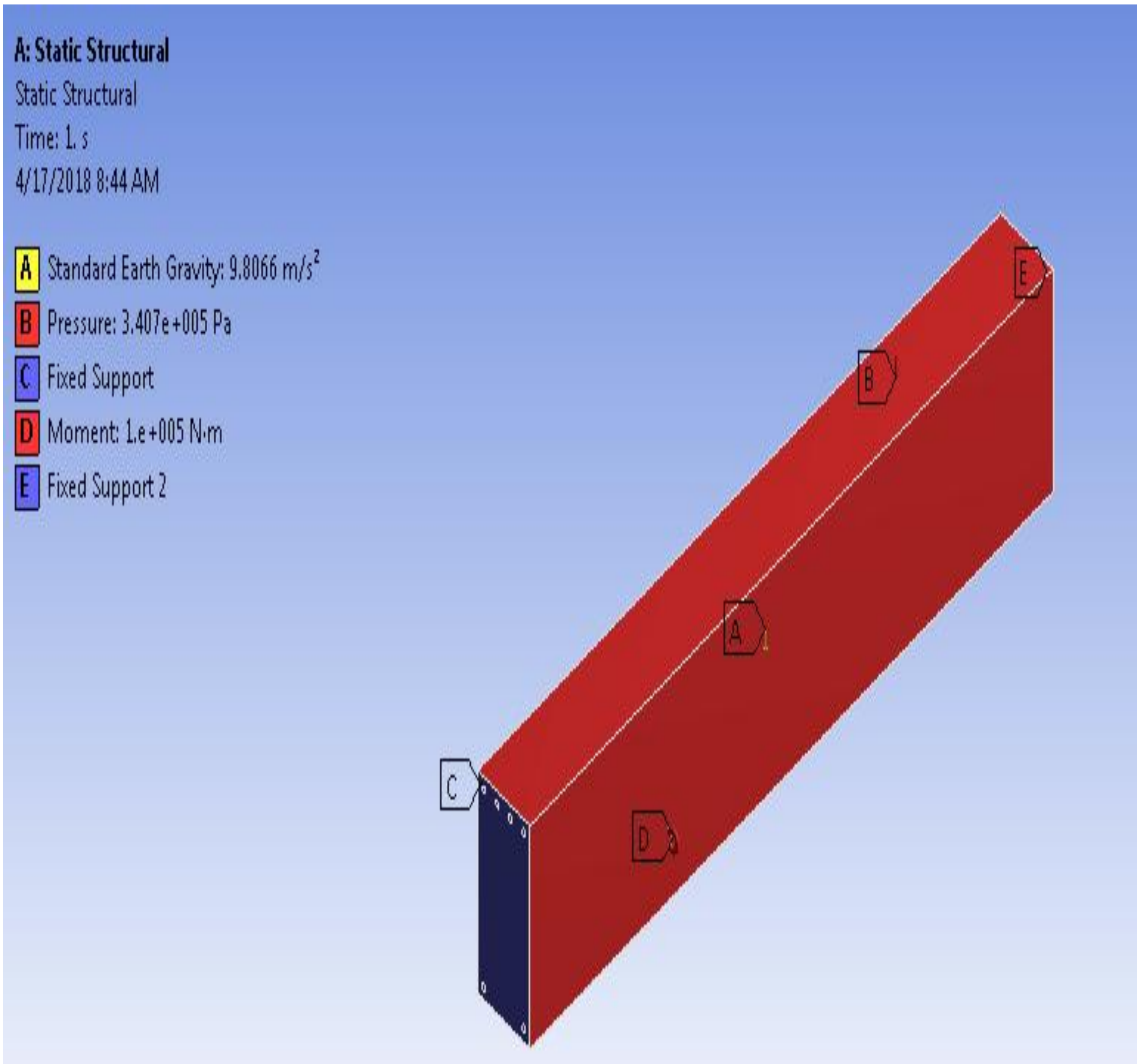


Fig. 10 Loading diagram of reinforced beam under combined flexure and torsion

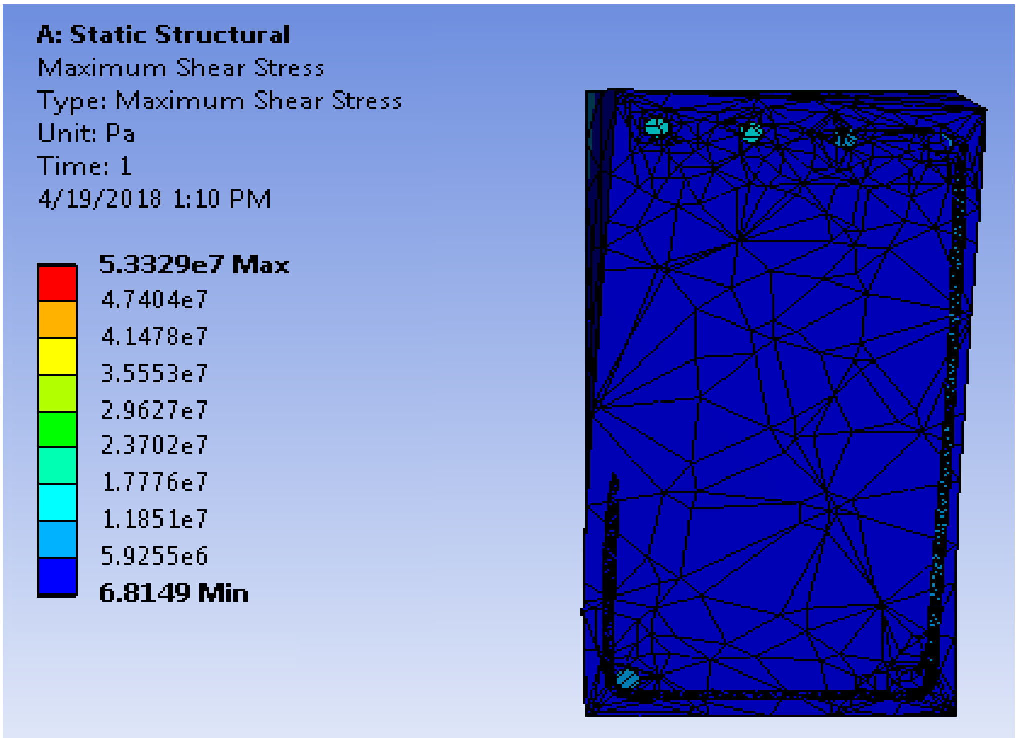


Fig. 11 Maximum shear stress profile of reinforced beam under combined flexure and torsion

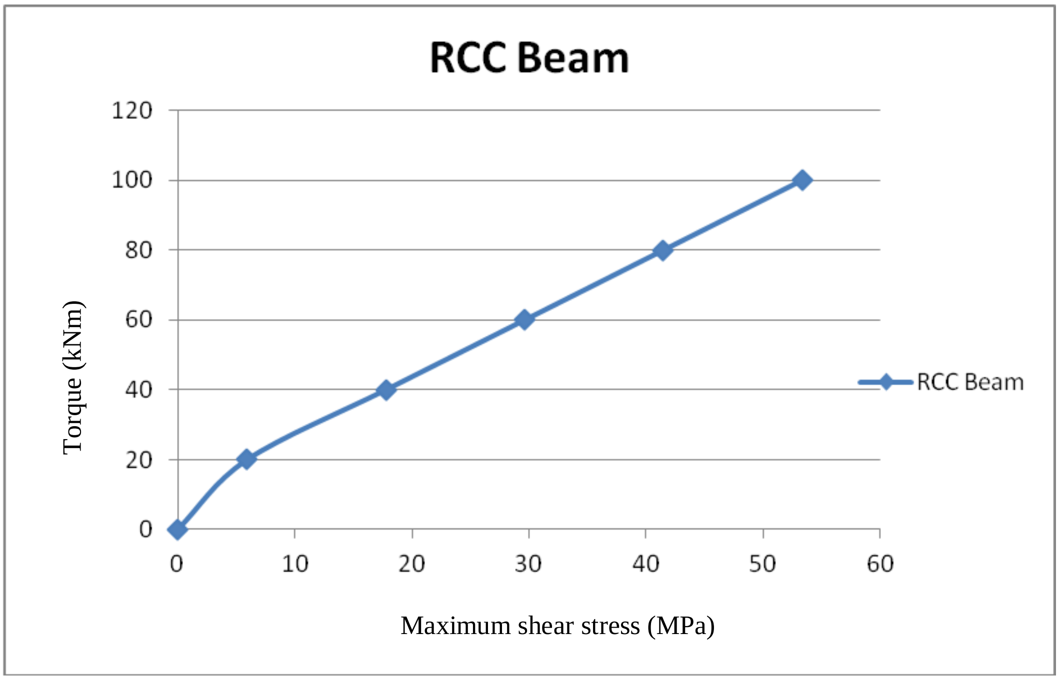


Fig. 12 Relation between the applied torque and maximum shear stress under flexure and torsion

VII. PRECAST ENCASED COMPOSITE BEAM UNDER COMBINED FLEXURE AND TORSION

In this case, the efficient encased composite beam under flexure ie. beam with ISHB 200 is taken for combined action of flexure and torsion over a span of 3m. In this study, the warping of beam is not restrained. ie, beams undergoes free warping. Torsion under St. Venant’s theory is only taken into consideration. Under rigid boundary condition, the imposed load of 340.7 kPa is considered along with dead load. In addition, a maximum torque of 100 kNm is applied about its longitudinal axis. Standard concrete of grade M40 and rebars of Fe 415 has been used. An effective cover of 50mm is provided. In first case, lateral stirrups of 10mm dia. at 200 mm c/c spacing are used and in second case, lateral stirrups of 10mm dia. at 150 mm c/c spacing are used.

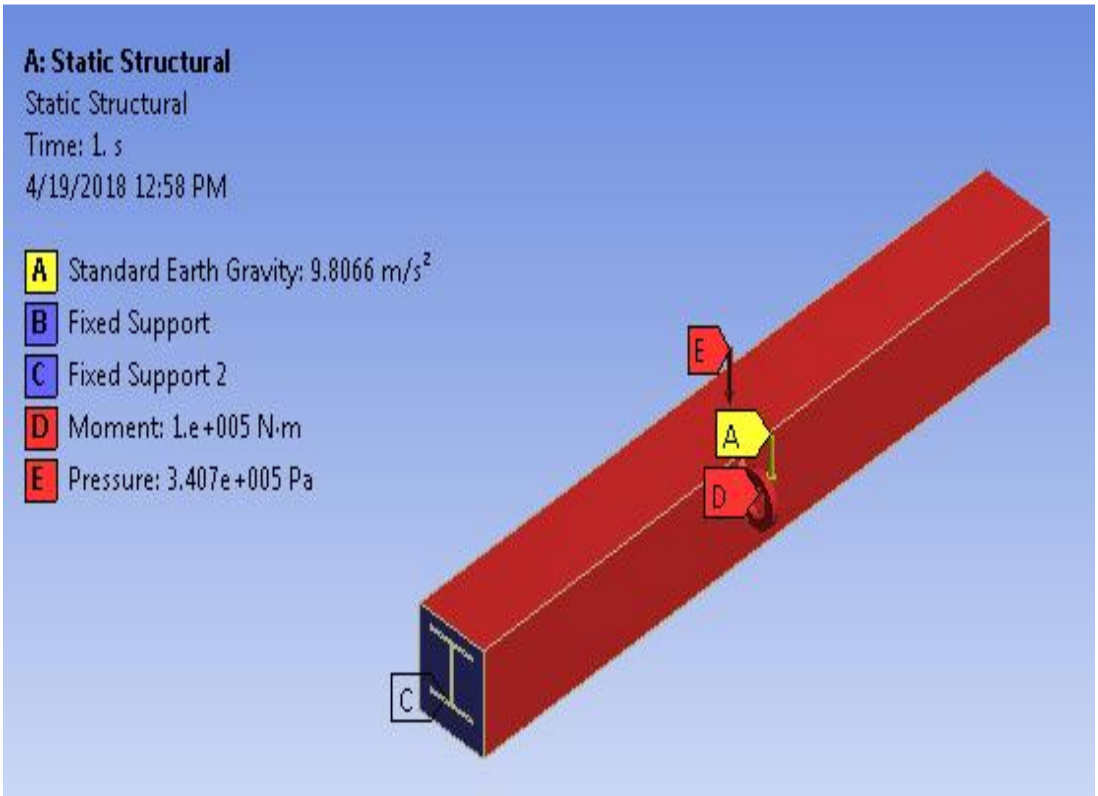


Fig. 13 Loading diagram of encased composite beam under combined flexure and torsion

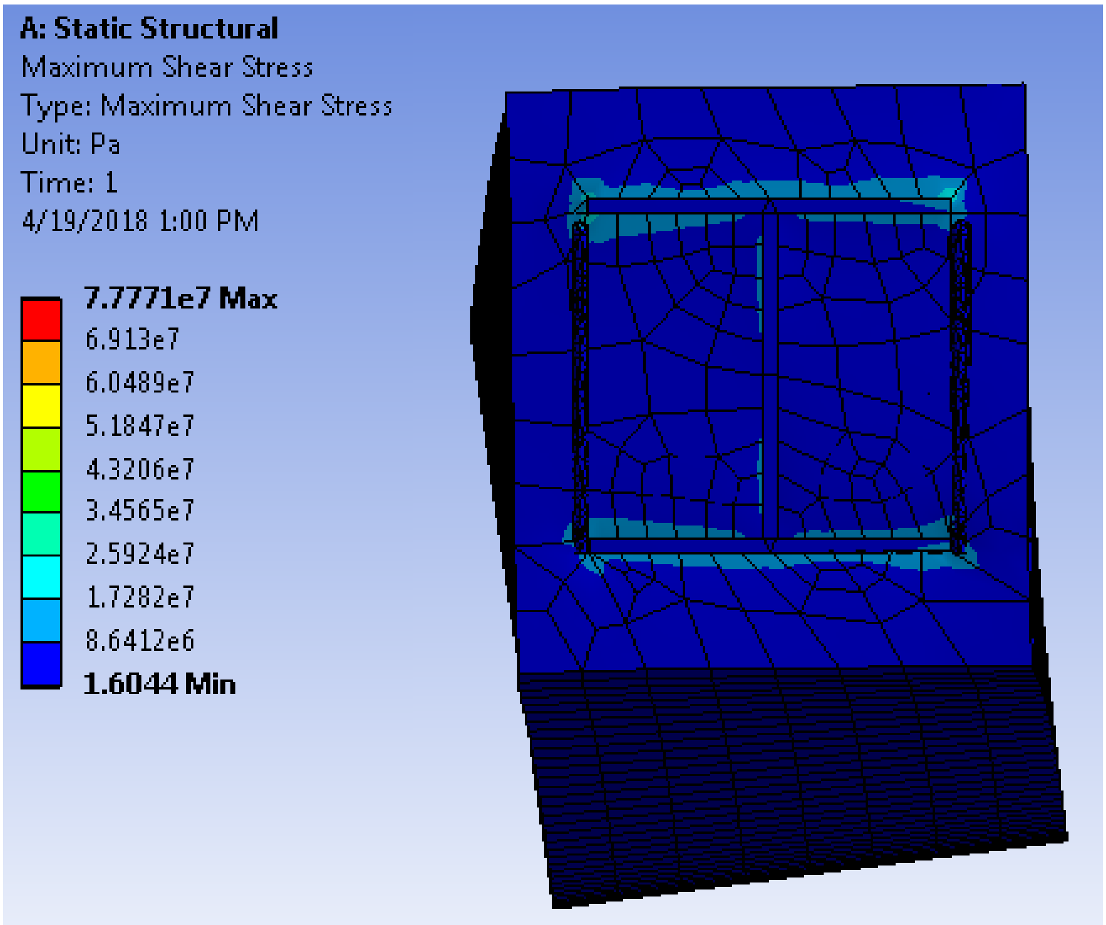


Fig. 14 Maximum shear stress profile of encased composite beam under combined flexure and torsion

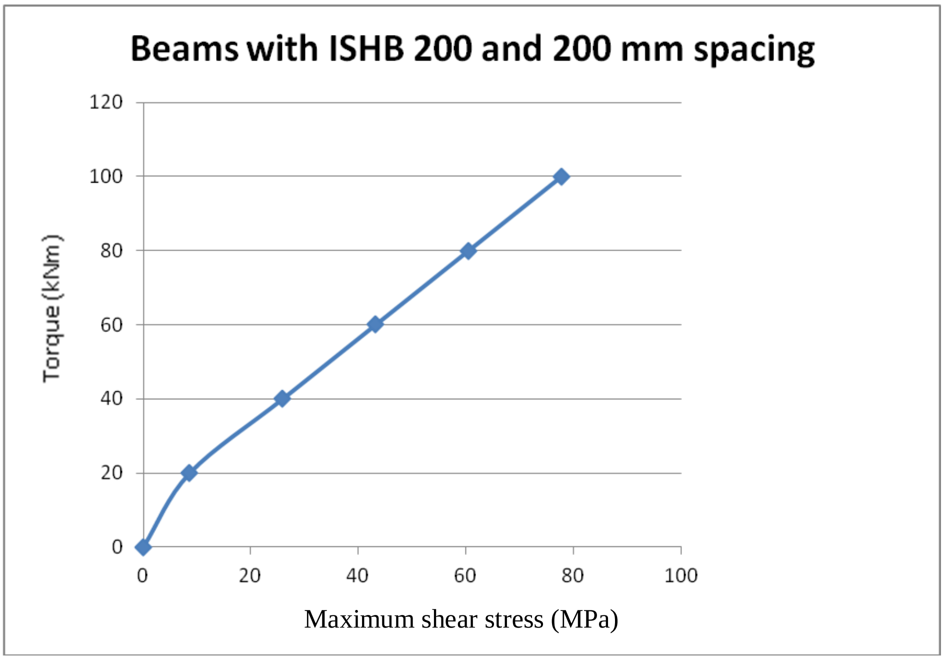


Fig. 15 Relation between the applied torque and maximum shear stress for 200 mm c/c spacing of stirrups

VIII. COMPARISON OF REINFORCED BEAM WITH ENCASED COMPOSITE BEAMS UNDER FLEXURE AND TORSION

As in the case of RCC beam, with decrease in spacing of lateral stirrups, shear capacity is improved under combined action of flexure and torsion. It also offers a reduced depth of beam section which significantly reduces the dead load of the structure compared to RCC beam. From the stress profile, it is observed that along with lateral stirrups, I section ie ISHB 200 itself can adapt the shear under torsion to a certain extent.

8.1 Parametric Studies

In this case parameter under consideration is spacing of lateral stirrups. As in the case of RCC beam, shear stress intensity is reduced in encased composite beams with the use of lateral stirrups. With decrease in spacing of lateral stirrups, intensity of shear stress is reduced to a great extent. At the same time, spacing of stirrups cannot be decreased further as there occurs horizontal stress concentration at the contact area between stirrups and flanges of I section. Therefore, the spacing is limited to 150mm c/c.

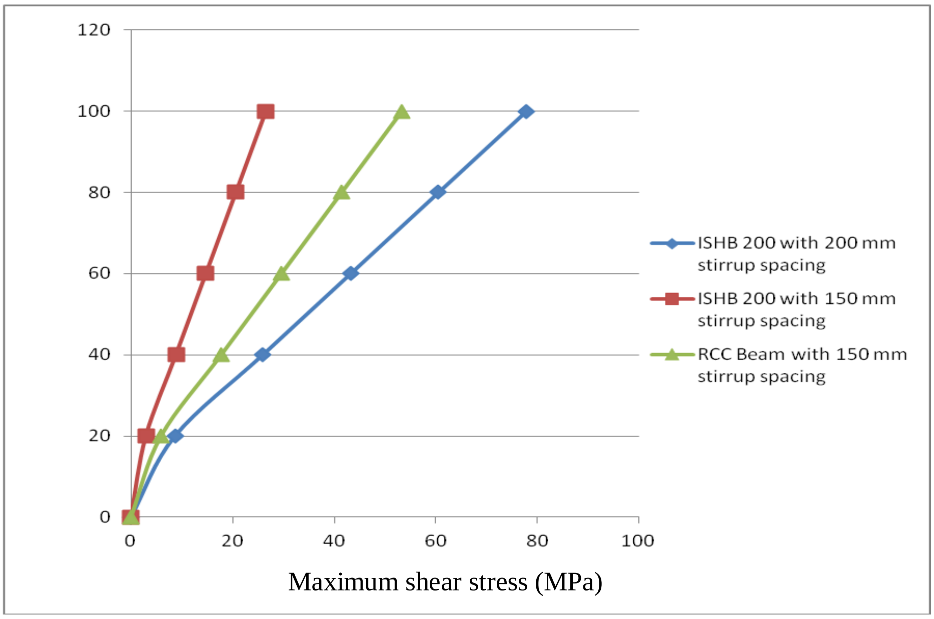


Fig. 16 Relation between the applied torque and maximum shear stress for various spacing of stirrups

IX. RESULTS AND DISCUSSIONS

- There is increase in load carrying capacity of encased composite beams compared to reinforced beams under flexure.
- The depth of composite section also reduced to a significant rate wrt reinforced beams
- The stress concentration is reduced for encased composite beams under flexure
- There is increase in shear strength of encased composite beams with a stirrup spacing of 150 mm c/c compared to reinforced beam under combined flexure and torsion

Table 2. Flexural results for various beam specimens

Specimen	**Size (mm)**	**Load (kN)**	**Deflection (mm)**	**Maximum principle stress (MPa)**
Reinforced beam	300 x 550	500	21.63	133.46
Encased composite beam with ISHB 150	200 x 250	500	13.12	198.3
Encased composite beam with ISHB 200	250 x 300	500	1.706	26.93
Encased composite beam with ISMB 225	200 x 350	500	7.96	158.59
Encased composite beam with ISLB 250	200 x 350	500	8.51	129.24
Encased composite beam with ISWB 200	220 x 330	500	8.55	178.88

Table 3. Torsional results for various beam specimens

Specimen	Size (mm)	Pressure (kPa)	Torque (kNm)	Maximum shear stress (MPa)
Reinforced beam with 150 mm c/c spacing of stirrups	300 x 600	340.7	100	53.32
Beam with ISHB 200 and 200 mm c/c spacing of stirrups	250 x 300	340.7	100	77.77
Beam with ISHB 200 and 150 mm c/c spacing of stirrups	250 x 300	340.7	100	26.47

X. CONCLUSION

- The Ansys model presented in this study is capable of tracing behavior of encased composite beams under flexure and torsion
- Being an under reinforced section, the steel at tension zone reaches yield strain at loads lower than the load at which concrete reaches the failure strain in the considered continuous beam under flexure. With the influence of hogging moment at intermediate supports, the tension zone exist at top fibres of beam section.
- The performances of five encased composite beams are evaluated and compared with reinforced concrete beam. From the stress profile, it is observed that the stress handled by longitudinal bars in RCC beam is safely adapted by the top and bottom flanges of I section in encased composite beams at a reduced stress intensity.
- When reinforced beam undergoes yielding beyond a loading of 350 kN, encased composite beams can withstand higher load of about 500 kN under small deflections.
- With an optimum flange thickness and depth of section, beam with ISHB 200 has shown a better load carrying capacity under reduced deformation and stress intensity. It is also observed that too much reduction in depth can also adversely affect the load carrying capacity of section as the flexural rigidity of the section is lost.
- As in the case of RCC beam, shear stress intensity is reduced in encased composite beams with the use of lateral stirrups. With decrease in spacing of lateral stirrups, intensity of shear stress is reduced to a great extent
- At the same time, spacing of stirrups cannot be decreased further as there occurs horizontal stress concentration at the contact area between stirrups and flanges of I section. Therefore, the spacing is limited to 150mm c/c.

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