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Effect of Rolled Steel Sections as Main Reinforcement on Structural Properties of Beams

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ABSTRACT
Composite members as structural element made up of concrete and steel which provides high performance and speedy construction. The composite beams has other advantage also such as increased fire resistance, increased load carrying capacity, stiffness in local buckling, Hence composite construction requires less steel and gives economical designs and Stiffness in bending as compared to Reinforced concrete beam. Also basic requirement of high rise construction is ductility of framed structure. There is lot of congestation of reinforcement in beam column joint which poses problem in maintaining the joint ductile. Hence to overcome such problem rolled steel sections are used as main reinforcement in place of normal tmt steel bars. To study the effect of rolled steel section – angle section and channel sections as main reinforcement on structural properties of beams such as ultimate load carrying capacity and deflection, flexure and shear strength experimentally as well as analytically using Ansy's 14.5 software. This research deals with the study of Concrete beam encased with rolled steel angle section and channel section as main reinforcement in place of conventional HYSD tmt steel experimentally as well as analytically using Ansys software. Such beams with composite action of rolled steel and concrete, proves to be an economical and effective alternative to more traditional structural systems where normal tmt steel is used as main reinforcement. Hence increase in ductility may be achieved by using such composite members and reduction in weight of structure can also be achieved, which in turn reduces lateral forces due to earthquake. For the analytical approach to the problem, a three-dimensional (3D) Finite Element (FE) model was created, using solid elements with material, geometrical and interfacial non-linearity. The effect of change in stirrups spacing is studied experimentally as well as analytically. For this study, the cross sectional dimensions of the beam, percentage of tension reinforcements is kept the same and spacing of stirrups is varied. The objective is to study the ultimate load carrying capacity, modes of failure and load deflection behavior of composite beams and there after compare the results experimentally as well as analytically. Also, comparison of load carrying capacity of 'Concrete Encased Composite Beams' with and without shear reinforcement is carried out.

Keyword: Composite beams, rolled steel sections – angle section and channel section, flexure and shear strength

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I. INTRODUCTION

Concrete is good in compression but has low tensile strength where as steel has high tensile strength but incapable off withstanding compressive forces. When combined together gives durability and stiffness against earthquake forces. Composite member construction consists of two material structural steel (rolled or built up) and concrete so that both their strength are utilized fully to increase the strength, stiffness and durability of the structure .In this way individual weaknesses of concrete and structural steel are overcome. Steel-concrete composite beams have been widely used in building and bridge construction. A composite beam is constructed by casting a reinforced concrete slab on the top of a steel beam. Composite action between the steel and the concrete is achieved by means of mechanical connectors. These connectors are generally dubbed as 'shear connectors'. They are typically connected by welding to the top flange of a steel beam and cast within the concrete slab. It is only through this connection that composite action is achieved, without these connectors, the concrete and the slab act independently and analysis is relatively simple.

- **Theoretical Aspect**

As we know the concrete is weak in tension and hence it is combined with steel to enhance the strength. Since steel is good in tension it is provided as main reinforcement on the tension side of beam. The main function of bottom reinforcement is to carry direct and bending tension. In present study plain cement concrete is combined with rolled steel section as main reinforcement. Present study aims in proving that Rolled Steel Section performs better in resisting deflection as compared to conventional TMT steel reinforcement. The serviceability limit of deflection requires control of excessive flexural deflection. Practically, the design requirement of deflection is limited to span to depth ratio. The limit is L/250 as per IS 456 200 clause no. 25.6.This is because the span is the principal factor governing the magnitude of deflection.

$\Delta = (K)\ Wl^3/EI$

In above expression we can see that deflection varies with cube of span. As the span increases, the depth increases leading to heavy beams. Hence the computed deflection on application of load shall be within the limits as specified by the code IS 456.Moreover, excessive deflection creates the feeling of:

- lack of safety.
- Affect the geometry of structure.
- Leads to deformation of structural members.
- Leads to cracks in walls ceilings floors etc.
- Leads to leakage problem.

In the present study the span to depth ratio corresponds to 700/250 = 2.8 mm which is in compliance with IS 456 2000.

In our Experimental work for all spacing the deflection is within limits. It is clear with combined load and deflection for N Type, A Type and C Type Beams for 0 mm spacing, 50 mm spacing, 100 mm spacing & 200 mm spacing.

Also, it is advisable that designed section should be under reinforced since failure will take place after yielding of steel with clear warning signals like excessive deflections and cracking before the ultimate failure. In under reinforced sections, the tension steel reaches yield strain at loads lower than the load at which concrete reaches the failure strain. When the steel yields earlier than concrete there will be excessive deflections and cracking with a clear indication of impending failure. Hence all the beams sample are under- reinforced.

- **Experimental Work**

The Constant parameters included in this study are Percentage of steel, Cross sectional area of member and Grade of concrete. In the present work, rolled steel angle sections are used in the members as bottom reinforcement with and without shear reinforcement. Also Normal tmt steel is used as bottom reinforcement with and without shear reinforcement. The percentage of steel and the cross-sectional area are kept same in the composite section and in the conventional section. Members are cured for 28 days and then tested on universal testing machine. Their failure load and deflection are noted. For this purpose, the criteria included is maximum and minimum tension reinforcement in beams as per clause 25.6 of IS 456-2000

Following members are recognized for experimental investigation:

- **Type NB**: Beams with Normal ie. Conventional TMT reinforcement.
- **Type AB**: Beams with rolled steel Angle sections as reinforcement.
- **Type CB**: Beams with rolled steel Channel Sections as reinforcement.

Table 1: Details of Beam Specimen

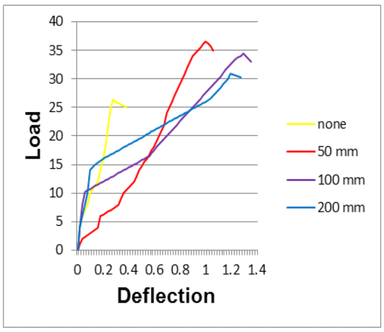
Nomenclature	Type NB	Type AB	Type CB
Size of Beam	150 x 150 x 700 mm	150 x 150 x 700 mm	150 x 150 x 700 mm
Bottom Reinforcement	2 #12	2 # ISA 20 x 20 x 3	3 # Channels 20 x 7 x 3
% of reinforcement	1.32 %	1.3 %	1.4 %
Top reinforcement	2 # 8	2 # 8	2 # 8
Stirrups	2 legged 8 mm dia	2 legged 8 mm dia	2 legged 8 mm dia
Stirrups Spacing	No Spacing, 50 mm, 100 mm, 200 mm	No Spacing, 50 mm, 100 mm, 200 mm	No Spacing, 50 mm, 100 mm, 200 mm
No. of samples casted	12 nos.	12 nos.	12 nos.
Type of Section	Under-reinforced	Under-reinforced	Under-reinforced
Grade of Concrete	M20	M20	M20

All types of beams were tested using Hydraulically operated UTM machine with 1.5 kN capacity. The two point load was applied at the middle third portion of the beam. The load was applied gradually and crack pattern was observed. Load at first crack, yield load and failure load along with corresponding deflection were observed. Graph of load v/s deflection was plotted. Hence the load carrying capacities and deformations for beams with rolled steel sections as main reinforcement were studied.

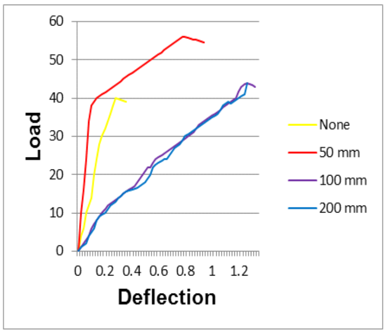
Table 2 : Load Deflection values for experimental results

Spacing of stirrups	Failure Load (kN)					
	Type NB		Type AB		Type CB	
	Load	Def.	Load	Def.	Load	Def.
None	26.00	0.30	40.00	0.28	39.00	0.30
50 mm	36.50	1.00	56.00	0.80	64.00	1.58
100 mm	34.50	1.30	44.00	1.26	48.00	2.80
200 mm	31.00	1.20	39.00	1.12	41.00	1.30

Combined load deflection curve for Type NB Beam specimen



Combined load deflection curve for Type AB Beam specimen



Combined load deflection curve for Type CB Beam specimen

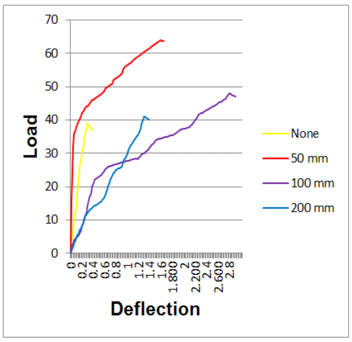


Fig 2 : Full scale model of beam Fig 3: One fourth model of beam Fig 4: Finite element model of beam

Fig 1: Graph showing experimental results for load deflection curve for NB Beam, AB Beam and CB Beam Specimen

- **Analytical Work**

For concrete, the element used is SOLID65, which is defined by eight nodes having three degrees of freedom at each node i.e. translation in x, y, and z directions. For the main reinforcement and stirrups, LINK8 spar element with three degrees of freedom at each node is used i.e. translation in x, y and z direction. It was observed that the region of load and the supports are facing a problem of stress concentration. Hence in order to arrest this problem, the supports and loading region are modeled with a steel block. The element used for this is SOLID45 with three degrees of freedom (u, v, w) at each node. The boundary conditions need to be applied at points of symmetry and where the supports and loading exist. Taking the advantage of symmetry, only one-fourth part of the beam model is considered in the analysis.

ANSYS provided the results corresponding to failure load, deflection plot of the model in x, y and z directions. The results are verified with the experimental investigation. It is observed that all the results are in close relationship with each other.

Table 3: Load Deflection values for Ansys results

Spacing of stirrups	Failure Load (kN)					
	Type NB		Type AB		Type CB	
	Load	Def.	Load	Def.	Load	Def.
None	29.00	0.34	43.50	0.31	3.00	0.34
50 mm	41.00	1.12	60.00	0.89	61.00	1.77
100 mm	39.00	1.48	43.00	1.44	45.00	3.27
200 mm	35.50	1.01	36.00	1.09	39.00	1.13

Fig 5: Graph showing experimental results for load deflection curve for NB Beam, AB Beam and CB Beam Specimen

- **Determination of Modulus of Elasticity, Development Length & Shear strength of beam Specimens**

Modulus of elasticity is a measure of stiffness of beam within elastic limit and stiffness is the measure of rigidity of a member ie the extent to which the member can resist deformation in response of applied load. For a given loading condition, the deflection can be obtained by the following formula: where *w* is self-weight of beam in N/mm and W is half the load at first crack in N.The experimental value of mid-span deflection is substituted in the above equation for each case. By substituting proper values of w, W, *l*, and I, the remaining unknown value i.e. E is evaluated.

Table 4: Modulus of elasticity for Experimental and Analytical results

Spacing of stirrups	Modulus of elasticity (N/mm²)					
	Type NB		Type AB		Type CB	
	Experiment	Ansys	Experiment	Ansys	Experiment	Ansys
50 mm	23055	26230	31004	34946	16000	17752
100 mm	17324	20037	18405	20962	8216	9498
200 mm	25071	21442	23897	23014	23213	20037

Development length is a length required to transfer the force from steel to concrete. In is necessary to transfer the force T in the bar to the surrounding concrete through bond. Let the length required to transfer a force T in the bar to the surrounding concrete by means of bond before it is terminated be L_d.

Force = Stress x Area $\rightarrow \sigma_s$ x (π x $d^2/4$). This force must be transferred from steel to concrete through bond acting over the perimeter of the bar (Ld)

$L_{d} \times \tau_{bd} \times \pi d = \sigma_s \times (\pi \times d^2/4)$

Hence, $Ld = \sigma_s \times (\pi \times d^2/4)/(\tau_{bd} \times \pi d) = \sigma_s \times$ (Cross sectional Area)/(τ_{bd} x Perimeter)

Table 5 : Development Length for Beam Specimen

Beam Specimen	Development length in mm
Type NB	483
Type AB	253.50
Type CB	181.50

Shear strength of the beam is considered as the ultimate load at which the diagonal cracks are formed. The first crack load that causes diagonal cracks corresponds to initiation of shear failure mechanism. The ultimate failure load is not much different from the load causing diagonal cracks. In case of beams the shear strength at ultimate state(Vc) is the joint action of ultimate shear taken by concrete (Vuc) which is constant for a particular grade of concrete and ultimate shear resisted by web steel (Vus). Also the shear reinforcement increases the ductility of beam and reduces the possibility of sudden failure in beams.

Stirrups spacing	Type NB			Type AB			Type CB		
Shear strength in kN	Vu	Vuc	Vus	Vu	Vuc	Vus	Vu	Vuc	Vus
Without stirrups	13.2	12	1.2	20.2	11.46	8.74	19.7	12.28	7.42
50 mm	18.45	12	6.45	28.2	11.46	16.74	32.2	12.28	19.92
100 mm	17.45	12	5.45	22.2	11.46	10.74	24.2	12.28	11.92
200 mm	15.7	12	3.7	19.7	11.46	8.3	20.7	12.28	8.42

II. RESULT AND DISCUSSION

Based on the comparison of results obtained experimentally and analytically using Ansy's 14.5, following values were observed in graphical form which shows experimental analysis is supported by Analytical Analysis

. Fig 6: Graph showing comparison of experimental and analytical results for maximum deflection

Fig 7: Graph showing comparison of experimental and analytical results for load carrying capacity

- It can be observed that the experimental and analytical values are in close relationship with each other.
- It is obvious that Load carrying capacity of rolled steel angle and channel section encased beam is increased considerably as compared with normal tmt steel reinforced beam.
- Maximum permissible deflection is (span/250) 700/250=2.8 mm. Hence the deflection in all the types is within permissible limit (Clause 23.2 of IS 456).
- The deflection of angle reinforced beam is reduced as compared to normal tmt steel reinforced beam. This shows that stiffness is increased due to use of angle section reinforcement.
- There is increase in shear strength of beam when angle and channel section is used as compared to normal tmt steel reinforcement.

- For normal tmt steel reinforcement diagonal cracks were observed indicating shear failure and for angle and channel reinforcement diagonal as well as slight central cracks were observed indicating shear and flexure failure.
- As the spacing of stirrups is reduced the shear strength of beam is increased.
- Use of rolled steel Angle section as main reinforcement is economical as compared to rolled steel channel section.
- It is observed that development length is reduced for AB Type and CB Type beams as compared to NB Type beams. Hence use of rolled steel angle and channel sections as bottom reinforcement will lead to saving in steel at the beam end support and at the beam column junction.
- The modulus of elasticity for AB Type beams are comparative more as compared to NB Type and CB Type.

III. CONCLUSION

Following conclusion can be made based on analytical and experimental work:

- Use of rolled steel angle section as main reinforcement in place of conventional tmt steel leads to
- Increase in load carrying capacity in flexure and shear. Percentage increase for AB type of reinforcement as compared to NB type is 53.8 % for 0 spacing 64.7 % for 50 mm spacing; 27.5 % for 100 mm spacing and 25.8 % for 200 mm spacing.
  Percentage increase for CB type of reinforcement as compared to NB type is 50 % for without stirrups spacing; 85.5 % for 50 mm spacing; 39.1 % for 100 mm spacing and 32.2 % for 200 mm spacing.
- Decrease in deflection indicating more stiffness in AB Type beams. Average percentage reduction in deflection for AB type of reinforcement as compared to NB type is 6.67 % for without stirrups spacing; 20% for 50 mm spacing; 3.0 % for 100 mm spacing and 6.67 % for 200 mm spacing.
- There was increase in Modulus of Elasticity indicating increase in ductility and hence more suitability for earthquake resistant constructions.
- There was decrease in development length which leads to saving in steel at beam end support and beam column joint.
- As we go on reducing the spacing the load carrying capacity is increased and deflection is reduced leading to increase in ductility and stiffness due to the confinement effect of stirrups.

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