Strengthening of Steel Beams against Lateral Buckling and Lateral Torsional Buckling

Satish Gharabude[1], Vinod I Hosur[2]

[1]Post Graduate Student, KLS Gogte Institute of Technology, Belagavi, Karnataka, India
[2]Professor, KLS Gogte Institute of Technology, Belagavi, Karnataka, India

---

Abstract: *We have focused on lateral buckling and Lateral Torsional Buckling behavior of steel I-beams strengthened with steel plate and steel angle section. Five specimens were taken for this study. Length of all specimens were taken 1800mm and section is ISMB150. The strengthening patterns includes different position of steel plate section and steel angle section to the steel I-beam. The finite element model is developed using ANSYS 19.2 Software. The beam considered is laterally unsupported which is simply supported beam. The finite analysis has been carried out using ANSYS 19.2 Software. The analytical results showed that strengthening of steel I-beam at its compression flange using steel plate section and steel angle section reduces the lateral buckling and lateral torsional Buckling of steel beams. The percentage of lateral deflection of the Specimen No 4 reduces up to 50% which is strengthened with steel angle section on the Compression Flange along its Full length as compared to control beam. The weight of steel beam increases consequently cost has been increased. The Percentage of Lateral deflection of the Specimen No 2 reduces to 42.85% which is strengthened using Steel Plate at intermediate Points and also it is Economical. Finally, we can conclude that the Steel beam strengthened with steel plate at its compression flange is a new technique to reduce the Lateral deflection.*

Keywords: Lateral Buckling, Lateral Torsional Buckling, FEM model, ANSYS 19.2, Lateral Deflection

1. INTRODUCTION

Strengthening of existing steel structures is a general way to resist failure due to alter in function or construction defects. Strengthening of steel structures using FRP is a more economical method. It has enhanced strength and ductility of these structures [5]. This have more advantages such as high Stiffness-to-weight ratio, Strength-to-weight ratio, Corrosion resistance and Chemical attacks [1]. Strengthening and repairing of steel members using FRP sheets having more advantages, but application involving steel I-beams have been limited due less influence on Elastic Stiffness[1].Strengthening of steel members using welding of steel plates is very popular method due to its availability, cheapness, uniform material properties (isotropic), easy to work, High ductility and high fatigue strength[1]. Lateral Torsion-flexure buckling (LTB) is important criteria for design of steel members consisting of thin walled I-sections and subject to bending. LTB is depending upon the Shear center and point of application of loads [9]. In case of cold formed steel sections providing flange-Lips increases its Lateral Buckling and Ultimate loads of the beams [7]. Even-though, there is a lot of experimental and analytical research on the lateral torsional capacity of built-up cross-sections.

2. LITERATURE REVIEW

Dr.N M Yossef et al(2015) they studied the Effect of Reducing Deflection of steel I-beams strengthened while loading. The steel cover plate is welded after the deflection of the beam is reduced. The finite element method by using ANSYS software was used to analyze the model and verified by experimental results. They concluded that, the cover plate and cross-section area is the more important parameter which affects the strengthened beam. The welding pattern affects the behavior and strength of the strengthened beam. Strengthening steel beams while under loading shows that the pre-loaded ratio was minor cause on the ultimate strength of the strengthened beam, even so the welding of the steel plate preferences to yield enhances the beam behavior put the increment of the ultimate capacity decreases. Reducing beam deflection before welding has minor effect on the beam strength.

Sherif A Ibrahim et al (2015) they investigated on lateral buckling behavior and strengthening techniques of coped steel I-beams. In this paper, the experimental study was done by using six full scale tests of coped I-beams were taken to obtain the lateral torsional strength. These beams are subjected to two symmetrical point loads both experimentally and using finite element analysis with ANSYS software. They concluded that the reduction of the ultimate buckling capacity due to coping and it depends on the cope length and cope depth. The inelastic buckling load was decreases due to coping by more than 60% compared to un-coped buckling lateral torsional buckling capacity. The coped beams stiffened using vertical and horizontal stiffeners in coped region.

Dr N M Yoessef (2015) they investigated on Strengthening steel I-beams by welding steel plates before or while loading. The tests conducted on six -specimens strengthened with steel cover plates with IPE sections. They were conducted the test under four-point load with one end hinged and other is roller. Four specimens were strengthened before loading and two specimens was strengthened while under load by using new welding technique. The new welding technique is derived on reducing deflection before welding of cover plate. They showed that area and length of the cover plate affected on ultimate load carrying capacity. The proposed. Welding technique which is used weld cover plate while under load increased load capacity and reduced the maximum deflection.

Wael F. Ragheb (2007) they investigated on Improvement in local buckling capacity of pultruded FRP I-sections using Flange Lips. They had analytical study on finite element model of an I-beam in four-point bending using ANSYS. They compared with experimental results. They modelled beams had Flange lips of a constant width and varying height. They showed that providing of compression flange with lips increases the lateral buckling resistance and ultimate loads of the beams.

Jan Barnat et al (2016) they studied on experimental analysis of lateral torsional buckling of beams with selected cross-section types. The preparation of experimental analysis was done with the monitored of difference between the behavior of the monosymmetric and asymmetric cross-section. In this study the four different welded I-section were selected. The geometrical variation of cross-section was developed by movement of top of flanges. The tests were performed on four-point bending test. The experiment test concluded that final stress is a combination of stresses developed by bending and the torsional effect by the cross-section torsional displacement.

E. Y. S. Ahmed et al (2004) they studied A numerical investigations and prepared equivalent moment factor equations. In this study, a numerical model established on the finite element technique is used to determine the critical moment of steel I-beams subjected to various types of loading. Results of the finite element model are related to the critical moment of a simply supported beam subjected to a constant moment in order to determine the equivalent moment factor for each analysis conditions of loading. The analysis is then extended to investigate the effect of the load location with respect to the shear center of the beams cross-sections on the critical moment and equivalent moment factor.

3. PROBLEM STATEMENT

The many research has been established on steel beams with FRP but functions involving wide flange beams have been limited due to the minute increase in elastic stiffness. Since, the welding of steel plates or angles to the compression flange of steel I-beams to enhance the lateral buckling and lateral torsional buckling.

4. METHOLOGY

To investigation of this research, the following procedure has been used.

1) Selection of beam section i.e. ISMB150, Type of beam and Length of the Steel beam.
2) Adopting the strengthening patterns to the selected sections.
3) Preparation of Models in AUTOCAD-2016.
4) Apply the engineering properties to the specimens in ANSYS Workbench.
5) Importing the AUOCAD models into ANSYS 19.2 Space-claim
6) Discretization of the Specimens i.e. meshing
7) Apply the boundary conditions.
8) Apply the load 25%,50%,75% and 100% of the ultimate moment capacity of the section to the respective Specimens.
9) Analyze the established FEM models in ANSYS 19.2 software.
10) Compare the ANSYS results of control beam with Four strengthening specimens.
11) Conclusions

5. GEOMETRIC MODELLING

5.1 Mechanical and Geometrical Properties of the Specimen

The Geometric Models have been prepared using AUTOCAD-2016 and imported to ANSYS 19.2 Workbench. The steel beam Specimens have taken ISMB150 with grade Fe250 and ultimate tensile strength 460MPa.Typical Loading arrangement of the steel beam as shown in Figure. 1 and cross-sections of the beam as shown in Figure .2

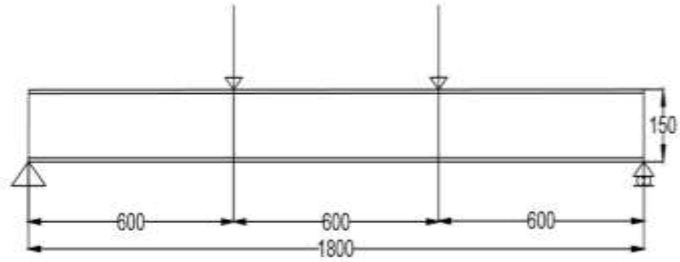


Figure 1. Typical Loading Arrangement of the beam

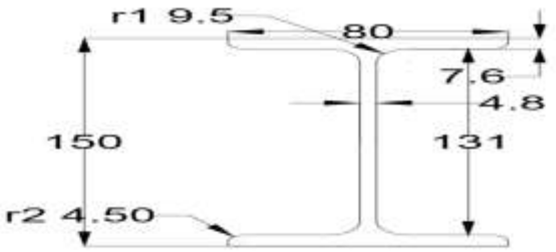


Figure 2. Typical Cross-Sections of the beam

5.2 Strengthening Patterns:

The Typical Strengthening patterns are adopted for the steel beams using steel plate and steel angle section as shown in Figure 3.

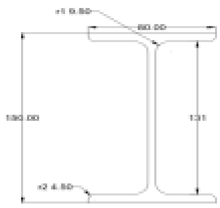
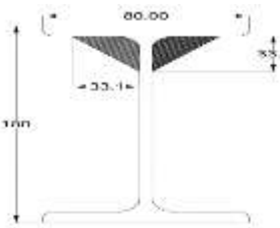
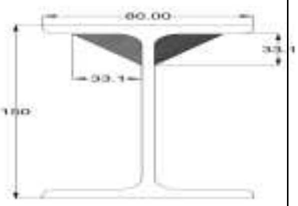
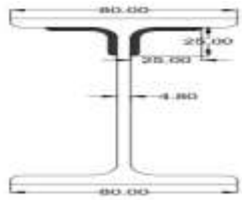
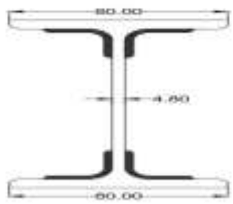
Specimen No	Strengthening Pattern	Description
1		• Control beam
2		• Steel Beam strengthened with steel plate on bottom of compression flange at intermediate points
3		• Steel Beam strengthened with steel plate on bottom of compression flange throughout its full length.
4		• Steel Beam strengthened with steel angle section on bottom of compression flange along its full length.
5		• Steel Beam strengthened with steel angle section on bottom of compression flange and top of tension flange along its full length.

Figure 3. Typical Strengthening Patterns of the Steel I-Beams

6. FEM Analysis

The Finite Element models are developed by using ANSYS 19.2 Software. Apply mechanical properties to the specimens and the prepared models in AUTOCAD-16. The prepare models according to geometrical properties in AUTOCAD 2016 and imported to ANSYS. The typical geometry of specimen in ANSYS as shown in Figure 4.

The geometry of the specimens has discretized to know the exact behavior of the steel I-section of the beam. In the ANSYS 19.2 it will discretize the specimens into element's with according to geometry of the models and also it will take element size automatically. For example, the specimen no 1 element size is 3.1mm. Number of 25157 and Number of elements 12380 respectively. The typical image of meshing of FEM models in ANSYS as shown in Figure 5.

In this investigation, we have selected the laterally unsupported beam which is considered as simply supported beam. Therefore, we have been considered one end is hinge and another end is roller. Since, one is restrained all moments and another end restrained in Y-direction only.

In this investigation, we have been selected Laterally Unsupported beam with Two-point loads at one third of the span of the steel beam. The distance between the point of application of loads is 600mm.The steel plate 80mmX80mmx10mm has been created during modelling of the Specimens. In this plate only we have been applied the loads.


Figure.4 Typical FEM modelling in ANSYS 19.2

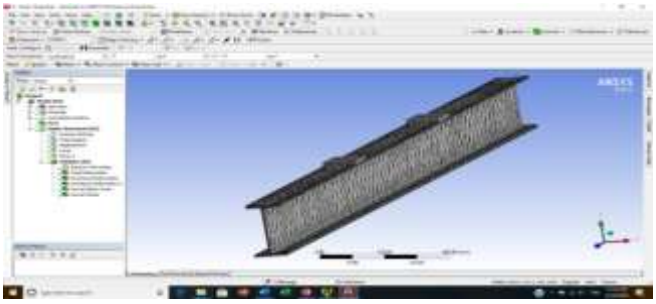


Figure.5 Typical FEM Meshing in ANSYS 19.2

After providing boundary conditions and application of loads into the FEM specimens. The typical results of vertical deflection, Lateral deflection, Maximum strain and Bending stresses as shown in Figure 6, Figure 7, Figure 8 and Figure 9 respectively.

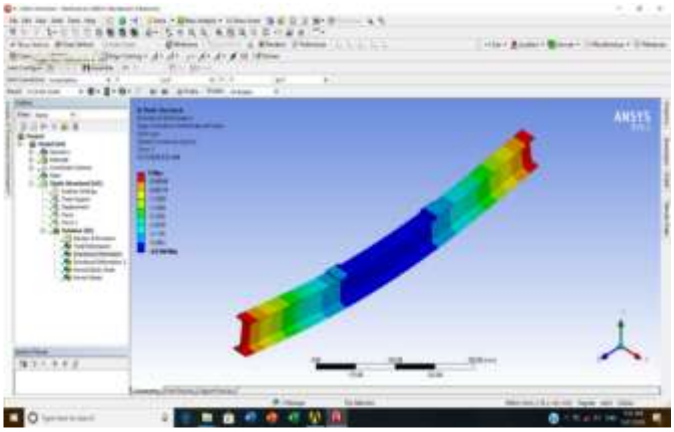


Figure 6. Typical Vertical deflection of FEM Specimen

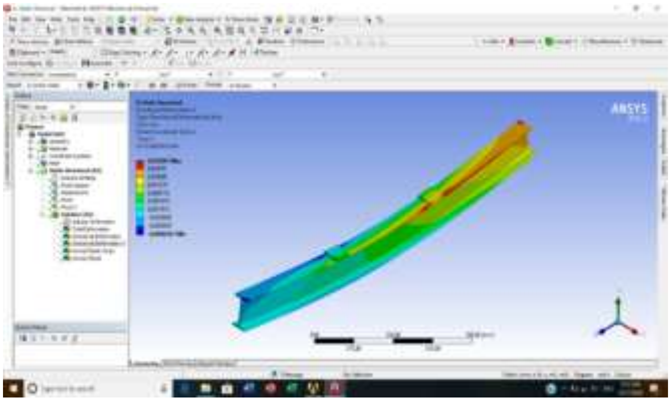


Figure 7. Typical Lateral deflection of FEM Specimen

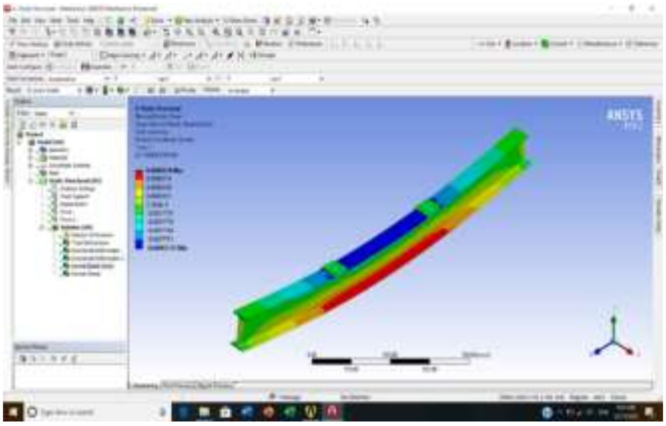


Figure 8. Typical Normal Elastic Strain of FEM Specimen

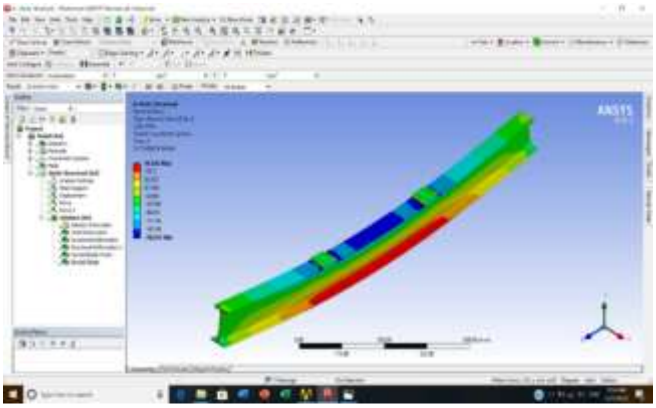


Figure 9. Typical Bending stresses of FEM Specimen

7. Results and Discussions

The FEM analysis has done by using ANSYS 19.2 Software. The results are tabulated such as Vertical deflection, Lateral deflection, Maximum strain at its midspan and Bending Stresses according to application of loads. The comparison of results of control beam with strengthening specimens are as follows.

7.1 Load versus Vertical Deflection

The Vertical deflection of Specimen 4 such as strengthening of steel I-beam using steel angle section at both compression flange and tension flange along its full length is very less. Similarly, the specimen 2, Specimen 3 and Specimen 4 Percentage of vertical deflection decreases as compared to control beam such as 1.00%,26% and 12% respectively. The typical comparisons of vertical deflection of all specimens as shown in Graph 1.

7.2 Load versus Lateral deflection

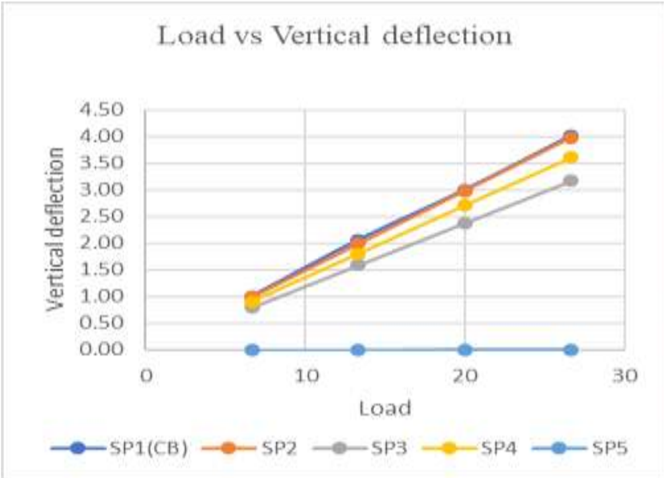
the Lateral deflection of Strengthening specimens has been reduced due to laterally stiffness developing against deformation about minor axis. The Percentage of Lateral deflection decreases of the Specimen 2, Specimen 3 and Specimen 4 as compared to control beam such as 42.85%,34.37% and 50% respectively. However, the Specimen 5 which is strengthening of both compression flange and tension flange the Percentage of lateral deflection increases 15.61%. The typical comparisons of Lateral deflection of all specimens as shown in Graph 2.

7.3 Load versus Normal Elastic Strain

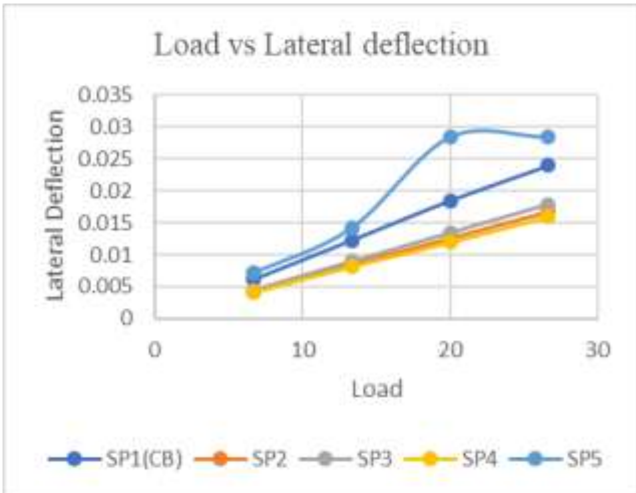
The Normal Elastic Strain has been reduced due Strengthening of the specimens using steel plate section and steel angle section. The percentage of reduction in bending stress of the specimen 2. Specimen 3, Specimen 4 and Specimen 5 as compare to control beam are 2.625%, 3.924%,2.625% and 26.69% respectively. The typical comparisons of Normal Elastic Strains of all specimens as shown in Graph 3.

7.4 Load versus Bending Stress

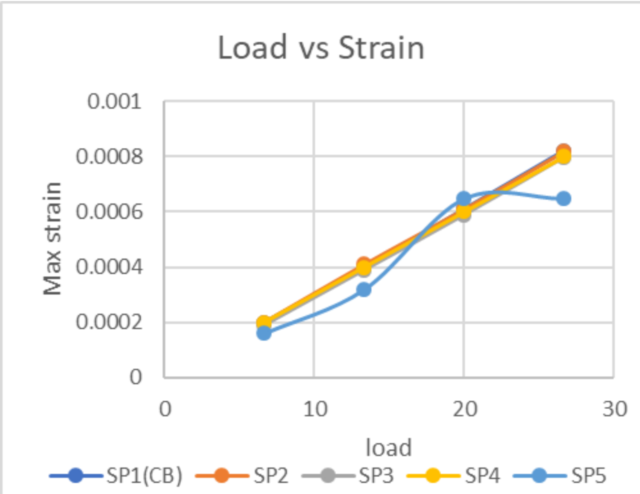
the bending stresses has been reduced due Strengthening of the specimens using steel plate section and steel angle section. The percentage of reduction in bending stress of the specimen 2. Specimen 3, Specimen 4 and Specimen 5 as compare to control beam are 0.86%, 2.600%, 1.87% and 26.46% respectively. The typical comparisons of Bending stresses of all specimens as shown in Graph 4.



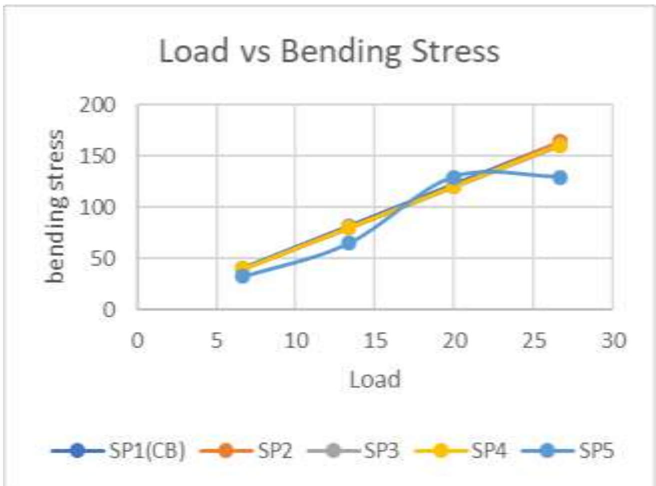
Graph 1. Comparison of Vertical Deflection of all the Specimen



Graph 2. Comparison of Lateral Deflection of all the Specimen



Graph 3. Comparison of Normal Elastic Strain all the Specimen



Graph 4. Comparison of Bending Stresses all the Specimen

8. Conclusions

Referring Various FEM analysis results it has been cleared that Strengthening of steel I-beam at its compression flange using Steel Plate section and Steel Angle Section is a significant technique. The various conclusions are listed below.

(1) Strengthening of steel I-beams using Steel Plate and Steel Angle section on the flanges causes increment in Elastic behavior of beams and consequently gives higher yield point value.

(2) The vertical deflection of the Specimen no 5 which is strengthened using steel angle section on both bottom and top flanges is very less due to in-plane bending strength is more. Hence Specimen no 5 is more significant for considerations of Vertical deflection.

(3) The Percentage of decrease in lateral deflection of the Specimen no 2, Specimen no 3 and Specimen no 4 as compared to control beam are 42.85%, 34.37% and 50% respectively. As per Lateral deflection considerations Specimen no 4 is more significant but it is strengthened using Steel Angle Section along its full Length due to this weight of the steel beam will increase consequently cost of the steel beam will more.

(4) The Percentage of decrease in Lateral deflection of the Specimen No 2 is 42.85%, which is strengthened using steel plate on compression flange at intermediate points. This specimen No 2 is more significant because it is more economical due to reduction in the weight of the steel.

(5) The Percentage of increase in Lateral deflection of the Specimen No 5, which is Strengthened using steel angle section along its full length on both the flanges, is 15.61%. Hence, we can conclude that the strengthening of tension flange using steel angle section is not recommended.

(6) The Percentage of reduction in strain at its midspan of Specimen No 2, Specimen No 3, Specimen No 4 and Specimen No 5 are 2.625%, 3.924%, 2.625% and 26.69% as compared to Control beam. Hence, The Specimen No 5 is more significant as compared to all the specimens.

(7) The Percentage of reduction in Bending Stress of the Specimen No 2, Specimen No 3, Specimen (vii) The Percentage of reduction in Bending Stress of the Specimen No 2, Specimen No 3, Specimen No 4 and Specimen No 5 are 0.86%, 2.600%, 1.87% and 26.46% respectively. Hence, the Specimen No 5 is more significant as per considerations of bending stresses.

REFERENCES

[1] N M Yossef (2015) "Effect of Reducing Deflection of steel I-beams strengthened while loading," International Journal of Engineering Research & Technology, Vol.4, pp.573-580.

[2] Ismail Amer, E. F. Sadek, M. A. Khalaf, M. M.Abdel-Wahab(2017) "Enhancing the End Anchorage of Strengthened Steel I-Beams Using CFRP Laminates," International Journal of Scientific & Engineering Research Vol.8,pp.404-414.

[3] Yi Liu and Liam Gannon (2009) "Experimental behavior and strength of steel beams strengthened while under load," Journal of constructional steel Research, Vol.65 pp.1346-1354.

[4] Omar H. Elkhabeery, Sherif S.Safar and Sherif A.Mourad (2018) "Flexural Strength of Steel I-beams reinforced with CFRP at tension flange," Journal of constructional steel Research,Vol.148, pp. 572-588.

[5] Sadashiv Tavashi, V S Kshirsagar, Rahul Kapase and Avinash Thorat(2017) "Flexural Behavior of Steel I–Beams Bounded With Different Fiber Reinforced Polymer Sheets," International Journal of Engineering Trends and Technology, Vol.54,pp.135-140.

[6] Faikha V.P.1, Nandhu Ramesh, Shilpa S, Sulthan Nassar, and Adila Abdulla Kunju (2019) "Flexural Strengthening of Steel Beams using CFRP Sheets," International Research Journal of Engineering and Technology, Vol.06, pp. 6016-6022.

[7] WAEL F RAGHEB (2007) "Improving Local Buckling Capacity of Pultruded I-beams using Flange Lips" Journal of Reinforced Plastics and Composites Vol.26, No.15/2007.pp1513-1521.

[8] Sherif. A.Ibrahim, Abdelrahim K Dessouki and Seham.A.El-Saeed(2015) "Lateral Buckling Behaviour and Strengthening Techniques Coped Steel I-Beams," Journal of Constructional Steel Research,Vol.108,pp.11-22.

[9] E. Y. S. Ahmed (2004) "Lateral Buckling of Steel I-Beams: A Numerical Investigation and Proposed Equivalent Moment Factor Equations," Al Azhar University Engineering Journal Vol. 7, pp. 111-123.

[10] K.C. Rockey and D.A. Nethercot (1971) "Stabilisation of Beams Against Lateral Buckling," International Specialty Conference on Cold-Formed Steel Structures. Vol.4. pp. 126-135.

[11] M. Kamruzzaman, M.Z. Jumaat, N.H.R. Sulong, I.M.I. Qeshta and K. Narmashiri (2017) "Effects of Lateral Bracing and Stiffeners on the CFRP Failure of Strengthened Steel Beams," International Technical Postgraduate Conference.Vol.210, pp.1-17.

[12] Jan Barnat, Miroslav Bajer, Martin Vild, Jindřich Melcher, Marcela Karmazínova and Jiri Pijak (2017) "Experimental Analysis of Lateral Torsional Buckling of Beams with Selected Cross-Section Types" Journal of Procedia Engineering, Vol.195 pp.56-61.

[13] Y. L. Xu, Y. J. Shi, Y. R. Wu and H. Y. Ban (2018) "Experimental and Numerical Study on Lateral-Torsional Buckling Behavior of High -Performance Steel Beams" International Journal of Structural Stability and Dynamics, Vol. 18, pp.1-29.

[14] M. Z. Kabir and A. E. Seif (2011) "Lateral Torsional Buckling of Steel I-Beam Retrofitted Using FRP Sheets: Analytical Solution and Optimization" International Conference on FRP Composites in Civil Engineering, Vol.5, pp.916-918.

[15] Sepehr Movaghati (2019) "Strengthening beam sections of industrial buildings against lateral torsional buckling" Proceedings of the Annual Stability Conference Structural Stability Research Council, Vol.1, pp.1-12.

BIOGRAPHIES

SATISH GHARABUDE PG student,
Dept of Civil Engineering,
KLS Gogte Institute of Technology,
Belagavi, Karnataka, India

Dr. Vinod I Hosur Professor,
Dept of Civil Engineering,
KLS Gogte Institute of Technology,
Belagavi, Karnataka, India