Study of bending behavior of horizontally curved steel beams using ansys

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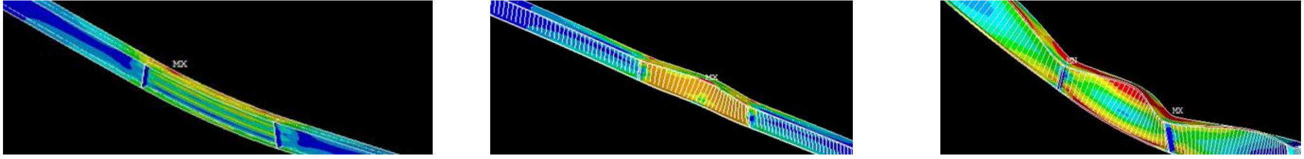
ABSTRACT

The primary objective of this paper is concerned with the study of nonlinear behavior of horizontally curved steel I-beams. Non-linear analysis of single span curved steel beam is done using finite element modeling in ANSYS software. Parametric studies are carried out where the variables include the radius of curvature to span ratio (R/L), width to flange thickness (B/t_f) and depth to flange width (D/t_w). Ultimate load carrying capacity, flexural behavior for different radii of curvature to span ratio with varying width to flange thickness and depth to web thickness are investigated. They are having transverse actions that are perpendicular to its plane of curvature. Vertically curved beams like arches which are having loading actions in their plane are not considered in the study. The load which is vertical produces vertical bending in horizontally curved beam and thereby produces twist rotations and vertical displacements. In the construction of modern highway bridges and major buildings, horizontally curved steel beams are commonly used.

KEY WORDS: Horizontally curved beams, nonlinear analysis, finite element analysis, ANSYS.

1. INTRODUCTION

Horizontally curved beams are used in construction of balconies, interchange facilities, modern highway bridges etc. Horizontally curved beams are having transverse action that is perpendicular to its plane of curvature. There arises the need for more elaborate investigations to be done for better understanding and design of horizontally curved steel beams. This paper deals with inelastic nonlinear analysis of horizontally curved steel I-beams. Vertically curved beams like arches which are having loading actions in their plane are not considered in the study. The load which is vertical produces torsion effect and vertical bending in horizontally curved beam. Thereby it produces twist rotations and vertical displacements. The primary bending vertical deflections twist rotations, torsion, together develops second-order bending action in curved beams. In horizontally curved beam early yielding and nonlinear behavior are observed and hence the ultimate load-carrying capacities reduce significantly. The inelastic response of curved beams with varying included angle is shown in Figure.1. For curved beams with a small included angle ($\theta \leq 1°$), bending is major action and the inelastic behavior of curved beams is similar to straight I-beams. For curved beams with included angle between 1° and 20°, inelastic behavior shall be due to both bending and torsional response. Similarly, as included angle increase more than 20°, bending action decreases and significance of torsion increases.



For $\theta \leq 1°$ 1°< θ < 20° θ > 20°

Figure.1. Response of curved beam for varying included angle

Shanmugam (1995), investigated on steel beams curved in plan experimentally. Ultimate load behavior of curved I-beams is also dealt two I beam sets namely built-up sections and rolled sections were experimented by them. Ultimate strength found from finite element analysis and experimental results were found to be in agreement. Radius of curvature to span-length ratio (R/L) and effects of residual stresses on ultimate strength were studied by them. With the decrease in R/L ratio, load-carrying capacity also decreases. This is more evident in welded sections. Khoury (2014) did computational studies of horizontally curved, longitudinally stiffened, plate girder webs in flexure, and ABAQUS software was used for studies. Low shear and high bending moment were applied vertically on girder cross section. The various positioning of the longitudinal stiffeners were recommended after studies, which was almost similar to that in straight plate girders. It was concluded from their studies that web stability can be enhanced by horizontal curvature. At times to increase flexural strength of cross section, curvature alone can be increased without using longitudinal stiffeners. Yong-Lin Pi (1995) developed a model of curved beam in finite element for the material and geometric nonlinear analysis. Major action is bending when the curved beam is having small initial curvature. Then it is found to have similar behavior of straight beam. Bending and non-uniform torsion occurs when initial curvature is large and thus results in nonlinear inelastic behavior at an early stage. Since both effects occur, it is different from straight beam's inelastic flexural-torsional buckling behavior.

2. METHODOLOGY

Finite Element Validation: A representative model is validated against experimental data. In order to validate the analytical model, experimental results on steel I beam curved in plan reported by Thevendran (1998) are used for comparison, in which the ultimate load behavior is taken into account. The selected steel section is a hot rolled section 5 m length which was cold bent to required horizontal curvature using a hydraulic press. The beam used for validation is having a radius of 20 m and arc length 5 m between the supports. A point load is applied at a distance of 3.8 m from the support. Supports are provided at the beam ends so that the vertical displacements are effectively prevented. The specimen is also restrained in the lateral direction at the load point. The specimen modeled using ANSYS software is given in Figure.2.

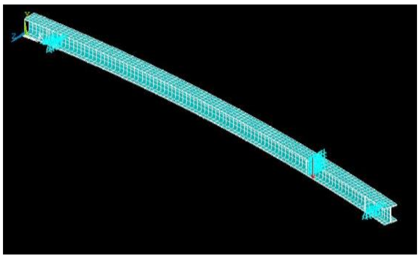


Figure.2. Finite element modelling – validation beam

A plot between experimental loads versus mid-span vertical deflection reported by authors was compared with the analytical results, shown in Figure.3. The ultimate load as per ANSYS results is 176.9 kN. The experiment result value is 192 kN. The results obtained from ANSYS are almost matching with the experimental values reported by above mentioned researchers. The accuracy was found to be 93%.

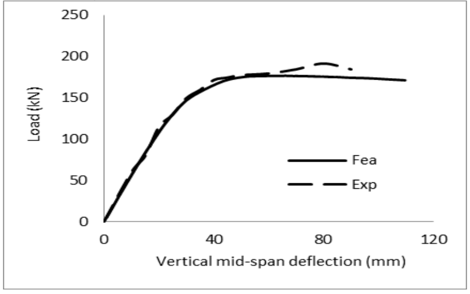


Figure.3. Comparison of experimental and analytical results

Modeling and Analysis: ANSYS 12.0.1 is used in modeling the parameters. Finite element modeling and analysis of structural members like beams, columns, slabs and walls, etc. shall be performed up to the inelastic range. ANSYS is an appropriate tool for problems of structural analysis. It can deal with high degree of material nonlinearities and geometric nonlinearities. The loading conditions, geometry, in-plane boundary conditions, out-of-plane restraint conditions, stress–strain behavior of the material are the parameters to be addressed in finite element modeling. Accurate representation of the above said features when incorporated in the models can still show differences in the measured behavior of the test specimens and analytical behavior of the models. Regarding numerical study, the element type and size, mesh layout, material model, initial residual stresses are parameters to be considered. A dense mesh of four node nonlinear shell finite elements was used for the construction of beam models. Agrawal (2016) studied behavior of RC two way slabs by modelled and analyzed using ANSYS. The SHELL181 from the element library of ANSYS is employed in the study. It is a 4-node element with 6 degrees of freedom at all nodes. For nonlinear applications, this node is well suited. Both linear and non-linear properties of high strength steel grade given by IS 2062:2011 are opted in modeling.

Linear properties:

- Young’s Modulus – 2 x 10^5 N/mm^2
- Poisson’s ratio-0.3

Non-linear properties:

- Yield strength (f_y) - 650 N/mm^2
- Ultimate strength (f_u) - 780 N/mm^2
- Percentage elongation - 0.12

The sizing of the mesh was kept 50 mm, support conditions are a single span simply supported curved beam of 5 m, which is shown in Figure.4, (between supports) is used for the study. The beam consists overhang of 200 mm on both side and two concentrated loads at 2 m from either side of supports. Along the length of a simply supported curved I-shaped beam assembly are imposed; the stiffeners are positioned at the supports and at the loading positions.

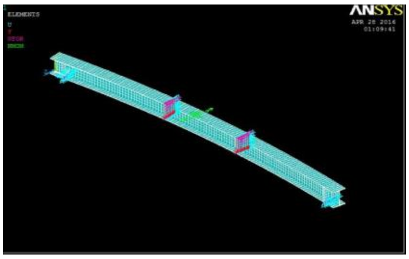


Figure.4. Restrained conditions and loading position of the curved beam

Parametric Study: Parametric studies are carried out where the variables include the radius of curvature to span ratio (R/L), width to flange thickness (B/t_f) and depth to web thickness (D/t_w).Width to flange thickness (B/t_f) and depth to web thickness (D/t_w) are chosen as per IS 800-2007.The various classes are chosen for the study namely plastic, compact and semi-compact sections. Ultimate load carrying capacity, flexural behavior and torsional stiffness for different radii of curvature to span ratio with varying width to flange thickness and depth to web thickness are investigated. A single span simply supported curved beam of 5 m, between supports is used for the study. The overhang is 200 mm on either side. Mehdi and Shi (2015) studied the flexural strength of hybrid steel I beam using various parameters such as web and flange slenderness and investigated the effects of local flange buckling, web local buckling and lateral torsional buckling modes. The radii of curvature to span (R/L) ratios chosen for study are 4, 6, 8 and 10. The depths to web width (D/tw) ratio chosen are 30, 40 and 50. The width to flange thickness (B/t_f) ratios opted for studies are 4, 6, 8 and 10.

3. RESULTS AND DISCUSSION

Flexural behavior: The bending behavior of horizontally curved beams is not easy to understand and identify. The curved beam with included angle less than 1° behaves similar to straight beams leading to major bending failure. The beams with angle more than 20° provide torsional failure rather than bending. Also the beams are within the two ranges, it is the designer's responsibility to identify the behavior of the beam in inelastic range. In this case, these beams fail in bending and lateral torsional buckling when the included angle moves towards 1° and 20° respectively. In this parametric study, different radius of curvature to span of the beam ratio (R/L), such as 4, 6, 8 and 10 are used to understand the bending behavior of horizontally curved beams. A plot between load and vertical mid-span deflection is made for all R/L values. From Figure.5, it is understood that, the beams with lesser R/L ratio provide lesser bending resistance than the higher R/L ratio beams. As the radius of curvature increases, the beams provide more flexural resistance. It is because, the higher value of R/L beams perform similar to straight beams. Therefore, the higher value of the radius of curvature to span ratio provides higher and lesser value of radius to span ratio provides lesser bending resistance to the horizontally curved steel beams.

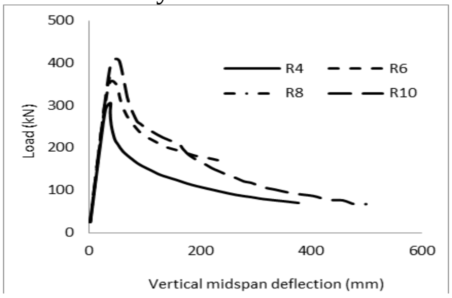


Figure.5. Plot between load versus vertical mid-span deflection

Flange Slenderness: The flexural behavior of the horizontally curved beams is influenced by flange width to thickness ratio. The flange width of the beams is calculated based on the conditions given for plastic, compact and semi-compact sections as per IS 800:2007. Figure.6 shows the comparison of load with vertical mid-span deflection of R/L equals to 10, for all flange width to thickness ratio values such as 4, 6, 8 and 10.

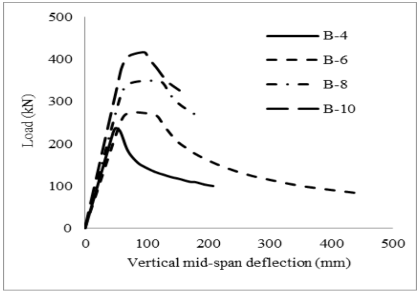


Figure.6. Plot between load versus vertical mid-span deflection – for varying flange slenderness

Similarly, the variations of ultimate load in comparison with all radius of curvature to span ratios also plotted which is shown in Figure.7. From these two graphs, it is observed that, the ultimate load carrying capacity of the beam is influenced by both R/L and flange width to thickness ratio. The ultimate loads corresponding to various R/L values show linear variation for all flange slenderness values.

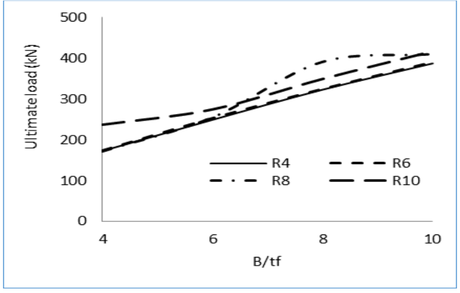
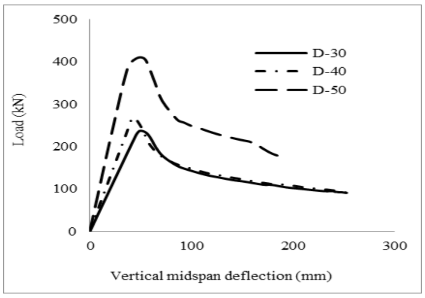


Figure.7. Plot between Ultimate load versus flange slenderness

Web Slenderness: In this parametric study, the web depth to thickness was varied to identify the effect on inelastic bending behavior of horizontally curved beams. The web slenderness shows the notable difference than the other parameters studied. From Figure 8, it can be seen that the higher value of D/tw provide higher bending resistance as anticipated. To avoid the buckling of web before the bending failure, the limits of D/tw were carefully set according to IS 800:2007.



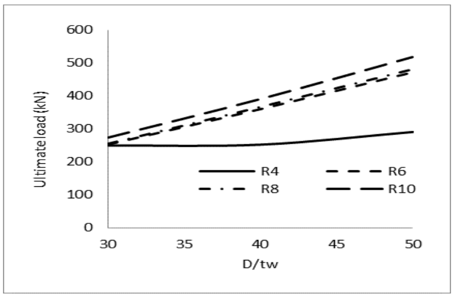


Figure.8. Plot between Load versus deflection – varying web slenderness

Figure.9. Plot between Ultimate Load versus web slenderness

From Figure.9, we can note that, although the higher D/tw beams provide higher ultimate load, the beams with R/L ratios 6, 8 and 10 are increasing linearly related to higher web slenderness values. The beam with R/L ratio 4 give gentle increase and almost straight line, which shows the lesser radius of curvature beam with any web depth to thickness ratio, will not have effect on its bending resistance.

4. CONCLUSION

The main objective of this study is to understand the inelastic behavior of horizontally curved beams. A parametric study considering various radius of curvature to span ratio, flange slenderness and web slenderness was carried out. From the study conducted the following conclusion points are drawn.

- Using finite element programming tools, the nonlinear behavior of the any member can be depicted. In this study, the experimental inelastic behavior of horizontally curved beam was validated using ANSYS software. The results obtained using analytical method is matching with results reported experimentally by the researchers with the accuracy of 93%.
- From the parametric study, it is understood that as the radius of curvature increases, the flexural resistance of the beam also increases. It is because, the higher value of R/L beams perform similar to straight beams. Therefore, the higher value of the radius of curvature to span ratio provides higher and lesser value of radius to span ratio provides lesser bending resistance to the horizontally curved steel beams.
- The flange slenderness has considerable effect on flexural resistance of horizontally curved steel beams. The higher value of B/tf provides higher flexural resistance than the smaller B/tf beams. Hence, as the flange width of the beams increases, the bending resistance of the beam also increases provided that the outstanding length beyond gauge line should be within the limitations. Otherwise, it will lead to the local buckling of flanges before the beam reaches its yield stress due to bending.
- Although the higher value of D/tw provides higher bending resistance as anticipated, the beam with smaller R/L ratio gives gentle increase and almost straight line, which shows the lesser radius of curvature beam with any web depth to thickness ratio, will not have an effect on its bending resistance.

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