Comparative Behavioural Study of Curved Composite Steel Box and I Girder Using MIDAS

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Abstract – As the development today includes the consideration of having fewer disturbances and more economic, curves in flyovers or bridges are an obvious attempt to maintain it. Curved girders are mostly provided in steel in India as it is more economical as compared to steel. The curvature of the bridge can be varied as required but in some cases there are no options due to the surrounding restrictions. There are various types of steel girders that can be provided at curves, I girders and Box girders are the most common among them. In this paper the detail analytical study of both the types will be carried with an objective to find which type of cross section is suitable in which case to be more economical. The design of bridges depends mainly on the radius of curvature and the diaphragm spacing in case of curved girder especially. In this paper, models of box girder and I girder bridges are created in MIDAS Civil software which is found to give very accurate results. The models are made with varying radius of curvature and bracing spacing to study their influence in the analysis results. Torsion study will be the main area of research in this paper. The results will be studied and the conclusion will be drawn and also the most economical design and the type of bridge for curves.

Keywords: Curved steel girder; Composite bridges; I girder; Box girder; Torsion; Construction stages; Metro loading

Introduction

Steel has been well recognized as the economic option around the world for the infrastructure from very large to very small. It is a versatile and effective material that provides efficient and sustainable solutions. It dominates the markets for long span bridges, railway bridges, footbridges, and medium span highway bridges. It is now also the choice for shorter span highway structures due to its light weight property and quick erection. When steel girders are curved in plan, torsional effects are introduced and these effects must be considered when designing the beams. Society gains in many ways from the benefits delivered by the infrastructure development. Landmark steel bridges involve good design, they are fast to build and have stimulated the regeneration of many former industrial, dock and canal side regions.

Steel bridges are an essential feature of a nation's infrastructure and landscape. There have been numerous manmade structures until now that have been constructed and have marked themselves as the landmark in different localities.

Steel bridges when compared with concrete girders, have an advantage of offsite prefabrication of steel components that causes construction time on site, often in hostile environments, is minimised. The speed of bridge construction made possible by steel allows the disruption to road and rail users to be kept to a minimum. The low self weight allows of steel permits the option of longer spans and faster erection by different ways. Sometimes the whole span is erected at a go if the equipment has enough capacity and if the spans are too long there is segmental construction with splicing at weaker junctions. After the girder is erected the slab has to be casted over it using the formwork and hence until the wet concrete dries the girder has to take the concrete weight. But, once the concrete hardens there is composite action taking place due to the interference of two different materials with the help of shear connectors that are provided in the form of steel studs or channels at required spacing and are welded to the flange of the girder section. Steel also has greater efficiency than concrete structures in resisting seismic forces and blast loading and also has greater life.

Plate girders have a very low torsional stiffness and a very high ratio of major axis to minor axis moment of inertia. Therefore when they bend about the major axis, high lateral torsional stability occurs. To avoid this instability, has to be provided with lateral bracings for the bending of the girders and the flanges of the girders is taken care by the deck slab. Loads acting on the girders also cause lateral bending like wind load forces and hence the lateral bracing must be designed for the same.

This paper includes the comparison of box and I girder types in curves. As discussed earlier the I girder has more instability in lateral bending due to its section properties where as in case of box girders, since the moments of inertia in the major and minor axis does not differ much there is more stability and is therefore expected to be more suitable in case of curved girder. If the choice of curve layout is available the type of girder and the radius could be fixed in such a way that the design is economical.

Since the box girder is more stable in torsion than that of I girder section and hence the spacing of lateral bracings become more important in that case. The behaviour of the I girder would vary with different bracing spacing and this will be studied in this paper. The radius of the curve is fixed by the horizontal profile of the highway or the railway line. in case of the trains the radius is generally limited to 90m because of the bogie length. In this paper three different radii of each type of bridge will be studied to understand the change in the behaviour and analysis of the curved girder with respect to the radius. In case of the I girder, different analysis is done for both the varying radii as well as varying lateral bracings to study their effect as well.

The Midas civil software uses the grillage model analysis for all the loads and the required conditions including the moving load cases and the construction stages. To check the accuracy of the analysis results of the grillage analysis one model is done using finite element analysis using Midas Fea. It has to be checked if the practical conditions at site are met within the modelling using software.

The vehicle taken in this paper for the moving load case is a metro rolling stock on the two lanes. The construction stages are also defined as they are critical in case of curved bridges. When the slab is hardened the deck slab helps in restraining the top flanges of the I girders but, before the concrete hardens the girder has high instability which has to be deeply studied in the construction stages. In the final stage, when the bridge is composite, the torsion effects result in a different distribution of vertical bending between the girders and in bending of the bottom flange between bracing positions.

I. METHODOLOGY

A. *General section*

A general steel section of curved I girder and tub girder is considered for the modelling as shown in the figures. The single span of 66m bridge is taken from the reference papers and existing bridges with different radii of 90m, 155m and 250m in each model. The spacing of the bracing are also varied in case of I girder bridge which is provided in the form of X bracings using double angle sections at 6m and 3m in different models. It is a general composite section as the concrete deck slab is casted over the steel girder. The thickness of the slab is taken as 250mm and wearing course as 80mm.

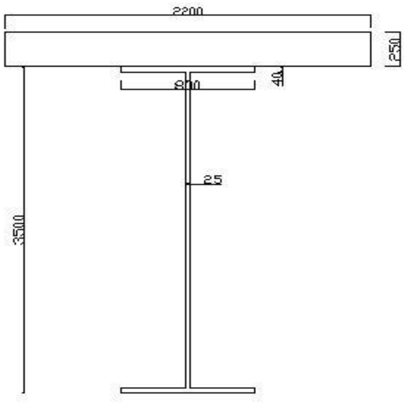


Fig 1: General section for I Girder Curved Bridge

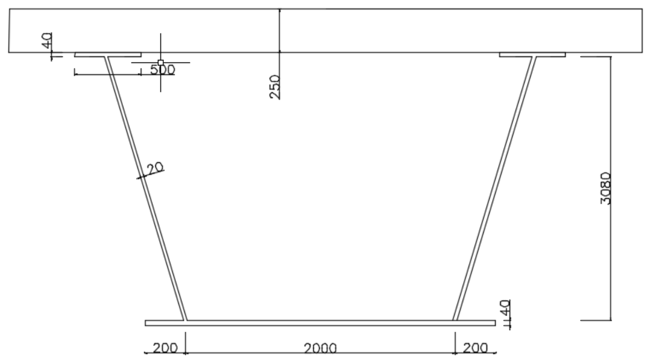


Fig 2: General section for Tub Girder Curved Bridge

B. *Modelling*

The composite girder bridge is modelled in Midas Civil using the Steel composite bridge wizard, which is used to create a three dimensional grillage model of the I girder. The tub girder is modelled as line element to obtain the three dimensional model.

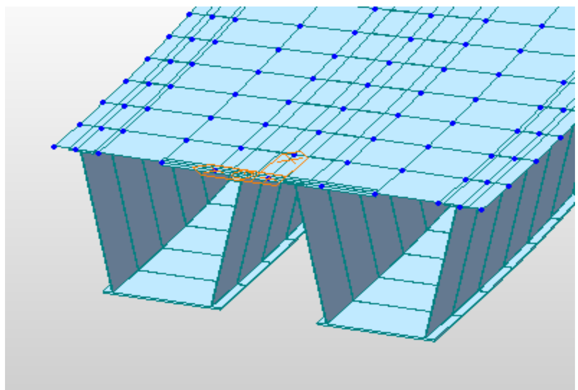


Fig 3: 3D Model of Curved Tub Girder

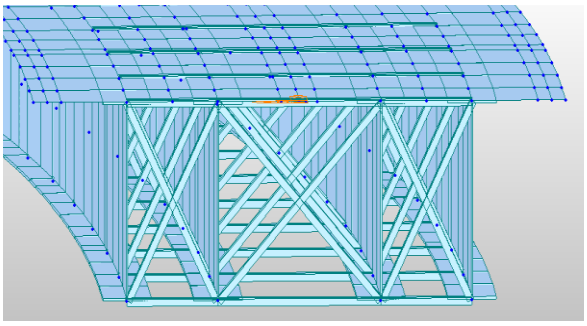


Fig 4: 3D Model of Curved I Girder

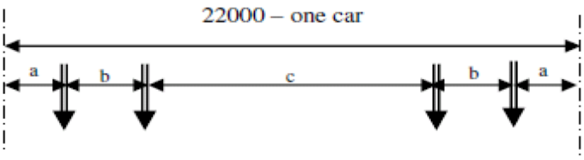
C. *Material Properties*

The material properties are assigned to concrete and steel as follows:-

a) Concrete:-
M40
b) Steel:-
Fe 490

D. *Live Load*

The curved bridges are assumed to be functioned as metro bridges and therefore the loading of the modern rolling stock is applied on the bridge. The two lanes are defined as per the standard track width of a metro train both moving in the opposite direction. The live load case is defined as moving load case in which the software will place the loads at various points within the defined lane width and the maximum effect is taken as critical.



Configuration:

a = 2.5 m , b = 2.30 m , c = 12.4 m

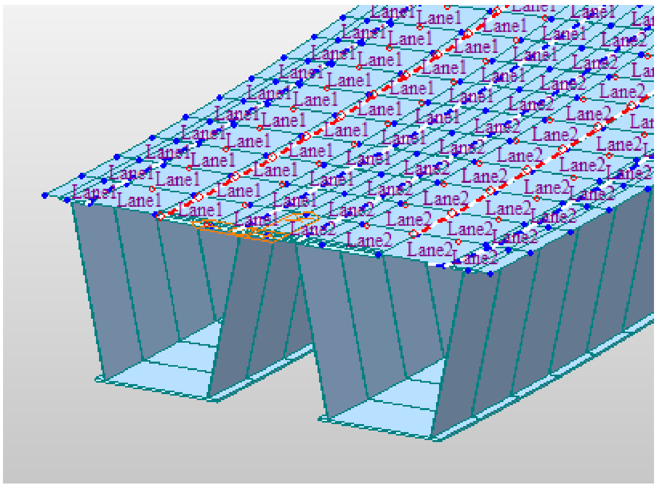


Fig 5: Metro Rolling Stock and lane configuration

E. *Boundary conditions*

The curved bridges are provided with fixed – fixed supports as single span models are created. These are the permanent supports. As the span of 66m is too long to be erected with the end supports alone and therefore temporary supports are provided at the required distances below the steel girders. Since the bridge is composite it requires construction stages and these temporary supports are removed once the wet concrete hardens and the composite action takes place.

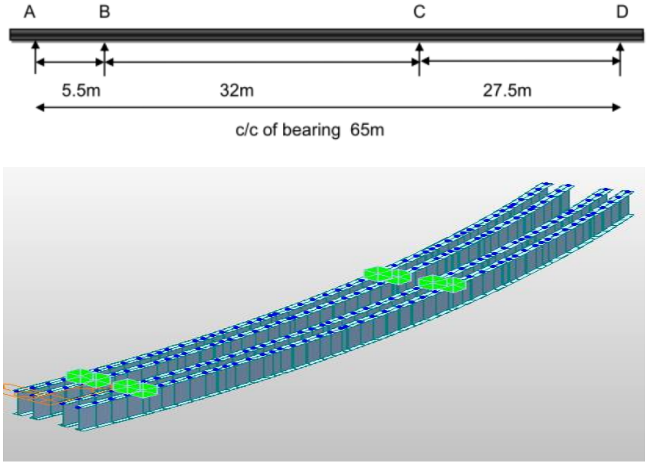


Fig 6: Position of temporary supports during construction

F. *Construction Stage Load*

As discussed in the introduction, the composite action becomes active when the wet concrete deck slab hardens. There are four different stages of construction that are defined to activate and deactivate different structure group and load cases. Temporary supports are activated in the first stage where the wet concrete load is carried by the steel girders and when it hardens the temporary supports are deactivated and also the wet concrete load.

Construction Stage

Name	Duration	Date	Step	Result
Stage1	10	10	0	Stage
Stage2-1	10	20	0	Stage
Stage2-2	0	20	0	Stage
Stage3	10	30	0	Stage
Stage4	10000	10030	0	Stage

Fig 7: Summary of Construction stages

a. Composite Section for Construction stage

Since the steel girder and the concrete deck act as separate elements before the composite action, the composite section is to be defined mentioning the stages at which each element would be activated.

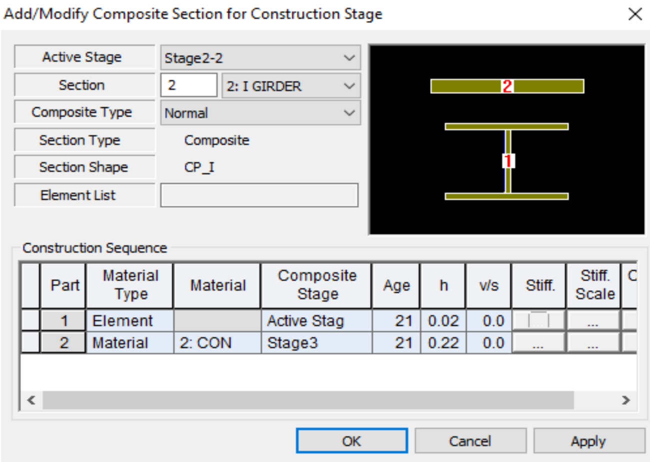


Fig 8: Activation of Composite section during Construction stage

G. *Other Loads*

The other loads that are applied on the models include the wearing surface, additional load of dead manufacture and utilities. The wet concrete loads are applied at the required construction stages before composite action takes place. The formwork loads are not considered for the analysis. All these loads are applied are uniform area loads throughout the carriage width. Since the bridge is considered as a metro bridge no footpath or crash barrier loads are applied on the models for the analysis.

H. *Analysis*

The model is analysed with moving load analysis and construction stage analysis along with other dead loads and additional components. The stresses, torsional moments and deformations are obtained at critical points and interpreted for different load cases and construction stages. Comparison between both the type of bridges as well as variation with radii and bracing spacing is done which is discussed under the results. Six models of I girder bridges and three models of tub girder bridges are analysed and the results are obtained as follows.

II. RESULTS

The grillage analysis for moving load and construction stage analysis of both the type of models were carried out and the results are discussed as follows. Output figures of one model of each I girder and box girder have been shown for visual understanding. However, comparison details and graphs will be later plotted for all the models during interpretation and conclusion section of the paper.

A. *Total deformation*

The deformation was studied in both the type of bridge models and a typical displacement contour was obtained as shown below.

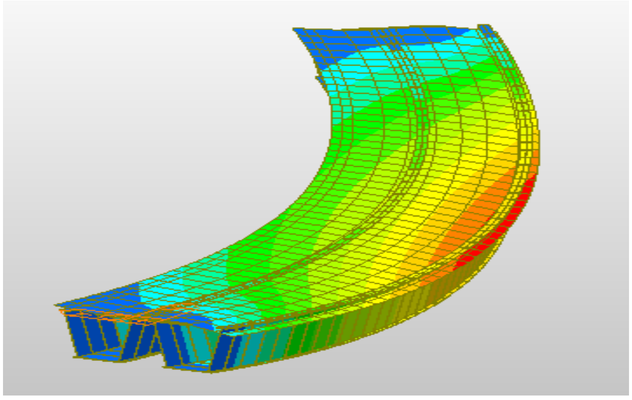


Fig 9: Displacement contour of box type curved girder

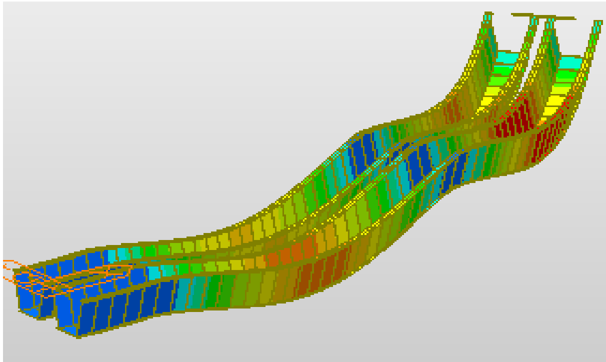


Fig 10: Displacement contour of box type curved girder during Construction stage 1

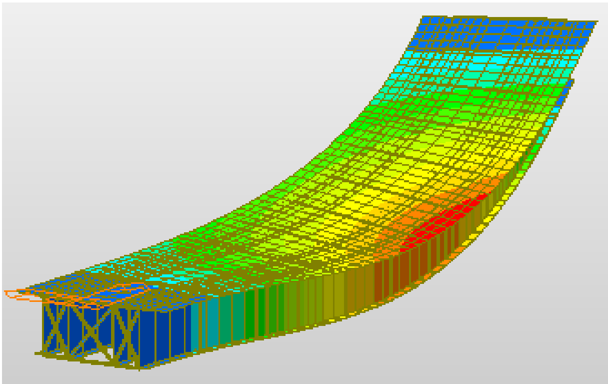


Fig 11: Displacement contour of I type curved girder

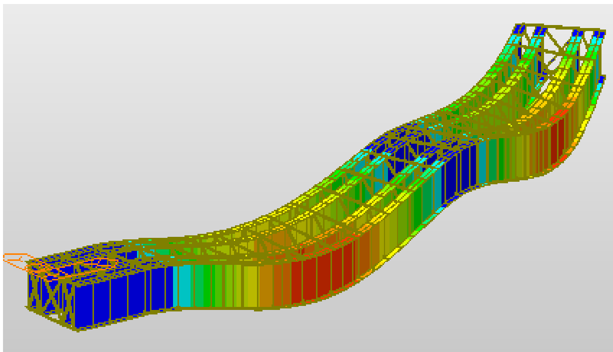


Fig 12: Displacement contour of I type curved girder during Construction stage 1

B. Torsional Moment

Due to the presence of the curvature of the girders and their section properties, these steel sections tend to bend out of their plane and this force is called as torsion. As described in the introduction the box girders are found to have less torsion and the variation with other parameters is plotted in the conclusions. This property is the most governing in the curved girder steel bridges. The bridges are designed for the obtained torsion. The most economical type of girder can be concluded from this factor.

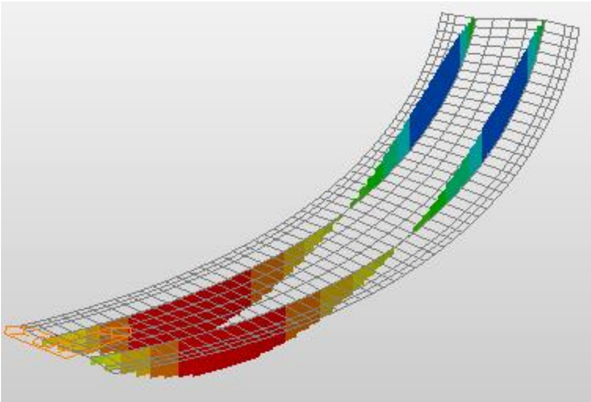


Fig 13: Torsional moment diagrams in Box girder bridge model

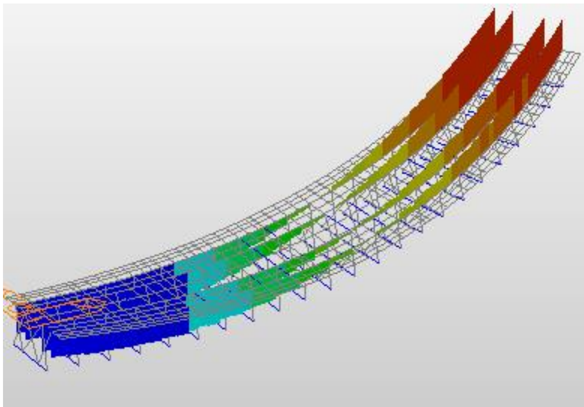


Fig 14: Torsional moment diagrams in I girder bridge model

C. Beam stresses

Due to the presence of torsion in the curved girders the cross section tends to twist and therefore causes axial stresses which are shown below as contour diagram. The bending stresses in major axis are also shown. The torsion causes additional forces to occur in the girder which will act in opposite directions on either side of the centre of gravity. Therefore the stresses add up on one side and get deducted on the other side effectively.

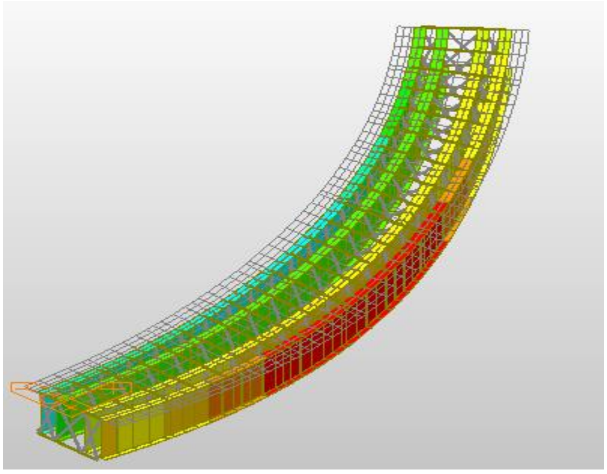


Fig 15: Axial Beam stress contour in I girder model

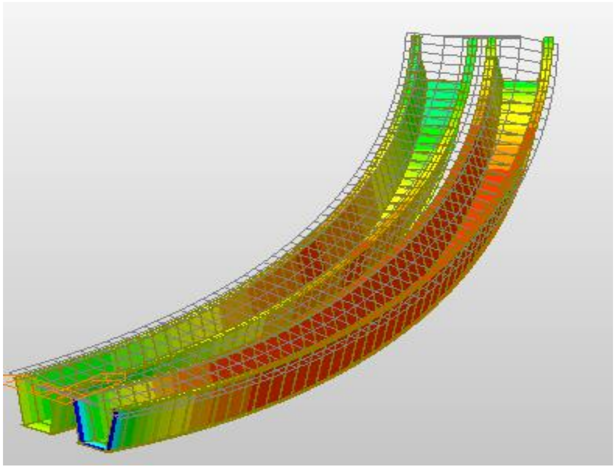


Fig 16: Bending stress contour in Box girder model

D. Influence Line Diagram

The moving load tracer can be used to find the placing of the vehicle load for the most critical output of an element.

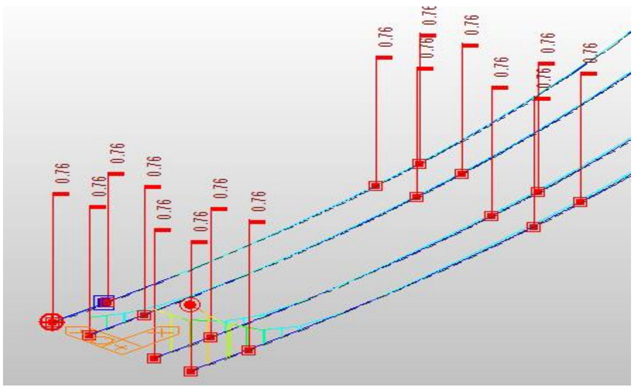
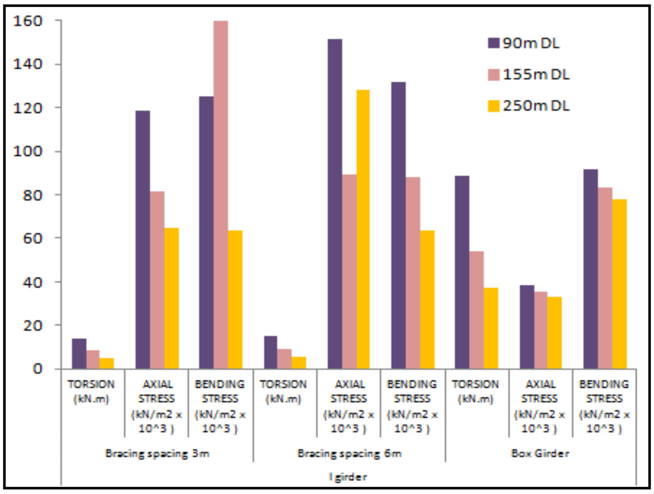
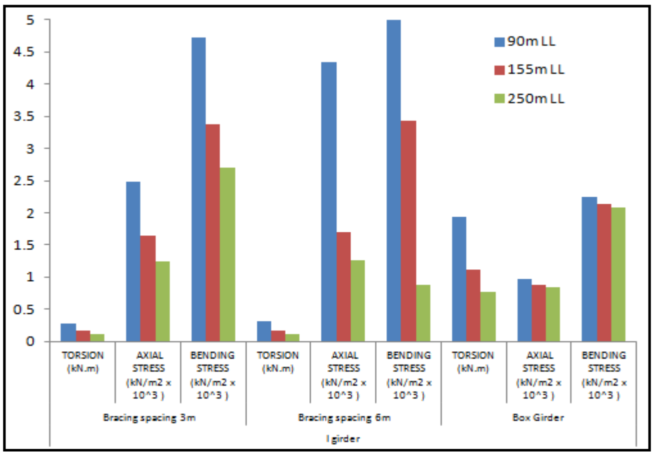


Fig 11: Position of Live load for Moving load analysis.

III. CONCLUSIONS



Graph 1: Comparative results for the Dead load



Graph 2: Comparative results for the Live load

Following conclusions can be inferred from the above graphs for Dead load and Live load values:-

i. It can be observed from the comparison of values with the varying radii that the torsional moments and stresses increase with decrease in the radii and therefore minimum radius of curvature must be provided as possible.

ii. It can be observed from the comparison of values with different bracing spacing that the torsional moments and stresses are more in case of less centre to centre spacing of bracing hence must be provided as such.

iii. It can be observed from the torsional moment values that its value is almost negligible in case of I girder bridge compared to that of Box girder bridge due to shear flow through the cross section of the box.

The main objective of this paper was to find the effect of torsion on different type of steel girders and radius of curvature and from the above conclusions it can be found that the I girder curved bridges are more economical as compared to box girder curved bridges. Also, less radius of curvature and bracing spacing would be more economical.

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