Seismic Analysis & Optimization of Prestressed Concrete Box Girder Bridge Superstructure

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Abstract- *Bridges are the important structures should be capable to withstand static as well as dynamic loads specially, earthquake-induced load to achieve a structure that behave at the level of life safety under enormous earthquakes. The present article shows the linear dynamic behaviour of Optimised Rectangular girder and Optimised Trapezoidal box girder bridge deck and compares static as well as dynamic behaviour. Response spectrum analysis has been performed by using FEM based software i.e SAP2000 in order to check the resonance criteria of bridge and to determine most favourable option from above two. The results show that response parameters for trapezoidal box girder such as frequency, bending moment, shear forces, deflection, time period, Torsion and displacement are compared with the span length. The response parameters increase with the span length; while fundamental frequency and spectral acceleration decreases. From the study it is finalized that trapezoidal box girder is safer as compared to Rectangular girder bridge superstructure*

Keywords- Rectangular box girder, Trapezoidal box girder; Static and Seismic response; Time History analysis, Response Spectrum; SAP 2000

I. INTRODUCTION

With the rapid technology in Structural Engineering, very long spans bridges with large span to depth ratios are built in structural steel or Prestressed concrete as it have excellent riding characteristics that minimize traffic vibrations, torsional rigidity, and strength hence results in stable, dynamic, long lasting and graceful bridges. Bridges are structure which gains an international importance as they are essential part of any road and rail way network.

An effective design of bridge superstructure is a prerequisite to achieve ultimate strength and overall structural performance. Dynamic analysis of bridges are essential to ensure overall structural performance and stability during severe ground shaking motion. The main objective of performing Dynamic analysis is to provides an accurate measure of expected structural response for a given earthquake or any kind vibrations and to improve the response of bridges during earthquake forces.

The most important factors affecting dynamic response are the basic flexibility of the structure and, more specifically, the relationship between the natural frequency of the structure and exciting frequency of the vehicle. One of the aspects to be considered while evaluating the dynamic response of bridges subjected to live loads is the problem of vibration. Any passage of load cause the span deflected from its equilibrium position and result in oscillation of bridge. This process continues until it goes back to its equilibrium position or another load acts upon it. Therefore, “dynamic behaviour of bridge deck” is essential.

The present study is the design and optimization of bridge superstructure is done manually as per IRC Specifications for 80 m to 100m span. The most obvious choice of superstructure for this span range is Rectangular and Trapezoidal Box Girder. They have their own characteristics and limitations as box girders has complex, excellent torsional rigidity comprising closed cellular section extensively used for large spans bridges

The main objective of this study is to study the dynamic behaviour of concrete PSC Rectangular box girder and Trapezoidal box girder bridge decks in order to check the resonance criteria of bridge and to determine most favourable option from above two. The decisions based on essential characteristics of engineering that are safety, serviceability and economy.

1.1 Dynamic behaviour of bridge deck

The dynamic characteristics of bridges are frequency, time period, mode shapes, base shear and damping ratio of its normal mode of vibration. These can be governed by the excitation of bridge, measure of response, analysis of data.

Frequency and the amplitude of vibrations are natural properties of structure apparently occur and hence uncertain parameters against occurrence of extreme vibrations. Hence, dynamic analysis needs to accomplish to study dynamic parameters.

In this proposed study, bridge model is analysed by Response Spectrum Analysis and Time History Analysis .

1.2 Time History Analysis:

Time History analysis is a non-linear dynamic statistical analysis for structural seismic analysis especially when the evaluated structural response is nonlinear. To perform such an analysis, a representative earthquake time history is required for a structure being evaluated.

Time history analysis is a step-by step analysis of the dynamic response of a structure to a specified loading that may vary with time. Time history analysis is used to determine the seismic response of a structure under dynamic loading of representative earthquake

II. LITERATURE REVIEW:

Ima Muljati and Warnitchai et.al [1]: evaluated the inelastic seismic response of multi-span concrete bridges, using the nonlinear modal pushover analysis (MPA) and showed a similar tendency with the MPA in a linear range. The MPA results provided an acceptable accuracy besides simplicity.

Magdy Samaan et.al [2]: presented a dynamic analysis of curved continuous multiple box girder bridges, using the finite element method. Evaluated their natural frequencies and mode shapes and experimental tests are conducted on two continuous twin-box girder bridge models of different curvatures to substantiate the finite-element model.

Payoshni Mali et al. [3] analysed that the trapezoidal section of box girder is subjected to less shear force and bending moment than that of rectangular section for same loading, span and dimensional properties due to its geometry. Torsional moment developed in trapezoidal section is also less as compared to that of rectangular section. The purpose of this study is to focus over the advantages of trapezoidal section with respect to the structural efficiency over the rectangular section of box girder.

P.K. Gupta et.al[4] presented comprehensive FE investigation was conducted on box Girder with circular, rectangular and trapezoidal cross sections was carried out. The linear analysis has been carried out using SAP2000 for complex behaviour of different box girders it was concluded that rectangular cross section is excellent to trapezoidal and circular sections.

Miss P.R.Bhivgade et.al [5], analysed that the two lane simply supported PSC box girder which is liable to be subjected under moving loads is checked at various span/depth ratios, deflections and stress criteria are checked as per IRC specifications. Analysis is done using SAP 2014. Comparison is done on the basis of Prestressed force, deflection as well as stresses acquired for various span/depth ratios.

The authors showed that most important factors affecting dynamic response are the basic elasticity of the structure especially; relationship between the natural frequency of the structure and exciting frequency of the vehicle has major influence on vibration of structure as well as enhanced the knowledge about Rectangular and Trapezoidal Box Girder to intensify structural performance of bridge superstructure.

Description of Structure

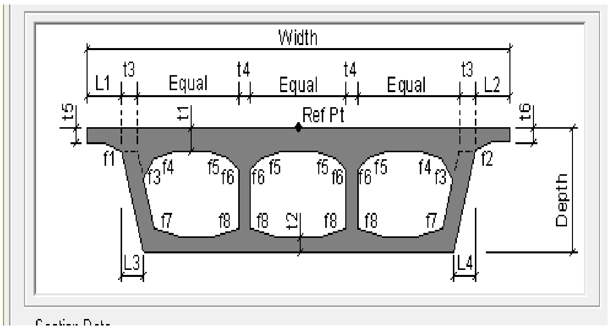
Cross section=Rectangular and Trapezoidal Multi celled box girder
Carriageway width =7.5 m
Kerbs=600 mm on each side
Foot Paths=1.25 m wide on each side
Thickness of wearing coat=80 mm
Lane of bridge=Two lane
Longitudinal girders=4 main girders at 2.5 m interval
Spacing of cross girders=5 m
Cell dimensions=2 m wide by 1.8 m deep
Thickness of Top & Bottom Slab=300mm &300 mm
Overhang Thickness=180 mm
Thickness of web=300 mm
Span=80,90, 100m
Grade of concrete=M60
Material =Prestressed Concrete
Loss Ratio=0.80
Type of tendons=High tensile strands of 15.2 mm diameter Confirming to IRC: 6006-2000.
Anchorages Type=27K-15 Freyssinet type anchorages.
Type of Supplementary Reinforcement=Fe-415 HYSD bars
Loading Considered=Dead load, wind & Prestressed, Class 70R-Wheeled vehicle, and Seismic forces
Design of bridge deck=Class-1 type of structure confirming to the codes IRC:6-2014,IRC:21-2000, IS:1893-1987,IS: 875 (Part-III) – 1987

III. MODELLING AND ANALYSIS

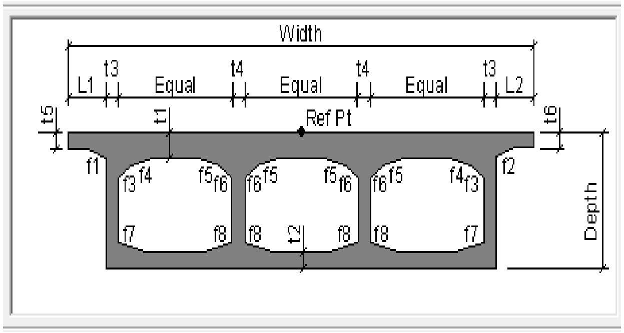
As per Indian Standard Specification, Design of Prestressed Concrete Rectangular and Trapezoidal box girder deck has been done and after satisfying all checks optimized cross section geometry is considered w.r.t. span length for present study. Time History Analysis is performed on both the models in SAP2000 software. The parameters selected to define Rectangular and Trapezoidal Box Girder deck are as follows:

Static and Dynamic responses such as Frequency of vibration, Time period, Base shear as well as Bending moments, Shear forces, longitudinal and shear stresses, deflection/span ratio of all the spans are determined. On the basis of which the serviceability criteria is checked. With the help of dynamic response parameters, possibility of resonance is checked

Cross Section of Trapezoidal Box Girder:



Cross Section of Rectangular Box Girder:



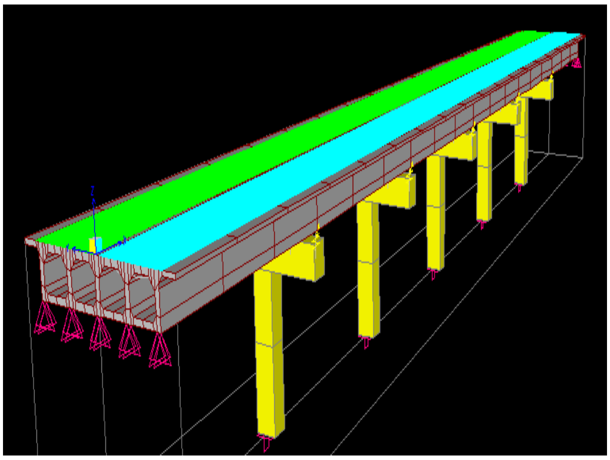


Fig. 1: Finite Element model of Rectangular box girder bridge Superstructure created in SAP 2000

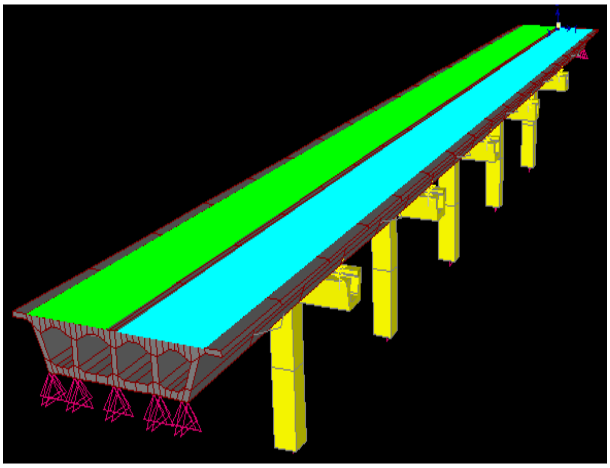


Fig. 2: Finite Element model of trapezoidal box girder bridge Superstructure created in SAP 2000

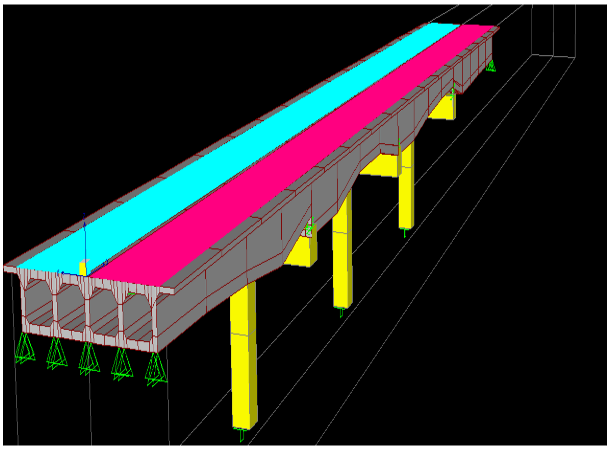


Fig. 3: Finite Element model of Rectangular box girder bridge Superstructure created in SAP 2000

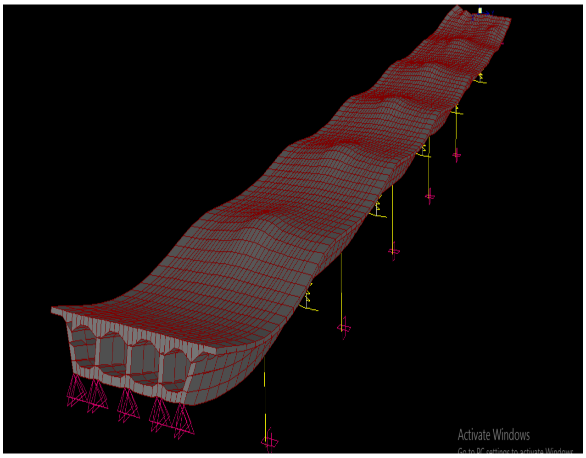
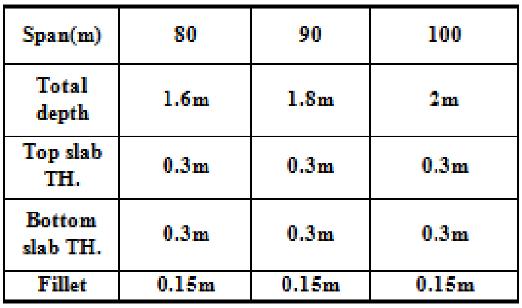
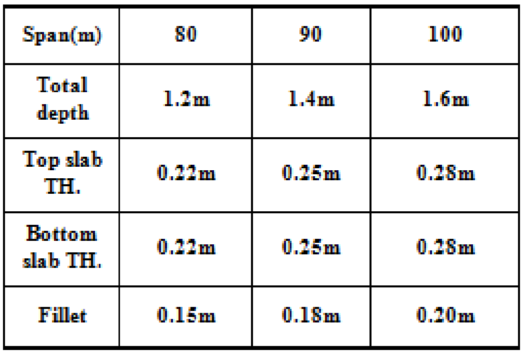


Fig. 4: Finite Element model of Trapezoidal box girder bridge Superstructure created in SAP 2000



Span(m)	80	90	100
Total depth	1.6m	1.8m	2m
Top slab TH.	0.3m	0.3m	0.3m
Bottom slab TH.	0.3m	0.3m	0.3m
Fillet	0.15m	0.15m	0.15m

Table No.1 Optimised Dimensions of rectangular box girder bridge Superstructure



Span(m)	80	90	100
Total depth	1.2m	1.4m	1.6m
Top slab TH.	0.22m	0.25m	0.28m
Bottom slab TH.	0.22m	0.25m	0.28m
Fillet	0.15m	0.18m	0.20m

Table No.2 Optimised Dimensions of trapezoidal box girder bridge Superstructure

IV. RESULTS AND DISCUSSION

Analysis is done for both Rectangular and trapezoidal box girder bridge superstructure models. The corresponding results are shown in graphs for both the conditions.

1. Frequency and time period:

For each span first mode shape gives least frequency and max. time period. For shorter span frequency is on higher side which goes in reducing with the increase in span and with the increase in span, time period goes on increasing.

As per IRC Specification, Limiting Value for deflection/span ratio = 1/375 = 2.66x10-3

Frequency of vehicle considered = 3 – 5 Hz.

This frequency need to be avoided to prevent resonance.

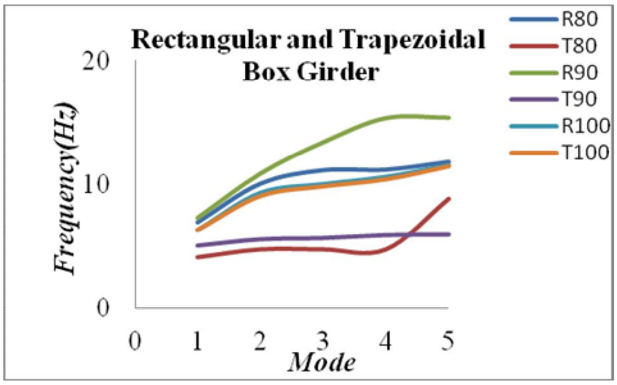


Fig. 5: Variation of Frequency w.r.t. Span

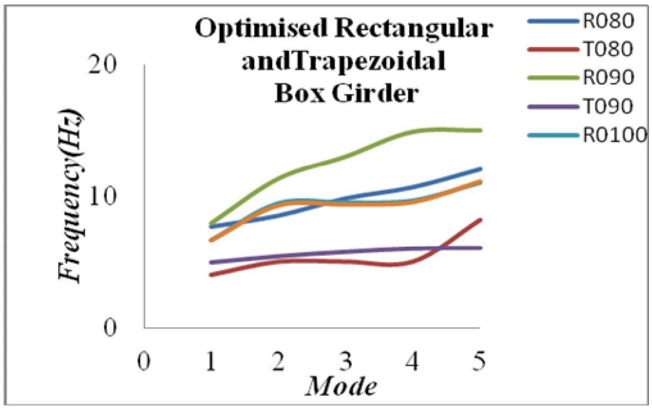


Fig. 6: Variation of Frequency w.r.t. Span

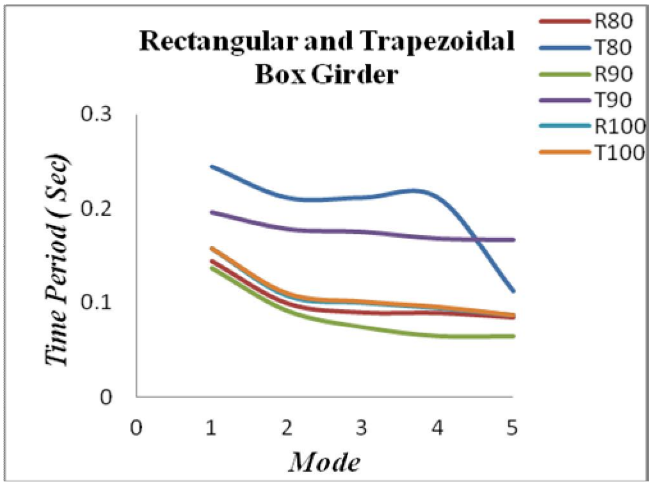


Fig. 7: Variation of time Period w.r.t. Span

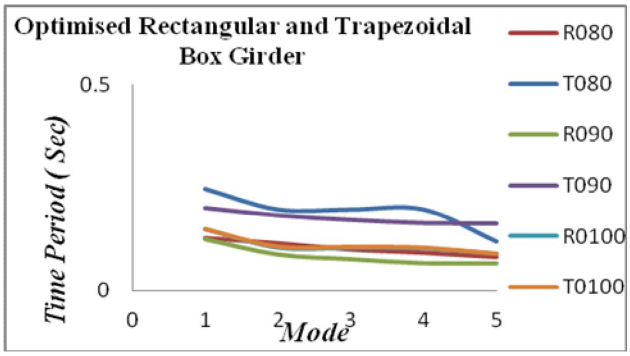


Fig. 8: Variation of time Period w.r.t. Span

2.Deflections:

Maximum deflections of Rectangular and trapezoidal box girder cross-section before and after optimization for combined load case of DL+LL+EQ+Prestress w.r.t span length of 80m to 100m.

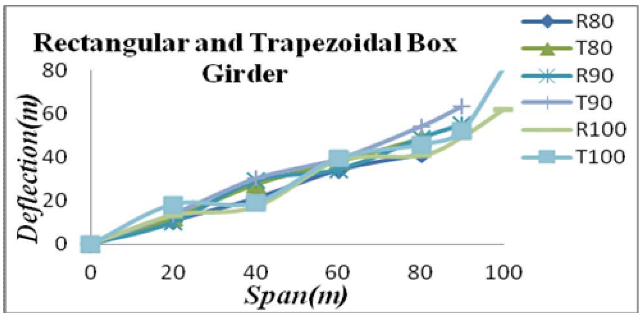


Fig.9: Variation of deflection w.r.t. Span

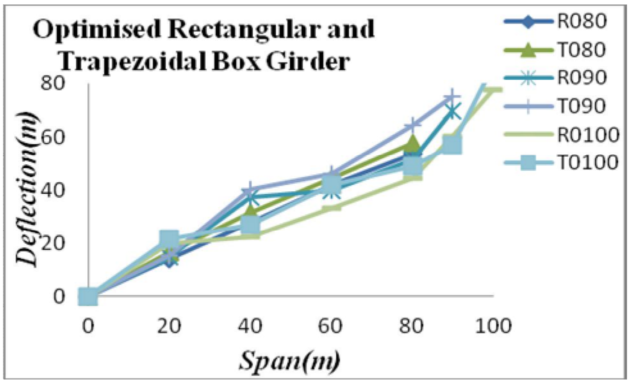


Fig.10: Variation of deflection w.r.t. Span

3.Bending stresses and Shear Forces:

The variation bending moment and shear forces at entire bridge section for combined load case of DL+LL+EQ+Prestress for both the girder section and optimized cross-section w.r.t span length of 80m to 100m span are represented in fig.11,12,13 & 14.

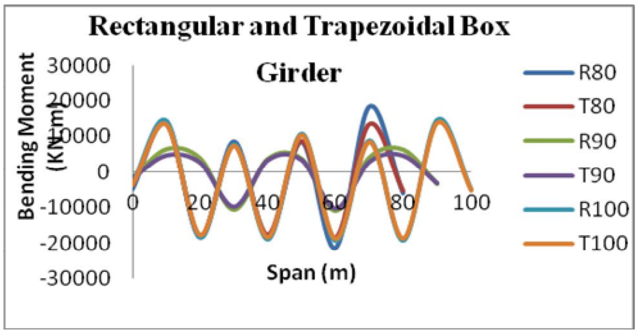


Fig. 11: Variation of bending moment w.r.t. Span

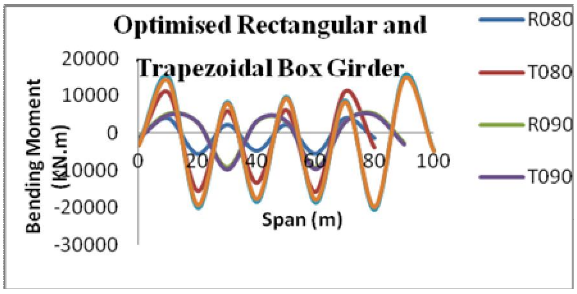


Fig. 12: Variation of bending moment w.r.t. Span

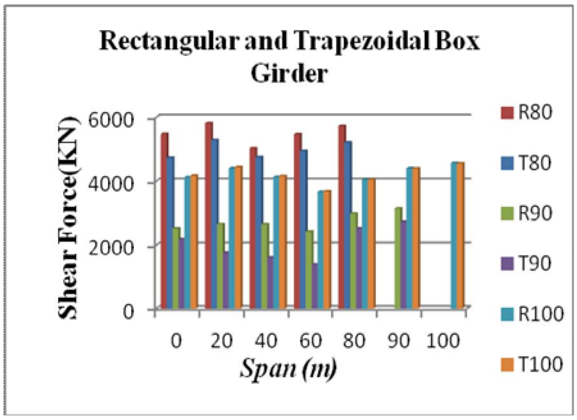


Fig. 13: Variation of Shear forces w.r.t. Span

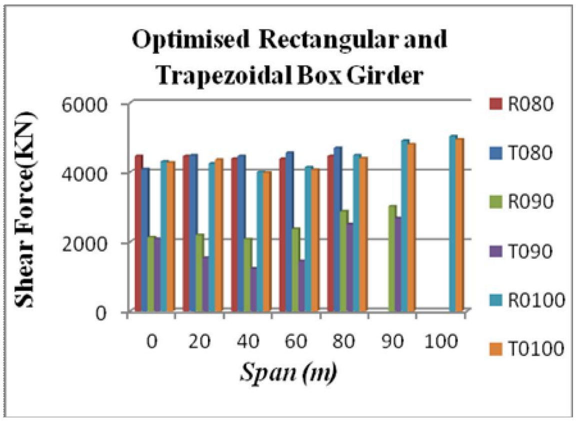


Fig. 14: Variation of Shear forces w.r.t. Span

4. Torsion:

The variation of maximum Torsion at entire bridge section of Rectangular Box Girder is compared to trapezoidal box girder for combined load case (DL+LL+PT+EQ) w.r.t span length of 80m to 100m.

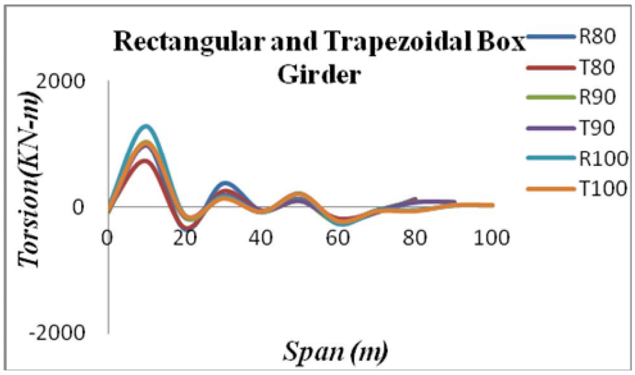


Figure 15: Variation of Torsion w.r.t. span for Box Girders

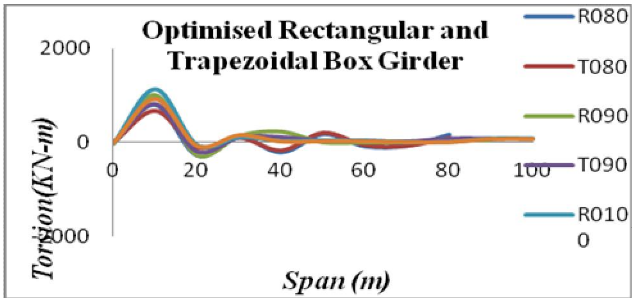


Figure 16: Variation of Torsion w.r.t. span for optimised Box Girders

5. Base Shear:

The base shear in X direction is calculated by response spectrum method and Time History Analysis. Base shear varies from structure to structure and depends on the stiffness and weight of the structure and also on the intensity of earthquake force applied to the structure. The base shear of both types of girder and optimized girder cross-section under consideration were found out and comparison is done.

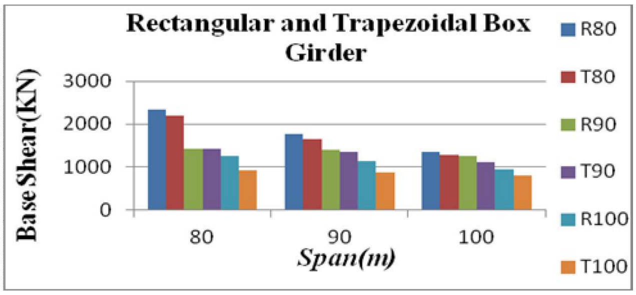


Figure 17: Variation of Base Shear w.r.t. span for Box Girders

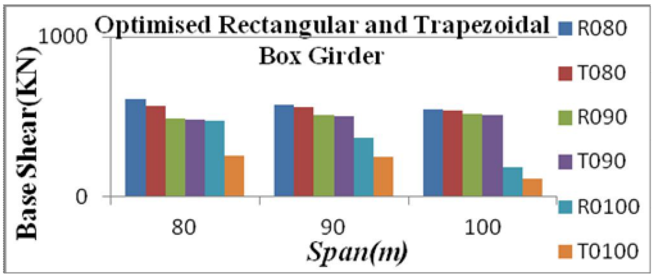


Figure 18: Variation of Base Shear w.r.t. span for optimised Box Girders

6.Displacement:

The displacement in X direction is calculated by response spectrum method and Time History Analysis. Displacement varies with span and depends on the stiffness and weight of the structure and also on the intensity of earthquake force applied to the structure. The displacement of both types of girder and optimized girder cross-section under consideration were found out and comparison is done

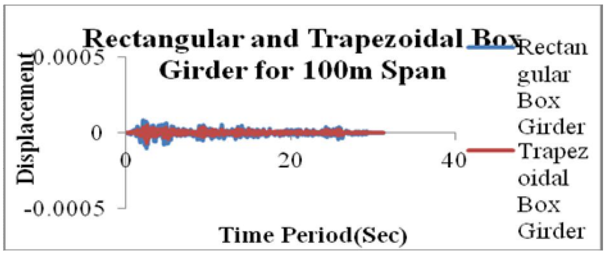


Figure 19: Variation of Displacement w.r.t.Time Period for Box Girders

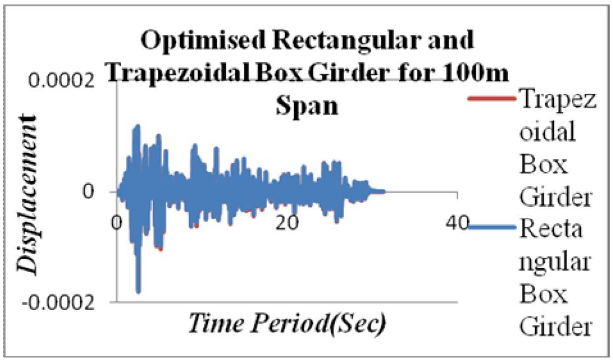


Figure 20: Variation of Displacement w.r.t.Time Period for optimised Box Girders

V. CONCLUSIONS

1. Frequency: Natural Frequency of bridge superstructure should not fall in the range of vehicle frequency band to avoid resonance. As the results shows that for 80m & 90m span for trapezoidal box girder bridge will be subject to vibration problems. The span having span length more than 90m will not subject to vibration problem. The Rectangular Box Girder has 37.37% greater frequency than Trapezoidal Box Girder. The Optimised Rectangular Box Girder has 35.42% greater frequency than Optimised Trapezoidal Box Girder.

2.Time Period: With the increase in span, time period goes on increasing and the Rectangular Box Girder has 2.27% less time period than that of Trapezoidal Box Girder. The Optimised Rectangular Box Girder has 3.75% less time period than Optimised Trapezoidal Box Girder, it has been observed that rectangular has less time period of vibration than trapezoidal box girder bridge.

3. Bending Moment: Due to change in the cross-section of the girder and as self-weight of the trapezoidal box girder bridge is less. Therefore the bending moment in rectangular box girder is 18% more compared to trapezoidal box girder for combined load case (DL+LL+PT+EQ) as trapezoidal box girder is a rigid section. The optimised Rectangular Box Girder has 12% more bending moment than optimised Trapezoidal Box Girde, it has been observed that bending moment for optimised Rectangular box girder is 12.11% less than Rectangular box girder and optimised Trapezoidal Box Girder is 5.74% less than Trapezoidal Box Girder

4. Shear Forces: The Rectangular Box Girder has 11% more average shear force than Trapezoidal Box Girder. The optimised Rectangular Box Girder has 24% average more shear force than optimised Trapezoidal Box Girder. , it has been observed that average shear force for optimised Rectangular box girder is 17.31% less than Rectangular box girder and average shear force for optimised Trapezoidal Box Girder is 13.75% less than Trapezoidal Box Girder for combined load case (DL+LL+PT+EQ).

5. Deflection: The Rectangular Box Girder has 18.08% more average deflection than Trapezoidal Box Girder. The optimised Rectangular Box Girder has 8.33% more average deflection than optimised Trapezoidal Box Girder for combined load case (DL+LL+PT+EQ).

6. Torsion: The variation of maximum Torsion at entire bridge section of Rectangular Box Girder is 21.88% more Torsion than Trapezoidal Box Girder, the optimised Rectangular Box Girder has 18.28% more Torsion than optimised Trapezoidal Box Girder for combined load case (DL+LL+PT+EQ) w.r.t span length of 80m to 100m.

7.Base Shear: The Maximum Average Base Shear for Rectangular Box Girder is 1626.546 KN and the maximum average Base Shear for Trapezoidal Box Girder is1086.050 KN and for optimised Rectangular Box Girder is 532.78 KN,for optimised Trapezoidal Box Girder is 341.34 KN. Rectangular box girder has slightly more base reaction compared to trapezoidal box girder section.

8.Displacement: The displacements at entire bridge section are more in trapezoidal box girder than rectangular box girders, but the stresses are within the limit.

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