Dynamic Analysis of Prestressed Concrete Box Girder Bridge Superstructure

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Abstract*-The prestressed concrete box girder bridges have attained spacious acceptance in freeway, highway flyovers, and in modern metro rail systems extensively used for large spans bridges as it have excellent riding characteristics that minimize traffic vibrations, torsional rigidity, and strength and moment resistance capacity. As 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 Rectangular box and Trapezoidal box girder bridge deck and compares static as well as dynamic behaviour. Response spectrum analysis has been performed by using FEM based software. The results show that response parameters such as bending moment, shear force, deflection, base reaction, time period, longitudinal stresses and shear stresses are increases as the span length increases while fundamental frequency decreases. From the study it is finalized that trapezoidal box girder is safer as compared to rectangular box girder bridge superstructure.*

Keywords-Box girder; IRC Class 70R loading, Static and Seismic response; Response Spectrum.

I. INTRODUCTION

In Structural Engineering, Prestressed concrete box girders have become day by day popular as results in stable, dynamic, long lasting and graceful bridges. With the benefit of applying box girders, deck slab have supporting system with large span to depth ratios excellently suited as it is composed of extreme strength prestressing steel.

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 thenatural 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.

Using IRC Class 70R loading, static and dynamic responses are evaluated using Response Spectrum analysis has been performed in SAP 2000 software. In spite of checking the resonance criteria of bridge, the dynamic analysis of computer modal is interpreted.

1.1 Dynamic behaviour of bridge deck

The dynamic characteristics of bridges are frequency, time period, displacement, 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 analyzed by Response Spectrum Analysis.

1.2 Response Spectrum Analysis:

Response spectrum analysis is a linear-dynamic statistical analysis which quantifies the contribution of each mode of vibration to specify the possible peak seismic response of primarily elastic structure.

Presently, a principal conception in earthquake engineering, the response spectrum provides convenient means to compile the peak response like pseudo-spectral acceleration, displacement, time period, deflections, modes and frequency of vibration are useful to comprehend the behaviour of structure.

It has been accepted as a standard method of representation of effect of ground acceleration on structures. It also provides a realistic approach to implement the knowledge of structural dynamics to the design of structures and initiation of lateral force specification in the building codes.

II. LITERATURE REVIEW

D.p.Thambiratnam et.al [1]: This paper analyzes bridge superstructure model as grillage for precisely evaluating the fundamental frequency of vibration, corresponding mode shapes and dynamic modulus of elasticity of concrete and develops a simplified method after comparing field observation with theoretical idealizations.

Gupta et al. [2] analyzed different cross-sections of box girder bridge. Linear response spectrum method of analysis used for this study in SAP 2000 v12.0.0 software.

Broquet et al. [3] carried out performance study, based on the bridge-vehicle interaction, to examine dynamic amplification factors on overall bridge deck superstructure.

Abd. El-Hakim Khali et.al [4], presented behaviour of box girder under pure torsion also introduced prestressing strengthening techniques for concrete box beams with web opening and without opening. Huang and Wang et al.[5] analyzed thin-walled box girder bridges subjected to moving vehicle for obtaining the dynamic response and impact factor characteristics using free-vibration analysis considering torsion, bending moment and deflection.

Cheung and Li [6] presented spline finite strip method for free vibration analysis of curved box-girder bridges. Comparision of responses is also done with finite element method.

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 efficient prestressing techniques in box girder bridge superstructure to intensify structural performance of bridge superstructure.

III. MODELLING AND ANALYSIS

As per Indian Standard Specification, Design of Prestressed Concrete Rectangular and Trapezoidal box girder deck has been done and optimized cross section geometry is considered for analysis. Dynamic analysis is performed on both the models by Response Spectrum Analysis with the help of SAP2000 software. The parameters selected to define rectangular and trapezoidal box girder deck are as follows:

Type of Bridge Superstructure	**Box girder Bridge**
Span	30,40m
Carriageway width	7.5 m
Foot Paths	1.25m
Thickness of wearing coat	80mm
Web thickness	300 mm
TH. Of Top & Bottom Slab	300 mm
Grade of concrete	M60
Loss Ratio	0.80
Type of tendons	High tensile strands of 15.2 mm dia. Confirming to IRC: 6006-2000.
Anchorages Type	27K-15 Freyssinet type anchorages.
Type of Supplementary r/f	Fe-415 HYSD bars
Loading Considered	Dead load, wind & Prestress, 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

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.

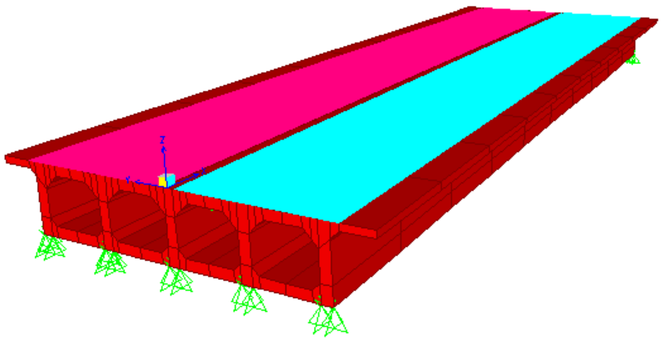

Fig. 1: Finite Element model of four-cell rectangular box girder bridge Superstructure

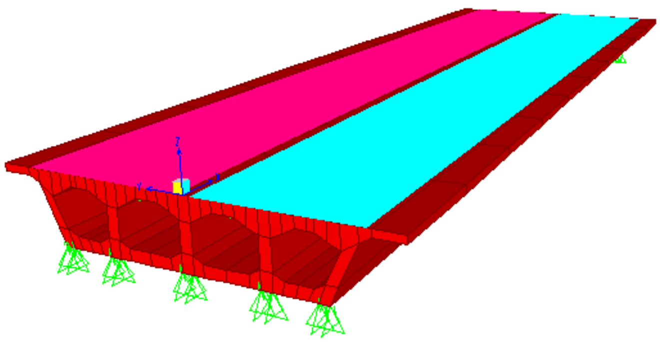

Fig. 2: Finite Element model of four-cell trapezoidal box girder bridge Superstructure

IV. RESULTS AND DISCUSSION

Response Spectrum Analysis is done for both trapezoidal as well as rectangular 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 are represented in fig. 3 to 6.

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.

Rectangular Box girder bridge	Mode	Frequency (Hz)	Time Period (sec)
30 m Span	1	6.51	0.153
40m Span	1	3.76	0.265
Trapezoidal Box girder bridge			
30 m Span	1	5.90	0.169
40m Span	1	3.41	0.293

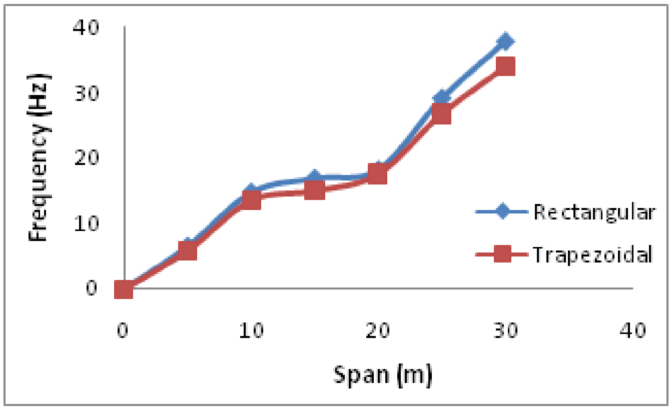

Figure 3: Variation of frequency w.r.t span for different cross section

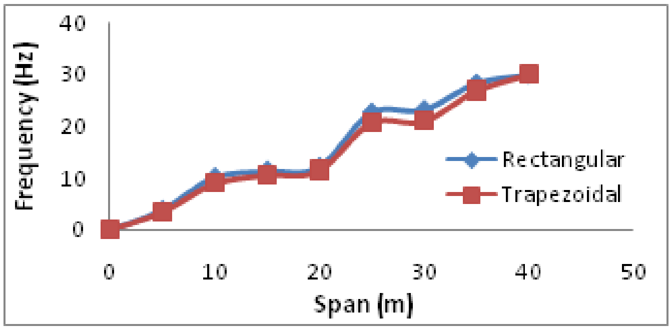

Figure 4: Variation of frequency w.r.t span for different cross section

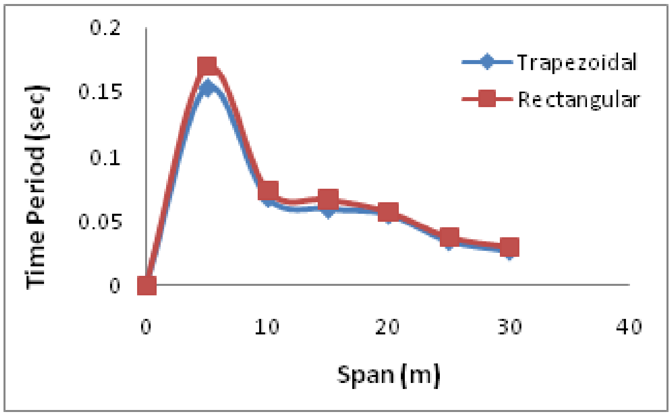

Figure 5: Variation of time period w.r.t span for different cross section

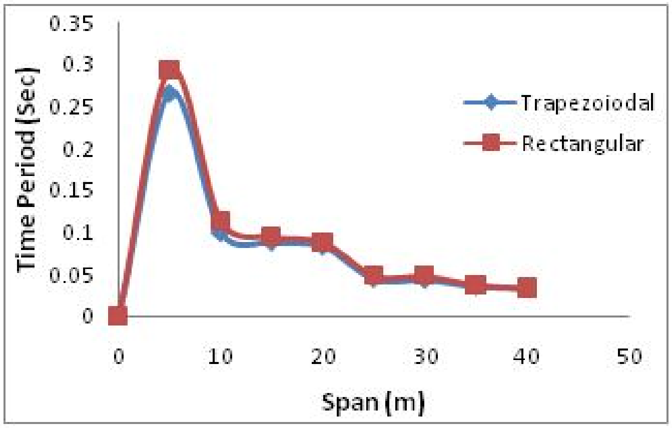

Figure 6: Variation of time period w.r.t span for different cross section

2. Deflection :

The variation of deflection along the span of the bridge at 5 m interval for four-cell trapezoidal and rectangular box girder bridge for combined load case DL+LL+EQ+Prestress w.r.t span length of 30m and 40m span are represented in fig. 7 and 8.

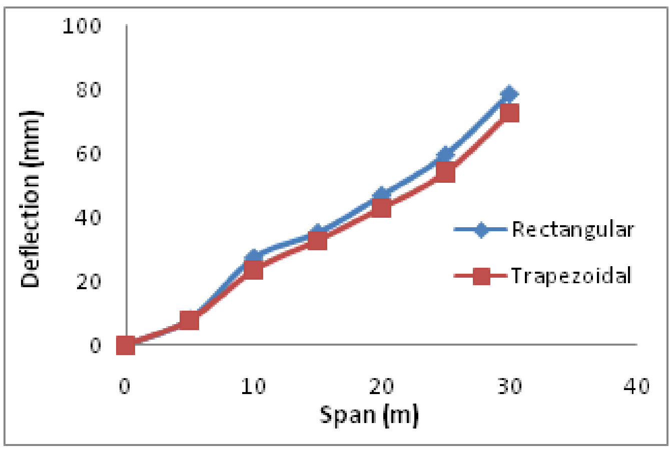

Fig. 7: Variation of deflection w.r.t span for different cross-section

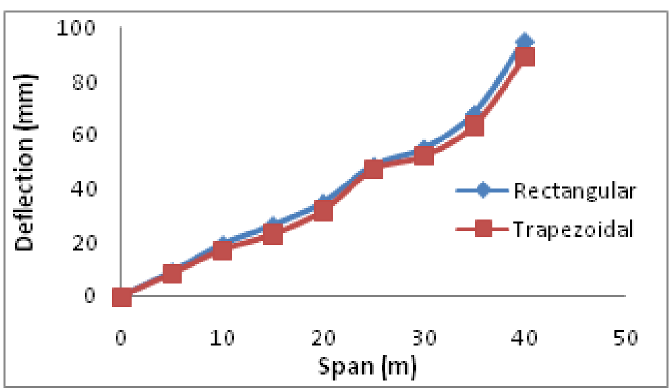

Fig. 8: Variation of deflection w.r.t span for different cross-section

3. Bending Moment:

The variation bending moment at entire bridge section for combined load case of DL+LL+EQ+Prestress for Rectangular and Trapezoidal box girder w.r.t span length of 30m and 40m span are represented in fig.9 & 10.

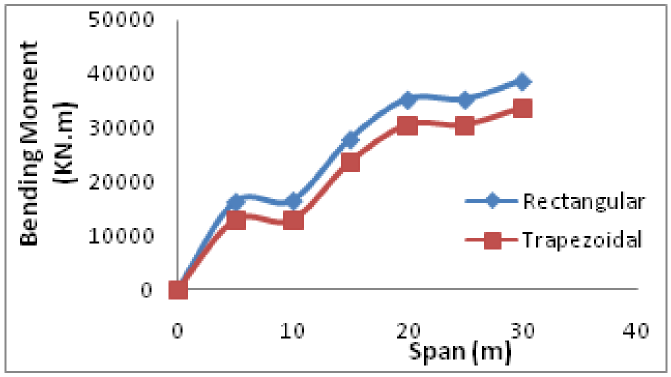

Fig. 9: Variation of Bending Moment w.r.t span for different cross-section

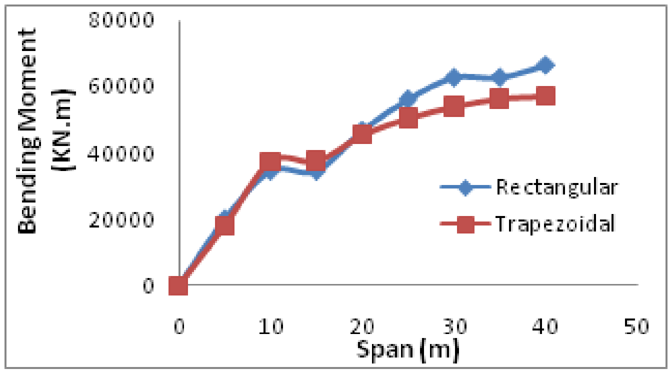

Fig. 10: Variation of Bending Moment w.r.t span for different cross-section

4. Shear Force:

The variation shear force at entire bridge section for combined load case of DL+LL+EQ+Prestress for Rectangular and Trapezoidal box girder w.r.t span length of 30m and 40m span are represented in fig.11 & 12.

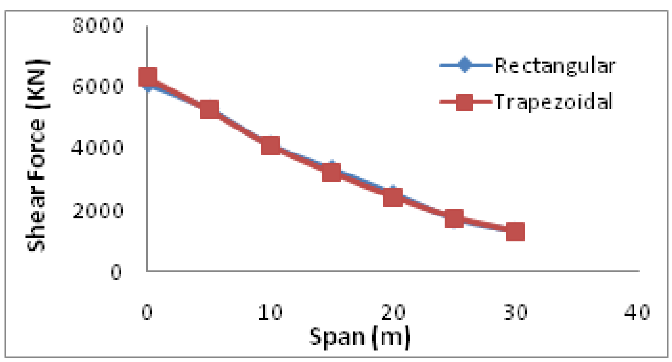

Fig. 11: Variation of Bending Moment w.r.t span for different cross-section

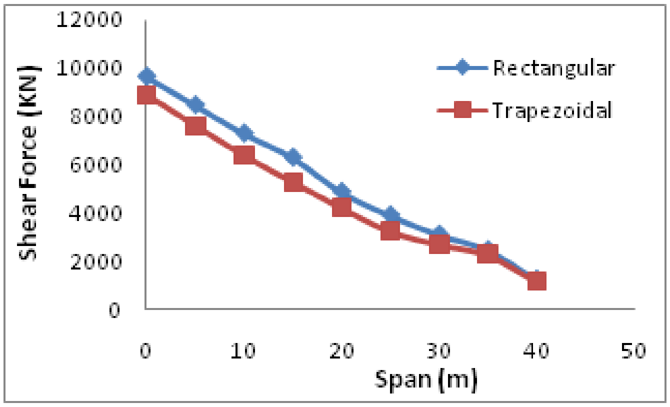

Fig. 12: Variation of Bending Moment w.r.t span for different cross-section

5. Base Reaction:

Base reaction in X direction for Rectangular and Trapezoidal box girder are represented by fig.13

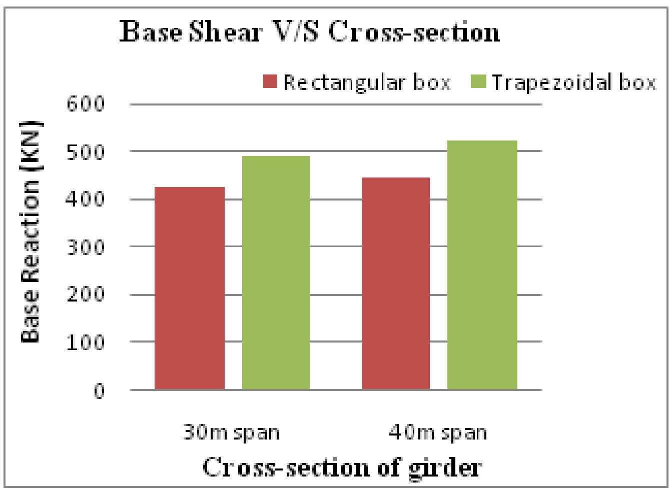

Fig 13: Maximum Base Shear v/s span for both girder cross-sections

6. Longitudinal & Shear Stresses:

Variation of longitudinal and Shear stresses for Rectangular and Trapezoidal box girder w.r.t span length of 30m and 40m span are represented in fig.16 & 19.

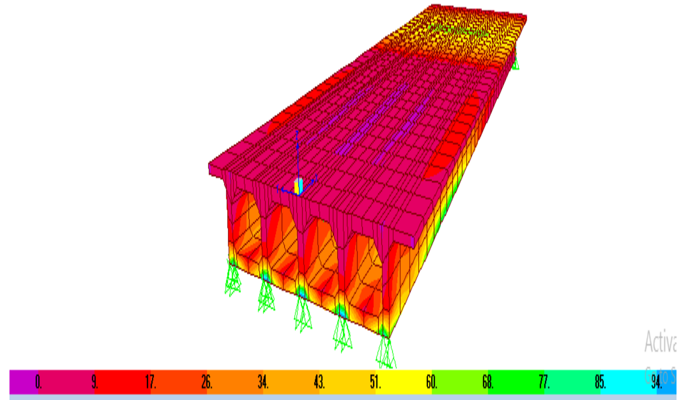

Fig. 14: Longitudinal Stresses in Rectangular Box Girder Bridge.

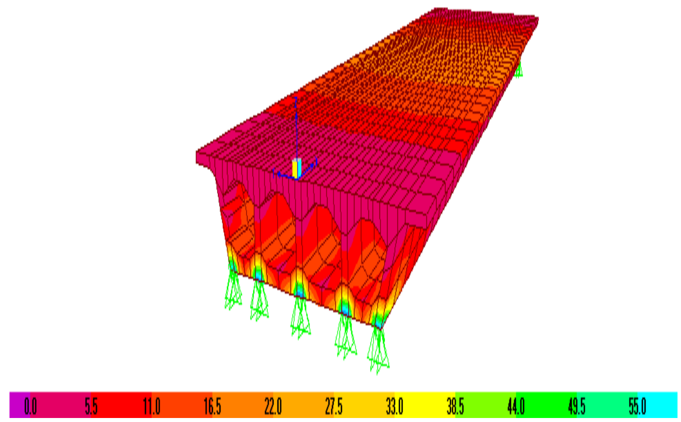

Fig. 15: Longitudinal Stresses in Trapezoidal Box Girder Bridge.

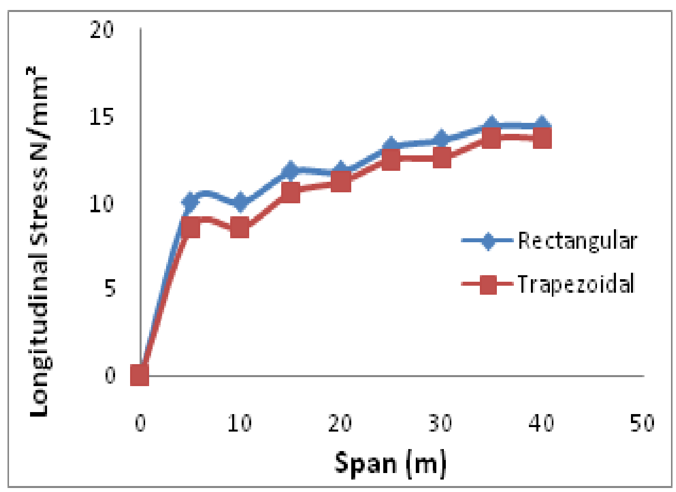

Fig. 16: Variation of Longitudinal Stress w.r.t span for different Cross section

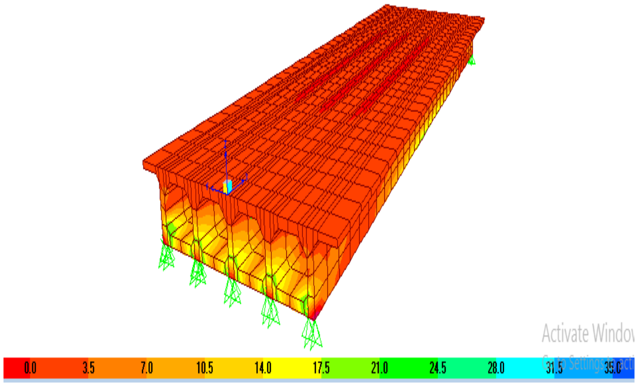

Fig. 17: Shear Stresses in Rectangular Box Girder Bridge

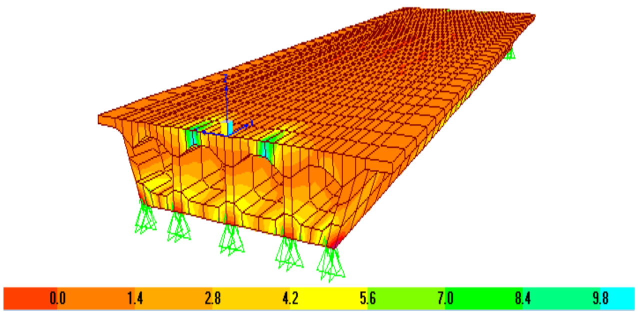

Fig. 18: Shear Stresses in Trapezoidal Box Girder Bridge.

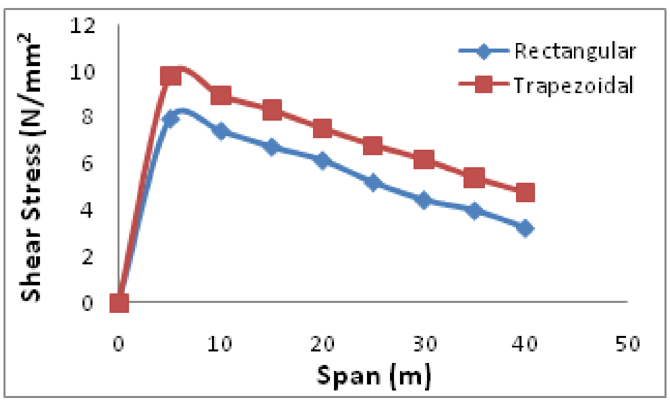

Fig. 19: Variation of Shear Stress w.r.t span for different Cross Section

V. CONCLUSIONS

The behaviour of trapezoidal and rectangular box girder proposed for two lane bridge Superstructure of spans 30m and 40m is studied. By conducting Response Spectrum analysis it was clear that trapezoidal box girder is an efficient and economical cross section as compared to rectangular section as it minimizes weight, while maximizing high torsional stiffness and strength and by comparing following static and dynamic responses:

1) Frequency range of bridge superstructure and vehicle should be different in order to avoid resonance. As the results shows that vibration problem will be in 40m span bridge. However, there is no specific problem in too short or too long span bridges.

2) With the increase in span, time period goes on increasing and trapezoidal box girder has less time period of vibration than rectangular box girder.

3) Deflection of rectangular box girder is increased by 23% when it is compare to trapezoidal box girder for combined cases of load (DL+LL+PT+EQ).
4) Due to change in the shape of the box girder the self weight of the trapezoidal box girder bridge is reduced. Therefore the bending moment in rectangular girder is 16% more as compared to trapezoidal box girder for combined load cases.

5) Shear force is increased by 10% in rectangular girder compare to trapezoidal box girder in combined load case.

6) Trapezoidal box girder has slightly more base reaction because the area is reduced in trapezoidal section.

7) The longitudinal stresses at top are 9% more in rectangular box girder compared to trapezoidal box girder which shows that the trapezoidal section is in more compression.

8) The shear stresses are 13% more in trapezoidal box girder but the stresses are within the limit. Overall the performance of box girder of trapezoidal section is better.

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