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Dynamic Analysis & Optimization of Prestressed Concrete Box Girder Bridge Superstructure

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The prestressed concrete bridges have excellent riding characteristics that minimize traffic vibrations, torsional rigidity, less likely to crack prematurely continuous span, strength and the most noteworthy characteristic is natural frequency of vibration hardly matches with vehicle frequency therefore attained spacious acceptance in freeway, highway flyovers, and in modern metro rail systems. 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 girder 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 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 bending moment, shear forces, deflection, time period,are increases as the span length increases 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

Bridges are structure which gains an international importance as they are essential part of any road and rail way network. 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. 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.

A. 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 analyzed by Response Spectrum Analysis and Time History Analysis .

B. *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.

a principal conception in earthquake engineering, the response spectrum accepted as a standard method of representation of effect of ground acceleration on structures and is useful to comprehend the behaviour of structure.

C. *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

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.

Rashmi R Koushik et.al [2]:This paper gives the Deflection diagram inverted after the application of pre-stressing force for Simply Supported and Continuous bridges, For Overhang bridges, the deflection is maximum when subjected to Pre-stressing.After the application of Pre-stressing force, the deflection values reduce gradually for Simply Supported, Continuous and Overhang Bridges respectively.

Amit Saxena and Dr. Savita Maru [2] analyzed T-beam girder and box girder bridge Superstructure for balanced cantilever bridge to determine the most favorable solution and cost effective section. Modelling is done using STAAD PRO.

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

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.

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.

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 bridgesuperstructure.

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

Type of Bridge Superstructure	T-beam Girder Bridge	Trapezoidal Box Girder Bridge
Cross section	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	

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Cell dimensions	2 m wide by 1.8 m deep
TH. of Top & Bottom Slab	300mm,300 mm
Overhang Th.	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 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.

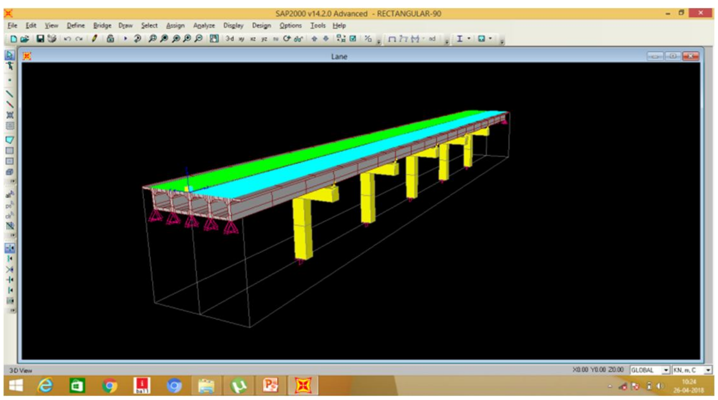


Fig. 1: Finite Element model of Rectangular box girder bridge Superstructure created in SAP 2000

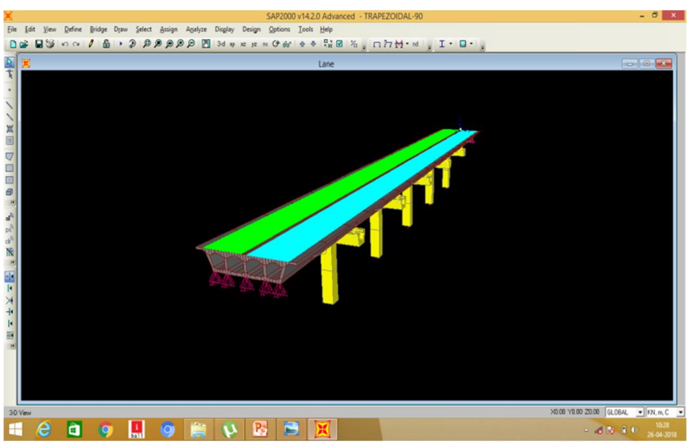
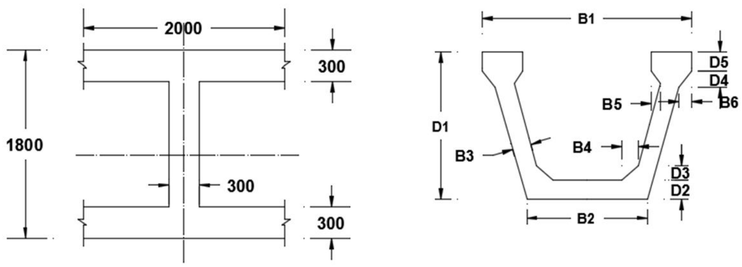


Fig. 2: Finite Element model of trapezoidal box girder bridge Superstructure created in SAP 2000

Span	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

Optimized Cross Section of Trapezoidal Box Girder



Cross Section of Trapezoidal Box Girder

Span	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

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.

A. *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.

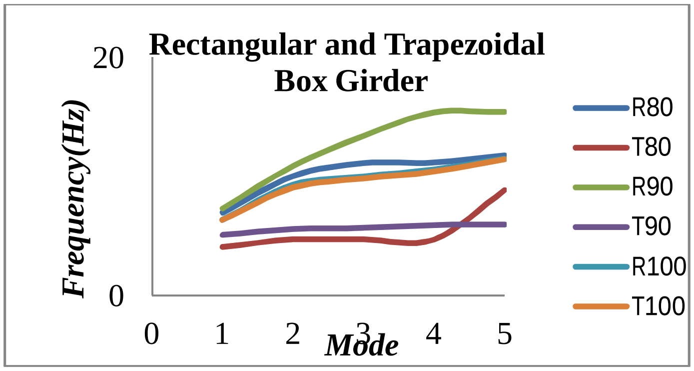


Fig. 3: Variation of Frequency w.r.t. Span

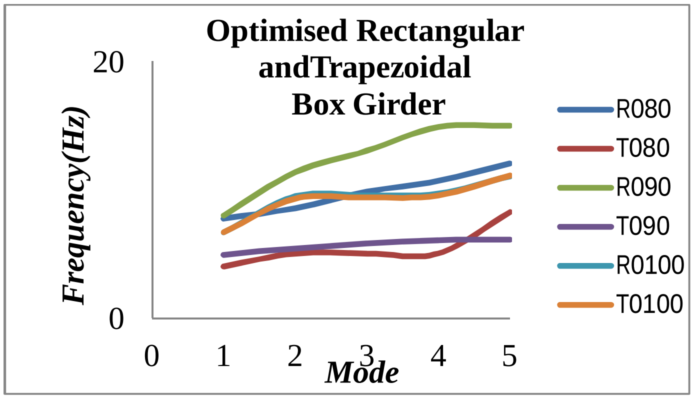


Fig. 4: Variation of Frequency w.r.t. Span

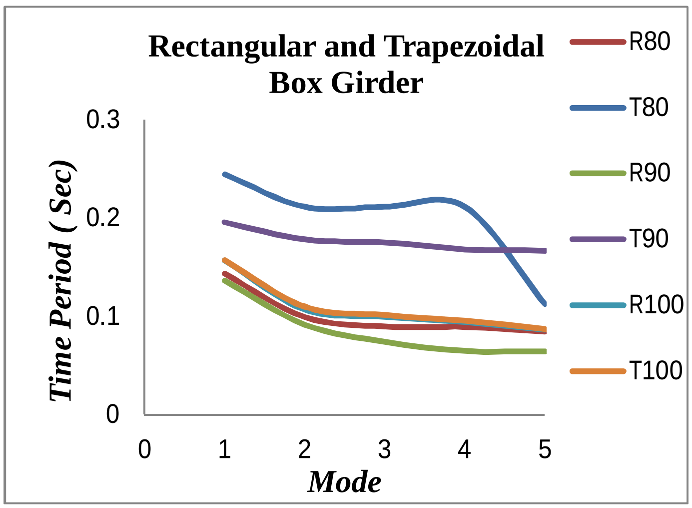


Fig. 5: Variation of Frequency w.r.t. Span

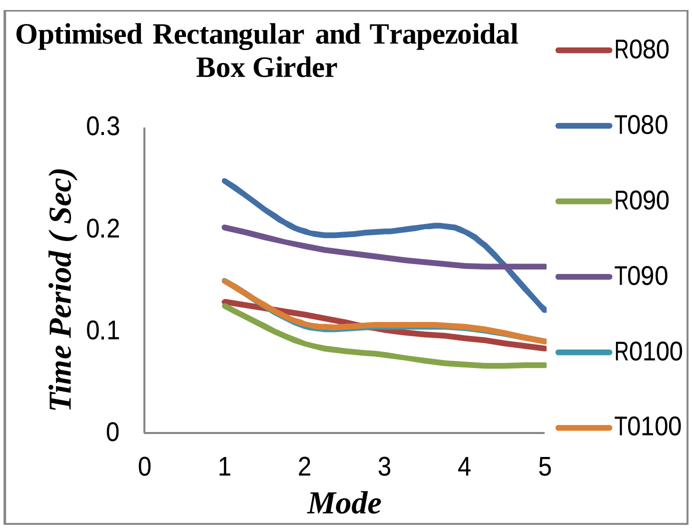


Fig. 6: Variation of time Period w.r.t. Span

B. 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.

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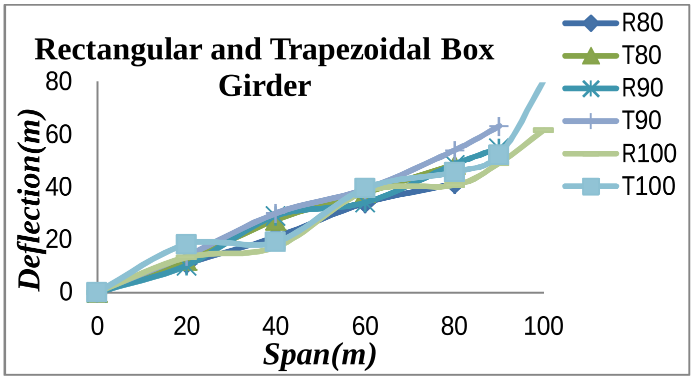

Fig.7: Variation of deflection w.r.t. Span

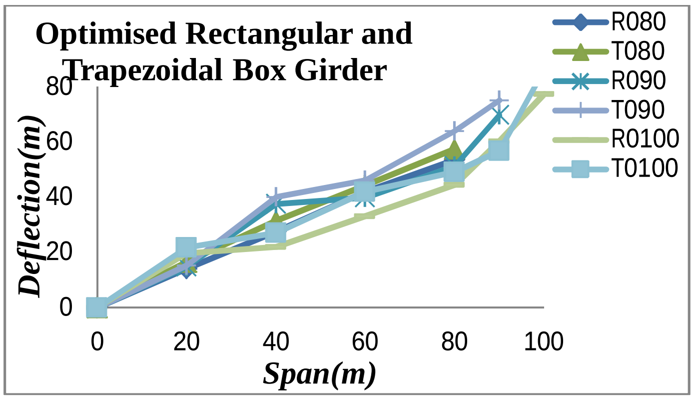

Fig.8: Variation of deflection w.r.t. Span

C. 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. 7 & 8.

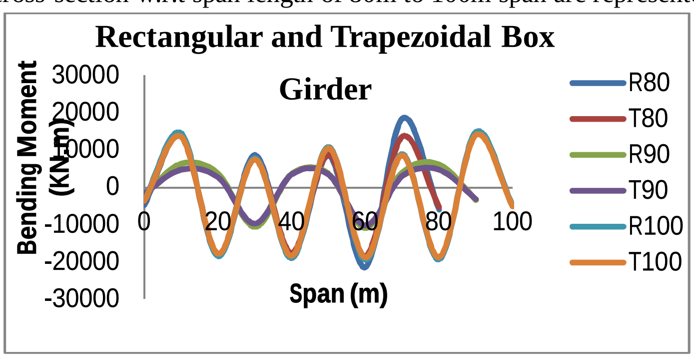

Fig. 9: Variation of bending moment w.r.t. Span

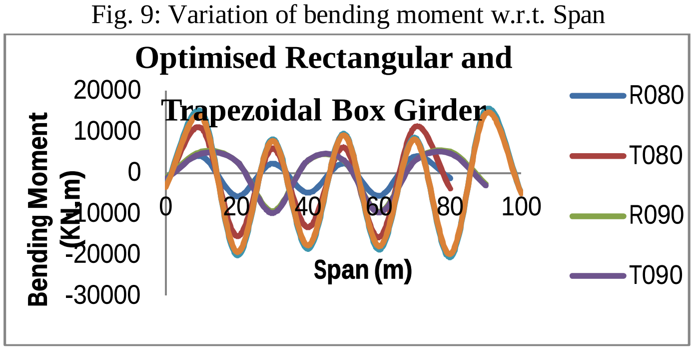

Fig. 10: Variation of bending moment w.r.t. Span

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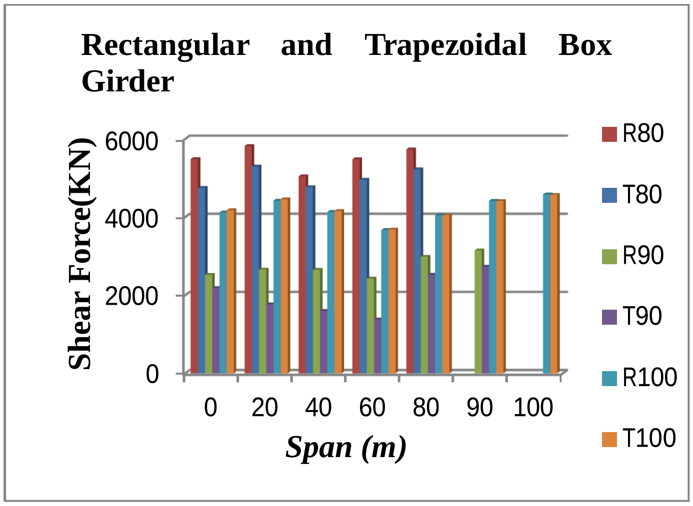

Fig. 11: Variation of Shear forces w.r.t. Span

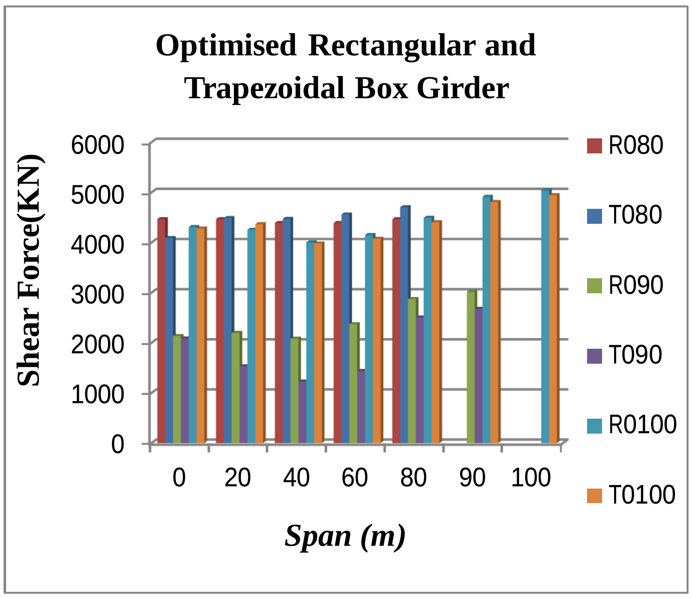

Fig. 12: Variation of Shear forces w.r.t. Span

V. CONCLUSIONS

The behaviour of Rectangular and trapezoidal box girder proposed for two lane bridge Superstructure of spans 80m to 100m is studied. By conducting Time History analysis it was clear that trapezoidal box girder is an efficient and economical cross section by optimization of cross-section as compared to Rectangular box girder section by comparing following static and dynamic responses:

A. Frequency of bridge superstructure should not fall in the range of vehicle frequency band to avoid resonance. As the results shows that for 80m and 100m span trapezoidal box girder bridge will be subject to vibration problems. Whereas 80m span Rectangular box girder will be subjected to vibration. Hence, it is clear that too short or long span bridges may not create vibration related problems.

B. With the increase in span, time period goes on increasing and Rectangular box girder has less time period of vibration than Trapezoidal box girder bridge.

C. Deflection of Rectangular box girder is increased by 18% compared to trapezoidal box girder for combined load case (DL+LL+PT+EQ).

D. The bending moment in Rectangular box girder is 8% more compared to trapezoidal box girder for combined load case.

E. The shear forces in Rectangular box girder is 6% more compared to trapezoidal box girder for combined load case.

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