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Parametric Study on Post-Tensioned Concrete Box Girder Bridge in Earthquake

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Abstract

In this research comparative study of rectangular and trapezoidal sections of post tensioned box girder for same width, depth and loading conditions is done. For this research, a three dimensional finite element (FE) model of two-lane Box Girder Bridge made up of prestressed concrete has been developed using commercially available software CSiBridge v23.3.1. Three dimensional 4-noded shell elements have been employed for discretization of domain and to analyze the complex behavior box girders. The linear analysis has been carried out for moving load with maximum eccentricity at mid span. Also the study intends to present the parametric study for deflections, longitudinal bending moment, shear force, consumption of concrete and stiffness for these cross-sections. And draw fragility curve to identify the probability of exceedence for the defined damage state conditions.

Keywords

Concrete box girder, Push over analysis, Time history analysis, Fragility analysis

1. Introduction

A box girder is a bridge in which the main beams comprise girders in the shape of hollow box. The girder normally comprises either prestressed concrete, structural steel, or a composite of steel and reinforced concrete. The box girder bridge type is linked to providing construction methods and maximizing material use for a given span. As the span increases, the dead load also increases, which is a crucial aspect. Box girders or cellular structures have been created as a result of the removal of unneeded components from sections in order to reduce dead load. Better torsion resistance is provided by box girders, which is advantageous in particular if the bridge deck has a curved in plan. Additionally, because two webs enable the use of broader and therefore stronger flanges, larger girders can be built. This permits longer spans. This type of superstructure is generally used for spans between 20 to 50 m.

The box section also possesses high bending stiffness and there is an efficient use of the complete cross-section. Due to its structural effectiveness, superior stability, greater serviceability, cost-effectiveness during construction, and appealing aesthetics, box girders have become widely accepted in the motorway and bridge systems. Due to its 3-D behavior, which includes bending, distortion, and torsion in both the transverse and longitudinal directions, the study and design of these box girder bridges is relatively complicated. Box beam structures are well suited to bridges with large curvature because of their excellent torsional resistance. They can be built as single, double, or multi-cell structures using box girders in various geometries, including circular, trapezoidal, and rectangular.

The general objective of this research is to determine the overall performance of prestressed Box Girder Bridge of different span and sections with constant depth. Similarly, the specific objectives have been listed below:-

- To analyze the structural behavior of Post-tensioned concrete Box Girder Bridge for different sections with varying span.
- To determine the structural capacity of the bridge pier by nonlinear static analysis and structural demand using nonlinear dynamics analysis excited by different ground motion time histories.
- To quantify the seismic vulnerability of the

bridge for different deck sections with the help of fragility curves.

2. Methodology

A finite element analytical model of different cross-section i.e., Trapezoidal and Rectangular box girder of different span length were modeled in CSi Bridge v23. Parametric study of these different models were done for different load case such as dead load, live load (IRC Class 70R loading) and Gorkha earthquake. Also comparative study for different cross section of box girder was done by fragility curve analysis. Both structural demand and capacity was calculated in terms of displacement ductility which is the ratio of maximum top pier displacement and the rebar first yield displacement[1]. Push over analysis is performed in order to evaluate the structural capacity. Also, Time history analysis is performed in order to evaluate the structural demand considering the three different ground motion data (Gorkha, Kocaeli and Northridge)[2]. Comparative study of both girder section were done by considering probability of exceedance for slight, moderate, extensive and collapse damage states respectively due to Maximum Considered Earthquake and Design Basis Earthquake.

3. Modelling

3.1 Superstructure modelling

The bridge used in this study is a prestressed concrete, two Lane Bridge with carriageway width 7.2 m with 1.5 m footpath on both sides. It consists of two span continuous over a pier cap. The dimensions of the bridge are verified as per "Post Tensioned Box Girder Design manual", Federal Highway Administration (U.S. Department of Transportation)[3].

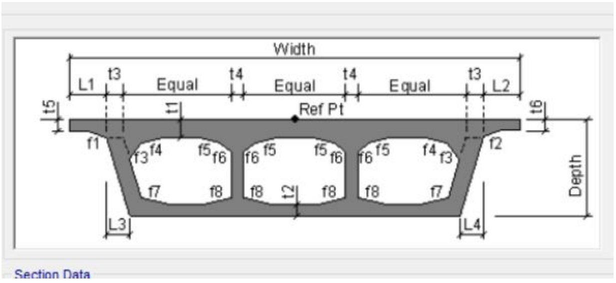


Figure 1: Typical section detail of Trapezoidal box girder

Table 1: Section details for Box girder

Description	Trape-zoidal	Rectan-gular
Total depth (m)	2.4	2.4
Top width (m)	10.2	10.2
Bottom width (m)	6.04	7.2
Top Slab Thickness (t1) (m)	0.35	0.35
Bottom Slab Thickness (t2) (m)	0.25	0.25
Exterior Girder Thickness (t3) (m)	0.35	0.35
Exterior Girder Bottom Offset (m)	0.58	0.58
Overhang Length (L1 & L2) (m)	1.5	1.5
Horizontal fillet (f1, f2, f4, f5, f7, f8) (m)	0.6	0.6
Vertical fillet (f1, f2, f4, f5, f7, f8) (m)	0.125	0.125
Overhang Thickness (t5 & t6) (m)	0.25	0.25
Cross-sectional Area (m^2)	6.437	6.856

3.2 Substructure modelling

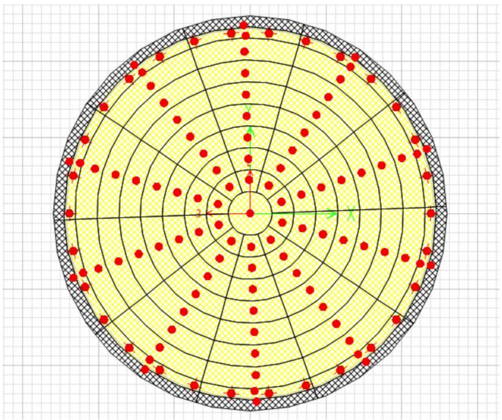


Figure 2: Fiber distribution in cross section of pier

Multicolumn pier with circular cross section with diameter 1.3 m and clear height 6.5 m is used in bridge. Thirty numbers of longitudinal reinforcement of 32 mm diameter and stirrups of 12 mm diameter at 150mm c/c spacing are used as shear reinforcement. Cap beam of length 10.5m is used having cross section of 2m × 1m at edge and 2m × 2m at center. Grade of concrete is M25 and that of reinforcing steel is Fe500.Degradation of stiffness of member due to cracking of concrete, yielding of reinforcement due to flexural yielding and strain hardening can be represented using fiber hinge[4].

3.3 Loading Placement

Since it is noted that the critical moment is generated for Class 70R wheeled vehicle loading; therefore, parametric study was done by placing Class 70R wheeled vehicle loading. Two loading cases are considered for each bridge model, eccentric IRC Class 70R loading, bridge dead load and earthquake load.

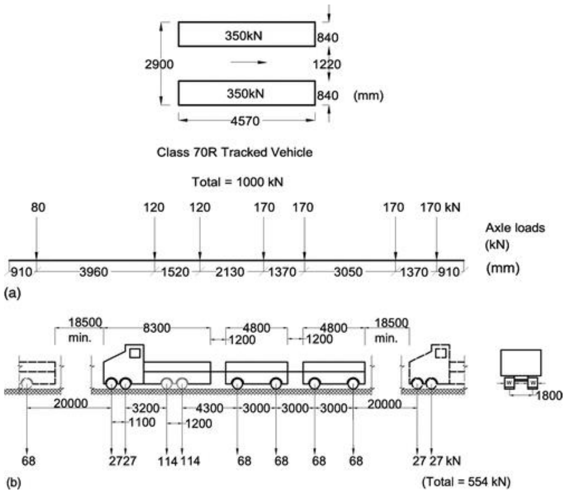


Figure 3: Longitudinal and transverse positioning of IRC Class 70R loading

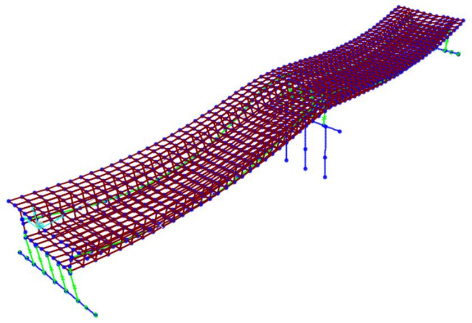


Figure 4: Deformed shape of Trapezoidal Box Girder Model

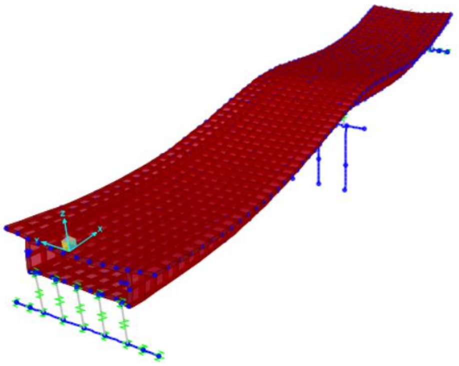


Figure 5: Deformed shape of Rectangular Box Girder Model

4. Result and Discussion

In the parametric study two cross sections namely rectangular and trapezoidal for different span of box girder are analyzed. The result obtained for various span of bridges are compared for different loading configuration dead load (self-weight) live load (IRC Class 70R) and earthquake load. The loads are placed in accordance with IRC: 6-2000, Standard Specification and Code of Practice for road and bridge.

4.1 Along U1 direction

The span of the bridge is aligned along U1 direction. The E-W component of the Gorkha Earthquake is considered for the analysis of all the bridge model in U1 direction. The output time step considered was 0.05 sec with 1200 steps and total time of 60 sec. The results obtained are summarized below:

Table 2: Bending moments for different Span length

Span (m)	Trapezoidal	Rectangular
30	56222.73	59286.34
45	69288.89	76479.37
60	99776.01	118153.82

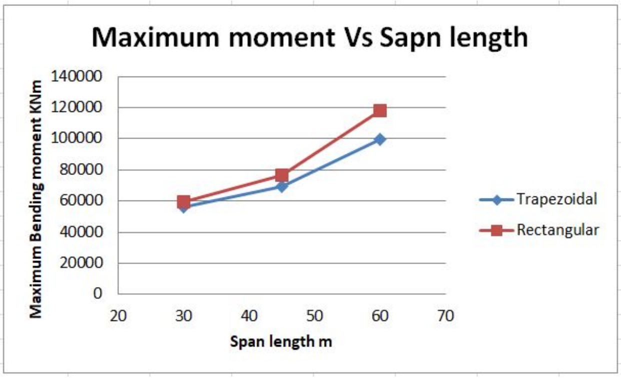


Figure 6: Maximum Bending moment of different span length

Table 3: Shear force for different Span length

Span (m)	Trapezoidal	Rectangular
30	-3417.67	-3524.87
45	-3665.2	-3874.29
60	-4364.32	-4656.2

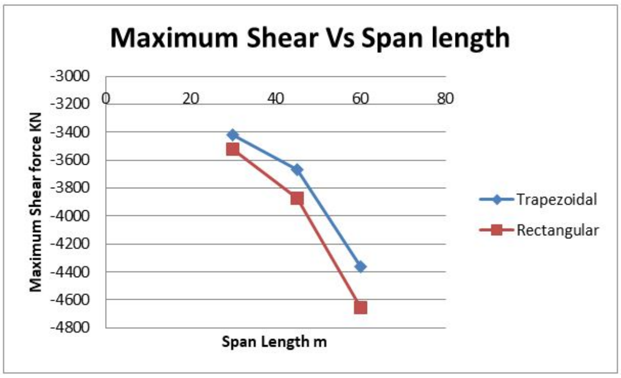


Figure 7: Maximum Shear force of different span length

Table 4: Deflection for different span

Section	Span (m)	Displacement (m)
Trapezoidal	30	0.0039
	45	0.0049
	60	0.0064
Rectangular	30	0.0036
	45	0.0043
	60	0.00528

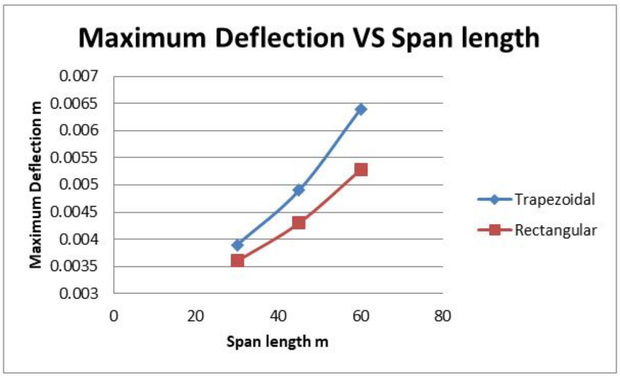


Figure 8: Maximum Deflection of top flange for different span length

Result of Cross-section Variation:
From the result obtained, it can be concluded for a constant depth of bridge model, the maximum bending moment of trapezoidal is 5.44%, 6.03%, and 8.33% less than rectangular models of spans 30m, 45m and 60m.The maximum shear force of trapezoidal is 3.13%, 6.17%, and 11.2% less than rectangular models of spans 30m, 45m and 60m.The nodal displacement of trapezoidal is 7.69%, 12.24%, and 17.5% more than rectangular models of spans 30m, 45m and 60m.

Result of Span Variation:
From the result obtained, it can be concluded for a constant depth of bridge model, the maximum bending moment increases by 29.76% and 56.34% when span varies from 30m to 45m and 45m to 60 m respectively and maximum moment of Trapezoidal section increases by 23.24% and 44.93%.The maximum shear force increases by 35.18% and 64.75% when span varies from 30m to 45m and 45m to 60 m respectively and maximum shear of Trapezoidal section increases by 28.34% and 57.23%.

4.2 Push Over Analysis

From Pushover curve for pier with Trapezoidal deck section, the maximum base shear is 2705.798KN, maximum base shear for pier with rectangular deck section is 2905.798KN. Median Ductility capacity for all damage states are higher for pier with Trapezoidal section.

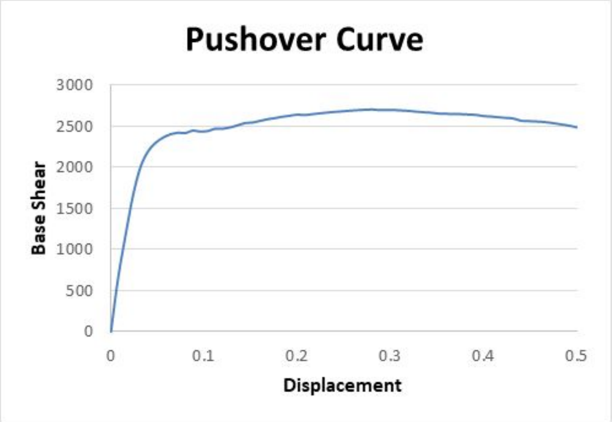


Figure 9: Pushover Curve for Pier with Trapezoidal Deck section

Table 5: Quantification of damage states for Trapezoidal deck sections

Damage states	Displacement (mm)	Ductility Ratio(μd)	Median Ductility Capacity (Sc)
Slight/ Minor	8	1	1.56
Moderate	17	2.12	5.62
Extensive	73	9.12	12.49
Complete	127	15.87	15.87

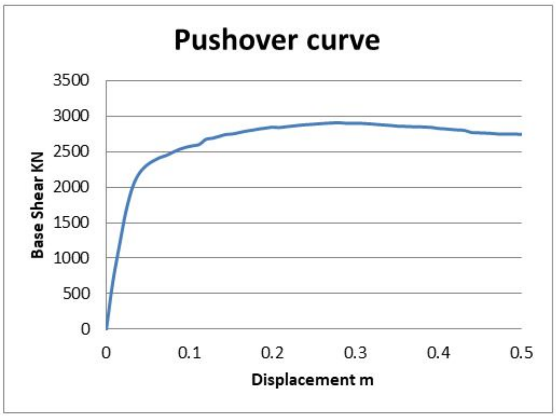


Figure 10: Pushover Curve for Pier with Rectangular Deck section

Table 6: Quantification of damage states for Rectangular deck section

Damage states	Displacement (mm)	Ductility Ratio(μd)	Median Ductility Capacity (Sc)
Slight/ Minor	11	1	1.36
Moderate	19	1.72	3.95
Extensive	68	6.18	9.635
Complete	144	13.09	13.09

4.3 Time History Analysis

Three numbers of ground motion records are used during the analyses which are Gorkha, Northridge and Kocaeli. Twenty number of time histories data are generated by scaling each ground motion from 0.1g to 2g at the interval of 0.1g. These generated time histories are subjected to modeled bridge at foundation level in transverse and longitudinal direction altogether having 60 numbers of time history analyses for each bridge pier. Maximum displacement time history of pier top due to ground motion subjected in both longitudinal and transverse directions are monitored. In all cases maximum displacement is more in transverse direction so all displacement values used in further calculation are of the transverse direction.

Regression Analysis:
Displacement ductility and Peak ground acceleration are plotted on ordinate and abscissa respectively in this analysis. The result of this analysis is trendline for the plotted 60 numbers of data shown on Figure 11 and Figure 12.

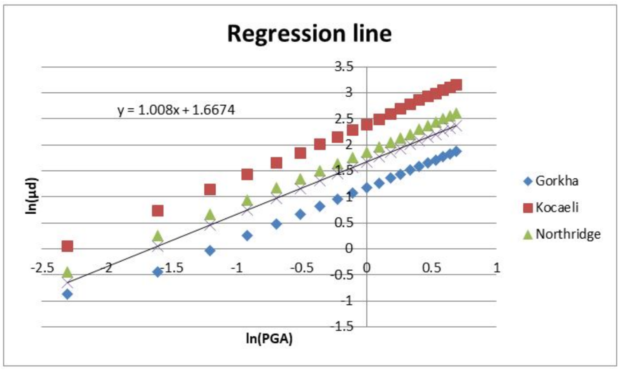


Figure 11: Regression analysis of Time History Results for Rectangular deck bridge pier

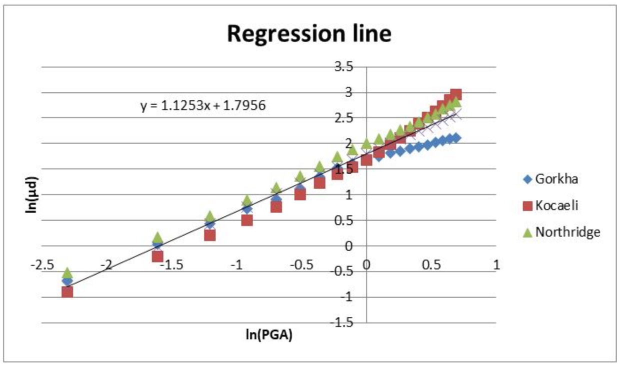


Figure 12: Regression analysis of Time History Results for Trapezoidal deck bridge Pier

$$ln(\mu d) = 1.008 ln(PGA) + 1.6674$$
$$ln(\mu d) = 1.1253 ln(PGA) + 1.7956$$

These are the trendline equations for Rectangular and Trapezoidal deck section bridge pier. These Equations are used in the fragility analysis for determining displacement ductility for arbitrary value of PGA.

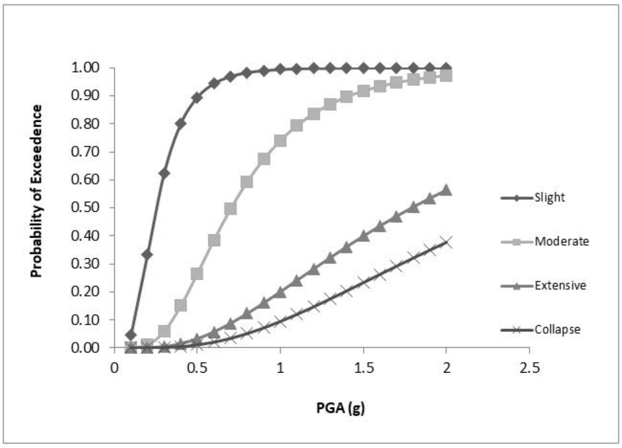


Figure 13: Fragility curve for Rectangular deck section pier

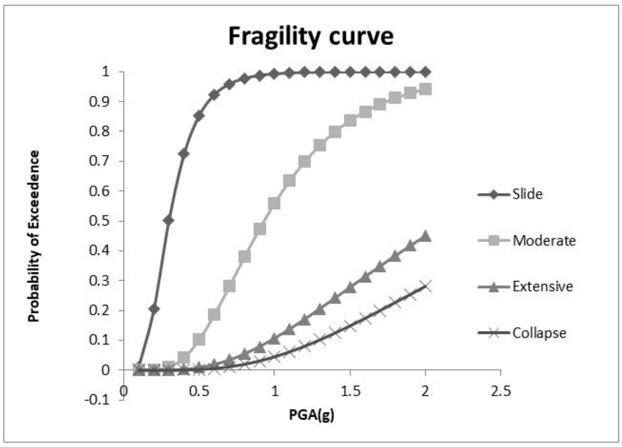
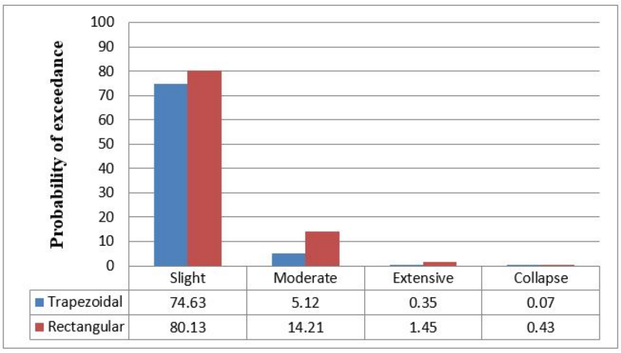
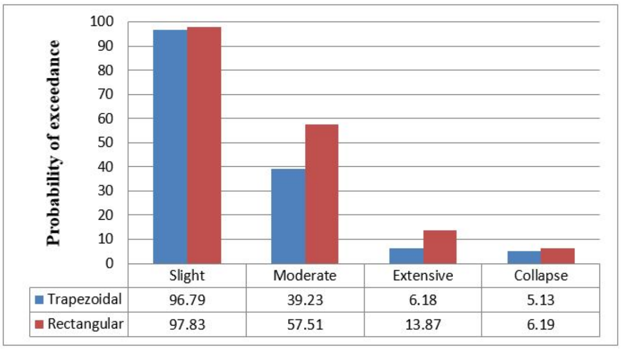


Figure 14: Fragility curve for Trapezoidal deck section pier



	Slight	Moderate	Extensive	Collapse
🟦 Trapezoidal	74.63	5.12	0.35	0.07
🟥 Rectangular	80.13	14.21	1.45	0.43

Figure 15: Probability of exceedance for Design Basis Earthquake



	Slight	Moderate	Extensive	Collapse
🟦 Trapezoidal	96.79	39.23	6.18	5.13
🟥 Rectangular	97.83	57.51	13.87	6.19

Figure 16: Probability of exceedance for Maximum Considered Earthquake

4.4 Discussion

We analyze the different box girder bridges with different cross-sections for different number of spans. From the result of nonlinear time history analysis, the maximum shear force and maximum bending moment of rectangular box girder is higher than that of trapezoidal box girder section. This is because of the stiffness of the bridges and center of gravity lies different for both sections of girders. And, nodal displacement is higher in a trapezoidal box girder hence the rectangular box girder section is the stiffest one.

From the span variation result, when the span varies from 30 m to 45 m i.e. increase by 50% then the maximum bending moment, maximum shear force and maximum nodal displacement increase by only less than 50%. Also, when the span length varies from 45 m to 60 m i.e. increase by 33.33% then all the response parameters increased by grater than 50%. Hence, from span variation for the given section of the box girder, 45 m span length is the effective one.

From the fragility curve analysis, the probability of exceedance for rectangular box girder section is higher as compared to the trapezoidal one for all damage states i.e. slight, moderate, extensive and collapse in both design basic earthquake and maximum considered earthquake. This is because the center of gravity for trapezoidal section lies above as compared to rectangular section and difference in stiffness for the sections. Hence the rectangular section bridge is vulnerable as compared to the trapezoidal section bridge when the seismic event is happened. Seismic vulnerability of bridges can be assessed using fragility curves obtained using analytical methods of formulation.

5. Conclusion

The result presented highlight the effect of span length and the cross-sectional shape on the behavior in terms of deflection, bending moment, shear force and fragility curve analysis in different box girders.

- Among the rectangular and trapezoidal cross-section box girders for all span length, the deflection is higher in trapezoidal section thus it can be concluded that rectangular section is stiffest section.

- Bending moment and shear force in rectangular sections are higher than in trapezoidal sections for all span length.

- From span variation, as the span increases the deflection, shear force and bending moment are increases which is not in linear proportion and 45 m span length is effective one.

- The probability of exceedance of rectangular deck section pier are 80.13%, 14.21%, 1.45% and 0.43% for slight, moderate, extensive and collapse damage states respectively due to Design Basis Earthquake.
- The probability of exceedance of rectangular deck section pier are 97.83%, 61.51%, 13.87% and 6.19% for slight, moderate, extensive and collapse damage states respectively due to Maximum Considered Earthquake.
- The probability of exceedance of trapezoidal deck section pier are 74.63%, 5.12%, 0.35% and 0.07% for slight, moderate, extensive and collapse damage states respectively due to Design Basis Earthquake.
- The probability of exceedance of trapezoidal deck section pier are 96.79%, 39.23%, 6.18% and 5.13% for slight, moderate, extensive and collapse damage states respectively due to Maximum Considered Earthquake.
- Probability of failure of trapezoidal deck section pier is less as compared to rectangular deck section pier having same pier and foundation.

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