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Parametric Study of Pre-Stressed Box Girder Bridge with Different Inclination Angle of Web

Bickey Lakha [a], Rajan Suwal [b]

[a, b] *Department of Civil Engineering, Thapathali Campus, IOE, Tribhuvan University, Nepal*
[a] bickey.762539@thc.tu.edu.np, [b] rajan-suwal@ioe.edu.np

Abstract
Nowadays, civil engineer are more focused on both structural as well as aesthetic appearance of the bridge. So, there is an emerging need of pre stressed box girder bridge which meet both the structural and aesthetic needs and also tends to be more economic and effective in term of seismic performance and cost. However this type of bridge are mostly used for longer span. In this study, the parametric study of pre stressed box girder bridge with different inclination angle of bridge has been done. With variation in the inclination angle of the web at constant cross sectional area of box girder, there is change in the seismic performance of the bridge. The inclination angle is changed at the interval of 6 degree starting from 90 degree and up to 72 degree inclination with all together four models. Then for various inclination angle of web corresponding seismic performance has been determined and the maximum performance point is obtained for inclination angle of 90 degree in both transverse and longitudinal direction for both design based earthquake and maximum credible earthquake. Hence the box girder bridge with 90 degree inclination angle is recommended as the best shape in terms of seismic performance.

Keywords
Seismic Performance, relative yield displacement, pier top displacement, Pushover analysis, Time history analysis

1. Introduction

A bridge is an infrastructure that provides a passage over an obstacles without disturbing the obstacle.The pre stressed Box Girder is a hollow channel shaped beam containing two (or more) side webs and two flanges in which tendons are stressed before placing and curing of concrete. The box shape can be trapezoidal or rectangular. The box girder is now being widely used due to its better serviceability, aerodynamic stability, economy, higher structural efficiency and splendid aesthetic appearances. The box girder also have high bending stiffness and also whole cross section of the bridge is fully utilised. This paper provides ideas for the parametric study of pre stressed box girder bridge with variation of angle of inclination of web with same cross sectional area.

Many studies has been done in the field of analysis of box girder bridge. Similaly, the parametric study of the box girder bridge for various inclination angle has been also done. As per [1] the deflection and magnitude of stresses is least in rectangular section than in trapezoidal and circular sections. Similarly, [2] concluded that deflection of box girder increases with decrease in inclination angle whereas torsional moment decrease with increase in inclination angle. In addition to it [3] concluded that the parameter such as strength and stiffness of the Rectangular box girder bridge is more than that of the Trapezoidal and Circular box girder bridge. Also [4] concluded that deflection is more in trapezoidal section as compared to rectangular section. However most of the study have been done for the box girder concrete bridge without considering the seismic performance of the bridge. Therefore, the effective shape of pre stressed box girder bridge with variation of inclination angle of web for the best seismic performance of the bridge is still to be found out. Hence this major gaps in the research shall be well addressed in this paper.

2. Objectives

1. To determine the seismic performance of the bridge with variation of inclination angle of web

of pre stressed box girder bridge.

2. To recommend the best shape of box girder bridge for effective seismic performance of the bridge.

3. Methodology

The following activities have been carried out to meet the objectives of the research.

- Literature Review
- Selection of Bridge and Data Collection
- Modelling of of bridge using CSi Bridge
- Assigning various loads and load cases
- Defining parametric variations for Model Analysis
- Carry out Model Analysis
- Comparatives Analysis of result and evaluation of seismic performance
- Conclusion

The detailed process of the above mentioned methods has been elaborated below.

3.1 Bridge Description

A reinforced double span Box Girder bridge has been chosen for the analysis with following detailed information to meet the objectives of the research.

- Bridge Name: Bidhuwa Khola Bridge
- Total Length of bridge: 110.35 m
- Length of each span of bridge: 52.30 m
- Number of Span: 2

Diameter of pier:2.3 m
Longitudinal reinforcement(pier): 52 no, Ø32 mm
Transverse reinforcement: Ø 16 mm, @ 100 mm c/c from pier top & bottom and 200 mm c/c on remaining
Overall Width of Bridge: 11.0 m
Carriage way width: 7.5 m
Pier clear height: 7.0 m
Elastomeric bearing size: 0.5 x 0.32 x 0.05 m

3.2 Bridge Modelling

For the detailed seismic study of the bridge, the structural model of the bridge is developed using a structural program CSi Bridge V22. The information regarding the structural geometry of the bridge is abstracted from the drawing obtained from the Bridge Unit, Department of Road. The deck slab, longitudinal girder and cross girders are modeled as four node plane shell elements. The abutment is modeled as fixed foundation spring. Rigid link is assumed to connect deck slab, longitudinal girder and cross girders. Elastomeric Bearing is modeled numerically by independent linear springs (link elements) in the direction of vertical, horizontal and rotational. The model can be simplified to Beam stick model for analysis purpose. In, simplified beam stick model the superstructure is represented by single beam element which have the equivalent property of the entire deck. The pier and pier cap are modelled as 3D beam column element. Auto PMM hinge is assigned in the pier section of the bridge for analysis of nonlinear characteristics for various seismic loading.

A parametric study is conducted on the bridge model to study and analyse the various responses. Responses in terms of Torsional Moment, Deflection and Displacement are studied. The only parameter that is varied is the inclination angle of web with same cross sectional area.

3.3 Selection of model for various inclination angle of box girder

For both pushover and time history analysis various box girder are modelled in CSi bridge V22. The inclination angle of the web of the box girder is varied at the interval of 6 degree with all together 4 model ranging from 90 degree to 72 degree.

Table 1: Selection of various configuration of box girder with constant cross sectional area.

SN	Top	Bottom	Height	Inclination Angle
1.0	4.3	4.3	3.10	90
2.0	4.3	3.78	3.25	84
3.0	4.3	3.15	3.46	78
4.0	4.3	2.34	3.79	72

3.4 Selection of Ground Motion Data

The nonlinear response of the structures is very sensitive to the structural modelling and ground motion characteristics. Therefore, a set of representative ground motion that accounts for the uncertainties and difference in frequency, severity and the duration characteristics has to be used to predict the possible deformation of the structures for seismic performance evaluation purposes. Typically, the series from recorded ground motion with various magnitudes(Mw) and PGA (g) range are chosen.

Actual ground motion near to the site should be selected for better result. However, actual earthquake records in Nepal is limited. The earthquake which resemble to the site should be considered. For this, target spectrum is defined according to IS 1893 (part I):2016. The earthquake data is taken from PEER Earthquake Database (NGA west 2). The downloaded data are the raw input data for time history. It is matched using Seismomatch software considering the target spectrum for both design based earthquake and most credible earthquake. The output from the Seismomatch software gives matched time history data which is used for nonlinear time history analysis

Table 2: Selected ground motion data.

SN	R.N.S	Earthquake	Date	Mw	PGA
1	181	Imperial	1979	6.53	0.57
2	779	Loma	1989	6.93	0.447
3	821	Erzican	1992	6.69	0.496
4	828	Cape	1992	7.01	0.591
5	879	Landers	1992	7.28	0.725
6	1085	Northridge	1994	6.69	0.853
7	1120	Kobe	1995	6.9	0.618

4. Analysis and Results

4.1 Modal Analysis

Modal analysis is used to determine the vibration mode of a structure. The dynamic behavior of the study bridge is investigated in terms of change of periods of vibration. The time period for first 10 modes is given.

Table 3: Fundamental time period of bridge.

Mode	90 deg	84 deg	78 deg	72 deg
1	1.97441	1.96241	1.95927	1.94639
2	1.95078	1.94722	1.92166	1.92069
3	1.9483	1.94533	1.92081	1.91590
4	1.93347	1.92982	1.90470	1.90121
5	1.16314	1.15283	1.14655	1.14136
6	1.15436	1.14392	1.13725	1.11012
7	0.41392	0.40185	0.38009	0.35669
8	0.40833	0.39592	0.37401	0.35000
9	0.14062	0.13986	0.13728	0.13574
10	0.11605	0.11333	0.10819	0.10336

4.2 Nonlinear (Pushover) Analysis

It is static non linear analysis in which direct lateral loads are applied on the structure based on certain specific load patterns. The displacement controlled method is used where the lateral load is monotonically increased to targeted level of displacement. The first yielding point in terms of displacement is obtained. Hence, the status of plastic hinges formed is used as gauge to evaluate seismic performance of the structure in terms of displacement corresponding to specified ground motion (the particular response spectrum).

The base shear – control node displacement curve is obtained from pushover analysis which is the most important result of the analysis. This curve is also called as pushover curve. The non-linear static procedure converts the properties of multi degree of freedom (MDoF) structures to corresponding single degree of freedom (SDoF) equivalents using various approximations. Here Capacity Spectrum method of ATC-40 is used for the pushover analysis.

The pushover analysis is conducted using Auto PMM hinge in pier. The use of Auto hinges gives clear state of hinges with change of color. The hinges are assigned to the pier as per plastic hinge length formulation recommended by [5]

Table 4: Relative yield displacement at top of pier.

SN	angle	pushover	1st yield (mm)	dir
1	90	Pushover X	10.3629	U1
	90	Pushover Y	10.4381	U2
2	84	Pushover X	10.30361	U1
	84	Pushover Y	10.4027	U2
3	78	Pushover X	10.277	U1
	78	Pushover Y	10.337	U2
4	72	Pushover X	10.271	U1
	72	Pushover Y	10.311	U2

The relative yield displacement of pier is almost same for different inclination angle of box girder using Auto PMM hinge. But, the relative yield displacement of pier decreases as the inclination angle decreases. The main reason for the result is that with decrease in the inclination angle the stiffness of box girder decreases, hence the yield displacement also decreases. The relative yield displacement is obtained maximum for 90 degree inclination angle. Hence box girder having 90 degree inclination angle has more yielding capacity as compared to all other sections.

Here, the pushover curve for various inclination angle is obtained. It is found that the graph for the curve is straight for all inclination angle of box girder. This is due to the use of auto PMM hinge instead of fibre hinge. For smooth curve, the analysis can be done using fibre hinges.

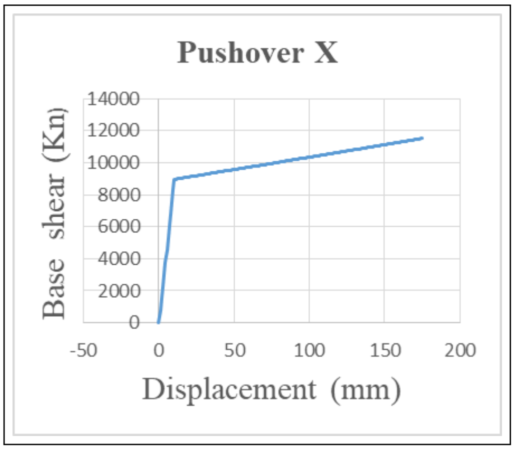

Figure 1: Pushover curve for inclination angle of 90 degree

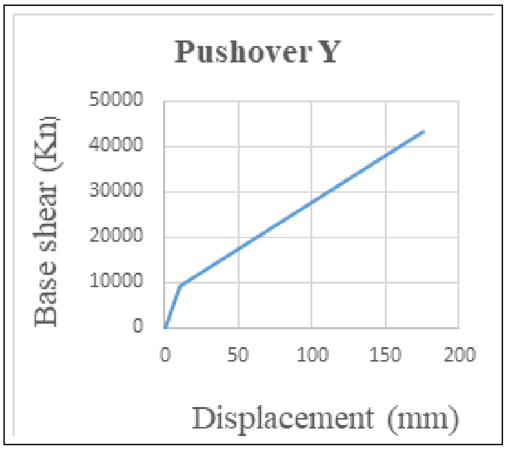

Figure 2: Pushover curve for inclination angle of 90 degree

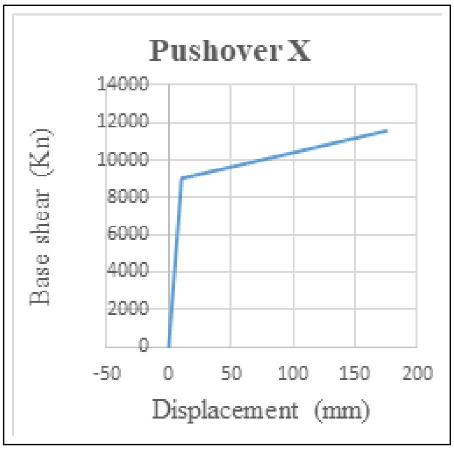

Figure 3: Pushover curve for inclination angle of 84 degree

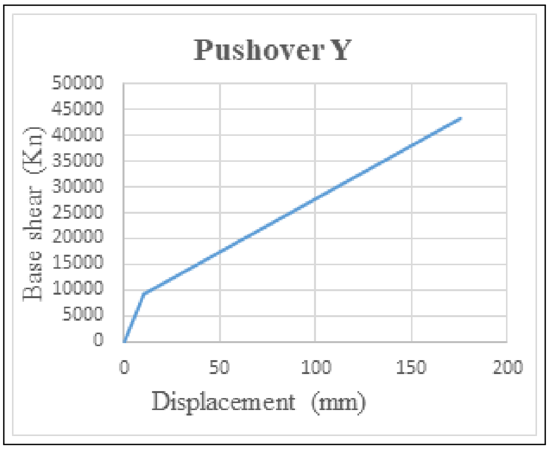

Figure 4: Pushover curve for inclination angle of 84 degree

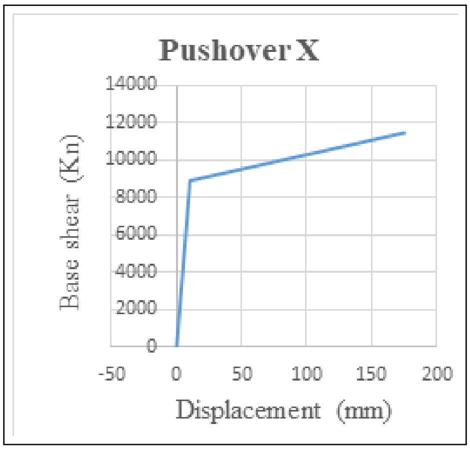

Figure 5: Pushover curve for inclination angle of 78 degree

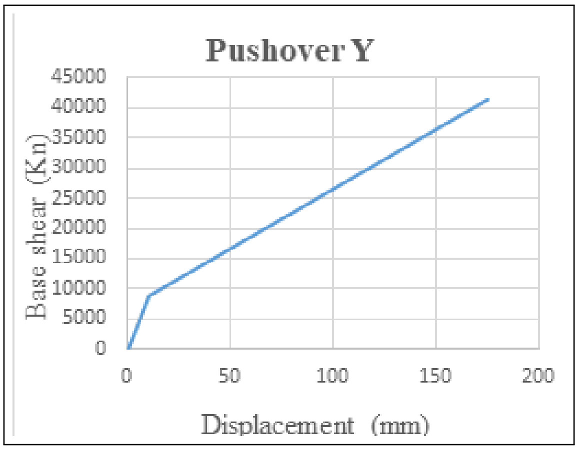

Figure 6: Pushover curve for inclination angle of 78 degree

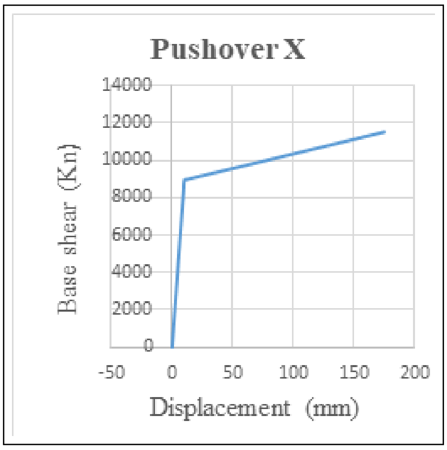

Figure 7: Pushover curve for inclination angle of 72 degree

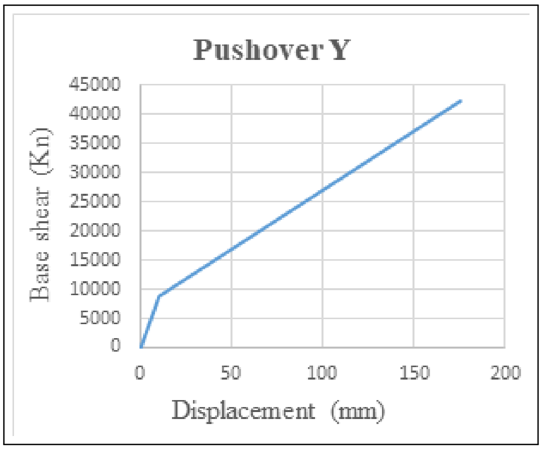

Figure 8: Pushover curve for inclination angle of 72 degree

Table 5: Performance point for various inclination angle

SN	angle	pushover	DBE(sd)	MCE(sd)
1	90	Pushover X	114.13	228.26
	90	Pushover Y	115.44	230.88
2	84	Pushover X	113.128	226.256
	84	Pushover Y	114.581	229.162
3	78	Pushover X	112.206	224.412
	78	Pushover Y	113.806	227.612
4	72	Pushover X	112.105	224.21
	72	Pushover Y	113.256	226.512

The performance point is obtained for both longitudinal and transverse direction. The displacement (Sd) decrease for decrease in inclination angle of box girder (Sd).The maximum performance point is obtained for inclination angle of 90 degree in both transverse and longitudinal direction for both design based earthquake and maximum credible earthquake.

4.3 Nonlinear Time History Analysis

It is non linear dynamic analysis in which step-by-step analysis is performed for obtaining the various dynamic responses of a structure to a specified time history loading that varies with time. The most common method for analysing the dynamic response of structure is the direct numerical integration of dynamic equilibrium equation (Wilson, 2002). Direct numerical integration aims to calculate the value of parameter and its derivatives at discrete intervals of time, Δt. Nowadays, various integration methods are easily available each with specific algorithms. In this research Hilber-Hughes-Taylor-alpha (HHT) method was used for the analysis.

For nonlinear time history analysis, full bridge with spine deck is modelled .The nonlinear time history analysis is performed and the seismic response of bridge due to variation of inclination angle of web of box girder is obtained. The seven selected ground motion histories, matched with IS 1893:2016 is used as seismic input for the nonlinear time history analysis which is in the form of acceleration values. The nonlinear time history analysis is performed for two hazard levels i.e.(DBE) and (MCE). The analysis is carried out for both longitudinal and transverse directions of the bridge. The time history responses such as pier top displacement, deck slab displacement, bending and torsional moment at pier, longitudinal moments at mid span of deck slab, mid span deflection of deck slab and shearing force at bearing are obtained from the analysis.

5. Conclusion and Recommendations

Pushover analysis and time history analysis of a typical bridge considering variation of inclination angle of box girder and seismic effect is carried out. The result of current research provided following major conclusions.

1. The relative yield displacement of pier is almost same for different inclination angle of box girder using Auto PMM hinge. But, the relative yield displacement of pier decreases as the inclination angle decreases. The relative yield displacement is obtained maximum for 90 degree inclination angle for both longitudinal

and transverse direction. Hence box girder having 90 degree inclination angle has more yielding capacity as compared to all other sections.

2. The performance point is obtained for both longitudinal and transverse direction for both (DBE) and (MCE). The displacement (Sd) decrease for decrease in inclination angle of box girder (Sd).The maximum performance point is obtained for inclination angle of 90 degree in both transverse and longitudinal direction for both design based earthquake and maximum credible earthquake.
3. The absolute maximum pier top displacement increases significantly for decrease in inclination angle of web of box girder. The absolute pier top displacement is obtained maximum for the inclination angle of 72 degree whereas it is minimum for the inclination angle of 90 degree.
4. The absolute maximum torsional moment of the bridge increase with decrease in the inclination angle of the box girder.
5. The absolute maximum mid span deflection of deck slab of the bridge decrease with increase in the inclination angle of the box girder

From the above results, it is concluded that the box girder bridge with 90 degree inclination angle is best section as compared to all other sections. The main reason for above conclusion is that the box girder bridge with 90 degree inclination angle has maximum performance point i.e displacement (Sd) than all other box girder with different inclination angle. Also, the absolute torsional moment is least for the bridge with 90 degree inclination angle. In addition to it, the bridge has high first yielding capacity as compared to all other bridges with different inclination angle.

Similarly, the mid span deflection of deck slab and pier top displacement is minimum for the box girder bridge with 90 degree inclination angle. also the box girder bridge with 90 degree inclination angle has higher flexural stiffness than all other bridge with different inclination angle. Hence box girder having 90 degree inclination angle is recommended as best section than other section.

However there are certain limitations in this studies. In this research the parameter considered is only the inclination angle of web of girder maintaining the same cross sectional area. For better result, more parameters can be considered for same cross sectional areas and different cross sectional area. The research could be extended with development of fragility curves for different bridge components and the bridge system. Bridge abutment is idealized in this research. So three dimensional finite element model of the abutment should be modelled and then analyzed for better result.

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