Parametric Study on Curved Bridges Subjected to Seismic Loading

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Abstract - As India is developing, the infrastructure is gaining a lot of importance. This project aims at infrastructure development such as bridges. The curvature in the bridges is usually introduced to eliminate the support irregularities or presence of important structures which cannot be demolished. Due to the curvature in the bridge there will be large centrifugal reactions on the vehicles. Apart from the reaction a large torsional moment will be induced on the supporting girders. The column's location and orientation is also a major design criteria in bridges. When the columns are tilted from the normal angle the column is said to be skewed. Skewed column decreases the stability of structures as seen in the previous literatures. Skewed columns along with some degree of horizontal curvature to the bridges create a lot of instability. In this project bridges subjected to seismic loads and its behavior when the bridge is curved horizontally at deck section and skewed at column or pier section is dealt.

The bridge model considered for the project consisted of 2 spans each of 50m, with abutments at both ends and piers at mid section. 2 columns of 1.5m diameter were considered at mid section. In this project Box girder bridge and I girder bridge are compared with horizontal curvature being (R= inf, 150m, 250m) and column skewness with (0, 15, 25 degrees) variation. The results of the study such as modal results and pushover results were tabulated and compared with other bridge models. The software used for the study is CSI Bridge 2016 v18 subjected to seismic load subjected to code of 1893 2002 and IRC 6 for vehicle loading.

Key Words: Box girder Bridge, I girder Bridge, Radius of Curvature, Column Skewness

1. INTRODUCTION

From past few decades the infrastructure has seen a great boom in the world. To access any inaccessible areas bridges were built. Hence building bridges became mandatory for infrastructure development. During the ancient time natural bridges were created by nature as in tree trunks extended to the inaccessible areas. Then humans started building their artificial bridges to travel to other side of the valley or non transportable point. The bridges built by humans were usually made of wood or bamboo thatch. As the population increased the need for bigger and sturdier bridge was more. This led for innovation in bridge building techniques thus many types of bridges were formed.

There are many classifications of bridges. The bridge which is under study is girder bridges subjected to some radius of curvature that is also known as curved bridge. The curvature in the bridges is usually introduced to eliminate the support irregularities or presence of important structures which cannot be demolished. Due to the curvature in the bridge there will be large centrifugal reactions on the vehicles. Apart from the reaction a large torsional moment will be induced on the supporting girders. Box girders greatly reduce the torsional moment giving greater stability to the structure. The columns location and orientation is also a major design category in bridges. When the columns are tilted from the normal angle the column is said to be skewed. Skewed column decreases the stability of structures as seen in the previous literatures. Skewed columns along with some degree of horizontal curvature to the bridges create a lot of instability. The design of such bridges is always governed by code books and designed very carefully. The study deals with bridges subjected to seismic loads and its behavior when the bridge is curved horizontally at deck section and skewed at column or pier section.

The bridge will be subjected to many kinds of loads such as earthquake, wind and vibration loads created by the live load on the bridge.

1.1 Seismic loads

Seismic loads create a large impact on the structure. Ground motions are typically measured and quantified in three primary directional components. Two of these components are orthogonal and in the horizontal plane, while the third component is in the vertical direction. The vertical component of ground motion is known to attenuate faster than its horizontal counterparts. Therefore, the impact of vertical ground motion on a bridge structure is typically minimal for bridges located at distances approaching 100 km from active fault. For structures in moderate-to-high seismic regions and close proximity to active faults (<25 km), the vertical component of ground motion is much more prominent, and may be damaging in parallel with horizontal components.

1.2 Vehicle loads

For live load purposes vehicular load is taken as the live load on the bridge. The load of vehicles is taken according to the IRC 6. There are 3 types of standards types

- IRC class AA
- IRC class A
- IRC class B

Class AA – This type of class is a tacked vehicle with 70 tonne weight or a wheeled vehicle with 40 tonne weight as shown in the figure.

Class A – wheel load train composed of a driving vehicle and two trailers of specified axle spacing's.

Class B is loading of temporary structure and for bridge in some special cases.

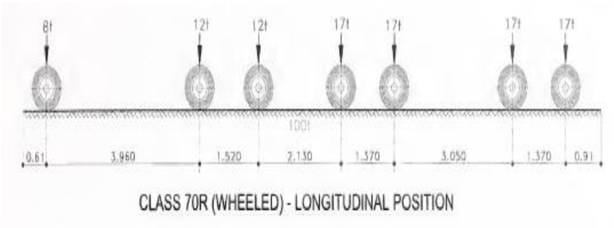

Figure 1 - Class 70 R wheel load

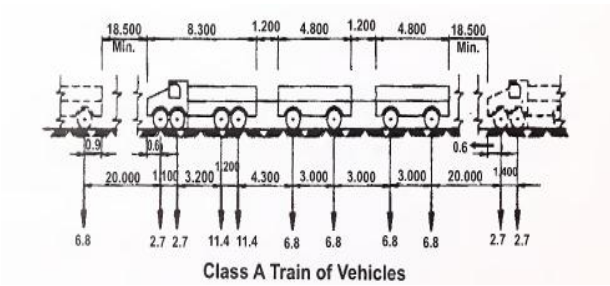

Figure 2 - Class A wheel load

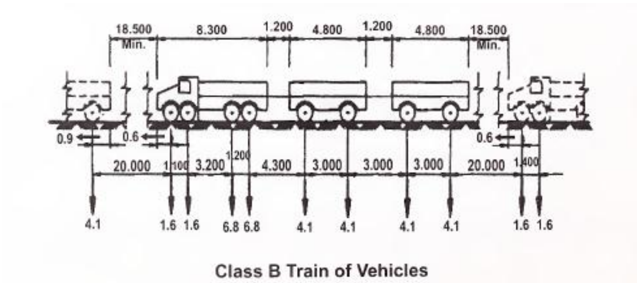

Figure 3 - Class B wheel load

2. OBJECTIVE OF THE PROJECT

- To study the behavior of Box girder bridge subjected to various parameters such as radius of curvature (inf, 250m, 150m) and skewness of column (0, 15, 30) when it is subjected to seismic loading.
- To study the behavior of I girder bridge subjected to various parameters such as radius of curvature (inf, 250m, 150m) and skewness of column (0, 15, 30) when it is subjected to seismic loading.
- Comparison between both the bridge I girder Bridge and Box girder bridge.

3. METHODOLOGY

3.1 General

This chapter emphasizes on the method used to study the behavior of curved bridges. The details of software used and the steps followed for analysis is dealt in this chapter.

3.2 Methodology adopted

- The models of the bridge are created in the software for analysis. Loads are applied to structure including self weight, vehicle load and seismic load.
- Linear static analysis is carried out on the structure and results are noted.
- Then the parameters of study are changed and model is prepared again.
- Analysis is done and results are tabulated.
- The process is repeated for all the models.
- Comparison of the results is done and safe combination is determined.

3.3 Description of model

The software used for modeling and analysis is CSI BRIDGE. The components of bridge are

- Foundation
- Abutments
- Columns
- Column cap
- Bearings
- Support structure
- Deck
- Spans
- Lanes

Inputs given in the software for the components are

1. Foundation – The foundation will be considered as spread footing fixed. No changes will be made in this part of the bridge.
2. Abutments – Abutments are constructed near the solid surface or a rough definition would be corner columns. The dimensions given are 1.2m in width and 2.5 in depth.
3. Columns – Columns will be made up of concrete M30 grade. Will be circular in shape. Fe 500 steel will be used for reinforcement. The diameter of the columns considered is 1.5m.
4. Column Cap – A beam which connects the columns and supports bridge support structure is column cap. The width cap is equal to the diameter of columns which is 1.5m and depth of 1.5m equal to bridge support girder.

5. Bearing- All the translational degree of freedom are fixed and not allowed to move where as the rotational degree of freedom is kept free.
6. Support structure – 2 types of bridge support girders will be analyzed. First with multi frame box girder and second with I girder. The depth of each will be kept constant equal to 1.5m. width is box girder will be equal to that of deck.
7. Deck – Deck will be made up of concrete M30 and a depth of 300mm.
8. Spans – 2 spans of 50m each will be analyzed for vehicle and seismic loads.
9. Lanes – 2 lanes each of 3.75m with an offset of 1m in between will be modeled.

3.3 Parameters under study

The following parameters will be varied

1. Column skewness – The skew angle is the angle with which a column is rotated to accommodate the bridge. The skew angle will be varied in 0, 15, 30 degrees and analyzed accordingly.
2. Span curvature – The span will be analyzed for straight bridge(R=inf) and 2 curved bridges (R=150m and 250m)
3. Support structure – 2 types of supports will be considered
    1. Concrete Box girder
    2. I girder

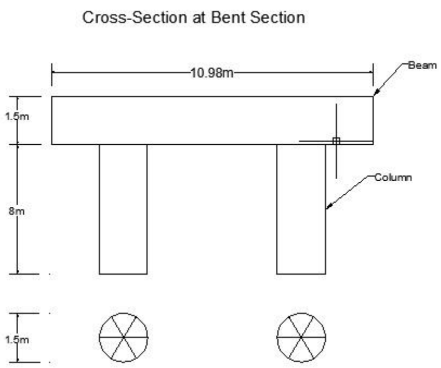

Figure 4 - Cross section of Bent Section

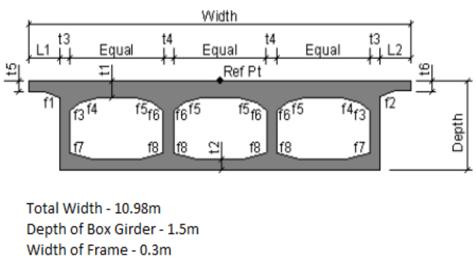

Figure 5 – Cross-section of Box girder

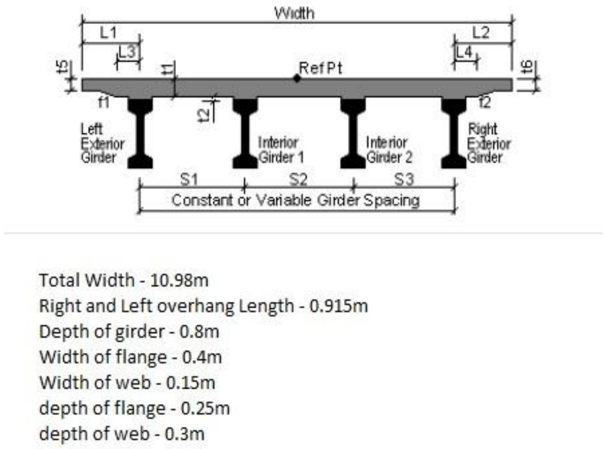

Figure 6 – Cross-section of I girder

3.4 Loading pattern

1. Vehicle load – Load is applied according to IRC A, IRC AA and IRC 70 R wheel load.
2. Seismic load – The region under consideration is Mangalore with Seismic zone factor z = 0.16 and soil zone III with following periods and acceleration.

Table -1: Loading pattern of response spectrum for the above soil and zone

Period	Acceleration
0	0.16
0.1	0.4
0.67	0.4
0.8	0.334
1	0.2672
1.2	0.2227
1.4	0.1909
1.6	0.167
1.8	0.1484
2	0.1336
2.5	0.1069
3	0.0891
3.5	0.0763
4 – 10	0.0668

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4. RESULTS AND DISCUSSION

The models were analyzed separately and results were noted. The results were compared.

4.1 Analysis of straight bridge

Inputs given

1. R= infinity, 150m, 250m
2. Span length between supports = 50m
3. Column skewness = 0, 15, 30

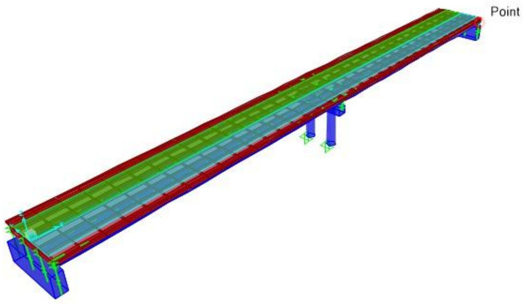

Figure 7 - 3D View of Straight Bridge

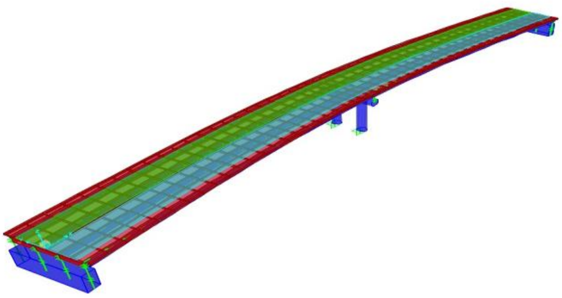

Figure 8 - 3D view of Curved Bridge (250m)

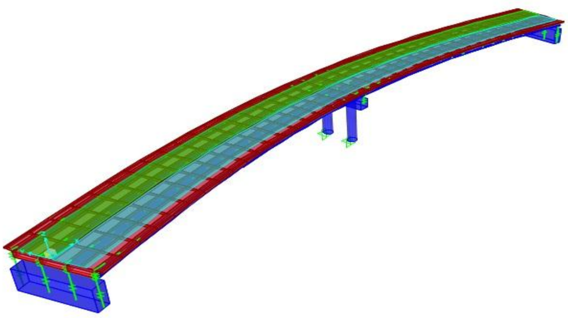

Figure 9 - 3D view of Curved Bridge (150m)

4.2 Modal Analysis results were tabulated and compared with other models.

The bridge was modeled for Box girder and I girder with varying radius of curvature(inf, 250m, 150m) and column skewness (0, 15, 30) and subjected to seismic load. The modal period for first transversal and longitudinal vibrations were tabulated and compared.

Table -2: Period of first transversal vibration mode in seconds for skew angle and radius of curvature

Angle of Skew	Box Girder Bridge			I Girder Bridge		
	Inf	250	150	Inf	250	150
0	0.8271	0.82817	0.75152	1.22245	1.19279	1.19171
15	0.82817	0.81099	0.73417	1.21593	1.18736	1.18599
30	0.83715	0.73799	0.71744	1.19188	1.16818	1.6681

Table -3: Period of first longitudinal vibration mode in seconds for skew angle and radius of curvature

Angle of Skew	Box Girder Bridge			I Girder Bridge		
	Inf	250	150	Inf	250	150
0	0.51653	0.52496	0.53697	0.83891	0.83069	0.84938
15	0.51651	0.50960	0.53237	0.83767	0.82830	0.84964
30	0.50432	0.50773	0.50155	0.8280	0.81952	0.83617

4.3 Pushover analysis (Non linear analysis)

Response spectrum analysis was carried out according IS 1893 2002 with the seismic zone and soil type as mentioned in methodology. As bridge structures are subjected horizontal reactions a non linear pushover analysis will be conducted on the bridge models. The below results show the pushover analysis of the straight bridge, curved bridge (150m and 250m) subjected to skewness with different supporting girders.

4.3.1 Results of box girder bridge

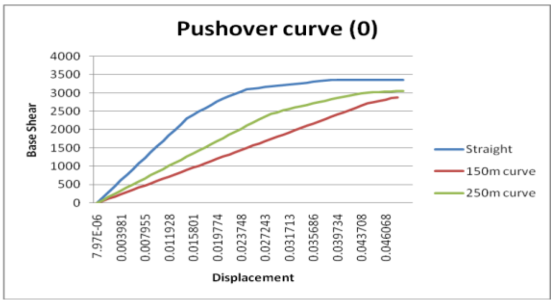

Chart 1 - pushover graph for 0 degree skew.

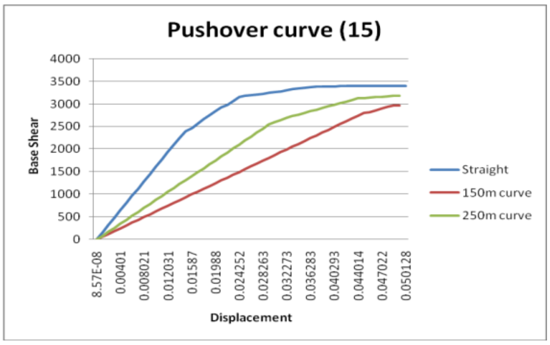

Chart 2 - pushover graph for 15 degree skew.

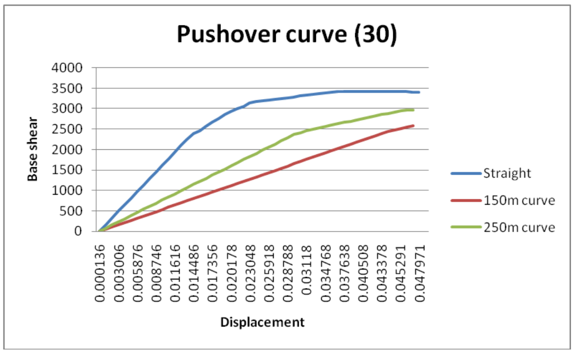

Chart 3 - pushover graph for 30 degree skew.

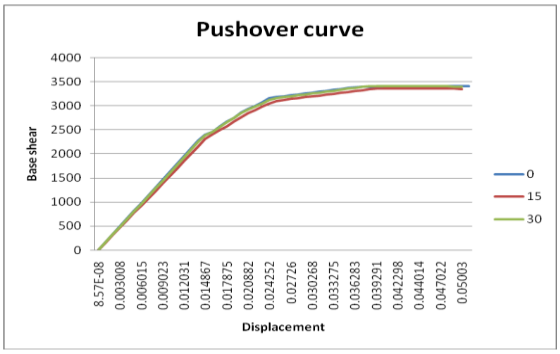

Chart 4 - pushover graph for straight bridge with varying skew.

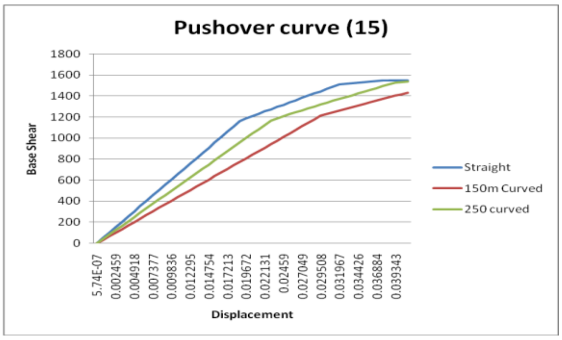

Chart 6 - pushover graph for 15 degree skew.

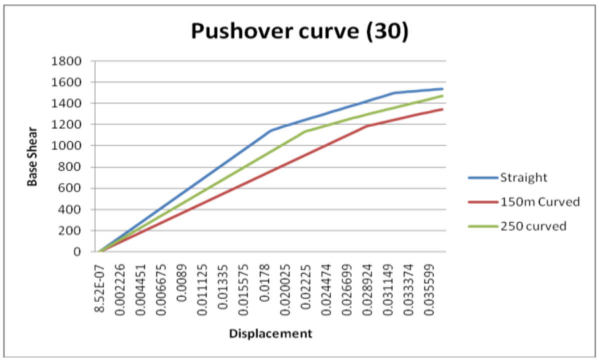

Chart 7- pushover graph for 30 degree skew.

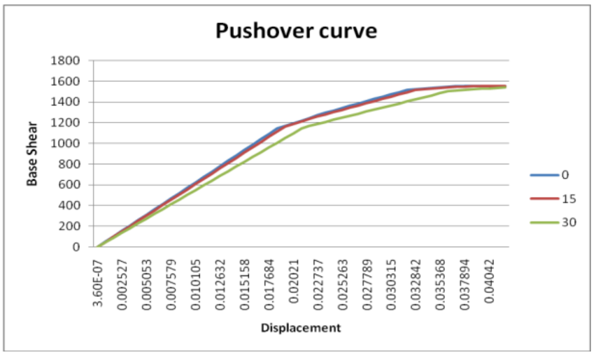

Chart 8 - pushover graph for straight bridge with varying skew.

4.3.2 Results of I girder bridge

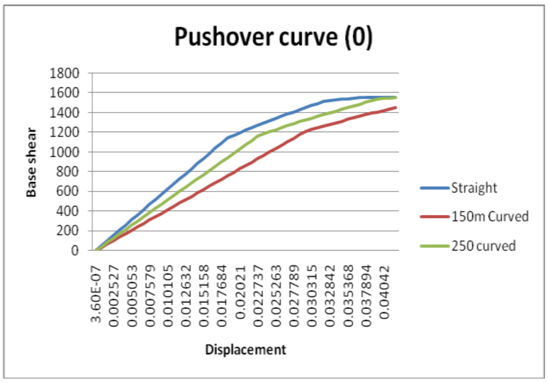

Chart 5 - pushover graph for 0 degree skew.

4.3.3 Comparison between I girder bridge and box girder bridge

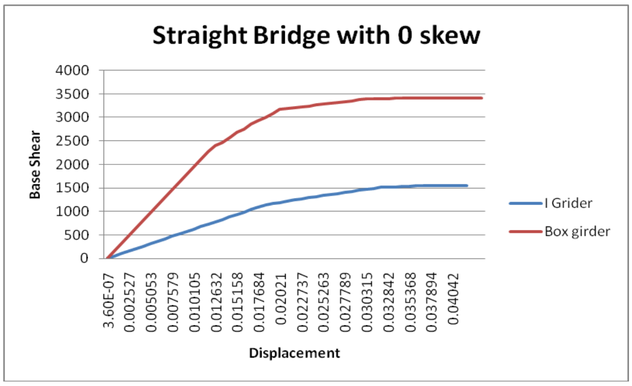

Chart 9 - pushover graph for straight bridge.

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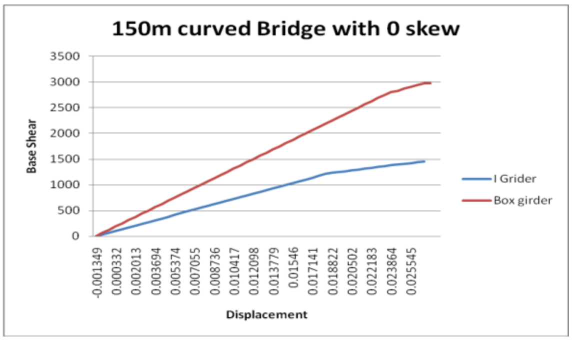

Chart 10 - pushover graph for 150m curved bridge.

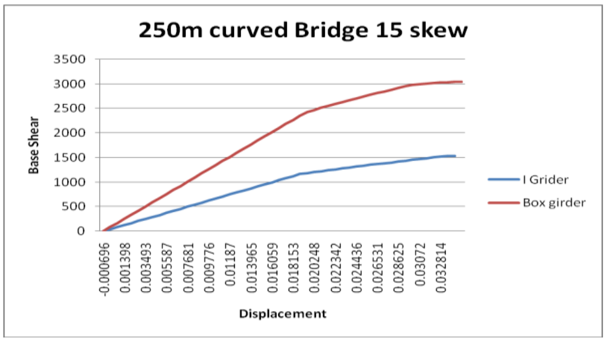

Figure 18 - pushover graph 250m curved bridge.

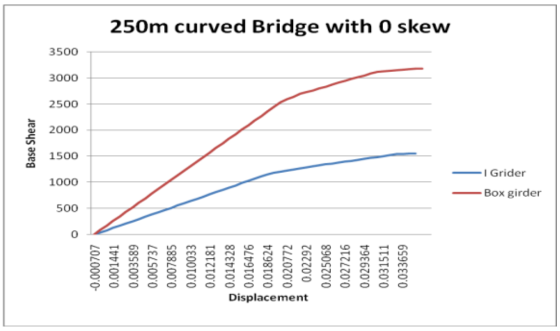

Chart 11 - pushover graph 250m curved bridge.

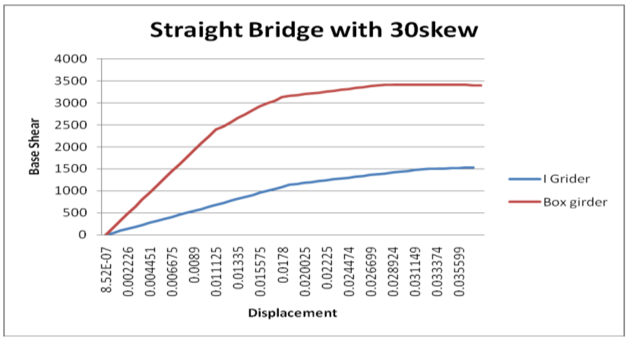

Chart 14 - pushover graph for straight bridge.

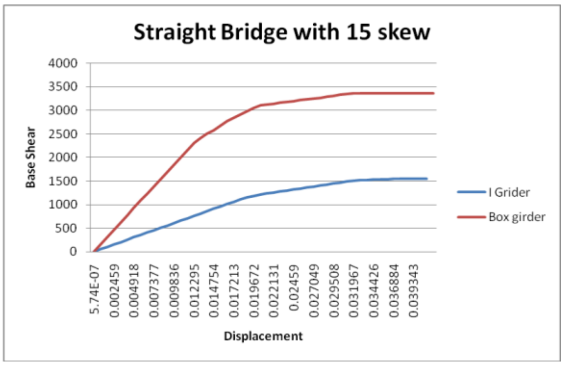

Chart 12 - pushover graph for straight bridge.

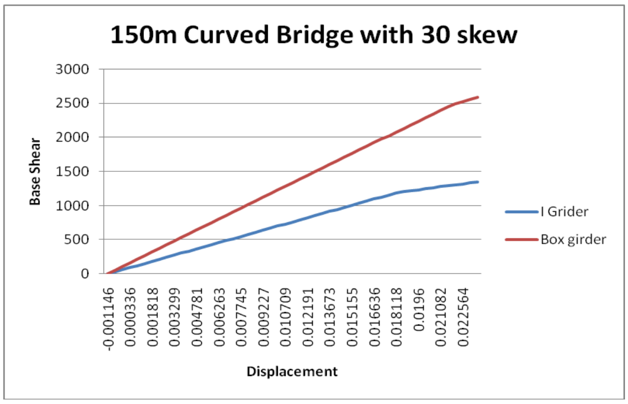

Chart 14 - pushover graph for 150m curved bridge.

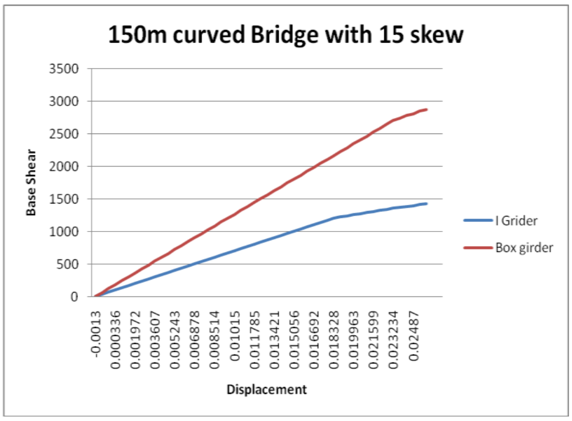

Chart 13 - pushover graph for 150m curved bridge.

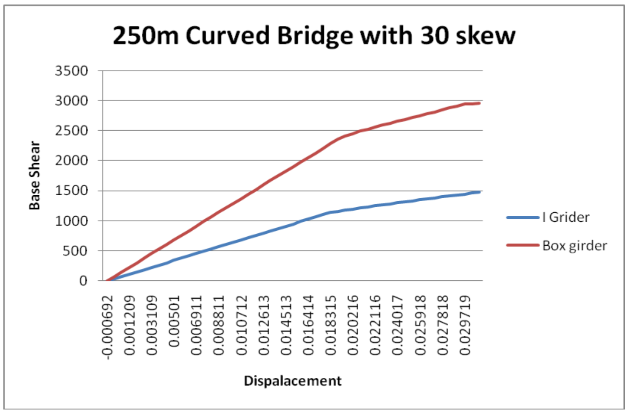

Chart 15- pushover graph 250m curved bridge.

4.4 Discussion of results

1. By the modal analysis results we can see that as the radius increases there is decrease in transversal vibration period. This is due to formation of a couple at column section which opposes the transversal vibration.
2. Compared to Box girder, I girder's vibration in both transversal as well as longitudinal vibrations are greater.
3. As column skewness increases there is increase in transversal vibrations and decrease in longitudinal vibrations.
4. The pushover analysis results show that as radius of curvature increases the base reactions decreases. This indicates for high radius of curvature the bridge is more stable.
5. For box girder and I girder bridge the max base reaction for the straight bridge for degree of skewness.
6. Pushover graphs showed only marginal differences when a straight bridge with different skewness was compared.
7. Box Girder Bridge showed better performance in pushover analysis than I Girder Bridge for all the three types of radius of curvature and for all the different skewness.

5. CONCLUSION

From the results we can conclude that the Box girder bridge is more stable and sustainable compared to I girder bridge when subjected to seismic loading. The effect of radius of curvature is large in reduction of base reaction. This is substantially large thus increasing the risk of the structure. Effect of skewness on the base reaction was very less and showed very little importance. But the combined effect of both radius and skewness is matter of concern. Straight bridge showed better results in pushover analysis hence proving to be more stable than the curved bridge. Hence provision of radius of curvature should be carefully designed when the bridge is subjected to seismic loads.

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