# 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, 30 degrees) variation. 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. The pushover results showed that combined effect of both radius of curvature and skewness of column greatly reduces the base shear reaction ie for Box girder section the base reaction reduced to 1600 for 30 degree skew and 150m radius of curvature.**

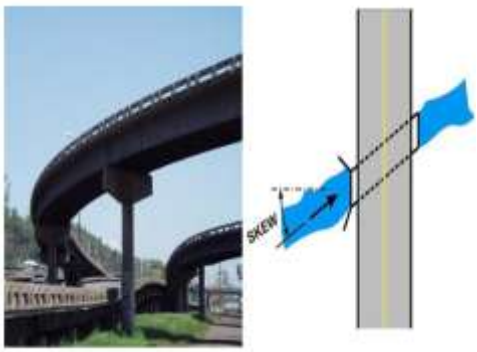
***Keywords*: Box girder Bridge, I girder Bridge, Radius of Curvature, Column Skewness**

## 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 up 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. 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 literature [1]. 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.



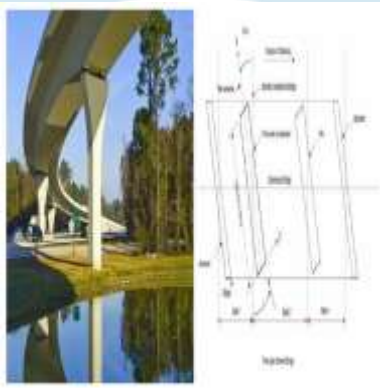



**Figure 1.1 - fig showing curved bridge and skewed columns**

**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**

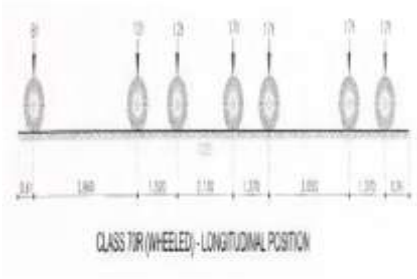
For live load purposes vehicular load is taken as the live load on the bridge. The load of vehicles is taken according to the IRC 6. There are 3 type of standards types

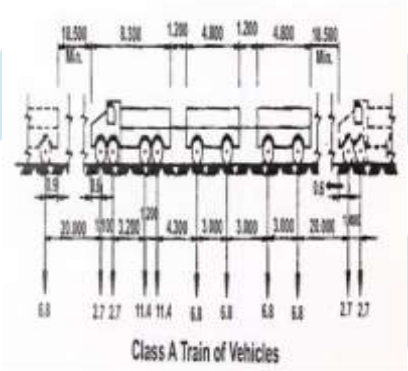
- IRC class AA
- IRC class A
- IRC class B

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.



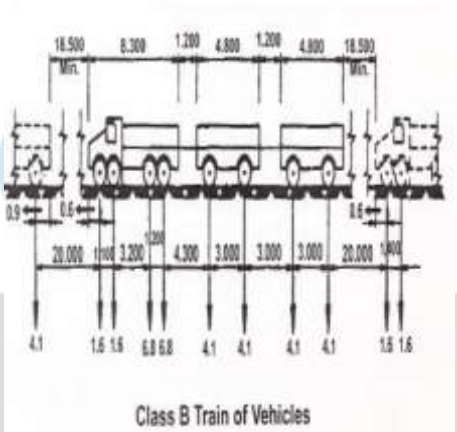




**Figure 1.2 Vehicle load classes**

### 1.3Software used

The software used for the project is CSI bridge. It's a tool for designing bridges proposedby Computers and structures Inc. Through this software we can easily define complexbridge geometries, boundary conditions and load cases. The bridge models are definedparametrically, using terms that are familiar to bridge engineers such as layout lines, spans, bearings, abutments, bents, and hinges and post-tensioning. The software creates spine, shell or solid object models that update automatically as the bridge definition parameters are changed.

### 1.4 Pushover analysis

Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. The lateral forces are increased until some members yield. The structural model is modified to account for the reduced stiffness of yielded members and lateral forces are again increased until additional members yield. The process is continued until a control displacement at the top of building reaches a certain level of deformation or structure becomes unstable.

### 1.5 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 of seismic performance between both the bridge I girder Bridge and Box girder bridge.

## 2OVERVIEW OF LITERATURE

### 2.1 Literature review

Nina Serder, Randomic Folic [1] studied on "Comparative analysis of modal responses for reinforced concrete (RC) straight and curved bridges". This study was conducted on Montenegro territory for mid range spans for curved and straight bridges. Three models were with radius of curvature (R) 0, 150, 250 were considered and piers were bent up with a skew angle 0, 20, 30. Modal analysis and static nonlinear analysis was carried out on all the 9 bridge prototypes. Results were tabulated and were compared. It was found that the decrease in radii of curvature results in reduced vibrations of structure. Increase in column skewness leads to increase in period of transverse direction and decrease in period of longitudinal direction for both bridges. The transition from straight to curved resulted in decrease in capacity of displacement by 35%.

Thomas Wilson, [2] worked on "Seismic performance of skewed and curved reinforced concrete bridges in mountainous states". The damages observed in Chile in 2010 were maximum in case of bridges. Hence the author tested the bridge geometrical properties in mountainous west region with skew and curvature installed bridges. 8 bridge models were modeled with a box girder as support. Nonlinear time-history analysis was carried out on each bridge configuration using detailed finite element (FE) models. The results obtained were tabulated and compared with other bridge combination. Skewed columns induced a planar rotation thus resulting in transverse moment and longitudinal shear. Even the curvature installed a larger moment at the principal axis and hence lowering the capacity of structure.

Shervin Maleki [6] studied on "Deck modeling for seismic analysis of skewed slab-girder bridges". In this journal the author assumed the deck to be rigid concrete deck on top the girders. This rigidity simplified the analysis by replacing the whole deck by just bars and analyzed the bridge. The columns were skewed from angle 0 to 60 and the span was kept 30m. Seismic analysis was done as per AASTHO code. Linear finite element response spectrum analysis was done and the results obtained were studied. The results showed that rigid deck slabs showed better resistance to earthquake compared to flexible decks.

Jong-Su Jeon et.al [3] did research on "Geometric parameters affecting seismic fragilities of curved multi-frame concrete box-girder bridges with integral abutments". In this the author studied the variation of the behavior of the box girder bridge when certain geometric parameters such as horizontal radius of curvature column skewness and height of column when the bridge is subjected to earthquake loading. The author has considered the California region for the study. In this three dimensional inelastic models were created with integral abutments. The box girders were two frame and 3 frame types. 5 piers with different height were examined and tested whether height influences the results of seismic resistance. The results indicated that increase in the horizontal curvature decreased the fragility curves. Abutment skewness showed little impact on the fragility of structure whereas the column height and fragility of column were inversely proportional hence increasing the structures vulnerability.

Ronald R. Wakefield et.al [4] conducted research on "ANALYSIS OF SEISMIC FAILURE IN SKEW RC BRIDGE". In this author conducted a case study on S. E. Bridge, Foothill Boulevard Undercrossing, in the San Fernando Valley, Calif which suffered huge damage in 1971 earthquake. A model with skewed box girder was created and analyzed in linear and non linear matter. The time history analysis done on the bridge yielded sufficient results. The results showed that the columns behave as rigid bodies when the deck is not rigidly fixed to the columns. The rigid bodies undergo translational as well as rotation hence the case study and the failure modes of the structure were same.

## 3METHODOLOGY

### 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

#### 3.2.1 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.
- Modal Analysis and pushover analysis are done and results were tabulated.
- The process is repeated for all the models.
- Comparison of seismic performance results is done and safe combination is determined.

**3.2.2 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 1.5m in width and 3m 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. Width of 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

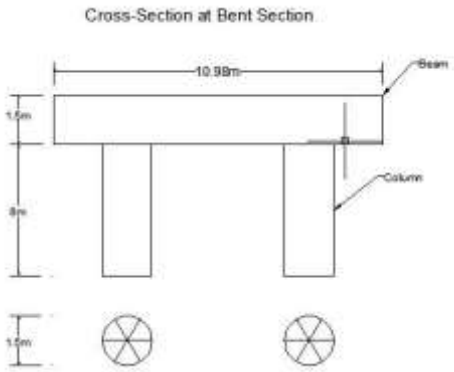



**Figure 3.1 - Cross-section at Bent section**

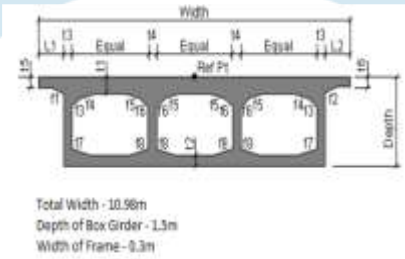



**Figure 2.2 – Cross-section of Box girder**

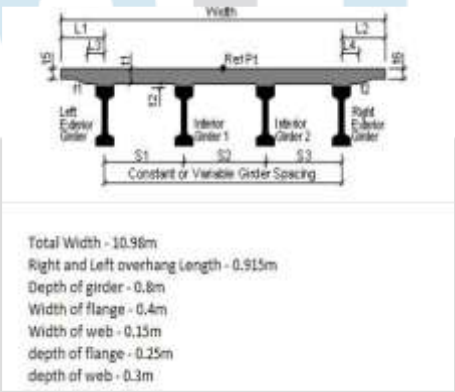



**Figure 3.3 – Cross-section of I girder**

### 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 3.1 – 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 |

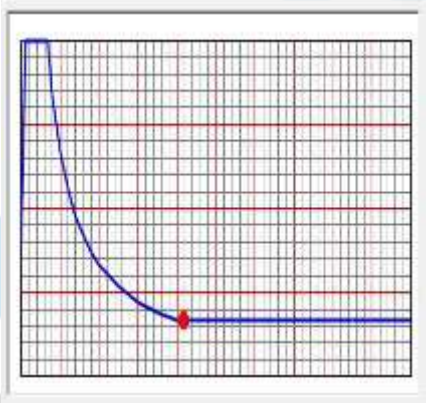


**Figure 3.4- Graph of seismic function**

## 4 RESULTS AND DISCUSSION

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

### 4.1 Analysis of bridge

Inputs given

1. R= infinity, 150m, 250m

2. Span length between supports = 50m

3. Column skewness = 0, 15, 30

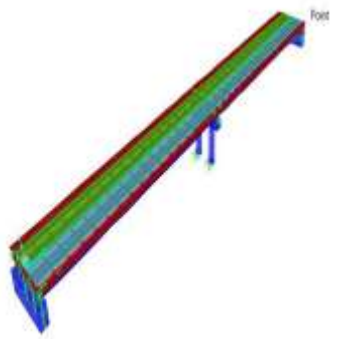


Figure 4.1 - 3D view of Straight Bridge

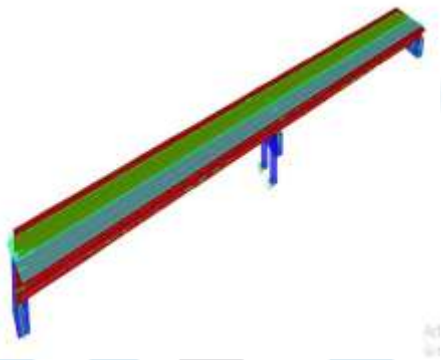


**Figure 4.2 - 3D view of Straight Bridge with 15 degree skew**

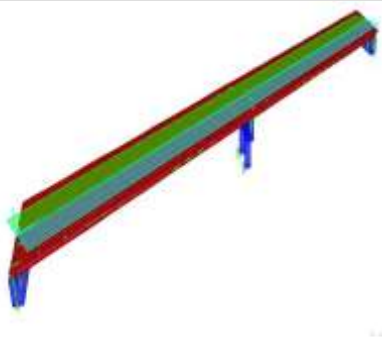


**Figure 4.3 - 3D view of Straight Bridge with 30 degree skew**

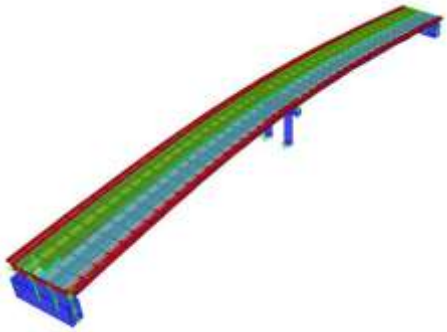


**Figure 4.4 - 3D view of Curved Bridge (250m)**

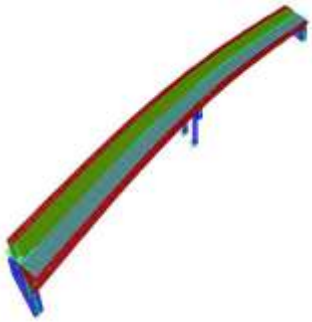


**Figure 4.5 - 3D view of Curved Bridge (250m) with 15 degree skew**

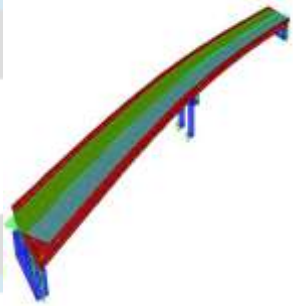


**Figure 4.6 - 3D view of Curved Bridge (250m) with 30 degree skew**

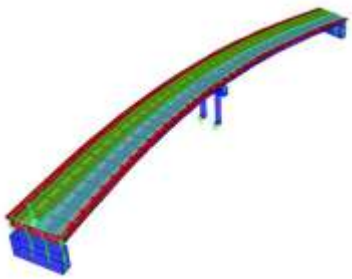


**Figure 4.7 - 3D view of Curved Bridge (150m)**

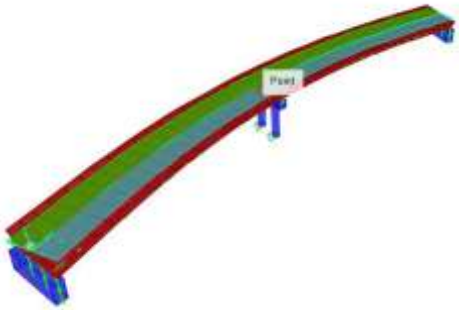


**Figure 4.8 - 3D view of Curved Bridge (150m) with 15 degree skew**

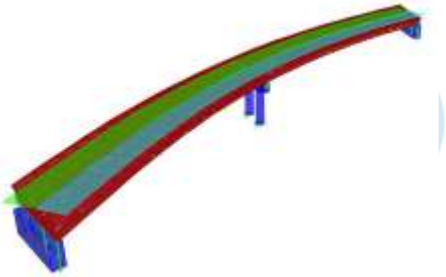


**Figure 4.9 - 3D Curved Bridge (150m) with 30 degree skew**

4.2 Modal Analysis results were tabulated and compared

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 4.1 - Period of first transversal vibration mode in seconds for skew angle and radius of curvature

| Angle of Skew | Box Girder Bridge | | | I Girder Bridge | | |
|---|---|---|---|---|---|---|
| | Straight | 250 Curved | 150 Curved | Straight | 250 Curved | 150 Curved |
| 0 | 0.8271 | 0.82817 | 0.83715 | 1.22245 | 1.19279 | 1.19171 |
| 15 | 0.8149 | 0.73799 | 0.81099 | 1.21593 | 1.18736 | 1.18599 |
| 30 | 0.75152 | 0.73417 | 0.71744 | 1.19188 | 1.16818 | 1.6681 |

Table 4.2 - Period of first longitudinal vibration mode in seconds for skew angle and radius of curvature

| Angle of Skew | Box Girder Bridge | | | I Girder Bridge | | |
|---|---|---|---|---|---|---|
| | Straight | 250 Curved | 150 Curved | Straight | 250 Curved | 150 Curved |
| 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 (Nonlinear 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.

**THE RESULTS OF BOX GIRDER BRIDGE**

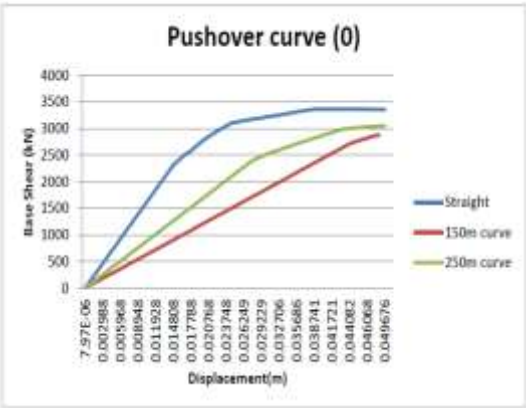



**Figure 4.10 - pushover graph for 0 degree skew.**

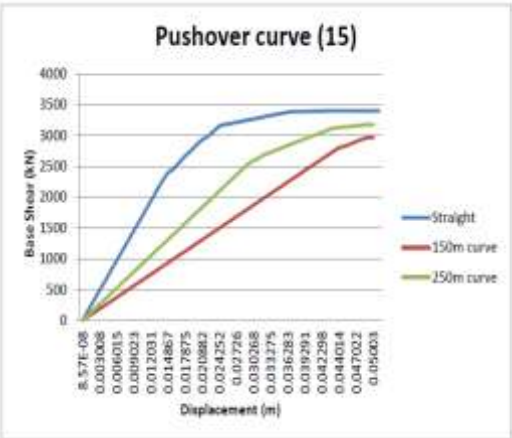



**Figure 4.11 - pushover graph for 15 degree skew.**

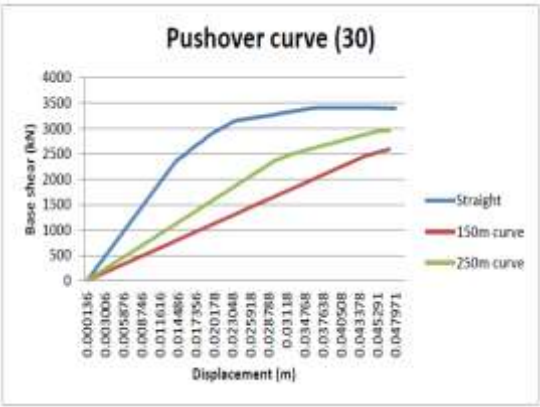



**Figure 4.12 - pushover graph for 30 degree skew.**

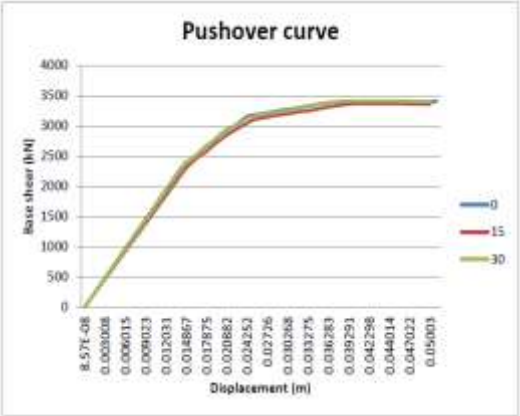



**Figure 4.13 - pushover graph for straight bridge with varying skew.**

**THE RESULTS OF I GIRDER BRIDGE**

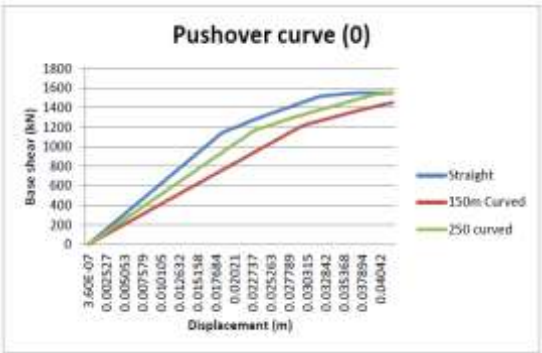



**Figure 4.14 - pushover graph for 0 degree skew.**

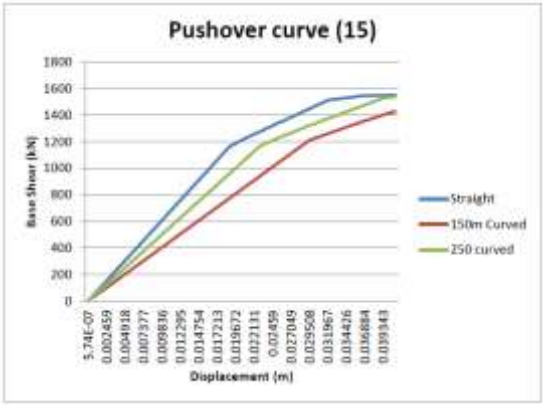



**Figure 4.15 - pushover graph for 15 degree skew.**

THE RESULTS COMPARISON BETWEEN I GIRDER BRIDGE AND BOX GIRDER BRIDGE

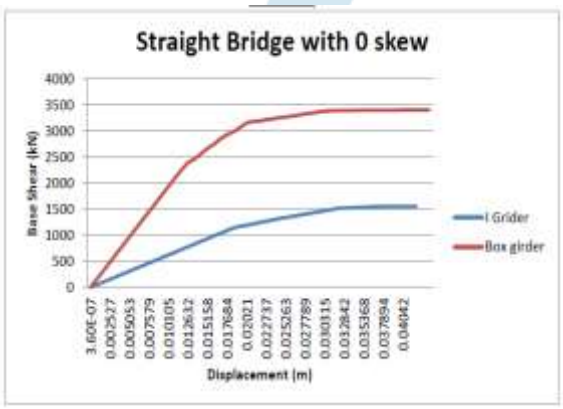



**Figure 4.18 - pushover graph for straight bridge.**


**Figure 4.19 - pushover graph for 150m curved bridge.**

**4.4 Discussion of results**

1. By the modal analysis results we can see that as the radius increases there is increase in transversal vibration period.

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 decrease in transversal vibrations and decrease in longitudinal vibrations. This is due to formation of a couple at column section which opposes the transversal vibration.

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 stable and sustainable compared to I girder bridge when subjected to seismic loading. From pushover results it can be concluded that as radius increase there is substantial decrease in base reaction. This reduction in base reaction thus increases the risk of damage or collapse to the structure. Effect of skewness on the base reaction was very less as seen above. But the combined effect of both radius and skewness is matter of concern since there is reduction in base shear reaction. 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.

### 5.1 Future scope of study

- In the present study bare Pushover analysis is performed. However time history analysis can be studied in the next phase of the work.
- Only geometric non linearity is considered in the present study. However material nonlinearity also plays an important role, hence material non linearity with dynamic analysis can be performed.
- Structures used in the study have same height of columns. In the next phase an variations in abutments and column height can be used for the study.

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