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Investigation of Skew Curved Bridges in Combination with Skewed Abutments under Seismic Response

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ABSTRACT

The present study investigates the seismic response of skew-curved concrete box-girder bridges under free vibrations and forced vibrations. A bridge having in-plan curvature in combination with the skewed abutments is termed as skew-curved bridge. 3-D models of the bridge with varying configurations are generated in the CSiBridge. The curvature angle for the parametric study has been varied as 0°, 30°, 60° and 90° in combination with skew angles of 0°, 15°, 30°, 45° and 60°. Modal analysis and response spectrum analysis for all the bridge models has been performed. Modal response of the various bridge configurations has been presented in graphical form in order to have knowledge of the mode shapes, time periods and fundamental frequencies of the bridges. Furthermore, mode participation factor for three orthogonal directions also have been determined for every configuration of the bridge considered. After performing response spectrum analysis, variation of out-of-plane bending moment, in-plane bending moment, and longitudinal torsion along with the span length under horizontal (i.e. longitudinal and transverse) and vertical component of seismic excitations has been also presented using graphical representation. Results indicate that increase in skew angle leads to decrease the time period ratios in first vertical mode of vibration.

KEYWORDS: *Skew-curved bridges, Modal Analysis, Seismic Analysis, Skew Angle, and Curvature Angle*

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INTRODUCTION

Bridge is a structure which facilitate a passage over an obstacle without closing the way under it. The obstacles can be a river; valley, railway, roads etc. and the required passage may be for different purposes such as railway, pedestrians and roads. As evident by many past earthquakes, bridges suffer a serious damage when strong earthquake occurs. Several types of seismic failures such as pier failure, expansion joint failure, deck unseating failure, etc. have been observed due to severe earthquakes, such as San Fernando Earthquake in 1971, Costa Rica Earthquake in 1991, Northridge Earthquake 1994, Kobe Earthquake in1995, and Chi-Chi Earthquake in 1999. Skewed and horizontally curved bridges suffered more damages because of the superstructure's rotation or due to shift towards outside of the curve line.

a) Hospital Overpass Bridge Collapse b) Collapse of Miraflores Overpass

Figure 1.1 Failure of bridges under seismic excitations [4]

In 2010 Maule, Chile, earthquake, two-span Hospital Overpass Bridge with skew angle of 45°, located at Highway No. 5 suffered damages [4] as shown in figure 1.1(a). Thesedamages occurred due to rotation of deck which occurred because of skewness. A1 & A2 are two abutments, P1 is the centre pier, D1 & D2 are two simple spans.

In figure 1.1 (b), the damage of Miraflores Overpass is shown. The acute corner of the outer ring has been noticed to shift nearly 1.5m towards skewed transverse direction during the earthquake. Due to this transverse movement, unseating occurred at abutments of Miraflores Overpass which was three skewed overpass bridge in Santiago.

Skew bridges, curved bridges and skew-curved bridges have complex geometry as compared to straight bridges and hence the load distribution pattern will be different for these type of bridge structures. Therefore, it is of utmost importance to examine the seismic behaviour of such kind of bridges. Modal analysis is the first step in seismic analysis of the structure. Modal analysis makes one aware of structure's response under free vibrations. To examine the structure's response of the structure under forced vibrations, there are several methods.In this study, response spectrum analysis method has been used to examine the seismic response of skew-curved bridges. Response spectrum analysis method gives the peak response of the structure and is used when spectrum of ground motion is available.

In this dissertation, the behaviour of skew-curved bridges under free and forced vibrationhas been investigated in CSi Bridge. Three-dimensional finite element models have been modelled and their modelling has been explained in detail in Chapter 3. Next to modelling, modal analysis and response spectrum analysis has been carried out for skew-curved bridge models. Modal behaviour of skew-curved bridges i.e. behaviour of skew-curved bridges under free vibrations has been deliberated in Chapter 4 in brief. Chapter 5 conveys the results of seismic response of skew curved bridges under different directions of seismic excitaions

Skew Angle and Curvature Angle

Skew angle is the angle between the alignment of the intermediate or end support & normal drawn to the longitudinal axis of bridge-deck. It is represented by "θ" in figure 1.2(a) and(b). Curvature angle is shown in figure 1.2(b) which is represented by "β".

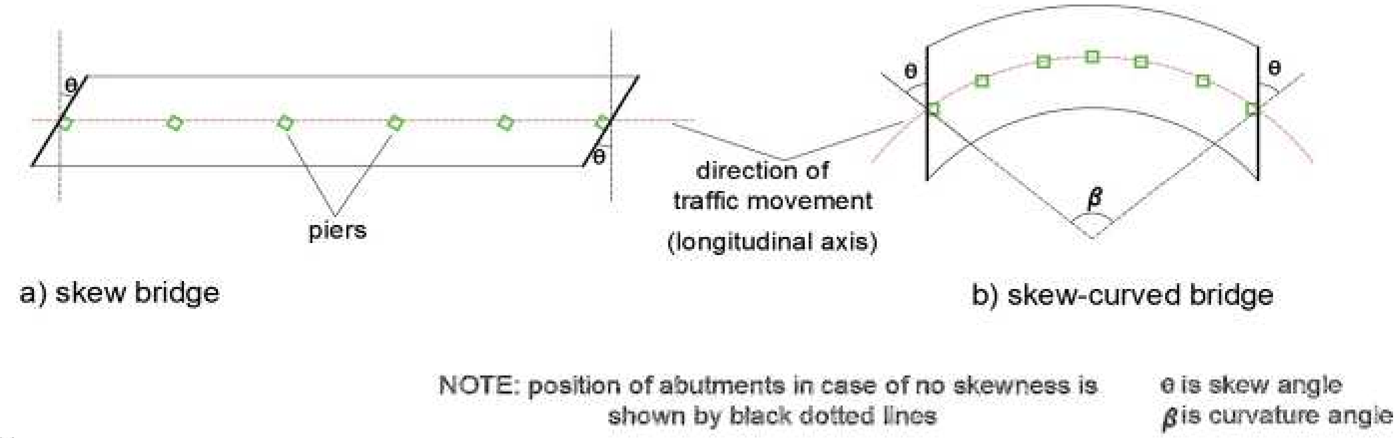

Figure 1.2 Representation of skew angle and curvature angle in different bridge configurations

Skew and Skew-Curved bridges

There are several kinds of bridge-classifications based on various factors. Based on the alignment, bridges are classified as straight and skew bridges. Bridges in which the bridge deck and substructure (piers and/or abutments) alignment are not perpendicular to each other are termed as *skew bridges.* Figure 1.3 shows the geometry of skew bridge having skewangle ‘θ’.

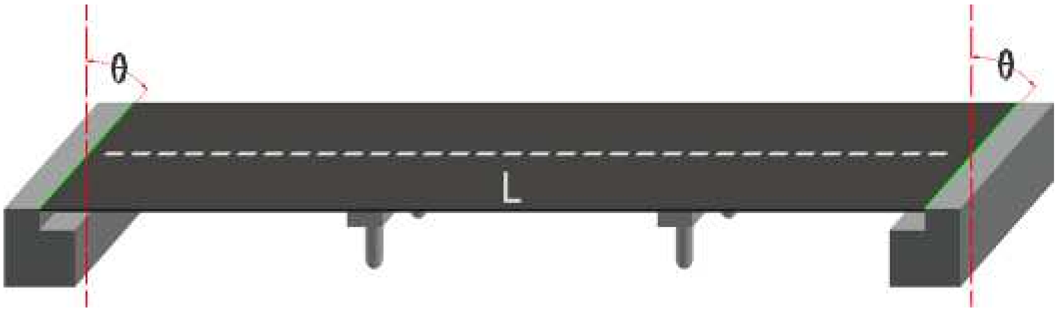

Figure 1.3 Skew Bridge Geometry

In *horizontally curved bridges* i.e. the bridges having in-plan deck curvature; the gravity load itself induces warping normal stresses, torsional shear stresses, and flexural stresses in the structural components of bridges due to its complex geometry. *Skew-curved bridges* are the bridges in which the deck slab have the in-plan curvature in combination with skewed substructure elements.

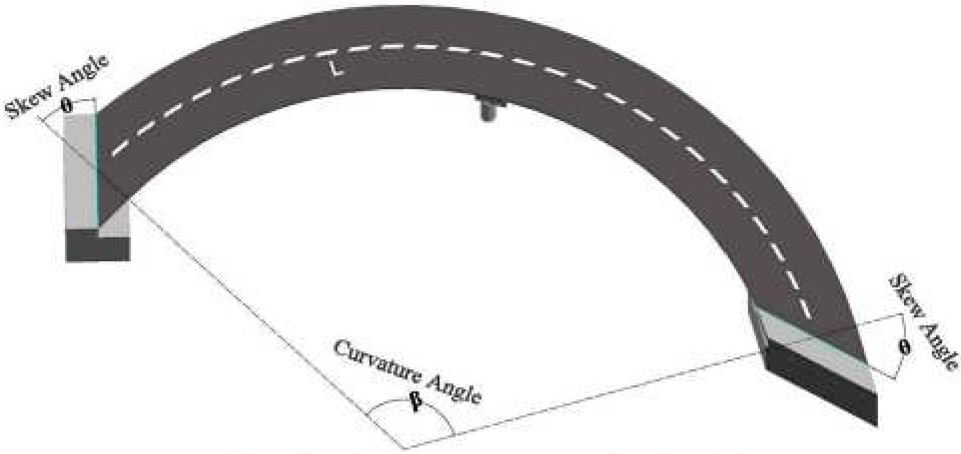

Figure 1.4 Skew-Curved Bridge Geometry

Transportation system of any city heavily rely properly designed skew-curved highway bridges as they provide easy access or exit from complex intersections, which are valuable in dense urban areas & they also have ability to conform to existing layouts. Nowadays, skew-curved bridges are mostly constructed in modern transportation system of many cities.

Problem Statement

This dissertation aims to investigate the investigate the modal and seismic behaviour of skew- curved bridges. When a structure undergoes seismic excitations, during that interval a large amount of horizontal force is applied on the structure in short period. Bridge’s behaviour under the effect of applied seismic force, decides its seismic performance. Under seismic and serviceloads, behaviour of skew and/or curved bridges become more complex due to the influence of its unconventional geometry. Due to the action of seismic waves, the vibrations occur in the bridge system generates internal deformations and stresses which governs seismic response of bridge. Investigation for seismic response of skew-curved bridges has been performed based on parameters such as seismic input and dynamic characteristics of structural system. Finally, the response parameters which affect the seismic behaviour of skew-curved bridges under seismic excitations has been also studied.

Objectives

- To investigate the mode shapes, time periods and natural frequency of the skew- curved bridges under free vibrations using finite element models.
- To examine the contribution of each mode and their mass in affecting the response ofthe skew-curved bridges by studying the modal participation factor and mass participation factor.
- To determine the variations of three principal moments along with the span for skew- curved bridges under longitudinal, transverse and vertical component of seismic excitations usingResponse Spectrum Analysis.

METHODOLOGY

1. Methodology which has been followed to achieve the objectives of this dissertation has been discussed in this section. To perform modal analysis and response spectrum analysis of skew- curved bridges, 3-D finite element models have been modelled using the finite element program CSi Bridge. Modal analysis has been carried out first which is then followed by response spectrum analysis.
2. In modal analysis, the degree to which the mode shapes, time periods and mass participation factors of skew-curved bridges are affected have been investigated using finite element models.

Bent modelling of the bridge models

Intermediate bents of the bridge have been modelled as three-dimensional frame elements as shown in the figure 3.9. Bents consists of two parts i.e. bent cap and the column. Different frame elements have been used to model each part. Non-prismatic frame elements have been used to model the tapered portion of the bent.

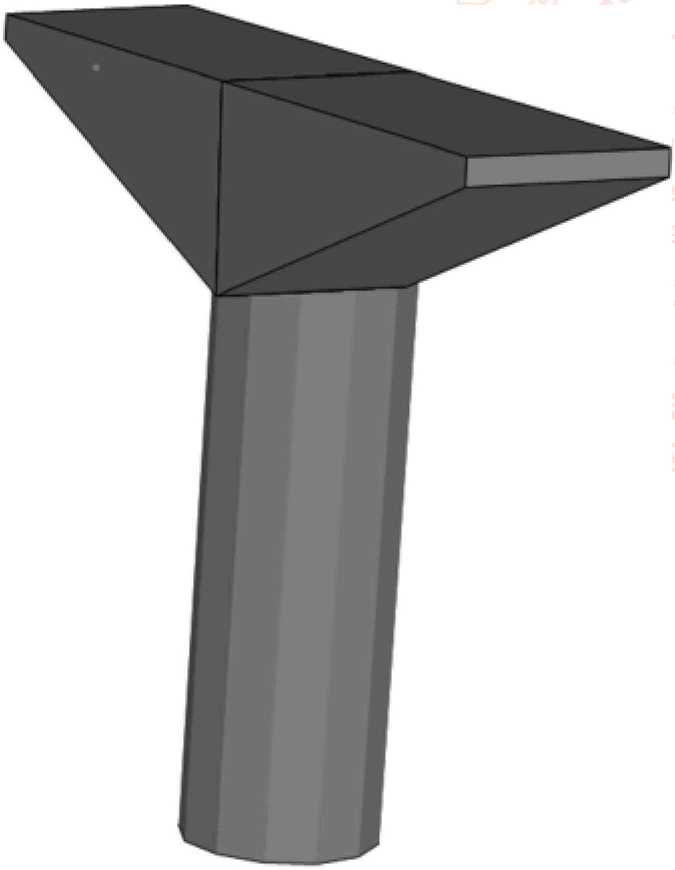

Figure 1.5 Bent of the bridge

Conclusions

In this dissertation, seismic behaviour of skew-curved bridges has been studied under free and forced vibrations. Various skew-curved 3-D bridge models have been modelled in CSi Bridge. Skew angles of 0°, 15°, 30°, 45° and 60° has been taken and curvature angle has been varied as 0°, 30°, 60° and 90°. Modal analysis and Response Spectrum Analysis for the various skew- curved bridge configurations have been carried out using finite element analysis program CSiBridge. To facilitate the study of results for both modal and response spectrum analysis of skew-curved bridges, the changes have been made in the benchmark bridge which was a horizontally curved concrete box-girder bridge

1. Increase in curvature of the bridge deck leads to decrease the time period ratios of first horizontal (in-plane) vibration mode of the structure whereas increase in skew angle, increases the time period ratios.
2. For first longitudinal vibration mode, the time period ratios usually increase with increase in both skewness and curvature which signifies the decrease in natural frequency of the bridge structures. Therefore, stiffness of the structure should be increased to increase the natural frequency of the structure.
3. Modal analysis indicates time period ratios of horizontal vibration modes precedes the time period ratios of vertical vibration modes irrespective of skewness and curvature of the bridge.
4. Increase in skew angle causes the time period ratios to decrease usually in first out of plane vibration mode whereas increase in curvature angle causes increase in time period ratios of first out of plane vibration mode.

Mode participation factor of first in-plane vibration mode commonly increases withincrease in skewness and curvature which signifies that this mode will contribute more significantly affect the dynamic behaviour of the structure as compared to the case of straight bridge configuration.

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