

Modeling and analysis of a three spanned concrete Deck girder bridge under seismic loading

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ABSTRACT

This research paper presents the results of a research work aimed at the analysis of a three-span concrete deck girder bridge under seismic loading. A finite element model to analyze the deck girder bridge has been developed by using finite element software ANSYS. This research work has been carried out in two steps. In the first step, a three dimensional model of the bridge has been subjected to equivalent static earthquake loading by following AASHTO code. In the second step, Response Spectrum analysis has been performed. Then the design forces and moments at column bases of the bridge are obtained by using the above two methods. Finally a comparative study of the design values has been performed between those two methods. From the study it has been found that the magnitudes of the axial forces are almost same in two methods but the design moments and shear forces vary significantly. In case of design moment, the result found from response spectrum method (RSM) is about 1.74 times of the design value obtained from equivalent static force method (ESFM). Therefore it can be said that there is a possibility of achieving under design of the bridge if the seismic analysis follows the ESFM. Based on overall findings, it can be suggested that the response spectrum method should be performed for seismic load analysis of the bridge to achieve more reliable and safer design.

Keywords: Bridge dynamics, Deck-girder bridge, Earthquake loading, Finite element model, Response spectrum analysis

1. Introduction

The current philosophy behind earthquake resistant design of common structures such as bridges is to ensure that i) hazards to life be minimized ii) design ground motions have low probability of being exceeded during normal lifetime of bridge iii) function of essential bridges is maintained iv) there are no damages (or only slight but repairable nonstructural damage) due to design earthquakes v) collapse is prevented during more severe earthquakes, which is achieved by ensuring ductile, rather than brittle behavior of the structural response. However, if the frequency of the applied seismic load is close to the natural frequency of vibration of the bridge, the structure will amplify the loading and large potentially destructive forces will be generated within the bridge (Penzien, J. and Watabe, M., 1975). The 1971 San Fernando earthquake was a major turning point in the development of seismic design criteria for bridges. Earthquake resistant bridge design must ensure that the bridge structure withstand the lateral forces generated during an earthquake. However, there is no specified method to determine the design forces accurately for the seismic load. AASHTO suggests an approximate method using some semi-empirical formulas to determine the design seismic

forces. Apart from that, there are also lots of analysis procedures to determine the design seismic forces. In this research study, two analysis cases according to AASHTO code I) Equivalent static force method and II) Response Spectrum analysis have been considered for the seismic load analysis of the bridge.

The behavior of a bridge structure under the influence of seismic load has been a major point of interest for engineers over a long period of time. Although significant advances have been achieved in the design and construction of an earthquake resistant bridge, numerous gaps still remain in the understanding of the seismic behavior of bridges. The major objectives of the research work are as follows:

1. The present study is aimed at the better understanding of the behavior of bridge under seismic loading by modeling a concrete deck girder bridge. The finite element package ANSYS v.10 is to be used for the development of the model.
2. To analyze the longitudinal and transverse earthquake ground motion of the bridge.
3. To determine the design forces and moments at the column bases following the equivalent static force method and response spectrum method.
4. To carry out a comparative study of the design forces and moments found from those two methods.

2. Methodology of the work

The model of the concrete deck girder bridge having three spans and two bays has been shown in figure 1. The bridge has a total span length of 109.728m, column height is 7.62m.

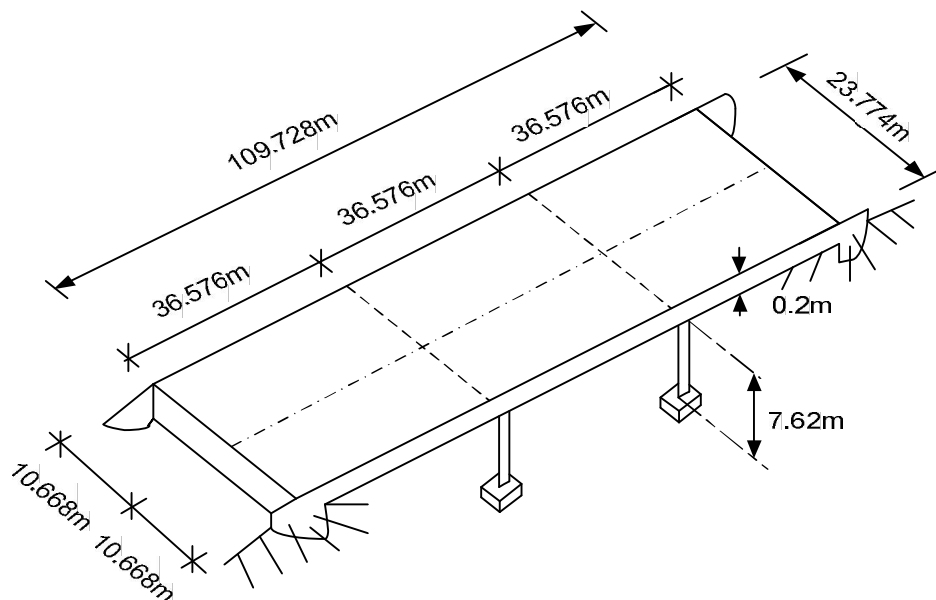


Figure 1: Dimensions of a Three Span Deck Girder Bridge

The material properties and geometric properties used for modeling the bridge are given in table 1 and 2 respectively.

Table 1: Material properties of concrete for the bridge

Properties	Unit	Value
Modulus of elasticity	N/m ²	20 × 10 ⁹
Density	N/m ³	2645
Poisson's ratio	----	0.2
Damping ratio	----	5%

Table 2: Geometries of the deck-girder bridge

Parameters	Unit	Value
Span of bridge		
Total span length	meter	109.728
No. of span	-----	3
Length of each span	meter	36.576
Total width of the bridge	meter	23.774
Bay of bridge		
No. of bay	-----	2
Length of each bay	meter	10.668
Thickness of the slab	meter	0.2
Columns		
Height	meter	7.62
No. of column	-----	6
Girders		
No. of longitudinal girders	-----	9
Width	meter	0.6096
Depth	meter	2.438
No. of cross girders	-----	4

In this research work a linear finite element analysis has been performed using finite element software package ANSYS. The finite element analysis includes modeling of deck, longitudinal and transverse girders, columns of the bridge, application of longitudinal and transverse earthquake loading using AASHTO code (AASHTO, 1995), generation of finite element mesh. In finite element modeling, two noded uniaxial element having six degrees of freedom per node has been used to model girders and columns. The concrete deck of the bridge has been modeled using four noded shell element with six degrees of freedom at each node.

To investigate the bridge under seismic loading, boundary conditions are applied at the bases of the columns and at the two ends of the slab. All six degrees of freedom are restrained at all bases of the columns. Apart from that, only vertical displacement is restrained at the two ends of the slab except the midpoints of the two ends where both vertical and transverse displacements are obstructed. A three dimensional view of the finite element mesh has been shown in figure 2.

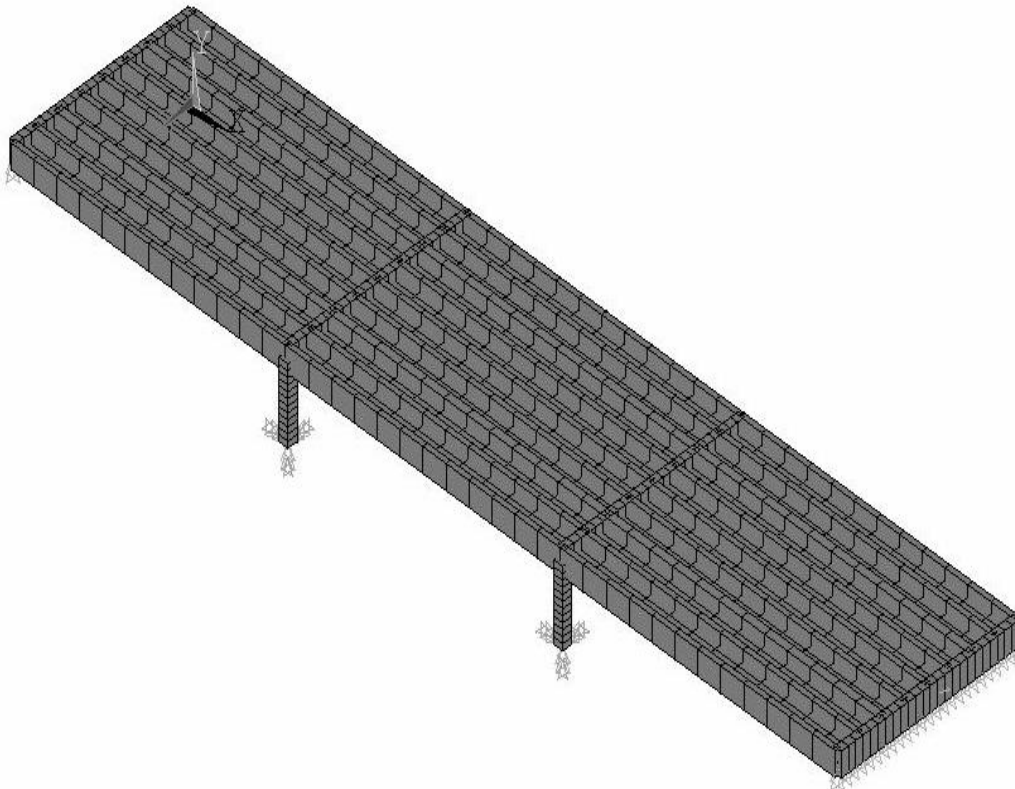


Figure 2: Finite element model of the deck-girder bridge

3. Seismic analysis of the bridge

In the present research study, both equivalent static force method (ESFM) and response spectrum method (RSM) have been used for performing the seismic load analysis.

3.1 Equivalent Static Force Method

In ESFM, the axial deformation of the deck is neglected. It should be noted that the bridge is idealized so that the abutment does not contribute to the longitudinal stiffness. This is done for the purpose of simplicity and it is assumed that the columns alone resist the longitudinal and transverse motion. Generally any structure is subjected to simultaneous ground motion in three orthogonal directions. In this analysis method, two horizontal (longitudinal and transverse) components of motion are accounted and vertical component of the motion is ignored. The following figures 3a and 3b show the longitudinal and transverse equivalent static seismic loading acting on the bridge model respectively.

However, the equivalent static earthquake loading is evaluated using some semi-empirical equations according to AASHTO guidelines for both longitudinal and transverse directions. According to AASHTO code, in case of transverse earthquake motion, a uniform transverse loading P_0 is applied over the length of the bridge to establish a deflected shape for the model that has been shown in figure 4.

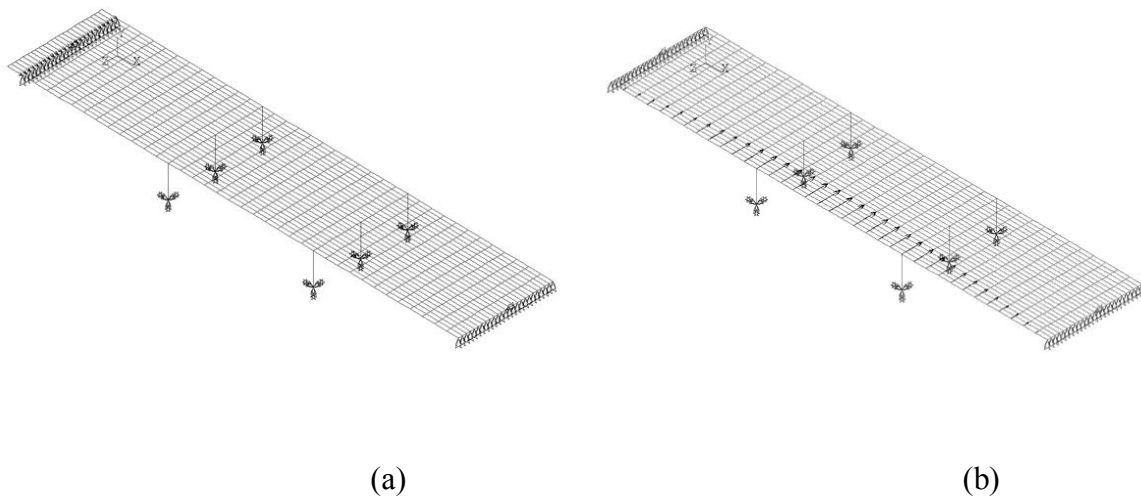


Figure 3: The bridge subjected to (a) longitudinal and (b) transverse equivalent static seismic loading

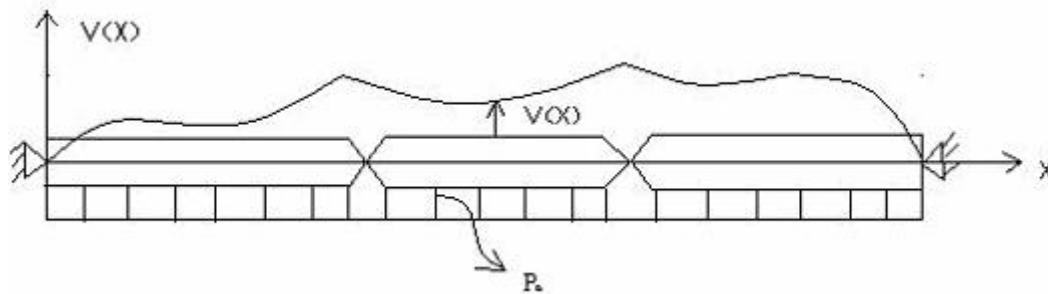


Figure 4: Deflected shape due to transverse static loading

Then the intensity of the seismic loading $P_e(x)$ is obtained from the following equation:

$$P_e(x) = \frac{\beta C_s}{\gamma} w(x) v_s(x) \quad (1)$$

$$C_s = \frac{1.2AS}{T^{\frac{2}{3}}} \quad (2)$$

where C_s = Elastic response coefficient

A = Acceleration coefficient

S = Site coefficient

$w(x)$ = Dead weight per unit length of the superstructure

$v_s(x)$ = Resulting displacement at different locations

T = Period of the vibration of the bridge

$$T = 2\pi \sqrt{\frac{\gamma}{P_0 g \alpha}} \quad (3)$$

where g = Acceleration due to gravity

Here α , β and γ these 3 factors are calculated by evaluating the integrals numerically from equation 4, 5 and 6 respectively.

$$\alpha = \int v_s(x) dx \quad (4)$$

$$\beta = \int w(x)v_s(x) dx \quad (5)$$

$$\gamma = \int w(x)v_s(x)^2 dx \quad (6)$$

After applying the equivalent static loading $P_e(x)$ to the bridge, the resulting member forces and moments are combined according to two combination methods as suggested by AASHTO to calculate the design forces and moments.

Load combination 1: 100% forces or moments of longitudinal directional analysis + 30% forces or moments of transverse directional analysis.

Load combination 2: 30% forces or moments of longitudinal directional analysis + 100% forces or moments of transverse directional analysis.

In this seismic analysis, load combination 2 controls which is used to determine the design seismic forces and moments.

3.2 Response Spectrum Analysis

Modal analysis is a pre-requisite to response spectrum analysis. In this analysis, the total numbers of modes are taken fourteen. As provided in various research outputs the goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during vibration. It must be ensured that the total number of modes extracted should be enough to characterize the structure's response in the frequency range of interest. Some of the modal shapes with corresponding natural period of vibration have been shown in figure 5a through 5f. The frequency and time period for different modes of vibration are given in table 3.

Table 3: The frequency and time period for different modes

Mode of vibration	Frequency	Time Period (T) in second
1	1.1763	0.8501
2	2.1743	0.4599
3	2.6066	0.3836
4	2.6405	0.3787
5	2.8069	0.3563
6	3.1696	0.3155
7	3.6142	0.2767
8	3.8531	0.2595
9	4.1557	0.2406
10	4.4485	0.2248
11	5.0191	0.1992
12	5.2799	0.1894
13	5.4191	0.1845
14	5.6421	0.1772

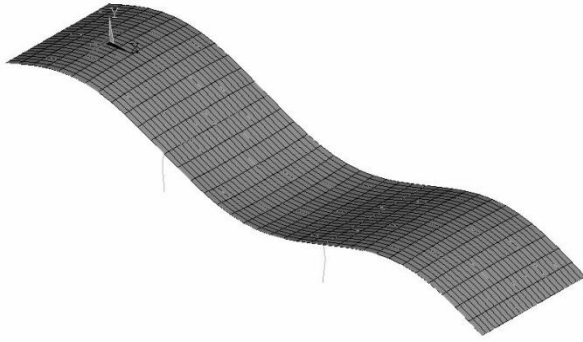


Figure 5a: 2nd Mode (T = 0.4599s)

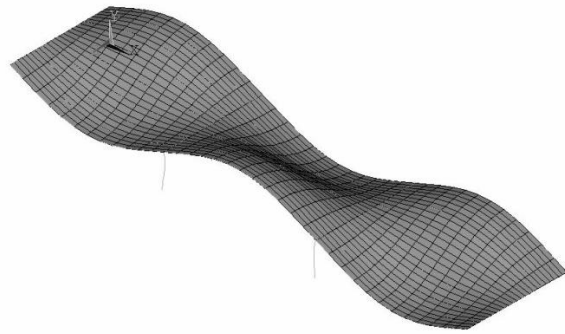


Figure 5b: 5th Mode (T = 0.3563s)

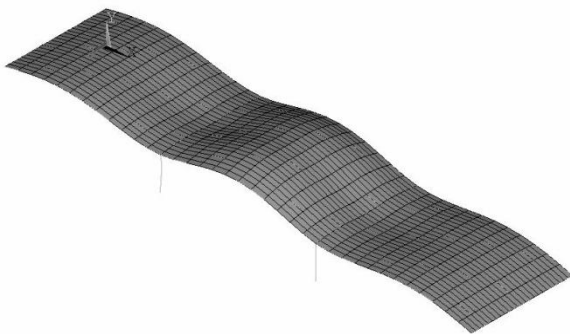


Figure 5c: 7th Mode (T = 0.2767s)

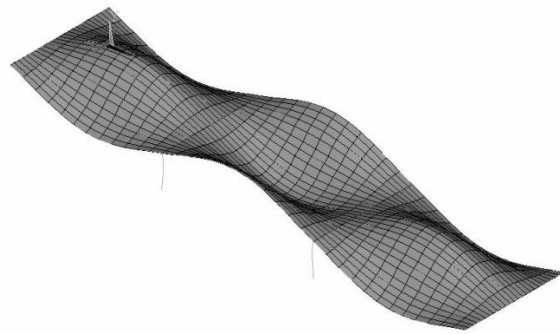


Figure 5d: 9th Mode (T = 0.2406s)

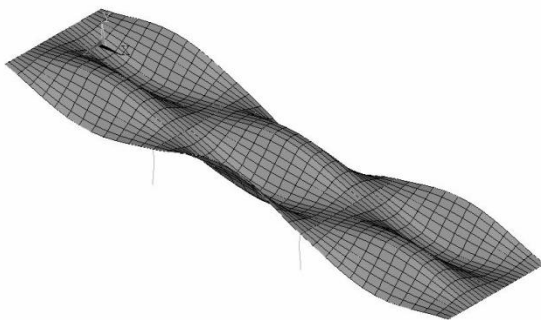


Figure 5e: 12th Mode (T = 0.1894s)

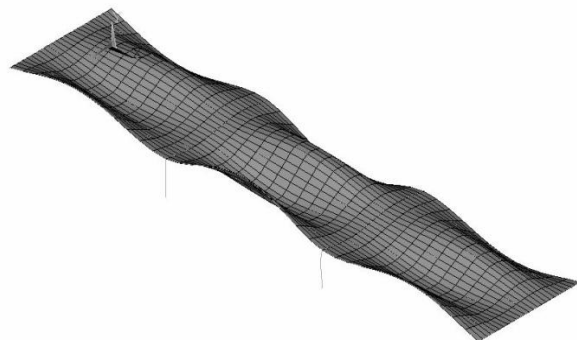


Figure 5f: 14th Mode (T = 0.1772s)

For modal combination, complete quadratic combination (CQC) method has been considered. The response spectrum analysis procedure provides maximum responses of the structure when it is vibrating in each of its significant normal modes. However, because these maximum modal responses will not occur at the same time during earthquake ground motion, it is necessary to use approximate procedure to estimate the maximum composite response of structure. Such procedures are typically based on an approximate combination of maximum individual modal responses (M. A. Ansary et al., 2000). A simple and accurate modal

combination approach that satisfies the requirement is CQC method. This relatively new method of modal combination method was first published in 1981 (A. Der Kiureghian, 1981). It is based on random vibration theories and has found wide acceptance by most engineers and has been incorporated as an option in most modern computer programs for seismic analysis. It is assumed here that the duration of the earthquake shaking is long when compared to the fundamental period of the structure and the design response spectrum exhibits slowly varying amplitudes over a wide range of periods that include the dominant modes of the structure.

A response spectrum represents the response of single DOF systems to a time-history loading function. It is actually a graph of response versus frequency where the response might be displacement, velocity, acceleration or force. There are two types of response spectrum analysis - 1) Single-point response spectrum 2) Multi-point response spectrum. Here single-point response spectrum analysis is performed. The single-point response spectrum curve is shown in figure 6a. From the figure, it is observed that only one spectrum curve is specified at all supports of the model and in this analysis the spectral value, s is considered as acceleration. Most importantly, for soil type 2 (deep cohesion less or stiff clay soils) and damping ratio of 5%, the normalized response spectra according to BNBC has been used at all supports of the bridge model which has been shown in figure 6b.

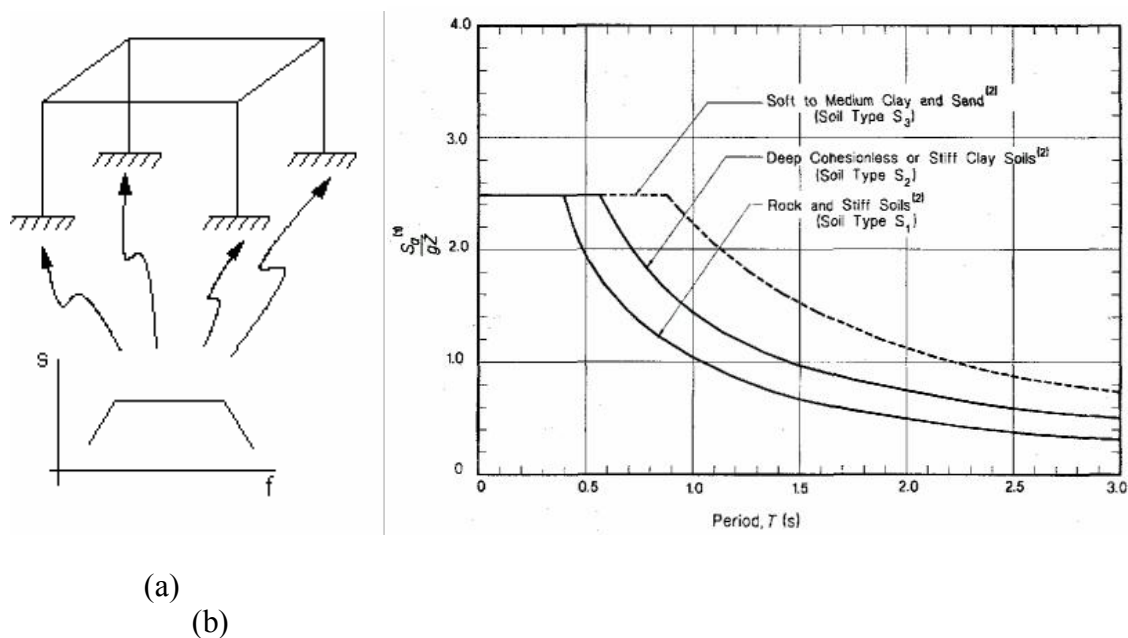


Figure 6: (a) Single-Point Response Spectra and (b) Normalized Response Spectra for 5% Damping Ratio (BNBC, 1993)

4. Results

The longitudinal and transverse shear force, axial force, longitudinal and transverse moment, design moment for centre column obtained from both equivalent static force method and response spectrum method has been shown in the following bar graphs from 7a to 7b:

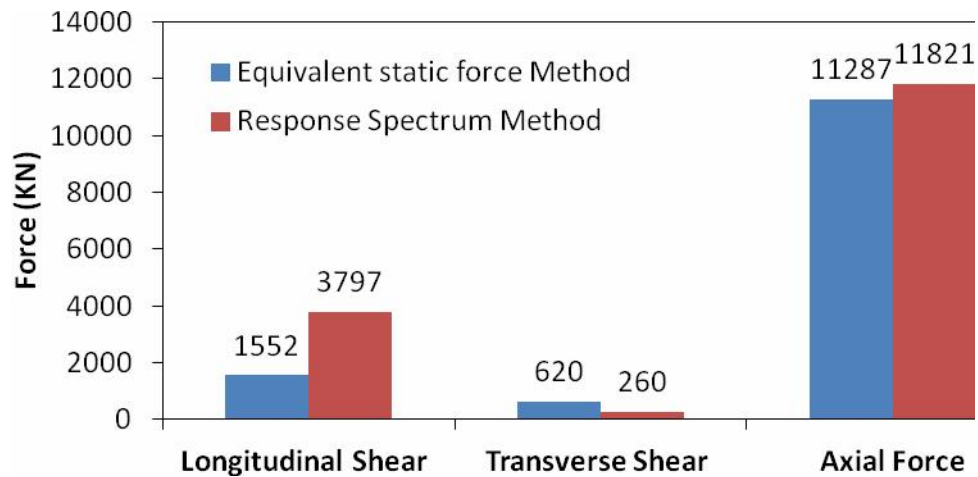


Figure7a: Comparison for different forces of centre column

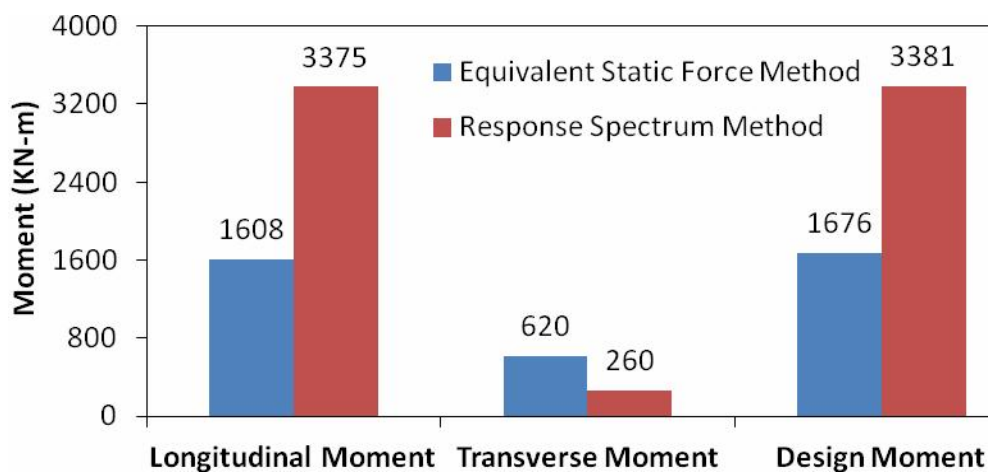


Figure 7b: Comparison for different moments of centre column

5. Conclusions

The important conclusions derived from the study of the three span deck girder bridge are summarized as follows:

- The axial forces are almost equal for both ESFM seismic analysis and Response spectrum analysis.
- In Response Spectrum analysis the longitudinal moments of outer column and centre column are about 206% and 210% of ESFM seismic analysis respectively. Thus the longitudinal moment for both cases varies significantly.
- In Response Spectrum analysis the longitudinal shear forces of outer column and centre column are 240% and 245% of ESFM seismic analysis respectively.
- In Response Spectrum analysis the transverse moments of outer column and centre column are 77% and 42% of ESFM seismic analysis respectively.

- e) In Response Spectrum analysis the transverse shear forces of outer column and centre column are 63% and 42% of ESFM seismic analysis.

From the study, it has been revealed that it is more likely to achieve unsafe bridge design if the seismic analysis is followed by equivalent static force method (ESFM). Therefore it can be concluded that response spectrum method (RSM) should be followed for seismic analysis of the bridges.

6. References

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