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Seismic analysis of a three-span deck girder bridge

Zasiah Tafheem & Nazmus Sakib
Ahsanullah University of Science and Technology, Dhaka 1208, Bangladesh
K.M. Amanat
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

ABSTRACT: This paper presents seismic analysis of a three-span deck girder bridge. A finite element model to analyze the deck girder bridge has been developed by using finite element software called ANSYS. The entire 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 guideline. In the second step, Response Spectrum analysis has been performed. Then the design forces and moments at the 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 mentioned above. From the entire study it has been found that the magnitude of the axial forces are almost same in those 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 by equivalent static force method (ESFM). Therefore it can be said that there is a possibility of achieving under design of the bridge if 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 a safer design.

1 INTRODUCTION

Earthquake could be defined as chaotic motion of the earth's crust, characterized by time dependent amplitudes and frequencies. From the past historical records of earthquake occurrence, it has been seen that earthquake is one of the most feared natural disasters which has caused incalculable destruction of properties and injury and loss of lives to the population. Earthquakes occur due to the instability of the earth crust and the sudden release of accumulated stress deep inside the crust. The sudden release of energy during an earthquake may lead to ground shaking, surface faulting, and ground failures. Stresses are generated in structures due to the ground shaking and if a structure is incapable of resting these additional stresses, it will suffer damage. The current philosophy behind earthquake resistant design of common structures 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. Bridges may suffer damage but have low probability of collapse due to earthquake motion v) Collapse is prevented during more severe earthquakes, which is achieved by ensuring ductile, rather than brittle behavior of the structural response. Like a set of falling dominoes, sections of a major bridge collapsed into the Tubul River near the tiny seaside fishing village of Tubul following the February 27 earthquake in Chile. Photographer Nicolás Piwonka captured the scene from a small plane on March 6, 2010. The coastal city was one of the hardest hit following the magnitude 8.8 earthquake which killed 497 people—downgraded from an original estimate in the 800s—and destroyed at least 500,000 homes, the Associated Press reported.

Earthquake resistant bridge design must ensure that the bridge piers withstand the lateral forces generated during earthquake. AASHTO recommends some semi analytical procedure to determine the design seismic forces. There are also a lot of analysis procedures developed in different finite element software to determine the design seismic forces. In this paper two analysis cases are considered- I) Equivalent static force method according to AASHTO guideline II) Response Spectrum Analysis.

Figure 1: A bridge damaged by 8.8M Chile earthquake on February 2010 Figure 2: 7.1 M Honduras earthquake on May 28, 2009

2 SCOPE AND OBJECTIVE

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 objective of the present research is to analyze the longitudinal and transverse earthquake motion of the bridge and to determine the design forces and moments at the column bases following the equivalent static force method and response spectrum method. Then a comparative study of the design forces and moments found from these two cases has been performed. It is expected that the findings of this study will lead to a better understanding of the behavior of bridge under seismic loading. For simplicity of the analysis, linear material behavior and fixed support conditions are assumed in this study.

3 METHODOLOGY

A three dimensional isometric view of the continuous three-span deck girder bridge is shown in figure 3 with dimension and boundary conditions. The model of the bridge has a total span length of 109.728m. Column height is taken as 7.62m and slab width as 23.774m.

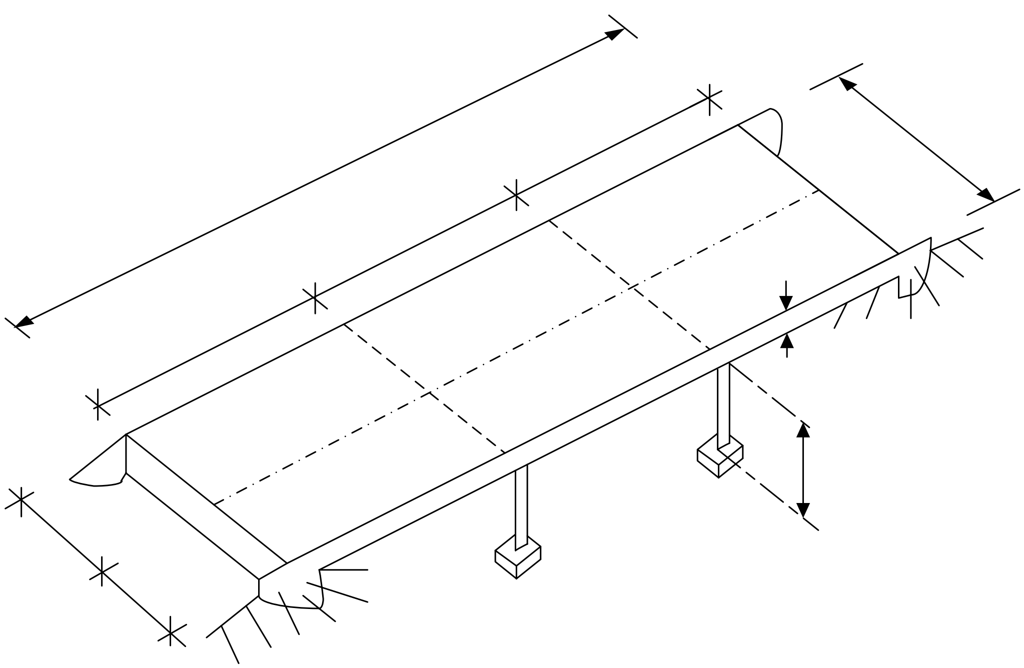

Figure 3: Dimension of a Three Span Deck Girder Bridge

Material properties and geometric properties used for designing the bridge are given in Table 1 and Table 2.

Table 1: Material properties of concrete for the designed bridge

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

Table 2: Geometries of the designed 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 of bridge	
Height	meter	7.62
Diameter	meter	1.219
No. of column	------	6
	Longitudinal Girder	
No. of longitudinal girder	-----	9
Width	meter	0.6096
Depth	meter	2.438
Girder to girder spacing	meter	3.048
	Cross Girder	
No. of cross girder	----	4
Width	meter	0.914
Depth	meter	2.438

4 FINITE ELEMENT MODELING

A three dimensional modeling of the bridge has been done by using finite element analysis software ANSYS10.0. A 3D view of the finite element mesh is shown in figure 4. To model the bridge two nodded uniaxial element having six degrees of freedom per node has been used for girders and columns. The concrete deck of the bridge has been modeled using four nodded 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. Furthermore, 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.

5 SEISMIC ANALYSIS OF THE DECK-GIRDER BRIDGE

Both equivalent static force method (ESFM) and response spectrum method (RSM) have been used to obtain the design force and moment at the column bases under seismic loading. In equivalent static force method (ESFM), the axial deformation of the deck is neglected and it is assumed that the deck behaves as a rigid member. 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. The equivalent static earthquake loading is evaluated using AASHTO guidelines for both longitudinal and transverse direction. Then those loads are applied to the bridge which has been shown in the following figures. Finally the member forces are obtained using ANSYS

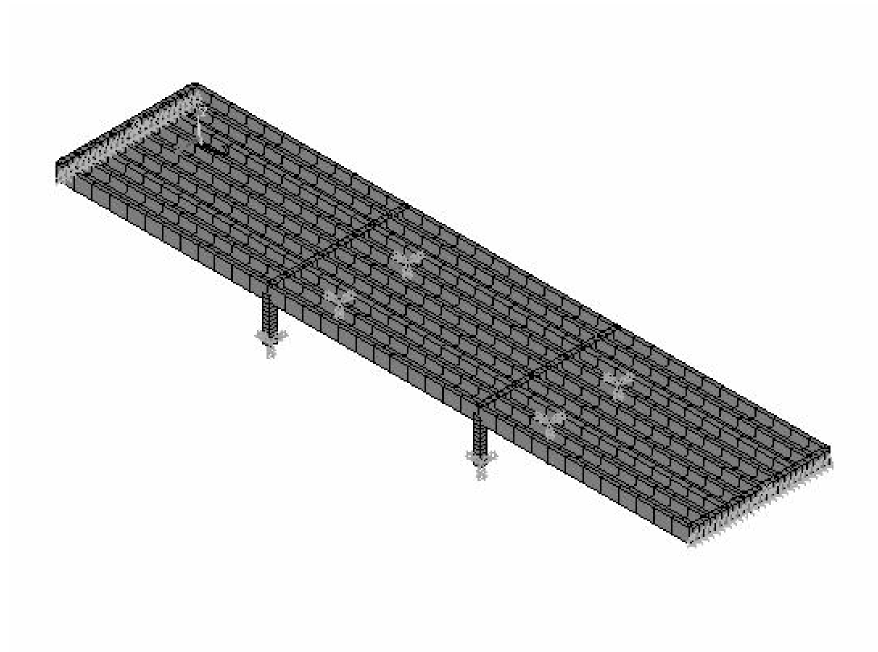

Figure 4: Finite element model of the deck-girder bridge

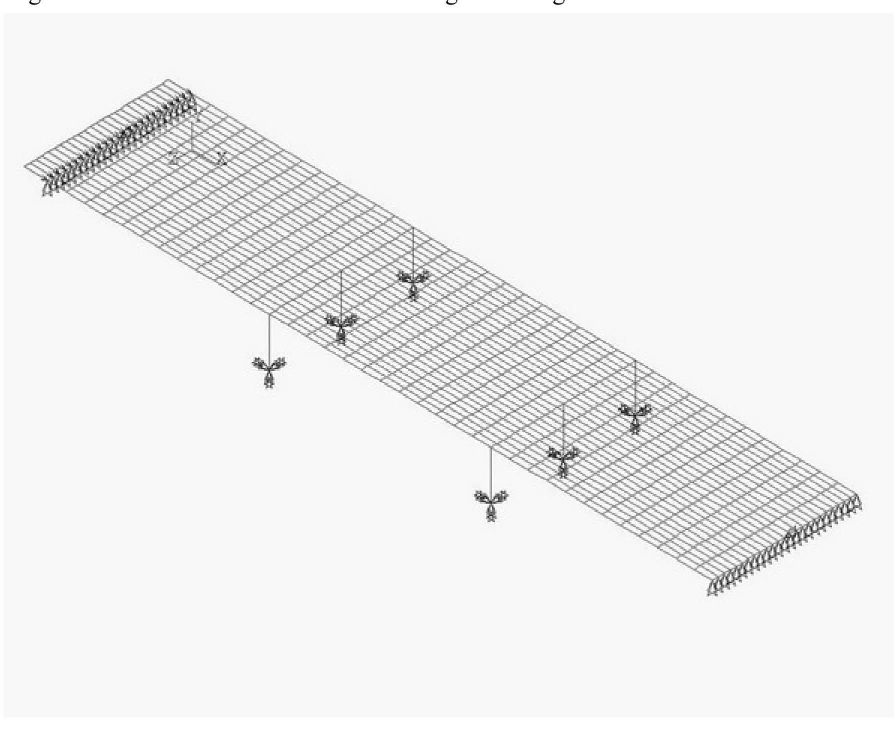

Figure 5: The bridge subjected to longitudinal equivalent static seismic loading

Modal analysis is a pre-requisite to response spectrum analysis. In this study, the total numbers of modes are taken fourteen. 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 are shown in the following figures with natural period of vibration.

For modal combination, CQC (complete quadratic combination) 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. A simple and accurate modal combination approach that satisfies the requirement is CQC method

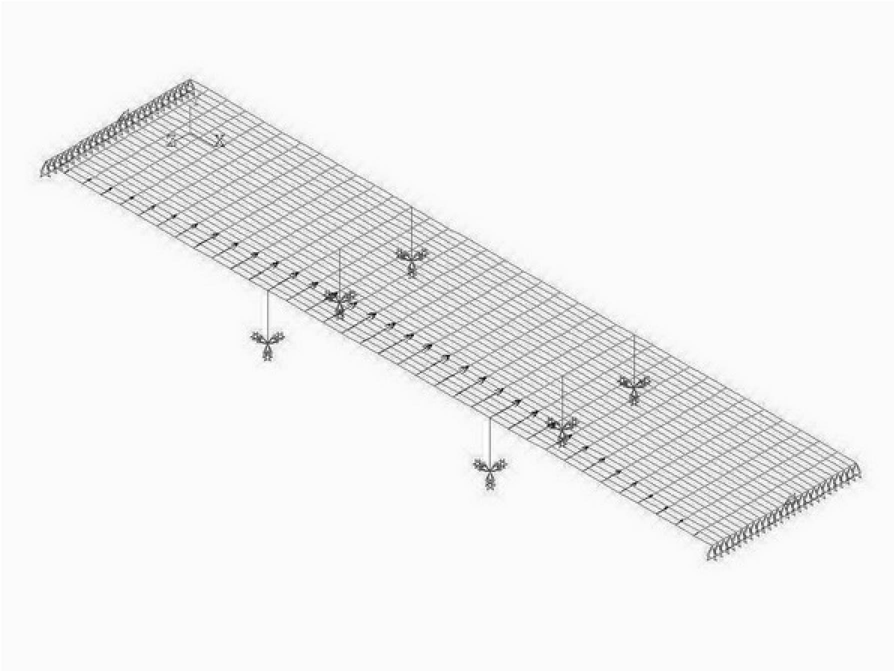

Figure 6: The bridge subjected to transverse equivalent static seismic loading

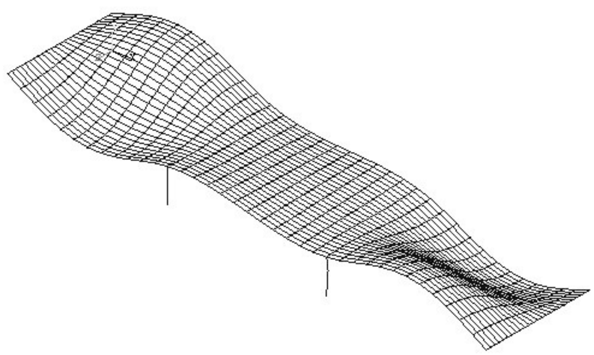

Figure 7: Fifth mode of vibration
(Time period T= 0.3563 sec)

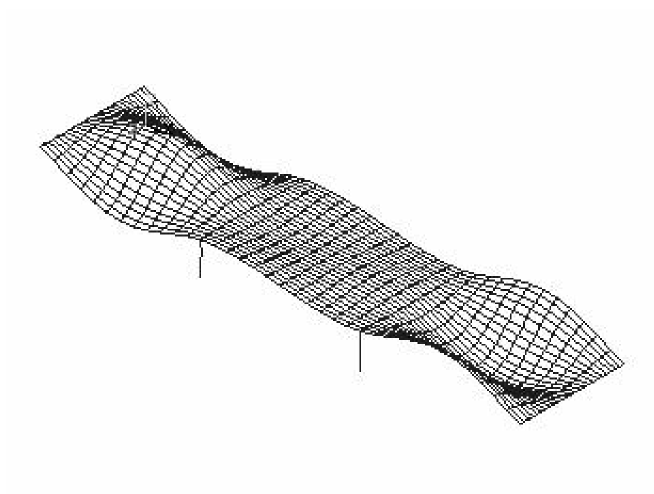

Figure 8: Tenth mode of vibration
(Time period T= 0.2248 sec)

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 in which only one spectrum curve is specified at all supports of the model and the spectral value is considered as acceleration.

Most importantly, for soil type 2 (deep cohesion less or stiff clay solids) and damping ratio of 5%, the normalized response spectra according to BNBC has been used at all supports of the bridge model which is shown in fig.9.

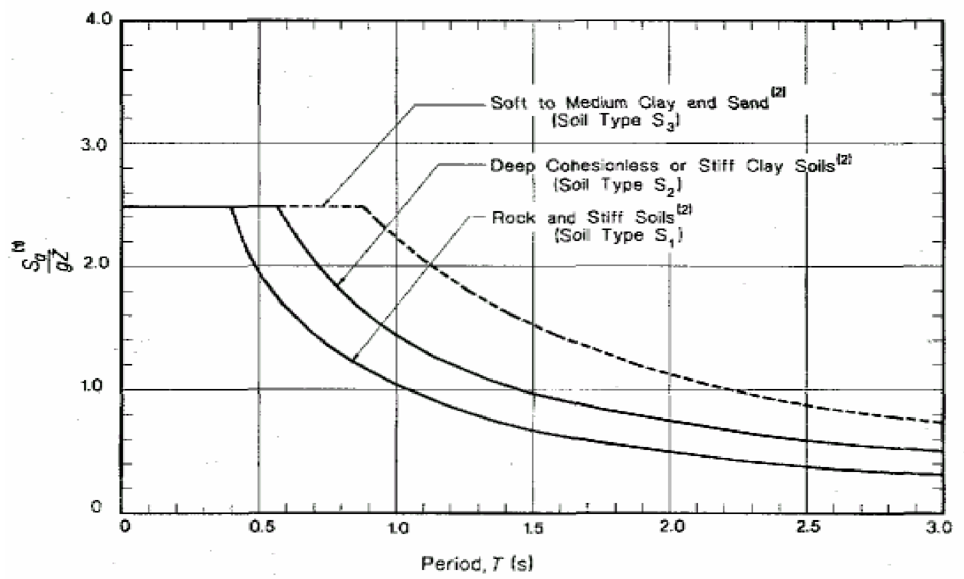

Figure 9: Normalized Response Spectra for 5% Damping Ratio

6 RESULTS

The results of longitudinal and transverse shear, longitudinal and transverse moment, axial force and design moment for outer and centre column obtained from ESFM and Response spectrum analysis are given in the following Tables 3 and 4. The comparison of column shear force, axial force and design moment according to ESFM and Response spectrum analysis has been shown in the following bar graphs:

Table 3: Design forces for case I (Equivalent Static Force Method)

Component	Outer column	Centre column
Longitudinal shear $V_{x'}$ (KN)	1579.006	1552.304
Longitudinal moment $M_{z'z'}$ (KN-m)	1627.128	1607.879
Transverse shear $V_{z'}$ (KN)	851.463	620.064
Transverse moment $M_{x'x'}$ (KN-m)	1149.91	474.5
Axial force $P_{y'}$ (KN)	5070.78 or 4317.86	11286.92 or 10933.88
Design Moment (KN-m)	1992.45	1676.43

Table 4: Design forces for Case II (Response spectrum Analysis)

Component	Outer column	Centre column
Longitudinal shear $V_{x'}$(KN)	3790.486	3797.332
Longitudinal moment $M_{z'z'}$ (KN-m)	3356.83	3374.989
Transverse shear $V_{z'}$ (KN)	535.2	259.54
Transverse moment $M_{x'x'}$ (KN-m)	888.527	196.92
Axial force $P_{y'}$ (KN)	5405.402 or 3983.24	11821.48 or 10399.32
Design Moment (KN-m)	3472.43	3380.73

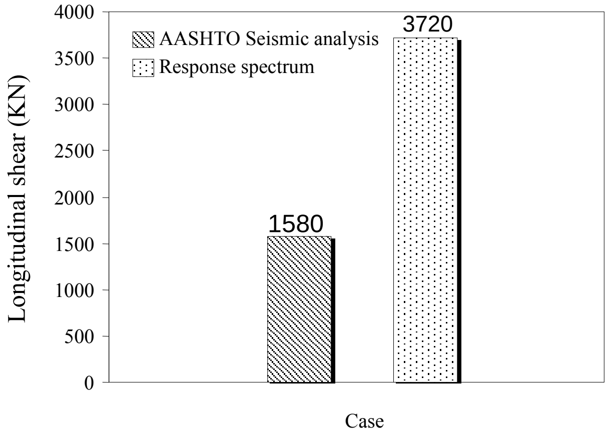

Figure10: Comparison of longitudinal shear force for outer column

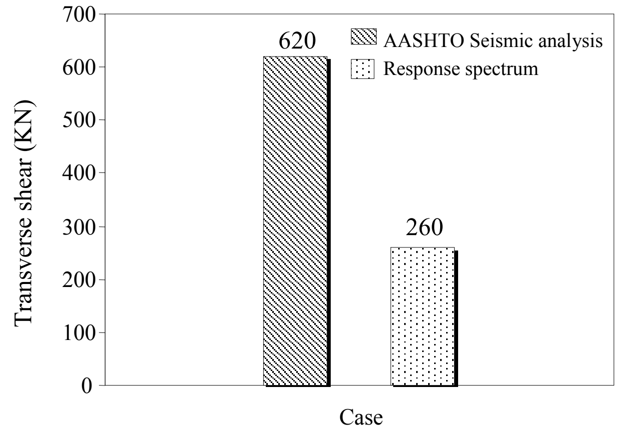

Figure11: Comparison of transverse shear force for centre column

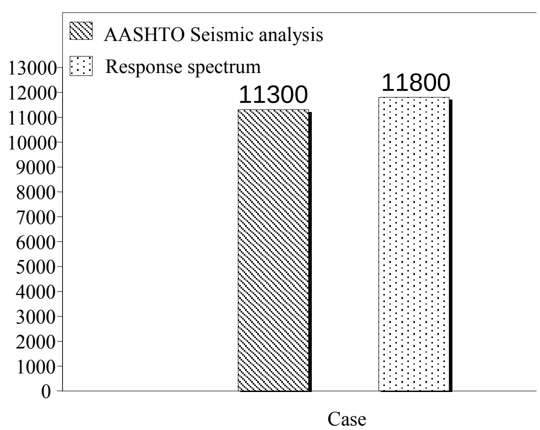

Figure12: Comparison of total axial force for centre column

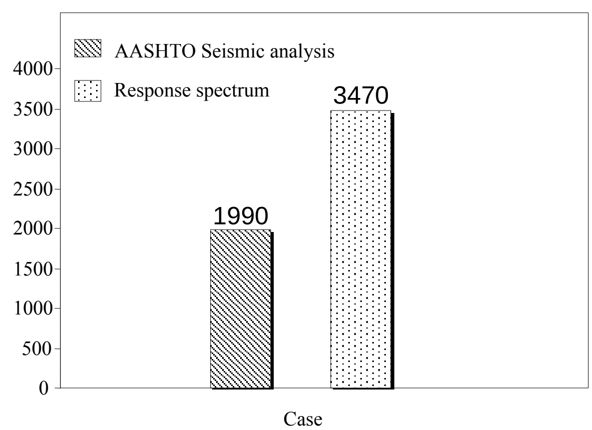

Figure13: Comparison of design moment for outer column

7 CONCLUSIONS

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

- Design axial forces are almost equal for both AASHTO seismic analysis and Response spectrum analysis.
- In Response Spectrum analysis the longitudinal moments of outer column and centre column are respectively 204% and 209% of AASHTO seismic analysis. Thus the longitudinal moment for both cases varies significantly.
- In Response Spectrum analysis the longitudinal shear forces of outer column and centre column are respectively 235% and 245% of AASHTO seismic analysis.
- In Response Spectrum analysis the transverse moments of outer column and centre column are respectively 77% and 41% of AASHTO seismic analysis.
- In Response Spectrum analysis the transverse shear forces of outer column and centre column are respectively 62% and 42% of AASHTO seismic analysis.
- From the entire study, it has been observed that it is more likely to achieve an unsafe bridge design if the seismic design is followed by equivalent static force method (ESFM). Therefore it can be concluded that response spectrum method (RSM) should be followed for safe seismic design of the bridges.

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