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Seismic Performance Evaluation of Bridge Structures Using 3D Finite Element Methods in South Korea

Woo Young Jung, Bu Seog Ju

***Abstract*—**This study described the seismic performance evaluation of bridge structures, located near Daegu metropolitan city in Korea. The structural design code or regulatory guidelines is focusing on the protection of brittle failure or collapse in bridges' lifetime during an earthquake. This paper illustrated the procedure in terms of the safety evaluation of bridges using simple linear elastic 3D Finite Element (FE) model in ABAQUS platform. The design response spectra based on KBC 2009 were then developed, in order to understand the seismic behavior of bridge structures. Besides, the multiple directional earthquakes were applied and it revealed that the most dominated earthquake direction was transverse direction of the bridge. Also, the bridge structure under the compressive stress was more fragile than the tensile stress and the vertical direction of seismic ground motions was not significantly affected to the structural system.

***Keywords*—**Bridge, Finite Element, 3D model, Earthquake, Spectrum.

I. Introduction

With the increase of seismic events, the safety assessment or evaluation of civil infrastructures such as bridges, dams, and power plants has been issued in Korea. The failure of bridge structures leads to disruption of traffic flow and emergency access in the area and also the significant economic losses can be caused during a strong earthquake. Therefore, many bridges passing significantly increased traffic have been taken account for seismic risk assessment or seismic retrofit to mitigate the structural damage of bridges under extreme events. Also, seismic performance evaluation of bridge structures using the linear or nonlinear Finite Element (FE) analysis has been studied. An urban steel bridge in metropolitan Tehran City, using three dimensional nonlinear FE model associated with static procedure was studied based on probabilistic seismic hazard analysis [1]. Usami et al. [2] investigated the inelastic behavior of steel arch bridges subjected to strong ground motions and the bridges consisted of a reinforced concrete deck, steel I-section girders and steel arch ribs. Additionally, in order to evaluate the seismic behavior of the bridge, a three dimensional analytical model was developed and the 1995 Hyogoken-Nanbu earthquake in Japan was applied. Li et al. [3] studied effect of FE model effects of concrete-filled steel tubular arch bridge using the structural health monitoring and the stochastic vibration analysis was investigated in this studied. Consequently, this study evaluated the seismic performance of Samoonjin bridge structure, constructed at one of four major rivers and located near Daegu metropolitan city in Korea. In order to investigate the seismic behavior of the bridge, three dimensional simple linear elastic FE model using ABAQUS platform was developed in this study and then design response spectra in accordance with the earthquake direction were applied to the bridge structure. The design response spectra were generated by Korean Building Code (KBC) 2009 and also the design response spectra were used to obtain the maximum values of displacements and member forces corresponding to each modes of the bridge system and to reduce the significant amount of computational time for a seismic analysis.

W.Y. Jung is with the Department of Civil Engineering, Gangneung -Wonju National University, Gangneung, Korea (corresponding author; e-mail: woojung@gwnu.ac.kr)
B.S. Ju is with Institute for Disaster Prevention, Gangneung -Wonju National University, Gangneung, Korea

II. Description of FE Model of Bridge Structure

Fig. 1 showed Samoonjin bridge structure and the FE model using ABAQUS platform [4].

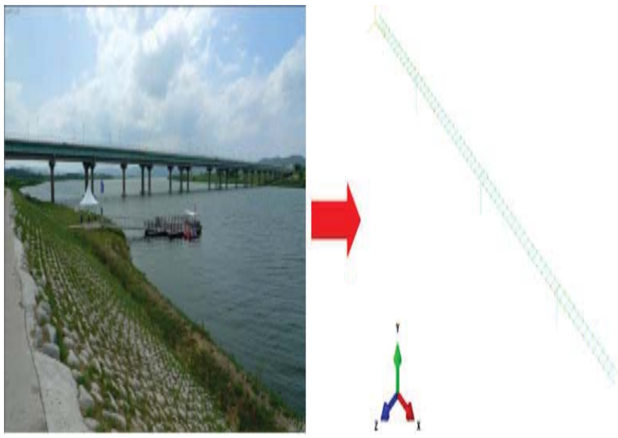

Fig. 1 Samoonjin bridge structure and the FE model

TABLE I
THE ELEMENT TYPES OF FE MODEL OF BRIDGE STRUCTURE

	Element Type	Number of Elements	Number of Nodes
Deck	3D Beam	620	682
Girder		162	164
Column		60	63
		842	909

The simple three dimensional FE model to investigate the seismic behavior was created and then the slab, girder, and column was modeled based on linear elastic models, in order to remain elastic range during an earthquake. For the super structures and columns, 3D beam elements were used and each column with foundations was simply fixed with translational and rotational boundary conditions. 842 elements and 909 nodes for the bridge structures were generated. The all connection areas such as decks, girders, and columns were simply tied in ABAQUS. Table I illustrated the detailed element types of FE model.

III. Design Spectrum Based on KBC 2009

The dynamic analysis of the typical Multiple Degree of Freedom (MDOF) system subjected to three dimensional seismic ground motions can be written as [5],

$$\ddot{y}(t)+2\xi\omega_n\dot{y}(t)+\omega^2 y(t)=\Gamma_{nx}P(t)_{nx}+\Gamma_{ny}P(t)_{ny}+\Gamma_{nz}P(t)_{nz} \quad (1)$$

where, Γ is a modal participation factor and *P(t)* is the force. In order to evaluate the maximum responses due to three directional earthquake or two directional earthquakes, it was necessary to address the modal combination for design response spectrum method. Therefore, design response spectrum based on KBC 2009 [6] was generated in this study. Fig. 2 described the design response spectrum in Korea. Short (F_a) and long (F_v) period site coefficient was listed in Tables II and III.

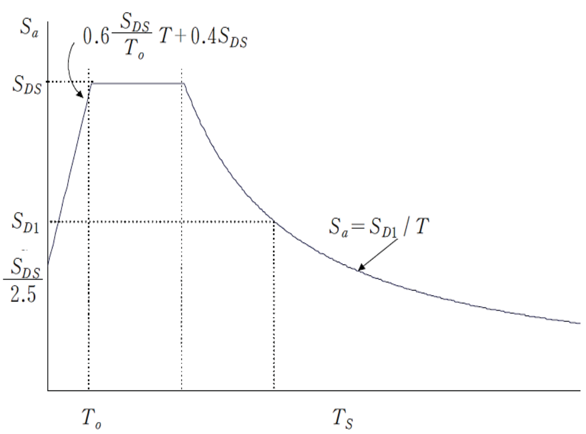

Fig. 2 Design Response Spectrum

TABLE II
Short Period Site Coefficient

Site Class	Seismic Zone		
	S_S<0.25	S_S=0.5	S_S=0.75
S_A	0.8	0.8	0.8
S_B	1.0	1.0	1.0
S_C	1.2	1.2	1.1
S_D	1.6	1.4	1.2
S_E	2.5	1.9	1.3

TABLE IIII
Long Period Site Coefficient

Site Class	Seismic Zone		
	S<0.1	S=0.2	S_S=0.3
S_A	0.8	0.8	0.8
S_B	1.0	1.0	1.0
S_C	1.7	1.6	1.5
S_D	2.4	2.0	1.8
S_E	3.5	3.2	2.8

Also, spectral response acceleration at shot periods sec corresponding to 5% damping can be expressed as,

$$S_{DS}=\frac{2}{3}S_{MS},\quad \left(S_{MS}=F_a S_s\right) \quad (2)$$

Equation (3) showed the spectral response acceleration parameter at a period 1 sec.

$$S_{D1}=\frac{2}{3}S_{M1},\quad \left(S_{M1}=F_V S_1\right) \quad (3)$$

In addition, the fundamental period of the structure was depicted in (4):

$$T_0=0.2\times\frac{S_{D1}}{S_{DS}},\ T_S=\frac{S_{D1}}{S_{DS}} \quad (4)$$

Based on acceleration parameters, site coefficients, seismic zone factor, and fundamental periods, the design response spectrum was developed in this study (Fig. 3)

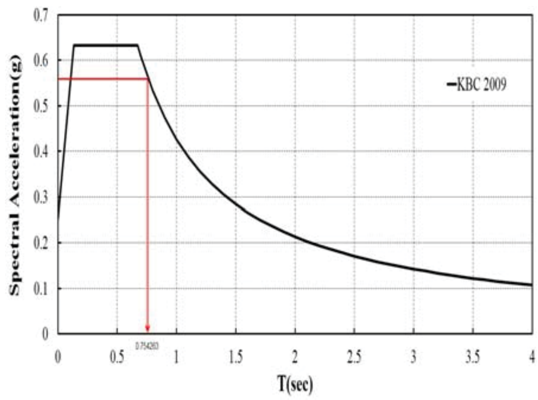

Fig. 3 KBC 2009 Design Response Spectrum

IV. Design Spectrum Analysis of Bridge Structures

In order to obtain the structural dynamic properties of the bridge structures, eigenvalue and eigenvector analysis was conducted. Table IV summarized the dynamic properties of Samoonjin bridge structure.

TABLE IV
Mass Participation and Natural Frequency

MODE No.	Z-dir	Z-dir(%)	Frequency (cycle/sec)	Period (sec)
1	1293.4	8.687	1.3258	0.75426
2	1.725	0.12	1.5097	0.66238
3	5.027e^{-20}	7e^{-10}	1.8474	0.54130
4	192.85	12.95	1.9097	0.53640
5	0.885	0.06	2.1066	0.47469
6	8.607 e^{-20}	1.19e^{-9}	2.1090	0.47415
7	4.236 e^{-20}	6e^{-10}	2.1100	0.47393
8	2.691 e^{-19}	1.01e^{-9}	2.1601	0.46294
9	1.515 e^{-20}	3e^{-10}	2.1673	0.46140
10	4.307 e^{-20}	6e^{-9}	2.1999	0.45456
Total	1488.9	100	-	-

As can be seen in Table IV, the most dominated mode for the structure was mode 1 (mass participation: 87%) and mode 4 (mass participation: 13 %), and mode 1 was illustrated in Fig. 4.

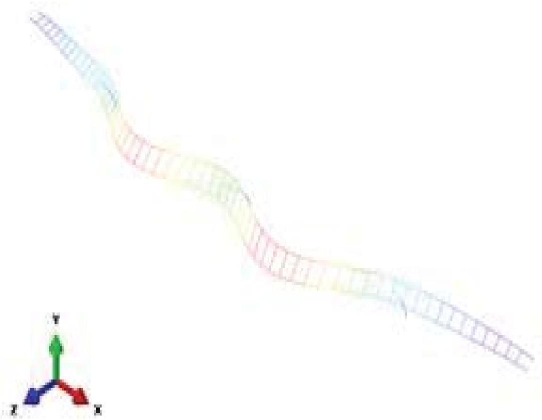

Fig. 4 The Bridge Structure Mode Shape 1

In particular, the bridge structure was evaluated by the earthquake direction and the Square Root of the Sum of the Squares (SRSS) approach for the modal combination through all modes of the structures was used in this study. The direction of the input earthquake motion was classified into three different cases: 1) longitudinal direction; 2) transverse and longitudinal direction; 3) two horizontal and one vertical direction earthquake. As a result, the maximum tensile and compressive stress of the bridge structure subjected to the longitudinal direction earthquake (direction x) was 0.511 *MPa* and 0.8544e^{-3} *MPa*, respectively. From case 2, the structural responses (maximum tensile stress-134.24 *MPa* and maximum compressive stress-6.566 *MPa*) were significantly increased due to mode 1 and mode 4. Finally, analysis case 3 of the bridge structure illustrated the effect of vertical direction earthquake, using SRSS method. Figs. 5-10 showed the maximum stresses of the bridge structure. As can be seen in figures, the bridge structure modeled in simple linear elastic condition was not influenced by the vertical directional earthquake. Also, the maximum displacement of the structure was 138.23 *mm* from the analysis case 2.

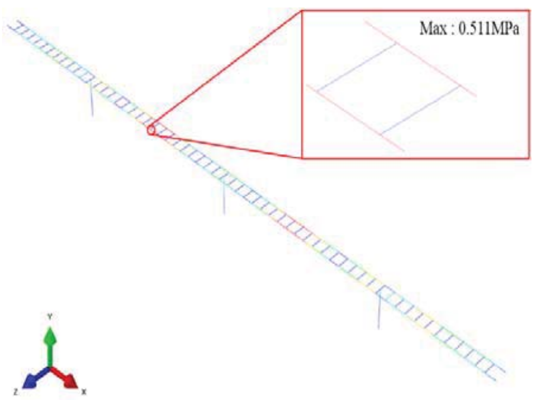

Fig. 5 Case 1 – Maximum Tensile Stress

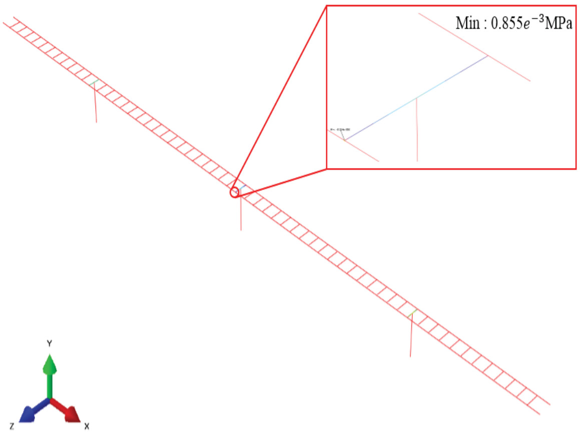

Fig. 6 Case 1 – Maximum Compressive Stress

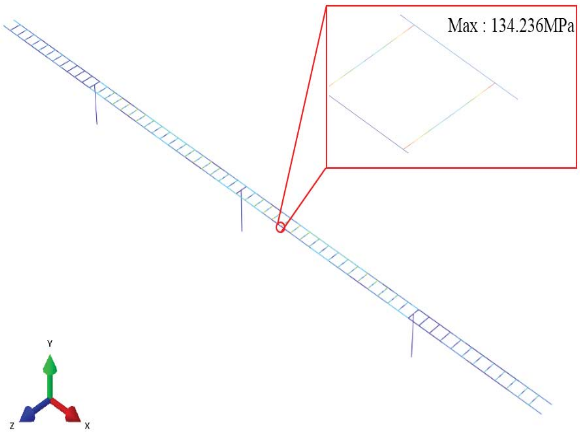

Fig. 7 Case 2 – Maximum Tensile Stress

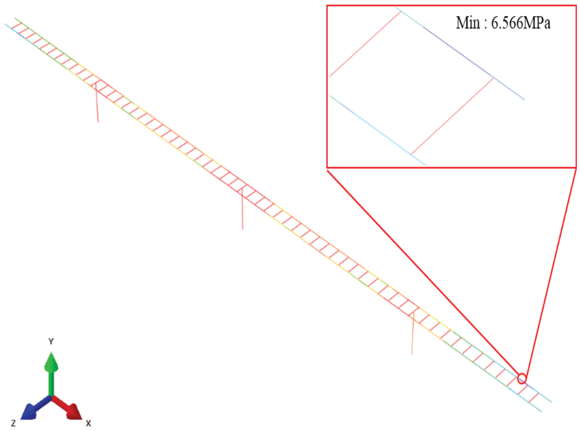

Fig. 8 Case 2 – Maximum Compressive Stress

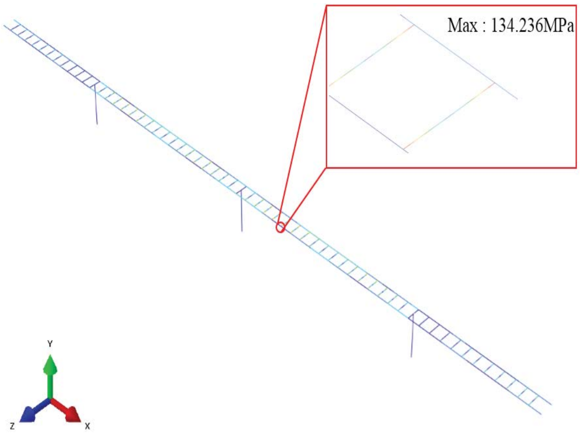

Fig. 9 Case 3 – Maximum Tensile Stress

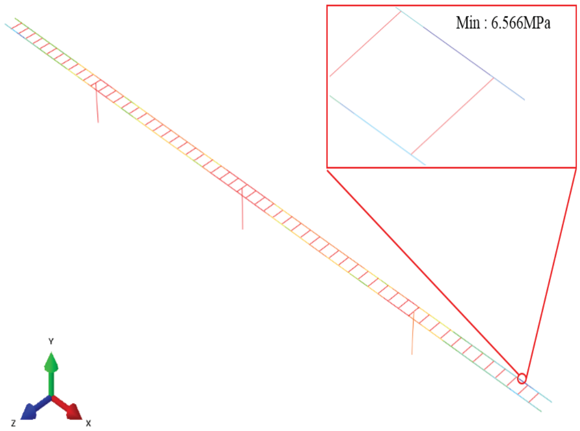

Fig. 10 Case 3 – Maximum Compressive Stress

V. CONCLUSION

This study presented the seismic behavior of bridge structure located near DaeGu metropolitan city in Korea. Also, in order to understand the seismic performance of the bridge structure, simple linear elastic FE model was developed in ABAQUS. Besides, for the seismic performance evaluation, the design response spectrum based on KBC 2009 was generated in this study. Consequently, the most dominated mode of the bridge structure was mode 1 and 4 through eigenvalue analysis. The maximum tensile and compressive stress was 134. 24 *MPa* and 6.566 *MPa*, respectively. Also it was interesting to find that the bridge structure was not influenced by vertical direction earthquake component. Further, to consider the structural uncertainty of the bridge, nonlinear dynamic analysis must be conducted.

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REFERENCES

[1] A. Nicknam, A. Mosleh, H. Hamidi Jamnani, “Seismic performance evaluation of urban bridge using static nonlinear procedure, case study: hafez bridge,” *Procedia Engineering*, volume 14, pp. 2350-2357, 2011.

[2] T. Usami, Z. Lu, H. Ge, T. Kono, “Seismic performance evaluation of steel arch bridges against major earthquakes. Part 1: dynamic analysis approach,” *Earthquake Engineering & Structural Dynamics*, volume 33, Issue 14, pp. 1337-1354, 2004.

[3] X. Li, D. Zhang, W. Yan, W. Xie, and M. Pandey, “Effects of model updating on the estimation of stochastic seismic response of a concrete-filled steel tubular arch bridge,” Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance, volume 10, Issue 12, pp. 1620-1637, 2014.

[4] ABAQUS, Ver.6.13, Dassault Systemes.

[5] A. K. Chopra, Dynamics of Structure-Theory and applications to earthquake engineering, Pearson Education, Prentice Hall, New Jersey, USA.

[6] Architectural Institute of Korea. Korean building code and commentary; 2009.