International Balkans Conference on Challenges of Civil Engineering, BCCCE,

19-21 May 2011, EPOKA University, Tirana, ALBANIA.

Simplified Earthquake Analysis of Suspension Bridges by Finite Element Method

Süleyman Adanur[1], Mehmet Akköse[1], Alemdar Bayraktar[1], A. Aydın Dumanoğlu[2]

[1]*Department of Civil Engineering, Karadeniz Technical University, Trabzon, Turkey*
[2]*Department of Civil Engineering, Avrasya University, Trabzon, Turkey*

ABSTRACT

This paper presents the finite element analysis of a suspension bridge subjected to earthquake ground motion using simplified models. For this purpose, two simplified models are considered. It is assumed that each element compose of the deck, cable and hangers in the first model. As second model, the elastic foundation analogy method is used. Also, actual bridge model is selected. Finite element earthquake analyses of the simplified and real bridge models are performed. One of the world's longest modern type suspension bridges, Fatih Sultan Mehmet Bridge, is selected as a numerical example. As ground motions, Kocaeli earthquake occurred on August 17, 1999 in Kocaeli, Turkey is chosen since it took place at the vicinity of the bridge. The response values obtained from simplified and actual bridge models are compared with each other.

INTRODUCTION

Suspension bridges are complex structures made of deck, tower, cable, anchorage and hanger. Analysis of suspension bridges, both in the static and dynamic fields required experience. Suspension bridges are designed correctly today by making extensive use of finite element method and computers [1]. This paper aims to compare the analysis results by simplified models and classical model using finite element model. In addition to the classical model, two simplified models are used in the analyses. The first simplified model takes into account the characteristics of both the cable and deck [2]. The cable and deck are idealized by beam elements. The cable and deck elements connected by rigid hangers form the bridge element. The elastic foundation analogy method is used as second model [3].

DESCRIPTION OF THE BRIDGE

Fatih Sultan Mehmet (Second Bosporus) Suspension Bridge connecting the Europe and Asia Continents in Istanbul, Turkey has a box girder deck with 39.4 m wide overall and 1090 m long. There are no side spans and the steel towers rise 110 m above ground level. The hangers are vertical and connect to the deck and cable with singly hinged bearing. The horizontal distance between the cables is 33.8 m and the roadway is 28 m wide, accommodating two four-lane highways. The roadway at the mid-span of the bridge is approximately 64 m above the sea level. Figure 1 shows the view of the bridge.

As the deck, towers, and cables of the selected bridge are modeled by beam elements; the hangers are modeled by truss elements. A finite element model of the bridge with 144 nodal points, 142 beam elements, 60 truss elements are used in the analyses (Figure 2). This model has three degrees of freedom at each nodal point, namely, two translational degrees of freedom in vertical and longitudinal axes and one rotational degree of freedom in lateral axis [4]. So, the finite element model of the bridge is decreased to 418 degrees of freedom and therefore a 2D analysis is adopted in the vertical plane of the bridge.

The GBZ000 component of the August 17, 1999, Kocaeli, Turkey earthquake (Figure 3) is chosen as ground motion since it took place at the vicinity of the bridge. For earthquake response analysis of many types of structures, the vertical component of ground motion may not be important. For long-span bridges like suspension bridges, however, vertical ground motion is important. In this study, only the vertical component of the ground motion is applied to the bridge to determine the vulnerability of this bridge to earthquake ground motion. The first 15 modes of vibration are adopted for the response calculations. 2% damping ratio is used for the bridge models. For a detailed finite element analysis (FEA), the general purpose commercial FEA software, SAP2000 (1997), is used. Figures 4 and 5 show the elastic foundation analogy and discretization models of the bridge, respectively.

Figure 1 The view of Fatih Sultan Mehmet Suspension Bridge

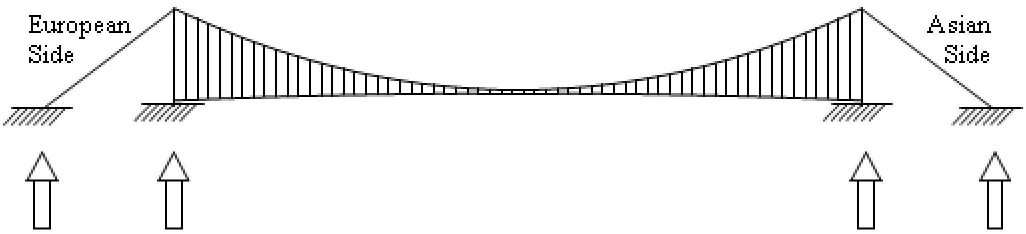

Figure 2 2D finite element model of the suspension bridge

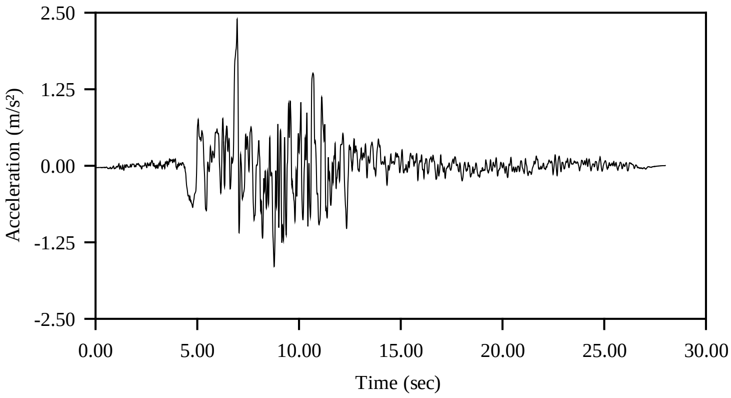

Figure 3 GBZ000 component of August 17, 1999 Kocaeli earthquake

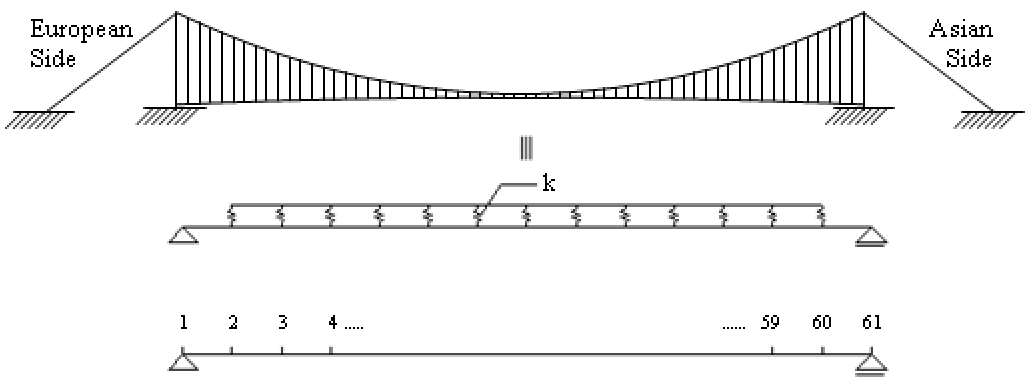

Figure 4 Elastic foundation analogy model of the bridge

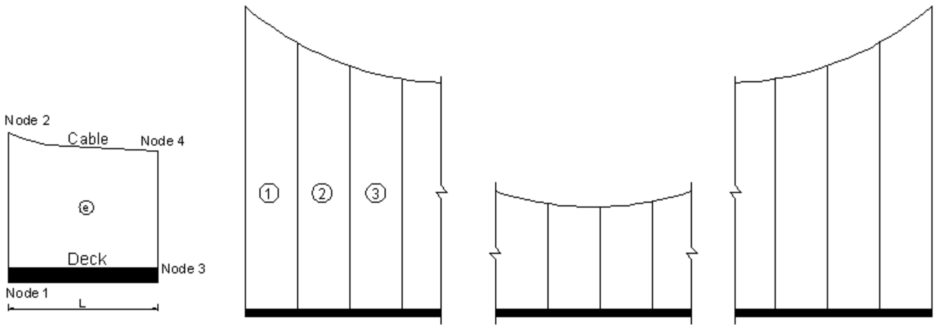

Figure 5 Discretization model of the bridge

EARTHQUAKE RESPONSE OF THE BRIDGE

Tower Responses

Variation of displacements and internal forces such as bending moment, axial forces and shear forces with height of European side tower subjected to Kocaeli 1999 earthquake ground motion for each analysis is shown in Figure 6. It can easily be seen in Figure 6 that the horizontal displacements increase along the height of the tower and that those corresponding to discretization model (DM) motion are bigger than classical model (CM) results.

Deck Responses

Variation of displacements and internal forces such as bending moment and shear forces along to the bridge deck subjected to Kocaeli 1999 earthquake ground motion for each analysis is shown in Figure 7. It can easily be seen in Figure 7 that the vertical displacements increase along the middle of the bridge deck and that those corresponding to elastic foundation analogy (EFA) model are bigger than classical (CM) and discretization (DM) models results. Also, there is a good agreement between the result obtained from EFA and DM models.

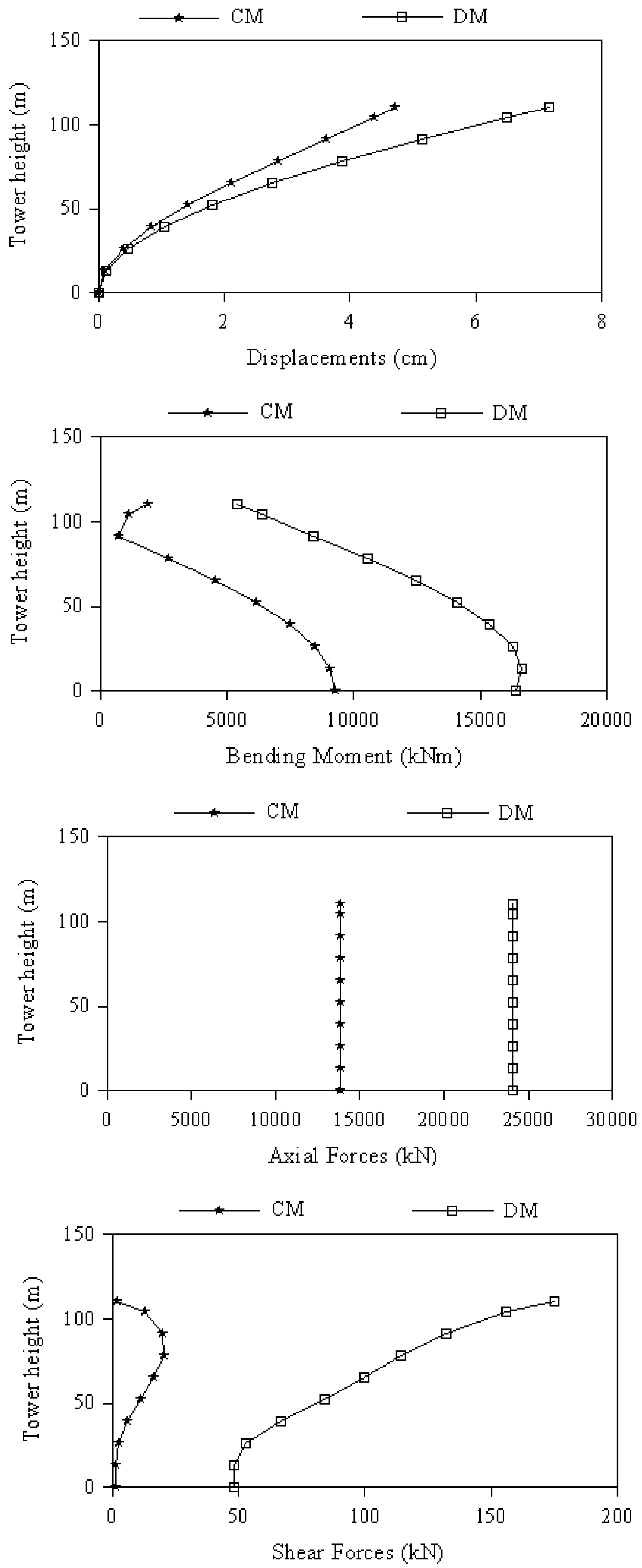

Figure 6 Horizontal displacements and internal forces along the height of European side tower

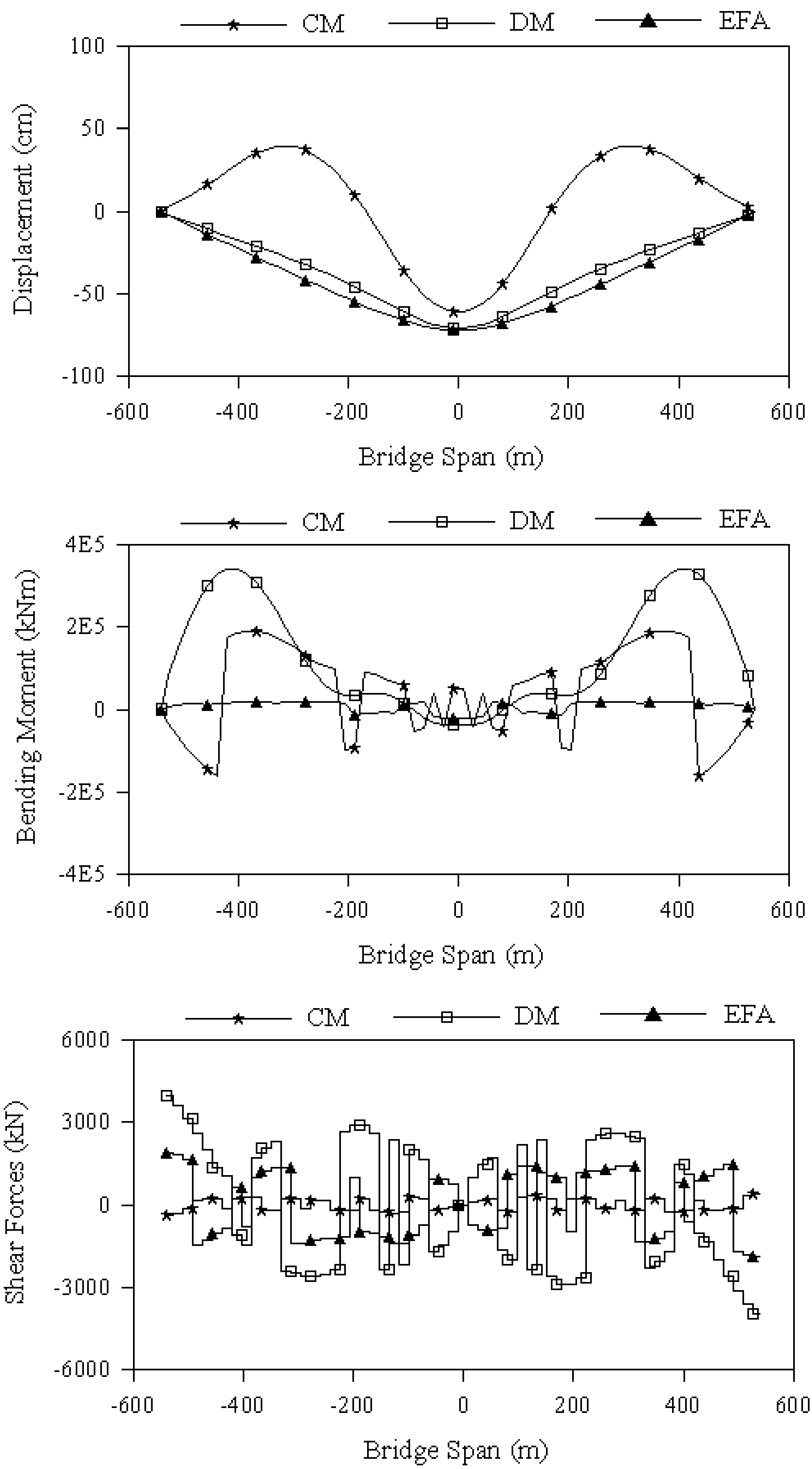

Figure 7 Vertical displacements and internal forces along the bridge deck

The time histories of vertical displacements on the deck point where maximum value took place for each models are presented in Figure 8. The maximum displacements for CM, DM and EFA are obtained as 60.76 cm, 70.65 cm, and 72.01 cm, respectively.

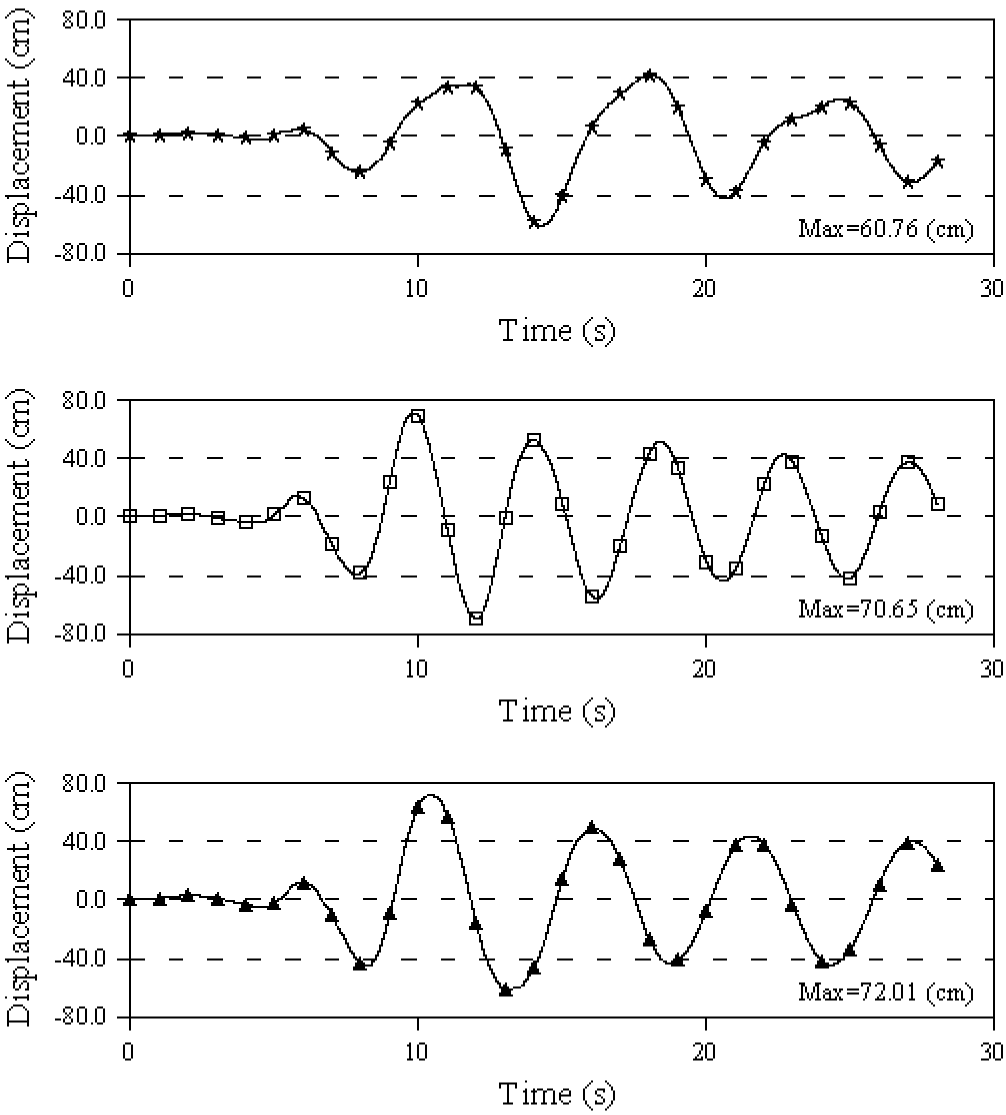

Figure 8 The time histories of vertical displacements for each models

The time histories of maximum bending moments on the deck point where maximum value took place for each models are presented in Figure 9. The maximum bending moments for CM, DM and EFA are obtained as 2.2E4 kNm, 3.34E5 kNm, and 1.7E5 kNm, respectively.

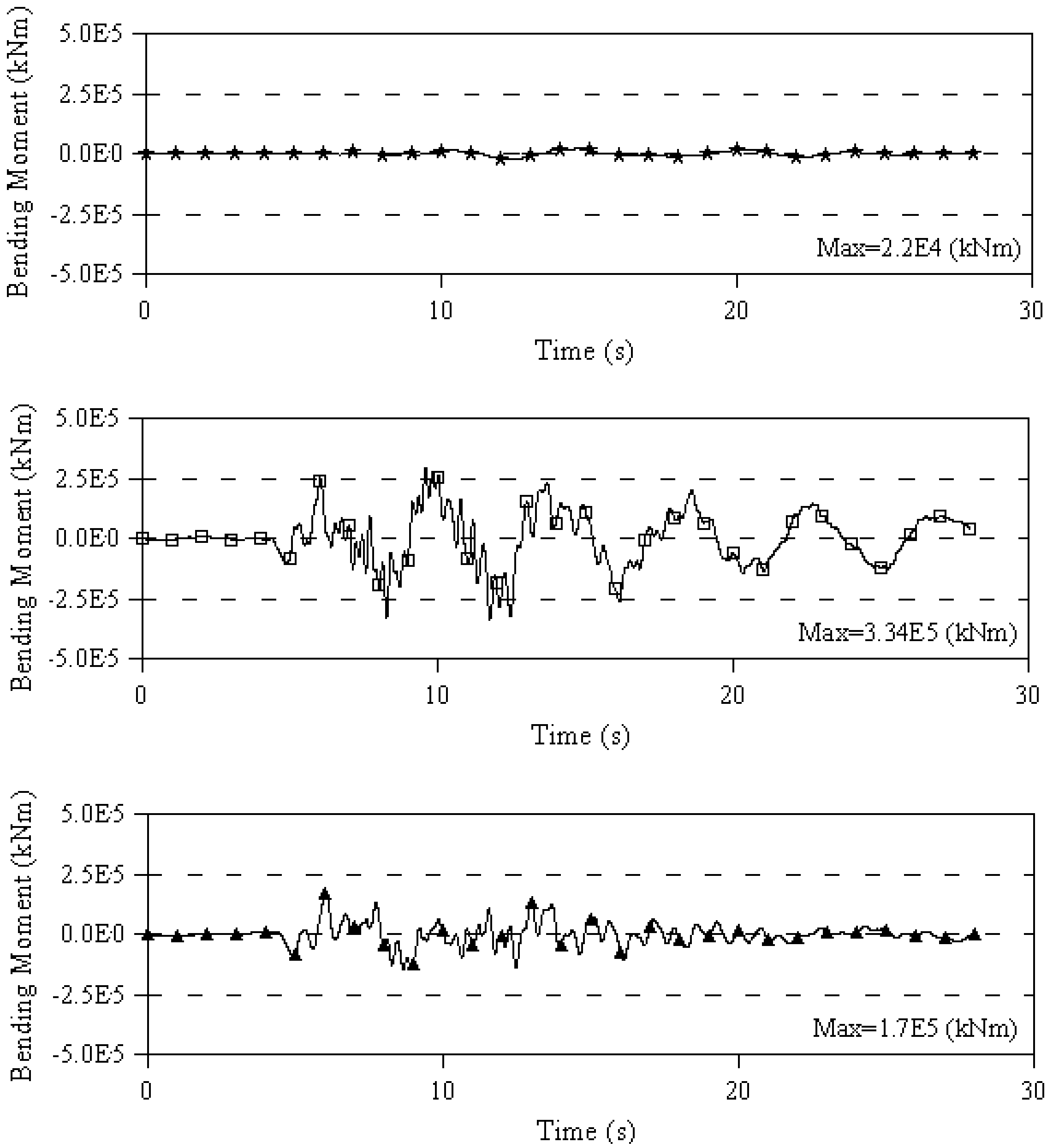

Figure 8 The time histories of bending moments for each models

CONCLUSIONS

This paper presents the finite element analysis of a suspension bridge subjected to earthquake ground motion using simplified models. For this purpose, two simplified models are considered. One of the world's longest modern type suspension bridges, Fatih Sultan Mehmet Bridge, is selected as a numerical example. As ground motions, Kocaeli earthquake occurred on August 17, 1999 in Kocaeli, Turkey is chosen since it took place at the vicinity of the bridge. The following conclusions can be drawn from this study:

- Horizontal displacements increase along the height of the tower and that those corresponding to discretization model (DM) motion are bigger than classical model (CM) results.
- Vertical displacements increase along the middle of the bridge deck and that those corresponding to elastic foundation analogy (EFA) model are bigger than classical (CM)

and discretization (DM) models results. Also, there is a good agreement between the result obtained from EFA and DM models.

- The time histories of vertical displacements on the deck are obtained as 60.76 cm, 70.65 cm, and 72.01 cm, respectively.
- The time histories of maximum bending moments on the deck are obtained as 2.2E4 kNm, 3.34E5 kNm, and 1.7E5 kNm, respectively.

Although the simplified models are coarser than the classical model, the results obtained from the simplified models are bigger. So, it can be said that the design of bridges according to the simplified models are reliable.

REFERENCES

[1] Cobo del Arco, D. and Aparicio, A.C. (2001) Preliminary Static Analysis of Suspension Bridges. *Engineering Structures*, **23**, 1096-1103.

[2] Hawwari, A.R. (1992) *Suspension Bridge Response to Spatially Varying Ground Motion*. PhD Thesis, Michigan State University, USA.

[3] Pugsley, A. (1953) A Simple Theory of Suspension Bridges. *Journal of the Institution of Structural Engineers*, **31**, 75-82.

[4] Dumanoglu, A.A., Brownjohn, J.M.W. and Severn, R.T. (1992) Seismic Analysis of the Fatih Sultan Mehmet (Second Bosporus) Suspension Bridge. *Earthquake Engineering and Structural Dynamics*, **21**, 881-906.