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RESPONSE OF FATIH SULTAN MEHMET SUSPENSION BRIDGE UNDER SITE-SPECIFIC MULTI-POINT EARTHQUAKE EXCITATIONS

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ABSTRACT

In the present study, it is aimed at how Fatih Sultan Mehmet suspension bridge behaves under site-specific multi-point earthquake excitations, in accordance with, determining the structural earthquake performance of the bridge. For this aim, based upon recently-proposed 3-D finite element model of the bridge is updated and response parameters of the bridge are determined, and site-specific strong ground motions in x, y and z directions are produced for each support of the bridge considering the Mw=7.5 scenario earthquakes on the main Marmara Fault. Non-linear earthquake time-history analysis of the bridge subjected to multi-point excitation is then carried out using these seismic ground motion time-histories. By means of this analysis, the effect of site-specific multi-point earthquake excitations on the bridge is investigated and earthquake response characteristics of the bridge are compared to those obtained from uniform support excitations.

INTRODUCTION

As a result of the 1999 İzmit and Düzce earthquakes Mw=7.4, there has been an increased awareness about the seismic vulnerabilities of transportation systems in Turkey, especially in İstanbul. Bridge structures, particularly suspension bridges are the most significant component of them, and also the area around Istanbul has long been known as a region of high seismicity, with the famous North Anatolian Fault-NAF lying 80 km kilometers to the southeast of Istanbul (Erdik et al., 2003). Therefore, it becomes a critical point to know structural behavior of the bridges in Turkey under a new major earthquake in future.

Concerning suspension bridges in Turkey, Bosporus Ataturk and Fatih Sultan Mehmet suspension bridges in Istanbul, there is limited number of studies on determination of seismic response of these bridges. In this regard, Apaydin (2002) carried out both analytical and experimental study for the aim of determining the dynamic properties of Fatih Sultan Mehmet suspension bridge and developed a detailed three-dimensional finite element model with line elements. Erdik and Apaydin (2005) determined the natural frequency and corresponding mode shapes of two Bosporus suspension bridges in their dead and live load. Dumanoglu and Brownjhon (1992), Brownjohn et al. (1992) studied on the natural dynamic properties for Fatih Sultan Mehmet (Second Bosphorus) bridge. They used auto power spectrum methods to find the modal frequencies. They indicated that the measured and computed values were relatively compatible for the low frequency range. Nevertheless, they presented an increasing divergence for frequencies with higher value. Brownjohn (1994) also looked into the effect of nonlinear behavior on modal properties of Bosporus and Fatih Sultan Mehmet Bridge, and determined that non-

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linear behavior was appeared under low-level dynamic excitation. Erdik and Uckan (1989) conducted ambient vibration survey of the Bogazici Suspension bridge for comparing their values with that of the previous studies. The detailed study to determine the influence of site-specific uniform ground motions on suspension bridges with large spans in Istanbul is done by one of the author of the present study (Apaydin, 2010). In that study, Bosporus and Fatih Sultan Mehmet suspension bridge were exposed to uniform earthquake excitations consisting of three simulated earthquake ground motions in x, y and z direction. In the present study, further earthquake time-history analysis of Fatih Sultan Mehmet Bridge is carried out. For this analysis, twelve site-specific simulated multi-point excitations in x, y and z directions act simultaneously on each support of the bridge. In the light of these considerations, it is aimed at investigating multi-point earthquake excitations on the bridge and then determining earthquake performance of the bridge.

GENERAL OUTLINE OF THE BRIDGE

Sectional and material properties of the bridge are available in (Apaydin, 2002), and also general arrangement and principal dimensions of the bridge are shown in Fig. 1.

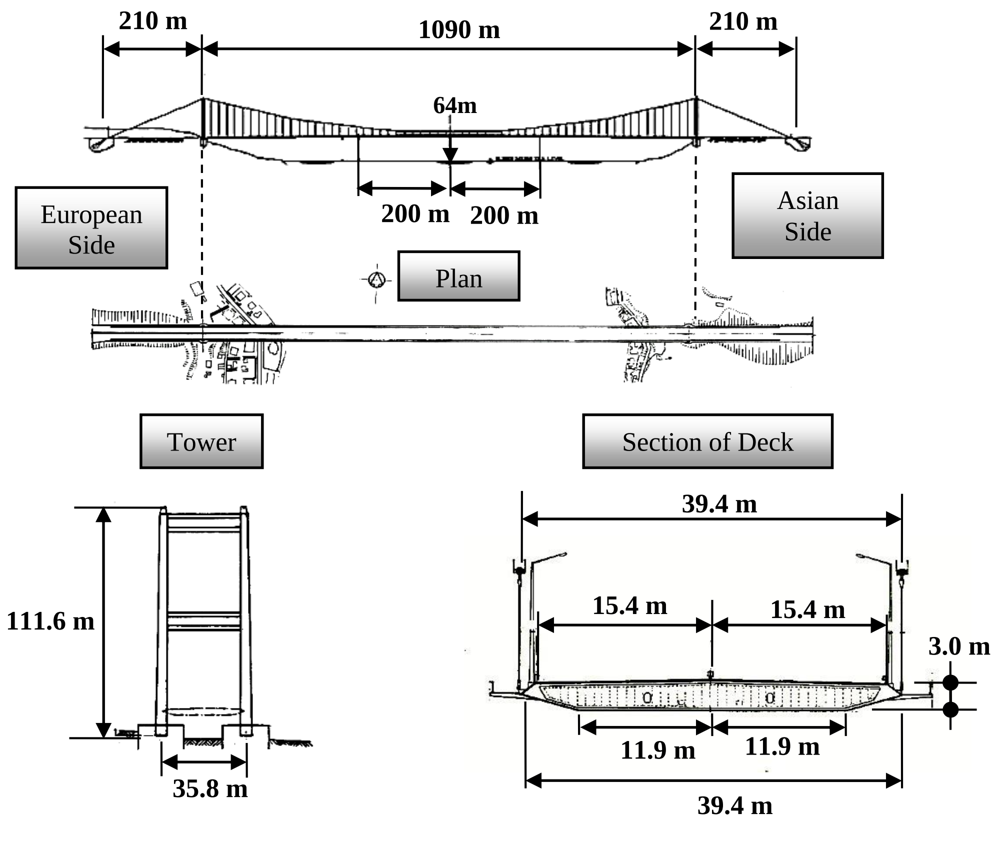

Figure 1. General arrangement of Fatih Sultan Mehmet Suspension Bridge (Fox and Partners, 1988)

DYNAMIC VIBRATION PROPERTIES OF THE SUSPENSION BRIDGE

All beams and columns of the bridge are regarded as frame element, whereas main cable, hangers and backstay cable have been considered as cable element. The sources of geometric nonlinearity i.e. change of cable geometry under different tension load levels (cable sag effect), change of the bridge geometry due to large displacements, and axial force, bending moment interaction in the bridge deck and pylon (P-Δ effect) are taken into account in existing 3-D finite element model.

3-D finite element model of the bridge is adjusted depending upon the recently-proposed model. For finite element modelling of the bridge, the latest version of SAP2000 (CSI, 2012) is utilized to be able to do multi-point earthquake analysis of the bridge. The 3-D finite element model of the bridge is revealed in Fig. 2.

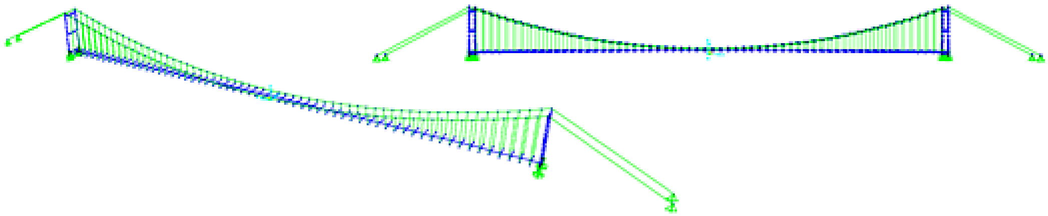

Figure 2. Finite element model of Fatih Sultan Mehmet Bridge

Dynamic analysis of suspension bridges is performed with relatively detailed model using finite element program SAP2000 and the results of dynamic modal analysis of Fatih Sultan Mehmet Bridge are presented. Up on calculating natural frequencies of vibration and the corresponding mode shapes in service loads, longitudinal, transverse and vertical direction are considered. The further mode shapes for extended structures such as tall buildings and suspension bridge become so important that these modes can affect the earthquake analysis of the structures considerably. In the scope of the study, the first 50 natural periods and associated mode shapes were attained, and the most effective first 5 mode shapes are denoted in Fig. 3, and detailed knowledge of the first 5 mode shapes were also given in Table 1. The modal participation mass ratios that provide a mean for judging the “significance” of a vibration mode can also be determined.

Table 1. The results of Free Vibration Analysis of Fatih Sultan Mehmet Bridge

Mode Number	Mode Shape	Period	Frequency
		Sec	Cyc/sec
1	1st Lsym	14.37981	0.06954
2	1st Vasym Long	10.02130	0.09979
3	2st Vasym Long	6.74467	0.14827
4	1st Vsym	6.39717	0.15632
5	1st Lasym	4.81284	0.20778

Lsym: Lateral symmetric; Vasym: Vertical asymmetric
Vsym: Vertical symmetric; Long: Longitudinal.

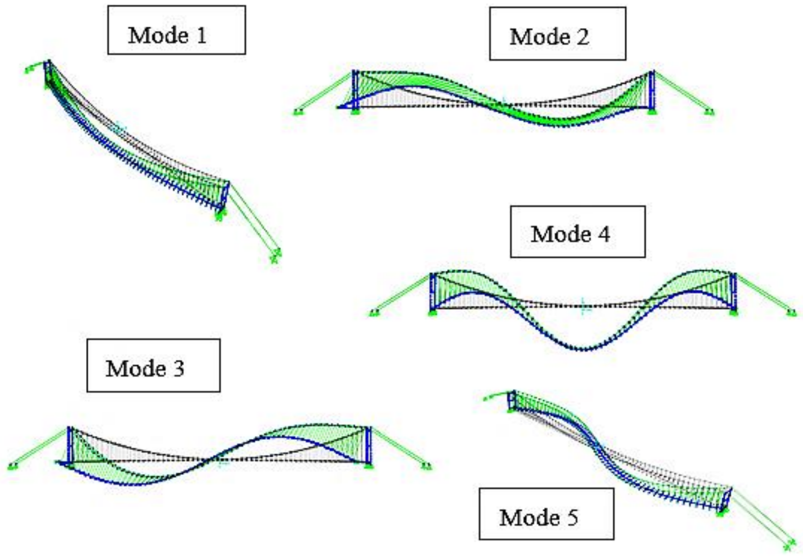

Figure 3. The first 5 mode shapes of the bridge

As expected before carrying out dynamic analysis, the dominant mode shape that is crucial for earthquake effect on structures is in the direction of transverse of the bridge because higher degree of freedom of the bridge is in this direction. With considering the first 50 mode shapes of the bridge, 99 percent of the total mass ratio in x, y and z directions which is necessary for structures to regard earthquake effect as accurate is provided.

PROPERTIES OF SIMULATED SITE-SPECIFIC GROUND MOTION

The distance of Bosporus straits on the location of the bridge is approximately 850 m; nevertheless, the length between towers of the bridge is 1090 m.

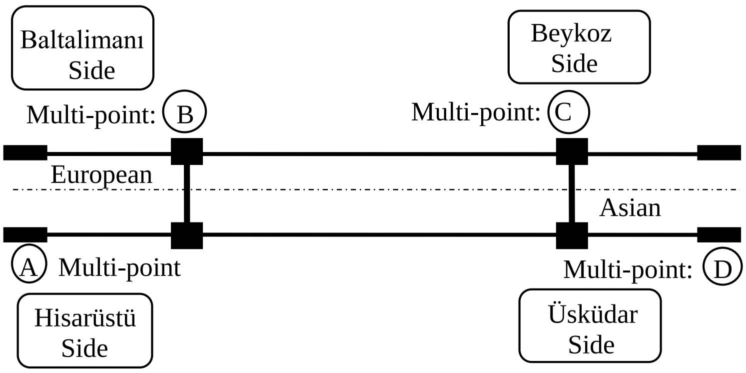

Figure 4. Locations of supports for multi-point earthquake time history analysis

Taking soil conditions of the bridge supports into account, site specific earthquake motions in x, y and z directions for each supports are generated by Earthquake Engineering Department of Bosporus University. The locations of the supports point are shown at Fig. 4 and their global geographic coordinates are given from Fig. 5. The bridge has two towers and two anchorages supports at each

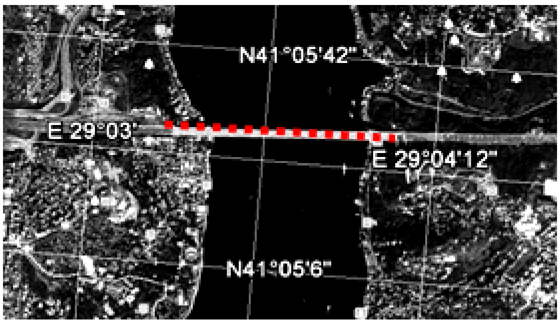

Figure 5. Global geographic coordinates of Fatih Sultan Mehmet suspension bridge

the two banks of Bosporus. Every tower is also supported by two restrains. Thus, it can be said that the bridge has eight different sup-ports, and four locations are considered for deter-mining site-specific multi-point earthquake input motions because two supports at each tower and anchorage point which are close enough (35.8m) in Fig. 6 have same site properties

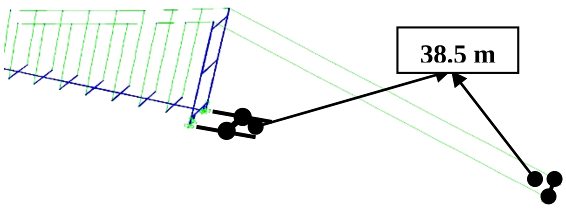

Figure 6. Supports at pylon and anchorage points

In the light of these considerations, 12 site-specific simulated ground motions for 8 supports (4 pylons and 4 anchorages) are stochastically produced in longitudinal, transverse and vertical direction by taking into account the Mw=7.5 scenario earth-quakes on the main Marmara Fault and site proper-ties of the two banks of the Bosporus on which the bridge is located. For the purpose of making multi-point earthquake analysis, 12 site-specific simulated ground motions are used. These ground motions are shown in Figs. 7-10.

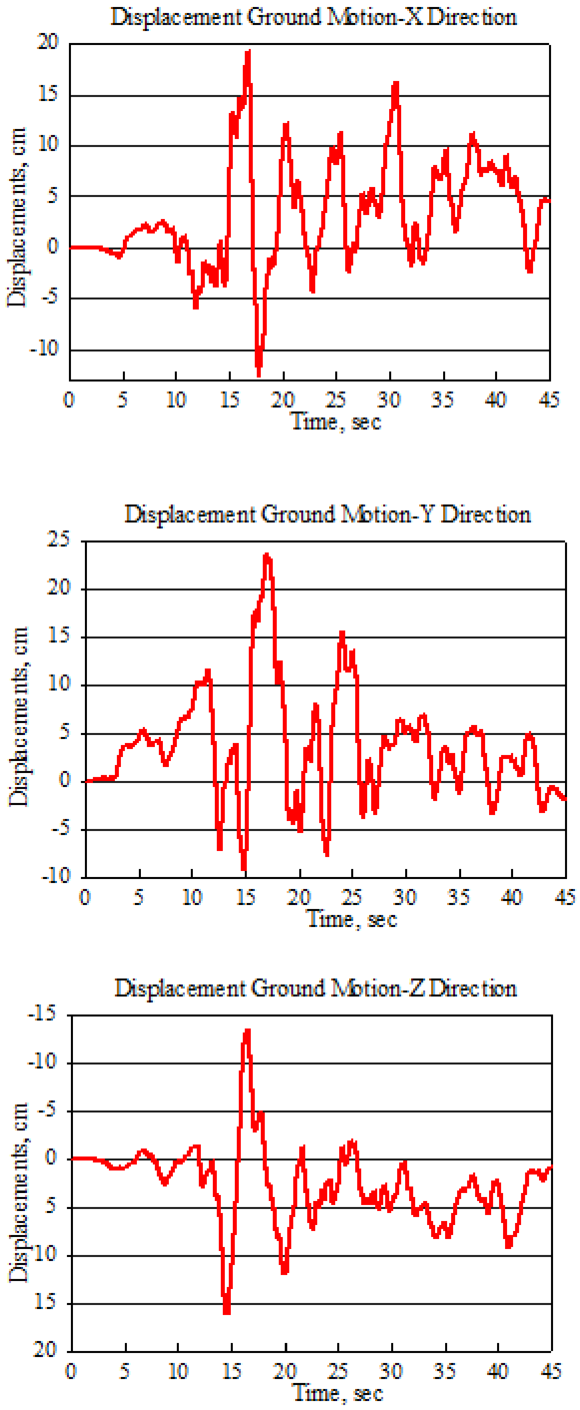

Figure 7. Time-history records for multi-point A

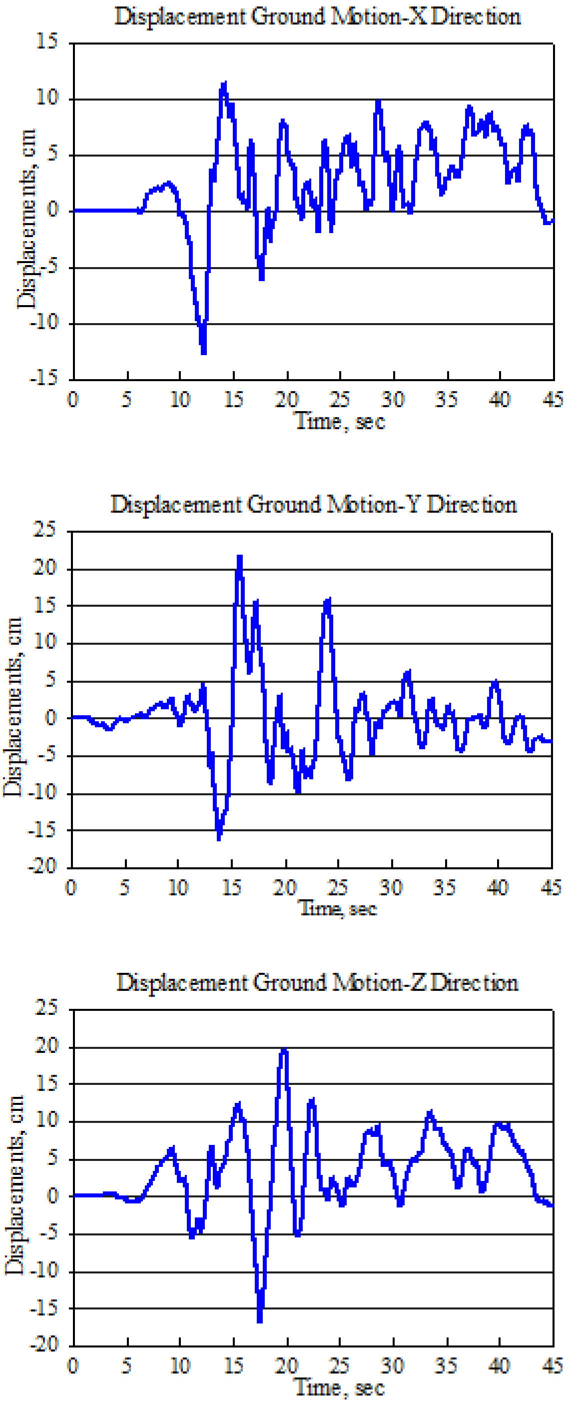

Figure 8. Time-history records for multi-point A

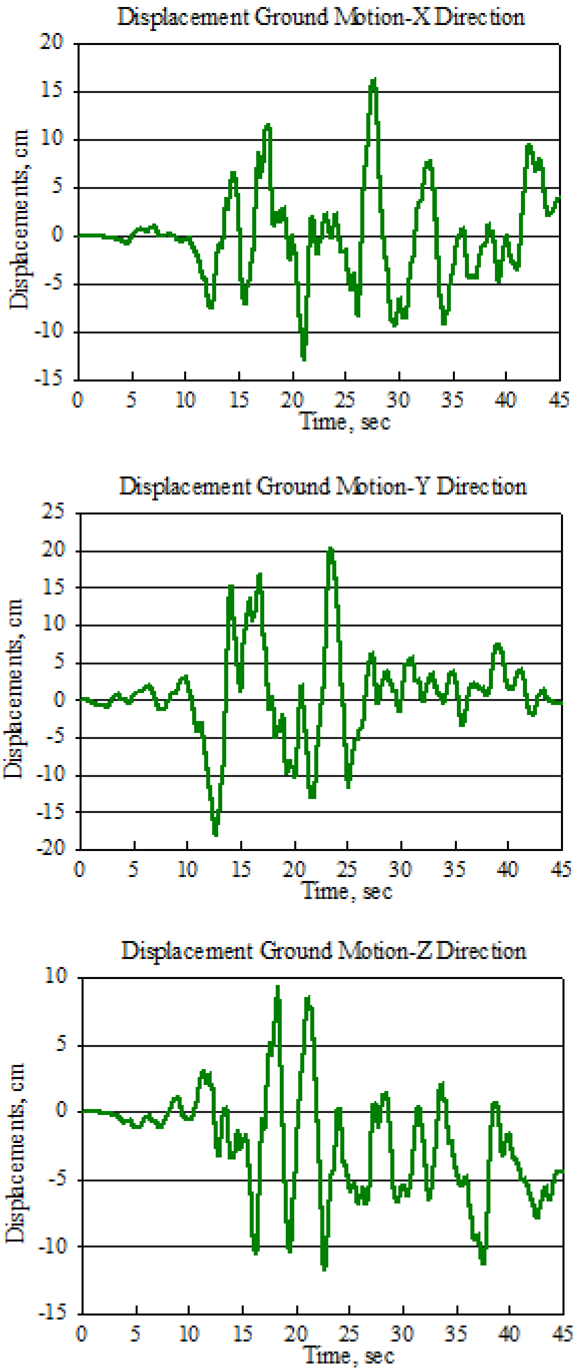

Figure 9. Time-history records for multi-point A

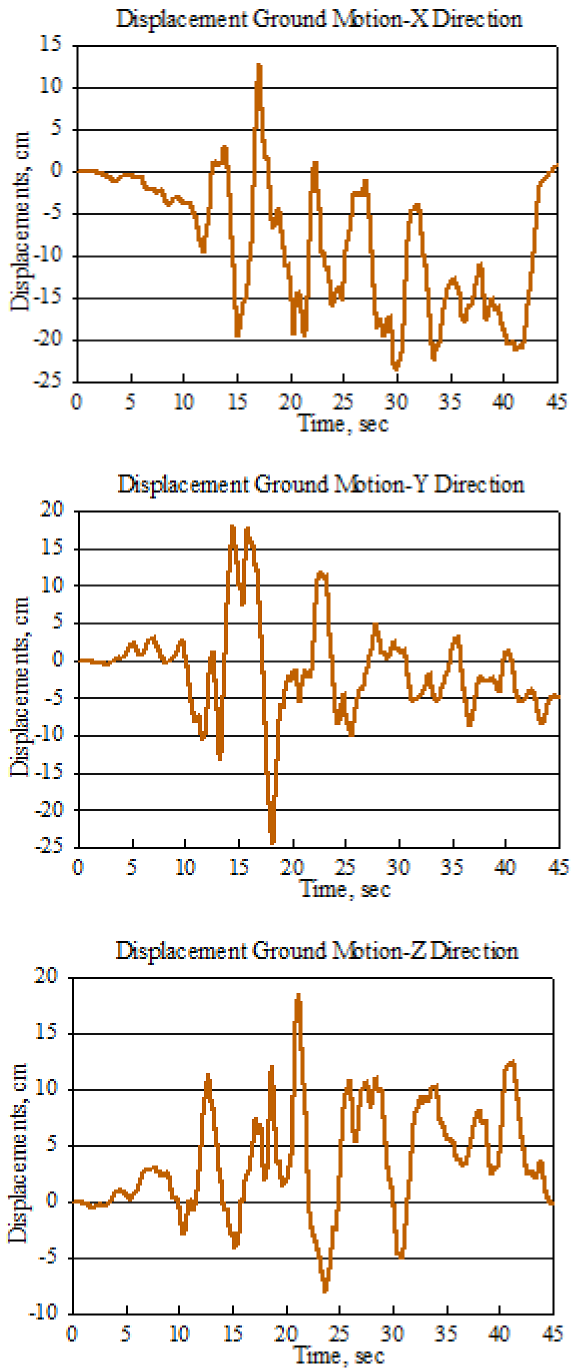

Figure 10. Time-history records for multi-point A

MULTI-POINT EARTHQUAKE TIME-HISTORY ANALYSIS OF THE BRIDGE

For this type of sophisticated analysis method, earthquake ground motions are regarded as dis-placement time-history record instead of acceleration time-history record which is general assumption for earthquake analysis of structures. In this chapter, the general steps of this analysis method are summarized by following.

It is the primary to determine the displacement time-history earthquake motion record calculated from site-specific acceleration ground motion by means of any numerical integration method. After unit displacement is implemented separately for each support, the displacement-time history earthquake motions are acted on the related supports. Lastly, the combined time-history analysis is carried out.

Those stages above are usually valid for every type of structures because all section forces or sup-port reactions of the bridge result from the support displacement changing with time. In this study, multi-point earthquake analysis of Fatih Sultan Mehmet is performed taking into consideration the effect of support displacements. For this purpose, the bridge is analyzed by using the latest version of SAP2000 under site-specific simulated ground motions.

CONCLUSION

As a consequence of the non-linear time-history analysis using site specific multi-point earthquake records, the results listed below were concluded. Firstly, towers are moving in the opposite direction to each other in the transverse direction. All results and the schematic representation of the towers are given in Table 2 and Fig. 11, respectively. This situation gives extra strain to the main and side cables.

Table 2. Maximum Displacements of Tower Top Saddle.

Load Case	Location	Max.displacement of top point of tower (m)	
		Direction	
		Transverse (m)	Longitudinal (m)
Multi-Point Earthquake	European Side	0.18	0.74
	Asian Side	-0.23	-0.90

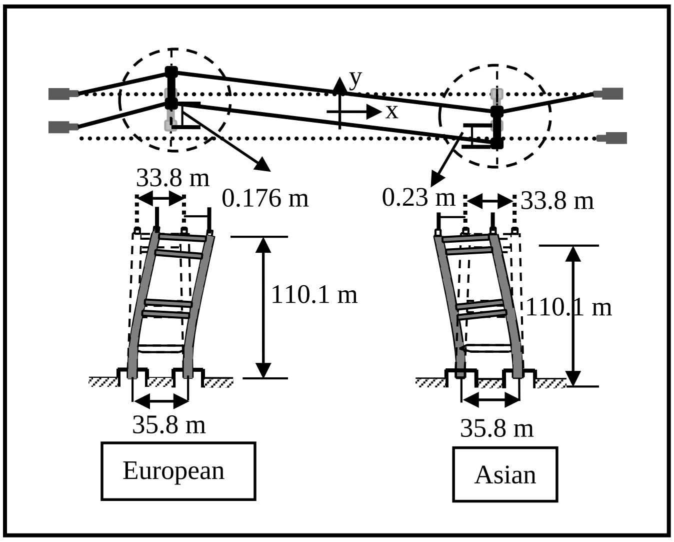

Figure 11. Displacement of tower top saddle for multi-point earthquake excitation

As a result, axial tensile stresses of the main and side cables increased. The transverse direction due to the movement of the base of the towers, the tower in the same way there was an increase in shear force. It can be seen from Table 3.

The results obtained from simple-point and multi-point excitation analysis when compared, while the rate of increase was 2% at the main cable, this range was 1.2% at the side cable. The reason for the lower rate of increase in the side span cable can be seen as fixed points at the anchor point.

As a result of increase in axial tension forces in the main and back-stay cables, axial load at the top of the tower increased. This increase in the base of the tower has caused an increase of the axial force. Lastly, as a result of the decrease in shear force at the top of the tower, bending moment in the base of the tower has decreased.

Table 3: Seismic Performance Assessment of Fatih Sultan Mehmet Bridge.

Structural Elements of the Bridge.	Multi-point Earthquake Analysis (Max.) Current Study	Simple-point Earthquake Analysis (Max.) (Apaydın, 2010)
Tensile Force of Main Cable (kN)	188650	183500
Tensile Force of Side Span Cable (kN)	201229	198900
Axial Force of Main Cable at Tower Top Saddle (kN)	159698	156400
Shearing Force of Main Cable at Tower Top Saddle (kN)	1960	3866
Base Section of Tower Column Axial Force (kN)	181689	167700
Base Section of Tower Column Shearing Force (kN)	6192	3807
Base Section of Tower Column Bending Moment (kN.m)	152047	189208

This findings show the effect of site-specific multi-point earthquake excitation. As can be seen here, suspension bridges are the important structures and such long span bridges should be analyzed using site-specific ground motion for their different supports to obtain reliable responses to earthquakes.

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