Soil Dynamics and Earthquake Engineering 84 (2016) 44–54

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Response of the Fatih Sultan Mehmet Suspension Bridge under spatially varying multi-point earthquake excitations

Nurdan Memisoglu Apaydin [a,*], Selcuk Bas [b], Ebru Harmandar [c]

[a] General Directorate of State Highways, 1st Division Directorate, Kağıthane, 34408 Istanbul, Turkey
[b] Department of Civil Engineering, Faculty of Engineering, Bartin University, Bartin, and Structural and Earthquake Engineering, Faculty of Civil Engineering, Istanbul Technical University, Maslak, 34469 Istanbul, Turkey
[c] Kandilli Observatory and Earthquake Research Institute, Department of Earthquake Engineering, Bogazici University, Cengelkoy, 34684 Istanbul, Turkey

ARTICLE INFO

Article history:
Received 7 January 2014
Received in revised form
30 September 2015
Accepted 23 January 2016
Available online 19 February 2016

Keywords:
Suspension bridge
Structural earthquake performance
Non-linear earthquake time-history
Multi-point earthquake excitation
Spatially varying ground motion

ABSTRACT

The study aims at investigating the structural behavior of the Fatih Sultan Mehmet Suspension Bridge, i.e. the second Bosphorus Bridge in Turkey, under multi-point earthquake excitations, and determining the earthquake performance of the bridge based on the results obtained from this analysis. For this objective, spatially varying ground motions in triple direction were produced for each support of the bridge considering the Mw=7.4 scenario earthquakes on the main Marmara Fault. In order to simulate the ground motions, modified stochastic finite-fault technique was utilized. Taking the ground motions into account, non-linear time-history analysis was carried out, and the results obtained from the analysis were compared to those from uniform support earthquake excitation to identify the effects of multi-point earthquake excitations on the seismic performance of the bridge. From the analysis, it was determined that modal response of the towers and the deck was mostly effective on dynamic response of the entire bridge rather than other structural elements, such as cable and approach viaduct. Compared to the results obtained from simple-point earthquake excitation, noticeable axial force increase in the cable elements was obtained under multi-point earthquake excitation. The changes at the main cable and the side span cable were determined as 21% and 18%, respectively. This much increase in the cable elements led to increase in axial force at the towers and in shear force at the base section of the tower column. These changes in the structural elements were closely related to response of the deck and the towers since they had considerable contribution to response of the entire bridge. Based on the findings from the study, spatially varying ground motions has to be considered for long span suspension bridges, and the multi-support earthquake analysis should be carried out for better understanding and obtaining reliable results necessary for retrofitting and performance evaluation.

1. Introduction

In order to determine the effects of earthquake load on engineering structures, a well-known idealization in engineering practice is to suppose that structure is entirely excited from uniform earthquake ground motions. This assumption is generally accurate for the structures small in plan, such as buildings and short-span bridges. For long-span structures, however, such as suspension bridges, multi-point earthquake excitations should be considered.

Owing to noticeable importance of suspension bridges, analytical and experimental studies were conducted in literature. Abdel-Ghaffar et al. [1–3] proposed some methods to find the lateral vibration characteristics of suspension bridge using finite element method. Besides, Ghaffar and Scanlan [4,5] performed ambient vibration test to determine dynamic properties of the suspended members and the towers of the Golden Gate Bridge. They compared the measured frequencies to those obtained from numerical model of the bridge. Abdel-Ghaffar and Rubin conducted certain studies on the lateral and the vertical seismic response of the Golden Gate Bridge subjected to multi-support earthquake excitations [6–8]. In the first study, they also presented the vertical and lateral seismic responses of the Golden Gate Bridge to traveling earthquake excitations [9]. In the second study, Abdel-Ghaffar and Stringfellow showed that the majority of modes were considered so as to obtain a reasonable representation of the lateral response similar to the vertical response analysis [10]. Der Kiureghian et al. proposed response spectrum method for seismic analysis of multiple supported structures. Spatially varying ground motions resulting from the loss of coherency with distance and local soil conditions were used in their studies. They concluded that spatial variability decreased the dynamic response of the structures subjected to uniform ground motions, and that the response was generally

* Corresponding author. Tel.: +90 533 6267355; fax: +90 212 312 1717.
E-mail addresses: napaydin@kgm.gov.tr, napaydin@boun.edu.tr (N.M. Apaydin), selcukbas@itu.edu.tr, sbas@bartin.edu.tr (S. Bas), ebru.harmandar@boun.edu.tr (E. Harmandar).

http://dx.doi.org/10.1016/j.soildyn.2016.01.018
0267-7261/

magnified under the rapid loss of coherency with distance due to an increase in the quasi-static component of response [11]. Dumanoglu and Soyluk [12] estimated the general features of stochastic analysis of a cable-stayed bridge taking into account site-specific earthquake ground motions. For this study, random vibration based spectral analysis method was used. They marked the importance of spatially varying ground motion for the supports of the bridge. Dumanoglu and Severn [13] investigated the response of suspension bridges to earthquake motion considering the stochastic effect. Soyluk [14] conducted a study to estimate the effects of the spatial variability of ground motions on two deck-type arch bridges and a cable-stayed bridge. In the study, a random vibration-based spectral analysis approach and two response spectrums were considered. It was found that structural dynamic response of the bridges considerably relied on the intensity and frequency contents of power spectral density functions.

As a consequence of Izmit (1999) and Duzce earthquakes with Mw=7.4, there has been an increased awareness about seismic vulnerabilities of the transportation systems in Turkey, especially in Istanbul. Bridge structures particularly suspension bridges are the most significant component of these systems, and the area around Istanbul has been known as a region of high seismicity due to the famous North Anatolian Fault – NAF, which extends to the southeast of Istanbul [15]. Therefore, it becomes an important priority to estimate the structural behavior of the bridges in Turkey under potential earthquake in the future.

When it comes to the suspension bridges in Turkey (the Bosphorus Ataturk and the Fatih Sultan Mehmet and the ongoing project of the Yavuz Sultan Selim Bridges), limited studies on the seismic response of the bridges were performed. Apaydin [16] carried out both analytical and experimental studies to determine dynamic properties of the Fatih Sultan Mehmet Suspension Bridge. Erdik and Apaydin [17] identified the natural frequency and corresponding mode shape of two Bosphorus suspension bridges. Dumanoglu and Brownjohn [18–20] studied the dynamic properties of the Fatih Sultan Mehmet (the Second Bosphorus) Bridge. In that study, they used auto power spectrum method to find the modal frequencies of the bridge. They also indicated that the measured and computed results were relatively in good agreement in the low frequency range. However, in higher frequency range such outcome was not obtained. Brownjohn [21] also investigated the effect of non-linear behavior on modal properties of the Bosphorus and the Fatih Sultan Mehmet Bridges, and concluded that non-linear behavior was observed under low-level dynamic excitation. Erdik et al. conducted ambient vibration survey (AVS) for the Bosphorus Suspension Bridge to compare the results obtained from AVS with those from the previous studies [22]. The detailed study was performed by Apaydın, one of the authors of the present study [23]. The study aimed at determining the influence of site-specific uniform ground motions on the suspension bridges in Turkey. In that study, the Bosphorus and the Fatih Sultan Mehmet Suspension Bridges were subjected to simple-point earthquake excitations in x, y and z directions.

In literature, there are a limited number of studies on the multi-point earthquake analysis of suspension bridges. In general, many of them were carried out considering uniform earthquake excitations for all supports whereas multi-point earthquake excitations have been used in some studies [12,14,24–31].

Table 1
Principal dimensions of the bridge [16].

Main span (m)	Length between the anchorages (m)	Clearance (m)	Height of deck (m)	Width of slab (m)	Carriageway (Lanes)	Height of tower (m)	Cross-section of tower (on the base) (m)
1090	1510	64	3.00	39.4	2 × 4	107.1	5.00 × 4.00

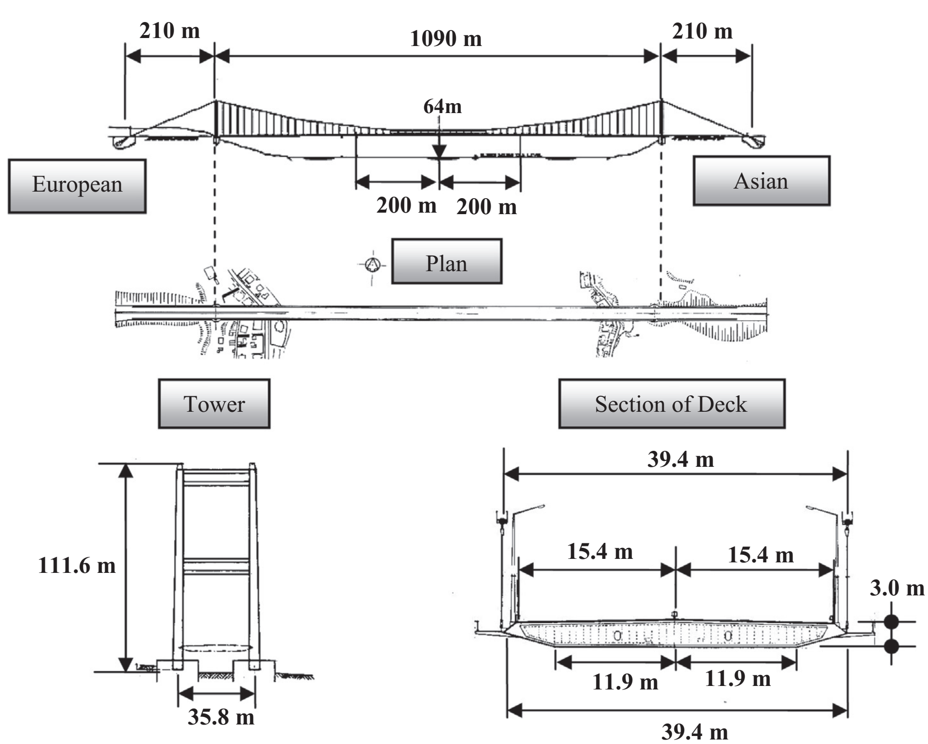

Fig. 1. General arrangement of the Fatih Sultan Mehmet Suspension Bridge [34].