Soil Dynamics and Earthquake Engineering 89 (2016) 5–11

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

2D non-linear seismic response of the Dinar basin,TURKEY

H. Khanbabazadeh [a,*], R. Iyisan [b], A. Ansal [c], M.E. Hasal [d]

[a] Bosphorus University, Kandilli Observatory and Earthquake Research Inst., Istanbul, Turkey
[b] Istanbul Technical University, Civil Engineering Faculty, Maslak, 34469 Istanbul, Turkey
[c] Ozyegin University, Civil Engineering Department, Istanbul, Turkey
[d] Bursa Metropolitan Municipality, Department of Housing and Urban Development, Bursa, Turkey

ARTICLE INFO

Article history:
Received 11 February 2015
Received in revised form
6 February 2016
Accepted 29 July 2016

Keywords:
Site effects
Dynamic behavior
Basin edge effect
Numerical modeling

ABSTRACT

Local geological conditions generate significant amplification of ground motion and concentrated damage during earthquakes. The highly concentrated damages at the edges of the Dinar basin during occurred earthquakes at regions close to rock outcrop bring up the effect of the inclined bedrock effect on the dynamic behavior of the basin with 2D geometry. In this study, first the idealized 2D model of the basin based on the results of the underground explorations and geologic investigations is proposed. Results show that Dinar basin has an asymmetric 2D geometry with two different bedrock angles at edges. Then, a numerical study using finite difference based nonlinear code which utilizes appropriate static and dynamic boundary conditions, and includes hysteresis damping formulation based on the user defined degradation curves is conducted using real earthquake motions of different strength and frequency content. The constructed model is subjected to the collection of 16 earthquakes with different PGA's of 0.1, 0.2, 0.3 and 0.4 g, four motions for each PGA. It was seen that the dynamic behavior of the basin is broadly affected by the two dimensional bedrock. The results indicates the higher effect of the 6° bedrock inclination at east part on the amplification with respect to the steeper 20° bedrock slope at the west. Also, the results show the insignificant effect of the bedrock at the depth more than 150 m on the amplification of the east edge. While the effect of the 6° bedrock angle at the east part continues until 1500 m from the outcrop, it affects the amplification until 700 m from the outcrop at the west part with 20° bedrock angle.

1. Introduction

The existence of the inclined bedrock at the sides of the basins bring about the concentration of the damages, which well known as basin edge effect [1–6]. At the high frequencies, the trapped waves at the basin edges bring about the concentration of the waves which results in the 2D effects. In this case, the behavior of the central part of the basin can be estimated using 1D analysis. At the low frequencies, along with the decrease in the concentration, the refraction of the waves from edges causes the formation of the surface waves which travels towards the central parts. The occurrence of interaction between surface waves and existing body waves cause the fluctuation in amplification at the surface. The seen damage pattern during 1st October 1995 earthquake at Dinar town, Turkey, where located at the edge of an alluvial basin is among the examples of such effect.

The insufficiency of the 1D analyses at the basin edge has been shown by researchers [7,8]. The application of the 2D and 3D analytical methods could results in better estimation of the dynamic behavior of the basins with different material properties and geometries during earthquakes [9–16].

The common method in modeling wave transmission in layered sites and dynamic soil-structure interaction in geotechnical earthquake engineering is the equivalent-linear method. On the other hand, the fully nonlinear method follows any prescribed nonlinear constitutive relation. Using a nonlinear material law, interference and mixing of different frequency components occur naturally; a proper plasticity formulation of the built-in models causes plastic strain increments to be related to stresses; shear and compression waves are propagated together in a single simulation. Although, this method correctly represents the physics but demands more user involvement and needs a comprehensive stress-strain model in order to reproduce some of the more subtle dynamic phenomena [17,18]. The progresses in the field of the numerical modeling have result in the application of the different methods for investigating 2D and 3D dynamic behavior of the sites [19–25].

* Corresponding author.
E-mail address: hadikhanbabazadeh@gmail.com (H. Khanbabazadeh).

http://dx.doi.org/10.1016/j.soildyn.2016.07.021
0267-7261/

The results of the 2D nonlinear analyses of the symmetric hypothetic basins with different bedrock angles showed the basin edge effect on the amplification [26]. It was seen that the amplification patterns of the sandy and clayey basins are different. Besides, the spectral amplification level and pattern of the different clay and sand types were different. Whole these results can be affected with the change of the depth and stratification [27,28]. In the present study, it is tried to analyze 2D dynamic behavior of a real basin with asymmetric geometry. For this purpose, the Dinar basin with the depth of 220 m which showed basin edge effect during a M 5.9 earthquake in 1995 was selected. The idealized asymmetric geometry and material properties of the basin was proposed using the results of the extensive laboratory and field explorations, and its 2D behavior under the effect of the 16 strong ground motions is investigated.

2. Dinar basin

Dinar town is located at the edge of an alluvial basin in the southwest Anatolia, Turkey. On 1 October 1995, an earthquake with the magnitude of ML = 5.9 occurred in Dinar, Turkey, causing heavy damage and fatalities within the town borders. Following the earthquake, in order to understand the effects of local site conditions on the earthquake intensity variation, extensive in-situ studies including SPT, CPT, PS-logging tests as well as microtremor measurements were carried out throughout the town. Fig. 1 shows the location of boreholes [29–34].

2.1. Geology and seismotectonics of Dinar

While Quaternary alluvial sediments lay in the western part of Dinar town, Eocene limestone and sandstone exist in the northern regions. The geological formations at eastern and southern regions are mainly composed of jura-cretaceous limestone and schist. The soil layers beneath the main settlement areas, which experienced high damage during the earthquake, are composed of quaternary alluvial deposits. During the underground explorations using water wells Oligocene conglomerate underlie the alluvial sediments between 100 and 200 m depths was observed [2,34].

There are two main fault systems around Dinar Town. One of them is Dinar-Civril fault which lays in the NW-SE direction and the other is Akdag fault with N-S direction. The Dinar-Civril fault which was the source of seismic activity during the 1995 Dinar earthquake, have got a 75 km long normal fault with a slight oblique left lateral component [35].

These two fault systems had caused to form a seismotectonic structure consisting of two grabens and a horst. A characteristic geological section of Dinar lying in the E-W direction which reveals the horst-graben structure is presented in Fig. 2.

2.2. Geotechnical site conditions and bedrock depth

In order to estimate the shear wave velocity profile of soil layers, at two of the pre-drilled boreholes suspension PS-logging tests until the approximate depths of 40 m were done. As an example, the results of the SPT and PS-logging test that were carried out at Dinar meteorological station site are shown in Fig. 3.

In order to determine the shear wave velocity profile and slope of edge bedrock, microtremor array measurements were carried out at three different sites as shown in Fig. 1. The results of microtremor array studies were combined with the in-situ test results, geological and topographical data to determine the two dimensional shear wave velocity profile and dynamic properties of soil layers in the basin [36,37].

3. Two dimensional model of Dinar basin and material

Based on the results of the underground explorations, and with respect to the E-W geologic cross section given at Fig. 2 the idealized geometry of the Dinar basin is proposed at Fig. 4.

As can be seen, the basin is located between two horsts. The bedrock has got 6° inclination at the east edge until the 180 m depths. From this depth until 220 m the bedrock angel decreases to 2°. At the west part steeper bedrock with 20° angle continues until the depth of 220 m. At the other parts, horizontal bedrock with the depth of 220 m is modeled. The width of the 2D basin model has been taken 6 km. Corresponding soil specifications are presented at Table 1.

A linear variation of the properties over basin depth has been provided as in Table 1. The 220 m basin depth is divided to two 200 m and 20 m layers on the bedrock in order to model the 20 m transient layer between bedrock and basin.

With respect to the selected soil properties, the corresponding G/G_{max} curves have been estimated based on relation proposed by Ishibashi and Zhang [38] and is presented at Fig. 5.

4. Strong ground motions and boundary conditions

In this study the constructed models are subjected to the collection of 16 earthquakes with different peak ground accelerations (PGA) level of 0.1, 0.2, 0.3 and 0.4 g, four motions for each PGA. The list of used earthquakes is presented at Table 2.

For missing the effect of soil layers on selected accelerograms they have been chosen from among those recorded on stiff layers during real earthquakes, or deconvoluted to the corresponding bedrock motion. These records are of different peak ground accelerations, frequency contents and durations.

The 2D dynamic analysis of this study is done using FLAC3D code. The combination of two advanced dynamic boundary formulation is used at the models boundaries. To model the real situation of interaction between bedrock and soil at the base of the model the flexible base logic [17] which utilizes quiet boundary is applied at the horizontal boundaries, while free-field boundaries are set at the vertical boundaries to simulate the infiniteness of the media at sides. To prevent the numerical distortion, and with respect to the frequency content of the input waves and the wave speed characteristics of the system, based on Kuhlemeyer and Lysmer [39–41] the spatial element size was selected smaller than one tenth to one eighth of the wavelength associated with the highest frequency component of the wave. Also, the formulation of the hysteresis damping is implemented by modifying the strain-rate calculation so that the mean strain-rate tensor (averaged over all subzones) is calculated before any calls are made to constitutive model functions.

The verification of this analysis has been done by comparing to the solution of Kawase and Aki [42], and presented at Iyisan and Khanbabazadeh [26] and Khanbabazadeh and Iyisan [27,28]. The solution of the trapezoidal valley by Kawase and Aki [42] has been tested by Ramos-Martinez [43], Zahradnik [44] and Gil-Zepeda et al. [45], among the others.

5. Results and discussion

In this section the results of the dynamic analyses of Dinar basin is presented. For evaluation of the spectral amplification the spectral acceleration response of the surface points are calculated. Using the spectral acceleration response of each point the amplification factor with respect to the reference rock site is estimated. After that, for each surface point the average of resulted spectral