

## The Basin Edge Effect on Dynamic Response: Dinar Basin Model<sup>†</sup>

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### ABSTRACT

*Earthquake ground motion is affected from local soil conditions, geological structures as well as earthquake source properties. The amplitude and frequency content of the strong ground motion can be changed by local site effects. Local site conditions such as seismic bedrock depth, bedrock slope of the edge, geometry and characteristics of soil layers and topographical irregularities are the most important factors affecting soil amplification. One dimensional (1D) equivalent linear dynamic analysis method is the simplest approach to investigate local site effects. 1D approach becomes valid especially for the sites far from edges or in shallow and wide valley models. In narrow and deep basins, body waves transform into surface waves especially at the edges during earthquakes and two dimensional (2D) resonance modes occur, the frequency content and amplitude of strong ground motion may vary with the distance from basin edge to its center. In this study, to investigate the effects of basin edge on the variation of surface motion under different strong ground motion acceleration records, one and two dimensional dynamic analyses were performed by using the Dinar basin edge model and the results were compared. The variations of the spectral acceleration ratios (2D/1D) were evaluated for the different points on the ground surface with the changing distance from the valley edges. A relationship between the results of one and two dimensional dynamic analyses was established. Shear wave velocity profile and bedrock depth in Dinar were obtained from microtremor array measurements.*

**Keywords:** Dinar, Microtremor Array, Bedrock Slope, Dynamic Analysis, Spectral Ratio

### 1. INTRODUCTION

In a specific site, the earthquake characteristics are mainly dependent on tectonical structure, rupture mechanism, hypocentral distance as well as site geology and local soil conditions. The local soil conditions may have important effects on the amplitude, frequency content and duration of strong ground motion, and the seismic waves may also change the dynamic properties of soil layers [1]. The changes in amplitude, frequency content and duration of earthquake waves which occur while passing through near surface soil layers is defined as soil amplification. Local site conditions such as seismic bedrock depth, bedrock slope of the edge, geometry and characteristics of soil layers and

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topographical irregularities are the most important factors affecting soil amplification [2,3]. Topographical irregularities include both geological formations such as basins and valleys, the two and three dimensional geometry of subsurface soil layers and also the limiting bedrock boundaries. As a result, local site effects affect the damage variation occurred during the earthquakes and play an important role in the design of earthquake resistant structures. The purpose of the studies for local site effects is to determine the properties of earthquake design motion which is used for calculating the dynamic forces acting on structures during earthquakes.

The difference of specific impedance between soil layers or soil layers and bedrock is the main reason for the changes in the characteristics of the seismic waves due to local site effects while propagating from bedrock to softer surface layers. One dimensional (1D) equivalent linear dynamic analysis method is the simplest approach to investigate local site effects which are generally complex because of the non-linear soil behavior. 1D dynamic analysis is usually the preferred method because of its ease in usage. It is based on the principle of vertically propagating body waves in the horizontally layered soil medium without lateral boundaries [4].

The assumptions and boundary conditions of 1D approach become valid especially for the sites far from edges when the half-width of soil layers is much greater than its depth in shallow and wide basin models. However in the nature, the soil deposits form mediums which can be defined only with two or three dimensional models [5]. This kind of mediums with lateral discontinuities has a strong effect on the surface waves reverberating forth and back especially at the lateral boundaries. In case the seismic waves interfere with each other, amplification may reach its highest values especially when they are in phase with each other [6]. In narrow and deep basins where the half-width of soil layers is comparable with their thickness, body waves transform into surface waves at the edges during strong earthquake excitation. As a result; two dimensional (2D) resonance modes occur, the frequency content and amplitude of strong ground motion may vary with the distance from basin edge to its center [7].

The change in the frequency content of strong ground motion is affected by basin depth, width, edge slope, soil stratification and characteristics of the bedrock motion. When all of those parameters are taken into consideration, edge slope value can be accepted as one of the most important factors which may affect the damage variation in the settlements located at basin edges. Consequently, soil amplification values at basins mainly depend on the types and dynamic properties of soil layers, frequency content of bedrock motion and the location of the site where the dynamic behavior is evaluated [8,9].

In this study, one and two dimensional dynamic analyses were performed by using the Dinar basin edge model to investigate the effects of basin edge on the variation of surface motion under different strong ground motion acceleration records and the results were compared. The variations of the spectral acceleration ratios (2D/1D) were evaluated for the different points on the ground surface with the changing distance from the basin edges.

Shear wave velocity profile and seismic bedrock depth and bedrock slope in Dinar basin were obtained by microtremor array measurements. The effect of edge bedrock slope on surface ground motion were investigated for four different slope values by performing 1D and 2D dynamic analyses on Dinar basin model. The acceleration time histories and

absolute acceleration spectrums were obtained for different points on the basin surface. The 2D/1D spectral acceleration ratios were calculated by dividing the absolute acceleration spectrums obtained from 2D and 1D dynamic analyses, and the change in 2D/1D spectral acceleration ratio values with the distance from basin edge was investigated for different period values. A relationship depending on basin edge slope was suggested between absolute acceleration spectrums obtained by 1D and 2D dynamic analyses in order to reflect the effects of 2D behavior at basin edge on 1D analysis. 1D and 2D dynamic analyses were performed by using Dyne-q and Quake/W softwares based on equivalent linear soil model, respectively. Dyne-q software operates in the frequency domain and Quake/W software works in the time domain.

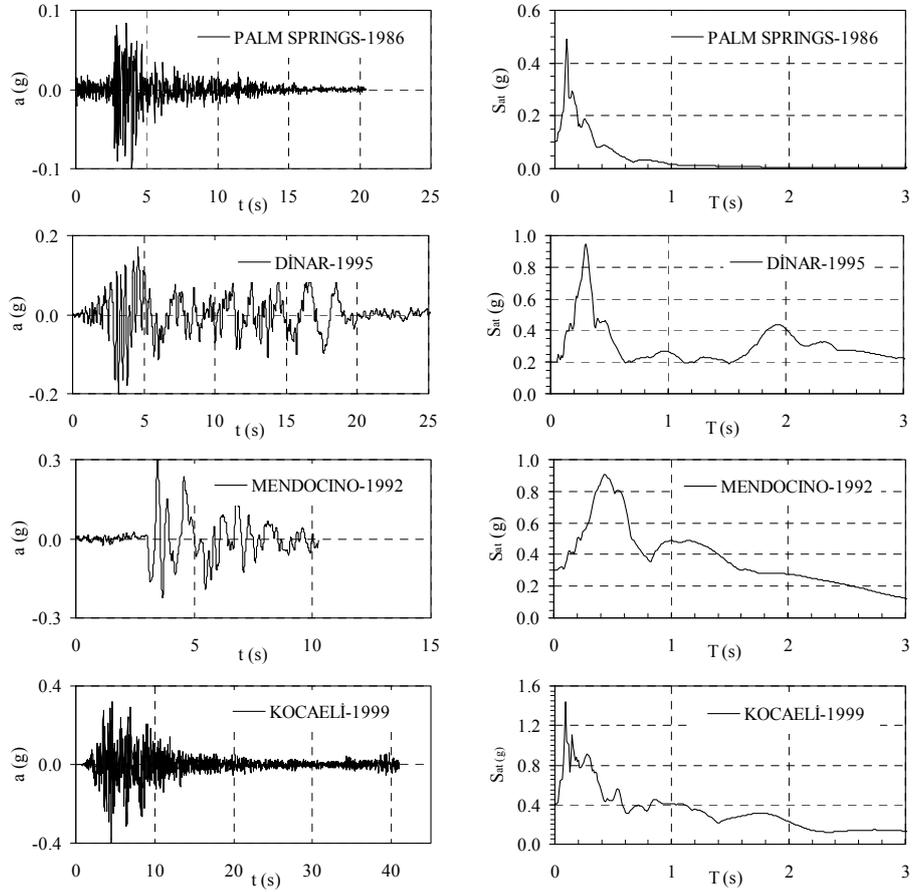
## **2. CHARACTERISTICS OF STRONG GROUND MOTION USED IN THE STUDY**

In order to reflect the characteristics of bedrock motion to the dynamic behavior of soil layers, four different acceleration time histories with different intensity parameters and frequency content were used in the dynamic analyses. Two of those accelerograms belonged to Turkey earthquakes and the others were from strong ground motion records of San Andreas Fault system that has similar characteristics with the North Anatolian Fault.

One of the accelerograms used in the dynamic analyses was obtained by using the E-W component of Dinar Meteorology Station acceleration time history which had been recorded at Dinar Earthquake on 1 October 1995. In the region where Dinar Meteorology Station was located, microtremor array measurements had been carried out and it was found out that seismic bedrock lies at great depth from the surface. The recorded surface ground motion of E-W component of 1 October 1995 Dinar Earthquake was deconvoluted to bedrock by 1D dynamic analysis by using the soil profile obtained from the extensive field and laboratory studies carried out in the region [10,11]. This accelerogram was used as a bedrock motion in the dynamic analyses. The other strong ground motion which belonged to Turkey earthquake excitations was recorded at the building of Sakarya Public Works and Settlement Directorate on 17 August 1999 Kocaeli earthquake. Strong ground motion of 1986 Palm Spring and 1992 Mendocino earthquakes were recorded at San Andreas Fault system.

The acceleration time histories and absolute acceleration spectrums of earthquake excitations used in the analyses were illustrated in Figure 1. These accelerograms were band-pass filtered between 0.10-25 Hz and baseline corrections were done. Then, their peak accelerations were scaled to the nearest values among 0.1g, 0.2g, 0.3g and 0.4g [12]. The properties of selected accelerograms used in this study are given in Table 1.

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**Figure 1.** The strong ground motion accelerograms used in dynamic analyses and their absolute acceleration spectrums

**Table 1.** The general characteristics of strong ground motion acceleration records used in the study [12]

Earthquakes	Palm Springs 1986	Dinar 1995	Mendocino 1992	Kocaeli 1999
Station	Silent Valley	Meteorology	Cape Petrolia	Sakarya Pub.
Formation	Weathered Granite	Deconvolution	Rock	Sandstone
Magnitude	$M_L=5.9$	$M_L=5.9$	$M_L=6.5$	$M_d=7.4$
Depth (km)	11.1	12.0	14.6	18.0
Distance (km)	19.5	2.0	15.0	35.0
$a_{max}$ (g)	0.10	0.20	0.30	0.40

### **3. MICROTREMOR ARRAY MEASUREMENTS AND BEDROCK DEPTH**

Microtremors can be defined as vibrations with very small amplitudes ( $10^{-2}$ ~ $10^{-3}$  mm) which are mainly caused by natural sources such as wind, waves, geothermal reactions, small scaled earthquakes and cultural noise such as traffic and human activity. In order to observe the microtremors, very sensitive receivers - seismometers are required, and they work like a pendulum based on the principle of electric current generation due to ground oscillation. Single point microtremor measurements are widely used in geotechnical earthquake engineering to determine the local site predominant period, amplification and microzonation studies [13,14,15].

In order to determine the shear wave velocity profile from microtremor measurements and estimate the depth of seismic bedrock which can be defined as the media where the bedrock is rigid and its elastic properties remain nearly the same, the microtremors should be recorded continuously and simultaneously at multi-receiver instead of single point measurements. It is assumed that the microtremors recorded at receivers are generated from the same source without any change in their waveforms. The comparison of microtremors recorded in an array having a predetermined geometry and their frequency content, provide important data about dynamic properties of soil layers. This method is based on the determination of dispersion characteristics of surface waves. Its has some advantages as compared with other seismic in-situ tests such as ease of application, low cost, not needing boreholes and applicability in urban sites [16].

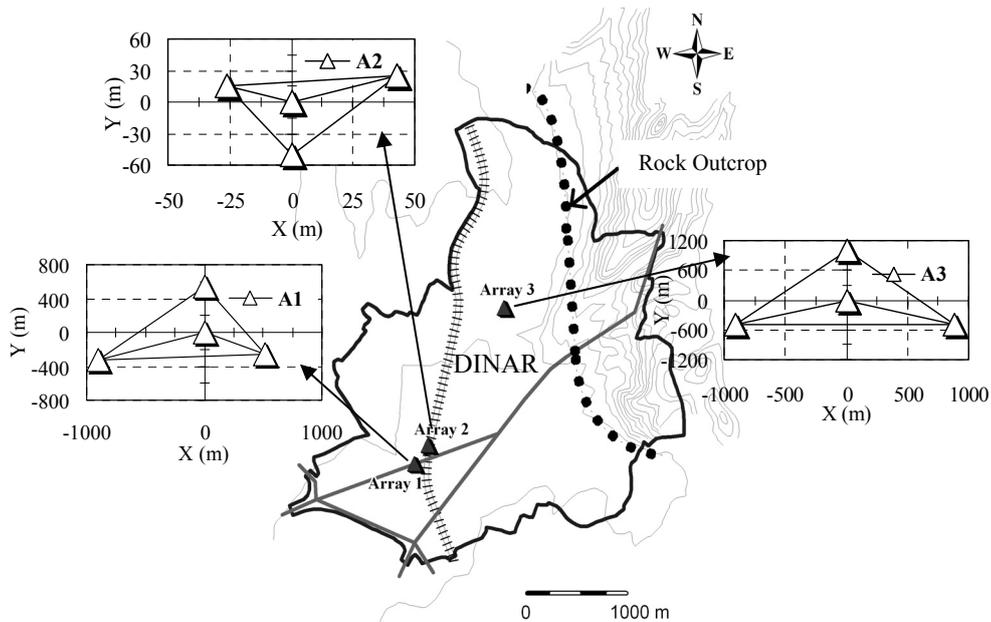
The determination of bedrock geometry is very important before executing 2D dynamic analyses. The microtremor array measurements become very useful for estimating the seismic bedrock depth in case the boreholes are not deep enough to reach the bedrock. The shear wave velocity profile at three different sections of Dinar basin was determined by microtremor array measurements. The data from microtremor array studies were combined with the topographical properties and geological section in Dinar to obtain two dimensional shear wave velocity profile and engineering properties of surface layers in the basin.

#### **3.1. Array Geometry Setup**

In microtremor array measurements both of the receiver location geometry and the distance between each other may vary depending on the depth of soil layers in which their dynamic properties are being investigated. In order to obtain appropriate data from microtremor measurements, it is recommended that the array diameter should be greater than 1/3 of the longest wavelength being considered and the distance between the nearest receivers should be smaller than half of the shortest relevant wavelength. It is suggested that at least four receivers must be used in microtremor array measurements. An array consisting of receivers located at the corners and center of an equilateral triangle can be given as an example. In case there is no available space to form a triangle array geometry, receivers can be located linearly as well [16].

In order to determine the shear wave velocity profile and slope of edge bedrock in Dinar basin, microtremor array measurements were carried out at three different sites in Dinar as shown in Figure 2. Microtremor data with sampling frequency of 100 Hz were simultaneously recorded by 4 receivers placed on the ground surface in predetermined

distance. The array diameters were increased to obtain a precise phase velocity-period relation by keeping the center receiver fixed and removing the corner receivers far from the center and sufficient number of records were taken.



**Figure 2.** The locations of the microtremor array measurement in Dinar and geometry of the arrays

The most distant locations of the receivers used in the microtremor array measurements in Dinar were given in Figure 2. The triangles in the map symbolize the center receivers for each of the three observations. In the start small array microtremors were recorded at any receiver location during 15 minutes then the receiver locations were changed four times to attain the large array by moving the corner receivers far from the center of the triangle array. This process was also repeated at the other sites. The timing of the records was adjusted by the clock installed in the digitizer, so it became possible to compare the waveforms that were recorded at the same time interval.

### 3.2. Analysis of Microtremor Records and Estimation of Shear Wave Velocity Profile

In microtremor observations Rayleigh waves composed of vertical components of surface waves are mainly recorded. Rayleigh waves are dispersive, in other words the velocity of Rayleigh waves ( $V_R$ ) varies depending on the frequency ( $f$ ) and wavelength ( $\lambda$ ) values ( $V_R = \lambda f$ ). The velocity of seismic waves for a specific frequency value can be defined as phase velocity ( $c$ ). The graphics show that the variation of phase velocity with frequency or

period is called the dispersion curve. This curve can be obtained theoretically for a given soil profile and it is a function of the shear wave velocity ( $V_s$ ), pressure wave velocity ( $V_p$ ), unit weight ( $\gamma$ ) and thickness of soil layers. As a result, the phase velocity values and their variation with frequency can be used to estimate the dynamic characteristics of the soil layers where the array measurements were carried out [16, 17]. To this aim, the microtremors that were recorded with the receivers in an array are transferred into frequency domain from time domain by the spectral analysis technique. This process can be easily executed with the help of the Fast Fourier Transformation (FFT) method. After this, the cross-power spectra between microtremor waveforms such as  $x(t)$  and  $y(t)$  that were recorded at two neighbor receivers having predetermined coordinates is calculated with the help of FFT technique by using the relation given below [18].

$$CPS_{x,y}(f) = LS_x(f) \cdot LS_y^*(f) \quad (1)$$

In this equation,  $LS_x(f)$  is the linear spectrum of microtremor record  $x(t)$  (or its Fourier spectrum),  $LS_y^*(f)$  is the complex conjugate of linear spectrum of  $y(t)$  and  $f$  is the frequency. This function gives the phase difference between two wave records for each frequency ( $\theta_{x,y}$ ), thus the interval time,  $t_l(f)$ , for a microtremor wave between two considered receivers is calculated with Equation 2.

$$t_l(f) = \frac{\theta_{x,y}(f)}{360 \cdot f} = \frac{\theta_{x,y}(f)T}{360} \quad (2)$$

As it is known, phase difference value of  $360^\circ$  is equal to the arrival time of one period. Frequency-wave number (f-k) spectral analysis is the simplest theoretical method used to obtain the spreading velocity of microtremor waves at different frequencies. f-k spectrum is a Fourier transformation shows the plane and direction of wave propagation. The f-k spectrum of recorded waves at any two receivers can be given as below [18].

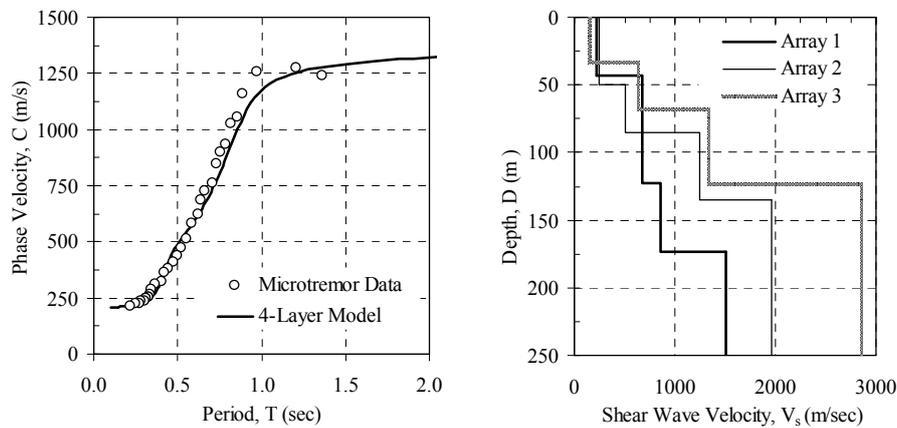
$$P(f, k) = \sum_{x,y=i}^n CPS_{x,y} \cdot e^{ik(X_x - X_y)} \quad (3)$$

In Equation 3,  $X_x$  ve  $X_y$  are the receiver coordinates,  $n$  is the number of receivers and  $k$  shows the vector of wave number with a dimension of 1/km. Phase velocity,  $c$ , can be calculated as below for the greatest value of f-k spectrum.

$$c = \frac{2\pi f}{k} = \frac{\omega}{k} \quad (4)$$

In this equation,  $\omega$  is the circular frequency. This calculation process is repeated for every frequency, so dispersion curves can be obtained and the dynamic characteristics of the soil layers can be estimated by using the inversion theory. In order to obtain acceptable values for dynamic characteristics, the theoretical values calculated by analyzing a selected soil profile with assigned soil properties must be similar to observed values. The dispersion

curve of a layered soil profile is controlled mainly by shear wave velocity ( $V_s$ ) and thickness ( $D$ ) of layers. As a result of the array observations carried out at three different sites of Dinar, the vertical microtremor records were analyzed by the method which was briefly mentioned above, thus their dispersion curves were obtained and the relevant soil properties were estimated by using the inversion theory [19]. In order to succeed in this process, model parameters of the theoretical dispersion curve calculated for four layered soil profile, was changed until the theoretical dispersion curve became very close to the observed one from the microtremor measurements. The dispersion curve obtained from the first microtremor array measurements performed with a dimension of 1000 m and the variation of shear wave velocity profiles which were estimated for all of the three array measurements by using inversion method with theoretical soil properties, were shown together in Figure 3.



**Figure 3.** Field dispersion curves and the variation of shear wave velocity with depth

The characteristics of the soil layers calculated by the microtremor array measurements carried out at three different sites were given in Table 2. In the table  $\gamma$ ,  $V_p$ ,  $V_s$  and  $D$  represent the values of unit weight, pressure wave velocity, shear wave velocity and layer thickness respectively.

As it can be seen from Figure 3 and Table 2, the seismic bedrock ( $V_s \approx 1000$  m/s) was reached at 175 m depth for the first microtremor array measurements which had been performed at the basin center; however it was reached at 85 m and 68 m depths for the other sites respectively. These results pointed out that seismic bedrock at basin edge was positioned in the NE-SW direction with a slope of 1/10 [12]. The layer thickness and shear wave velocity values obtained at three microtremor array measurement sites were used to constitute the two dimensional model of the Dinar basin.

**Table 2.** The estimated soil characteristics from microtremor array measurements

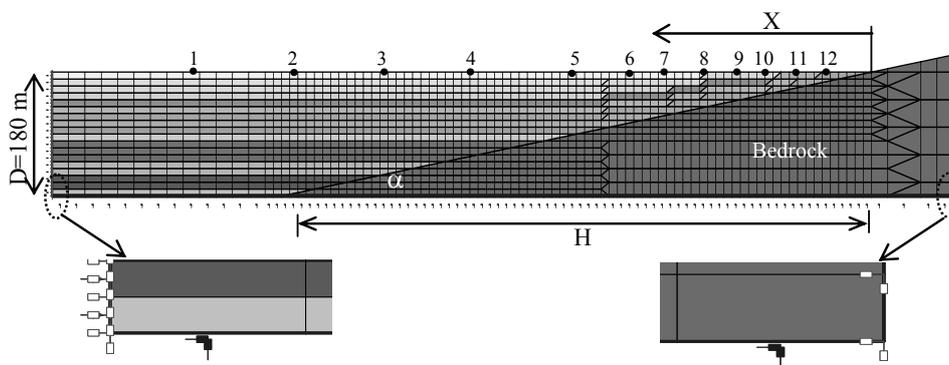
Layer No	$\gamma$ (kN/m <sup>3</sup> )	$V_p$ (m/s)	$V_s$ (m/s)	D (m)	Measurement
1	19.0	1500	220	43	Array 1
		1500	249	50	Array 2
		1500	152	34	Array 3
2	20.0	2040	676	80	Array 1
		1850	506	35	Array 2
		2000	636	34	Array 3
3	21.0	2236	851	50	Array 1
		2675	1248	70	Array 2
		2750	1332	56	Array 3
4	22.0	2958	1503	$\infty$	Array 1
		3472	1966	$\infty$	Array 2
		4460	2862	$\infty$	Array 3

#### 4. DINAR BASIN MODEL

Bedrock slope at basin edge, the frequency content of bedrock earthquake motion, depth and width of basin affect the dynamic behavior of soil layers during strong earthquakes. In order to investigate the effect of basin edge slope on surface motion, Dinar basin model was set up initially and dynamic analyses were done for models with four different basin edge slope values. When the geological section of Dinar and extensive field studies carried out in the basin were taken into consideration with the shear wave velocity profile obtained from microtremor array observations, it was estimated that bedrock at basin edge was dipping towards basin center with a slope of 1/10 (6°). In the basin, sandy and silty low-intermediate plasticity clay layers were lying above the bedrock consecutively. In order to obtain the properties of near surface soil layers, the results of former in-situ and laboratory test results were used [20,21]. In the study, initially the effect of the seismic bedrock accelerogram of 1 October 1995 Dinar Earthquake on Dinar basin model was investigated. The acceleration time history of bedrock motion had been obtained by deconvolution of the surface accelerograms to seismic bedrock at 180 m depth. After this, it was aimed to consider the second dimension and edge effect on basin model generally, thus in order to achieve this, the changes in the dynamic behavior of the basin model was tried to be evaluated by using different edge slope values and bedrock accelerograms. With this aim, 1D and 2D dynamic analyses were executed for 12 different sites at basin edge by using 4 different edge slope values ( $\alpha=6^\circ, 11^\circ, 27^\circ, 45^\circ$ ) as given in Table 3 and results of the analyses were compared. The finite element mesh of Dinar basin model which was used in dynamic analyses and its boundary conditions are illustrated in Figure 4.

**Table 3.** The geometrical properties of Dinar Basin

Model No	D (m)	H (m)	H/D	$\alpha$ (°)
1	180	1800	10	6
2	180	900	5	11
3	180	360	2	27
4	180	180	1	45



**Figure 4.** Dinar Basin model, the selected boundary conditions and finite element mesh to be used in dynamic analyses

In this figure D shows bedrock depth, H is the basin edge width and X can be defined as the distance from edge of bedrock outcrop to basin center. In the analyses, the soil profile over bedrock was divided into 18 different layers with 10 m thickness each and shear wave velocity values of 200 m/sec and 1000 m/sec were assigned to the uppermost layer and seismic bedrock respectively. The soil layers above seismic bedrock were assumed to be composed of intermediate plasticity clay (CI,  $I_p = 20\sim 25$ ). The variation of damping ratio with cyclic shear strain and stiffness degradation was obtained by using Ishibashi-Zhang [22] relation. Also it was assumed that the transition zone between rigid bedrock and soil layers was composed of weathered rocks, so the change in damping ratio values with cyclic shear strain and stiffness degradation for this zone was modeled with the relation proposed by Schnabel and others [23].

## 5. TWO DIMENSIONAL DYNAMIC ANALYSES

In two dimensional dynamic analyses, Quake/W finite element software [24], which is based on the principle of equivalent linear method, was used. The vertical and horizontal boundary conditions become very important for two dimensional dynamic analyses. It is appropriate to put viscous dashpots at the vertical boundaries in order to transmit the energy

of pressure and shear waves and to prevent reflection of seismic waves at the boundaries [12]. The restraint conditions of horizontal boundary also become important in addition to vertical boundary conditions in two dimensional dynamic analyses. In case the base of the model is fixed with restraints in both directions and especially when studied with strong ground motion acceleration which cause nonlinear behavior of the soil layers, the soil amplifications at the surface layers may reach unrealistically high values during the numerical analyses. For this reason, viscous dashpots in two directions should be put at the base boundaries of the model. These dashpots have coefficients proportional to pressure and shear wave velocity values of soil layers. In addition to the dashpots, the effect of the 1D free field motion was added to the model by applying time dependent stress functions at both of the vertical boundaries. Those boundary forces were calculated by multiplying the 1D particle velocity values of the soil layers with the relevant horizontal dashpot coefficients and applied to the 2D model at the boundaries as stress functions changing throughout the earthquake ground motion. After the 2D analyses, the maximum absolute horizontal acceleration values obtained at the surface ( $a_{\max\_S}$ ) for 12 different points of the model as shown in Figure 4, were normalized by the peak horizontal acceleration at rock outcrop ( $a_{\max\_R}$ ). These normalized values were defined as soil amplification ( $a_{\max\_S} / a_{\max\_R}$ ). The variation of the soil amplifications calculated for different earthquakes with bedrock slope and X/D dimensionless distance was given in Figure 5.

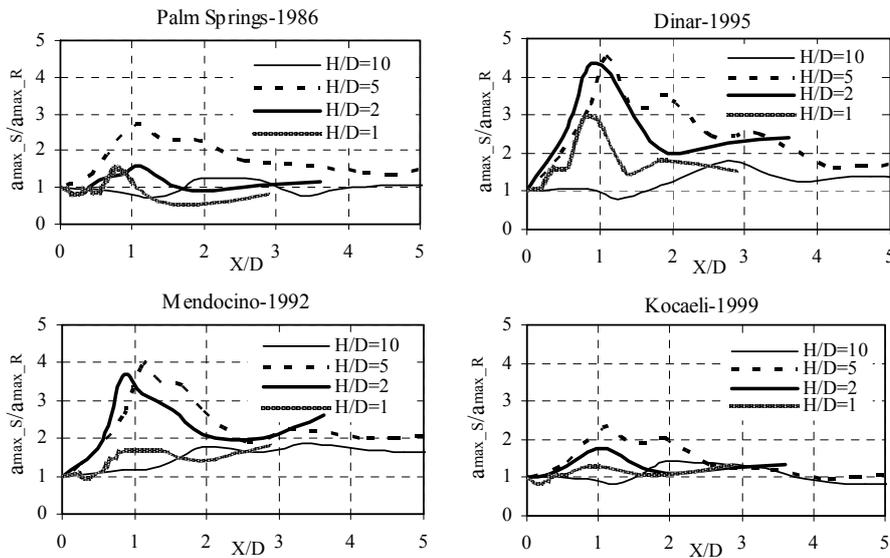


Figure 5. Soil amplifications calculated for different earthquakes and bedrock slopes

Acceleration spectrum intensity, ASI, which had been proposed to define the behavior of rigid structures with predominant periods lower than 0.5 sec under strong ground motion is given below [25]. In the equation  $S_a$  and  $\xi$  show acceleration spectrum and damping ratio

respectively and  $T$  is the period. ASI values can be related to the behavior of rigid structures with predominant periods lower than 0.5 sec.

$$ASI = \int_{0.1}^{0.5} S_a(\xi = 0.05, T) dT \quad (5)$$

The change in ASI values with the distance from edge outcrop to middle sections of basin are illustrated in Figure 6 for models with different edge bedrock slope values. As it can be seen from Figure 5 and 6, soil amplification and ASI values reach their peak at a definite edge section while moving away from rock outcrop to basin center and afterwards, with the increase in  $X/D$  value they converge for every earthquake excitation without depending on the bedrock slope.

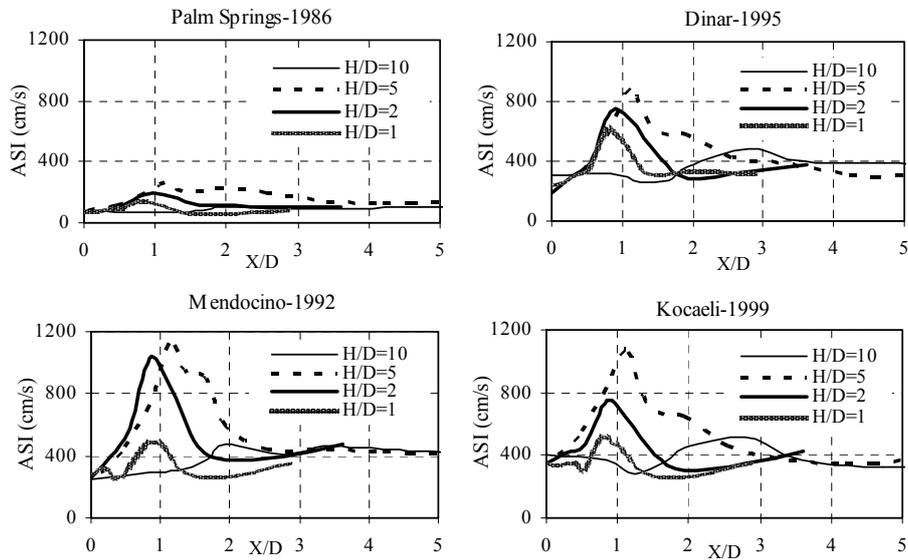


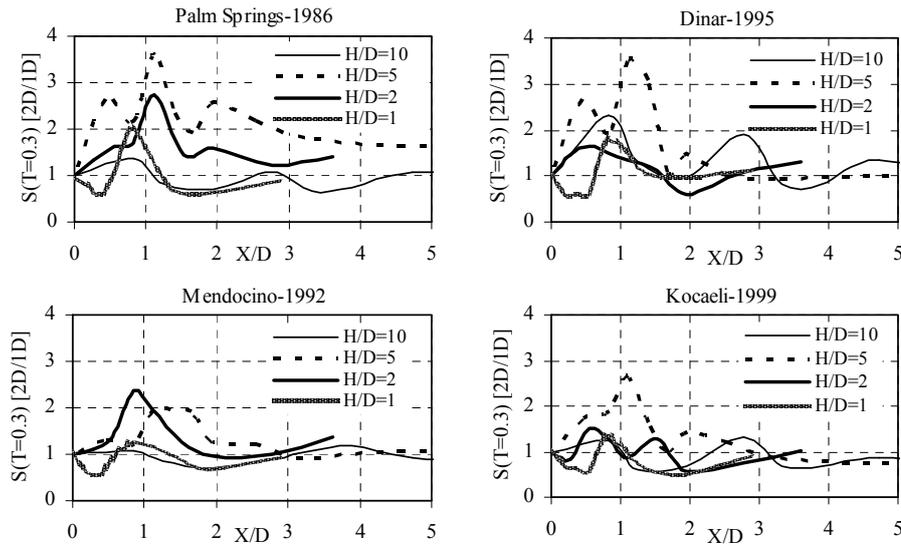
Figure 6. The ASI values calculated for different earthquake and bedrock slope

## 6. COMPARISON OF ONE AND TWO DIMENSIONAL DYNAMIC ANALYSES

In order to estimate the surface ground motion at basin edges with different bedrock slopes, a two dimensional finite element method which is based on the equivalent linear method was used in the dynamic analyses for different earthquake excitations and the findings were compared with the results of one dimensional dynamic analysis. This way, absolute acceleration spectrums were obtained for different sections of all models by using the acceleration time histories obtained from one and two dimensional dynamic analyses. Dyne-q software [26] that had been developed based on the modified equivalent linear method was used to perform one dimensional dynamic analysis.

The difference between two and one dimensional dynamic behaviors was evaluated by proportioning the acceleration spectrums that were calculated by two and one dimensional analyses respectively. The ratio of the acceleration spectrums that are obtained as a result of two and one dimensional dynamic analyses is defined as the “aggravation factor” [27]. In order to investigate the effect of surface ground motion on structures with different rigidity or period values, 2D/1D spectral acceleration ratios were calculated for 5 different period values ( $T=0, 0.3, 0.4, 0.6, 0.9$  s) by using different basin edge geometry and earthquake excitations. The relevant 2D/1D spectral acceleration ratio (aggravation factor) curves are shown in Figure 7 for the case of  $T=0.3$  s.

2D/1D spectral acceleration ratios reached their peak values at a definite edge section and afterwards, while moving away from the rock outcrop to basin center; spectral acceleration ratios approximately converged to 1 for every period value. Also it can be realized that 2D/1D spectral acceleration ratios approached each other after a definite value of  $X/D$  ( $X/D=3$ ) regardless of the edge bedrock slope values. Spectral acceleration ratios took values between 2 and 4 depending on the edge bedrock slope and they reached their peak values especially when  $H/D$  is equal to 5 ( $\alpha=11^\circ$ ).



**Figure 7.** The variation of 2D/1D spectral acceleration ratios with  $X/D$

Without depending on the magnitude of the period, average 2D/1D spectral acceleration ratio values converged to 1 after the point of  $X/D=5, 4, 2$  and  $1.5$  when the edge bedrock slopes were  $\alpha=6^\circ, 11^\circ, 27^\circ$  and  $45^\circ$  respectively. After these points, two-dimensional effects were much reduced. By means of these results, the limits of the sections at basin edges where 2D dynamic behavior under earthquake excitation should be taken into

account can be obtained. In Figure 8, the validity limits for 1D and 2D dynamic analysis are depicted for related models depending on varying values of basin geometry.

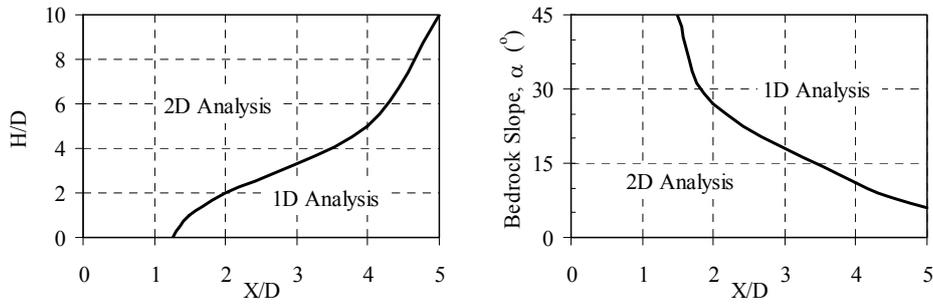


Figure 8. The variation of the dynamic approach effectiveness with the edge geometry at Dinar basin models

## 7. EVALUATION OF FINDINGS AND DISCUSSION

The absolute acceleration spectrums were obtained for different sites of basin surface as a result of one and two dimensional dynamic analyses which were performed on basin models with different edge bedrock slope values by using different bedrock accelerograms. 2D/1D spectral acceleration ratios were calculated for 5 different period values in order to investigate the relation between spectral acceleration values that were obtained by one and two dimensional dynamic analyses and to estimate the effect of two dimensional geometry on the spectral acceleration values calculated from one dimensional dynamic analyses. 2D/1D spectral acceleration ratio values were assumed to be normally distributed for different earthquake excitations and the variation of average ratios with both of X/D and period values were illustrated as 3D surfaces in Figure 9 for 4 different edge bedrock slope values. As it can be seen from the figures, spectral acceleration ratio values reached their peak values for the model with H/D=5. The 2D/1D spectral acceleration ratios especially decreased for the models with lower edge bedrock slope values. The highest spectral acceleration ratio values were obtained at the period interval of 0.2~0.5 s for all basin models. As the edge bedrock slope value decreased, the difference between spectral acceleration values also decreased.

In the dynamic analyses performed, the variation of 2D/1D spectral acceleration ratios with X/D dimensionless parameter were investigated for the basin edge. With this purpose, the average of spectral acceleration ratios at different periods were calculated and after evaluating the results, the relationship given below was obtained on condition that X/D>0.

$$\left(\frac{2D}{1D}\right) = e^{\left\{a + \frac{b}{(X/D)} + c \ln\left(\frac{X}{D}\right)\right\}} + 1 \quad (6)$$

In this relation,  $X$  is the distance from rock outcrop at basin edge,  $D$  is the depth to seismic bedrock, all of  $a$ ,  $b$  and  $c$  show the coefficients that are dependent on edge bedrock slope and period values. The values of these coefficients depend on each other and for the model with  $H/D=5$ , where spectral acceleration ratios reach their highest values, they took values of 14, -14 and -10 respectively. Equation 6 was very successful at estimating the variation of  $2D/1D$  spectral acceleration ratio values with  $X/D$  however it could not model the behavior of some aggravation factor curves which had more than one maximum and minimum value. However, it is thought that the behavior of sudden increase and decrease in the aggravation factor values which was perceived close to the bedrock outcrop at edges of some models can not be formed perfectly. The reason for this consideration is generally the existence of soil layers at basin edges that are stiffer or denser than sedimentary formations lying at middle parts of basin surface. Those stiffer soil layers can be classified as talus and residual soil which were formed by accumulation of rock fragments at the base of cliffs and by chemical/physical weathering of native bedrock in place respectively. For this reason, the small scaled secondary increments and decrements in the values of aggravation factors for the zones of alluvium located near the edge bedrock outcrop were neglected.

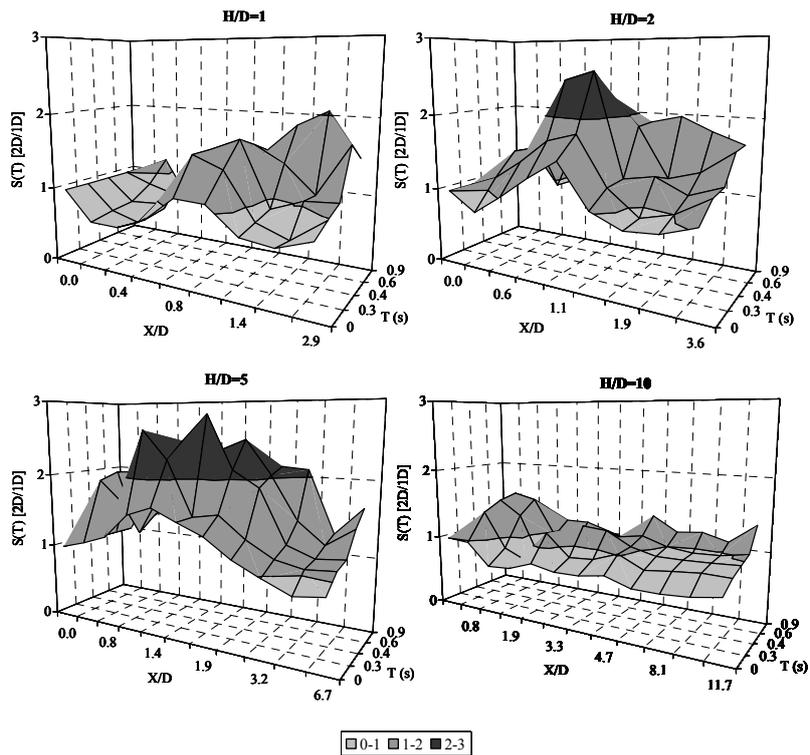


Figure 9. The variation of  $2D/1D$  spectral acceleration ratios with  $X/D$  and period values

## **8. RESULTS**

The limited width of the soil layers may cause wave transformations and surface waves to occur at basin/valley edges, the frequency content of strong ground motion may vary with the distance from edges to mid sections of the basin/valley and the duration of surface ground motion may increase because of lateral discontinuities. Also basin edge slope, local soil conditions, basin depth and width, bedrock motion characteristics affect the alteration of surface ground motion. As a result it can be stated that one of the most important factors that can affect the damage distribution of settlements at basin/valley edges is the edge slope value. Thus, soil amplification in basins and valleys, mainly depends on the location of the site being investigated in addition to local soil conditions and bedrock motion characteristics.

In this study, the effect of basin edge slope on surface ground motion was estimated by performing 1D and 2D dynamic analyses on Dinar basin model for 4 different slope values. With this aim; acceleration time histories, acceleration spectrums, intensity parameters were obtained for basin surface and the variation of these values with the distance from the edge of the bedrock outcrop were investigated for different bedrock earthquake excitations. In order to determine the difference between the results of one and two dimensional dynamic analyses, the acceleration spectrums which were calculated for different sections of basin by using 2D dynamic analyses were divided by the ones calculated with 1D dynamic analyses, so that 2D/1D acceleration spectrum ratios were obtained. After this, the change in 2D/1D spectral acceleration ratio values with the distance from edge rock outcrop was studied and a relationship between the acceleration spectrums of 1D and 2D dynamic analyses were established. The depth and edge bedrock slope value for two dimensional models were obtained from the shear wave velocity profile calculated from microtremor array measurements.

The maximum increments in horizontal acceleration and acceleration spectrum intensity–ASI values, which were calculated as a result of the dynamic analyses performed on models with varying edge bedrock slope values by using different earthquake bedrock excitations, appeared between the beginning of edge bedrock outcrop and  $X/D=3$  point, especially for the edge bedrock slope angle values of  $11^\circ$  and  $27^\circ$  ( $H/D=5$  and  $2$ ) in comparison with other models.

The calculated 2D/1D spectral acceleration ratios reached their maximum values at a certain zone ( $X/D<3$ ) near the basin edge for every investigated period. At this zone, average aggravation factors took values between 0.5 and 4.0 for different strong ground motions. While approaching to center of basin models, especially at the zones after  $X/D=3$  point it can be noticed that spectral acceleration values generally converged to 1 regardless of the edge bedrock slope values. At these sections, 1D and 2D dynamic analyses give similar results. For all the basin models with different edge bedrock slope values, the maximum average aggravation factors were relatively obtained for the edge bedrock slope angle value of  $11^\circ$  ( $H/D=5$ ). With the decrease in edge bedrock slope ( $H/D=10$ ,  $\alpha=6^\circ$ ), the difference between 1D and 2D spectral acceleration values became negligible. For all the models, the highest average spectral acceleration ratios were calculated when the related period values were between  $T=0.2\sim 0.5$  s. The average spectral acceleration ratio values vary between 2 and 3 for this period interval. By using the 2D/1D aggravation factor–spectral acceleration ratio relation obtained in this study, it will be possible to reflect the

second dimension effect to the spectral acceleration values calculated from 1D dynamic analysis depending on edge bedrock slope value and  $X/D$  term.

This relation was obtained for the case of the Dinar basin model with varying edge bedrock slope values subjected to four different earthquake bedrock accelerograms. By using new data, it will be possible to develop and change the relevant relation which was obtained for a limited number of analytical results. Nevertheless, it is expected to be useful for estimating the effect of second dimension on the spectral acceleration values obtained for basin edge sections from 1D dynamic analysis.

### Symbols

$\alpha$	: Bedrock slope at basin edge
$\theta$	: Phase angle
$\xi$	: Damping ratio
$\lambda$	: Wavelength
$\gamma$	: Unit weight
$\omega$	: Natural circular frequency
1D	: One dimensional dynamic analysis
2D	: Two dimensional dynamic analyses
2D/1D	: Spectral acceleration ratio
a, b, c	: The coefficients dependent on bedrock slope and period values
$a_{\max}$	: Peak absolute horizontal acceleration value of strong ground motion
$a_{\max_S}$	: Peak horizontal acceleration value of surface motion
$a_{\max_R}$	: Peak horizontal acceleration value of rock outcrop motion
ASI	: Acceleration spectrum intensity
c	: Phase velocity
CI	: Intermediate plasticity clay
CPS	: Cross power spectrum
D	: Layer thickness
f	: Frequency
g	: Gravitational acceleration
H	: Basin edge length
$I_p$	: Plasticity index
i	: $\sqrt{-1}$

LS	: Fourier spectrum of microtremor data
S <sub>at</sub>	: Absolute acceleration spectrum
t	: Time
T	: Period
V <sub>p</sub>	: Pressure wave velocity
V <sub>R</sub>	: Rayleigh wave velocity
V <sub>s</sub>	: Shear wave velocity
X	: Distance from rock outcrop at basin edge

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