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Nonlinear dynamic behavior of the basins with 2D bedrock

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ABSTRACT

Resonance due to impedance contrast, focusing due to subsurface topography, conversion of the body waves to surface waves and subsurface topography are among the factors influencing the amplification specification of the sites, which can only be considered by the application of suitable nonlinear analysis method. In this study, using the fully nonlinear analysis method, along with a hysteretic-type model and no extra damping, the effects of the basin edge on the dynamic behavior of the basins is investigated in more accurate manner. To make the results useful at engineering affaires, the investigated basins are classified into sandy, clayey and layered basins. Special degradation curves for each of the (soft, medium plasticity and stiff) clay and (loose, medium dense and dense) sand types have been extracted and fitted to the continuous functions which is used by the nonlinear method's hysteretic-type damping scheme. The results exhibit the differences in the amplification behavior of the basins with different soil types under the different excitation levels. Also, the sensitivity of the different parts of the basin surface with 2D geometry to different period levels is investigated. This finding can be used at dynamic structural design of the buildings on basins with 2D bedrock inclination.

1. Introduction

Seismic amplification of the ground motion at the basin surface is strongly influenced by the geological and geotechnical characteristics of the soil [1–9]. 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 [10].

Among the different methods of the seismic response assessment, the numerical methods allow to analyze and investigate the effects of the characteristics of the bedrock, soil deposits and the excitation specification [11,12]. Based on the investigation requirements one, two and three dimensional approaches can be selected. In some situations local amplification can be inferred reasonably using simple 1D shear models. However, lateral heterogeneity at alluvial valleys may give rise to focusing and to locally generated surface waves; therefore, the estimates for local amplification using 1D model may be wrong [13–17]. 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 [18].

The concentration of the damages at Dinar town, Turkey, where located at the edge of an alluvial basin during 1st October 1995 earthquake is among the samples of the dominant effect of the subsurface topography. The investigations on this kind of sites show the insufficiency of the approaches based on 1D site response [19–23].

These methods are mainly categorized into linear and nonlinear methods [24]. In the linear method, the nonlinear behavior is approximated by an iterative procedure using equivalent linear soil properties. Because of the simplicity, it is common in earthquake engineering for modeling wave transmission in layered sites and dynamic soil-structure interaction. The interference and mixing phenomena that occur between different frequency components in a nonlinear material are missing from an equivalent linear analysis. Besides, the method does not directly provide information on irreversible displacements and the permanent changes that accompany liquefaction, because only oscillatory motion is modeled. These effects may be estimated empirically, however. Getting to accurate results can be possible by paying more time and cost using nonlinear methods. The finite element and finite difference methods, the boundary element method (direct and indirect methods) and hybrid techniques are among the most used analytical methods [25–34].

After publication of some parts of the findings of our investigation program, which has been being begun since 2009, in this article a

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collection of the results regarding different basin conditions and excitation levels are presented. With respect to the importance of the issue, at the present study, using a fully nonlinear analysis method, the 2D dynamic behavior of the basins with bedrock inclination at the edges and filled with different types of sands and clays are carried out. Since the application of finite difference method provides flexibility in the modeling of the irregular geometries and nonlinear behavior of the soil [35], which carries more importance at 2D analyses, FLAC3D code [36] which uses explicit finite difference scheme to solve the full equations of motion is utilized in this research.

2. The analysis method

The calculation procedure in FLAC3D code (Fast Lagrangian Analysis of Continua) is based on the explicit finite difference method to solve the full equations of motion. The most important aspect of this method is its power in the modeling of the nonlinearity. The method follows any prescribed nonlinear constitutive relation and since the strain increments (not tensors) relate to the stress tensors, therefore plastic yielding is modeled appropriately [36]. Both shear and compressional waves are propagated together in a single simulation, and the material responds to the combined effect of both components which can be very important, especially at the 2D dynamic modeling of the basin edges where the waves are trapped at low angle bedrock inclinations.

2.1. Basin geometry and material properties

The purpose of this study is to investigate the effects of the basin edge on the dynamic behavior of the basin. To attain this goal, hypothetical models with a bedrock inclination of 10° at the basin edges are modeled. In order to completely catch the two dimensional dynamic behavior of a basin, generally, the basin width to depth ratio should be taken at least 10–12. Thus, the width of the basin has taken too long (2000 m) so that these effects are caught. To apply the correct dynamic boundary conditions, despite the symmetric basin geometry, the whole length is modeled. The depth of the basins is 100 m. At layered basin models, two layer of 50 m thickness are utilized. Fig. 1 shows the geometry of the modeled basins. A 2D plain strain model has been constructed and analyzed by FLAC3D.

To investigate the effects of the basin edge on the dynamic behavior of the basins with different soil types and layers, a group of different sand and clay types have been selected. The geotechnical properties of the selected 6 soil types (three types for each of the sand and the clay) and their linear variation over 100 m basin depth have been presented in Table 1. It should be mentioned that at the inclined part of the basin, the velocity contrast is higher than the flat part of the basin. This is just like the real condition in the field that has been considered in this work. The properties of the used elastic bedrock are also presented. For the layered basins, the combinations of these soil types are utilized.

2.2. Strong ground motions

The constructed 2D models of the basins are subjected to the collection of 16 strong ground motion with different peak ground accelerations (PGA) level of 0.1, 0.2, 0.3 and 0.4 g, four motions for each PGA level. At Table 2 the specification of the selected earthquakes collection is presented. In the selection of theses motions, 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 records are baseline corrected and filtered by a 25 Hz low-pass filter. The excitations are applied as SV waves to the model bottoms.

2.3. Boundary conditions

To prevent the reflection of outward propagating waves back into the model, and allow the necessary energy radiation, the quiet-boundary scheme proposed by Lysmer and Kuhlemeyer [37] which involves dashpots are attached independently to the bottom boundary in the normal and shear directions. These viscous terms are not introduced directly into the equations of motion of the grid points lying on the boundary, but the normal and shear tractions are calculated and applied at every time step in the same way boundary loads are applied. The boundary conditions at the sides of the model must account for the free-field motion that would exist in the absence of the structure. The procedure is to “enforce” the free-field motion in such a way that vertical boundaries retain their non-reflecting properties. This approach used in the continuum finite difference code NESSI [38] are developed for FLAC3D via Free-Field boundary condition which involving the execution of free-field calculations in parallel with the main-grid analysis. The combination of these two advanced formulation are used in this research. Fig. 2 shows the schematic coupling of the main grid to free-field grids by viscous dashpots. Also, to prevent the numerical distortion, with respect to the frequency content of the input waves and the wave speed characteristics of the system, based on Kuhlemeyer and Lysmer [39] 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.

2.4. Damping

When hysteretic damping is used with an elastic/plastic model in FLAC3D, the modulus reduction technique is applied in the elastic range, and natural damping applies in the plastic range. 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. In this case, the combination of the Hardin/Drnevich hysteretic damping with a Mohr–Coulomb model is utilized Using the fully

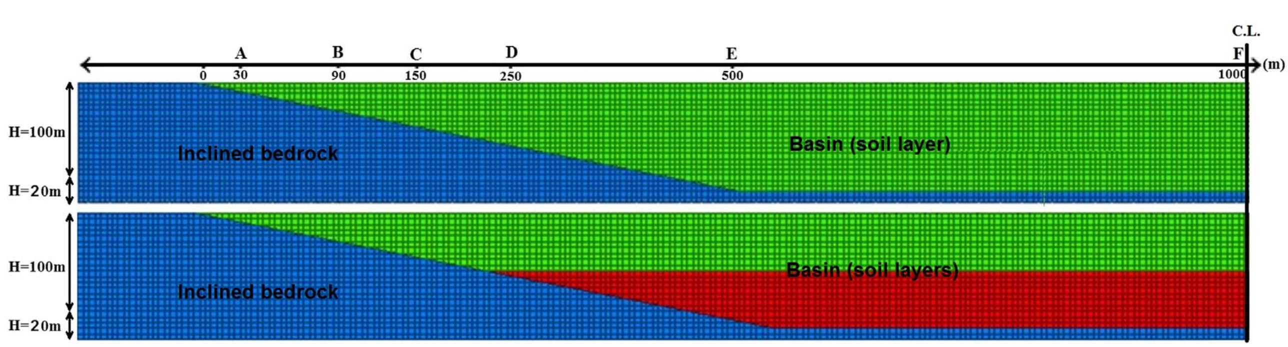

Fig. 1. Half width of the modeled basins and the arrays of recording points.