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Impact of geometrical and mechanical characteristics on the spectral response of sediment-filled valleys

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ABSTRACT

A comprehensive numerical analysis of the seismic response and site period of curved alluvial valleys was performed by taking into account the characteristics of sedimentary materials. This study presents a criterion as a combination of the three following geometrical and geotechnical characteristics of curved valleys in order to provide a simple method for code implementation of complex site effects: depth ratio, filling ratio and impedance ratio. The parametric studies were performed by a HYBRID program combining finite elements in the near field and boundary elements in the far field (FEM/BEM). The amplification patterns under above-mentioned characteristics were determined at the central point of valleys. The results are shown in the form of response spectra. Different impedance coefficients of materials were considered to evaluate effects resulting from combination with filling ratio and geometrical parameters. Finally, a criterion is proposed in terms of engineering applications to assess the spectral response at the surface of curved alluvial valleys.

1. Introduction

Local geological and geotechnical characteristics may generate significant amplification of ground motion and concentrated damage during large earthquakes. The modification of the seismic movement due to local topographical and geotechnical conditions is called *site effect*. These phenomena may raise the possibility of incident seismic motion and increase the consequences for structures and buildings. These site effects are mainly observed either at the top of hills or in alluvial valleys. Ground amplification due to soft soil layers has been shown to explain damage distribution during Mexico 1985 earthquake. The maximum acceleration recorded in the valley had been five times higher than that of a nearby site located on rock. Certainly in the recent past, there have been numerous cases of recorded motions and observed earthquake damage pointing towards geometrical and geotechnical amplification as an important effect. Geometrical and geotechnical characteristics of a site modify the nature of seismic waves in transition from depth to the surface. There are so much evidence from destructive earthquakes that can be attributed to these effects; The 1985 Chile earthquake [1], Whittier Narrows earthquake [2], the 1989 Loma Prieta earthquake [3], the 1994 Northridge earthquake [4,5], the 1995 Egion earthquake [6] and the 1999 Athens earthquake [7] are outstanding examples which verify the fact that local site condition can significantly affect earthquake damages. In addition to the damage observations, some instrumental earthquake recordings were reported that have been at least partially attributed to topographic effect namely the very high accelerations recorded at Pacoima dam (1.25 g) during San Fernando earthquake [8].

One-dimensional (1D) site effects have already been considered in current building codes. This consideration allows for measurement of the influence of nature and thickness of the sedimentary layer on the vertical propagation of volumetric waves regardless of lateral heterogeneities. A large number of studies have indicated site effects using empirical, analytical and numerical approaches. Depending on the problem limitations, each of these methods can offer some advantages and disadvantages. From the empirical point of view, different techniques (such as different inversion of Fourier amplitude spectra) using microtremor measurement and weak or strong motion earthquake records have been applied. Most of these studies have focused on relevance of input motion to ground motion on top of the soft soil in determination of the amplitude of the transfer function. An empirical method based on records of ambient noises has been presented by Nakamura [9]. Analytical methods have been developed for simple configurations since 1980s. Trifunac [10,11], Wong and Trifunac [12,13], Sanchez-Sesma

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[14] and Sanchez-Sesma and Velazequez [15] applied theoretical methods to improve the perception of physical phenomena involved in site effects. More recently, the development of numerical methods has made it possible to study site effects in case of more complicated configurations. Many authors have studied seismic behavior of 2D configurations via finite element method [16], finite difference method [17–19], boundary element method [20–26] and hybrid type methods [27,28]. Gatmiri et al. [29–40] have developed a program to study 2D wave scattering, combining finite elements in the near field and boundary elements in the far field (FEM/BEM) referred to as HYBRID.

2. Summary of previous works

Several parametric analysis of site effects have been performed by Gatmiri et al. In order to better clarify the usage of HYBRID program, some of these studies are mentioned in the following. It should be noted, that sediments are modeled by finite elements and substratum is represented by boundary elements which is adapted to the study in the far field.

Gatmiri et al. [40,41] studied various configurations and considered the influence of configuration of irregularities, slope angle of irregularities and dimensionless frequency of incident wave. The several salient features of topographic effects obtained are as follows:

The seismic ground motion was amplified at the crest of ridges, at the upper corner of slopes and at the edges of canyons; it was systematically attenuated at the base of these reliefs. This conclusion was normally verified for the cases of low dimensionless frequency.

The ground motion was not homogeneous as in case of the half-space, but it strongly varied on the free field. There were successive regions that movements of ground were attenuated. The magnitude of response at a location on the top surface was dependent on the distance from this location on the relief. This distance was a function of the frequency content of the relief itself.

The effects of topography were also influenced by the slope angle of the relief. Generally, the stiffer the slope of the relief was, the more the effects of topography due to this relief were accentuated. The topographic effects of a relief on the seismic response of that relief strongly depended on the frequency content of the excitation. In general, the higher the excited frequency was the more significant and complex were the site effects due to relief, and the wider the region influenced by the presence of the relief was, especially for the wavelengths comparable to or lower than the characteristic dimension of the relief.

Gatmiri and Arson [42] studied several parametric analysis in order to characterize the combined effects of topographical irregularities and sedimentary filling on ground motion under seismic solicitation due to vertically incident SV Ricker wave.

Indeed, the horizontal displacement in a canyon tend to be attenuated at the center and slightly amplified at the edge but in an alluvial basin, horizontal displacements are amplified at the center and can be locally attenuated near the edge if depth is large enough. A qualitative comparison between seismic response of the filled and empty was carried out suggesting that 2D geotechnical effects increases with depth and steep sidedness.

Gatmiri et al. [43,44] studied acceleration response spectra of different empty valleys. Curves were collected on a unique figure which characterized topographical effects in a quantitative and qualitative way in the spectral domain. The results showed that maximum amplification was reached at the edge point of valleys. The spectral acceleration responses were classified according to a unique geometrical criterion except for elliptical valleys: the "S/A" ratio (where S is the area of the valley opening, and A indicates the angle between the horizontal line and slope in the above corner) (Fig. 1). The spectral response increased by increasing the parameter of S/A, in elliptical valleys for each depth ratio.

Fig. 1. Definition of parameters S, A.

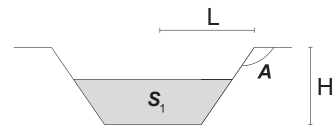

Fig. 2. Definition of parameters S_1, H/L.

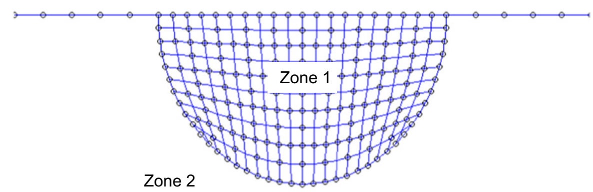

Fig. 3. Schematic layout of the bounded FE and the unbounded BE zones.

Sedimentary aspect of alluvial valleys was underlined by Gatmiri and Foroutan [45]. New criteria were offered in order to develop simple methods to incorporate 2D combined site effects in building codes. Filling ratio effects of Non-curved alluvial valleys and the influence of the changes in impedance ratio between sediments and the bedrock were investigated. The derived conclusions are presented briefly as follows:

Existence of sediments could smooth valley's response at the edge and amplify it at the center. When combining the depth and shape effects, two geometrical parameters S/A and $\sin(A)$ were presented; by increasing S/A, $SR*\sin(A)$ increased (S and A are similar to prior work).In order to combine filling ratio and depth ratio effects, the two geometrical parameters S_1/A and H/L were considered. As increasing the S_1/A, $SR*H/L$ increased (S_1, the area which was occupied by sediment, and H/L was the valley's depth ratio) (Fig. 2). Spectral ratio had an inverse relation to impedance ratio. By sediment softening in comparison to rocky bed, the spectral ratio increased and the seismic response of a configuration became more and more complicated and the data sequencing became more and more difficult. Finally, variation $S_1/A*1/\beta$ as a function of dimensionless parameter $SR*\sin(A)*H_1/L$ (H_1 was sediments depth) was plotted as a linear trend.

The effects of the changes in impedance ratio between sediments and the bedrock on the seismic response of curved alluvial valleys have not been investigated in these previous studies. So it should be stated clearly that the aim of this work is to propose a simple criterion that combines geometrical parameters and mechanical characteristics for estimation of the amplification of seismic response in the aforementioned configurations. In this paper, the behavior of curved valleys at different impedance and filling ratios was studied. We computed horizontal displacements at the surface of sedimentary valleys by using the HYBRID code. At a fixed impedance contrast, the critical points of maximum amplification under existence of sediments were determined and then parametric studies were performed on these points, and results were analyzed. Subsequently, effective parameters were introduced. Finally, impedance ratio coefficient was considered in combination with the geometrical parameters and practical graphs