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# EXTENDED ABSTRACT

# Amplification Pattern of Gaussian-Shaped Orthotropic Valley

Saeed Mojtabazadeh-Hasanlouei [a], Mehdi Panji [a*], Mohsen Kamalian [b]

[a] *Department of Civil Engineering, Zanjan Branch, Islamic Azad University, Zanjan, Iran.*
[b] *Geotechnical Engineering Research Center, International Institute of Earthquake Engineering and Seismology, Tehran, Iran.*

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## 1. Introduction

Studies indicate that the behavior of various materials, such as soils and rocks forming topographic features like valleys, which are plentiful on the Earth's surface, is influenced by anisotropy (Ting, 1996). In earlier research, isotropic cases were predominantly examined due to their simplicity in modeling and analysis. Although these studies provided valuable insights into the seismic behavior of valleys at the time, their findings notably diverge from the actual behavior observed in nature. These solutions are typically classified into analytical and numerical methods. Numerical approaches offer greater flexibility, facilitating the modeling and analysis of complex problems, divided into volumetric (FEM & FDM) and boundary methods (BEM) (Sánchez-Sesma *et al.*, 2002). The utilization of BEM provides advantages such as reducing one dimension in models, satisfying wave radiation conditions at infinity. Compared to domain approaches, employing BEM results in mesh concentration exclusively around the desired topographic boundary, automatic fulfillment of wave radiation conditions at far boundaries, reduced input data volume, substantial reductions in random-access memory, storage space, and analysis time. Significantly, the method offers extremely high accuracy in results due to the significant contribution of analytical processes in problem-solving (Mojtabazadeh *et al.*, 2022a). In this area, the studies of Panji *et al.* (2020), Panji & Mojtabazadeh (2018, 2020 & 2021), and Mojtabazadeh *et al.* (2020 & 2022b) demonstrate the seismic behavior of various topographic features using a straightforward process in half-space time-domain BEM. Notable researchers in the development of anisotropic BEM include Dravinski (2003), Daros (2013), and Chiang (2018). Additionally, Wang *et al.* (1996), Zhang (2002), Wunsche *et al.* (2009), Furukawa *et al.* (2014), and Parvanova *et al.* (2016) illustrated wave propagation in anisotropic mediums. Furthermore, Zheng & Dravinski (1998 & 2000) and Dineva *et al.* (2014) investigated the scattering of seismic waves in an orthotropic half-space. Recently, Mojtabazadeh *et al.* (2024) were able to analyze the seismic responses of heterogeneous orthotropic hill-shaped topographies by a time-domain boundary element method (TD-BEM) based on half-space Green's functions. The historical review of anisotropic studies not only underscores a notable gap in the comprehensive exploration of orthotropic topographic features but also draws attention to a similar gap in the investigation of hollow valleys. Therefore, this paper presents the seismic response of an orthotropic Gaussian-shaped valley subjected to incident *SH*-waves. The time-domain orthotropic half-space boundary element method, previously proposed by the authors for analyzing the aforementioned problem, is employed. Material damping is indirectly applied using logarithmic functions in the formulation. Additionally, the results are validated through a convergence approach for a circular valley, assuming certain key model parameters such as isotropy factor, valley aspect ratio, and frequency content. The obtained responses are primarily presented as two/three-dimensional graphs in both the time and frequency domains.

* Corresponding Author
*E-mail addresses:* mojtabazadeh@iauz.ac.ir (Saeed Mojtabazadeh-Hasanlouei | www.mojtabazadeh.ir), m.panji@iauz.ac.ir (Mehdi Panji), kamalian@iiees.ac.ir (Mohsen Kamalian).

## 2. Problem Statement

According to Fig. 1, an arbitrary-shaped valley embedded in an elastic attenuated orthotropic half-space subjected to vertical incident *SH*-waves of the Ricker type.

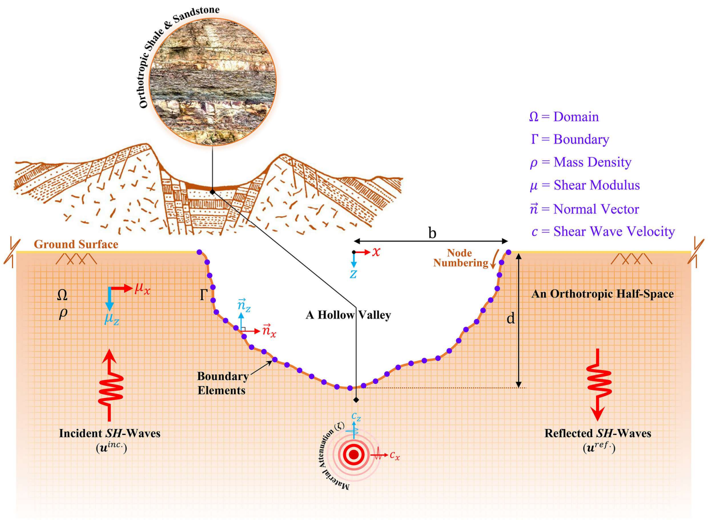


**Fig. 1.** The problem geometry of an arbitrary-shaped valley embedded in an elastic attenuated orthotropic half-space subjected to vertical incident *SH*-waves.

The shear-wave velocity (c) is set at 900 m.s$^{-1}$ and the mass density (ρ) at 2300 kg.m$^{-3}$ for the isotropic domain. The Barkan method is employed to incorporate physical attenuation, implemented as a logarithmic reduction that decreases the amplitude in each time-step. In the isotropic state, $\mu_x$ and $\mu_z$ are equal, so $IF = 1.0$, but when the model is orthotropic, the values of $\mu_x = 2\mu_z$, $\mu_x = 1.5\mu_z$, $1.5\mu_x = \mu_z$, and $2\mu_x = \mu_z$ are considered, which create the isotropy factors ($IF$) of 0.707, 0.816, 1.225, and 1.414, respectively.

## 3. TD-Response

Figure 2 illustrates the wave scattering patterns on the surface in the time-domain. The isotropy factors ($IF$) of 1.414, 1.0, and 0.707, along with vertical incident angles with SR=1.0 & 2.0 and a surface range of -3b to 3b, are considered to calculate the responses. The reflection and dispersion of incident waves, applying *SH*-waves to the model reveals three distinct phases in the wave dynamics marked by stations (D), (R), and (C) in the responses. The direct phase (D) represents the scattered waves from the fault as the source, while (R) shows the reflected phase due to an interface, boundary of a feature, or ground surface. Finally, (C) represents the crawler phase on the valley's surface.

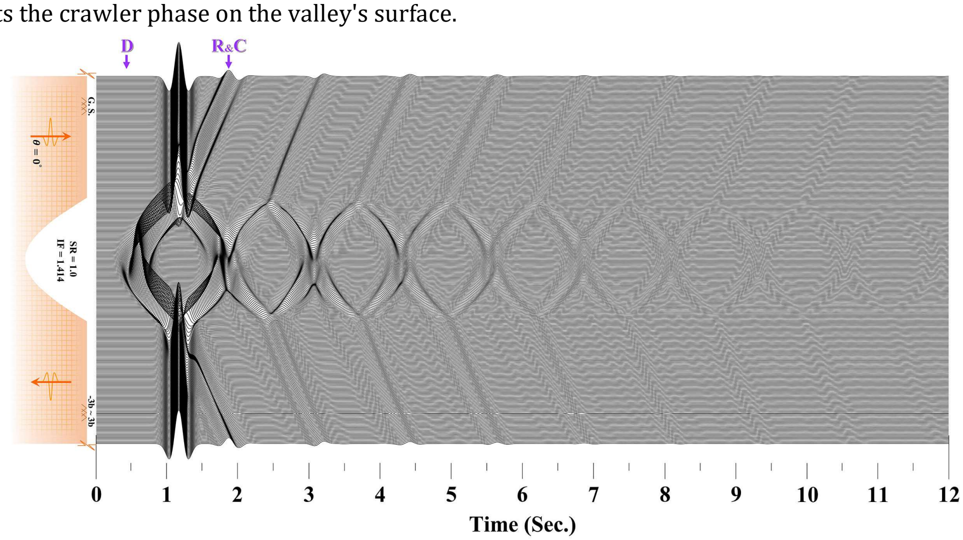


**Fig. 2.** The synthetic seismogram of the surface exposed to the vertical incident *SH*-waves for an attenuated orthotropic half-space with $IF$=1.414 in the presence of a Gaussian-shaped valley ($\zeta = 5\%$).

## 4. FD-Response

Based on Fig. 3, presenting the results in the frequency-domain proves to be the most effective method for clarifying the overall pattern of orthotropic ground surface displacements in the presence of a Gaussian-shaped valley. It also serves to illustrate the surface response when exposed to seismic waves. The factor $\eta$ utilized in presenting the frequency-domain responses is the dimensionless frequency, defined as $\eta = \omega b/\pi c$ where the angular frequency illustrated by $\omega$, $b$ is the half-width of the hill, $\pi$ is equal to 3.14, and $c$ is the equivalent shear-wave velocity.

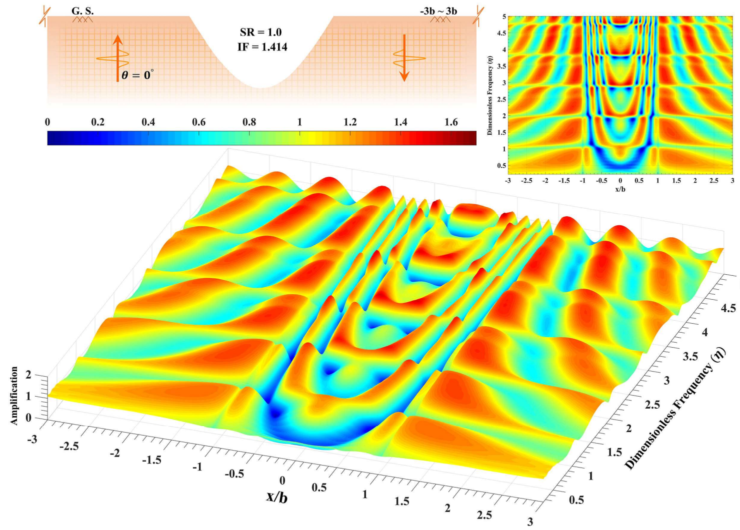


**Fig. 3.** The amplification pattern of the surface exposed to the vertical incident *SH*-waves for an attenuated orthotropic half-space with $IF$=1.414 in the presence of a Gaussian-shaped valley ($\zeta = 5\%$).

## 5. Conclusions

In this paper, the surface amplification of a Gaussian-shaped valley in an orthotropic half-space subjected to vertical incident *SH*-waves is presented. The time-domain orthotropic half-space boundary element method, previously proposed by the authors, was employed to analyze the aforementioned problem. Upon validation of the results using a convergence approach, a comprehensive parametric study focusing on certain key parameters such as isotropy factor, valley aspect ratio, and frequency content was conducted. The results were primarily presented as snapshots and three-dimensional outcomes in both the time and frequency domains. The results indicated that the material properties of the valley and the orientation of geological formations significantly affect the seismic amplification pattern of the ground surface. Moreover, the maximum valley amplification of 2.14 occurred for periods less than 0.5 and the assumed maximum isotropy factor.

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