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Seismic response of the trapezoidal alluvial hill above a circular cavity: Vertically incident SH-wave.

M. Panji* , S. Mojtabazadeh-Hasanlouei, M. Habibivand

Department of Civil Engineering, Zanjan Branch, Islamic Azad University, Zanjan, Iran.

ABSTRACT: A direct time-domain numerical approach named the half-plane Boundary Element Method (BEM) is proposed based on the half-space Green's functions for seismic analysis of the trapezoidal alluvial hill above a circular cavity, subjected to vertically propagating incident SH-waves. In the use of the method, the meshes were only concentrated around the boundary of the desired features. First, the problem is decomposed into two parts, including a pitted half-plane and a trapezoidal-filled solid on the surface. Then, the influence coefficients of the matrices are obtained by applying the method to each part. By satisfying the boundary/continuity conditions on the interfaces, a coupled equation is formed to determine unknown boundary values in each time-step. After implementing the method in an advanced developed algorithm, its efficiency is investigated by solving some practical examples and compared with those of the published works. To complete the results, the sensitivity analysis was carried out to obtain the seismic response of the hill by considering the key parameters, including impedance and shape ratios. In this regard, the effect of a subsurface cavity on the amplification pattern of the surface was studied as well. The results showed that the impedance and shape ratios of the trapezoidal alluvial hill were very effective on the seismic response of the surface. The results of the present study can be used to complete the accuracy of existing codes around the subject of geotechnical earthquake engineering. .

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1- Introduction

Studies on the role of surface/subsurface topographic features such as hills and cavities or the combination of them on the amplification/de-amplification of the earthquake were investigated as one of the major issues in the field of geotechnical engineering. Furthermore, the effects of heterogeneous shapes and materials were considered as important factors on the response of the ground surface [1]. In this regard, some approaches are developed where can name three main methodologies, including analytical, semi-analytical and numerical methods based on technical literature [2]. For the first time, researchers [3] presented an analytical response in the frequency domain for different types of hills using the matched asymptotic expansion of the wave function. In the following years, other researchers [4] used the same method to solve the hill problems. Recently, using a semi-analytical region-point matching technique, researchers [5] presented the surface responses of the deep semi-elliptic canyon to incident plane SH-waves. Despite obtaining accurate responses by analytical and semi-analytical methods, due to the lack of flexibility of mentioned approaches in modeling and analysis of complex topographical features that are visible in nature, the use of numerical methods is inevitable.

In recent years, numerical methods have gained more interest by researchers than analytical/semi-analytical processes. By dividing the common numerical methods into two general categories, the domain methods and boundary methods can be pointed out. The main domain methods include the finite element method (FEM) [6] and the finite difference method (FDM) [7]. Although boundary approaches include some constraints such as complex formulation and less development in nonlinear, plastic and multiphase media, their use can result in the automatic satisfaction of wave radiation conditions in far boundaries, the concentration of meshes only around the boundary of features, lower volume of input data and analysis time beside high accuracy of results due to the large contribution of analytical processes [8]. BEM is divided into two categories, including full-plane and half-plane, each being developed in frequency and time-domain. [9] used full-plane frequency-domain BEM and the researches of [8, 10-13] were carried out by half-plane time-domain BEM.

As the literature review shows, the scattering of transient SH-waves in the presence of alluvial trapezoidal-shaped hills located on an underground circular cavity has not yet been directly analyzed in the time domain. Thus, after implementing the proposed method in the general DASBEM algorithm [14], its validity was evaluated by analyzing several practical examples in the analysis of similarly combined topographies. Then, the response of the alluvial trapezoidal-shaped hill surface was sensitized by changing

*Corresponding author's email: m.panji@iauz.ac.ir

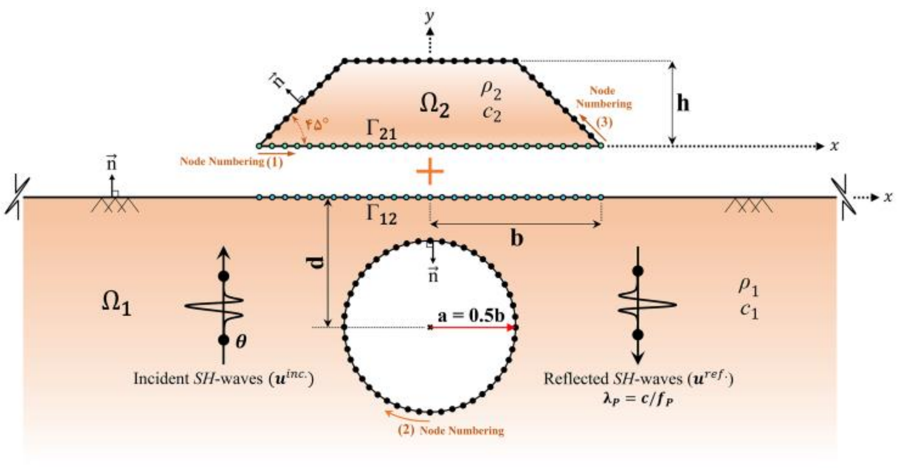

Fig. 1. The geometry of the problem.

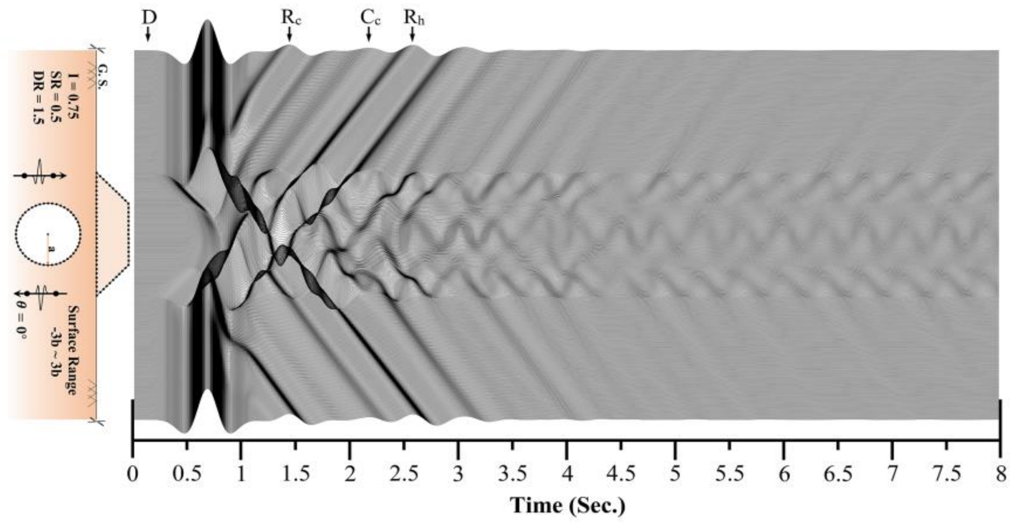

Fig. 2 Synthetic seismogram of the trapezoidal hill, including shape and impedance ratios of 0.5 and 0.75.

some key parameters of the model, such as the impedance and the shape ratio of the hill. The results were presented in terms of normalized displacement amplitude as well as three-dimensional diagrams in the time and frequency domains.

2- Problem statement

As illustrated in Figure 1, a linear elastic homogeneous and isotropic half-plane is considered as the medium of the model where an alluvial trapezoidal hill is located on an underground circular cavity.

The model is subjected to the vertical incident SH-waves of the Ricker type. The impedance ratios (I) of 0.75, 1.0 and 1.5 and the shape ratios (SR) of 0.1, 0.3, 0.5, 0.7 and 0.9 are considered in the models, respectively. First, to illustrate the reflections and diffractions of the incident waves, the results of the time-domain are presented and then, the responses of frequency-domain in 3D and 2D mode are illustrated to demonstrate the general pattern of amplification and displacements of the surface.

3- Time-Domain Responses

Figure 2 shows the scattering of the SH-waves in the presence of an alluvial trapezoidal hill with “I=0.75” and SR=0.5 above an underground circular cavity.

Three stations are marked on the figures by D, R, and C which show the paths of the direct, reflected, and crawled waves, respectively. The subscripts of “c” and “h” demonstrated the role of cavity and hill in the dispersion of the incident waves as well.

4- Frequency-Domain Responses

Figure 3 shows the 3D amplification pattern in the presence of an alluvial trapezoidal hill with “I=0.75” and SR=0.5, which are placed above an underground circular cavity. The amplification is the ratio of the surface response amplitude to free-field motion. The dimensionless frequency (η) is considered between 0.25 and 5.0. η is defined as (η=ωb/πc) where ω is the angular frequency of the wave, b is the half-width of alluvial hill and c is the shear-wave velocity.

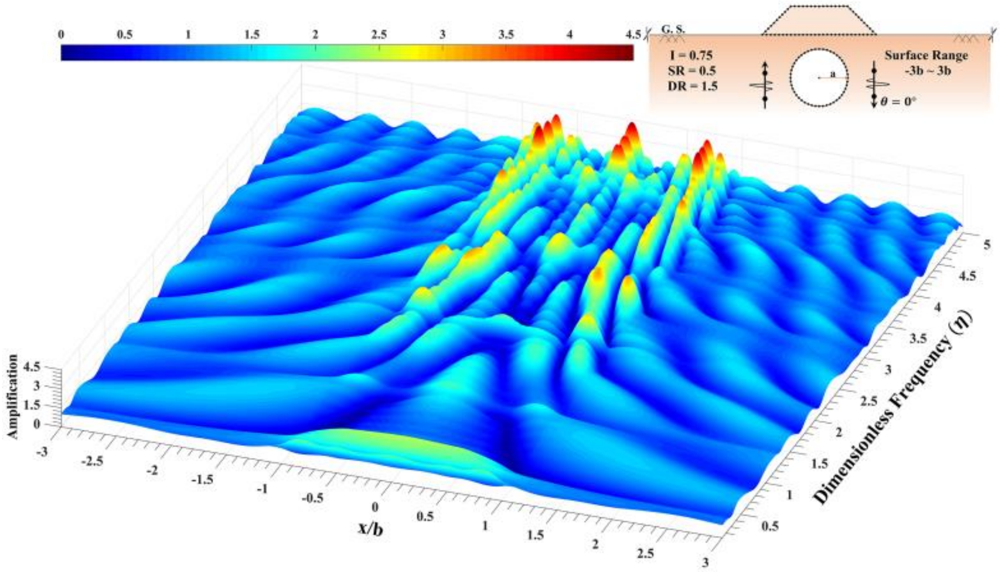

Fig. 3. The 3D amplification of the surface of the trapezoidal hill including shape and impedance ratios of 0.5 and 0.75.

5- Conclusions

The most important results of the parametric study can be summarized as follows:

1. The surface response was absolutely influenced by the shape dimensions/material properties of the hill.
2. Decreasing the impedance ratio increased the vibrations in time-domain results.
3. In the absence of cavity, decreasing the impedance ratio increased the amplification where the maximum amplitude of 4 was achieved in minimum impedance and maximum shape ratio. The presence of the cavity reduced the responses to 3.4 as well.
4. By increasing the shape ratio of the alluvial hill, the critical state of the response in time/frequency-domain results was intensified.
5. Although the presence of the cavity was effective on the reduction of peak points in some cases, it generally increased the vibrations and convergence time in both time and frequency-domain responses.

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