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Determining anti-plane responses induced by oblique-truncated semicircular canyon using systematic hybrid method with mapping function

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ABSTRACT

This paper proposes a novel strategy for the investigation of displacement amplitude ($|u_y|$) near and along an oblique-truncated semicircular canyon subjected to shear horizontal (*SH*) waves. Transfinite interpolation (TFI) was used to obtain the coordinates of nodes and determine the sequence of node numbering in the inner finite region including the canyon. The hybrid method, comprising finite element method and a Lamb series, was applied in conjunction with TFI to study the effects of canyon geometry, incident angle of *SH* waves (θ), and dimensionless frequency (η) on $|u_y|$. We detailed the amplification of $|u_y|$ in the illuminated zone and variations in $|u_y|$ due to canyon-decay-effect along the canyon surface as well as the decay of $|u_y|$ resulting from the shield effect in the shadow zone. Interestingly, oblique-effects play an important role in the magnification of $|u_y|$ along the inclined bottom of canyons, and variations in θ and η dominate the patterns of $|u_y|$.

1. Introduction

At the site of surface irregularities such as canyons, ground motion resulting from earthquakes can increase the amplitude of responses in the frequency domain and/or extend the period of vibration. This phenomenon can be attributed to the scattering and diffraction of propagating waves. Developing an understanding of the mechanisms underlying the scattering of waves by surface irregularities is crucial to structural design. Several theoretical and numerical methods have been proposed to analyze the scattering of shear horizontal (*SH*) waves induced by various types of canyon: semi-cylindrical [1], circular cylindrical with various depth-to-width ratios [2], semi-elliptical [3], semi-parabolic cylindrical [4], symmetrical V-shaped [5–7], U-shaped [8], non-symmetrical V-shaped [9], and truncated semicircular [10] as well as cylindrical canyons of arbitrary shape [11] and cylindrical canyons with a circular-arc cross-section [12]. No previous study has reported the scattering of *SH* waves induced by an oblique-truncated semicircular canyon using either theoretical or numerical methods.

The wave function expansion method based on the separation of variables has been used to obtain theoretical solutions for canyons with simple geometric shapes (such as semi-circular or semi-elliptical) subjected to *SH* waves. The results are presented by a set of orthogonal basis functions. This is made possible by the following: (1) unlike in-plane problems, such as the canyon subjected to pressure (*P*) waves or shear vertical (*SV*) waves, the scattering of *SH* waves induced by semi-circular (or semi-elliptical) canyons can be analyzed without the need to consider mode conversion, which usually appears in in-plane problems [13]; and (2) the unknown coefficients of the basis function, used to represent the scattering of waves, can be determined using the Hankel function (for cylindrical coordinate systems) or the Mathieu function (for elliptical coordinate systems) in conjunction with the traction-free boundary condition. Further, in cases of symmetrical V-shaped canyons and cylindrical canyons with a circular-arc cross-section, multiple sets of basis functions and Graf's addition formula must be combined to analyze the scattering of *SH* waves.

A variety of numerical methods, such as domain methods [14], boundary methods [15–20], and hybrid methods [21–24], have been proposed to deal with scattering and diffraction problems of canyons with arbitrary cross sections. For example, Yeh et al. proposed a hybrid method combining finite element method (FEM) and series method under the assumption of a half-space, comprising an inner finite sub-region including surface irregularities and an outer infinite sub-region [24]. In that case, the problem was solved procedurally. FEM was used to discretize the finite inner sub-region and a series capable of satisfying traction-free and radiation conditions was used for the outer infinite sub-region. Moreover, the point collocation

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method was utilized to identify the boundary between these two sub-regions [24].

Hybrid methods can be used to solve problems involving the scattering of *SH* waves by semi-cylindrical or semi-elliptical canyons [23]; however, meshing the irregularities of a discretized region can be very difficult. Employing the hybrid method requires that the following conditions be met: (1) the boundary between two sub-regions must be a semi-circle; and (2) the nodes on the boundary must be numbered by a special sequence to ensure compatibility with FEM node numbering. Unfortunately, this increases the difficulty of meshing the irregularities of complex surfaces using conventional FEM meshing methods.

Therefore, this study presents a novel strategy with which to investigate the scattering of *SH* waves by an oblique-truncated semicircular canyon embedded within an elastic half-plane. Transfinite interpolation (TFI) [25] was first used to map an arbitrary finite domain (physical region) within a rectangular domain (logical region) in order to determine the coordinates of nodes and the sequence of node numbering in the physical region. This study proposed a hybrid method combining FEM with a Lamb series to numerically solve the scattering and diffraction problems associated with oblique-truncated semicircular canyons. We investigated the degree to which the shape of the oblique-truncated semicircular canyon influences responses in the frequency domain. We compared the numerical predictions of truncated semicircular canyons with the findings reported by Tsaur and Chang [10]. We also conducted displacement amplitude ($|u_y|$) comparisons of semi-elliptical canyon [3] as well as circular-arc canyon [2] and those obtained using the proposed hybrid method in conjunction with TFI. Fig. 1 outlines the research conducted in this study.

2. Numerical model

2.1. 2-D oblique-truncated semicircular canyon

Fig. 2 presents a schematic of a 2D oblique-truncated semicircular canyon embedded within an elastic half-space on the x–z plane excited by a *SH* wave of unit-amplitude (perpendicular to the x–z plane) with a circular frequency (ω) and incident angle (θ). Symbols a, d_1, and d_2 in Fig. 2 represent the semi-width, the depth on the left side, and the depth on right side of the oblique-truncated semicircular canyon, respectively; (x_{d_1}, d_1) and (x_{d_2}, d_2) are the coordinates in

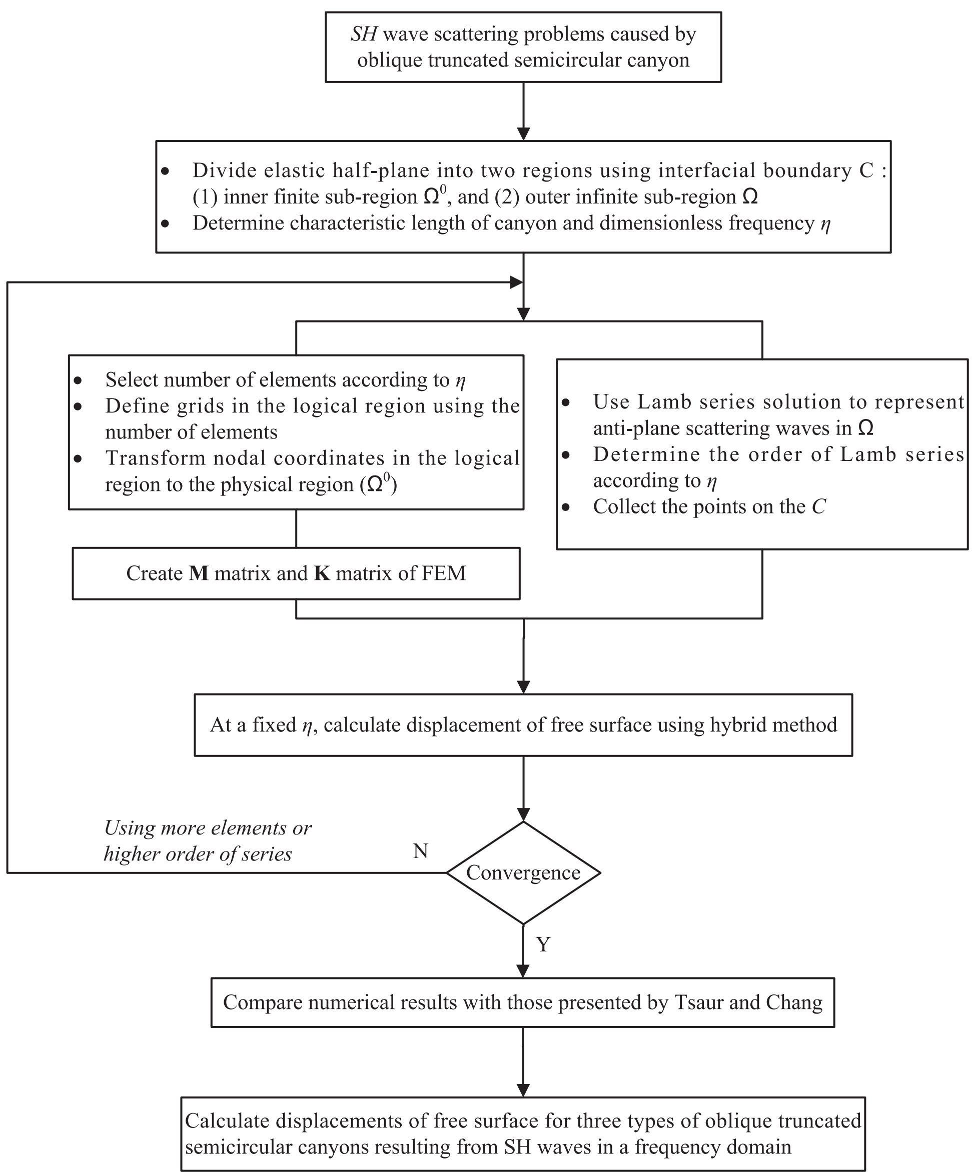

Fig. 1. Outline of research conducted in this study.