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Simulation of Seismic Wave Scattering by Embedded Cavities in an Elastic Half-Plane Using the Novel Singular Boundary Method

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Abstract. In the present study, a numerical procedure for analyzing the seismic response of the linear elastic half-plane including buried cavities subjected to incident P and SV waves is proposed by means of the novel singular boundary method (SBM). The SBM is a recently developed boundary-type meshless collocation method, which applies the singular fundamental solutions as basis functions. In order to avoid the singularities of the fundamental solutions, the SBM introduces the concept of origin intensity factors at the origin. With the aid of the origin intensity factors of the Laplace and the plane-strain elastostatic problems, this study first derives the origin intensity factors for the traction boundary condition as well as the origin intensity factors for the flat boundary, in order to form the SBM formulation for wave scattering problems in the linear elastic half-plane including buried cavities. Results obtained with the SBM model are compared with the results obtained with the finite element method, which shows that the method is quite promising for studying seismic wave scattering problems.

AMS subject classifications: 65M80

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1 Introduction

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Due to the increasing construction of subway tunnels and underground structures in urban areas, wave scattering effects of embedded cavities in the elastic half-plane have attracted much attention in earthquake engineering [1–4]. It has been established that these cavities will certainly affect the ground motion and further lead to potential damage of nearby buildings. The potential damage to underground structures and ground buildings observed during the earthquakes indicates an urgent need for analytical and numerical methods to evaluate these effects. In the category of analytical methods, there are three major methods for the analysis of wave scattering problems with embedded cavities, namely, the method of wave function expansion, the method of integral equations, and the method of integral transforms [5]. Although analytical methods are important to show the physical nature and possess a better accuracy than numerical methods, they are limited to simple-shape cavities under idealized assumptions. Therefore, more general and real-world application problems should be analyzed by numerical methods.

The most commonly used numerical methods for seismic wave scattering studies with embedded cavities are element-based methods such as the finite element method (FEM) [6,7] and the boundary element method (BEM) [8–10]. The FEM is the most widely used numerical technique in real-world applications. The FEM is a domain discretization technique which discretizes the domain into small elements and needs special techniques for treating the infinite parts of the computational domains. In comparison with the FEM, the BEM only requires the discretization of the boundary of the physical domain and reduces the dimension of the problem by one, which makes it an attractive numerical analysis tool. Additionally, by using the fundamental solutions as the basis functions, the BEM formulations automatically satisfy the radiation conditions at infinity for infinite and semi-infinite domain problems [11]. The dynamic response of embedded cavities in a half-plane to seismic waves has previously been investigated. Rodriguez-Castellanos et al. conducted the 2D indirect BEM for P and SV waves in the frequency domain [12, 13]. Alielahi et al. [14, 15] presented an improved formulation of a time-domain 2D BEM to analyze the seismic response of underground structures. Von Estorff et al. [16] proposed the FEM-BEM hybrid scheme in the time-domain to study the dynamic behavior of a typical cavity. Stamos and Beskos [17] implemented a general numerical method which is based on the BEM in conjunction with the Laplace transform for determining the dynamic response of the seismic waves. Several other BEM formulations and numerical examples are presented and experimented in reference therein of the mentioned studies.

In contrast to the above-mentioned mesh-based methods, researchers have recently developed the so-called meshless or meshfree formulations which require neither domain nor boundary discretization, such as the method of fundamental solutions (MFS) [18, 19]. In the MFS, the solution to the problem is given by the linear combinations of the fundamental solutions of the governing equations with some unknown coefficients. Therefore, we may consider that the MFS applies the analytical fundamental solutions as basis functions which automatically satisfy the governing equations and radiation conditions at infinity. Unlike the BEM, the MFS does not require domain or boundary discretization. To avoid the singularity of the fundamental solutions, the source nodes