SURFACE MOTION OF A 3-D ALLUVIAL VALLEY IN LAYERED HALF-SPACE FOR INCIDENT PLANE WAVES

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ABSTRACT :

This paper presents a solution for surface motion of a 3-D alluvial valley in layered half-space for incident plane waves in frequency domain by indirect boundary element method (IBEM), based on the exact dynamic stiffness matrices and the dynamic Green's functions for uniformly distributed loads acting on an inclined plane in 3-D layered half-space by the authors. The free-field response is carried out to give the displacements and stresses on the curved plane which forms the boundary of the alluvial valley. The fictitious uniformly distributed loads are applied on the same curved plane to calculate the Green's functions for the displacements and stresses. The amplitudes of the loads are determined by the boundary conditions, and the displacements due to the free field and due to the fictitious loads are summed up to obtain the whole motion. The accuracy of the solution is verified by comparison with related solutions. The numerical calculations are performed for a hemispherical alluvial valley in one single layer over half-space for incident waves, and it is shown that, there exist distinct differences between the surface motion of a alluvial valley in layered half-space and that in homogeneous half-space; the dynamic characteristics of the soil layer significantly affect both the amplitudes and frequency spectrum of the surface motion.

KEYWORDS: Surface motion, 3-D alluvial valley, layered half-space, plane waves, IBEM

1. INTRODUCTION

The effect of alluvial valleys on seismic wave propagation is one of the most fundamental subjects in seismology and earthquake engineering. Trifunac (1971) gave an exact analytical solution for the surface motion of a semi-cylindrical alluvial valley for incident plane SH waves, and delineated the amplification pattern for various frequencies and incident angles. Then many studies were carried out on this topic using either analytical or numerical methods, e.g., finite difference methods, finite element methods, boundary element methods, etc., and the details may be found in a review by Sanchez-Sesma, et al (2002). In recent years elastic wave scattering by 3-D alluvial valleys has attracted more and more attention (Lee, 1984; Mossessian and Dravinski, 1990; Toshinawa and Ohmachi, 1992; Sanchez-Sesma and Luzon, 1995; Dravinski, 2007).

It should be noted that most of the contributions are still limited to homogeneous half-space. However, in reality, soil is not homogeneous, but often layered; and the soil layers determine dynamic characteristics of the site, which may affect wave propagation around alluvial valleys. Liang and Ba (2007a) showed there exist interactions between the valleys and soil layers for 2-D case. This paper presents a solution for surface motion of a 3-D alluvial valley in layered half-space for incident plane waves in frequency domain by indirect boundary element method (IBEM), and it is shown that the surface displacement amplitudes depend on both the scattering of incident waves by the alluvial valley and the dynamic characteristics of layered half-space.

2. METHODS

Figure 1 shows the model for scattering of plane waves by a 3-D alluvial valley in layered half-space. The indirect boundary element method (IBEM) in frequency domain is applied. At first, the free-field response is calculated using dynamic-stiffness matrices (Liang and Ba, 2007b) of 3-D layered half-space to determine the displacements and stresses on S which will form the interface between the alluvium and the half-space. Then fictitious distributed loads are applied on the interface S in the free-field half-space. The corresponding Green's functions acting on an inclined plane for the displacements and stresses are then calculated (Liang and Ba, 2007c). The amplitudes of the source loads are determined by the boundary conditions. These conditions are satisfied only in an average sense by using the method of weighted residuals. The surface displacements arising from the waves in the free field and from the fictitious distributed loads are summed up to obtain the solutions.

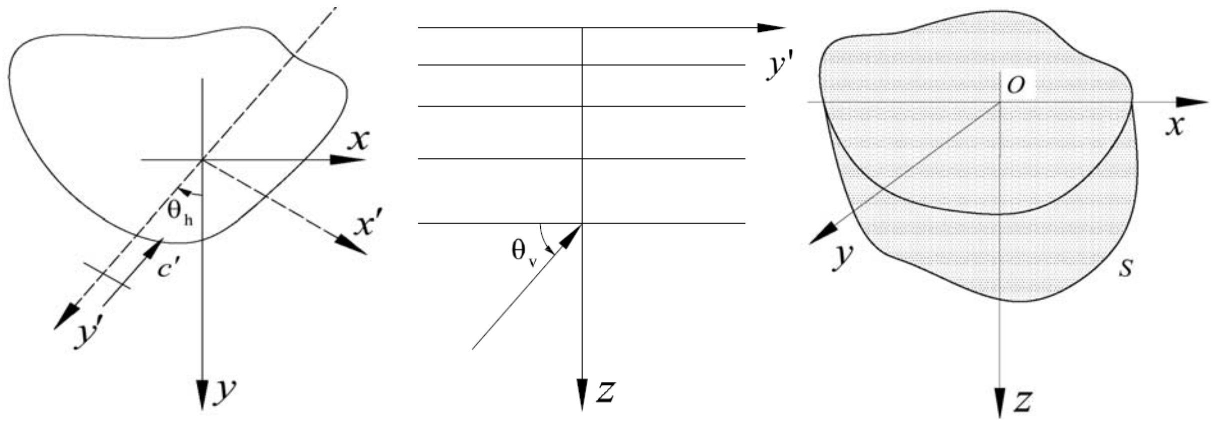


Figure 2 The model

3. VEFIFICATIONS

To verify the precision of the method, Figure 2 shows the surface displacement amplitudes of a hemisphere alluvial valley with radius a in homogeneous half-space compared with the results in Mossessian and Dravinski (1990). The parameters are as follows: the ratio of shear velocity of alluvium to half-space is 0.5, the ratio of mass density of alluvium to half-space is 2/3, Poisson's ratio is 1/3 both for alluvium and half-space, damping ratio is 0.005, dimensionless frequency $\eta = \omega a / \pi c_s^H$ =0.75, for incident plane P, SV and SH waves. The results of the present study agree very well with those in Mossessian and Dravinski (1990).

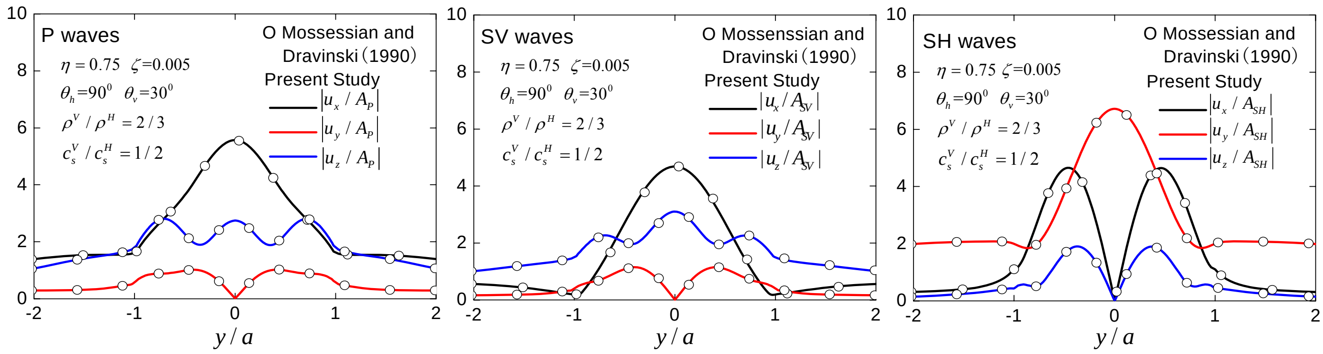
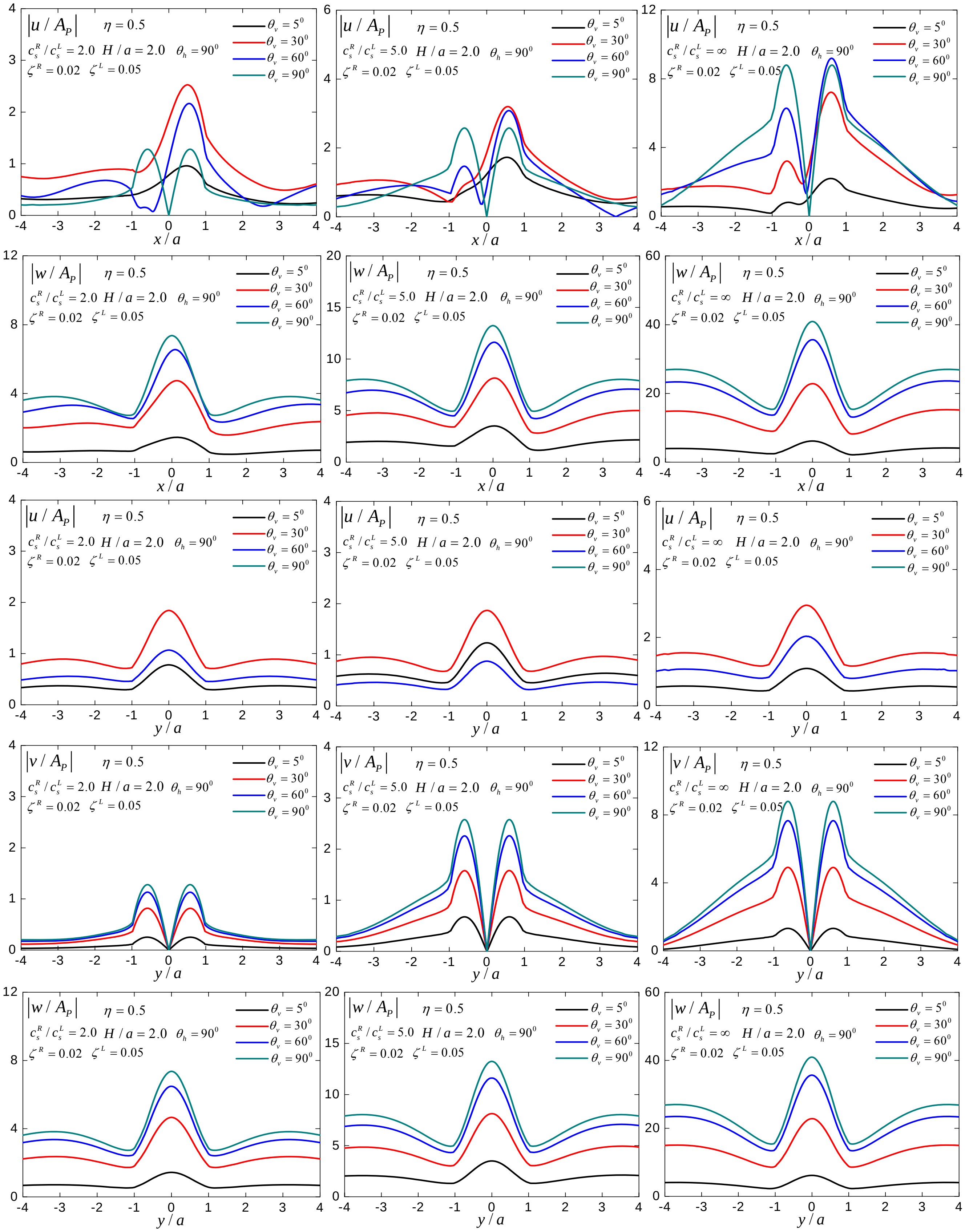


Figure 2 Comparison with the known results

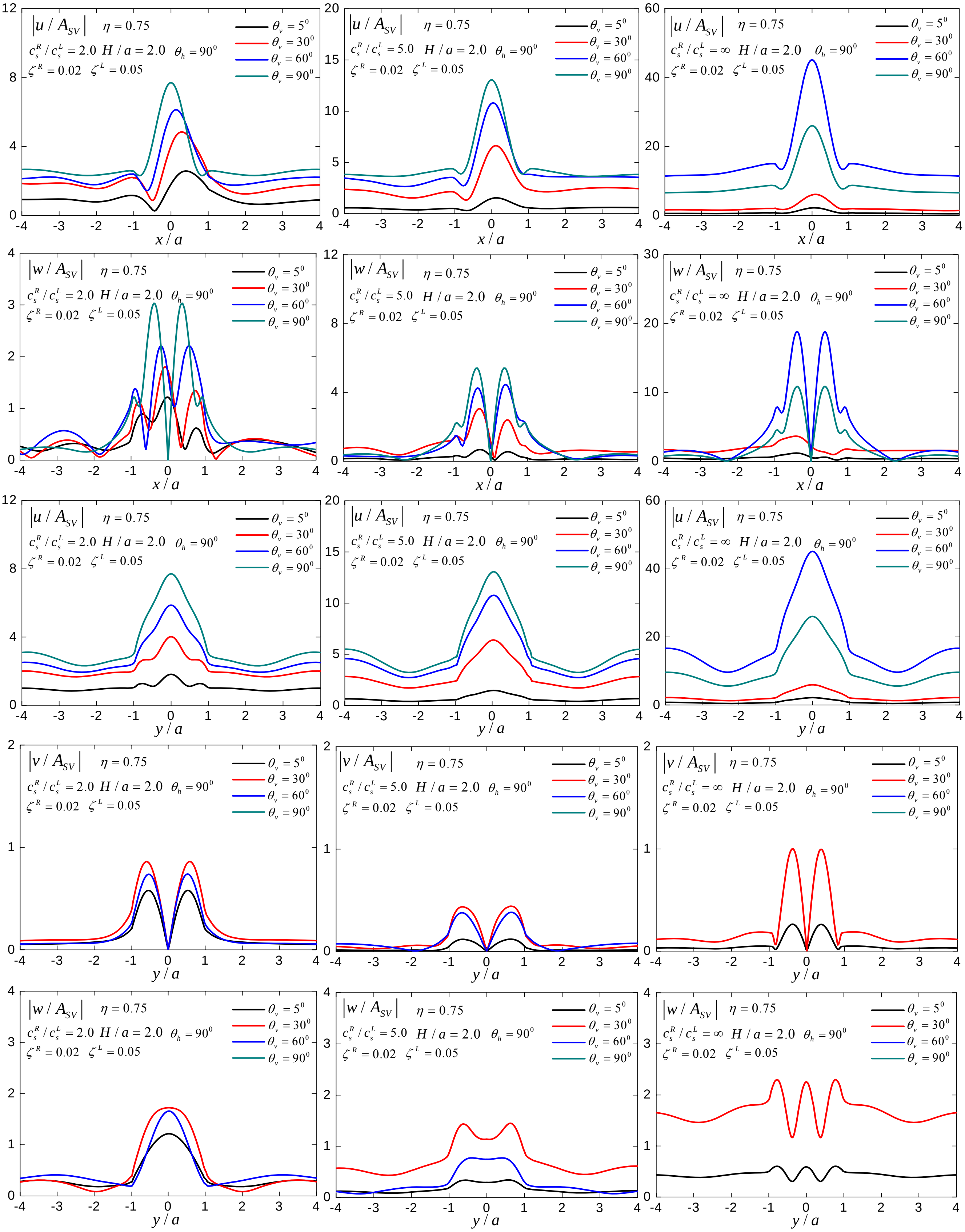
4. NUMERICAL RESULTS

A hemispherical alluvial valley in one layer over half-space is studied for simplicity. The parameters are defined as follows: the valley radius is a, the layer thickness is H; the velocity, mass density and damping ratio for bedrock, soil layer and alluvium are C_s^R, ρ^R, ζ^R, C_s^L, ρ^L, ζ^L and C_s^V, ρ^V, ζ^V, respectively; The



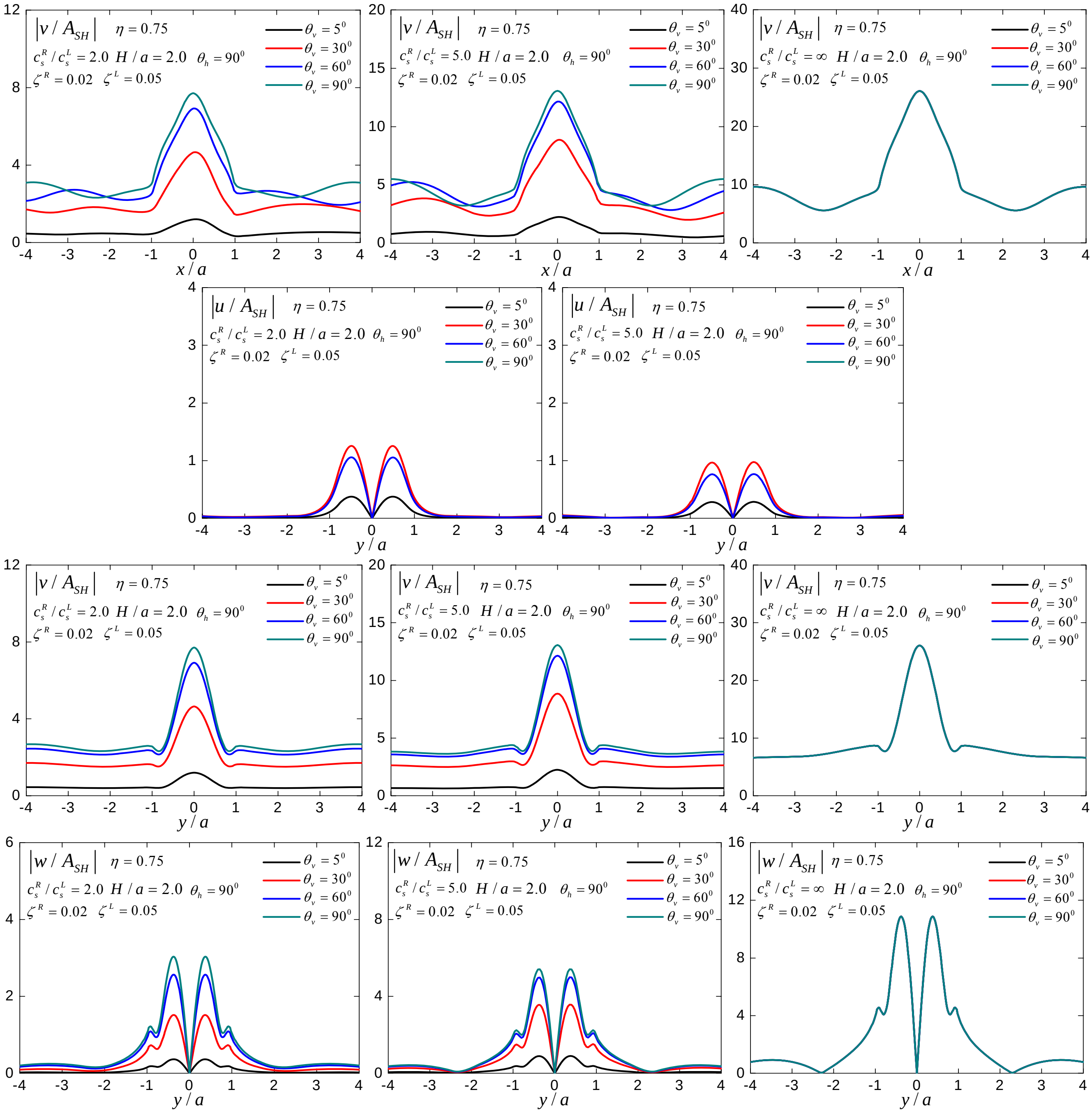
(a) Incident P waves

Figure 3 Surface displacement amplitudes due to variation of soil layer stiffness



(b) Incident SV waves

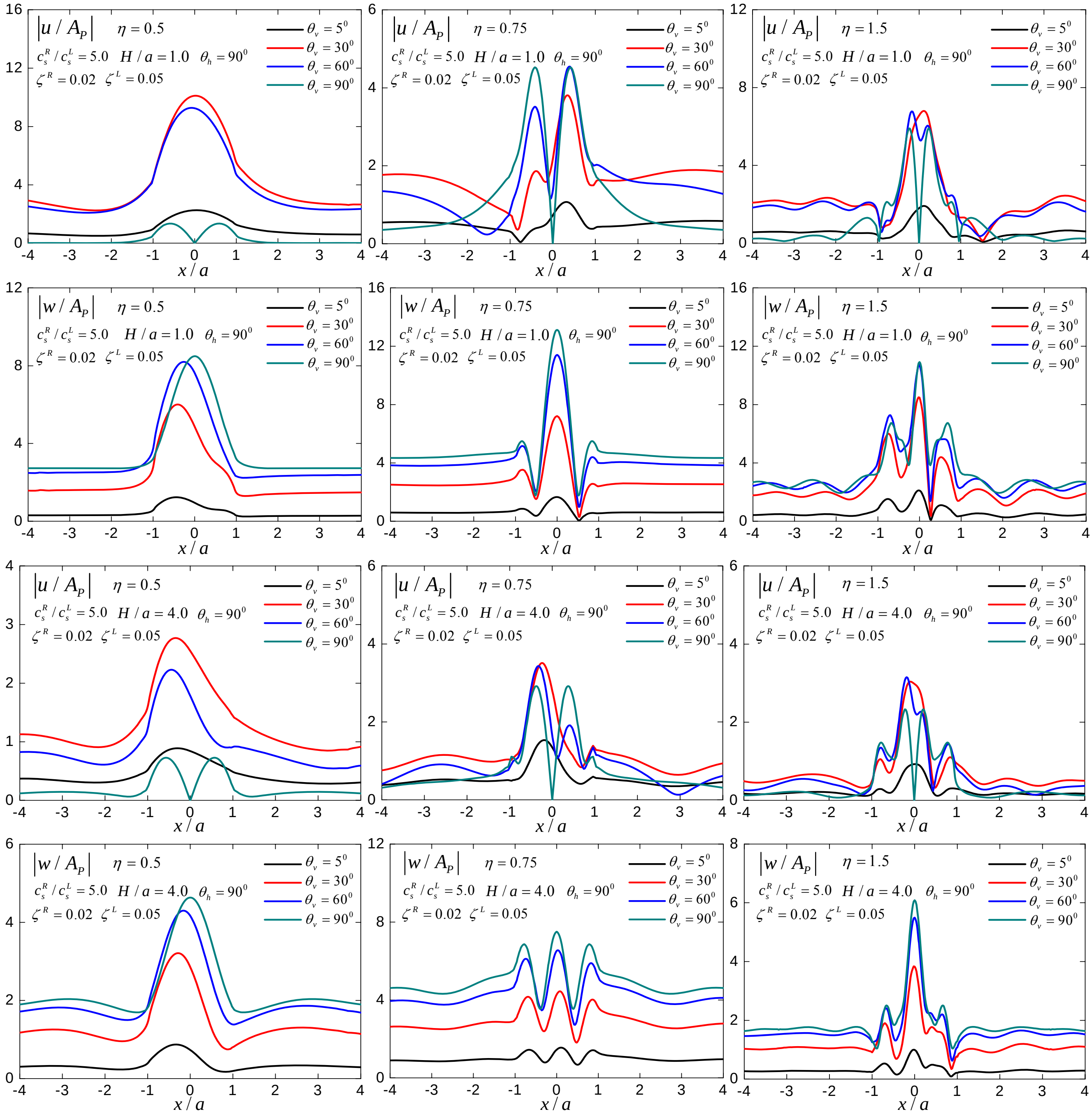
Figure 3 (Continued)



(c) Incident SH waves
Figure 3 (Continued)

Poisson's ratios for bedrock, soil layer and alluvium are all assumed to be ν=1/3 for all following calculations. The dimensionless frequency is defined as $\eta = 2a/\lambda^L$, where λ^L is the wavelength of the shear waves.

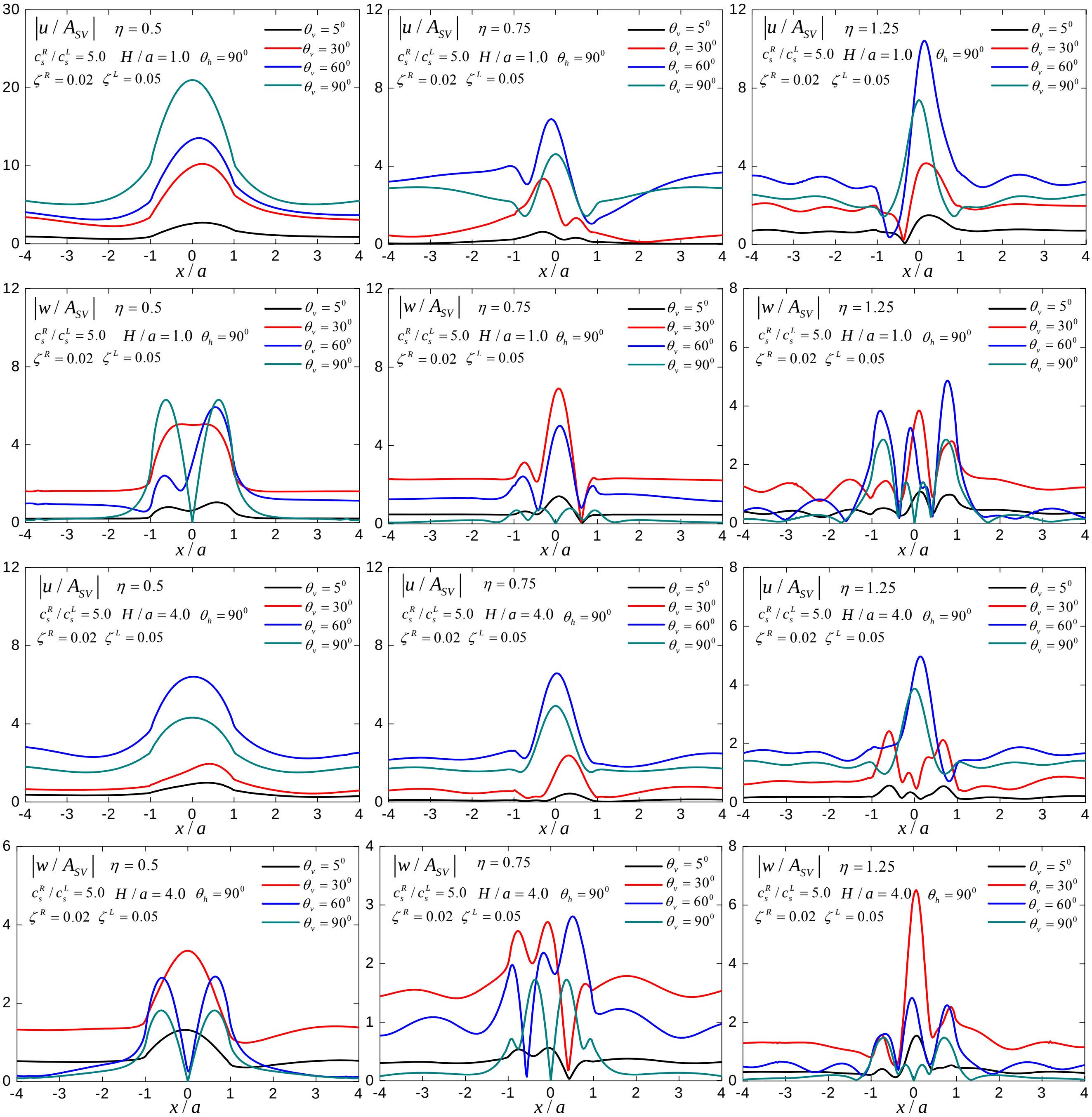
Figure 3 illustrates the surface displacement amplitude (in plane *y*=0 and *x*=0, respectively) around a hemispherical alluvial valley due to variation of soil layer stiffness. The parameters are defined as follows: *H*/*a*=2, C_S^R/C_S^L =2.0, 5.0 and ∞, respectively, C_S^L/C_S^V =2, ρ^R/ρ^L=1, ρ^L/ρ^V=1, ζ^R=0.02, ζ^L=0.05, ζ^V=0.05, horizontal incident angle θ_h=90°, vertical incident angle θ_v=5°, 30°, 60° and 90°, incident frequency η=0.5 for P waves and 0.75 for SV and SH waves. Figure 4 illustrates the surface displacement amplitude (in plane



(a) Incident P waves

Figure 4 Surface displacement amplitudes due to variation of soil layer thickness

y=0) due to variation of soil layer thickness with H/a=1 and 4, and C_S^R/C_S^L =5.0, and η=0.5, 0.75 and 1.5, respectively. It is shown from these figures that the surface displacement amplitude around alluvial valley in layered half-space highly depends on the velocity and thickness of the layer, or, the resonance characteristics of the layered half-space (the resonance frequencies of the layered half-space are η=0.5 and 1.5 ··· for P waves and η=0.25 and 0.75 ··· for SV waves in the case of H/a=2), besides the incident frequency. In other words, the surface displacement amplitudes depend on both the scattering of incident waves by the alluvial valley and the dynamic characteristics of layered half-space, and there are interaction between the scattering of waves by the alluvial valley and the dynamic characteristics of layered half-space.

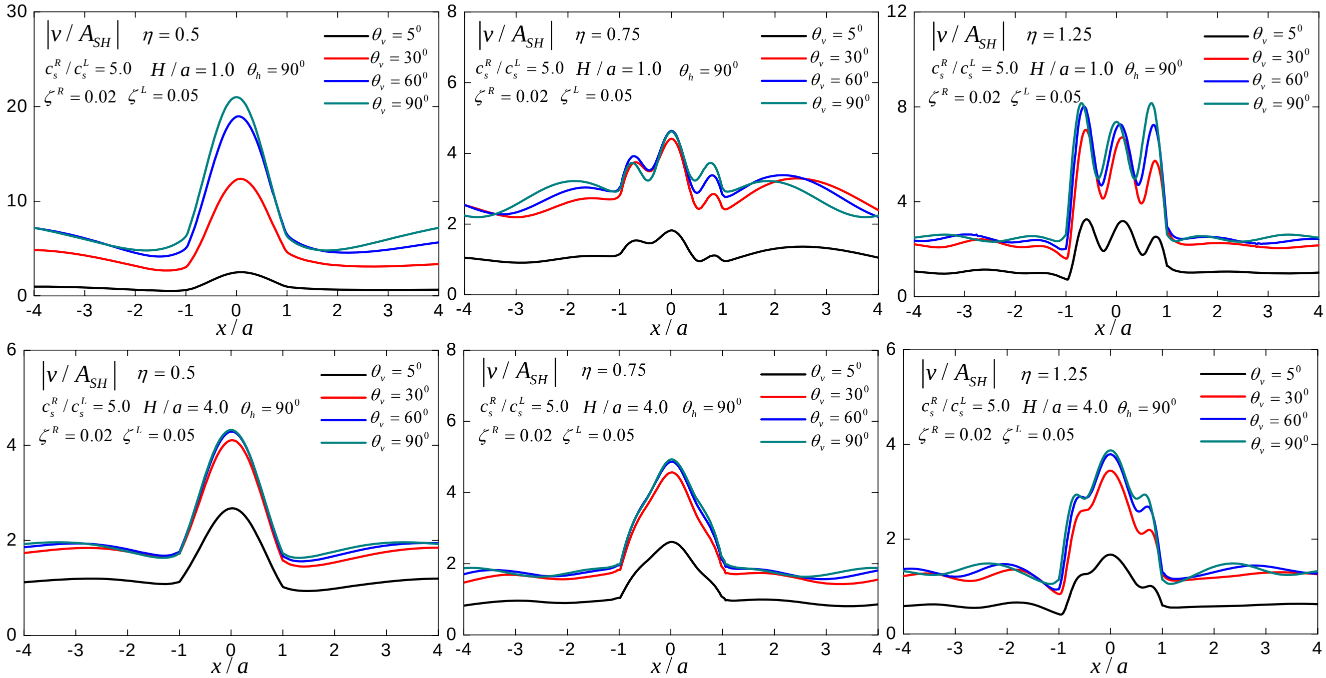


(b) Incident SV waves

Figure 4 (Continued)

5. CONCLUSIONS

This paper presents a solution for surface motion of a 3-D alluvial valley in layered half-space for incident plane waves in frequency domain by indirect boundary element method (IBEM), based on the exact dynamic stiffness matrices and the dynamic Green's functions for uniformly distributed loads acting on an inclined plane in 3-D layered half-space by the authors. The numerical calculations are performed for a hemispherical alluvial valley in one single layer over half-space for incident waves, and it is shown that there exist significant differences between the surface motion of an alluvial valley in layered half-space and that in homogeneous half-space, the surface displacement amplitudes depend on both the scattering of incident waves by the alluvial valley and the



(c) Incident SH waves

Figure 4 (Continued)

dynamic characteristics of layered half-space, and there are interaction between the scattering of waves by the alluvial valley and the dynamic characteristics of layered half-space, the dynamic characteristics of the layered half-space significantly affect both the amplitudes and frequency spectrum of the surface motion.

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