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Response of Alluvial Valleys to Incident SH, SV and P Waves Paper No. 10.17

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SYNOPSIS: Results of an extensive numerical study on two dimensional wave scattering by valleys of semi-elliptical cross section due to incident SH,SV and P waves are presented. The investigation has been conducted using a rigorous Boundary element algorithm. The influence of key parameters, such as, valley depth, impedance ratio, frequency, and angle of incidence on surface ground motion are studied in detail. Furthermore, the case of a valley within a layered half space is analyzed and results compared with those obtained for a valley within a homogeneous half space.

INTRODUCTION

Field observations after large earthquakes show that local site has an important impact on amplification of ground motion. Although numerous factors may have contributed significantly to such observations, it has been suggested that one of the principal causes for the observed distributions of damage may be attributed to the amplification of incident waves by local geological and soil conditions. For example, during the Michoacon, Mexico earthquake of 1985, great damage occurred to the structures atop the alluvial of the Mexico City sedimentary basin while the damage to the buildings atop the base rocks at the outskirts of the basin was considerably smaller (Anderson, et al (1986)). If one takes into account that most of the damage occurred in Mexico City, which is more than 350 km away from the earthquake epicenter, the role of the site effect in the amplification of strong ground motion appears to be of considerable importance. Similar phenomenon was also observed during the Niigata (Japan) earthquake of 1964 and the Lima (Peru) earthquake of 1974. From all these case studies it is evident that there is a need to explain in detail how local site conditions influence ground motions.

Since the initial work of Trifunac (1973) on the two-dimensional response of a semi-circular canyon subjected to SH-wave excitation, a considerable amount of work on wave scattering by canyons and valleys has been reported in the Geotechnical and Seismology literatures. A number of numerical methods have been used to solve wave propagation problems, such as the finite difference method, finite element method, and boundary element method. Among these methods, in recent years the boundary element method has become very popular for analysis of site response problems.

The Boundary Element Method (BEM) is well suited to deal with wave propagation problems because it avoids the introduction of fictitious boundaries, and reduces the dimensionality of the problem by one. The two-dimensional scattering and diffraction of SH waves of arbitrary angle of incident from irregular canyon-shaped topography has been formulated in terms of integral equations by Wong and Jennings (1975). BEM has also been coupled with the finite element method to solve wave propagation problems (Shah et al (1982)).

Direct Boundary Element formulations have been applied to solved two-dimensional scattering of harmonic elastic waves by canyons (Sanchez-Sesma, (1981)), alluvial deposits (Dravinski (1982)), and ridges (Sanchez-Sesma et al (1982)), for different types of waves and shapes of the scatterers. Sanchez-Sesma (1984) also used the direct BEM to solve a few three-dimensional problems of wave scattering.

The majority of the studies reported to date have considered two dimensional (plane strain) wave scattering by idealized semi-circular or elliptical shaped canyons or valleys within a homogeneous halfspace, subjected to incoming SH waves. Few results have been obtained which consider incident P and SV waves, or a layered half space, such as Kawase (1988) and Liu et al (1991).

In this paper a rigorous algorithm of the direct BEM for steady-state dynamics [Ahmad & Banerjee (1988)] is used to conduct an extensive parametric study of two dimensional wave scattering by elliptical valleys within an elastic half space (or layered soil) due to incident SH, SV and P waves. The influence of key parameters, such as depth and shape of the valley, ratio of shear wave velocity of the valley to that of the underlying soil, excitation frequency, incidence angle, and layered soil profile are studied and discussed. The study of these key parameters on surface ground motion for all types of body waves presented herein is more comprehensive and systematic compared to the earlier work on the subject. The purpose is to provide the practioner with a range of possible ground responses, emphasizing the most significant, and complex interelationships between attributes affecting wave scattering.

PROBLEM DEFINITION

Fig. 1 represents a half space containing a valley with an elliptical cross-section. Soil is assumed to be isotropic, homogenous and linear elastic. The contact between valley and half-space is assumed to be perfectly bonded. For studies involving a layered half-space a soft upper layer having a thickness equal to the width of the alluvial valley is considered. The incident SH, SV and P waves are assumed to have an incident angle θ, oscilation frequency ω, and a unit amplitude of displacement.

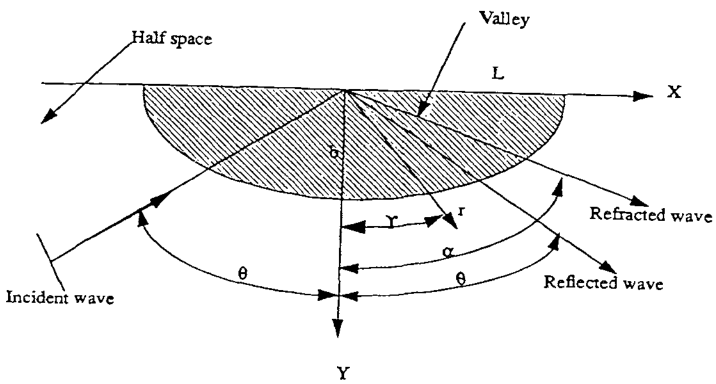

Figure 1. Semi-elliptical Valley and Surrounding half-space.

COMPARISON WITH PUBLISHED RESULTS

To establish the accuracy and reliability of the present analysis, results are compared with those from a limited number of cases available in the literature.

Vertically incident SH waves, corresponding to the two dimensional antiplane shear problem were considered by Wong and Trifunac (1974). Using the present BEM a semi-elliptical alluvial valley has been analyzed with depth to half width ratio $R=\frac{b}{L}=1.0$. The value of dimensionless frequency was $\eta = \omega L/\pi V_s = 0.5$. Comparison in fig. 2, of the present results (solid line) with exact solutions of Wong and Trifunac (1974) (points) show good agreement.

INFLUENCE OF IMPORTANT PARAMETERS

In what follows results of a parametric study intended to document the effects of valley shape, and impedance, and wave characteristics such as wave type, frequency and angle of incidence on

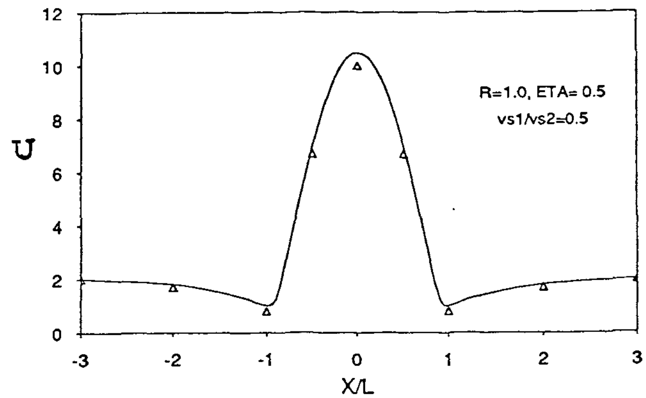

Figure 2. Comparison with Results of Wong and Trifunac (1974)

the wave scattering by alluvial valleys embedded in an elastic half space are described.

The parameters used in this work are defined as follows:

ρ_1 = mass density of the valley; ρ_2 = mass density of the half-space;

v_{s1} = shear wave velocity of the valley; v_{s2} = shear wave velocity of the half-space or upper layer; v_{s3} = shear wave velocity of bedrock underlaying the top layer (for layered half-space case).

η = $2L/\lambda = \omega L/\pi v_{s1}$ = dimensionless frequency; where ω is frequency of the incident wave.

L = half-width of the valley;

X/L = dimensionless distance from the center of valley

ρ_1/ρ_2 = ratio of mass density of the valley to the half-space (or top layer)

v_{s1}/v_{s2} = ratio of shear wave velocity of the valley to the half-space (or top layer)

θ = Angle of wave incidence.

For all figures presented in this study, ratios of shear-wave velocities, v_{s1}/v_{s2}, are taken as 0.3, 0.5, 0.75, 1.5, and 2.0. Values of dimensionless frequency, η, considered are 0.5, 1.0, 1.5, and 2.0. Ratio of depth to half width of the valley (R) considered are 0.05, 0.15, 0.5, 1.0, and 1.5 (R = 1.0 actually is the semi-cylindrical valley). The ratio of the densities of the half-space and valley is assumed to be 1.5. The Poisson's ratio for all materials is ν = 1/3. Figures present the surface displacement amplitudes plotted against the dimensionless distance, X/L, for various dimensionless frequency, η; shear wave velocity ratio v_{s1}/v_{s2}, and depth to width ratio of valley, R. The value of X/L = -1 corresponds to the left rim of the valley, and X/L = 1 to the right rim of the valley.

Effect of Valley Shape

Fig. (3) presents displacement amplitudes in the y-direction along the valley surface due to vertically propagating SH waves, for a range of valley shapes. The influence of the valley is much less significant for the shallow valley

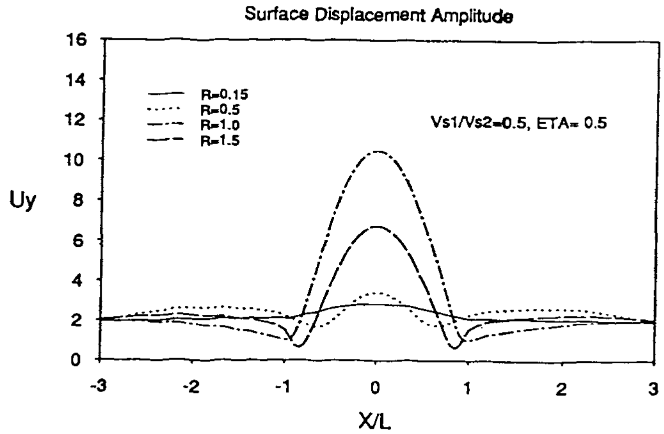

Figure 3. Effect of Valley Shape on Ground Motion Considering Vertically Incident SH Waves.

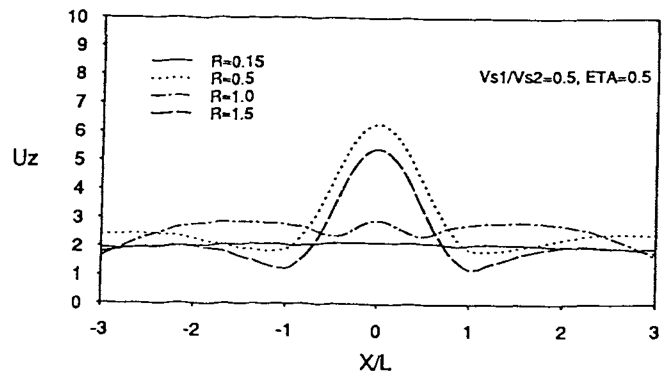

Figure 4. Effect of Valley Shape on Ground Motion Considering Vertically Incident P Waves

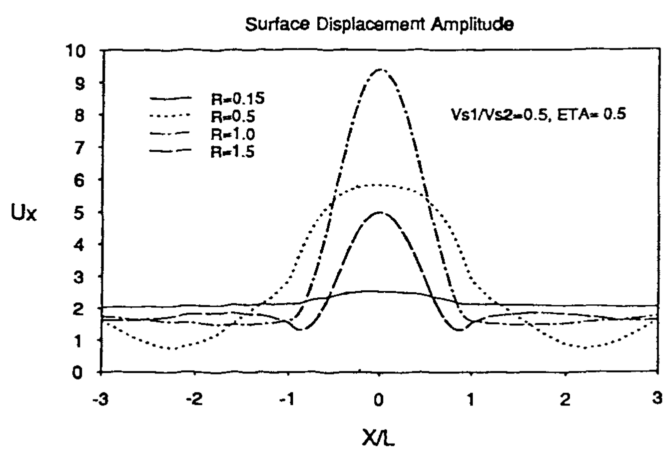

Figure 5. Effect of Valley Shape on Grouna Motion Considering Vertically Incident SV waves

case, when R = 0.15 and R = 0.5, and is much more pronounced for the deep valley case, R = 1.0, and 1.5. The valley does not considerably influence the ground motions unless the depth of the valley is equal to at least 1/4 the wavelength of the incoming wave.

Figs. (4) and (5) present similar results for plane P and SV waves. These results are different from the case of SH waves in the sense that a shallower valley (R = 0.5) has significant effect on ground motions. Compression waves, inherent to these scattered wave patterns, have a velocity of approximately twice the shear wave velocity. Therefore, with R = 0.5 the depth of the valley is 1/4 the wavelength.

Effect of Valley Impedance

Fig. (6) depicts the influence of impedence ratio (v_{s1}/v_{s2}) on the perturbation of surface displacements considering vertically propagating SH waves. When the valley material is stiffer than the half space, $v_{s1}/v_{s2} > 1$, a slight deamplification of ground motion occurs throughout the width of the valley. In general the effect of a soft valley to amplify ground motions increases as the stiffness of the valley decreases relative to that of the half space.

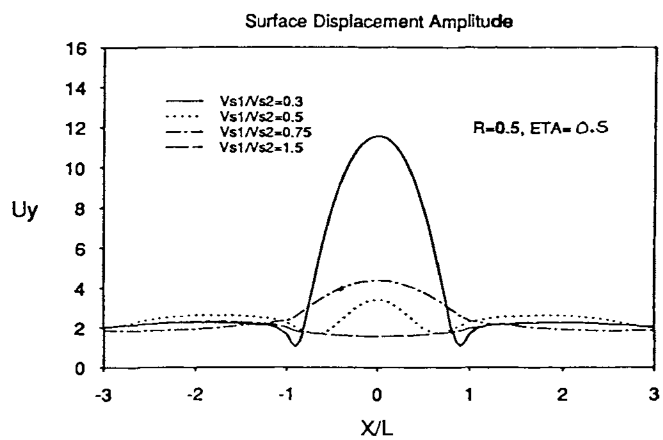

Figure 6. Effect of Impedance Ratio on Ground Motion Considering Vertically Incident SH Waves.

When the valley impedance is very low, v_{s1}/v_{s2} = 0.3, significant amplification of ground motion may occur even for lower frequency ratios (η<1.0) and shallower valleys (R < 0.5). For v_{s1}/v_{s2} = 0.3 the effect of the valley on ground motions may be significant even when the depth of the valley is less than 1/4 the wavelength of the incoming wave.

Figures (7) and (8) present similar results for the case of vertically incident P and SV waves, respectively. The same observations with respect to SH waves also apply to vertically incident P and SV waves. Although, compared to v_{s1}/v_{s2} = 0.3, higher amplification with v_{s1}/v_{s2} = 0.5 was observed for SV waves even for shallow valleys and low excitation frequency. This was not apparent under these conditions for other incoming wave types.

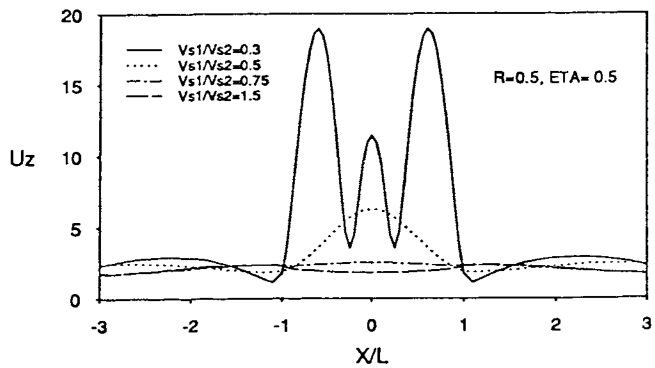

Figure 7. Effect of Impedance Ratio on Ground Motion Considering Vertically Incident P Waves

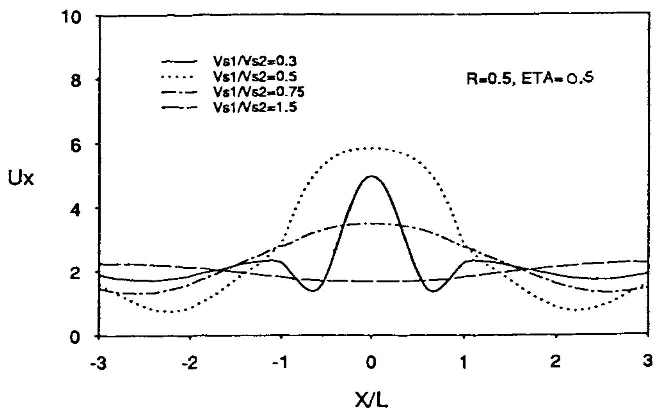

Figure 8. Effect of Impedance Ratio on Ground Motion Considering Vertically Incident SV Waves

Effect of Excitation Frequency

The effect of frequency ratio on the response of the valley surface to incident SH,P and SV waves is a complex phenomena whereby the influence of frequency, valley impedance, and shape are coupled. For a given impedance ratio and value of R the frequency affects the response in terms of the amount of amplification of ground motion due to the presence of the valley and also the shape of the displacement amplitude (admittance) function. In general the highest amplification occurs at the center of the valley for lower frequency ratios and shallow valleys. For higher frequency ratios and deeper valleys the peak response is closer to the edge of the valley, and the shape of the admittance function may contain several peaks and troughs. Figure (9) is a plot depicting displacement amplitudes as affected by frequency, along the valley surface for vertically incident SH waves. If one considers a column of soil above a point in the valley basin and applies the one dimensional theory of wave propagation, features of the valley response including the level and location of maximum displacement amplitude may be qualitatively explained in a rather general sense. However, there are cases when the amplification is higher, and resonance apparently occurs at lower frequencies than those predicted with a one dimensional idealization. Therefore the

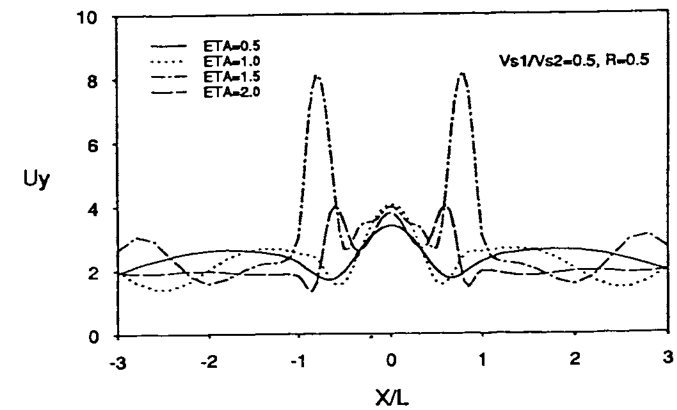

Figure 9. Effect of Frequency Ratio on Ground Motion Considering Vertically Incident SH Waves.

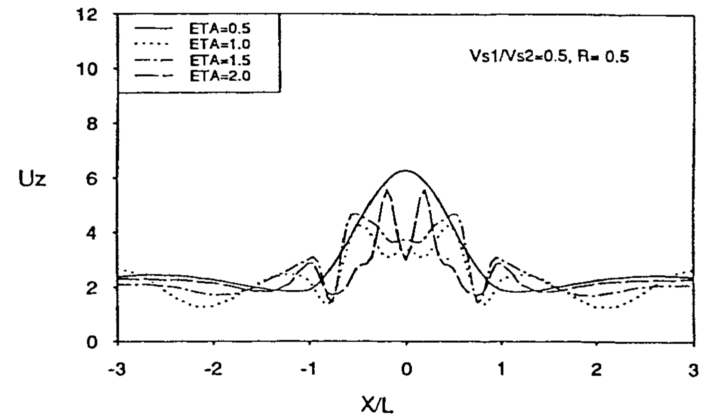

Figure 10. Effect of Frequency Ratio on Ground Motion Considering Vertically Incident P Waves.

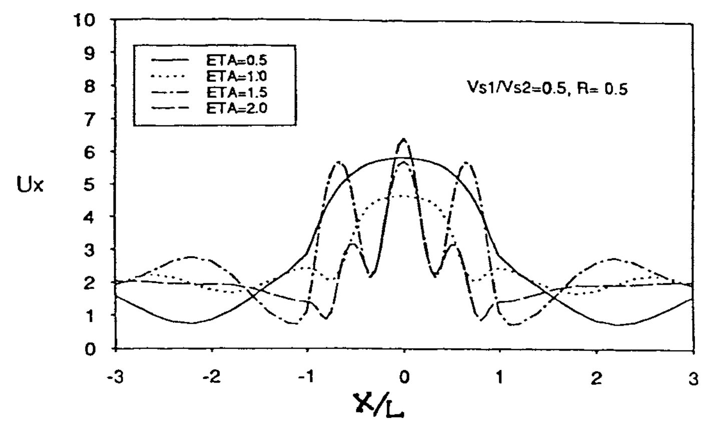

Figure 11. Effect of Frequency Ratio on Ground Motion Considering Vertically Incident SV Waves.

existence of a nonrigid basement and the two dimensional effects of wave scattering caused by the valley are considered significant.

Figures (10) and (11) show the effect of varying frequency for vertically incident P and SV waves, respectively. The same general relationships observed for SH waves are also evident for incident P and SV waves. Considering shallow valleys the amplification of ground motions due to SV waves and P waves is larger for higher frequencies compared to the response due to SH waves. This effect however, is not as prevalent for valleys with higher impedance ratios.

Effect of Incidence Angle

Figures (12), (13), and (14) depict the effect of angle of incidence, θ, on wave scattering by alluvial valleys considering incoming SH, P and SV waves. As expected for θ other than zero the shape of the admittance function is no longer symmetric with respect to the centerline of the valley. For incoming SH waves the point of maximum displacement amplitude shifts toward the far confluence as the angle of incidence becomes more oblique and may be twice as high as the maximum amplitude for $\theta = 0°$.

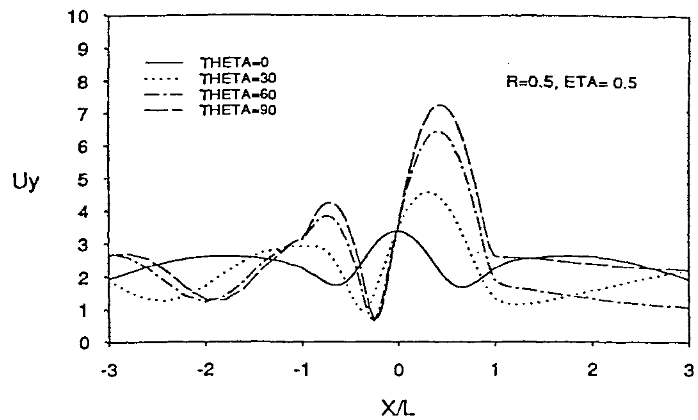

Figure 12. Effect of Angle of Incidence on Ground Motion Considering Incoming SH Waves.

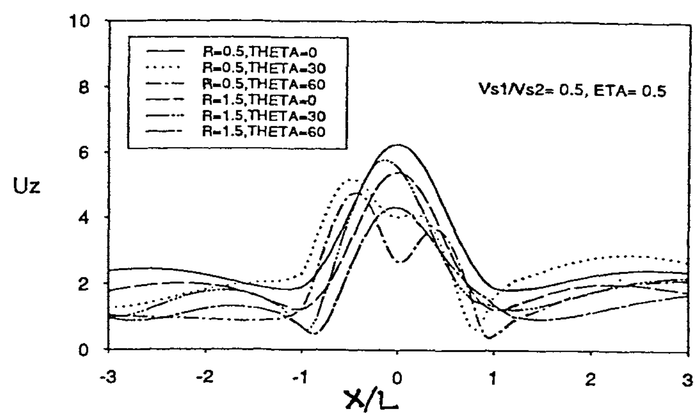

Figure 13. Effect of Angle of Incidence on Ground Motion Considering Incoming P Waves.

Results for vertical displacement amplitude, U_z, amplitude is presented for incident P waves. The displacement amplitude for the vertical component decreases with increasing angle of incidence. Furthermore, the largest vertical displacement amplitude occurs towards the near confluence or close to the middle of the valley.

With incident SV waves the maximum displacement amplitude increase with increasing angle of incidence. The U_x component of displacement amplitude for SV waves may be 4 to 5 times higher with $\theta = 60°$ than for $\theta = 0°$.

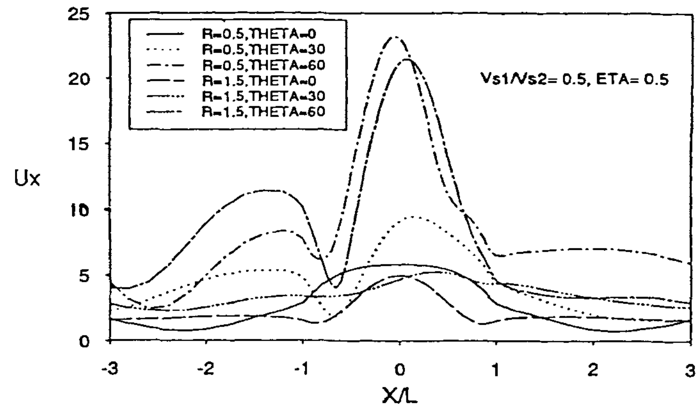

Figure 14. Effect of Angle of Incidence on Ground Motion Considering Incoming SV Waves.

Effect of Layerd Half-space

Wave scattering and diffraction by alluvial valleys within a layered half space may be studied and compared to results obtained for valleys within a homogeneous half space. Figures (15) and (16) show results obtained for a ratio of v_{s2}/v_{s3} equal to 0.4 considering vertically incident SH and SV waves. Valley shapes represented by R values ranging from 0.15 to 1.5, are considered. The dimensionless frequency, η, is maintained at 0.5 for all layered half space analyses presented herein.

Displacement amplitudes due to vertically incident SH waves are increased for valleys included in a soft upper layer. The degree to which the response is affected by half space layering depends mostly upon the shape of the valley, and the ratio of V_{s2}/V_{s3}.
With R = 1.0 and v_{s2}/v_{s3} = 0.4 the amplification of U_y is increased by 30% at the center of the valley compared to the homogenous halfspace results. Very little difference in results are realized for v_{s2}/v_{s3} = 0.8 compared to the homogeneous halfspace results.

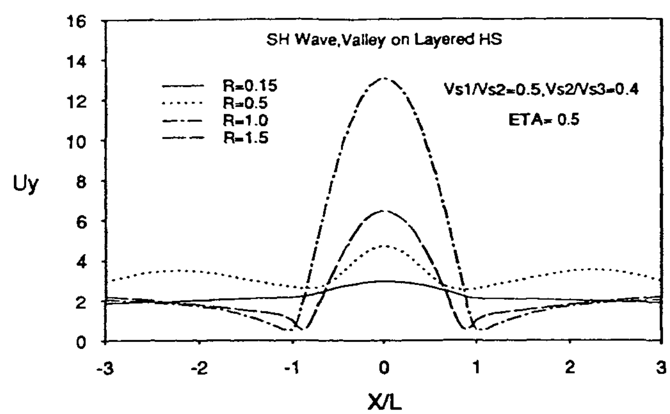

Figure 15. Wave Scattering by Elliptical Valleys in the Soft Upper Layer of a Half Space Considering Incident SH Waves.

Displacement amplitudes along the surface of alluvial valleys due to vertically incident SV waves are not much affected by the presence of the softer upper half space layer. Any increase in amplification realized is small and in some instances a reduction in amplification is observed compared to results obtained with a homogeneous half space.

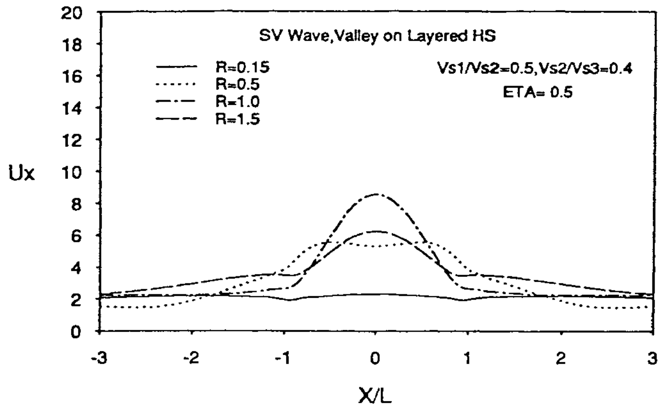

Figure 16. Wave Scattering by Elliptical Valleys In the Soft Upper Layer of a Half Space Considering Incident SV Waves.

CONCLUSIONS

The direct Boundary Element Method has been applied to the problem of ground motions at the site of an alluvial valley. A detailed evaluation of the influence of key parameters on ground motion was undertaken. Parameters were related to the geometry and impedance of the valley, and characteristics of incoming waves including frequency, angle of incidence, and particle motion. The occurrence of SH,SV, and P type body wave forms within homogeneous and layered elastic half spaces containing an alluvial valley have been analyzed and discussed.

In summary it was demonstrated that in general shallow valleys have little impact on ground motion, and the valley response is similar to free field. The effect of the valley on ground motion becomes significant if the depth of the valley is at least one quarter of the incoming wavelength. Wave scattering from the valley complicates ground motion for deep valleys and high frequency incoming waves. In these cases the two dimensional nature of the problem becomes important and one may not get a good qualitative or quantitative, understanding of the problem on the basis of 1-D analysis. Very soft valleys may impact ground motions even for shallow valleys and low frequency incoming waves. Conversely, if the valley impedance is higher than that of the half space a slight deamplification of ground motion within the valley may be realized compared to free field.

For vertical incidence, ground motions were most dramatically amplified within the valley for incoming SH waves, compared to SV or P waves. For a valley having an impedance at least half that of the surrounding elastic halfspace, ground motions within the valley due to incoming SH waves were amplified by a factor as high as six, and when the valley impedance was very low the factor was as high as twelve. However, for non vertical angles of incidence, the ground motions within the valley were most dramatic for incoming SV waves, with high angle of incidence.

The angle of wave incidence has a dramatic effect on ground motion within the valley. In general as the angle of incidence becomes more oblique the shape of the admittance function is less symmetric and the maximum amplitude of displacement is increased compared to the $\theta = 0°$ case.

Compared to results obtained with a homogeneous half space the effect of a soft layer overlaying the half space is to further amplify ground motions within the valley when incoming SH waves are considered. The valley shape and impedance of the upper layer have the most influence on the valley response. The presence of the soft upper layer had little effect on ground motions within the valley for incoming SV waves.

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