DEVELOPMENTS IN GEOTECHNICAL ENGINEERING 43

# SOIL-STRUCTURE INTERACTION

A.S. CAKMAK

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*Edited by*

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# PREFACE

The Earthquake Engineering Community has a long way to go, as despite advances in the field of Geotechnical Earthquake Engineering, year after year earthquakes continue to cause loss of life and property and leave continued human suffering in their wake in one part of the world or another.

We hope to provide the Earthquake Engineering Community with a forum to help develop further techniques and methods through the exchange of scientific ideas and innovative approaches in Soil Dynamics and Earthquake Engineering, by means of this volume and its companion volumes. This volume covers the following topics: Soil Structure Interaction Under Dynamic Loads, Vibration of Machine Foundations and Base Isolation in Earthquake Engineering and contains edited papers selected from those presented at the 3rd International Conference on Soil Dynamics and Earthquake Engineering, held at Princeton University, Princeton, New Jersey, USA, June 22-24, 1987.

The editor wishes to express sincere thanks to the authors who have shared their expertise to enhance the role of mechanics and other disciplines as they relate to earthquake engineering.

The editor also wishes to acknowledge the aid and support of Computational Mechanics Publications, Southampton, England, the National Center for Earthquake Engineering Research, SUNY, Buffalo, NY, and Princeton University, in making this conference a reality.

A.S. Cakmak
June 1987

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# CONTENTS

## SECTION 1: SOIL STRUCTURE INTERACTION UNDER DYNAMIC LOADS



## SECTION 2: VIBRATIONS OF MACHINE FOUNDATIONS



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# SECTION 1: SOIL STRUCTURE INTERACTION UNDER DYNAMIC LOADS

# Effects of an Irregular Soil Profile on Site Amplification

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## INTRODUCTION

Analysis of damage during earthquakes shows that the site amplification is highly influenced by the underground topography. This effect is not only noticeable at locations with very different soil profiles but also for points very close one to another in zones where the profile is not uniform along the horizontal direction. The Mexico City earthquake of September 1985 is an example of this influence. The most severe damage took place in a zone close to the boundary of the soil deposit on which Mexico City is located, while damage was very small in other zones of the town.

In this communication the effect of the position along the surface of a soil deposit resting on a limited zone of a bedrock which is much stiffer than the soil is studied. The influence of the slope of the deposit near the end zones is analysed. Waves propagating vertically and with a 60º angle of incidence are considered.

The diffraction of waves by soil deposits resting on elastic half-planes have been studied by several authors. Due to the fact that a close form fundamental solution exists for the antiplane problem, this type of problem has been considered most of the times (Sanchez-Sesma and Rosemblueth[1]; Trifunac[2]; Wong and Jennings[3]). Wong[4] and Dravinsky[5] used the source method to study the scattering of SV, P and Rayleigh waves by canyons and semielliptical alluvial valleys. In the present paper the frequency domain formulation of the Boundary Element Method (BEM) for a zoned viscoelastic plane is used. This method was applied previously by Abascal and Dominguez[6] in a parametric study of dynamic stiffnesses of foundations resting on the surface of a semielliptical soil deposit included in a compliant bedrock.

## SOIL DEPOSIT ON BEDROCK

In order to study the aforementioned effects, the soil profile is considered to consist of two different viscoelastic materials. One, the alluvial deposit, and the other the bedrock. Both materials have a Poisson's ratio equal to 0.4 and a 5% viscous damping. The bedrock is much stiffer than the soil deposit, the shear wave velocity of the rock being 50 times that of the soil.

Figure 1 shows the geometry of the model. The deposit consist of a horizontal layer, in the central part, and two end zones with constant slope. The half-width of the central part is 20 times the depth of the layer (D = 20 H) and the slope of the end zone takes three different values: 10º, 20º and 30º. The soil deposit is considered to be under the effects of vertically propagating P and SV-waves first. Then, P-waves with an angle of incidence of 60º are assumed.

## BOUNDARY ELEMENT MODEL

Due to the symmetry of the geometry, only one half of it has to be discretised. To do so, constant boundary elements are used. Figure 2 shows the discretization of the boundaries for the three different geometries of the soil deposit. In all cases the model extends to a distance from the end of the soil deposit equal to 20 times the depth H. This distance is big enough since the scattered part of the surface displacements damps out rapidly as the observation point moves away from the limits of the soil deposit. The boundary integral equation is written for the scattered field in both regions, and the equilibrium and compatibility conditions enforced along the internal boundary. The scattered field satisfies the radiation condition in the bedrock.

## VERTICAL WAVES

The model of Figures 1 and 2 is considered to be excited by vertically propagating SV and P-waves. First, SV waves which frequency is smaller than $a^1_{0S}$ are assumed; $a^1_{0S}$ being the first dimensionless natural frequency of a soil layer that extends to infinity in the horizontal direction ($a^n_{0S} = \omega^n H/C_S =$ $= (2n-1)\pi / 2$). The dimensionless natural frequencies of this one-dimensional problem for P-waves are $a^n_{0P} = (2n-1)\pi\ C_p/2C_S$. Figure 3 shows the horizontal amplification, computed as the ratio between the horizontal displacement of the surface points and the horizontal displacement that would be at the surface if the soil deposit did not exist and the whole half-plane were occupied by the rock. A horizontal dash line indicates the one-dimensional amplification for the horizontal layer.

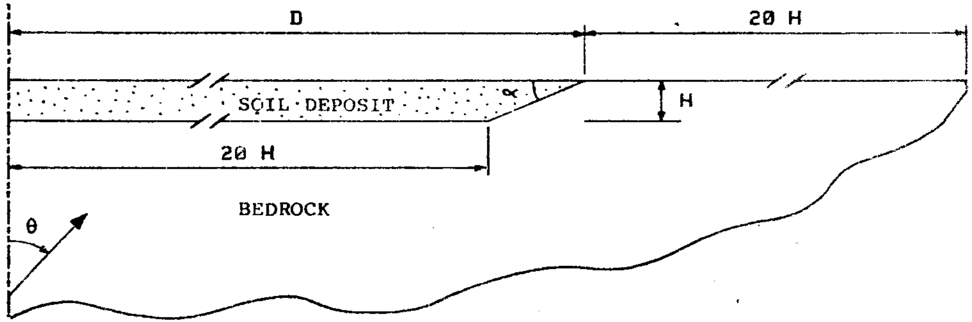


Figure 1.Soil deposit on bedrock

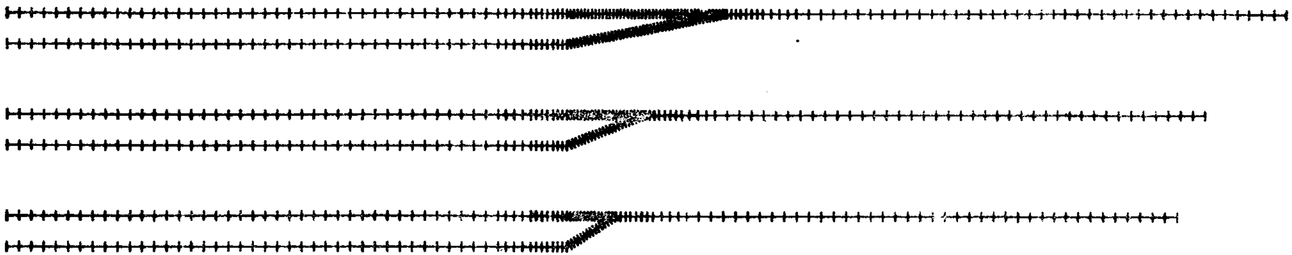

Figure 2. Boundary Elements models.

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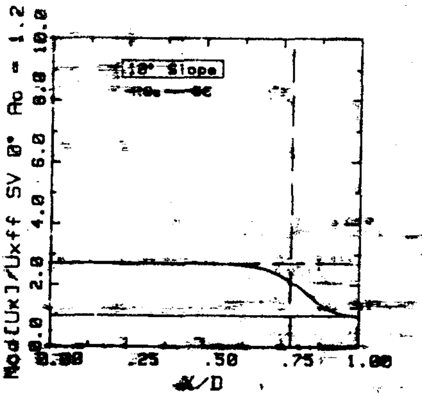


Figure 3. Low frequency amplification

The vertical line indicates the point where the depth of the soil deposit starts to decrease towards the boundary. In the case of Figure 3, the response in the central part of the soil deposit is uniform and equal to that of the one dimensional problem. As the observation point gets closer to the end zones, the response decreases toward the free field value. The effect of the slope is not important, and the curves corresponding to $\alpha$ = 20º and $\alpha$ = 30º are very similar to the one shown in Figure 3.

When the excitation frequency goes over the first natural frequency (Figure 4), displacements, velocities and accelerations in the central part of the soil surface are not uniform

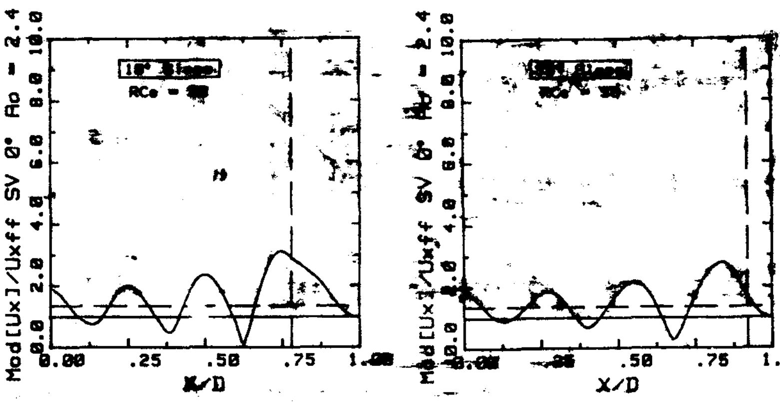


Figure 4. Horizontal amplification

many modes. The amplification oscillates and reaches values much larger than those of the one dimensional model. As can be seen in Figure 4, the maximum values take place near the end zones, the effect of the slope being small.

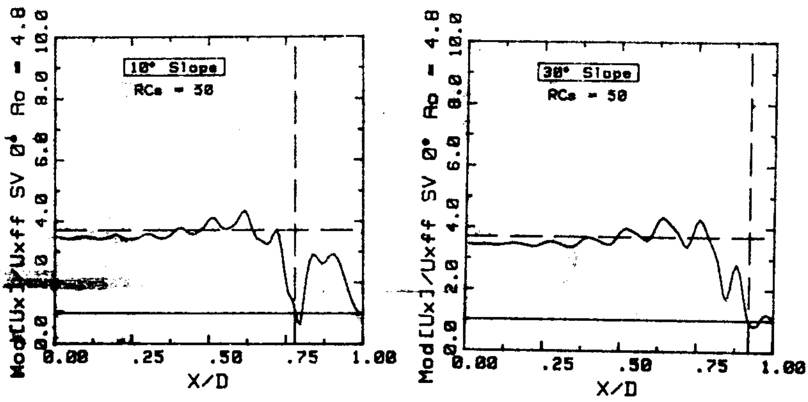


Figure 5. Horizontal amplification ($a_0$=4.8)

Figure 5 shows the amplification for a frequency $a_0$=4.8 that is close to the second natural frequency of the layer $a^2_{0S}$=4.71. The one-dimensional amplification is now large and the values near the end zones are only slightly bigger. The effect of the slope is not important as can be seen comparing the $\alpha$ =10º and the $\alpha$ =30º curves.

The response to SV-waves which frequency is $a_0$= 9.6 is shown in Figure 6. Now, the one dimensional amplification is very small and the end zones effect is very important. The amplification at certain points is much larger than that of the central part of the soil deposit. Changes in the value of the slope $\alpha$ have important effects on amplification. For instance, the maximum value for $\alpha$ =10º is almost double of that corresponding to $\alpha$ =20º.

When the model is excited by vertically propagating P-waves, the behaviour for frequencies lower than the first P-wave natural frequency of the layer is of the same type of that shown in Figure 3 for low frequency SV-waves. Figure 7 shows the amplification at the soil surface for two fre--quencies, $a_0$= 4.8 and $a_0$= 9.6, higher than the first natural frequency of the layer and lower than the second. In both cases the end effect is very important, the maximum values of the amplification corresponding to the cases where the slope is

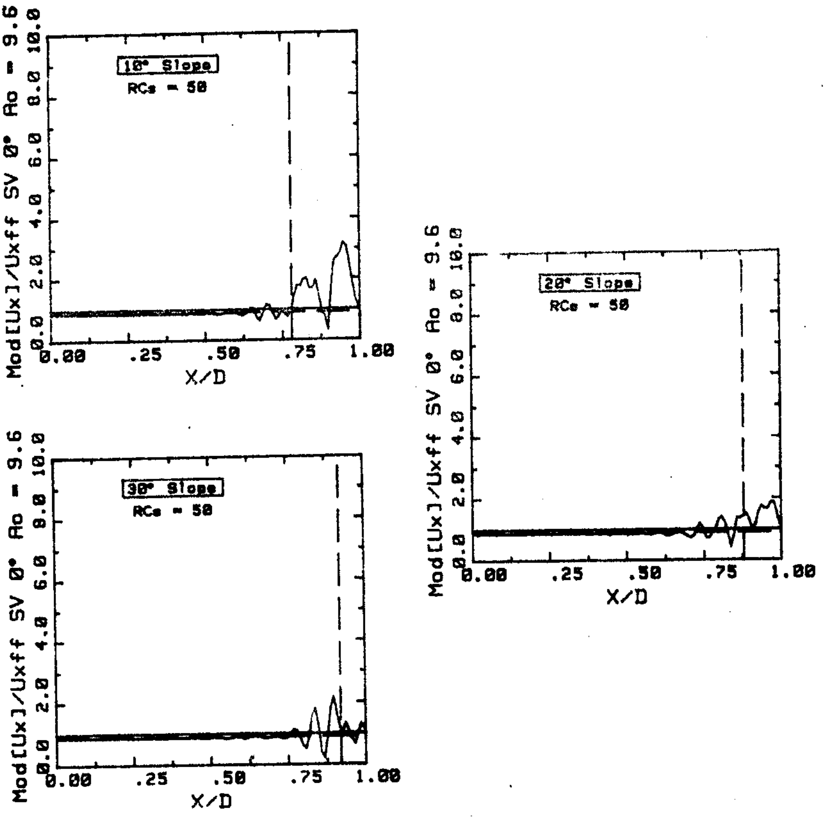


Figure 6. Horizontal amplification ($a_0$=9.6)

smaller and, consequently, the inclined zone of the bottom of the soil deposit larger. For $\alpha$ =10º and $a_0$=9.6, the amplification reaches values as large as 4 times the one-dimensional amplification of the constant depth horizontal layer. The importance of the effect of the slope of the end zones is obvious from Figure 7.

## INCLINED WAVES

To asses the effect of the geometry when waves impinge the soil deposit with an angle $\theta$ different to 0º, P-waves propagating with $\theta$ =60º are assumed. Since the bedrock is much stiffer than the soil deposit ($RC_s = C_{sr}/C_{sd}$ = 50), the response can be expected to be very close to the superposition of vertically incident P and SV-waves. An example of it may be seen in

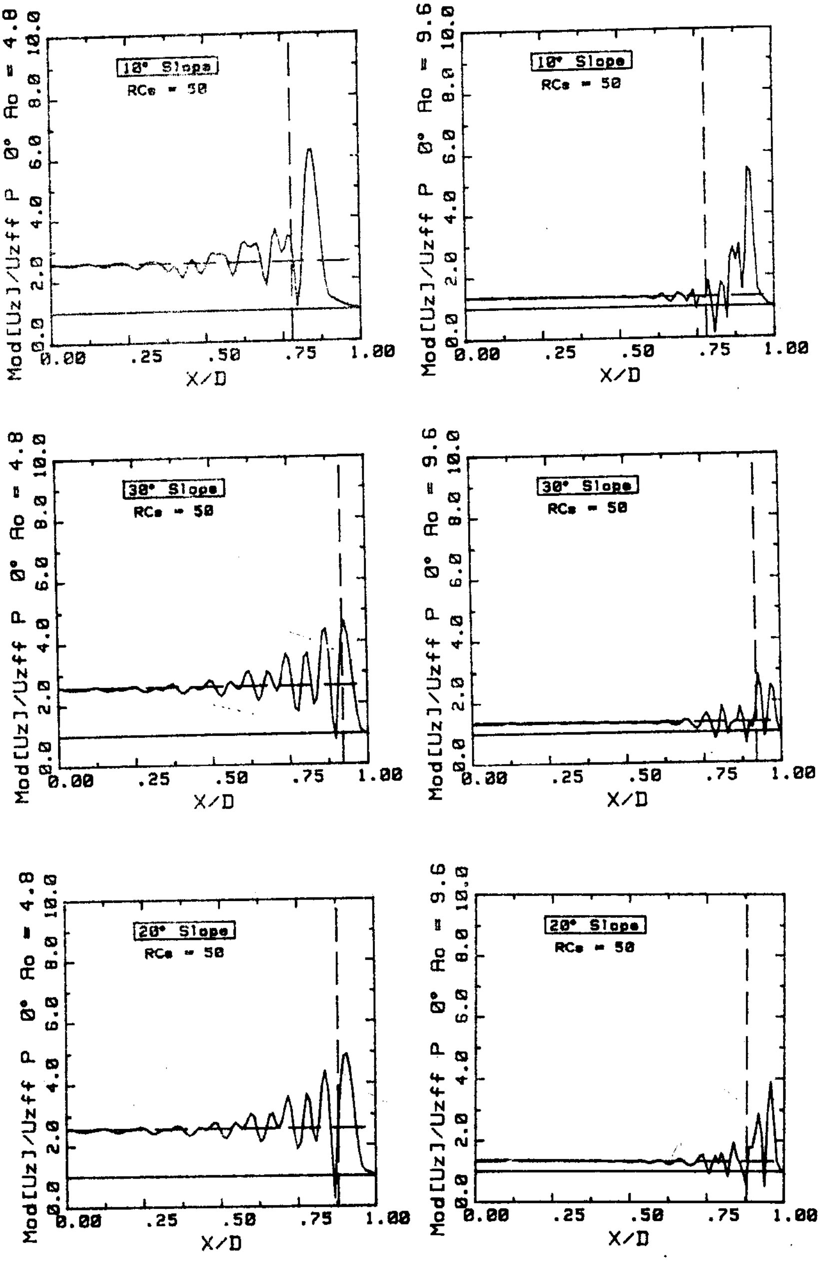


Figure 7. Vertical amplification ($a_0$=4.8 and $a_0$=9.6)

Figure 8, where the horizontal amplification for $a_0$=2.4 almost coincides with that shown in Figure 4 for vertical SV-waves. However, even for this value of the relative stiffness, the angle of incidence has significant effects for high frequencies.

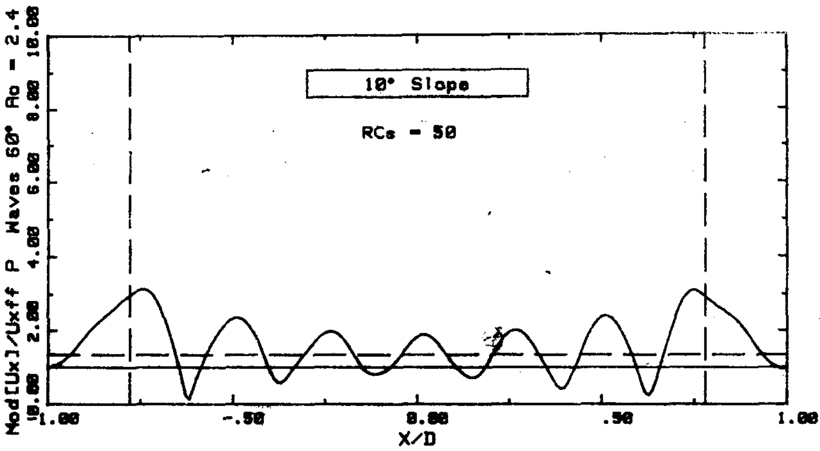


Figure 8. Horizontal amplification for inclined waves

Vertical amplifications for $a_0$=9.6 and values of $\alpha$=10º, 20º and 30º are shown in Figure 9. It is worth to notice the important differences between the amplification values at both end zones, none of them being like that of the vertical waves (Figure 7). Similar effects of the variation of the angle of incidence are observed in the horizontal amplification.

CONCLUSIONS

The effects of an irregular underground topography over the site amplification have been studied for the case of a soil deposit on a compliant viscoelastic bedrock. It has been shown how the motion on the soil surface may present important variations for points which are very close. It has also been shown how the site amplication is highly influenced by the proximity of the end zones of the deposit, the effects of the particular shape of this end zones being important. The variation of the angle of incidence of the waves, leads to significant variations of the surface amplification as compared to the vertical wave propagation case. This effect can be expected to be more important for lower values of the relative stiffness between the soil deposit and the bedrock.

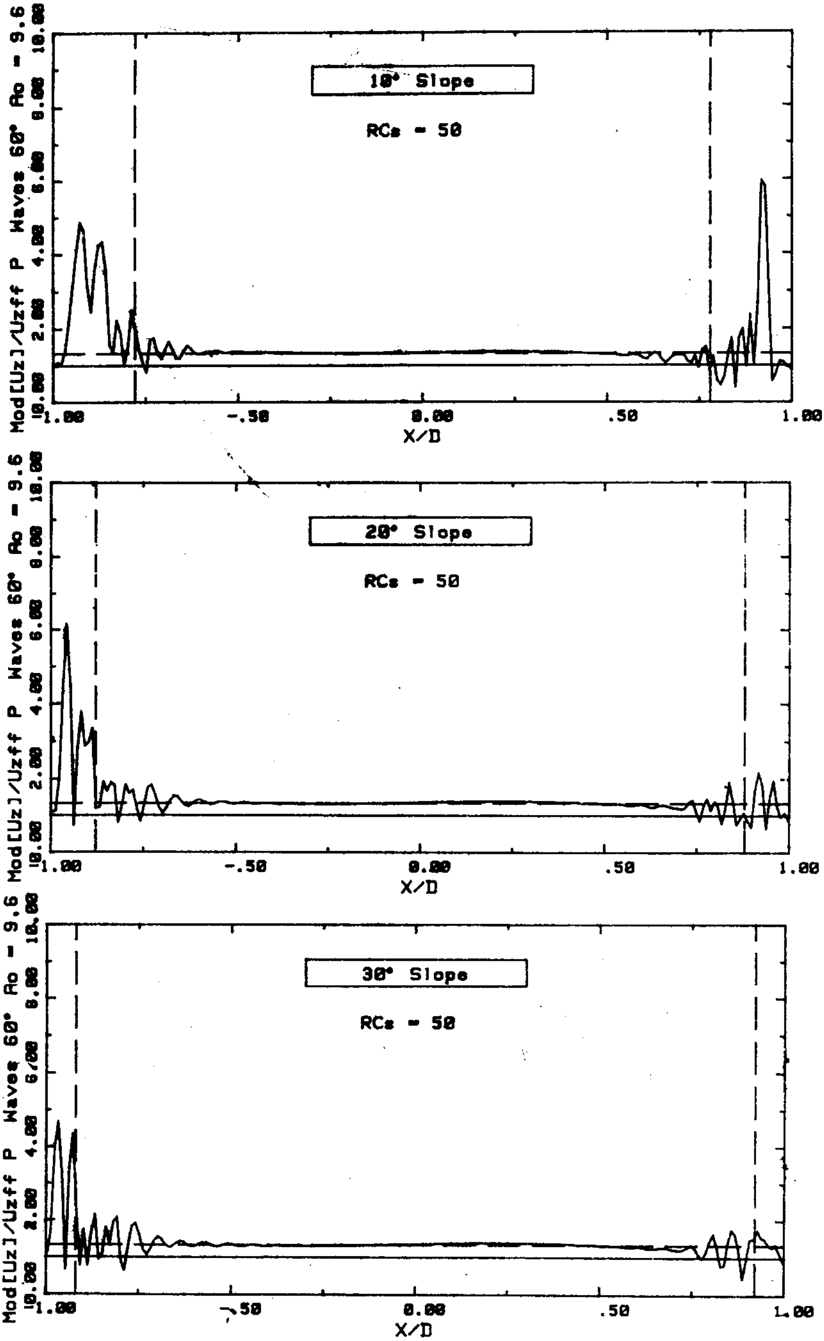


Figure 9. Vertical amplification for inclined waves ($a_0$=9.6)

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