STRONG GROUND MOTION IN THE LOS ANGELES BASIN:
INCIDENT SH WAVES

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Amplification of motion caused by diffraction and scattering of a plane harmonic SH-wave by layered medium of the Los Angeles basin is investigated by using an indirect boundary integral equation approach. The basin is modeled as a set of irregular dipping layers embedded into an elastic half-space. The material of the layers is assumed to be homogeneous, isotropic and linearly elastic. Perfect bonding between the layers is understood.

Displacement spectra are evaluated for different cross sections of the basin for a different number of layers and for various incident waves. Numerical results demonstrate that the presence of the dipping layers in the basin may cause very large amplification of the surface ground motion. The motion appears to be very sensitive upon the number and material properties of the layers, frequency and angle of incidence of the incoming wave, and the location of the observation point at the surface of the half-space.

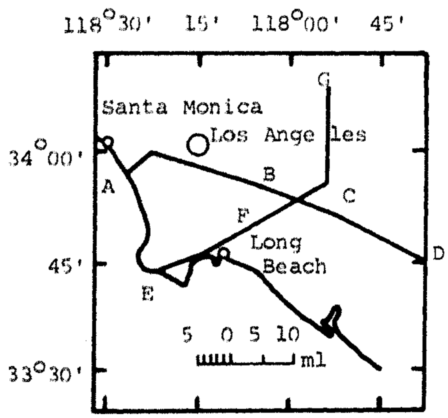

Fig. 1. Los Angeles Basin (after Yerkes et al., 1965)

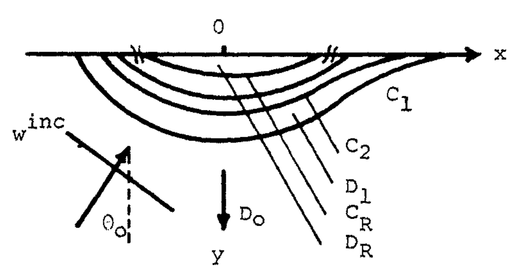

Fig. 2. Theoretical Model

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INTRODUCTION

The geology of the Los Angeles basin is characterized by great complexity. Still the structure of the basin has been investigated in considerable detail. Reference 17, for example, provided an elaborate account into the thickness of the sediments throughout the basin. The term 'Los Angeles basin' in this paper refers to the structure of the alluvium of Los Angeles and its vicinity, as shown by Fig. 1.

Complex geology of the Los Angeles basin precludes construction of the closed form analytical solution and one has to analyze the problem by using numerical techniques. Most commonly used numerical methods, finite differences and finite elements, require a computational grid to fill the solution domain of the problem model. As a result, these procedures appear to be ineffecient for geotechnical problems which involve large dimensions.

Often it is possible to construct a surface integral representation for the solution of the problem. Corresponding integral equations involve only the boundary and initial values. Solution of the integral equations then leads to the solution at any interior point of the problem model under consideration (Refs. 3 and 5). Since only the boundary of the model is being discretized, the number of unknowns is significantly reduced when compared to the finite element or finite difference procedures. For a detailed review of these methods, known as the boundary integral equations methods, (BIEM), the reader is referred to Ref. 2.

Indirect BIEM used in the present paper originates in the works of Refs. 4, 11, and 12. Extension of the method to wave propagation problems in geophysics and earthquake engineering is found in Refs. 1, 6, 7, 13, 14 and 16. Recently, the author extended the indirect BIEM to the problems involving dipping layers of arbitrary shape (Ref. 8). Therefore, the present work is an application of the method to the problem of strong ground motion of the Los Angeles basin.

SOLUTION OF PROBLEM

For the problem geometry presented by Fig. 2, a brief review of the method of solution is presented next. Spatial domain of each layer is denoted by D_j, $j=0,1,2,\ldots,R$, where subscripts $0,1,2,\ldots,R$ refer to the half-space, the first layer, ..., and the R-th layer, respectively. Interfaces between the layers are denoted by C_i, $i=1,2,\ldots,R$.

Since the problem model is assumed to be of the antiplane strain-type, the equation of motion for steady state waves is defined by

$$(\nabla^2 + k_j^2)w_j(x,y,\omega) = 0 \; ; \; j=0,1,2,\ldots,R \; ; \; \nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \qquad (1)$$

where w represents the only non-zero component of the displacement field acting along the z-axis, k is the wave number, and ω denotes the circular frequency. Solution of the problem must satisfy stress free boundary conditions along the surface of the half-space, continuity of stress and displacement field along the interfaces C_i, $i=1,2,\ldots,R$, and appropriate radiation condition at infinity.

The incident field is assumed of the form

$$w^{inc} = \exp -ik_o(x\sin\theta_o + y\cos\theta_o) + i\omega t \; ; \; i = \sqrt{-1} \tag{2}$$

where θ_o represents the angle of incidence.

The total wave field in the elastic medium can be described as (Ref. 8).

$$w_o = w^{ff} + w_o^s \; ; \; \underset{\sim}{r} \in D_o \tag{3a}$$

$$w_j = w_j^s \; ; \; \underset{\sim}{r} \in D_j \; ; \; j=1,2,\ldots,R, \tag{3b}$$

where superscripts ff and s denote the free and scattered wave field, respectively. The unknown scattered waves are determined to be

$$w_o^s(\underset{\sim}{r}) = a^o_{m_1} G_o(\underset{\sim}{r},\underset{\sim}{r}_{m_1}) \; ; \; \underset{\sim}{r} \in D_o \; ; \; \underset{\sim}{r}_{m_1} \in C_1^- \; ; \; m_1=1,2,\ldots,M_1 \; ; \tag{4a}$$

$$\begin{aligned} w_i^s(\underset{\sim}{r}) = b^i_{\ell_i} G_i(\underset{\sim}{r};\underset{\sim}{r}_{\ell_i}) + a^i_{m_{i+1}} G_i(r;r_{m_{i+1}}); \; \underset{\sim}{r}_i \in D_i, \; i=1,2,\ldots,R-1; \\ \ell_i=1,2,\ldots,L_i \; ; \; m_i=1,2,\ldots,M_i; \underset{\sim}{r}_{\ell_i} \in C_i^+ \; ; \; \underset{\sim}{r}_{m_i} \in C_i^- \end{aligned} \tag{4b}$$

$$w_R^s(\underset{\sim}{r}) = b^R_{\ell_R} G_R(\underset{\sim}{r};\underset{\sim}{r}_{\ell_R}) \; ; \; \underset{\sim}{r} \in D_R \; ; \; \underset{\sim}{r}_{\ell_R} \in C_R^+, \tag{4c}$$

where summation over repeated subscripts is assumed. The summation convention is suppressed for repeated indices if one index is a superscript and the other one is a subscript. Subscripted indices, such as ℓ_i and m_i, should be viewed as simple indexes ℓ and m, respectively. In equations (4a-c) G denotes the Green's function for a line load in a half-space and N_i, M_i, and L_i, $i=1,\ldots,R$ denote the orders of approximation of the solution. Therefore, the scattered wave field is represented in terms of the finite number of discrete line sources. The auxiliary surfaces C_i^{+-}, $i=1,2,\ldots,R$ and the location of sources is assumed, while the source intensities a's and b's are calculated in the mean-square-sense from the continuity condition of displacement and stress fields along the interfaces between the layers (Ref. 3).

EVALUATION OF RESULTS

Surface displacement spectras have been evaluated numerically for two sections of the Los Angeles basin. The sections ABCD and EFG are depicted by Fig. 1. Geology of these sections was investigated in considerable detail in Ref. 17. For the sake of simplification it is assumed that each cross-section has been rectified into a straight plane.

For numerical evaluation of the results all variables are presented in dimensionless form. For that purpose the wave velocity β_o and the shear modulus μ_o are chosen to be equal unity. All distances are normalized in such a way that one unit length corresponds to two kilometers of the basin and surface displacement amplitude is normalized with respect to the amplitude of the surface free-field motion. For convenience, a dimensionless frequency Ω is introduced as the ratio of the total length of the first dipping layer and the wavelength of the incident field.

Each interface $C_i, i=1,2,\ldots,R$ is defined by N_i collocation points through which a normalized cubic B-spline approximation is determined. This procedure permitted construction of an algorithm applicable to a wide range of interface shapes including the ones associated with the sections ABCD and EFG of the Los Angeles basin.

Results depicted by Figs. 3a,b correspond to the amplitude of the surface displacement spectra for cross section ABCD, modeled as a set of three dipping layers embedded into an elastic half-space. Several conclusions are apparent from analysis of the Figs. 3a,b: a) The presence of dipping layers may cause very large strong ground motion amplification effects, b) Surface ground motion amplification may change greatly within a very short distance, and c) Ground motion appears to be very sensitive upon the angle of incidence of the incoming wave.

Observations from some recent earthquakes (Ref. 10) indicate that the areas of damage can be highly localized. It has been noted that the intensity of ground shaking can change significantly within a short distance (Ref. 9). The results presented by Figs.3a,b clearly confirm these field observations.

An increase in the frequency of the incident field resulted in surface ground motion shown by Figs. 4a,b. Comparison of Figs. 3a,b with Figs. 4a,b indicate great sensitivity of the surface ground motion amplification pattern upon the frequency of the incident wave field. If one views the ground motion amplification as a result of interference between the incident and the scattered wave field, it is obvious from the presented results that the frequency of the incident wave affects that interference greatly. The interference may be constructive or destructive thus resulting in amplification or reduction of the surface ground motion. This phenomenon of local amplification (reduction) of the surface motion is very clearly displayed in Figs. 3a,b and 4a,b. The change in material properties of the layers appears to be a very important parameter for resulting surface strong ground motion of the basin. Results of Figs. 5a,b correspond to the same incident wave and geometry of the layers as in the case of results depicted by Figs. 3a,b. The change in material properties of the layers caused a very different surface ground motion amplification pattern. This is an indication that inaccuracy in the material properties of the subsurface irregularities will reflect very strongly upon the resulting surface motion.

For a cross section EFG of the Los Angeles basin (see (Fig. 1) the surface strong ground motion is depicted by Figs. 6a,b. As in the case of the section ABCD the model incorporates three dipping layers embedded into an elastic half-space. Earlier studies of strong ground motion amplification effects due to subsurface irregularities (Ref. 7) demonstrated that the surface motion is sensitive upon the embeddment depth of the irregularity. Consequently, in each cross section of the basin studied in the present paper, the interface C_1 (between the half-space and the first layer) is taken as the deepest one available from the field measurements of the sediment depth (Ref. 17). Although the wavelength of the incident field and the material properties of the layers is the same as for the section ABCD (see Figs. 4a,b) different geometry of the dipping layers caused a very different ground motion response. (Note, the dimensionless frequency changed from that in Figs. 4a,b since the width of the layers is different.) Thus, geometry of the dipping layers appears to be very important in the resulting surface motion of the soil medium.

Although very simple, the method of solution is not without difficulties. Namely, the location of sources along the auxiliary surfaces must be chosen very carefully to obtain accurate results. For this reason, an extensive testing of the indirect BIEM has been done (Refs. 6, 7, 8, and 16). It was found that the auxiliary surfaces C_i^{+-} should not be placed in the immediate vicinity of the corresponding interface C_i. In the present paper the auxiliary surfaces C_i^+ and C_i^- are obtained by scaling the corresponding interface C_i by a factor of 2 and 1/2, respectively. The order of approximation of the solution ($N_i, M_i, L_i, i=1,2,...R$ in equations (4a-c)) is chosen in such a way that their increase in value produced practically no change in the resulting displacement field. Testing of the program codes is done in the following way: The material properties and shape of the layers are assumed so that the problem reduces to ground motion amplification due to a semielliptical alluvial valley. In all cases the exact results of Ref. 15 are recovered.

ACKNOWELEDGEMENT

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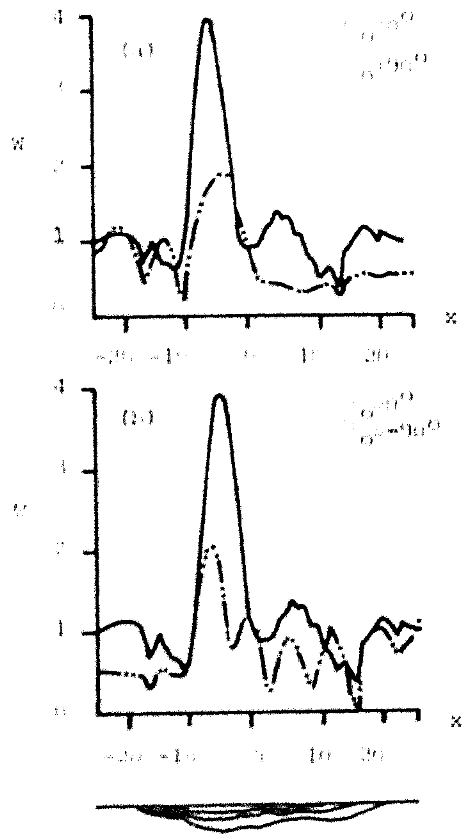

Fig. 3. Surface Displacement Spectral Amplitude: Section A-B-C-D. ($\mu_0=\beta_0=1$, $\Omega=2.59$, $\mu_1=0.6$, $\beta_2=0.6$, $\mu_3=0.1$, $\beta_3=0.4$)

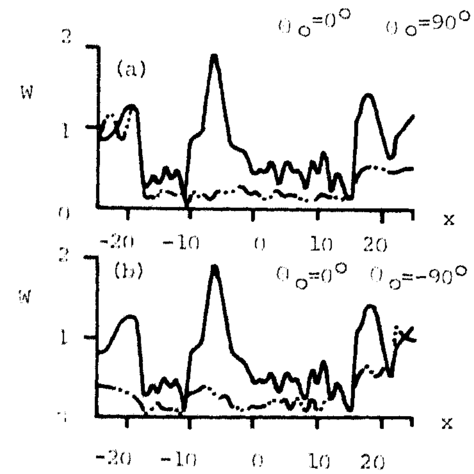

Fig. 4. Surface Displacement Spectral Amplitude: Section A-B-C-D. ($\Omega=5.18$)

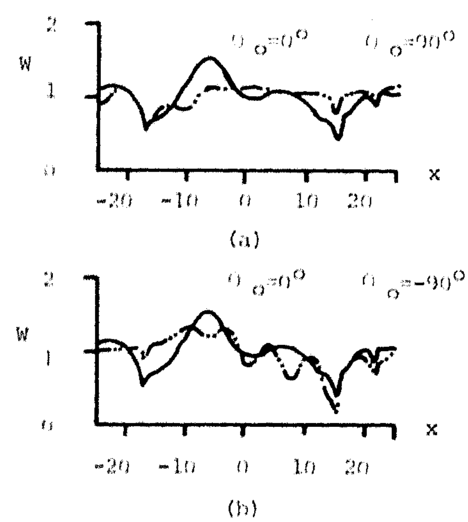

Fig. 5. Surface Displacement Spectral Amplitude: Section A-B-C-D. ($\Omega=2.59$, $\mu_1=0.8$, $\beta_1=0.9$, $\mu_2=0.6$, $\beta_2=0.8$, $\mu_3=0.4$, $\beta_3=0.7$)

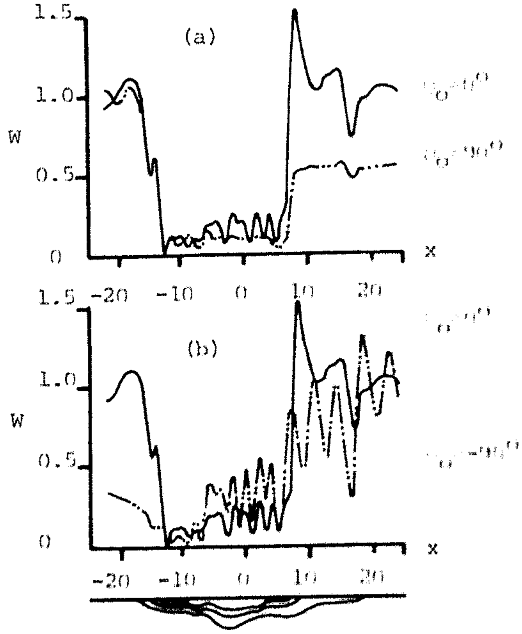

Fig. 6. Surface Displacement Spectral Amplitude: Section E-F-G. (Ω=4.38, μ_1=0.6, β_1=0.8, μ_2=0.2, β_2=0.6, μ_3=0.1, β_3=0.4)

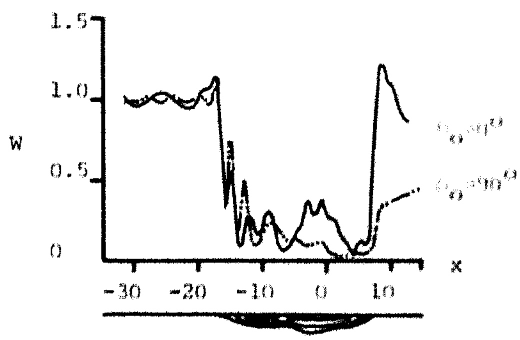

Fig. 7. Surface Displacement Spectral Amplitude: Section E-F-G. (Ω=2.88, μ_1=0.3, β_1=0.6, μ_2=0.1, β_2=0.4, μ_{31}=0.02, β_{31}=0.2, μ_{32}=0.02, β_{32}=0.2)