I - 287 Transient Wave Propagation in Layered Half-Space by Time Domain BEM

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INTRODUCTION

Layering or stratifying is a very common phenomena in our earth. Therefore, the response of a layered elastic half-space under dynamic loadings has always been an important topic in both academic studies and practical geotechnical or earthquake engineering. However, due to the complexity of the problems involved, there are only a very limited number of cases where the closed-form analytical solutions are available. In such a layered half-space, one has to deal with not only the phenomenon of wave diffraction by the traction-free surface, as in the homogeneous half-space, but also the wave reflecting and refracting effects among layers with different properties. This makes the dynamic response of a layered half-space much more complicated and quite different from that of a homogeneous one. To solve such problems, one has to resort to the numerical methods. A general time-domain BEM in cylindrical coordinates is thus proposed to cope with these problems.

The general advantages of BEM in dynamic analysis are well-known, such as the reduction by one in the spatial dimensionality, and the automatic satisfaction of the radiation condition at infinity. The present General Time-Domain BEM can further reduce the spatial dimensionality by one, which makes it possible to analyze a 4-D problem, transient time domain wave propagation in 3-D half-space, only by a 1-D discretization along the surface as well as the interfaces of the layered half-space. Thus, tremendous amount of computational efforts can be saved while a higher degree accuracy is expected as compared with the ordinary approaches.

Supposing a half-space is composed of several horizontal layers, and each layer is made up of elastic and homogenous material. For layer k (k = 1, 2, 3,..), the basic time-domain BEM equation has the form

$$\underset{\sim}{C}_{\alpha\beta}\{u_\beta(\mathrm{P},t)\}_k = \int_\tau\int_{\Gamma_k} \underset{\sim}{A}^{\mathrm{T}}(\mathrm{P})\underset{\sim}{U}_{ij}\underset{\sim}{A}(\mathrm{Q})\{s_\beta(\mathrm{Q},t)\}_k\,d\Gamma_k\,d\tau - \int_\tau\int_{\Gamma_k} \underset{\sim}{A}^{\mathrm{T}}(\mathrm{P})S_{ij}\underset{\sim}{A}(\mathrm{Q})\{u_\beta(\mathrm{Q},t)\}_k\,d\Gamma_k\,d\tau$$

Further modification on above equation can be made by decomposing the displacements and tractions into their Fourier components in the circumferential direction (see Ref. 1),

$$\underset{\sim}{C}_{\alpha\beta}\sum_{h=0}^{\infty}\begin{Bmatrix} u_{rh}^{sP}\cos(h\varphi) + u_{rh}^{aP}\sin(h\varphi) \\ u_{\theta h}^{sP}\sin(h\varphi) + u_{\theta h}^{aP}\cos(h\varphi) \\ u_{zh}^{sP}\cos(h\varphi) + u_{zh}^{aP}\sin(h\varphi) \end{Bmatrix}_k = \sum_{h=0}^{\infty}\int_\tau\int_{\Gamma_k}\underset{\sim}{A}^{\mathrm{T}}(\mathrm{P})\underset{\sim}{U}_{ij}\underset{\sim}{A}(\mathrm{Q})\begin{Bmatrix} s_{rh}^{sQ}\cos(h\psi) + s_{rh}^{aQ}\sin(h\psi) \\ s_{\theta h}^{sQ}\sin(h\psi) + s_{\theta h}^{aQ}\cos(h\psi) \\ s_{zh}^{sQ}\cos(h\psi) + s_{zh}^{aQ}\sin(h\psi) \end{Bmatrix}_k d\Gamma_k\,d\tau$$

$$-\sum_{h=0}^{\infty}\int_\tau\int_{\Gamma_k}\underset{\sim}{A}^{\mathrm{T}}(\mathrm{P})\underset{\sim}{S}_{ij}\underset{\sim}{A}(\mathrm{Q})\begin{Bmatrix} u_{rh}^{sQ}\cos(h\psi) + u_{rh}^{aQ}\sin(h\psi) \\ u_{\theta h}^{sQ}\sin(h\psi) + u_{\theta h}^{aQ}\cos(h\psi) \\ u_{zh}^{sQ}\cos(h\psi) + u_{zh}^{aQ}\sin(h\psi) \end{Bmatrix}_k d\Gamma_k\,d\tau$$

In the above equations, P and Q are the position vectors for the receiver and source points, the superscripts s and a indicate axisymmetrical and antisymmetrical, and the meaning of the other parameters can be found in Ref. 1.

EXAMPLES

After following procedures: (1) discretization in both time and space, (2) analytic treatment of time parameter, (3) using the compatibility and equilibrium conditions among the interfaces among the layers, (4) rearranging the unknowns and knowns, a general matrix equation can be obtained in which the unknowns are the displacement and traction vectors for each boundary node at present time, while the knowns are those vectors at previous time steps. So the displacement and traction fields of whole layered half-space are to be calculated in a step-by-step manner, if the initial conditions are known. The details of such a process are omitted here.

Without losing generality, a two-layer half-space model is used to demonstrate the versatility of the present approach. The parameters of the two layers are:

upper layer: $C_{s1} = 31$ m/s, $C_{p1} = 54$ m/s, $\rho_1 = 2000$ kg/m^3
under layer: $C_{s2} = 14$ m/s, $C_{p2} = 24$ m/s, $\rho_2 = 2000$ kg/m^3

It is easy to see that the ratio of elastic parameters G1/G2 = 5/1. Applying a horizontal force with Heaviside function in time onto the surface of the two-layer model, the displacement and traction fields among the half-space should be 3-D due to the fact that all three components in cylindrical coordinates, i.e., radial, circumferential and vertical, will remain by a non-axisymmetric external load. The circumferential displacement in the interface of layers is depicted in Fig. 1, and one can see the vivid step-by-step pattern of time domain transient wave propagation in a layered half-space.

REFERENCE

1. Wave propagation in layered media by time domain BEM, by Y.K. Cheung, L.G. Tham and Z.X. Lei, in Earthquake Engg. & Struc. Dynamics, Vol. 22,pp225-244

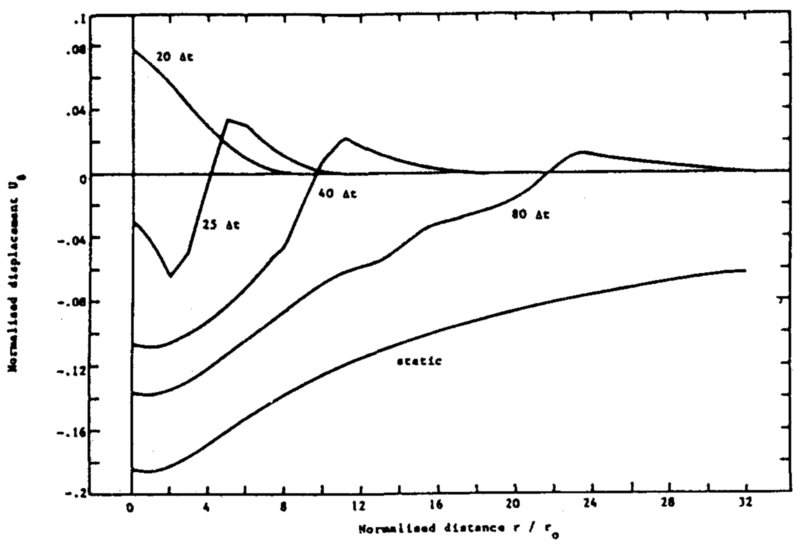

Fig. 1 Displacement (Circumferential) field in interface of two-layer