I - 573 Response of Tunnels to Incident inplane Seismic Waves

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INTRODUCTION

The response of tunnel during earthquake is a very important subject and attracts attentions of quite a few researchers. Though a few analytical solutions are available for very simple geometry and exciting loads, numerical methods are imperative for the practical projects with very complex geological conditions. As the problem involves the infinite medium, the radiation condition has to be considered in numerical methods. In this paper, the Finite Element Method was applied to the tunnels and part of surrounding soil, which is complicated in either material properties or geological conditions and limited in finite region, and Try Function Method to infinite half space with excavation, as shown in Fig.1. The incident wave can be P, SV or Rayleigh wave.

OUTLINE OF THE NUMERICAL METHOD

The finite part of soil as well as the tunnels are discretized with 8-node isoparametric elements. The influence of the infinite soil at the nodes on the interface corresponding to finite element mesh is given in the form of impedance matrix, which will be added on the impedance matrix of finite part, as shown in Eqn 1.

$$\begin{bmatrix} S_{rr} & S_{ri} \\ S_{ir} & S_{ii}+S^{g}_{ii} \end{bmatrix} = \begin{Bmatrix} F_r \\ F_i \end{Bmatrix} \quad (1)$$

in which i denotes nodes on interface and r for remaining ones. The superscript g denotes the infinite soil and F is the force acting on the nodes.

The S^{g}_{ii} is evaluated by Try Function Method. As shown in Fig.2, we suppose the displacement and traction along the interface are the linear combination of the Try Functions $L_u(s)$ and $L_t(s)$, which are chosen as Lamb's solutions due to surface load because they satisfy both free surface and radiation condition,

$$\{u(s)\} = [L_u(s)]\{p\} \quad (2)$$

$$\{t(s)\} = [L_t(s)]\{p\} \quad (3)$$

where $\{p\}$ are intensities.

To combining the continuous solution with discrete one, the principle of virtual work has been used, that is the integration of the product of the displacement and traction along the interface equals the sum of the product of nodal displacements and equivalent nodal forces for any possible displacement.

$$\int_s [L_u(s)]^T[L_t(s)]\{p\}ds = [U]^T\{f_b\} \quad (4)$$

Solving the $\{p\}$ from above and substituting into Eqn.2, and further taking the discrete nodal displacements on the interface, we arrive

$$\{u_b\} = [U][E]^{-1}[U]^T\{f_b\} = [F]\{f_b\} = [S^{g}_{ii}]^{-1}\{f_b\} \quad (5)$$

For the case of incident wave the $\{F_r\}$ is zero and $\{F_i\} = [S^{g}_{ii}]\{u^{g}_{i}\}$. Consider the traction free condition along the surface of excavation, we can derive

$$\{u^{g}_{i}\} = \{u^{f}_{i}\} - [U][E]^{-1}\int_S [L_u(s)]^T\{t^f(s)\}ds \quad (6)$$

in which f denotes the response of free field without excavation to incident wave. As [U] and [E] as well as $L_u(s)$ are same in Eqn.5 and Eqn.6, the computation can be carried out at same time.

NUMERICAL RESULTS

As an example of the proposed method, two parallel tunnels with circle section buried in uniform half space have been studied. The outer and inner diameters are 13.4m and 11.4m respectively. The top point is 17m below the free surface, and the distance between centers of tunnel is 27.8m. The properties of soil are $G = 2.8\times10^7 N/m^2$, $\rho = 1.4\times10^3 kg/m^3$ and Poisson ratio 0.47. Those of tunnel are $G_t = 1.382\times10^{10} N/m^2$, $\rho_t = 2.5\times10^3 N/m^3$ and Poisson ratio 0.23. The finite soil takes the shape of half circle of 40m in radius. 617 nodes with 53 on the interface are used in computation, as given in solid line in Fig.3. Same amplitude of displacement of incident wave was assumed in the computation.

It was found that the wave length of incident waves has strong influence on the response of the tunnels, so that for the same frequency, SV wave induced larger stress in tunnels than P wave. For same type of wave, the stress increases with frequency, so that it is difficult to predict the total stress correctly for real seismic wave if the high frequency component can not be evaluated accurately though the energy in high frequency may be small in the record. The responses vary with the incident direction too, especially for SV wave. In Fig.3, it is given in dash line that the real part of the response of finite part to incident SV wave of 5Hz and incident angle 30° to vertical line. Both tunnels are deformed in as the way of surrounded soil. But the maximum amplitude of stresses in two tunnels are different. In Fig.4 are given the circumferential stresses of two tunnels at outer face, the difference in imaginary parts is quite obvious, certain degree shadow effect can be observed. The other stress components are small compared with circumferential ones. This may be due to the special Poisson ratio of the soil, the tunnel seem to suffer the radial load only.

Beside the response of tunnel, the strong response of the soil near tunnels were also founded seeing Fig.3. Because the soil are almost saturate, liquefaction may occur.

For incident Rayleigh wave the responses were close to the case of SV wave, but usually no high frequency component in Rayleigh wave in practice.

CONCLUSION

The combined FEM and Try Function Method has been used to compute the response of underground tunnels to incident seismic waves. No artificial boundary is introduced in the numerical analysis. The influences of wave type, wave length, frequency and incident direction have been revealed. Other parametric study can also be carried out. There will be no difficult to get the response in time by FFT.

REFERENCE

H. Wang, H. Takemiya, 1993, On Evaluation of the Dynamic Impedance of Excavated Soil, *The Fourth East Asia-Pacific Conference on Structural Engineering & Construction.*

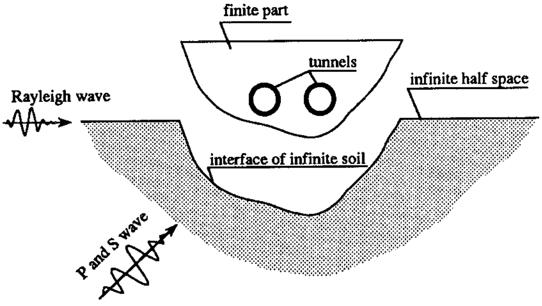

Fig.1 Dynamic Model of Soil-Structure Interaction

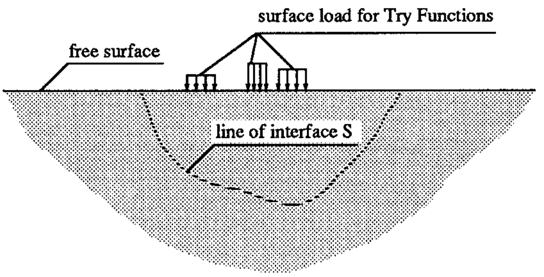

Fig.2 Try Function and Soil-Structure Interface

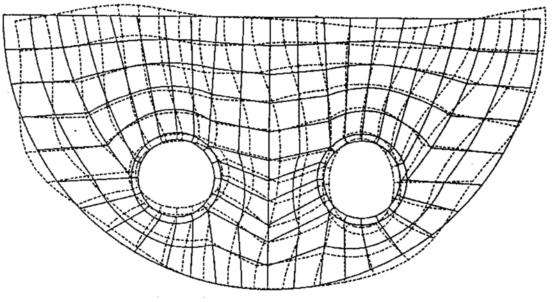

Fig.3 Mesh of FEM and Response of Displacement

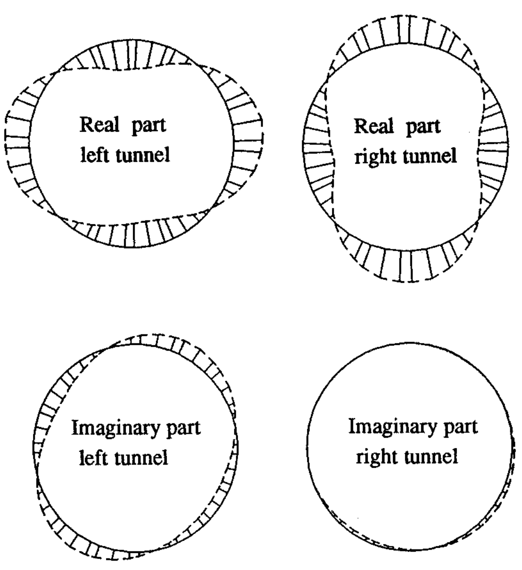

Fig.4 The Circumferential Stress in Tunnel.