VIBRATIONS OF UNDER GROUND STRUCTURE OR OF REVISED GROUND PORTION DUE TO EARTHQUAKE AND THOSE INFLUENCES TO THE SURROUNDING GROUND.

by

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SYNOPSIS

Recently, various types of structures are constructed on the soft-ground where could seldom be used. It may be supposed that the development of geo-technique makes it possible, and this tendency will be increasing. This paper deals with dynamical interaction problems between under-ground structure or revised ground portion and surrounding ground.

INTRODUCTION

When the ground under the upper-structure is revised with some materials or driven piles, the response characteristic of this portion is different from that of surrounding ground, since the rigidity and density of this portion become larger than those of surrounding ground. Similarly, when the under-ground structure is constructed, the response characteristic of this portion is also different from that of surrounding ground, for reason contrary to above. Comparing with surrounding ground, there are many kinds of changed portion which can not be regarded as rigid. In these cases, the strain in this portion may play an important part during earthquake. This paper treats this portion as three-dimentional visco-elastic body in the same manner as the surrounding ground, and analyzes followings,

(1) the response characteristic of changed portion.
(2) how far the effect of interaction between changed portion and surrounding ground propagates mutually.
(3) how intensely the changed portion receives various types of stresses from the surrounding ground during vibration.

GLOSSARY

u_j, v_j = relative displacement in r, θ-direction, respectively.
u = relative displacement on x-axis in x-direction.
u_i = horizontally applied displacement in x-direction from bed rock.
$\Delta_j, \widetilde{\omega}_j$ = dilatation and rotation, respectively.
$c_{L.j}, c_{T.j}$ = velocity of dilatational and rotational wave, respectively.
λ_j, μ_j = Lame's constants.
μ'_j = visco-elastic coefficient.
ρ_j = mass density.
ω_j = natural circular frequency $(= c_{T.j}\pi/2H)$.
h_j = critical damping ratio $(= \omega_j \mu'_j / 2\mu_j)$.
a, H = radius and depth (see Fig. 1).

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$$\xi_{nj} = \sqrt{n^2(1+i\,2\,h_j \frac{\omega}{\omega_j}) - (\frac{\omega}{\omega_j})^2}$$

$$L = \rho_j \frac{\partial^2}{\partial t^2} - \mu_j \frac{\partial^2}{\partial z^2} - \mu_j' \frac{\partial^3}{\partial t \partial z^2}$$

K_0, K_1, I_0, I_1 : modified Bessel function.
where, suffix j is g or s. If j = g, term refers to surrounding ground G, and if j = s, term refers to changed portion S.

MATHEMATICAL METHOD

To obtain the solution of above mentioned problems, we assume a mathematical model, which is composed of both the column (S) as the changed portion and the region (G) surrounding it which laterally extends infinitely as the surrounding ground (Fig. 1). Both G and S are homogeneous, and are settled on a rigid ground (termed a bed rock). Due to the horizontally applied displacement ($u_i e^{i\omega t}$) from bed rock in x-direction, both S and G move in the same direction. If the motion in z-direction can be neglected, those motions will be expressed by use of a clyindrical coordinates system (Fig. 2), with two kinds of equation, in which one is in r-direction and the other is in θ-direction, that is :

$$L(u_j) = (\lambda_j + 2\mu_j)\frac{\partial \Delta_j}{\partial r} - 2\mu_j \frac{\partial \tilde{\omega}_j}{r\partial\theta} + \rho_j u_i \cos\theta\, \omega^2 e^{i\omega t} \qquad (1)$$

$$L(v_j) = (\lambda_j + 2\mu_j)\frac{\partial \Delta_j}{r\partial\theta} + 2\mu_j \frac{\partial \tilde{\omega}_j}{\partial r} - \rho_j u_i \sin\theta\, \omega^2 e^{i\omega t} \qquad (2)$$

In these two obtained equations, performming the Finite Fourier Transformation with respect to z over the interval (2H), under consideration the shearing stress $\widehat{rz}$ must vanish at the surface z = H. Suitable solutions to behaviour of G and S are adopted. Namely, solutions for G and S are obtained as follows.

About surrounding ground G,

$$u_g(r,\theta,z) = \sum_{n=1,3,5\cdots}\Big[A_n\Big\{\frac{1}{r}K_1\Big(\frac{\omega_g\xi_{ng}}{C_{Lg}}r\Big) + \frac{\omega_g\xi_{ng}}{C_{Lg}}K_0\Big(\frac{\omega_g\xi_{ng}}{C_{Lg}}r\Big)\Big\} + B_n\frac{1}{r}K_1\Big(\frac{\omega_g\xi_{ng}}{C_{Tg}}r\Big) + \frac{4}{n\pi}\frac{u_i}{\xi_{ng}^2}\Big(\frac{\omega}{\omega_g}\Big)^2\Big]\cos\theta\,\sin\frac{n\pi z}{2H}e^{i\omega t} \qquad (3)$$

$$v_g(r,\theta,z) = \sum_{n=1,3,5\cdots}\Big[A_n\frac{1}{r}K_1\Big(\frac{\omega_g\xi_{ng}}{C_{Lg}}r\Big) + B_n\Big\{\frac{1}{r}K_1\Big(\frac{\omega_g\xi_{ng}}{C_{Tg}}r\Big) + \frac{\omega_g\xi_{ng}}{C_{Tg}}K_0\Big(\frac{\omega_g\xi_{ng}}{C_{Tg}}r\Big)\Big\} - \frac{4}{n\pi}\frac{u_i}{\xi_{ng}^2}\Big(\frac{\omega}{\omega_g}\Big)^2\Big]\sin\theta\,\sin\frac{n\pi z}{2H}e^{i\omega t} \qquad (4)$$

and, about changed portion S,

$$u_s(r,\theta,z) = \sum_{n=1,3,5\cdots}\Big[C_n\Big\{\frac{1}{r}I_1\Big(\frac{\omega_s\xi_{ns}}{C_{Ls}}r\Big) - \frac{\omega_s\xi_{ns}}{C_{Ls}}I_0\Big(\frac{\omega_s\xi_{ns}}{C_{Ls}}r\Big)\Big\} + D_n\frac{1}{r}I_1\Big(\frac{\omega_s\xi_{ns}}{C_{Ts}}r\Big) + \frac{4}{n\pi}\frac{u_i}{\xi_{ns}^2}\Big(\frac{\omega}{\omega_s}\Big)^2\Big]\cos\theta\,\sin\frac{n\pi z}{2H}e^{i\omega t} \qquad (5)$$

$$v_s(r,\theta,z) = \sum_{n=1,3,5\cdots}\Big[C_n\frac{1}{r}I_1\Big(\frac{\omega_s\xi_{ns}}{C_{Ls}}r\Big) + D_n\Big\{\frac{1}{r}I_1\Big(\frac{\omega_s\xi_{ns}}{C_{Ts}}r\Big) - \frac{\omega_s\xi_{ns}}{C_{Ts}}I_0\Big(\frac{\omega_s\xi_{ns}}{C_{Ts}}r\Big)\Big\} - \frac{4}{n\pi}\frac{u_i}{\xi_{ns}^2}\Big(\frac{\omega}{\omega_s}\Big)^2\Big]\sin\theta\,\sin\frac{n\pi z}{2H}e^{i\omega t} \qquad (6)$$

In thses solutions, the first term is due to dilatation Δ_j, the second is due to rotation $\hat{\omega}_j$, and the last is particular solutions in eqs. (1) and (2). Complex arbitrary constants A_n, B_n, C_n, D_n are determined by boundary conditions at interface G and S. For the sake of this determination, following four boundary conditions are introduced, that is :

(1) $u_g(a, \theta, z) = u_s(a, \theta, z)$ (2) $v_g(a, \theta, z) = v_s(a, \theta, z)$

(3) $\hat{rr}_g(a, \theta, z) = \hat{rr}_s(a, \theta, z)$ (4) $\hat{r\theta}_g(a, \theta, z) = \hat{r\theta}_s(a, \theta, z)$

where. $\hat{rr}_j$ and $\hat{r\theta}_j$ represent respectively normal and shearing stress, which are components of soil pressure.

On the actual structures, various kinds of upper-structures will be constructed on changed portion S. And this structure receives an excitation from S. Therefore, when the response characteristic of S is to be estimated, it may be rationable to consider the mean response of S. The mean response in x-direction is given by

$$U_x(Z) = \frac{1}{\pi a^2}\int_0^a\int_0^{2\pi}\left\{u_s(r,\theta,Z)\cos\theta - v_s(r,\theta,Z)\sin\theta\right\} r\,d\theta\,dr$$

CONCLUSION

From results of calculation, following paragraphs may become known.

(I) In the case that ρ_s is larger than ρ_g, (This coincides with the case of revised portion) (see Fig. 3). The dynamic characteristic of S changes considerably with variation of a/H, but does hardly with that of C_{LS}/C_{TS} (agree with that of possion's ratio in S).

(II) In the case that ρ_s is smaller than ρ_g. (This coincides with the case of under-ground structure) (see Fig. 4, 5).

(1) The dynamic characteristic of S similarly changes with variation of a/H, but response at second peak (excited by S) decreases with an increase of C_{LS}/C_{TS}.

(2) In spite of variation of a/H, mean response curves have still a peak which is excited by G. This is different from the case of revised portion.

(III) The frequency response curves of normal stress $\hat{rr}_s(a, 0, H)$ and displacement $u_s(a, 0, H)$ have almost similar property (Fig. 6).

(IV) The effect of interaction between changed portion (S) and surrounding ground (G) propagates at a considerable distance from S to G (Fig. 7).

When we perform aseismic design of upper-structure on S, the frequency characteristic of incident wave which enters into upper-structure should be estimated with consideration of above-mentioned.

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REFERENCE

H. TAJIMI : "Dynamic Analysis of a Structure Embedded in an Elastic Stratum" Proc. of 4th World Conference on Earthquake Engineering 1969.

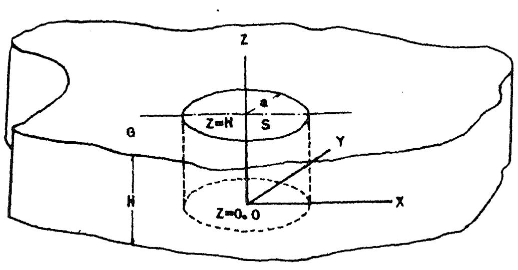

Fig. 1 Model

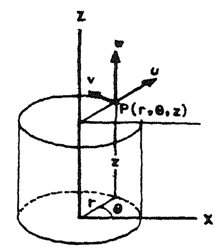

Fig. 2 Cylindrical coordinates

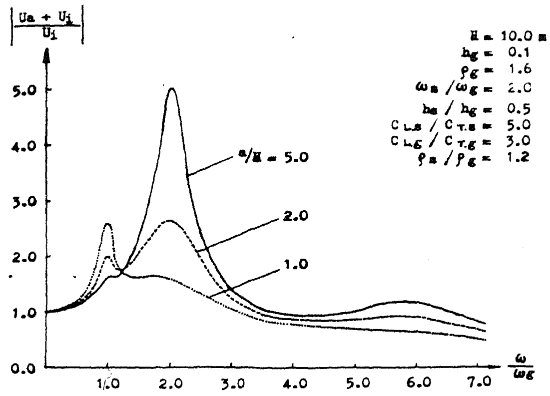

Fig. 3 Mean response of S (at z=H)

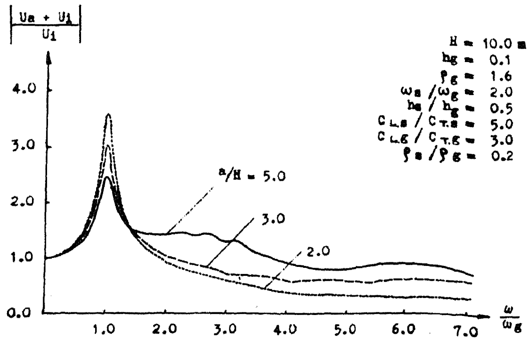

Fig. 4 The same $C_{Ls}/C_{Ts} = 5.0$

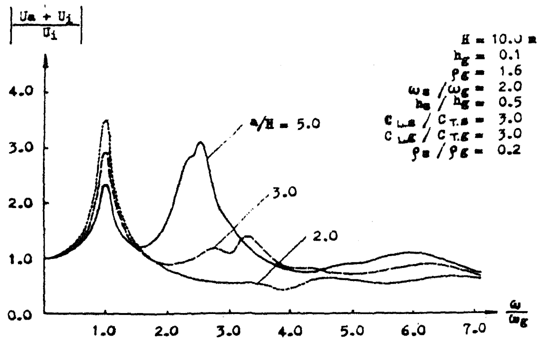

Fig. 5 The same $C_{Ls}/C_{Ts} = 3.0$

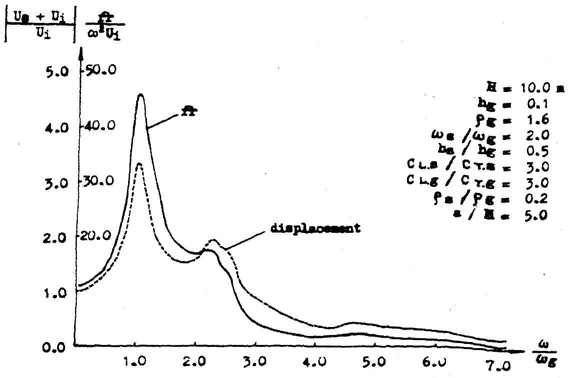

Fig. 6 Relation between $\tau_{r\theta s}(a,0,H)$ and $U_s(a,0,H)$

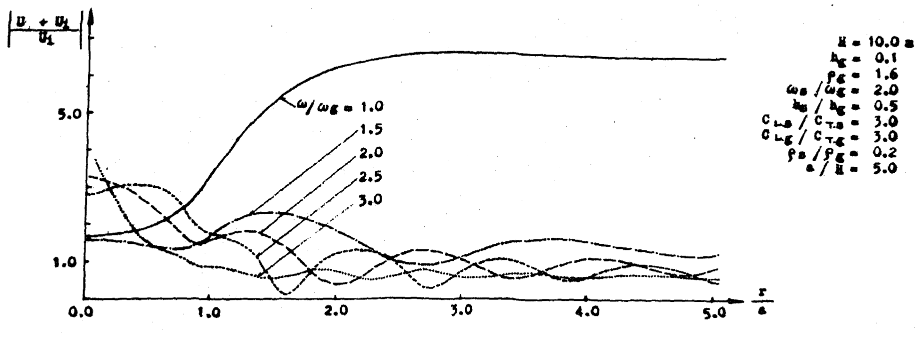

Fig. 7 Relative displacement of x-direction for S and G to Bed Rock.