EARTHQUAKE RESPONSE OF MULTI-STORY BUILDING
CONSIDERED SURFACE LAYER-BASEMENT INTERACTION

by

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SYNOPSIS

When earthquake motion act on a structure possesed basement, there are differences about following points by comparison with fixed type at the foundation. (1) Soil pressure act on a wall of basement for setting up a vibration of surface layer. (2) Surface layer have an effect spring and damping for a frequency depend function. For the purpose of consideration about these effects in a response analysis, we gain the solution in case of vibration of rigid body in elastic surface layer. Successively, simultaneous equations in regard to the above mentioned solution and shearing multi-story building are derived. From this equations, get the frequency transfer functions and after compute time dependent response using of procedure on the FFT. In this paper, we show the solution on Swaying motion for a rigid body in a surface layer, simultaneous equations as a whole and its several examples.

SOLUTION TO INTERACTION BETWEEN BASEMENT AND GROUND

Model of basement and physical variables show into Fig.-1. Basement is cylindrical rigid body, exists homogeneous isotropic elastic ground and supports in bed ground comparatively hard. This body permit Rolling and Swaying motion. Solution on a rolling vibration have announced in reference (1), likely we fined solution on a Swaying vibration. That result are denoted by eq.(1).

$$u = \frac{m_0 + \frac{8\rho a^2 H}{\pi}\sum_{n=1,3,\cdots}^{\infty}\frac{1}{n^2}\Omega_{Ln}}{k_0 - m\omega^2 + \frac{8\rho a^2 H}{\pi}\omega_g^2\sum_{n=1,3,\cdots}^{\infty}\xi_n^2\frac{\Omega_{Ln}}{n^2}} u_g\omega^2 = \frac{m_0 + D}{k_0 - m_0\omega^2 + S} u_g\omega^2 \cdots\cdots(1)$$

and to Rolling.

$$\varphi = \frac{m_0 H_G + \frac{16 a^2 \rho H^2}{\pi^2}\sum_{n=1,3,\cdots}^{\infty}\frac{(-1)^{\frac{n-1}{2}}}{n^3}\Omega_{Ln}}{k_R - I_0\omega^2 + \frac{32 a^2 \rho H^3}{\pi^3}\omega_g^2\sum_{n=1,3,\cdots}^{\infty}\xi_n^2\frac{\Omega_{Ln}}{n^4}} u_g\omega^2 = \frac{m_0 H_G + G}{k_R - I_0\omega^2 + F} u_g\omega^2 \cdots\cdots(2)$$

where

$$\Omega_{Ln} = \frac{K_1(\eta_{Ln}) + K_1(\eta_{Tn})A_n}{K_1(\eta_{Ln}) + \eta_{Ln}K_0(\eta_{Ln}) - K_1(\eta_{Tn})A_n}, \quad A_n = \frac{2K_1(\eta_{Ln}) + \eta_{Ln}K_0(\eta_{Ln})}{2K_1(\eta_{Tn}) + \eta_{Tn}K_1(\eta_{Tn})}, \quad \xi_n = \sqrt{n^2 - \left(\frac{\omega}{\omega_g}\right)^2 + i2h_g\frac{\omega}{\omega_g}n^2}$$

$\omega_g = C_T\frac{\pi}{2H}$, h_g = pseudo damping constant on surface elastic layer $K_\nu(z)$ = 2nd kind modified Bessel function, C_T =transverse velocity, C_L = longitudinal velocity, and significance of another symbols follow an implicit promise.

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'D' and 'G' in the eq. (1),(2) mean soil pressure, and real part of 'S' and 'F' mean spring effect, imaginaly part of these mean damping effect.

WHOLE EQUATIONS INCLUDING STRUCTURE

's','y' define Laplase's parameter and absolute displacements respectively, whole equations are gained like a eq. (3).

$$s^2[M]\{Y\} + s[C]\{Y\} + [K]\{Y\} = -[M_0]\{\ddot{U}_g\} \quad \cdots\cdots\cdots(3)$$

where $\{Y\}\subset\{y\}$, $\{U\}\subset\{u\}$

$$[M] = \left[\begin{array}{ccccc|c} m_n & & & & & m_nH_n \\ & m_{n-1} & & 0 & & \vdots \\ & & \ddots & & & \vdots \\ & & & m_i & & m_iH_i \\ & 0 & & & \ddots & \vdots \\ & & & & m_0 & m_0H_0 \\ \hline m_nH_n & \cdots & m_iH_i & \cdots & m_0H_0 & I_0+\sum_{i=1}^{n} m_iH_i^2 \end{array}\right]$$

$$[K] = \left[\begin{array}{cccccc|c} k_n & -k_n & & & & & \\ & k_n+k_{n-1} & -k_{n-1} & & 0 & & \\ & & \ddots & \ddots & & & \\ & & & k_i+k_{i-1} & -k_i & & \\ & & & & \ddots & \ddots & \\ & & & & & -k_1 & \\ & \text{SYM.} & & & & S+k_0+k_1 & \\ \hline & & & & & & F+k_R \end{array}\right]$$

$$[C] = \left[\begin{array}{cccccc|c} C_n & -C_n & & & & & \\ & C_{n-1}+C_n & -C_{n-1} & & 0 & & \\ & & \ddots & \ddots & & & \\ & & & C_i+C_{i+1} & C_i & & \\ & \text{SYM.} & & & \ddots & \ddots & \\ & & & & & C_1 & \\ \hline & & & & & & 0 \end{array}\right]$$

$$\{Y\} = \begin{Bmatrix} Y_n \\ Y_{n-1} \\ \vdots \\ Y_i \\ \vdots \\ Y_0 \\ \psi \end{Bmatrix} \qquad [M_0] = \begin{bmatrix} m_n \\ m_{n-1} \\ \vdots \\ m_i \\ \vdots \\ m_0+D \\ \sum_{i=1}^{n} m_iH_i+G \end{bmatrix}$$

In the matrix $[M_0]$ meaning external force, soil pressure D and G are added. Simultaneously, in the matrix of $[K]$ meaning stiffness, S and F are added. Where , 's' change the position to $i\omega$ ($i=\sqrt{-1}$), eq. (3) changes to frequency transfer function. In this equation, the displacement transfer function is defined as

$$D_j = Y_j(i\omega)/\ddot{U}_g(i\omega) \text{ for } j=1,2,\ldots,n, \text{ and } \psi(i\omega)/\ddot{U}_g(i\omega)$$

These transfer functions represent the amplitude and phase of the steady-state response of the building soil system subjected to a harmonic ground motion of unit amplitude. ($Y_j(i\omega)/\ddot{U}_g(i\omega)$ for $j=1,2,..,n$), $Y_0/\ddot{U}_g$, $\Psi/\ddot{U}_g$, represent the transfer function of j th story, Swaying, Rolling motion respectively. Time series responses are gained as a Fourier Inverse Transform what is called FFT.

NUMERICAL EXAMPLE

Upper structure are designed by following constants, 5 storys, mass, spring constant are 500 ton, 1000 ton/cm respectively each story, damping constant is 0.03. Basement mass is 1000 ton, moment of inertia is 25000 ton.cm^2. Physical constant of surface layer are defined that C_T ; 40 m/sec. C_L ; 80 m/sec., density ; 1.5 ton/m^3, depth of layer ; 20 m, therefore natural frequency of surface layer is 0.5 Hz. On bed layer, C_T, C_L, density are 80 m/sec., 160 m/sec., 2.0 ton/m^3 respectively. Input earthquake is adapted El-Centro NS 1940 300 gal maximum. Absolute values of transfer function of several storys are showed in Fig.-2 Likely, about Swaying, Rolling are showed in Fig.-3,4 respectively. Absolute displacement of time series response at 5 th. story is illustrated in Fig.-5, likely, Swaying, Rolling displacement are denoted Fig.-6,7 respectively.

CONCLUTION

1) From Fig.-3,4,6,7(transfer function on swaying, rolling and time dependent response), Swaying and Rolling motion of basement suffer the influence of ground vibration powerfully.
Time series response depend on almost component of ground natural frequency (=0.5 Hz).

2) From transfer function and time series response (Fig.-2,5), response of upper structure have a characteristic of vibration in case of structural foundation on fixed type. If the number of story increase or stiffnes of structure becames limp, above mentioned tendency is great.

3) Size of maximum value of response on the interactional system does not exist a rule in comparison with fixed type.

REFERENCE

(1) by Hiroshi TAJIMI, Dynamic Analysis of a Structure Embedded in an Elastic Stratum, Proc. of 4 th. World Conference on Earthquake Engineering 1969

(2) by Touru MASAO, Dynamic Interaction Problem of System on Ground and Basement, Proc. of A.I.J. 1972

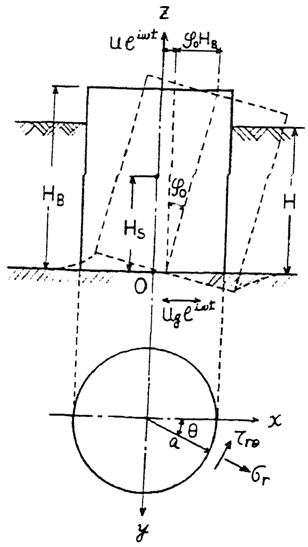

Fig.-1 Model of Basement

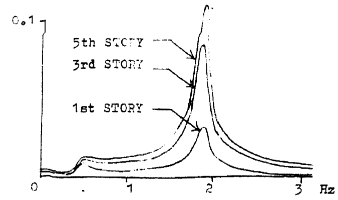

Fig.-2 Absolute value of transfer function about 5,3,1st. story

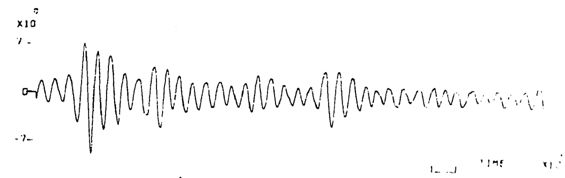

Fig.-5 Absolute displacement of time series response on 5th. story

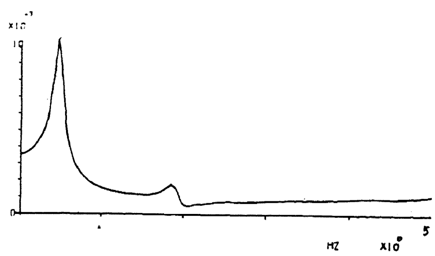

Fig.-3 Amplitude of transfer function on a Swaying

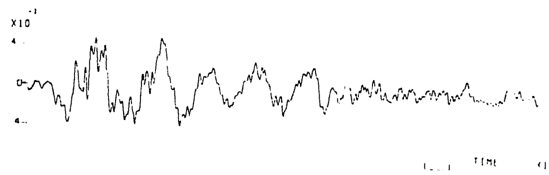

Fig.-6 Displacement of time series response on a Swaying motion

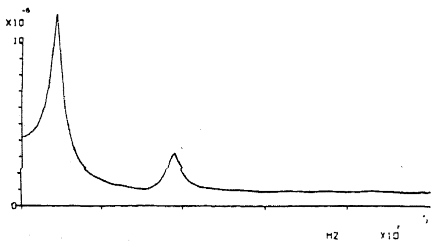

Fig.-4 Amplitude of transfer function on a Rolling motion

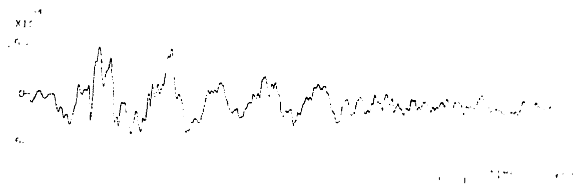

Fig.-7 Rolling angle of time series response on a Rolling motion (radian)