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DYNAMIC ANALYSIS FOR THE UNSYMMETRICAL TOWER-BUILDING-FOUNDATION-SOIL INTERACTION SYSTEM

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SUMMARY

Presented in this paper is the dynamic response of the unsymmetrical tower-building-foundation-soil interaction system under seismic exicitation. By simplifying exery part of the complicated system reasonally a mechanical model is proposed and the coupling stiffness matrix of the superstructure is obtained. Branch mode synthesis technique is used to analyse the characteristic of free vibration for the coupled system. The dynamic response of the interaction system under random wave forces including earthquake force and wind force are obtained by employing the Fast Fourier Transforms and frequency spectrum analysis method. And some problems about structural control are discussed.

INTRODUCTION

As to problems of interaction of tower-building, a lot of researches have been made as before. Kimura (Ref.1), using the dynamic system with two masses or multi-masses in replace of the combined building with steel tower and building, calculated the frequency of free vibration and the excited function, and represented the actural measures and the dynamic analysis results for the available steel tower. Yoshida (Ref.2), by measuring an actural structure (a 15-stories building with a 200m steel tower on the top) for many yeras, represented a careful calculation analysis for a typical tower model with three masses.

In respect of dynamic interaction of soil-structure, Finite Element Method and approximated analysis method in view of elastic half-space theory have been widely used, and the method of assemblage parameter of elastic half-space has also been used in most of cases. As to torsion vibration, researchers have emphasized that torsion is a nonnegligible problem for unsymmetrical structures.

A lot of researches as above have established a foundation for the complicated structural analysis of dynamic interaction of tower-building-foundation-soil presented in this paper.

<u>Calculation Model</u> For a structural system with interaction of unsymmetrical tower-building-foundation-soil (Fig.1), a space vibration model is proposed in Fig.2. The method to simplify model has been explained as follows.

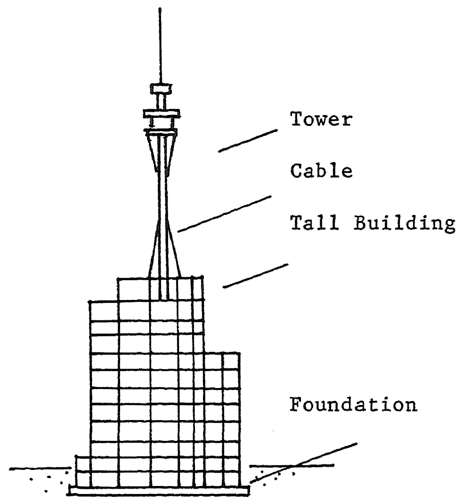

Fig.1 Scheme of the structure

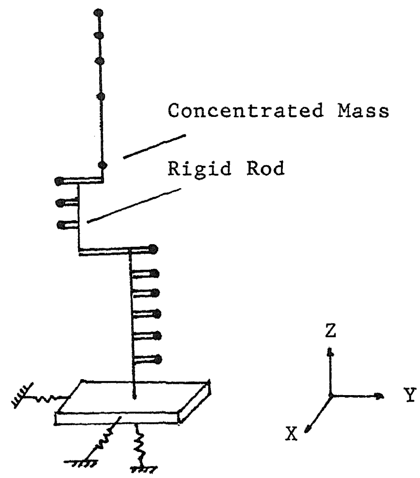

Fig.2 Scheme of the calculation model

For building, taking natural floor as floor element, every floor is simplified as concentrated mass at the mass centroid of building plate and longitudinal elastic rod at the rigid centroid of building floor. When the mass centroid isn't coincided with the rigid centroid of upper-below floors, by connecting with horizontal rigid rod, the harmonious effects of displacement of every floor operated by rigid floor of building are reflected. Thus, the mass characteristic parameter of every floor is equivalent concentrated mass m_i and mass inertia moment J_i of floor to the longitudinal axis of mass centroid. The stiffness parameter is six stiffnesses including axial, bending, shear and torsion stiffness of longitudinal elastic rod.

For tower, floor element is divided according to the distribution of concentrated mass like antenna platform and so on. Scattered the tower in corressponding system with single mass or multi-masses, equivalent concentrated mass and its inertia moment are certianed. And the tower is simplified as longitudinal elastic rod with six stiffnesses of axial, bending, shear and torsion stiffness.

Considering the interaction of soil and upper structure, the box foundation is simplified as rectangular rigid body buried under soil. And by using eqivalent assemblage method of original mass changable parameter, six eqivalent stiffnesses and eqivalent dampings in single direction are described as a function of excited frequency and Poisson ratio. Thus, the general mechanical model of dynamic interaction of structure-foundation-soil can be certained.

General stiffness of Unsymmetrical Tower-Building Taking mass centroids of every floors as original coordinate point, and considering structure as general unsymmetrical, assum x, y and z to be displacements of mass centroid in the directions of x, y and z, and q to be rotation angle of floor as z axis. According to deformations and cases subjected forces of standard floor element, general equilibrium equations are shown in matrices.

Equilibrium equations of standard floor elements are:

$$M_i^U = 2K_i^B(a_iQ_i + b_iQ_{i-1} - 3C_iR_i) \quad (1)$$

$$M_i^D = 2K_i^B(b_iQ_i + a_iQ_{i-1} - 3C_iR_i) \quad (2)$$

$$M_{i+1}^D = 2K_{i+1}^B(b_{i+1}Q_{i+1} + a_{i+1}Q_i - 3C_{i+1}R_{i+1}) \quad (3)$$

$$M_i^U + M_i^D = -Q_il_i + P_{oi}R_il_i \quad (4)$$

$$M_{i+1}^D + M_i^U = -P_{i+1}l_{1i} + P_il_{2i} \quad (5)$$

$$P_i = (Z_i - Z_{i-1} + Q_{xi-1}l_{1xi-1} - Q_{xi}l_{zxi} + Q_{yi-1}l_{1yi-1} - y_il_{zyi})K_{Ai} \quad (6)$$

$$M_{Ti} = (q_i - q_{i-1})K_{Ti} \quad (7)$$

In equation (1)-(7), symbols with subscripts of x and y respectively shown lateral displacements equilibrium equations in the directions of x and y.

By simultaneous equations, and eliminating rotation angles θ_x and θ_y of horizontal rigid rods in the directions of x and y, the relations of angle displacements R_x and R_y between floors and shear forces Q_x, Q_y and axial force P are reduced to:

$$[A_x]\ (R_x) = [B_x](Q_x) + [C_x](P) \quad (8)$$

$$[A_y]\ (R_y) = [B_y](Q_y) + [C_y](P) \quad (9)$$

$$[D]\ (P) = [I_1](Z) + [E_x](Q_x) + [E_y](Q_y) + [F_x][l](R_x) + [F_y][l](R_y) \quad (10)$$

$$(M_T) = [K^r][I_1](q) \quad (11)$$

The relations of angle displacement and mass centroid displacement are:

$$(R_x) = [l]^{-1}[I_1](x) - [l]^{-1}[H_y](q) \quad (12)$$

$$(R_y) = [l]^{-1}[I_1](y) - [l]^{-1}[H_x](q) \quad (13)$$

Substituting equation (12), (13) into equations (8)-(11), and taking inertia forces as every interforces, obtained by arrangement:

$$[M](u) + [K](u) = 0 \quad (14)$$

in which, (u) is displacement vector at mass centroid. Therefore, [M] is a diagonal matrix. The unsymmetrical submatrices in [K] reflects the coupled vibration relation.

Free vibration characteristic   Take the calculation model shown in Fig.2 to be divided into two braches: a). rigid tower-building on elastic soil; b). elastic tower-building on rigid soil. According to the space relation of model, taking rigid centroid of foundation as foundamental point, the transform relation of rigid displacement $(u)_a$ and displacement row vector (u_o) of foundamental point are obtained as below:

$$(u)_a = [R](u_o) \quad (15)$$

Therefore, the mass matrix as to foundamental point O are:

$$[M]_a^o = [R]^T[M][R] + \mathrm{diag}\,(m_o, m_o, m_o, J_{xo}, J_{yo}, J_{zo}) \quad (16)$$

in which, m_o, J_{xo}, J_{yo} and J_{zo} are respectively mass of foundation and its mass inertia moment.

Stiffness matrix as to foundamental point is a function of excited frequency:

$$[K]_a^o = \text{diag}\ (K_x(w),\ K_y(w),\ K_z(w),\ K_{Qx}(w),\ K_{Qy}(w),\ K_q(w)) \tag{17}$$

Characteristic equations of branch a is:

$$[K(w)]_a^o\ (u)_a = [M]_a^o(u)_a[\Omega]_a^o \tag{18}$$

By mode assemblage of $(u)_a$, main mode of branch a, and $(u)_b$, main mode of branch b, main mode of general system and its free vibration frequency can be obtained.

Comparision of Calculation and Experimental Results For comparing with calculated results, a model experiment on a 1/40 model of tower-building is made by using stable sine excitation and instantaneous hammered method. When tested, model is laid on natural soil to reflect the effect of soil to free vibration characteristic of upper structure.

Comparision of experimental results and calculated results by using Branch Mode Synthesis Method is shown as Table 1:

Table 1. Free Vibration Frequency (Hz) of Experimental Model

Calculate results				experimental results			errors
Mode No.	rigid soil	Mode No.	elastic soil	Mode No.	stable sine test	hammar method	%
1	20.54	1	20.1	1	20.6	21.15	2.43
2	20.54	2	20.2				
		3	32.9	2	28.5	27.86	15.44
		4	34.7				
		5	55.5	3	49.5	50.87	12.12
3	71.58	6	67.5	4	71.8	72.02	5.99

Notes: 1. errors in Table 1 is a comparision of calculated results considering elestic soil and stable sine tested results.
2. when tested, model of structure is escited in the direction of unsymmetrical axis (x axis).

Conclusion By analysing the calculated results as above, some conclusions are obtained as follows:

1. Dynamic interactions of interaction system of tower-building-foundation-soil are very complicated, and its characteristic is flexible at the two ends and rigid at the intermediate part. Foundamental frequency takes centilever bending of tower as main form. Therefore, in order to control the lateral displacement of antenna platform on the top of tower, the stiffness of tower must be taken as first.

2. Flexibility of soil causes building to generate rigid sway.

3. Space vibration model must be used for rotation vibration because of unsymmetrical of tower.

4. When carrying on response analysis, the effect of excited forces input

in variable directions must be considered.

5. The calculated model and methods used in this paper can reflect completely all of problems as above, and coincides with experimental results. Therefore, it is rational.

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