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EFFECT OF FLEXIBLE AND EMBEDDED FOUNDATION ON SEISMIC RESPONSE OF NUCLEAR POWER PLANT

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ABSTRACT

In this paper, an effect of flexible and embedded foundation on seismic response of nuclear power plant is investigated. The method, which is based on the convergent mass model and the mode superposition method, is used to conveniently analyze the effect of a containment shell of an nuclear power plant under the action of EL–Centro seismic wave (1940, southnorthern). The flexible and embendded foundations are also consided.

1. INTRODUCTION

Seismic analysis is the foundation theory of anti–seismic design. The structure design may be reasonably proceeded only by accuratly analyzing the dynamic response of every part of the structure. Since nuclear power plant is of huge weight, strong stiffness and a certain of buried depth. The interaction of soil and structure should be considered in the analysis. The current methods are finite element method and concentrated parameter's method, or the combination of two methods. In which the most simply method is the concentrated parameter's method. The key to this method is reasonably computing all paremeters, especially the parameters of the base spring and the damper, and every equivalent damping ratios. In order to obtain these parameters, the elastic half–space theory and the transfer function method will be used [1,2] . Paper [3] gives the approximate formula in the estimation of the effect of the buried depth. In that paper, the coefficient of the base spring and the damper, which were calculated by the elastic half–space theory, could be modified in depending on the coefficient modification, which is calculated from the poisson's ratio of the base soil and the extent of buried depth. In this paper, the seismic response of a containment shell of a nuclear power plant which is based on the embedded foundation and the flexible foundation is analyzed. The results of buried depth were alse considered. A numerical example shows the effect of the flexibility of the base soil and the buried depth to seismic responses.

2. EQUATIONS OF MOTION

Since the soil–structure interaction is obvious in the building based on the flexible foundation, there is no orthogonal modes in the structure dynamic analysis. The modal superposition method of real modes could only be approximately used to solve the problem in properly calculating the equivalent modal damping ratios. Therefore, it is necessary to respectively analyze the eigenvalue problems of the structure on the embedded foundation and the soil–structural interactive system on the flexible foundation.

The dynamic equations of a building on fixed foundation under the horizontal seismic action can be written in matrix form [2] :

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = -\ddot{u}(t)\{M\} \qquad (1)$$

where $\{x\},\{\dot{x}\},\{\ddot{x}\}$ are the displacement vector, the velocity vector and the acceleration vector respectively,

$[M],[C],[K]$ are the mass matrix, the damping matrix and the stiffness matrix respectively,

$\ddot{u}(t)$ is the ground acceleration,

$\{M\}=[M]\{1\}$.

The modes are assumed in orthogonality, i.e.

$$[\Phi]^T[M][\Phi] = \lceil I \rfloor; \qquad [\Phi]^T[K][\Phi] = \lceil \omega_j^2 \rfloor; \qquad [\Phi]^T[C][\Phi] = \lceil 2\beta_j\omega_j \rfloor.$$

The dynamic equations of a building on flexible foundation under the horizontal seismic action can be written in matrix form:

$$\left.\begin{aligned} &[M](\{\ddot{y}\} + \{\ddot{u}\}) + [C]\{\dot{x}\} + [K]\{x\} = 0 \\ &m_b(\ddot{y}_b + \ddot{u}) + c_x\dot{y}_b + k_x y_b = -\sum_{i=1}^{N} m_i(\ddot{y}_i + \ddot{u}) \\ &I_s\ddot{\psi} + c_\psi\dot{\psi} + k_\psi\psi = -\sum_{i=1}^{N} m_i h_i(\ddot{y}_i + \ddot{u}) \end{aligned}\right\} \qquad (2)$$

where $y=y_b+h_b\psi+x$,

y_b and ψ are the foundational horizontal displacement and its rotational angle to the ground,

m_b is foundational mass,

h_i is the ith floor height,

I_s is the summation of the individual centroidal mass moments of inertia,

c_x, c_ψ, k_x, k_ψ are the horizontal and the rotational damping coefficient and stiffness coeifficient respectively (they may be analyzed in elastic half–space theory).

At first, the eigenvalues and the eigenvectors of the undamping building on the fixed foundation can be obtained from Eq.(1). Then, Eq.(2) could be decoupled to obtain the modal equations. The transfer function method is used to calculate the equivalent modal damping ratios [2] . The method is to repeatedly iterate all modal damping ratios under the condition of which every resonance pattern of the accurate transfer functions should be equal to that of the approximate transfer functions in sensitive floor (generally in the top floor of the builfing).

3. THE EFFECT OF BURIED DEPTH

Most nuclear power plant exists great buried depth. It should be considered in seismic analysis. But the effect of buried depth is very complicated. It is concern with the factor of the soil quatity and compresional degree of backfill, buried depth and the structure type of nuclear power plant etc. There is no common analysis method. Paper [3] gives an approximate formulu to correct the base spring and the damping coefficient:

For the horizontal translation, one has:

$$\left.\begin{aligned} \frac{k_x}{k_{0x}} &= 1 + 0.55(2-\mu)\delta \\ \frac{c_x}{c_{0x}} &= \frac{1 + 1.9(2-\mu)\delta}{\sqrt{\dfrac{k_x}{k_{0x}}}} \end{aligned}\right\} \tag{3a}$$

For the rotation, one has:

$$\left.\begin{aligned} \frac{k_\psi}{k_{0\psi}} &= 1 + 1.2(1-\mu)\delta + 0.2(2-\mu)\delta^3 \\ \frac{c_\psi}{c_{0\psi}} &= \frac{1 + 0.7(1-\mu)\delta + 0.6(2-\mu)\delta^3}{\sqrt{\dfrac{k_\psi}{k_{0\psi}}}} \end{aligned}\right\} \tag{3b}$$

where μ is the poisson's ratio of the base soil,

$\delta =$ buried depth / radius of base plate,

"0" means that the base spring and damping coefficient are obtained from elastic half–space theory.

Paper [4] and paper [5] give nearly the same formula as Eq.(3a) and Eq.(3b).

4. NUMERICAL EXAMPLES

For simplicity, the seismic response of the containment shell with the internal structure is used as an example. The containment shell and the internal structure have the circle base plate with radiu 62.5ft and thickness 12ft. The height of the containment shell and the internal structure are 281ft and 80ft respectively. Fig.1 shows a containment shell that was assumed to be a shear bending beam with 4 concentrated mass and an internal structure of 2 concentrated mass shear beam.

Three cases of base soil are considered with $v_s = 600$, 1500, 2000ft / sec. In every case, the buried depth ($\delta = 1.472$) and non–buried depth are calculated respectively. The parameters are given in paper [6]. Under EL–Centro seismic wave action, Fig.2, Fig.3, Fig.5 show the top floor's (the 4th freedom) response of the containment shell.

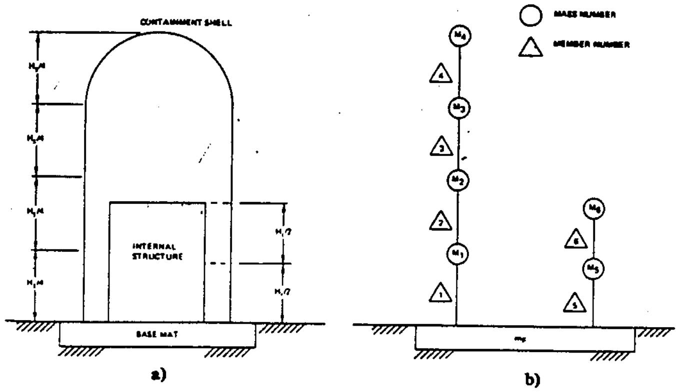
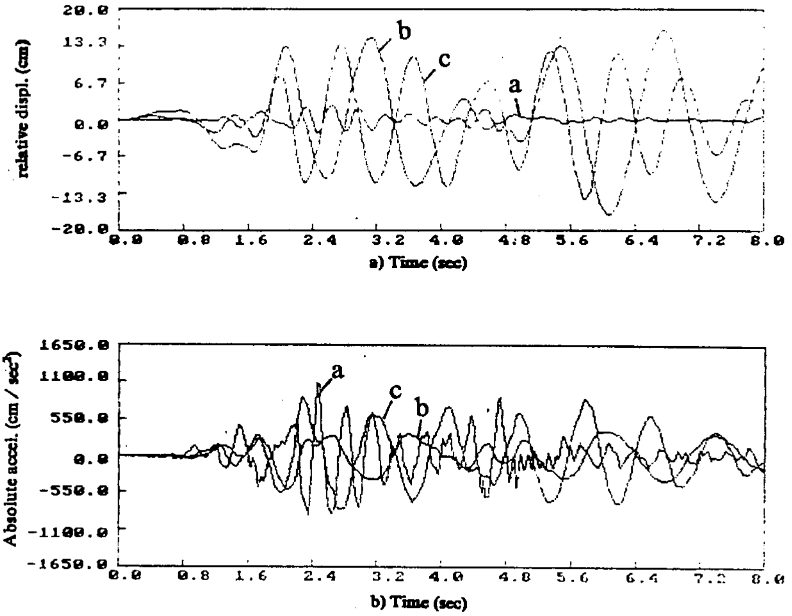


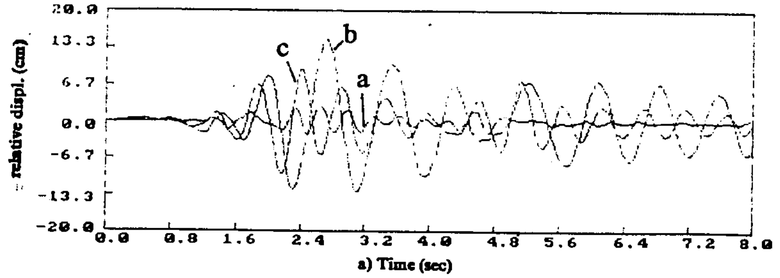
Fig.1 Containment shell a) structure b) model

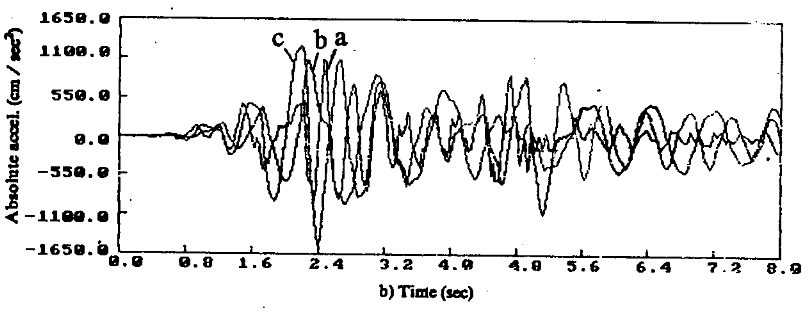


a, b, c—Fixed, Flexible, Embedded foundation

a) relative displacement b) absolute acceleration

Fig.2 $v_s = 600\mathrm{ft} / \mathrm{sec}$, the top floor's response

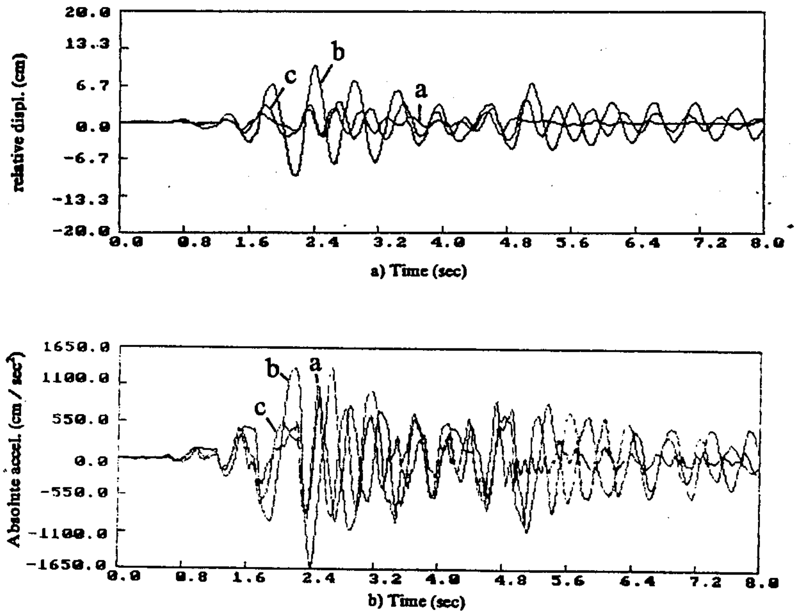




a, b, c—Fixed, Flexible, Embedded foundation

a) relative displacement b) absolute acceleration

Fig.3 $v_s = 1150$ft / sec, the top floor's response



a, b, c—Fixed, Flexible, Embedded foundation

a) relative displacement b) absolute acceleration

Fig.4 $v_s = 2000$ft / sec, the top floor's response

5. CONCLUSIONS

From the solutions of numerical examples, following results are obtained.

1). By the comparison of the flexible foundation and the embedded foundation, in the flexible foundation, the displacement is obviously increased, but the acceleration is obviously decreased. The more flexibility of the base soil, the more significant effect of the response was given. In the example, (ratio = flexible / fixed)

when $V_s = 600$ft / sec the ratio of relative displacements is 6.46,
the ratio of absolute acceleration is 0.47.

when $V_s = 1150ft / sec$, the ratio of relative displacements is 5.55,
the ratio of absolute acceleration is 0.98.
when $V_s = 2000ft / sec$, the ratio of relative displacements is 3.92,
the ratio of absolute acceleration is 1.50.

In the last case, the acceleration is amplified, the reason is that the period of the system (near 0.5sec) is close to the reasonant period of the base soil.

2). The effect of the seismic response of upper structure on flexible foundation is concern with both the upper structure and the base soil. It can be expressed by using foundational relative stiffness $\sigma = T_1 v_s / H$. In the example,
when $V_s = 600ft / sec$, $\sigma = 2.81$;
when $V_s = 1150ft / sec$, $\sigma = 5.39$;
when $V_s = 2000ft / sec$, $\sigma = 9.37$。

In general, when $\sigma > 7$, the effect can be ignored. [7] .

3). By the comparason of buried depth and non–buried depth, buried depth may obviously decrease the response of relative displacement. But the absolute acceleration is increased in buried case. Only when there is a certain hardness in the base soil, the acceleration is decreased. In the example, (ratio = buried / non–buried)
When $v_s = 600ft / sec$, the ratio of relatice displacement is 0.84,
the ratio of absolute acceleration is 1.70;
When $v_s = 1150ft / sec$, the ratio of relatice displacement is 0.65,
the ratio of absolute acceleration is 1.43;
When $v_s = 2000ft / sec$, the ratio of relatice displacement is 0.39,
the ratio of absolute acceleration is 0.59.

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