Analysis for the Variety of Piled Raft Foundations Rigidity and Subgrade Stress Based on Earthquake

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ABSTRACT

The pile raft foundations has very good earthquake resistance effect. Different from usually separating foundation calculation from subgrade calculation, pile-soil-structure interaction system combines pile raft foundations with ground soil for rigidity conformity, obtains total rigidity matrix of rigid foundations, and makes rigid foundations and the superstructure work together to analyze the characteristic of structure. Analyzing the variety of rigidity for structure foundation soil in earthquake action, it can be obtained the variety of characteristic value of subgrade bearing capacity. Considering pile-soil-structure interaction system, we can calculate stress and strain for subgrade and foundations, and estimate stabilization condition of subgrade and foundations.1

INTRODUCTION

Under the action of earthquake, the collapse of the building, overturning, bending and so on is the result of the interaction of the upper structure and the foundation. The deformation of the foundation causes the foundation to change the force of the foundation, thus directly affecting the stability of the upper structure and its damage form. Pile foundation deflection is much smaller than the deformation of
the foundation, the relative deflection is often a few times, regardless of overall bending of the raft[1], so the base plate can be seen as a rigid foundation. The study of soil-structure dynamic interaction is of great significance to the correct prediction of seismic response. Further analysis of the seismic action can also be analyzed by the ground motion parameters, which is related to the change and failure of the structure, which will produce a large deformation, which will affect the structural stiffness and the structural cycle change[2].

INTERNAL FORCE CALCULATION OF PILE-RAFT FOUNDATION AND FOUNDATION

Determination of Substrate Displacement and Reaction Force

First, we must find the basis of the rigid base of the base reaction and settlement, the base is divided into N rectangular grids parallel to the axes x and y, figure 1, its size can range. The base plate bottom plane remains flat due to the settlement of the rigid foundation under external load, then, the vertical displacement \( W_i \) of any point \( i \) in a rectangular grid can be expressed by[3]:

\[
W_i = \theta_x X_i + \theta_y Y_i + W_0 (i=1,2,3,\ldots,n)
\]

Where \( W_0 \) is the vertical displacement of the base bottom at the origin O of the coordinates, \( \theta_x \) and \( \theta_y \) are the corner (or inclination) of the base around x and y, respectively, as the base floor stiffness is large, is the overall tilt, \( \theta_x X_i \) and \( \theta_y Y_i \) are the coordinates of \( X_i, Y_i \) o point, due to the basis of the y-axis and x-axis rotation and increase the vertical displacement. In order to facilitate the computerization, the above formula is expressed in matrix form:

\[
\{W\} = [X][\theta]
\]

For the piled raft foundation, let the concentrated base bed coefficient on the i grid area \( f_i \) be \( K_i \), then the concentrated base reaction force is \( R_i = K_i S_i \), \( S_i \) is the base settlement of the i-grid, then there is for all the grids:

\[
\{R\} = [K][X]
\]

Where: \([K]\) is the foundation stiffness matrix.
Determination of Foundation Stiffness Matrix

Then the principle of superposition, the settlement of the midpoint of the grid should be the sum of the subsidence caused by the base pressure and pile pressure on all n grids, which is:

WHEN THE GRID UNDER THE BASE IS THE SOIL:

\[
S_n = \delta_{n1}P_1f_1 + \delta_{n2}P_2f_2 + \cdots + \delta_{nj}P_jf_j + \cdots + \delta_{nn}P_nf_n
\]  \hspace{1cm} (4)

When the j point for the pile, then the pile pressure \(Z_j\) instead of \(Pjf_j\). The above formula can be written in the form of a matrix as follows.

\[
\{S\} = [\delta][R]
\]  \hspace{1cm} (5)

among them \(\{S\} = \{s_1, s_2, \cdots, s_n\}\)

\(\{\delta\} = \begin{bmatrix}
\delta_{11} & \delta_{12} & \cdots & \delta_{1n} \\
\delta_{21} & \delta_{22} & \cdots & \delta_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\delta_{n1} & \delta_{n2} & \cdots & \delta_{nn}
\end{bmatrix}\)

\(\{R\} = \begin{bmatrix}
R_1 \\
R_2 \\
\vdots \\
R_n
\end{bmatrix}\)

\([\delta]\)is called the foundation flexibility matrix, where the settlement coefficient \(\delta_{ij}\) can be expressed by the formula[4]

\[
\delta_{ei} = \frac{1 - \nu^2}{\pi \phi E_i} \left[ a \ln b + \sqrt{a^2 + b^2} \right] + b \ln \left[ a + \sqrt{a^2 + b^2} \right]
\]  \hspace{1cm} (6)

Find out. Where \(E_t, \nu_t, \phi_1\), elastic modulus of soil, Poisson's ratio, post-earthquake stiffness reduction coefficient.

WHEN THE GRID UNDER THE BASE IS PILE:

\[
S_z = \delta_{11}P_1f_1 + \delta_{12}P_2f_2 + \cdots + \delta_{nj}P_jf_j + \cdots + \delta_{nn}P_nf_n
\]  \hspace{1cm} (7)

When the j point for the pile, then the pile pressure \(Z_j\) instead of \(Pjf_j\).

\[
\delta_{ij} = \frac{\Delta_s}{Z_i}, \text{which is } \delta_{ii}P_i = \Delta_s
\]

When the test pile is obtained, it can be checked whether the calculation of \(\delta_{ij}\) is accurate, which means that the pile is subjected to force \(Z_i\)(Measured by the test
pile)[5], its settlement is $\Delta$ (Measured by test pile). Pile soil flexibility coefficient $\delta_{ij}$ can be used the formula

$$
\delta_{ij} = \frac{1 - U_{z_i}^2}{\pi f_{z_i} E_{z_i}} \left[ \ln b + \sqrt{a^2 + b^2} \right] + b \ln \frac{a + \sqrt{a^2 + b^2}}{b} \] (8)
$$

In which $E_{zt}$, $V_{zt}$, $\phi_1$ are pile soil elastic modulus, the Poiss ratio, post-earthquake stiffness reduction coefficient, if simplified, can be replaced by a pile.

**Calculation of Base Reaction and Settlement**

The moments of the load force $P$ for the x and y axes are $M_x$ and $M_y$, respectively. According to the underlying static equilibrium condition:

$$
\begin{bmatrix}
 x_1 & x_2 & \cdots & x_i & x_n \\
 y_1 & y_2 & \cdots & y_i & y_n \\
 1 & 1 & \cdots & 1 & 1 \\
\end{bmatrix}
\begin{bmatrix}
 R_1 \\
 R_2 \\
 \vdots \\
 R_i \\
 \vdots \\
 R_n \\
\end{bmatrix}
= 
\begin{bmatrix}
 M_1 \\
 M_2 \\
 \vdots \\
 M_i \\
 \vdots \\
 M_n \\
\end{bmatrix}
\] (9)

which is: $[X]^T \{R\} = \{M\}$ (10)

Where $[X]^T$ is the transposed matrix of $[X]$, $[M]$ is the load column vector. According to contact conditions $\{S\} = \{W\}$, according to (2) and (3):

$$
\{R\} = [K][W] = [K][X][\theta]
$$

Substitute (17) is

$$
[C][\theta] = \{M\}
$$

Where $[C] = [X]^T[K][X]$ is the total stiffness matrix of the rigid foundation. After by (15) to the ternary system to solve the rigid basis of the tilt and settlement $\{\theta\}$, substituting (13) yields $\{R\}$, so each mesh substrate reaction force is $\{P\} = \{R/f\}$.

From the above calculation and analysis, it is found that the variation of the elastic modulus $E$ and the stiffness $K$ of the foundation has a great effect on the stress and deformation of the foundation, after a strong earthquake $E$ and $K$ will be greatly weakened, often causing catastrophic damage to the structure. Geotechnical
3D finite element program GEOTL uses the above principle to carry out foundation calculation and analysis.

**Simulation Calculations: The Effect of Vibration on Frequency and Damping Ratio**

In order to compare with the relevant test data, the structure and foundation according to the ratio of 1/10 to reduce the calculation, structural model design is: The upper structure adopts two-way single-span 12-story reinforced concrete frame with a layer height of 360mm; Under the frame column there are five prefabricated piles, pile size 40X40, pile length 1600m; Soil is divided into 4 layers, from top to bottom were silty clay, sandy silt, sand and sand layer, layer thickness were 600,600,800,800 mm.

<table>
<thead>
<tr>
<th>Working code</th>
<th>Soil surface</th>
<th>The vertex of structure</th>
<th>The vertex of Rigid foundation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f/Hz</td>
<td>Damping ratio/%</td>
<td>f/Hz</td>
</tr>
<tr>
<td>1R</td>
<td>9.42</td>
<td>8.646</td>
<td>3.11</td>
</tr>
<tr>
<td>10R</td>
<td>9.36</td>
<td>7.134</td>
<td>2.09</td>
</tr>
<tr>
<td>16R</td>
<td>9.16</td>
<td>8.188</td>
<td>1.49</td>
</tr>
</tbody>
</table>

Structural analysis and calculation of pile-raft foundation with GEOTL, and then use ALGOR FEAS SUPER SAP software program for post-processing. In the table, R is the free field test white noise condition. The data in the table reveals that the frequency of soil decreases gradually with the increase of vibration frequency, and the damping ratio increases gradually, which is the basic law of dynamic characteristic change. The reason for this phenomenon is that the dynamic shear strength and dynamic shear modulus of the soil decrease due to the increase of the pore water pressure under the vibration excitation, and the soil damping ratio increases, and the soil exhibits significant non-linear characteristics. Consider the dynamic interaction of the structure of a pile-based foundation system of frequency and damping ratio are quite different. The frequency of the interaction system is smaller than that of the rigid foundation, and the damping ratio of the structure is larger than that of the rigid foundation. It is greater than the damping ratio of the structural material, A structural interaction produces a greater dynamic response to the system. For the interaction system, the dynamic characteristics of the system change with the excitation frequency due to the softening of the soil, the expansion of the pile foundation and the crack propagation of the frame structure. For the structure of the rigid foundation, the frequency drop and the damping The increase is
the result of the beam, column cracking and crack propagation of the frame structure, the mechanism of the two dynamic response is different.

CONCLUSIONS

Under the action of earthquake, due to the interaction, the seismic response is not only related to the rigidity of the structure itself, but also has a close relationship with the foundation characteristics. Due to the participation of the foundation soil and the pile, the seismic response (including the displacement reaction and the internal force reaction) of the superstructure has a significant effect. And the greater the stiffness of the upper structure, the more soft soil foundation, the more obvious the effect of interaction. After the earthquake, the soil becomes soft, $E_i$ is smaller, $\delta_c$ is bigger, the foundation structure, the upper structure cycle become larger, the stiffness decreases, the soil shear strength becomes smaller, the bearing capacity of the foundation decreases. And then a larger intensity of the aftershocks occurred, has been weakened the foundation, the upper structure more easily damaged. It is a complicated process to solve the pile foundation of the piled raft foundation. The calculation results of the internal force and the settlement of the raft foundation are often inaccurate. The calculation model proposed in this paper solves this problem, compared with the recommended method, is accurate, and have very good project economic benefit.

REFERENCES