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Deformation Behavior of Rigid Pile Composite Foundation with Variable Stiffness

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Abstract:

According to the standard design, the bearing capacity of soil between piles of soft soil rigid pile composite foundation is often too high, and the settlement corresponding to its design bearing capacity is greater than that of composite foundation. In practice, this situation is impossible. Therefore, the bearing capacity of soil between piles can not be brought into play according to the design. The main reason is that the relationship between pile and soil deformation coordination is not considered. In order to reveal the internal essence of pile-soil deformation coordination and the problem that the bearing capacity of soft soil is excessively used, the hyperbolic tangent modulus method is used to calculate the P-S curves of pile and soil respectively. Then the P-S curve of composite foundation is superimposed to establish the deformation coordination relationship between pile and soil, so as to analyze the load sharing between pile and soil. After analysis, it is found that when designing according to the code method, the bearing capacity of soft soil is usually used too high and the bearing capacity of pile is designed too low. For example, the bearing capacity of single pile or its strength is insufficient, which is easy to lead to the damage of pile and composite foundation. In view of the shortcomings of the standard method, it is proposed that the reasonable design of soft soil rigid pile composite foundation should consider the relationship between pile and soil deformation, and the bearing capacity of soil between piles should be determined according to the P-S curve and the load corresponding to the corresponding settlement. The design and calculation method of soft soil rigid pile composite foundation considering the coordination of pile and soil deformation established in this paper can provide guidance for future design..

Keywords*: Variable Stiffness, Rigid Pile, Foundation Deformation, Performance Evaluation.*

I. INTRODUCTION

After years of evolution, the foundation treatment technology is becoming more and more mature, and the foundation treatment engineering is also widely used all over the country [1-2]. Up to now, the bearing capacity and settlement analysis and calculation theory of composite foundation have also made great progress. In this case, the theory of composite foundation also came into being and became the research direction of scholars. Before that, the foundation design was mainly in two forms: natural foundation and pile foundation. The former only relied on the soil to bear the building load, while the latter was borne by the pile without considering the bearing effect of the soil [3]. The composite foundation theory proposed

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that the load on the upper part of the building could be borne by the pile-soil, which was very persuasive at that time, and it was also in line with the actual situation of the pile-soil joint bearing effect after the natural foundation treatment.

The bearing capacity of natural foundation has been greatly improved after composite foundation treatment, but it also needs to have sufficient safety and economic requirements, which promotes researchers to further study and understand the treatment methods of soft foundation and special soil foundation. Marine and river soft soil are widely distributed in coastal cities such as Guangdong and Fujian and Jiangsu, Zhejiang and Shanghai [4-5]. Most of the types are silt or mucky soil, which generally has the characteristics of high natural water content, high compressibility and large void ratio. As a foundation, the bearing capacity is also relatively low. At this time, rigid pile composite foundation, as a type of composite foundation, is a very effective way to treat such soft soil layer. The theoretical and Experimental Research on rigid pile composite foundation can undoubtedly provide reference theoretical support and technical guidance for the treatment of these soft foundations. Compared with the theories of shallow foundation and pile foundation, the research of rigid pile composite foundation is not as deep and thorough as these theories [6].

It is still difficult to estimate the bearing capacity and settlement of rigid pile composite foundation relatively accurately. At present, the bearing capacity of rigid pile composite foundation is mainly estimated by the method in the technical code for building foundation treatment (JGJ79-2012), which is obtained by superposition of the characteristic value of vertical bearing capacity of single pile and the characteristic value of bearing capacity of soil between piles according to the area replacement rate [7]. However, the determination of the characteristic value of the bearing capacity of pile and soil in the code formula requires field test, and the exertion coefficient of the bearing capacity of soil between piles also needs to be taken according to the regional engineering experience, which brings uncertainty to the estimation of the bearing capacity [8-10]. Therefore, it is still necessary to conduct a more in-depth study on the calculation theory of settlement and bearing capacity of rigid pile composite foundation, so as to make a correct evaluation of the bearing properties of the foundation, make the design of this foundation treatment method more reasonable, apply it to the project more effectively, and obtain good economic benefits.

II. TANGENT MODULUS METHOD AND PILE-SOIL DEFORMATION COORDINATION PRINCIPLE

Pile, generally refers to the use of a composite foundation when set in the foundation piles to reinforce the foundation pile and soil between stakes jointly constructed, and the main longitudinal reinforcement composite. In the pile, the pile is a longitudinal reinforcement, and soil between piles was the matrix. With the improvement and development of the theory of pile foundation treatment technology, application engineering practice has been extended to the pile axial load, lateral load and axial transverse interaction situation; to withstand lateral load based piles have around protect pile, pile, anchor piles.

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Therefore, the "pile" broad concept should also include this type of piles and the substrate. Various types of piles and their diverse features that make it almost can be used in a variety of engineering geological conditions and various types of projects. In recent years, with the development of production and raise the level of science and technology, the kind and type, construction techniques and design theory and design pile method, are high-speed evolution and development. Many world famous building foundation pile foundation are used. Pile foundation usually bear a greater load as a basis for building, which has many advantages, such as high capacity, good stability, small and uniform settlement, ease of construction and other mechanization, adaptability. Compared with other deep foundation, pile foundation has a wide range of use.

Deep pile foundation is the basis of the most commonly used form, which can better adapt to a variety of geological conditions and a variety of loading conditions, generally it has a large capacity, good stability, settlement and other characteristics, in high-rise buildings, heavy plant , bridges, ports, offshore oil platforms and nuclear power plant project has been widely used. As the pile works in developing human applications of earthquake disaster areas, the seismic performance of pile foundation design has become an important issue in today's geotechnical earthquake engineering research. However, due to the structure and characteristics of pile foundation construction itself, plus damage both the pile foundation and the seismic response of the foundation, but also on the upper part of its vibration caused by seismic response of engineering structures, and these factors make the pile for seismic design problem therefore becomes very complicated.

In the dynamic case, dynamic interaction between soil and structure is very clear that some cases be considered without considering Soil Structure Interaction results differ particularly large. Compared with the bedrock foundation, the vibration characteristics of the structure of the media on the basis of soil will change, even dynamic performance of the structure may change. Most of the existing seismic calculation theory assumes a rigid foundation (assumed earthquake when the building foundation and the adjacent free space motion unanimously), the base of the upper structure design input ground motion. Such a rigid foundation is assumed that the interaction between the foundation soil and the upper structure is not taken into account, and in the actual earthquake, the inertia force of the upper structure back to the foundation by the foundation, causing local deformation of foundation.

If this part of the ground deformation than the seismic waves generated by the deformation is much smaller, the rigid foundation assumption is reasonable. Otherwise, as the basis of translation and rotation with respect to the foundation, it will have a great difference between the actual movement of the upper structure and the results of the calculation assumed by rigid foundation.

A structure dynamic interaction of pile-soil finite element method analysis of overall upper structure to frame structure, frame shear wall structure and shear wall structure for the study. Finite element analysis step shown in Fig. (1). Dynamic Seismic Soil body and structure interaction (Soil Structure Dynamic Interaction referred SSDI) is an important part of earthquake engineering and seismic research. Dynamic interaction of soil and structure, is a matter to soil dynamics, structural dynamics, interdisciplinary research

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of nonlinear vibration theory, earthquake engineering and computer technology, and many other disciplines, it is also related to a non-linear, large deformation, contact surfaces, and many other local discontinuity theory and cutting-edge research in the field of contemporary art hotspots mechanics, but it is also a practical research topics closely related to civil engineering, water, construction, municipal, transportation and other sectors, therefore, has been to China interest and foreign scholars.

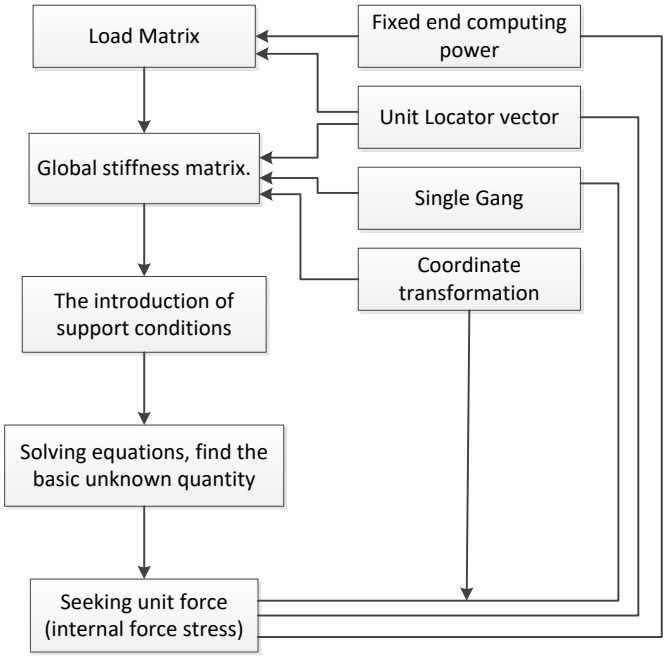

Fig. 1. Finite Element Analysis Step

III. DYNAMIC EQUATIONS AND CALCULATION METHODS

Pile-soil-equations of motion when the upper structure system in seismic input at any time t is:

$$M\ddot{u}(t)+C\dot{u}(t)+Ku(t)=F(t) \tag{1}$$

Where, M, C, K, F (t)-represent the system mass matrix, damping matrix, stiffness matrix and load vector nodes, are represented by the pile, and the upper structure of the soil matrix and vector corresponding to each unit integration.

$\ddot{u}(t),\dot{u}(t),\dot{u}(t)$ denote a system node acceleration, velocity vector nodes and node displacement vector. Dynamic equation is more complex than static, there are two differences, one will take into account the dynamic equations in the inertial force and the damping force; second load is a function of time, changes over time. For the formation and analysis damping matrix C is more complex, the project is the most widely viscous damping in the mathematical treatment is actually relatively easy. Damping means cause or

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causes of the vibration damping vibration energy dissipation. Damping force calculation unit theory is very complex. Viscous damping can be expressed as follows:

$$C_v = \int_{v_e} \mu_1 N^T N dV \tag{2}$$

$$C_x = \int_{v_e} B^T \mu_2 N B dV \tag{3}$$

In addition to finite element numerical methods, in pile foundation engineering there is a class of widely used, essentially Semi - analytical approach, the main idea of such approach is based on the elastic half-space theory, the use of the classical solution Middling or Bossnisqe; or experience-based and measured soil reaction function curve, seeking unearthed body in the pile - soil interface reaction force on the matrix, thereby solving the structural analysis of single pile, or by conventional matrix displacement method or finite difference method differential Equations pile group - soil interaction problem. Then the unit damping matrix can be expressed as follows:

$$C^e = C_v + C_s = \int_{v_e} \mu_1 N^T N dV + \int_{v_e} B^T \mu_2 B dV \tag{4}$$

In practical dynamic analysis and practical engineering, Rayleigh damping is widely used. In this paper, Rayleigh (Rayleigh) damping is used to calculated damping matrix. Rayleigh damping viscous damping basic assumptions, based on the overall damping matrix C structure with the overall quality of the matrix M and the overall stiffness matrix structure of K linear combination thereof.

$$C = \alpha M + \beta K \tag{5}$$

Foundation coefficient method: Because the lateral dimension of the pile is much smaller than its axial length, so the classical theory of beam deflection can be applied, whereby the introduction of differential equations pile:

$$EpIp \frac{d^4 u_p}{dz^4} = K(u_p - u_s) \tag{6}$$

Where EP and IP are elastic modulus and moment of inertia of the pile; up pile at depth z displacement, us without piles (not considering interactions) where the displacement obtained in soil. $K_h = f(z, u_p, u_s)$ is the foundation coefficient.

Poulson results show that when using this method to calculate the theoretical maximum bending moment of pile high value, and the value of the trailer coupling reaction force was low. Jaquelin in 1976 also conducted a similar study and found that the calculated values of soil horizontal displacement is often

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much smaller than the measured, only measured soil displacement value, before you can get a satisfactory result, and this is quite difficult. Another limitation of this method is only applicable to the case of single pile.

It presented not only consider the overall calculation of slope and sliding piles, but also includes a dispersion limit equilibrium theory Slalom slide soil calculated. The design and calculation method based on a theory by piles of establishing includes the following steps: calculation of flow resistance around the pile; ultimate design by piles - the overall slippage checking, checking Slalom slide, and the destruction of checking pile.

Limit design principle is assumed that each member involved in the work have reached the limit stress state, have played the maximum capacity, and then press the safety factor of their conversion. Just by piles, the limit state should be: just going to slide down the slope, pile just to break or dumping, but also happens to be between piles Slalom flow. Therefore, the calculations above steps are carried out in this particular state. So far, domestic and international research on the interaction between passive pile and soil is still not sufficient, many issues for further study.

The past 30 years, on the pile - soil - structure interaction problem, made a lot of computing model, research has turned to nonlinear problems from linear problem, even soil development from non-uniform soil from the pile Analysis Extension the analysis of pile groups. Pile - soil - structure dynamic interaction of soil and structure of main presence pile of earthquake response, therefore, the calculation model in the pile of soil - pile - structure interaction analysis is crucial. No matter what model should meet the dynamic equilibrium of soil, dynamic equilibrium structure, coordination and structure of the soil conditions. Pile is a complex pile-soil interaction system. For the common analytical model of the system, it is: lumped parameter model, dynamic Winkler foundation beam model, finite element model and boundary element models.

Nonlinear dynamic analysis, the load step and subset mainly precision control solution. Equilibrium iterations means within each sub-step so that the calculated result of the calculation is convergence, it is a method used to calculate non-linear.

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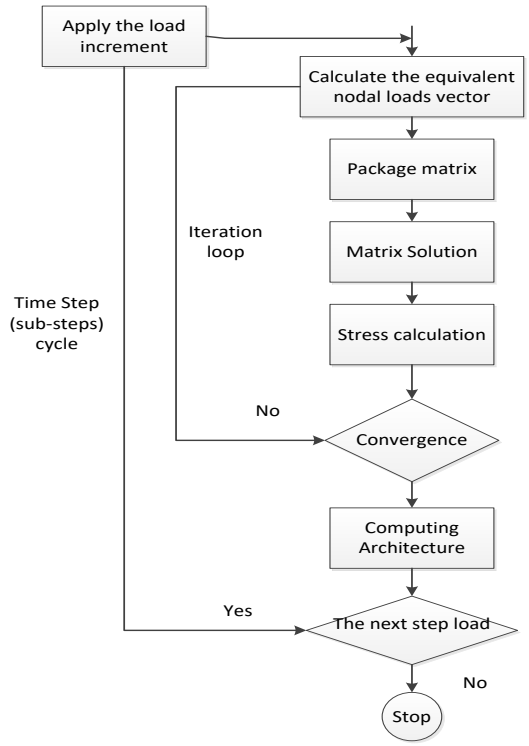

Fig. 2. Nonlinear Dynamic Equations Flowchart

Iterative method is applied to all loads, but in order to modify the displacement and strain, so as to meet the nonlinear stress - strain relation. Commonly used iterative method has: Newton-Raphson method, direct iterative method, modified Newton Raphson method. Incremental method refers to the load is divided into a number of increments, each application of a load increment. In each load increment is assumed to be constant stiffness matrix volume; in a different load increment, the stiffness matrix may have different values, and the stress-strain relation, respectively. Incremental method commonly used incremental arc length method, incremental method.

In the analysis of nonlinear problems, incremental and iterative each having advantages and disadvantages. Iterative method is relatively easy to use the preparation of Computer Program and consume less computational effort. The main advantage of incremental approach is its universal applicability. In addition to processing the softened material, it can be used for most of the non-linear case; it is a method of non-linear finite element analytical issues most commonly used.

IV. SLUMPED PARAMETER MODEL

For the upper structure, the structure of the lateral deformation properties were considered as shear or curved scissors multi-particle system, the quality concentrate on each floor, and the entire structure of the vertical load-bearing elements are combined into a total vertical rod thereby forming a cantilever-like particle-based model series. When the pile capping in contact with the bottom surface of soil, due to the mutual interference between the pile and soil, it is difficult to give exact solutions, usually approximate

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way, the rigidity against the foundation pile head superimposed on the corresponding horizontal and rotational stiffness in as the horizontal and rotational spring stiffness of the spring. This model takes advantage of the superposition principle of linear elastic and can not be considered non-linear soil, relatively simple and easy to use.

Although the lumped parameter model with respect to the finite element method for some other rough, but with the advantage of simple and convenient, but also highlighted the model reflects the dynamic response analysis of the nature of mass, stiffness and damping of the three factors, clear physical concept, dynamic interaction reveals the main contradiction, the quality of the established-stiffness- damping solution of dynamic equation model is more mature.

Similar guidelines determined: There are two equations to determine the conditions similar analysis and dimensional analysis. Equation analytical method, while the theory is simple, but during the model design before, must be clear functional relationship between physical phenomena studied in the various physical quantities. The relationship between the physical complexity of the function or unknown physical phenomena analysis using the equation will be difficult to obtain similar conditions, and dimensional analysis can compensate for this deficiency.

Dimensional analysis is the study of phenomena similar problems in the process, generated during the various physical dimensions to inspect. Its theoretical basis is about the mathematical theory dimensionless homogeneous equation. In general, for describing physical phenomena is homogeneous equation, which is derived from pi Theorem to analysis by dimension basis.

Selecting the correct parameters investigated its dimension by dimensional analysis, can be obtained and pi Theorem consistent functional relationship, and accordingly a similar phenomenon can promote. For all not completely understand the mechanism, the law did not adequately grasp the complex phenomenon, it is particularly evident. It can help people quickly approved correctness of the selected parameter similarity test, and deepen people's understanding of the phenomenon of the mechanism and regularity on the basis of this theory.

For the study of a pile of soil liquefaction caused by a structural dynamic interaction model shaking table test, the physical quantity of geometric similarity, the similarity of the mass density, dynamic elastic modulus similar, effective overburden pressure on the similarity of the dynamic response of pore water pressure similar resistance, the acceleration of gravity similarity, dynamic response acceleration, dynamic response and input angular displacement vibration similarity, etc. should be the main consideration; as damping ratio, vibration frequency and dynamic Poisson's ratio of similarity, although very important, but during the MODELING when it is difficult to achieve.

The data used are from Finland and single estimates not necessarily applicable to other regions. Migration patterns from Finland do not deviate much from the rest of Western Europe. Structure in rigid foundation under assumed earthquake response analysis of sub i do not consider the foundation soil and the

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upper structure interaction problems. And in the actual earthquake inertia force of the upper structure back to the foundation through the foundation, causing local deformation of foundation, if this part of the ground deformation is much smaller than the waves generated by earthquakes, the rigid foundation assumption is reasonable. Otherwise, as the basis of translation and rotation with respect to the foundation, it will have a great difference between the actual movement of the upper structure and the results of the calculation assumed by rigid foundation.

In the analysis of nonlinear problems, incremental and iterative each having advantages and disadvantages. Iterative method is relatively easy to use the preparation of Computer Program and consume less computational effort. The main advantage of incremental approach is its universal applicability. In addition to processing the softened material, it can be used for most of the non-linear case; it is a method of non-linear finite element analytical issues most commonly used.

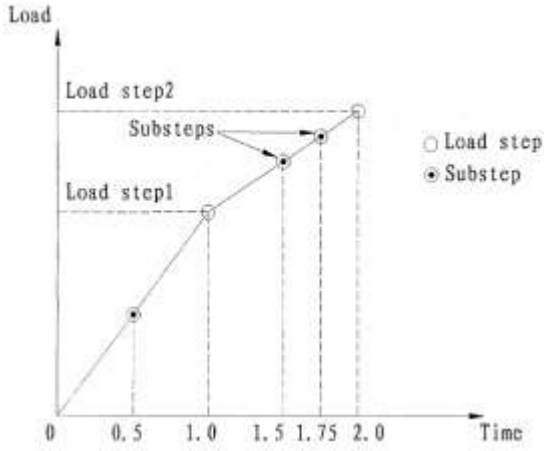

Fig. 3. Relationship between Load Step, the Sub-Step, Equilibrium Iteration and Time.

The basic requirement is the direct integration of convergence of the algorithm is good, when the step size is large computing systems and vibration cycle is short, linear accelerations may appear divergent case calculation, namely the reaction numerical increases, until overflow.

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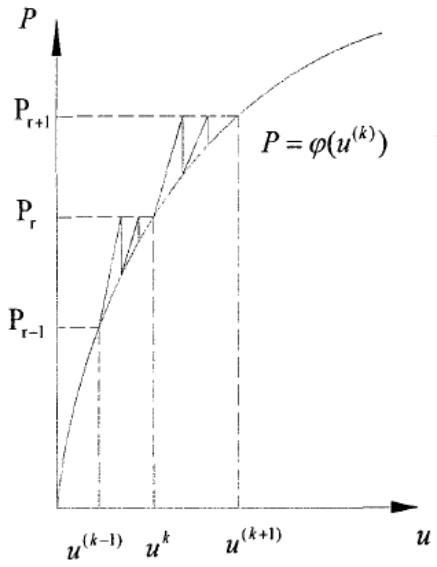

Fig. 4. Solving Schematic Through the Method Of Mixing.

For seismic analysis Structurally, t need to choose than the natural cycle and the periodic structure of the ground motion in the high frequency component is much smaller times (for example, 10 times or more) in order to ensure the necessary precision so that the method is a conditional convergence algorithm.

The main advantage of Newark method is an unconditionally stable algorithm, the time step t is mainly based on the accuracy of the calculation results to determine. And a larger time step and can also filter out high-end solution imprecise characteristics impact on the system. However, this method requires stiffness matrix inversion, so the calculation of very large quantities.

V. CONCLUSION

Soil-structure dynamic interaction in most cases the performance is very obvious, considering the soil structure interaction and without considering the results sometimes differ particularly large. Because soil medium, the vibration characteristics of the structure will change, even the dynamic performance of the structure may change. Most of the existing seismic calculation theory assumes a rigid foundation (assumed earthquake when the building foundation movement is consistent with its adjacent free space), shake the structure from the top to the base input design.

In the finite element calculation, if Moore - Coulomb failure criterion, it will make the plane deformation calculation of low intensity, high stress levels, calculates the displacement is too large. Some have been without damaging the cells are counted as destroyed unit. On the contrary, if the model used in Mises failure criterion, it is possible to calculate the displacement of the planar deformation small, could have destroyed unit is estimated to be no damage. Through a comprehensive summary of the relevant domestic and foreign soil - structure interaction and pile - soil interaction theoretical basis, the current

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research and development, derived pile interaction analysis can reflect the interfacial contact nonlinear finite element method models.

The model can accurately simulate real pile and soil geometry, and can reflect the pile, the soil in the course of joint forces in the pile - soil interface generates open spaces, contact nonlinear problems slip, while the pile - soil interface at the open, slip does have some influence on engineering safety.

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