Seismic Time History Analysis of Steel Box Tied Arch Bridge Foundation Considering Pile-soil Interaction

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Abstract: In order to study the dynamic response law of pile-arch bridge foundation under the action of seismic load, the reconstruction and expansion project of Zhoushantun-Dinghai Highway Xincheng Bridge is taken as an example. The linear finite element analysis software ANSYS is used to establish the linear sum. The nonlinear pile-soil interaction model is used to study the nonlinear time-history analysis of pile-soil interaction system under medium earthquake and large earthquake. The analysis results show that under the action of strong earthquakes, the interaction between pile and soil shows nonlinear behavior, and the soil exhibits obvious deformation deformation. Considering the nonlinear pile-soil interaction, the horizontal displacement of the pile body, the internal force and the internal force are significantly increased, which can provide reference for the seismic design of the pile foundation of the steel box tied arch bridge.

1. Introduction

In current seismic analysis, the pile-soil interaction is often calculated by the m method [1-2], and the m method is a linear elastic foundation reaction method [3]. Under the action of strong earthquakes, the combination of soil layers increases with the degree of deformation. Local plastic deformation will occur in the body [4-5], if calculated using the elastic theory, it will lead to a large deviation between the result and the actual. In addition, the contact state between the pile and the soil will also change non-linearly with the action of the seismic load, and the nonlinear interaction between the pile and the soil must also be considered [6]. In this paper, by setting nonlinear soil springs to consider pile-soil interaction, combined with engineering examples, the finite element model of main bridge pile foundation under medium and large earthquake loads is established, and the lateral non-linear dynamic response of piles and soils is carried out. The solution is compared and compared with the model established by the conventional m method. When analyzing, m is taken as 4000, which is the average value range of the soft clay m.

2. Pile-soil interaction

2.1 M method to determine the stiffness of soil spring

Many scholars have given calculation methods on how to calculate the interaction force and displacement in the system under the transverse axial load of the pile body. Among them, it is commonly used to calculate the differential equation of the deflection curve by the Winkler assumption, and the equilibrium conditions of the force are used to calculate the interaction force and displacement in the system of the piles. It is commonly used in the design of bridge pile foundations in China. The m method belongs to this method, and the m method is defined as

$$\sigma_{zx} = C \cdot X_z = m \cdot Z \cdot X_z \tag{1}$$

In this formula: σ_{zx} represents the lateral resistance of the soil to the pile in the position of the soil spring; the coefficient of reaction of the foundation; Z is the height of the soil layer of the soil spring; the lateral displacement of the height of the soil layer of the soil spring; the position of the soil spring The scale factor of the soil at the soil.

2.2 Nonlinear spring based on p-y curve method

Mcclelland and Focht [7] discussed the related concepts of the py curve method as early as 1958, and Chinese scholar Han Li'an [8] proposed a combination of soil layers of the py curve by comprehensively summarizing the selection of the pile foundation. The distribution of resistance is found in the construction of the more convenient py curve.

For soft clays with undrained shear strength Cu not greater than 96 kPa, the p-y curve can be determined using equation (2) as :

$$\frac{p}{p_u}=\begin{cases}0.5\left(\dfrac{Y}{Y_{50}}\right)^{\frac{1}{3}}, & Y/Y_{50}<8\\ 1.0\,, & Y/Y_{50}\geq 8\end{cases} \tag{2}$$

In this formula: P is the horizontal soil resistance standard value (kPa) acting on the pile at the depth of the soil layer below the mud surface; the lateral horizontal deformation (mm) of the pile at the depth of the soil layer below the mud surface; The standard value of the soil resistance per unit area of the pile side at the depth of the soil layer below the mud surface (kPa); when the pile soil reaches half of the ultimate level soil resistance, the lateral horizontal deformation (mm) of the corresponding pile.

When the undrained shear strength of clay is greater than 96 kPa, the p-y curve is more suiTable for the test pile data.

3. General Condition of Project

Taking the Zhoushan New Town Bridge as the research object, the main bridge type of the Xincheng Bridge is a medium-supported steel box tied arch bridge with a span of (36+148+36) m. The overall layout of the main bridge is shown in Figure 1. The main pier of the lower structure is elliptical, the longitudinal bridge is 17.9m long and the transverse bridge is 11.9m wide. The bearing platform is divided into two layers, each layer is 2.5m high, and the main pier foundation is seven φ1.8m bored piles are used. The pile height above the soil layer is 10m, the depth below the soil layer is 62m, and the total length of the pile body is 72m. The soil types around the pile foundation are soft clay and hard clay from top to bottom, and the weathered, slightly weathered and strong weathered tuff at the bottom. For the sake of research, it is assumed that all the soil around the makeup is soft clay.

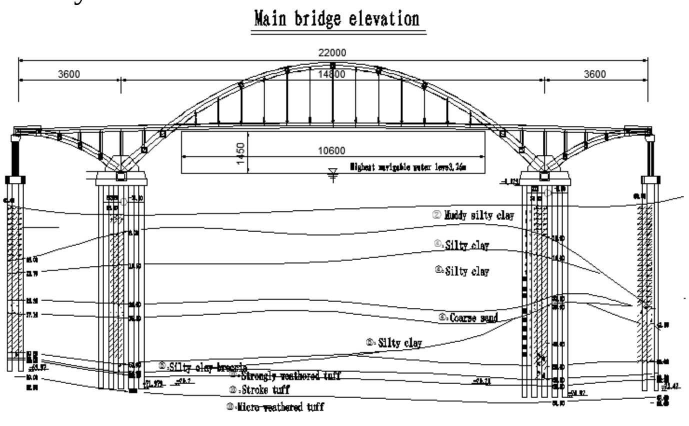

Fig.1. the overall layout of the main bridge

3.1 Establishment of finite element model

In this paper, the ANSYS software is used to build the pile foundation model from the top down. In the selection of the unit, the main pier and pile adopt BEAM188 unit, and there are 7 bored piles in the lower part of the main pier. Among them, when the unit is divided into units, each meter is divided into one unit. The superstructure weight was simulated using the MASS21 unit [9-10]. Concerning the interaction between pile and soil, the self-selected linear spring and non-linear spring are modeled in this analysis. In this analysis, the effect of soil on the horizontal direction of pile body is simulated through the soil spring in the horizontal direction. Because the soil around the bottom of pile is rock, the bottom of each pile is consolidated vertically. COMBIN14 unit is used to simulate the linear spring, while COMBIN39 unit is selected for the nonlinear spring. The finite element model is shown in Figure 2.

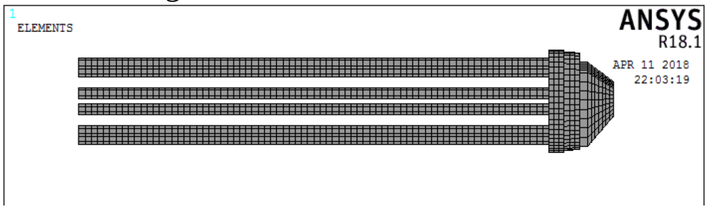

Fig.2 finite element model

3.2 Earthquake input

In this paper, El Centro [10-13] wave was selected and corrected in combination with geological conditions, so that the maximum corrected acceleration was 0.11g. The adjusted E1 seismic wave in the north-south and east-west directions was shown in figure 3 and figure 4. The peak acceleration of E1 seismic wave was increased to 0.38g by E2 seismic wave. The seismic load input mode of longitudinal + transverse (X+Y) is adopted for the finite element model, where the longitudinal direction is the X-axis direction of the coordinate system and the transverse direction is the Y-axis direction.

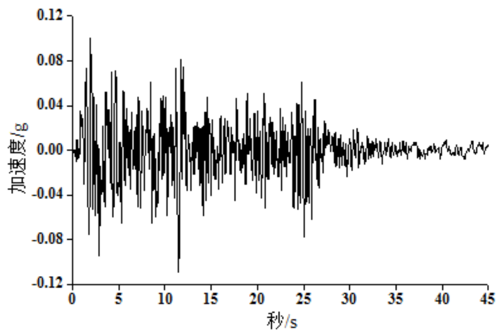

Fig.3 El Centro waves in the north-south direction of E1 earthquake

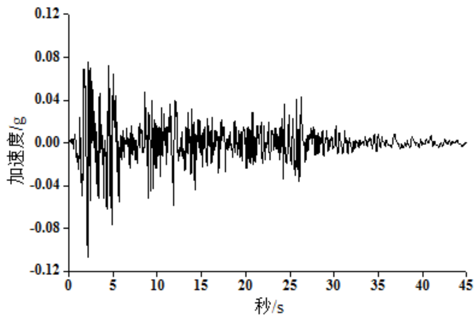

Fig.4 E1 ground motion east-west El Centro waves

4. Time history reaction analysis results

The modified El Centro wave is input into the finite element model, and the seismic response of pile foundation can be obtained through analysis. Fig.5 and fig.6 respectively show the comparison of maximum horizontal bending moment and horizontal displacement of middle row piles under the action of E1 and E2 earthquakes by p-y method and m method.

It can be seen from the results of time history analysis that the deformation and displacement of pile foundation under the p-y curve method are larger than those under the m method, indicating that with the deepening of soil layer, the stiffness of soil is not as large as that calculated by the m method.

(1) Under the seismic action of E1 (PGA=0.11g), the m-method and p-y-curve method have little difference in displacement and internal force above the soil layer under the action of two-way seismic combination. Below the soil layer, the smaller the internal force and displacement calculated by the m method to the bottom of the pile (a sharp decrease). The deformation reaches a zero point at a depth of about 25 m, and the deformation of the p-y curve method tends to be moderated until the bottom of the pile is reduced to zero.

(2) Under the seismic action of E2 (PGA=0.38g), the overall deformation and internal force of pile foundation under m method are linear. Under the p-y curve method, the deformation and internal force of pile foundation are roughly linear above the soil layer. Under the soil there is a strong non-linearity, However, the displacement and internal force of pier top still differ little, indicating that the non-linearity of pile foundation has little influence on pier body, but greater influence on pile body between pier and non-soil-driven pile, soil-driven pile and pile in pile.

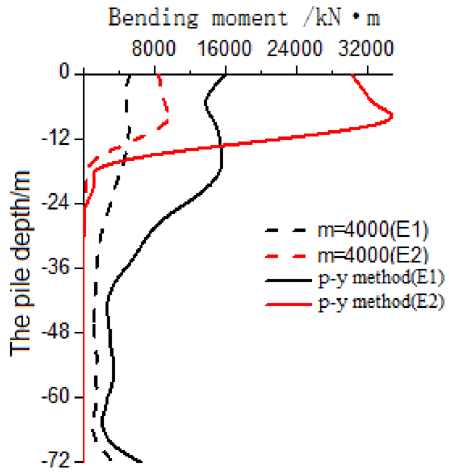

Fig. 5 The relationship between the maximum horizontal bending moment of the pile body and the pile depth

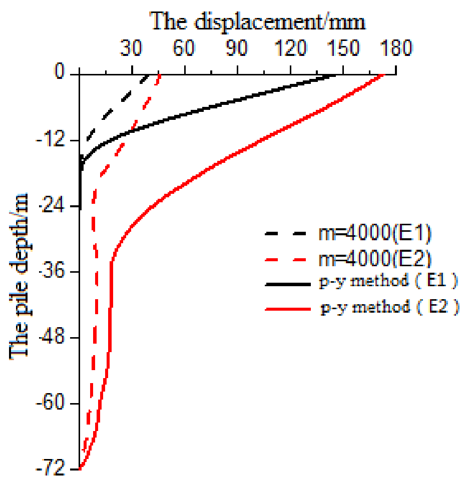

Fig. 6 The relationship between the maximum horizontal displacement of the pile and the pile depth

5. Conclusion

In this paper, the finite element analysis software ANSYS is used to simulate the main pier and pile foundation of steel box tied arch bridge. The dynamic analysis model of pile-soil interaction effect is simulated by m method and py curve method respectively, and nonlinear dynamics is adopted. The time-course analysis method is compared and analyzed, and the following points are obtained through calculation and comparative analysis:

(1) Pile foundation shows strong nonlinear behavior in the interaction between pile and soil in the process of seismic action. Therefore, it is not negligible to consider the nonlinear interaction between pile and soil in the calculation.

(2) When using the m method, the distance between the pile body and the internal force is small at a distance from the bottom of the pile, which is very different from the py curve method. This will lead to misjudgment of the sudden deformation region of pile. P-y curve method is adopted to simulate soil combination, and the true non-linearity of soil combination is taken as the withdrawal principle. The purpose of this is to ensure the authenticity of the final result as much as possible. Therefore, the m method is not safe for design and calculation, and the p-y curve method is more reasonable.

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References

[1] Liu Shannan, Hou Shengnan, Cai Zhongxiang. Analysis of the applicability of the horizontal bearing capacity of single pile in Shanghai area by m method [J]. Geotechnical Engineering Report, 2013, 3 5(s2):721-724.

[2] Hao Xiaomin. The application of m method in calculating the horizontal displacement of pile top of single pile foundation [J]. China High-tech Enterprise, 2017 (4): 122-123.

[3] Chen Lin. Review on the theoretical research status of pile foundation horizontal load calculation [J]. Jiangsu Architecture, 2013 (1): 76-79.

[4] Qian Jiahuan, Yin Zongze. Geotechnical principles and calculations [M]. Beijing: China Water Resources and Hydropower Press, 1996.401-451.

[5] Huang Bo, Liang Yulan. Seismic performance analysis of high-pile wharf under the combined action of pile and soil [J]. China Water Transport (the second half of the month), 2017, 17 (9): 174-175.

[6] Chen Qingjun, Jiang Wenhui, Li Zheming . Pile - soil contact effect and its effect on seismic response of bridge structures [J]. The Quarterly Journal of Mechanics, 2005, 2 6(4): 609-613.

[7] Matlock H.Correlation for Design of Laterally Loaded Piles in Soft Clay[C]// Proc.of theOffshore Technology Conference.1970:77-94.

[8] Han Li'an. Calculation of horizontal bearing piles [M]. Changsha: Central South University Press, 2004.