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Analysis of force characteristics of cap-pile system under earthquake action

This paper presents a three-dimensional finite difference numerical analysis of cap-pile system under earthquake. The deformation law of the cap-pile system and the variation characteristics of the axial force and moment of the pile are obtained. Under the action of earthquake, the settlement of the cap is increasing, and finally did not retrace, while the axial force and bending moment of the pile, present the trend of increasing first and then reducing, and the withdrawal efforts are great. The force and displacement are not completely corresponding relationship under the action of the earthquake. The moment of the pile swings at 0 o'clock under earthquake.

Keywords: *Pile cap; pile foundation; seismic force; force characteristics*

1. Introduction

Actually, as mentioned in the abstract section, it will be rather easy to follow these rules as long as you just replace the "content" here without modifying the "form".

Pile foundations are often used in soft soil sites due to the ability to provide a higher bearing capacity. Many scholars have studied the force characteristics, but there are few researches on pile foundation under earthquake load. Nikos Gerolymos et al. studied the working behaviour of the inclined pile foundation, and the load is seismic load, and the performance of different inclination angle is analyzed [1-3]. L. A. Padr´on et al. studied the dynamic stiffness and damping functions of single battered piles and of 2×2 and 3×3 pile groups with inclined elements [4-5]. Hussein Mroueh et al. present a three-dimensional nonlinear analysis of the response of battered piles to inclined pullout loads. Results show that the load's inclination affects the response of battered piles in both the lateral and axial directions [6-8]. Yong Shao et al. has analyzed the bearing capacity of the cap-tilted pile foundation, and it is concluded that the inclination of the pile does not significantly affect its bearing capacity [9-10]; the results show that horizontal bearing capacity doesn't decrease in the conditions of three tilt directions and inclined degrees from 0% to 12%. In other words, the horizontal displacement of an inclined pile is less than that of a vertical pile. Moreover, the top of the pile is subject to the maximum positive moment, whereas the bottom of the pile is subject to negative moment and the inflection point is 8-9 m below the top of the pile. Finally, the distribution of moment on tilted piles and vertical piles is influenced by the tilt degree. Wang Rui studied the method for computing axial force and settlement of pile foundation in consolidating and reconsolidating ground [11]; a beam on nonlinear Winkler foundation (BNWF) solution, in which the shaft friction capacity is updated as consolidation progresses proportional to the effective stress, is proposed to analyze the axial force and settlement of piles during consolidation and post-earthquake reconsolidation. The proposed method fully considers the effect of consolidation process on the axial force and final settlement of piles. The axial force and downdrag settlement by the proposed BNWF solution is compared to the measured ones from centrifuge tests on piles in both consolidating and reconsolidating ground. The proposed method produces more accurate estimates of pile settlement than the traditional neutral plane solution. Zhang De-wen proposed a simple evaluation method for the seismic performance of pile foundation [12]. This paper introduces the seismic PBD analysis piles using one-dimensional wave equation analysis and the so called PBEE analysis. A case study is discussed on the bridge pile foundations. The key issues in the analysis are design PGA, accelerogram, pile dimensions and the amount of steel bars issue. It is found that if the soil liquefaction influence could be negligible, then the maximum bending moment would occur at pile head, in which to increase the ductility of the pile at the pile head will help the seismic performance of the piles.

He Zhong-ying studied influence of group effect on the seismic performance of elevated pile-cap foundation in sand, the results show that: with group effect the lateral peak resistance is reduced; the lateral displacement of the cap and piles at peak value state is increased, the rotation of the cap is reduced, and the impact level of the group effect on such variables at the ultimate state mainly depend on the above ground height; the shearing force distribution is barely

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affected; the peak values of the bending moment are influenced lightly, but the distribution of bending moments and the peak values of curvature are influenced seriously, especially for the trialing row piles; the group effect is significantly influenced by both the above ground height and sand density[13]. Zhang Yong-liang studied seismic design method for high-speed railway bridge pile foundations considering soil-pile interaction effect, in view of the existing questions in seismic design of the high-speed railway bridge pile foundation under strong earthquakes, seismic performance of pile foundation based on multil-evel fortification goal is proposed and the corresponding evaluation index and rational values given. On the basis of the capacity spectrum method (CSM) put forward in FEMA440 including three kinds of soil-pile interaction effects, foundation flexible effect is simulated by using the curves of p-y, t-z and q-z, while the nonlinearity from pile members is analyzed by PMM hinge, capacity curve of the pier is obtained by pushover. By introducing a seismic demand spectrum modification algorithm from the FEMA440 considering foundation kinematics and damping interaction effects, the modification of demand spectrum is performed. The solving process of ductility demand on pile foundations and performance point is discussed by applying the performance point locus method [14].

This paper mainly studies the force characteristics of the cap-pile system under the action of earthquake load. The study is divided into three working conditions, one pile, two piles and four piles. Displacement, axial force and bending moment are compared and analyzed. The calculation method is finite difference method, and the numerical model is established by field data. The results of this paper can provide a reference for practical engineering.

2. Condition of the calculation

This calculation uses the finite difference software FLAC3D, The dynamic analysis option permits three-dimensional, fully dynamic analysis with FLAC3D. The calculation is based on the explicit finite difference scheme to solve the full equations of motion, using lumped gridpoint masses derived from the real density of surrounding zones (rather than fictitious masses used for static solution). This formulation can be coupled with the structural element model, thus permitting analysis of soil structure interaction brought about by ground shaking. The dynamic feature can also be coupled with the groundwater flow model. This allows, for example, analyses involving time-dependent pore pressure change associated with liquefaction (Section 3.5.2). The dynamic model can likewise be coupled with the optional thermal model in order to calculate the combined effect of thermal and dynamic loading. The dynamic option extends FLAC3D's analysis capability to a wide range of dynamic problems in disciplines such as earthquake engineering, seismology and mine rockbursts.

In the calculation process, the bearing units using solid elements to simulate, pile using the programme comes with the structural unit to simulate, the computational model is an elastic-plastic model with a failure criterion for the Mohr - Coulomb criterion. The model size is 25m ´40m, the static calculation of the bottom of the model using the whole constraint, that is, to limit its horizontal and vertical displacement, around the model to limit its horizontal displacement.

The numerical model is shown in Fig.1, the three calculation conditions are shown in Fig.2. Each working condition is divided into three types of pile length is 12m, 18m and 24m.

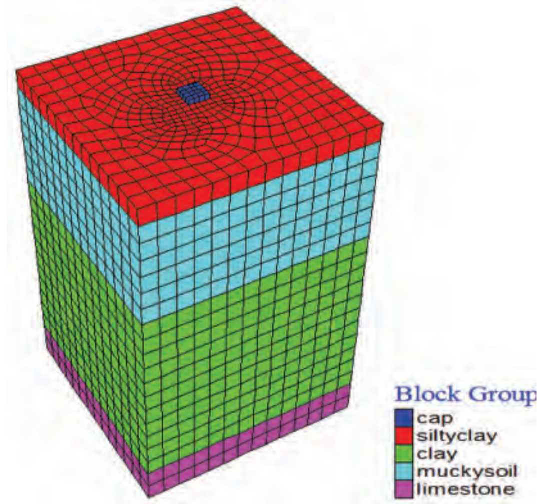


Fig.1 Numerical model

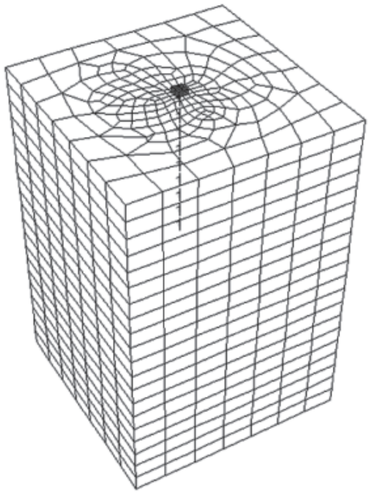
The physical and mechanical parameters of rock and soil are shown in Table 1. The second layer is mucky soil, which has a great influence on the bearing capacity of foundation.

In order to verify the reliability of numerical simulation, compared to the field measured data and numerical simulation data, shown in Fig.3. The figure shows the results of single pile bearing capacity comparison, it can be seen from the figure, numerical simulation and field measurement is basically the same.

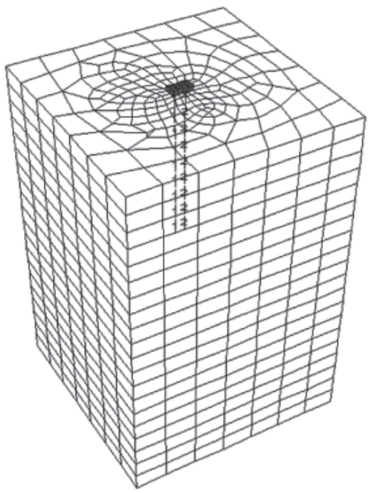
In numerical calculation, in order to be as close as possible to the actual situation, the load is applied above the

TABLE 1 PHYSICAL AND MECHANICAL PARAMETERS OF FOUNDATION SOIL

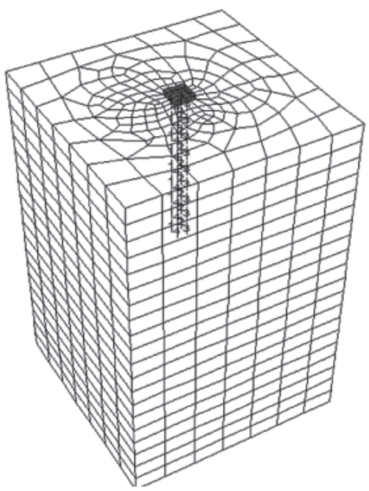
Type	Thickness (m)	r (KN/m^3)	Deformation modulus (MPa)	C (KPa)	φ(°)	Poisson's ratio
Silty clay	2	18.1	3.44	16	12	0.31
Mucky soil	12	17.3	1.41	11	8	0.34
clay	12	18.7	16.57	21	13	0.32
Lime stone	4	23.4	87.30	113	28	0.26



(1) Single pile



(2) Two pile



(3)Four piles

Fig.2 Three calculation conditions

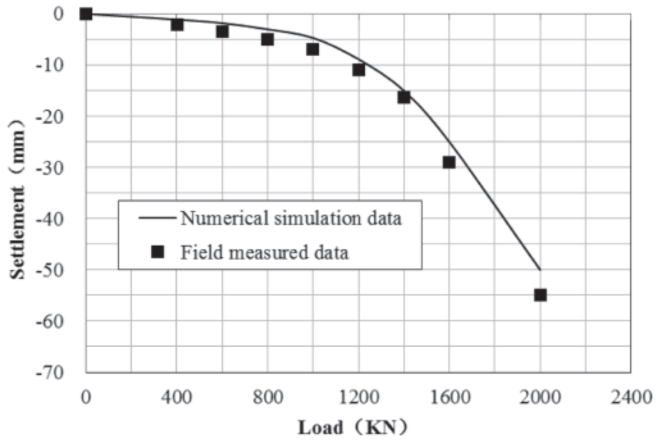
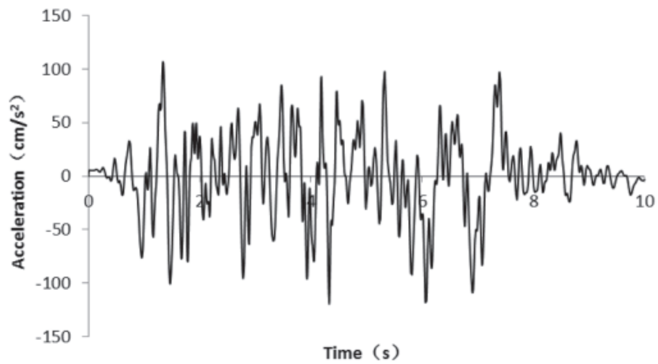


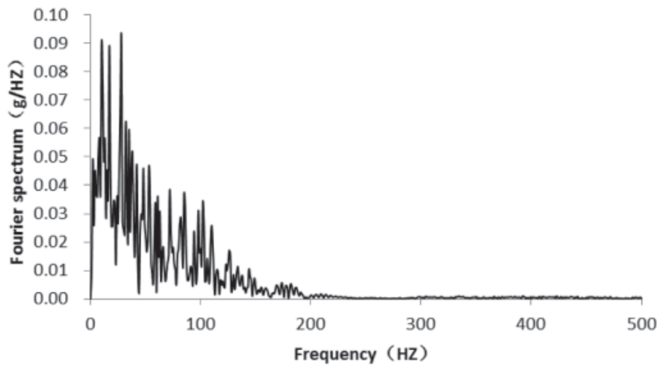
Fig.3 Comparison of field and numerical simulation data

cap, and its size is consistent with the characteristic value of the bearing capacity.

In the analysis of seismic action, synthetic seismic waves are used, as shown in Fig.4, the acceleration peak is 120cm/s^2, duration of 10s. In the bottom of the model input acceleration time history as a dynamic load, enter the dynamic load to the horizontal direction and vertical direction. The free field boundary condition is adopted in the dynamic calculation. The boundary is the same as the infinite field effect, so the surface wave is not distorted at the boundary.

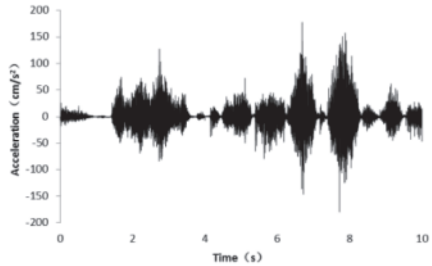


(a) Acceleration time curve

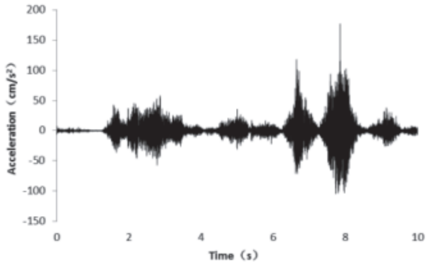


(b) Fourier spectrum

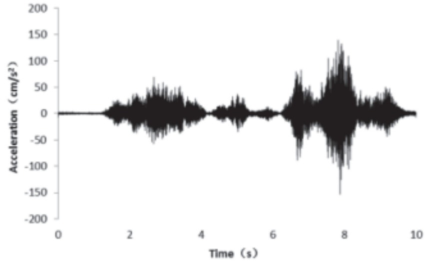
Fig.4 Artificial seismic wave



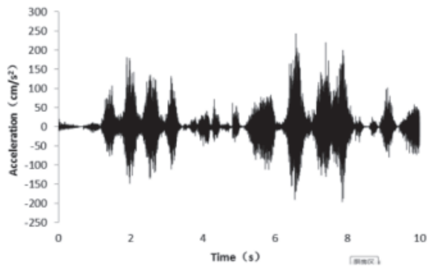
Single pile condition (12m)



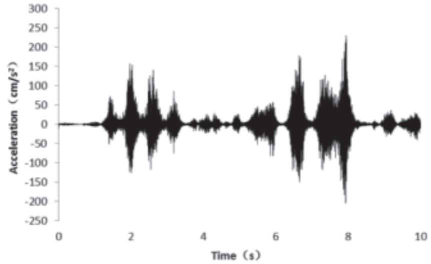
Two piles condition



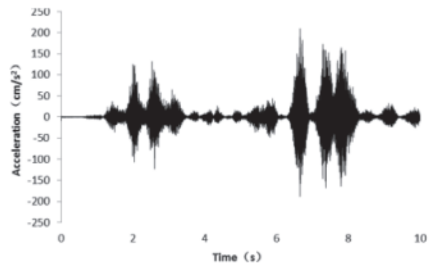
Four piles condition



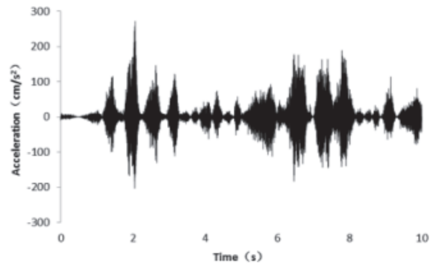
Single pile condition (18m)



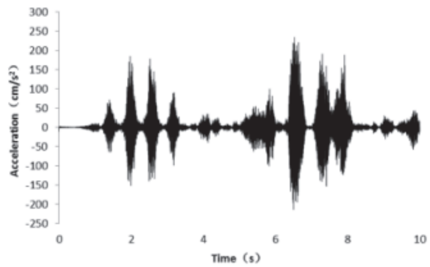
Two piles condition



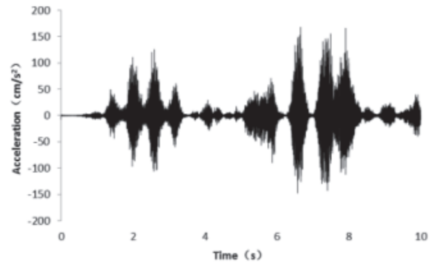
Four piles condition



Single pile condition (24m)



Two piles condition



Four piles condition

Fig.5 Acceleration time-history curve of each condition (Pile length: 12m\18m\24m)

The damping is carried out by Rayleigh damping [15-17]. Rayleigh damping was originally used in the analysis of structures and elastic continua to damp the natural oscillation modes of the system. The equations, therefore, are expressed in matrix form. A damping matrix, C, is used, with components proportional to the mass (M) and stiffness (K) matrices:

$$C = \alpha M + \beta K$$

where α = the mass-proportional damping constant; and β = the stiffness-proportional damping constant.

For a multiple degrees-of-freedom system, the critical damping ratio, ζ_i , at any angular frequency of the system, ω_i, can be found from.

$$\alpha + \beta \omega_i^2 = 2 \omega_i \zeta_i$$

or

$$\zeta_i = 0.5(\alpha/\omega_i + \beta\omega_i)$$

The critical damping ratio, ζ_i, is also known as the fraction of critical damping for mode i with angular frequency ω_i.

3. Calculation result analysis

3.1 Earthquake response

Under the action of earthquakes, the site generally has a magnification effect, so the monitoring point is set at the center of the cap. Fig.5 shows the resulting of acceleration time-history curve.

As can be seen from the Fig.5, the larger amplitude points are located at 2s and 8s respectively. Indicating that the two points of the earthquake force is greater. From the acceleration amplification point of view, the acceleration peak value of all condition is amplified, only the amplification factor is different, the comparison of the conditions is shown in Fig.6. The larger the pile length is, the greater is the magnification factor, The larger the number of piles is, the smaller is the magnification factor. From the perspective of seismic angle, using a shorter pile, the number of more piles, is more conducive to earthquake.

3.2 Force characteristics

Taking 12m long single pile as an example, the time course of settlement is shown in Fig.7, the time curve of force is shown in Fig.8, it shows the maximum value of force, regardless of positive and negative. It can be seen that the subsidence is increasing and retreated slightly at 6s, and it is different from force.

Axial force and moment history show that the value

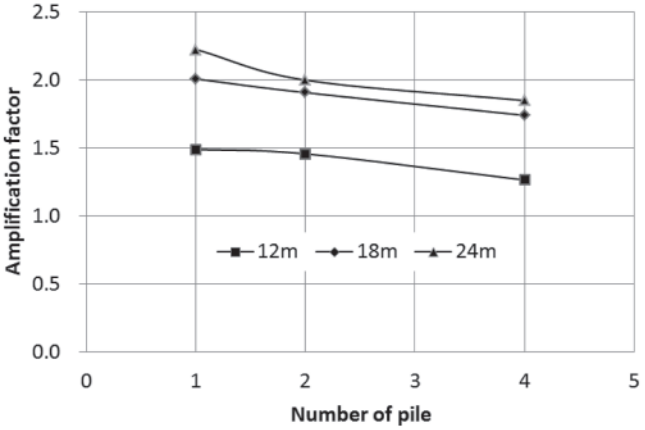


Fig.6 Amplification factor of acceleration peak in Various Conditions

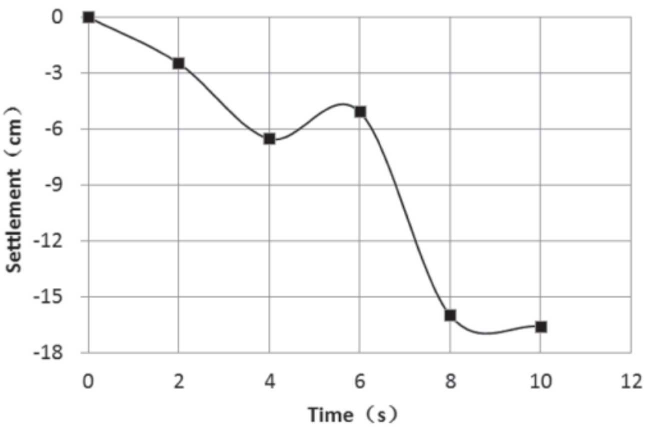


Fig.7 The time course of settlement

increases first and then decreases. Reaches the first peak at 2s and reaches the second peak at 8s.This is consistent with the characteristics of the acceleration curve in Fig.5, respectively, at 2s and 8s to reach a larger value.

Other cases are similar to the examples of the above analysis. The text will not repeat them. It can be found that the variation of displacement and force is not consistent. The maximum displacement occurs at the end of the seismic action, the maximum force occurs before the end of the earthquake. The force was retreated at the end of the earthquake, and the displacement did not. This is due to the geotechnical is elastic-plastic structure, while the pile is linear elastic structure, the pile can withstand greater force.

3.3 Force changes over time

The above analysis shows that the bending moment of the pile increases and decreases, giving the absolute value of the bending moment of the pile. In fact, the positive and negative values of the moment of the pile are also changing during the duration of the earthquake. The details are shown in Fig.9. It can be seen that the moment of the pile swings at zero. This is consistent with the nature of the seismic force.

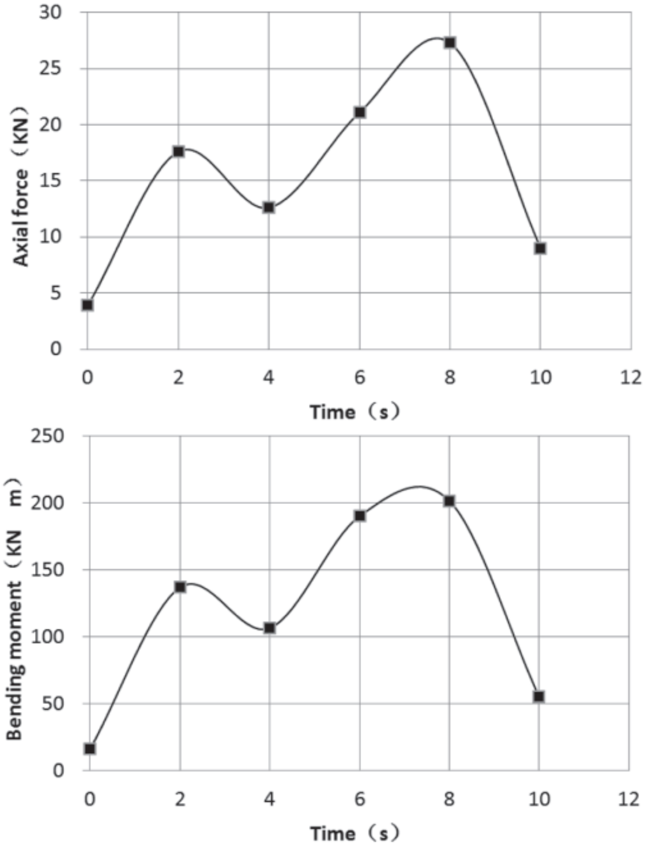


Fig.8 The time course of force

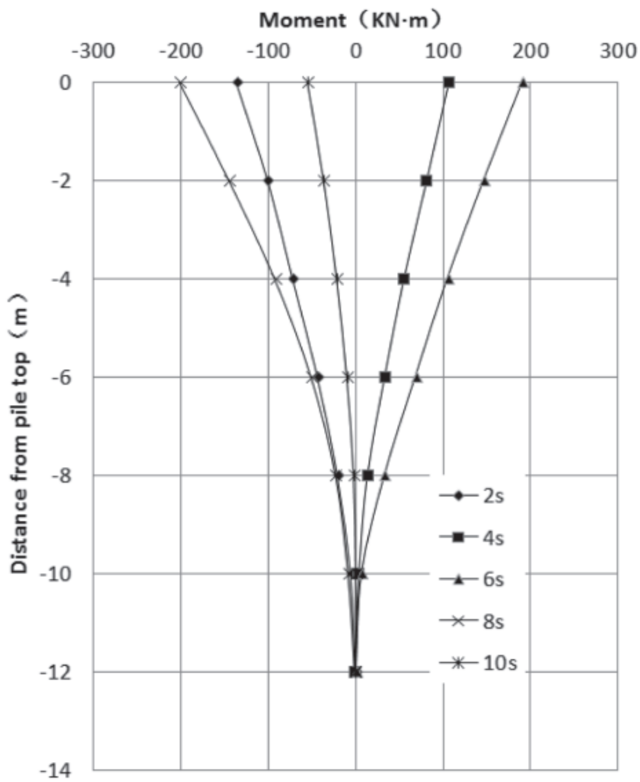


Fig.9 Moment changes with the duration of the earthquake

In addition, the maximum bending moment of the pile is at the top, which is caused by the cap.

4. Conclusions

This paper makes the cap and pile form a system, and study its dynamic characteristics, this is different from the previous analysis. Through the numerical simulation analysis, the following conclusions are obtained.

Pile foundation under the action of the earthquake, there is also the acceleration amplification effect. This is similar to the seismic response of the slope, that is, the height of the slope is different, the seismic amplification coefficient is also different. But in the pile foundation, the performance is the larger length of the pile, the more obvious the amplification effect, indicating that the length of the pile has an effect on the seismic response of the pile foundation.

The displacement is gradually increasing trend, it becomes permanent displacement at the end of the earthquake, and no retracement, indicating that the seismic displacement of the pile foundation, the amount of rebound after the earthquake is very small, most of which became permanent displacement. However, the force of the pile is increased first and then decrease, and the intensity of retracement is great.

The force and displacement are not completely corresponding relationship under the action of the earthquake, that is, the larger displacement does not correspond to the larger force. This is different from static analysis, under normal circumstances, the greater the force, the displacement is also larger. The calculation results also show that the force and deformation of pile-bearing platform are complicated under earthquake action.

Acknowledgments

This research has been financed by the following funding projects: The National Natural Science Foundation of China (No: 51678221); Key Project of Anhui Provincial Natural Science Research in Universities (No: KJ2017A405).

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