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Simplification of Vertical Live Loading for In-Service Bridge Pile Foundation and Application in Single Pile Model Test

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ABSTRACT. In order to calculate the static load model and the live load of the bridge pile foundation on the validation of the simplified, with a single pile in clay under vertical cyclic loads on the pile top settlement and axial force of pile model test, the effect of vertical cyclic loading condition, bearing capacity and settlement of single pile. The influence of cycle times on the settlement of pile head and the axial force of pile body is put forward, which provides the data support for the evaluation of the bearing capacity of the later bridge pile foundation.

1. INTRODUCTION

In the light of the scholars at home and abroad, some researches have been carried out on the settlement, bearing capacity and time effectiveness of single pile under vertical cyclic loading[1-7], some common test methods have been developed, and they have produced a series of fruitful theories, these studies showed that the bearing capacity of the pile under vertical cyclic loading was different from the static calculation. Most of the existing researches were carried out for the construction projects, marine engineering and plant loads, there were few researches on the effects of live load on the foundation of the highway, the action characteristics of the pile foundation, the live load, the frequency and the frequency of the pile, and the influence on the settlement and the axial force of the pile. Because of the concealment of the soil and the working characteristics between the piles and the soil, there were still many complex problems in the study between piles and soil, it was urgent to carry out deep and systematic research on the bearing capacity of highway bridge piles under different static loads and live loads.

In this paper, the calculation model of static load and live load on the simplified bridge pile foundation was the loading condition. The settlement of pile foundation and the axial force characteristic of pile body were studied. It provided data support for bridge bearing capacity test during operation.
2. DESIGN OF MODEL PILE
The model pile adopts the model design scheme of the fiber grating (string) adhered on the steel pipe surface, as shown in Figure 2 (a). The outer diameter of the steel pipe is 80mm, and the wall thickness is 4mm, 2 fiber gratings (string) were bonded on the surface of the epoxy resin[8-12], 7 grating points were distributed on each fiber grating (string) at the distance of 300mm. When the fiber grating (string) was bonded with epoxy resin, a layer of sand was adhered to the surface of the fiber grating to increase the surface roughness of the model pile.

(a) Surface pasted fiber grating  (b) A layer of sand on the surface of the model pile

Fig.1 Model test pile

According to the design requirements, positioning is carried out on the model pile, and the position of the fiber grating (string) was determined, and the wavelength range (nm) is 1525~1565. Model piles pasted with fiber gratings (strings) were shown in Figure 2 (a). Thereafter, a layer of sand was attached to the surface of the model pile, as shown in Figure 2 (b).

For clay, for static load test of pile (CST), to determine the bearing capacity of single pile in clay, the cyclic loading test of static load and partial cyclic loading amplitude, the completion of 3 groups (CCT10, CCT5, CCT1) single pile vertical cyclic loading test.

(1) PHYSICAL AND MECHANICAL INDEXES OF CLAY FOR TEST
According to the test requirements of CST static load test in the process of the filling clay samples, complete density, moisture content, water content limits shear, consolidation of soil test, to determine the physical and mechanical indexes of CST in the static load test of clay, see table 1.

| Type | w (%) | Pd g/cm³ | c (kPa) | Φ (°) | a (MPa⁻¹) | E (MPa) | w₁ | wr |
|------|-------|----------|---------|------|-----------|--------|----|----|
| Clay | 23.8  | 1.56     | 19.7    | 11.8 | 0.17      | 8.18   | 27.2| 18.9|

(2) SIMPLIFIED MODEL OF CYCLIC LOADING TIME AND LIVE LOAD
1) Live load Cyclic Loading Time
According to the common concrete beam bridge by different speeds of different span girder bridge, it calculated the load at the pile of time at which a car acts on a pile foundation (i.e. cycle) was between 1.20s-5.76s, taking into account the randomness of traffic, the period of live load will only be greater than this value. Therefore, the live load cycle was 5s for the model test.

Ignore the unevenness of the bridge surface, according to Xie Dingyi and other literatures[13-15], the comparative characteristics of dynamic loads induced by different causes in were known, when the load was on the soil for 2.0s-100s, it was considered the static problem. Therefore, loading and load simplification in the model test were considered the static problem.

2) Simplified Load Model
The calculation of live load, dead load, the relationship between time and cycle number, and according to the characteristics of vehicle load on the beam of the highway bridge in the operation period of the static load and live load load model was simplified as shown in Figure 2, and then to guide the single pile static load and cyclic loading model test.
Ps——dead load, $Ps=0.4Quk$, Unit (kN);
Pc——Cyclic load amplitude, $Pc=a(Ps+Pc)=\beta Quk$, $a$ is the ratio between the cyclic load and (dead load + live load), $a$ was taken respectively as 0.2 (20%), 0.4 (40%) and 0.5 (50%); $\beta$ is the ratio between cyclic load and ultimate bearing capacity of single pile, $\beta$ was taken respectively as 0.1 (10%), 0.2 (20%) and 0.25 (25%).
f——Cyclic load cycle, $f=0.2$Hz.

3. APPLICATION OF LOAD SIMPLIFIED IN MODEL TEST

According to the simplified model of the above-mentioned load, the model piles in the clay were subjected to model tests[13-14] of 100 thousand times and 10 thousand times respectively, and the loading conditions are shown in table 2.

| Loading mode | Ultimate bearing capacity (kN) | Cyclic load ratio $\beta$ | $P_s$ (kN) | $P_c$ (kN) | $f$ (Hz) |
|--------------|--------------------------------|--------------------------|------------|------------|----------|
| static load (kN) (Abbreviation CST) | 5.5 | 0 | — | — | — |
| Cycle $10^4$ (Abbreviation CCT10) | 6.5 | 0.1 | 2.2 | 0.55 | 0.2 |
| Cycle $10^4$ (Abbreviation CCT11) | 4.5 | 0.25 | 1.375 | 1.375 | 0.2 |

The analysis of the test results is as follows:

(1) ANALYSIS OF LOAD SETTLEMENT CURVE

Figure 3 was the relationship between the load at the top of pile and the settlement at the top of the pile. According to the loading and ending conditions in the code, the static load ultimate bearing capacity and the ultimate bearing capacity of the pile after the cyclic loading were determined, and the
cumulative settlement under various loads was recorded. As shown in table 3.

Table 3 ULTIMATE BEARING CAPACITY AND TOTAL SETTLEMENT AFTER STATIC LOADING AND CYCLIC LOADING FOR EACH PILE

| Loading mode | Ultimate bearing capacity $Q_u$ (kN) | Settlement of pile head $s_u$ (mm) |
|--------------|--------------------------------------|----------------------------------|
| CST          | 5.5                                  | 24.84                            |
| CCT10        | 6.5                                  | 37.35                            |
| CCT1         | 4.5                                  | 33.06                            |

Table 3 shows that under cyclic loading, the vertical compressive ultimate bearing capacity of the 100 thousand and 10 thousand test piles is 18.2% higher and 18.2% lower than the static load respectively, the ultimate load carrying capacity was increased by 50.3% and 33.1% respectively. From table 3, the larger the number of cycles, the greater the settlement of the pile head, mainly because of the great settlement of the pile during the cyclic loading process. This was related to the force characteristics of the clay itself, and the clay was prone to shear failure after repeated cyclic loading.

![Fig.4 The relation of settlement of single pile top and the numbers of load cycles](image)

Figure 7 showed that during the cyclic loading of CCT10 and CCT1, the settlement of the pile increases with the increase of the number of cycles. When the number of cycles was less than 5000 times and within 3000 times, the settlement rate of the pile body was very fast, and then the settlement rate decreases obviously. When the number of cycles reached 100 thousand times and after 10 thousand times, the cumulative settlement of pile top was 32.58 and 30.33mm respectively.

As shown in figures 6 and 7, the Q-s curve of the pile in the homogeneous clay under static loading showed a steep downward trend, indicating that the main bearing capacity was lateral frictional resistance and conforms to the bearing characteristics of the clay. In the course of cyclic loading, with the increase of soil residual deformation and the soil compactness at the end of pile, the settlement of pile body gradually decreased and tended to be stable. At the same time, because of the existence of soil shear strain, the pile side friction resistance reached the limit value at lower pile settlement, and this phenomenon was more obvious with the increase of cyclic load than the beta.
(2) ANALYSIS OF AXIAL FORCE OF PILE SHAFT

Figure 5 was a figure under static load of pile shaft trying to B and C respectively for 100 thousand cycles and 10 thousand times after loading to pile failure process of pile shaft. Figure 5 showed that the axial force of the pile decreases along the depth of the pile, under the static load at various levels, the axial force of the pile decreased slowly at 25% of the depth of the pile. When the depth of pile was between 60% and 100%, the axial force of pile decreased gradually. The results were shown that the axial force of pile was affected by pile depth in 0 ~ 25% of the pile depth, pile side friction is smaller, and the load of pile lateral soil is passed down with the increase of pile depth, pile side friction gradually to play, to the pile end position, pile end resistance increases gradually. Therefore, when the axial force of pile reaches the minimum. With the increase of the number of cycles, the reduction of the axial force of the pile under the same load decreases, and it showed that the cyclic action weakens the lateral friction of the pile body, and the more the number of cycles, the more serious the weakening.

4. CONCLUSION

Through the simplification of the live load on the top of the pile during the small and medium span operation of the highway bridge, and combined with the application in the test of the clay pile foundation, the bearing capacity of the single pile is analyzed, and the following conclusions are drawn:

1) The highway operation during the live load in small and medium span bridges was determined by calculation cycle of live load live load during small and medium span bridge driving speed, so as to simplify the calculation model of static load and live load, the ratio of static load and cyclic load for ultimate bearing capacity of single pile single pile model test guide the.

2) The influence of vertical cyclic loading on the settlement of a single pile and the axial force of the pile was obtained. The analysis results was shown that the cyclic loading leads to the decrease of the side friction and the increase of the pile end resistance.

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