Field test on Ultimate bearing capacity of Composite Pile made up of Jet-mixing Cement and PHC Pile with Core Concrete

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Abstract. Composite pile made up of jet-mixing cement and PHC pile with core concrete (CPCP) is a new kind of pile. It is formed by inserting PHC core promptly into the cement soil mixing pile. According to the single pile static load test and PHC pile cement soil bond strength test, differences between CPCP and pipe pile in bearing capacity and coordination deformation mechanism are studied. The results show that presence of peripheral cement soil has greatly improved the bearing capacity of CPCP. Three different loading modes have no obvious effect on CPCP bearing capacity, but the more significant effects on settlement. When the cement soil and soil interface destroyed, pile and cement soil interface friction resistance is much smaller than the bond strength, indicating that the bond strength can ensure coordination between the pile and cement soil. On this basis, the design formula for calculating the bearing capacity of CPCP pile is proposed. Comparing calculated values with field measured values, it has been found that the results are less error and the formula has a certain reliability in the calculation of vertical ultimate bearing capacity of CPCP pile, providing a certain reference for the design and calculation of this type of piles.

1. Introduction
In coastal and riverside areas, soft stratum with high moisture content, low strength, high compression and low vertical permeability is common, and there is a lot of underground rivers existing together[1]. This stratum is difficult to meet the requirements of the bearing capacity of the building so that foundation treatment or pile foundation is usually adopted to improve the engineering characteristics of this kind of soil. The CPCP pile is a new kind of composite piles formed by inserting a PHC pile into a cement mixing pile before its initial setting and it has been patented in China[2]. This type of pile takes advantage of the high strength PHC pile to bear the vertical load and uses the larger contact area of the cement soil mixing pile to provide the side friction resistance, combining advantages of both PHC pile and cement mixing pile. Its bearing capacity is much higher than that of the single cement soil mixing pile or PHC pile with the same pile diameter[3-6]. When this pile applied to the soft soil foundation, the design pile length can be greatly reduced and the suppression of settlement is also prominent.

At present, the research of the CPCP pile is still in the initial stage and the calculation of ultimate bearing capacity of this pile in engineering design is mostly based on the calculation method of the rigid pile. The results are conservative and bearing capacity is not fully utilized. Further research needs to be conducted on ultimate bearing capacity of the CPCP pile. This paper analyzes the differences between CPCP pile and pipe pile in bearing capacity and settlement based on the field tests. Moreover, it discusses the failure modes of the CPCP pile. PHC pile and cement soil bond strength is
also studied according to the field test. On this basis, a design formula for calculating ultimate bearing capacity of a single CPCP pile is concluded, which provides a reliable basis for its design and construction, and has important theoretical significance and engineering application value for the widely application and further research of this type of pile.

2. Field Test

2.1. Site Description
The test site is located at the construction plant of ZHONGTIAN RUNYUAN Project in Jiangsu Province of China. Its geomorphic type belongs to the coastal plain in alluvial plain of the lower reaches of Yangtze River. The site is mainly covered by the quaternary unconsolidated sediments with silty soil, silty sand and silty clay. Most of the site is the vacant land with the flat terrain and relatively smaller height difference (smaller than 0.6m). The elevation of orifice generally is 2.60-3.20m. The mechanical property index of foundation soil is shown in table 1.

Table 1. Mechanical parameters of soil layers.

| Soil layer                        | Thickness (m) | C (kPa) | \( \varphi \) (°) | \( E_s \) (MPa) | \( q_c \) (MPa) | \( f_s \) (kPa) | \( f_{ak} \) (kPa) |
|----------------------------------|---------------|---------|-------------------|-----------------|-----------------|------------------|-------------------|
| 1.Mixed fill                     | 1.0           | 16.6    | 10.4              | 3.04            | 1.31            | 32               | 50                |
| 2.Silty clay with silty soil     | 1.0           | 19.0    | 12.4              | 3.49            | 0.90            | 20               | 80                |
| 3-1.Muddy silty clay with silty soil | 1.2       | 13.8    | 6.3               | 5.25            | 0.50            | 18               | 60                |
| 3-2.Silty soil with silty clay   | 1.1           | 13.4    | 20.1              | 5.39            | 1.64            | 22               | 100               |
| 4.Silty sand with silty soil     | 3.2           | 5.1     | 27.6              | 9.72            | 3.93            | 32               | 135               |
| 5-1.Silty sand                   | 2.3           | 3.9     | 30.0              | 13.64           | 6.70            | 46               | 160               |
| 5-2.Silty sand with silty soil   | 1.0           | 5.0     | 27.5              | 9.96            | 3.28            | 32               | 130               |
| 5-3.Silty sand                   | 1.7           | 3.8     | 30.5              | 13.63           | 6.95            | 54               | 170               |
| 6-1.Silty sand with silty soil   | 2.5           | 4.7     | 27.4              | 9.86            | 3.60            | 34               | 135               |
| 6-2.Silty sand with silty soil   | 2.2           | 4.5     | 28.9              | 12.40           | 5.25            | 42               | 150               |
| 6-3.Silty sand                   | 2.9           | 3.1     | 32.4              | 15.76           | 8.78            | 65               | 180               |
| 6-a.Silty sand with silty soil   | 1.9           | 5.0     | 27.4              | 10.11           | 3.12            | 32               | 125               |
| 7.Silty sand                     | 2.9           | 1.9     | 35.0              | 18.95           | 14.04           | 90               | 230               |
| 8-1.Silty clay with silty soil   | 2.5           | 30.1    | 15.7              | 6.25            | 1.25            | 32               | 120               |
| 8-2.Silty clay                   | 2.9           | 42.4    | 14.0              | 6.19            | 1.84            | 56               | 160               |
| 9.Silty clay and silty sand interaction | 2.3          | 4.0     | 29.6              | 11.59           | 3.81            | 36               | 135               |
| 10.Silty sand with silty soil    | 2.9           | 3.1     | 31.9              | 14.97           | 8.08            | 65               | 185               |
| 11-1.Silty sand                  | 5.1           | 2.4     | 32.8              | 16.16           | 10.99           | 85               | 220               |
| 11-2.Silty sand with silty soil  | 1.5           | 4.7     | 28.9              | 12.82           | 5.89            | —                | 160               |
| 11-3.Silty sand                  | 6.0           | 3.1     | 32.4              | 15.56           | 9.51            | —                | 200               |
| 12.Fine silty sand               | 16.0          | 1.4     | 37.3              | 20.53           | 15.67           | —                | 250               |

The original design regards the 11-1 silty sand layer as the supporting layer and applies the pipe pile \((d=500mm)\) foundation. The required pile length is about 38m which needs a relatively high construction cost. The CPCP piles apply the middle compressed soil layer 6-3 silty sand layer as the supporting layer. The pile diameter is \(d=400mm\) or 500mm. The effective pile length is \(L=11.0m-13.0m\). As to the cement mixing pile, the diameter is \(D=800mm-900mm\) and the effective pile length is \(L=13.5-15.0m\). Before cement soil mixing pile is kept in the initial set, concentric PHC piles with the specifications of PHC400AB-(95) and PHC500AB-(125) are inserted into it. The curing agent of cement soil mixing pile selects level 42.5 of ordinary Portland cement with the incorporation ratio of 18%. The part below the pipe pile end is remixed by adding 5% again.
2.2. Static Load Test of Single Pile
The static load test applies a piling-up weight method. Before the test, static loader and displacement meter are firstly calibrated. In order to make the top of compound foundation pile stress evenly, a rigid plate with 15cm thick is placed on the top of pile. A jack is placed on the steel plate with the established counter-force beam, as shown in figure 1.

The test is implemented according to relevant requirements in Specifications on Construction Pile Measurement Technique (JCJ106-2014). The slow-speed maintenance load method is applied by the test, adding loads equivalently step by step. The grading load generally is the biggest loading capacity or the 1/10 of the predicted limit load. The first stage is 2 times of grading load. After loading at every stage, read it at the interval of 5min, 15min, 30min, 45min and 60min, respectively. Afterwards, read it at every 30min. The next-stage force is loaded when it reaches the stability until it is destroyed. Unload generally is half of the loading series, namely every unload amount is 2 times of loading. After unloading, read it every 15 minutes. After reading two times, read it again once every half an hour and then proceed to the next level of unloading. After the unloading is completed, it will be stable for 3 hours and record the total rebound amount.

2.3. Bonding Strength Test of Pile and Cement Soil
The CPCP pile is composed of PHC pile (inner core) and cement soil mixing pile (external core). The coordination between them is the key to develop its performance. It is necessary to study and analyze the bonding strength and discuss coordinative working mechanism between them.

In the test, 1.5m of soil should be excavated to expose the pile head. 20cm thick cement soil below the top of the pile should be dug out and the excavation face is leveling with cement mortar. 1m of cement soil below the open face is left. The cement soil below 1m to the excavation face should also be dug out. The counter-force device applies 1000kN static test reaction frame. The reinforced concrete block is used as the balancing weight. By loading through the jack of 1000kN, the load is controlled by the load sensor connected by the jack. The wall thickness between the jack and cement soil is 10mm of rigid annular tube. The section is the same to the external cement soil section of the pile. The plate thickness is 20mm. Load is transferred to the rigid annular tube, as shown in figure 2.

Due to lack of relevant standards on the bonding strength test between concrete and cement soil, the test combines with relevant stipulations of static load test for piles. According to the reference[8] that bonding strength coefficient of cement soil and core piles is 0.174-0.213, it is predicted that ultimate load is 550kN. The static load test for the reference pile applies the grading loading method. The loading difference at every stage is 25kN. The first load is 2 times of stage differences. After loading at every stage, read it at every 5min. The stable standard of loads at every stage means that
sinking rate of external cement soil pile is smaller than 0.1mm/10min. Meanwhile, datas are observed and recorded. The terminal conditions of loading: sedimentation of cement soil can’t be converged.

3. Ultimate bearing capacity

3.1. Ultimate bearing capacity of single pile

In the test, there are a total of 20 piles composed of 5 pipe piles and 15 composite piles. The pipe piles adopted the same bearing layer as the original design. The supporting layer same to the improved design scheme is applied to the composite piles. According to pile parameters, the composite piles can be divided into five categories and the pipe piles can be divided into two categories just as shown in table 2. Three different loading modes are adopted for each type of test composite pile. Loading mode I: chisel the pile head 80mm thick cement soil, the load is only pressed on the pipe pile; Loading mode II: the top of cement soil pile flush with pipe pile, pouring 100mm thick C25 concrete and filling sand to make it level, plate loading (The area of the load plate is the same as the intercepting area of the composite pile); Loading mode III: cut to 10~20mm thick cement soil pile head, laying 20~30mm thick sand to preload, plate loading (The area of the load plate is the same as the intercepting area of the composite pile). The ultimate bearing capacity of a single test pile and corresponding settlement are shown in table 3.

Table 2. The parameters of test piles

| Test pile | Pipe pile | Cement-soil mixing pile | Load mode | Test pile | Pipe pile parameter | Cement-soil mixing pile | Load mode |
|-----------|-----------|-------------------------|-----------|-----------|--------------------|-------------------------|-----------|
|           | $d$ (mm)  | $l$ (m)                 | $D$ (mm)  | $L$ (m)  | $d$ (mm)           | $l$ (m)                 | $D$ (mm)  | $L$ (m)  |
| SZ1-1     | 400       | 13.0                    | 800       | 16.5     | I                  | 500                     | 13.0      | 800       | 18.0     | III      |
| SZ1-2     | 400       | 13.0                    | 800       | 16.5     | I                  | 500                     | 14.0      | 900       | 18.0     | I        |
| SZ1-3     | 400       | 13.0                    | 800       | 16.5     | II                 | 500                     | 14.0      | 900       | 18.0     | II       |
| SZ1-4     | 400       | 13.0                    | 800       | 16.5     | III                | 500                     | 15.0      | 900       | 18.0     | I        |
| SZ2-1     | 400       | 14.0                    | 800       | 17.5     | I                  | 500                     | 15.0      | 900       | 18.0     | III      |
| SZ2-2     | 400       | 14.0                    | 800       | 17.5     | I                  | 500                     | 28.0      | —         | —        | —        |
| SZ2-3     | 400       | 14.0                    | 800       | 17.5     | II                 | 500                     | 28.0      | —         | —        | —        |
| SZ2-4     | 400       | 14.0                    | 800       | 17.5     | II                 | 500                     | 28.0      | —         | —        | —        |
| SZ2-5     | 400       | 14.0                    | 800       | 17.5     | III                | 500                     | 37.0      | —         | —        | —        |
| SZ3-1     | 500       | 13.0                    | 800       | 18.0     | I                  | 500                     | 37.0      | —         | —        | —        |

Table 3. Ultimate bearing capacity and settlement of test piles

| Test pile | Settlement (mm) | Ultimate Bearing capacity | Test pile | Settlement (mm) | Ultimate Bearing capacity |
|-----------|-----------------|---------------------------|-----------|-----------------|---------------------------|
|           | Max             | Spring Back | Amount (kN) | Settlement (mm) | Max             | Spring Back | Amount (kN) | Settlement (mm) |
| SZ1-1     | 21.92           | 12.59       | 4940        | 21.92           | SZ3-2           | 56.97       | —           | 4950           | 40.00        |
| SZ1-2     | 81.55           | —           | 4050        | 25.90           | SZ4-1           | 33.92       | 13.40       | 5000           | 33.92        |
| SZ1-3     | 35.12           | 11.33       | 4950        | 35.12           | SZ2-2           | 33.26       | 15.32       | 5000           | 33.26        |
| SZ1-4     | 49.68           | 16.37       | 4470        | 40.00           | SZ5-1           | 41.68       | 7.41        | 4780           | 40.00        |
| SZ2-1     | 24.55           | 11.93       | 4940        | 24.55           | SZ5-2           | 37.25       | 11.32       | 5460           | 37.25        |
| SZ2-2     | 28.18           | 11.44       | 4950        | 28.18           | GZ1-1           | 43.55       | —           | 2880           | 13.16        |
From the data in the table, it can be seen that the existence of the peripheral cement soil pile makes the bearing capacity of the composite pile greatly improved. The ultimate bearing capacity of 3 pipe piles (length=28m, using 8-2 silty clay layer as the bearing layer) are 2880kN, 3420kN, 2880kN which at a low level. The other 2 pipe piles (length=37m, using 11-1 silty sand layer as the bearing layer) have the ultimate bearing capacity of 5720kN and 5720kN which the bearing capacity has been improved compared with the former. In 15 composite piles, the minimum ultimate bearing capacity is 4050kN and most of them are close to or more than 5000kN. The bearing capacity of composite pile is greatly increased than that of pipe pile. The reasons are based on the following aspects: (1) The pile and cement soil interface has greater cohesive force, so that the load of the pipe pile can be effectively transferred to the surrounding cement soil pile. The pipe pile and cement soil pile can form a whole system to assume the upper load. (2) The diameter of the cement soil pile is 800mm and 900mm, which can provide greater side friction than the pipe pile with diameter d=500mm. (3) The penetration of pipe pile will squeeze the cement soil pile and the soil around the pile, which will make the contact between the soil particles more closely, and the ultimate lateral friction of the soil will be improved.

3.2. Pile foundation settlement and failure mode

From table 3, we can see that the settlement of the 3 pipe piles (length=28.0m) are 13.16mm, 14.83mm and 15.33mm when the ultimate bearing capacity is reached. Because the ultimate bearing capacity is smaller, the corresponding settlement is smaller. The settlement of the 2 pipe piles (length=37.0m) are 27.12mm and 30.23mm. For the 15 composite piles, the minimum settlement value is 21.92mm and the maximum value is 40.00mm, which the average value is 33.99mm. The settlement is more than the single pipe pile with length of 37.0m. The reason may be based on the different supporting layers and different section modulus of pile.

At the same time, the influence of different loading modes on the ultimate bearing capacity of the test pile is not obvious, but the settlement has great difference just as shown in figure 3. In the first loading mode, the settlement of the test pile is the smallest. The second is the second and the third is the largest. The reason may be based on that the larger elastic modulus of pipe pile section makes the smaller settlement of the mode I. The deformation coordination of concrete is stronger than that of sand so that the concrete bears more loads. The deformation of cement soil with pipe pile section is small under mode II. Although the loading mode I has the best effect on the settlement control, it is also most likely to cause the pile head to be crushed because of the stress concentration. From the engineering application point of view, in order to meet the settlement requirements, it is necessary to set the cushion to make the pipe pile and cement soil share the load together. It will avoid the pile side friction has not been brought into play, and the pile head is crushed first, resulting in material waste.
4. Bond strength of pile and cement soil

4.1. Test results

The test conducts two groups of bonding strength tests. The pipe pile specification is PHC500AB-(125). The effective pile length l=11.0. The diameter of cement soil pile is D=800mm. The effective pile length L=14.0m. The cement content is 18%. After the test forms a pile for 90 days. The core is taken from the external cement soil pile. The mean unconfined compressive strength of cement soil is 1.5MPa.

Take the maximal load before the damage and regard it as $Q_0$. The lateral surface area of pipe pile is $A_L$. $\tau_u=Q_0/A_L$ stands for the bonding strength or bonding stress. The ratio of bonding strength to the...
unconfined compressive strength of cement soil is defined as the bond strength coefficient and is expressed as $\alpha$, namely $\alpha = \frac{\tau}{f_{cu}}$. Testing results of bonding strength in two specimens are shown in table 4. The mean bonding strength coefficient is 0.197, namely the bonding strength of pipe pile and cement soil interface is the 0.197 times of unconfined compressive strength of cement soil. However, the shearing strength of cement soil generally is $(0.2-0.3)f_{cu}$.[9] Therefore, when the pipe pile and cement soil interface is damaged, cement soil doesn’t reach the ultimate shearing strength. This is the reason for failing to take place shearing failure in cement soil.

| No. | $A_L$ (m$^2$) | $f_{cu}$ (MPa) | $Q_u$ (kN) | $\tau_u$ (MPa) | Bond strength coefficient |
|-----|--------------|---------------|-----------|----------------|--------------------------|
| 1   | 1.57         | 1.5           | 450       | 0.287          | 0.191                    |
| 2   | 1.57         | 1.5           | 475       | 0.303          | 0.202                    |

Under the actual working conditions, pipe pile and cement soil assume upper load together. But rigidity of pipe pile is much greater than cement soil, cement soil just shares a few loads. Moreover, with the increase of pipe pile depth in soil, load is concentrated on the pipe pile. The load sharing ratio of cement soil is gradually reduced.

4.2. Formula revised for calculating the ultimate bearing capacity of single pile

(1) The calculation formula adopted at present

According to the Technical specification for strength composite piles(JGJ/T327—2014), the characteristic value of ultimate bearing capacity of single pile during preliminary design takes the smaller one in following two formula Eq.1 and Eq.2. The Eq.1 represents side failure surface of the composite pile is located between the interface of inner core and outer core. The Eq.2 represents side failure surface is located on the pipe and soil interface.

$$R_u = u(q_{ss}A_{cp} + q_{pa}A_p)$$

$$R_u = u\sum q_{ss}l_i + \alpha q_{pa}A_p$$

Where $R_u$ is vertical compressive bearing capacity characteristic value of strength composite piles for single pile(kN); $u$ is inner core pile perimeter(m) and $u$ is composite pile perimeter; $l$ is composite section length of composite piles(m) and $l_i$ is thickness of I soil layer(m); $A_{cp}$ is inner core pile section area($m^2$) and $A_p$ is entire section area of composite pile($m^2$); $q_{ss}$ is inner core side resistance characteristic value(kPa), which is suitable to take value by regional experience. When no regional experience provided, it is advisable to take 0.04~0.08 times of unconfined compression strength; $q_{pa}$ is characteristic value of end resistance of strength composite pile which should be according to regional experience (kPa); the bearing capacity characteristic value of pile-tip foundation soil without modification is also revised; $\alpha$ is pile terminal nature bearing capacity reduction coefficient of strength composite pile; $\xi_{ad}$ and $\xi_p$ are lateral resistance adjustment coefficient and end resistance adjustment coefficient of outer core I soil layer of strength composite pile composite section respectively, which should be taken by regional experience, those of non-composite section equal to 1.0.

According to the field test results, cement soil and soil interface was usually destroyed before pipe pile and cement soil interface, so Eq.2 is more commonly adopted to calculate the bearing capacity which calculating ultimate bearing capacity is on the basis of ultimate side friction and end resistance of soil layers. In Eq.1, value of inner core side resistance in composite section is based on regional experience, but the bond strength between core pile and cement soil is not considered to give informed calculation method when area experience was not provided.

(2) Formula revised
Based on the bond strength test, inner core side resistance can be considered in the formula. Under the actual working conditions, pipe pile and cemented soil assume upper load together, but rigidity of pipe pile is much greater than cemented soil, thus cemented soil just share a few loads. Moreover, with the increase of pipe pile depth in soil, load is concentrated on the pipe pile. The load sharing ratio of cemented soil is gradually reduced. Neglecting the sharing load of cemented soil pile, assuming that load of cemented soil pile is 0 and pipe pile assumes all loads, it can be observed from the shear displacement method\[11\]:

$$q_s = \pi D/\pi d$$

Where $q_{s1}$ is frictional resistance (kPa) on the pipe pile and cemented soil interface; $q_{s2}$ is frictional resistance(kPa) on the cemented soil and soil interface; $d$ and $D$ are the diameter(mm) of pipe pile and cement mixing pile respectively. According to the $q_{s2}$ provided, we can approximately calculate $q_{s1}$.

The failure mode of CPCP pile composed of PHC pile and cement soil pile is more complex than simple cement soil mixing pile or reinforced concrete jacked pile, so the following basic assumptions are made during carrying on the design of single pile ultimate bearing capacity: ①Pile top of core pile bears all vertical load; ②Because of the inclusion of soil and cement soil, the influence of buckling stability is not considered, longitudinal stability coefficient $\phi=1.0$.

Based on the above assumptions, formulas for calculating the characteristic values of ultimate bearing capacity are presented here, taking the smaller one in Eq.5 and Eq.6.

$$R_a = u \sum q_{pia}l_i + \eta f_{cu}A_p$$

$$R_a = u \sum \eta_i q_{sia}l_i + u \sum q_{sia}l_i + \eta p q_{psia}A_p$$

Where $u$ is perimeter of composite pile(m) and $u'$ is perimeter of inner PHC pile(m); $l_i$ is I soil layer thickness of composite section and $l_j$ is J soil layer thickness of non-composite section(m); $A_p$ and $A_p'$ are cross-sectional areas of PHC pile and composite pile respectively(m$^2$); $f_{cu}$ is unconfined compressive strength characteristic value of cement soil(kPa); $q_{sia}$ is ultimate lateral resistance characteristic value of I soil layer; $\eta_i$ is increasing coefficient of soil ultimate lateral resistance having PHC pill; $\eta_p$ is bearing capacity reduction coefficient of pile end natural foundation ranging between 0.4–0.6, low value is adopted when bearing capacity is high; $\zeta$ is strength reduction factor of pile body; $\zeta$ is the ratio of ultimate friction resistance value of pipe pile and cement soil interface to compressive strength of cement soil cube at corresponding position, taking 0.19–0.21; $q_{psia}$ is ultimate lateral friction resistance characteristic value of pipe pile and cement soil interface(kPa) which can be estimated from Eq.4.

(3) Case study

Comparing field measured value to the calculated results using normal formula and the revised formula in table 5, it shows that the ultimate bearing capacity of single pile calculated by the standard is conservative, having a large gap reaching 20%–40% at the side of the measured data. According to the revised formula, the error is smaller than the measured value, and the maximum error is only 18%, which it is illustrated that the formula is reliable to calculate vertical ultimate bearing capacity of single pile. Because the soil layer of the test site is mainly silty soil and silty sand with certain limitations, some empirical coefficients in the formula is applicable to the local soil conditions merely, requiring further improvement.

Table 5. Contrast of calculated and measured ultimate bearing capacity

| Pile No | Normal formula (kN) | Paper formula (kN) | Measured data (kN) | Difference percentage/% |
|---------|---------------------|--------------------|--------------------|--------------------------|
| SZ1-1   | 1300                | 2014               | 2470               | 47.37                    | 18.46                   |
5. Conclusions
According to the field test of single pile ultimate bearing capacity and bond strength of pipe pile and cement soil, the difference between CPCP and pipe pile in capacity and force mechanism has been studied. Presence of peripheral cement soil has greatly improved the bearing capacity of CPCP. Three different loading modes have no obvious effect on CPCP bearing capacity, but the more significant effects on settlement. Two failure modes appear in the test. The bonding strength of pile and cement soil interface is 0.191-0.202 times of unconfined compressive strength of cement soil, less than the shearing strength of cement soil. When the cement soil and soil interface destroyed, pile and cement soil interface friction resistance is much smaller than the bond strength, indicating that the bond strength can ensure coordination between the pile and cement soil. On this base of the research of bond strength, the design formula for calculating the bearing capacity of CPCP piles is revised. Comparing the bearing capacity value calculated by the formula proposed with measured value, its error is small, mostly within less than 10% and the maximum error is only 18%, so this formula has reliability in calculating vertical ultimate bearing capacity of single pile.

Acknowledgments
This work was financially supported by the iur prospective research program of Jiangsu Province(BY2014005-08).

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