Study on Performance of Cement Mixing Pile in Marine and Continental Deposition Soft Soil Area

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Abstract. Soft soil was widely distributed in the coastal area, and the key characters were high water content and low capacity. Cement Mixing Pile (CMP) is an effective method to treat soft soil foundation. While CMP construction quality was difficult to control and it was of different reinforce effect for different geology origin. In this paper, five geology origins have been divided for the littoral area, lagoon area, alluvial area (Yangtse River), alluvial area (Ancient Yellow River) and lacustrine area. CMP, used in 26 expressways which were constructed during the period of 2008 - 2016, has been divided two-part (Upper & Lower part) to test the construction quality of CMP through Standard Penetration Test (SPT), Unconfined Compaction Strength (UCS) and Cement Mixing Pile Quality Designation (CMPQD). Results show that geology origins have great influence on the construction quality of CMP at the same construction maintenance condition. Depth has a significant effect on UCS of the lower part of CMP while the little effect on UCS of the upper part. Construction quality of long CMP was more difficult to control than short CMP. The high quality of the upper part may cause the unqualified lower part evaluated as qualified or good, which may lead to some engineering accidents.

1. Introduction
Jiangsu province located in the eastern coast of China, Yangtse River, and Ancient Yellow River has been passed through here flowing into East China Sea [1-3]. Two of the four largest freshwater lake of China located in the middle and south of this province [4-6]. Geology origin can be divided into five area due to the rivers, lakes, and sea, therefore, geology condition in this area is complicated. Cement mixing pile was developed in the United States, and China began carrying out experience and developing construction machinery in 1977 [7]. Cement mixing pile plays an important role in the soft foundation treatment of highway in China [8]. Yin [9] introduced large-scale marine reclamation on soft Hong Kong marine deposits. Lorenzo [10] established consolidation model of lime pile and cement mixed pile composite foundation and found that the excess pore pressure of the pile cannot be assumed to be zero at any given time during the consolidation process of a Soil – Cement pile unit cell. Chew [11] reported the relationship between the microstructure and engineering properties of cement-treated marine clay. Yin [12] studied the mechanism of the consolidation deformation and failure of a composite foundation with a deep cement mixing column. Yin [12] used a physical model to test of a steel cylindrical mould composite foundation in order to understand the consolidation behaviour of the composite foundation treated by deeply mixed cement method. Chai [13] put forward a method to predict the consolidation settlement-time curve of floating soil-cement column on improved soft clayey. Pongsivasathit [14] illustrated the interaction behaviour between a floating column and the...
surrounding soil. As an effective soft soil foundation treatment method, the expressway constructed or under construction in Jiangsu province be using cement mixing pile has more than 200 million meters until 2015, and 25% - 54% of soft soil foundation treatment have been chosen cement mixing pile, it has produced great economic and social benefits in the construction. Cement mixing pile is a hidden project in expressway soft foundation treatment, if the quality problems occur, it will seriously affect the efficiency of soft foundation treatment and stability of subgrade. Therefore, it is necessary to study the impact of new construction technology on testing standards.

In this paper, cement mixing piles applied in 26 expressways in Jiangsu province from 2008 to 2016 were tested including traditional mixing pile and bidirectional mixing pile. The test includes the quality index of the pile, strength, standard penetration, upper, lower score, and comprehensive score. Then according to the regional distribution of soft soil, the testing results of mixing piles are divided, and the detection results and detection parameters of each partition pile have been analyzed.

2. Test Methods

2.1. Standard Penetration Test (SPT)
The free-falling weight method of automatic decoupling was adopted in SPT, reducing the frictional resistance between the guide rod and the hammer. SPT detail operation step and calculate equations of this test followed the test standard [15].

2.2. Unconfined compressive strength (UCS)
Unconfined compressive strength uses unconfined compression test apparatus, the loading rate of 0.2 - 0.5 MPa per second until the specimen was a failure (i.e. soft soil sample can be appropriately reduced the loading rate). The detail operation step and calculate equations of this test followed the test standard [16].

2.3. Cement mixing pile quality designation (CMPQD)
Recording each drill core length and using the following equation to evaluated CMPQD [15]:

$$CMPQD = \frac{\sum l_i}{L} \times 100 \quad (1)$$

Whereas, $L$ is roundtrip meter age; $l_i$ is length of drill core.

3. Analysis methods
In order to analyse the quality of cement mixing pile, 5 areas have been divided according to different sedimentary history, which are the littoral area, lagoon area, alluvial area (Yangtse River), alluvial area (Ancient Yellow River) and lacustrine area (Fig.1).

![Figure 1. Geological division in Jiangsu](image)
Littoral area soft soil area was located in the eastern coastal Jiangsu Province, the whole terrain was tilted from northwest to southeast, with an average altitude of 3 - 4 m. Lagoon area located in central of Jiangsu Province, belong to Yangtze River - Huai River Plain. A group of lakes and streams distributed in this low-lying region. Jiangsu province in the territory of the Ancient Yellow River 496 km, alluvial area (Ancient Yellow River) including Xuzhou, Suqian, Huai’an and Yancheng cities. Alluvial area (Yangtze River) located in Yangtze River delta plain, including the Yangzhou, Taizhou area. The main area of a lacustrine area are Suchow, Wuxi and Changzhou, this region deposited soft soil thickness was nearly 15 m.

In this construction quality test, set 5 m as the boundary, the CMP was divided into two parts, top surface to 5 m depth as upper part, below 5 m as lower part (see Fig.2), both upper and lower parts are respectively scored. The score of upper part above 75 can be evaluated qualified, and the score of lower part less than 60 can be evaluated not qualified. Then scores of a different part will be evaluated with the following equation:

$$t = (u	imes0.5) + (l	imes0.5)$$  \hspace{1cm} (2)

Whereas, $t$ is the total score, $u$ is the upper part score and $l$ is lower part score.

Then, the score can be divided into four grades as great, good, general and not qualified (can be seen as Table 1).

![Figure 2. Score boundary of cement mixing pile](image-url)

| Scored      | Grade    |
|-------------|----------|
| ≥90         | Great    |
| 80~89       | Good     |
| 67.5~79     | General  |
| <67.5       | Not qualified |

Different parameters (SPT, UCS and CMPQD) of Cement Mixing Pile have been independently tested to evaluate the qualities of the different part of the cement mixing pile.

4. Results of test in different area

Fig.3 (a) shows the relationship between mean SPT (Standard Penetrate Test) blow counts and depth. With the depth increases, the five areas SPT blow numbers were decreasing. The upper part construction quality was higher than the lower part. That quality of cement mixing in the top 5 m was easier to control, blew 5 m the quality will be decreased sharply.

The relationship between cement mixing pile strength and depth can be seen in Fig.3 (b). Data shows below upper part begin to disperse, and the strength is mainly blowing 1 MPa. For the strength, the trend of the mean value varies little with the depth in each area, and all of them gradually decreases with the increase of depth. For the littoral area and lacustrine area, strength was more stable than...
alluvial area (alluvial-Y and alluvial-A) and lagoon area. If simply consider the piles in the same area, the strength means a value of the upper part was more stable, and it was almost a straight line.
Cement mixing pile quality designation (CMPQD) distributed in 0 - 100, the higher score means the better quality. Fig.3 (c) indicated that depth was significantly affecting the score of CMPQD. It was no hard to find that CMPQD increased sharply before former 6 meters and decreased gradually after 6m.
The results indicated that the standard of CMP can set 6 m as boundary of upper and lower part.

5. Evaluation and discussions
In order to compare the quality with each area clearly, proportion diagram has been shown in Fig.4. There have 3 piles evaluated not qualified, in a proportion of 0.14 %; 67 piles evaluated general, in a proportion of 3.68 %; 517 piles evaluated good, in a proportion of 23.77 % and 1588 piles evaluated great, in a proportion of 73.01 %, the qualification rate has reached 99.86 % in the littoral area. No piles are evaluated in unqualified or general, 85 piles are evaluated in good, in a proportion of 7.01 % and 1,127 piles be evaluated in great, in a proportion of 92.99 %, the qualification rate of lagoon area has reached 100 %. Alluvial-A area has 49 piles be evaluated as general, 250 piles are evaluated as good and 570 piles are evaluated as great. Like the lagoon area, the qualification rate also reached 100 %. For the alluvial-Y area, 67.54 % piles were a judge to be great, 22.32 % piles to good, 9.8 % to general and 0.35 % to non-qualified. A lacustrine area including 81.14 % great piles, 14.14 % good piles, 1.64 % general piles and 3.03 % unqualified piles.
Geology condition can influence CMP strength efficiently, soil deposited in lacustrine and lagoon plain were relatively simple, and the quality of CMP accordingly was higher. Complicated engineering geology of the alluvial area (Yangtse River & Ancient Yellow River) and littoral area because of the multiple transgressive and regressive events, the quality was difficult to control. Piles have a significant quality problem in the top due to the initial consolidation but are still be evaluated qualified because of the score of another part. With pile length increasing, the numbers of a pile to be evaluated great and a good proportion are decreasing. The lower part of long CMP can more easily to get the lower score. This can lead the not qualified pile misevaluated as qualified, bring some engineering accident. It is necessary to correct the evaluation score parameters of a standard.

6. Conclusions
Based on deposition history, geology in Jiangsu province can be divided into five soft soil areas, littoral, lagoon, alluvial (Yangtse River), alluvial (Ancient Yellow River) and lacustrine area. Each Cement Mixing Pile in 26 expressways has been grouped into the upper part and a lower part by 5m, then SPT, UCS, and CMPQD results were statistics and analysed to evaluate the influence of quality in each geology engineering condition. The results can be seen as follows:
1. For the same construction maintenance condition, different geology origin affected the quality of Cement Mixing Pile remarkably. CMP is of higher quality in simple geological conditions than in complex conditions.
2. The length of the Cement Mixing Pile only has great influence on the lower part quality and has little influence on the higher part. Thus, it is difficult to control with long cement mixing pile.
3. The upper part’s score of the pile is generally higher than the lower, and the upper score has a great contribution to the final score. This may lead the not-qualified-pile misevaluated.
4. Based on the comprehensive evaluation results of the 5 regions, evaluate standards of SPT and UCS should be improved.

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