Experimental Research on Mixing Ratio of Cement Mixing Pile in Different Soil Layers in an aviation city project in Zhuhai, Guangdong

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Abstract. The Pearl River Estuary area is mostly formed by siltation of deltas, with obvious stratification. An indoor cement mixing pile mix ratio test was carried out on the soil samples of the silt, clay layer and sand layer in an aviation city project in Zhuhai, Guangdong. By changing the cement content and age and other parameters, it reveals the influence of the cement content and age on the compressive strength of cement-soil in different soil layers, and gives the optimal cement content for the treatment of different soil samples with cement mixing piles, which plays an important role in improving the strength of cement mixing piles, saving construction costs and guiding on-site cement mixing pile construction.

1. Preface
Cement mixing pile is a more effective method of foundation reinforcement. This method uses special mixing equipment to mix cement slurry into the soft soil foundation, and the physical and chemical interaction between the cement and the soil makes the foundation consolidation, which can quickly increase the bearing capacity of the original foundation. This method was first proposed by the Swedish Institute of Geotechnical Engineering and the Institute of Port Technology, Ministry of Transport of Japan, and conducted indoor tests and field tests from 1967 to 1974[1][2]. Cement mixing pile has a series of advantages, such as simple construction, fast speed, high construction efficiency, low vibration, low noise, and can effectively reduce and control settlement and post-construction settlement. China introduced cement mixing pile construction technology in the early 1980s. After nearly 40 years of application and improvement, this technology is currently used in railways, highways, municipal engineering, airport runways, artificial islands, ports, and industrial and civil buildings. At present, a large number of application researches have been conducted on cement mixing pile foundation treatment in China[3][4], mainly focusing on the cement-soil ratio, cement mixing pile construction technology, cement mixing pile composite foundation deformation calculation, composite foundation bearing capacity analysis and cement mixing pile quality inspection technology research etc., a series of research results have been achieved, but the current cement mixing and reinforcement methods all use a uniform cement content. Under the uneven distribution of the stratum in the Pearl River Estuary, there are problems such as uneven strength and large dispersion of the cement mixing pile during the foundation treatment. Therefore, it is necessary to carry out quantitative research on the treatment of soft soil foundation with cement mixing piles, and carry out quantitative research on the cement content of different soil layers. Based on an aviation city project in Zhuhai, Guangdong, a test study of the mixing ratio of cement mixing piles in different soil layers is carried out in this paper.
2. Project Overview

The site of an aviation city project in Zhuhai, Guangdong is uneven and undulating. A thick layer of miscellaneous fill and a flow-plastic silt layer are distributed in the site area, and the groundwater level is high. According to the revealed soil layer, the artificial fill layer (including construction waste and domestic waste) and silt layer in the site are widely distributed, and the thickness and buried depth vary greatly. The foundation soil has a high water content, large void ratio, high compressibility and low strength. The site contains two types of structures (buildings) loads: one is productive buildings and structures, which are characterized by large and concentrated loads, and the other is roads, pipelines, walls, etc., which are characterized by small loads and widely distributed. In view of the geological conditions and load characteristics of the site, the available foundation treatment options include dynamic compaction (replacement) method, stacking (vacuum) preloading method, deep mixing pile method, gravel pile method, reinforced concrete pile foundation, etc. The use of economical and effective methods to strengthen the original foundation soil to meet the technical requirements of the project is the primary problem to be solved urgently in this project. Combining the actual situation and engineering characteristics of the site, drawing on the construction methods and construction experience of similar projects, considering factors such as construction safety, construction environment, construction cost and construction efficiency, in a comprehensive comparison, it is proposed to adopt cement mixing pile construction technology as the main proposal for the foundation treatment of the project.

3. Materials and Experiment

3.1. Experiment material

The stratum in an aviation city project in Zhuhai, Guangdong is dominated by Quaternary marine and terrestrial sediments, including marine silt, alluvial clay, silt and sand. In this study, the stratum of the site was divided into three units: silt layer, clay layer and sand layer to conduct a mix ratio study. The basic physical indicators of the three types of test soil samples are shown in Tables 1 to 3.

| Natural moisture content | Natural density | Void ratio | Saturation | Soil gravity | Liquid limit | Plasticity index | Organic matter content |
|-------------------------|----------------|------------|------------|--------------|--------------|-------------------|-----------------------|
| ω                       | ρ              | e          | Sr         | Gs           | ωL           | Ip                |                       |
| 68.5%                   | 1.57g/cm³      | 1.904      | 97.2%      | 2.70         | 57.9%        | 26.6              | 3.9%                  |

| Natural moisture content | Natural density | Void ratio | Saturation | Soil gravity | Liquid limit | Plasticity index | Organic matter content |
|-------------------------|----------------|------------|------------|--------------|--------------|-------------------|-----------------------|
| ω                       | ρ              | e          | Sr         | Gs           | ωL           | Ip                |                       |
| 36.6%                   | 1.81g/cm³      | 1.037      | 96.5%      | 2.69         | 44.5%        | 19.3              | 2.1%                  |

| Granule/mm | 20~5 | 5~2 | 2~0.5 | 0.5~0.25 | 0.25~0.075 | 0.075~0.005 | <0.005 |
|-------------|------|-----|-------|----------|------------|-------------|--------|
| Granule content/% | 7.6  | 24.5 | 31.4  | 19.6     | 3.5        | 8.4         | 5.0    |

The test cement is Runfeng brand P.O 42.5 ordinary Portland cement.

3.2. Sample preparation

The dry sample preparation method is used in this test, and the cement-soil mix ratio parameters used are shown in Table 4.
Table 4. Design table of mix ratio of cement mixing piles in different soil layers

| Soil sample name | Number | Configure moisture content $\omega$ | Cement content | Water-cement ratio |
|------------------|--------|-------------------------------------|----------------|-------------------|
| Silt layer       | Y1     | 68.5%                               | 14%            | 0.55              |
|                  | Y2     | 68.5%                               | 16%            | 0.55              |
|                  | Y3     | 68.5%                               | 18.5%          | 0.55              |
|                  | Y4     | 68.5%                               | 21%            | 0.55              |
|                  | Y5     | 68.5%                               | 24%            | 0.55              |
| Clay layer       | N1     | 36.6%                               | 14%            | 0.55              |
|                  | N2     | 36.6%                               | 16%            | 0.55              |
|                  | N3     | 36.6%                               | 18.5%          | 0.55              |
|                  | N4     | 36.6%                               | 21%            | 0.55              |
|                  | N5     | 36.6%                               | 24%            | 0.55              |
| Sand layer       | S1     | 14.4%                               | 14%            | 0.55              |
|                  | S2     | 14.4%                               | 16%            | 0.55              |
|                  | S3     | 14.4%                               | 18.5%          | 0.55              |
|                  | S4     | 14.4%                               | 21%            | 0.55              |
|                  | S5     | 14.4%                               | 24%            | 0.55              |

3.2.1. Stirring of the specimen
The undisturbed soil samples retrieved from the site will be air-dried and crushed for later use. Prepare the natural moisture content sample of the undisturbed soil sample uniformly in the laboratory. First, the weighed cement and water are premixed into cement slurry, and then the weighed soil sample and cement slurry are put into the planetary mixer, and the soil sample and cement slurry are mixed evenly. Stir at low speed for 1 minute and then at high speed for 30 seconds. Stop stirring and scrape off the cement-soil mixture wrapped on the mixer blade and pot wall with a scraper within 30 seconds, repeat this 6 times until the mixing is even.

3.2.2. Forming of the specimen
- First, evenly spread the release agent in the trial mold of 70.7mm×70.7mm×70.7mm.
- After mixing, it should be shaped as soon as possible, and the molding time should not exceed 25 minutes.
- The mixed cement-soil mixture should be inserted in two layers, and the filling height of each layer should be equal. Each layer should be evenly inserted 15 times from the edge to the center according to the spiral direction. When inserting the bottom layer mixture, the ramming rod should reach the bottom of the trial mold. When inserting the upper layer, the ramming rod should penetrate through this layer and then be inserted into the next layer by 5mm ~ 15mm. When inserting, the ramming rod should be kept vertical. After inserting, use a putty knife or scraper to insert and pull out several times along the inner wall of the trial mold.
- The trial mold is tapped on the vibrating table, and the tapping time is 2 minutes. After tapping, the mixture should be higher than the upper edge of the trial mold.
- Scrape off the excess cement-soil mixture on the top of the trial mold, and cover with plastic film after smoothing.
3.2.3. Demolding of the specimen
- After the specimen is cured for 24 hours, the mold shall be removed, and the appearance of the specimen shall be inspected after the mold is removed. There must be no visible cracks, missing edges, corners, tilt and deformation.
- Weigh the mass \( m \) of the specimen before curing, accurate to 0.1g, and calculate the weight of the specimen after demolding according to the nominal size of the specimen. If the difference between the maximum or minimum and the average value of the same group of specimens exceeds 3%, or when the average value of the group of specimens is less than the weight of the natural soil, the group of specimens is invalid and re-prepared.
- The weighed specimens are placed in \((20\pm1)\)℃ water for curing, the interval between specimens is greater than 10mm, and the water surface is greater than 20mm above the surface of the specimen. The curing ages were 7d, 14d and 28d.

3.3. Unconfined compressive strength test
In order to understand the strength and stability of soil-cement-soil mixtures with different properties, the unconfined compressive strength (UCS) tests of different ages were carried out on 15 sets of samples prepared, and the UCS values curing of each sample were tested for 7 days, 14 days and 28 days after curing. The test instrument is the DT-227 pavement material strength tester produced by Beijing Century Chengda, and the loading rate is controlled at 1mm/min until the soil sample is broken.

4. Experiment results and discussion
4.1. Cement content
The cement content is the weight ratio of the cement content to the original wet soil sample. The results of the unconfined compressive strength test of the silt layer, clay layer and sand layer with different cement content and different ages are shown in Table 5. The curves of relationship between the various soil cement content and UCS strength are shown in Figure 1 ~ 3. It can be seen from Table 5, Figure 1, Figure 2 and Figure 3 that the strength of the silt layer, clay layer and sand-cement soil all increase with the increase of the cement content. The unconfined compressive strength of the sand-cement soil has the largest growth rate, followed by clay, and silt is the smallest. Therefore, it can be predicted that in actual construction, the unconfined compressive strength of the silt soil layer will rise slowly and the strength will be lower.

Table 5. The unconfined compressive strength of cement-soil under different cement content and age

| Soil layer | Age | Cement content |
|-----------|-----|----------------|
|           |     | 14%  | 16%  | 18.5% | 21%  | 24%  |
| Silt layer| 7d  | 1.07 | 1.41 | 1.34  | 1.47  | 2.04  |
|           | 14d | 1.33 | 1.71 | 1.59  | 1.67  | 2.58  |
|           | 28d | 1.46 | 1.92 | 2.08  | 2.20  | 2.95  |
| Clay layer| 7d  | 0.88 | 1.15 | 1.32  | 1.64  | 2.03  |
|           | 14d | 1.62 | 1.70 | 1.64  | 2.46  | 3.09  |
|           | 28d | 1.84 | 2.11 | 2.24  | 3.83  | 4.92  |
| Sand layer| 7d  | 1.49 | 1.77 | 2.84  | 2.53  | 2.82  |
|           | 14d | 2.39 | 2.42 | 3.54  | 4.03  | 3.89  |
|           | 28d | 3.23 | 3.49 | 4.73  | 5.64  | 5.89  |

Note: The unit of unconfined compressive strength in the table is MPa.

It can be seen from Figure 5 that under the condition of 28d curing age and the same cement content, the unconfined compressive strength of sand-cement soil is greater than that of clay and silt. The unconfined compressive strength of cement-soil in the clay layer is greater than that of the silt layer. This is because in the case of a certain amount of cement, if the water content is too high, after the
chemical reaction between the cement and the soil is fully carried out, there will be excess water. On the one hand, the excess water will cause the loss of effective components of cement, on the other hand, it is also difficult to form a stable and uniform cement soil, which greatly affects its unconfined compressive strength[1],[6].

4.2. Age
According to the test data in Table 1, the relationship curve between the age of the silt layer, clay layer and sand layer cement soil and the unconfined compressive strength can be obtained, as shown in Figure 5 ~ 8.

Figure 5. UCS variation curve of silt-cement soil with cement content.

Figure 6. UCS variation curve of clay-cement soil with cement content.

Figure 3. UCS variation curve of sand-cement soil with cement content.

Figure 4. UCS variation curves of with cement content in different soil layers at 28d.

Figure 5. UCS variation curve of silt-cement soil with age.

Figure 6. UCS variation curve of clay soil soil cement soil with age.
From Figure 5, Figure 6 and Figure 7, the following rules can be drawn: the compressive strength of soil-cement of each soil layer increases with age, the strength of cement-soil increases faster in the early stage, and slower in the later period. It can be found from Figure 8 that under different soil conditions, the strength of cement soil increases with age at different rates, and the time required to reach the design required strength is different. Among them, the medium-coarse sand cement has the best curing effect and the strength increases faster.

5. Site construction suggestions

Existing research results and construction experience show that the strength of piles formed on site under the same mix ratio is lower than that of indoor cement-soil tests. Factors such as construction team literacy, construction quality process control and construction technology will affect the effect of cement mixing pile reinforcement. Therefore, when designing the strength of the on-site cement mixing pile with reference to the test strength of the indoor cement-soil mix ratio, reduction is required. The reduction factor given in the specification is between 0.2 and 0.5. This paper selects a reduction factor of 0.35. According to the requirements of the relevant design documents of the project, the 28d unconfined compressive strength of the on-site coring test must be greater than 0.8MPa. In order to meet the design requirements, and combined with the test results in Figure 9 below, the cement mixing pile is recommended for treating silt layer at 22%, for clay layer at 19%, and for sandy soil at 14%. Taking into account the results of the unconfined compressive strength of the indoor cement-soil mix ratio, that is, the unconfined compressive strength of sand > the unconfined compressive strength of clay > the unconfined compressive strength of silt. In actual construction, it is recommended to reduce the water-cement ratio of the silt layer, that is, reduce the ratio of water to cement. The sandy soil layer can slightly increase the water-cement ratio. The specific water-cement ratio needs to be further explored.
6. Conclusion

- The indoor mix ratio test results of cement mixing piles show that the strength of the silt layer, clay layer and sand-cement soil all increase with the increase of cement content. Among them, the unconfined compressive strength of the sand-cement soil has the largest growth rate, followed by clay, and silt is the smallest;
- The unconfined compressive strength of soil in the silt layer, clay layer and sandy soil layer increases with age. The strength of the cement soil increases faster in the early stage and slower in the later period;
- For on-site cement mixing pile construction, it is recommended that the cement content of the silt layer is 22%, the cement content of the clay layer is 19%, and the cement content of the sand layer is 14%;
- Since the unconfined compressive strength of sand-cement soil > the unconfined compressive strength of clay-cement soil > the unconfined compressive strength of silt-cement soil, it is recommended to reduce the water-cement ratio in the silt-soil layer during actual construction, that is, reduce the ratio of water to cement. The sandy soil layer can slightly increase the water-cement ratio.

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