Physical and Mechanical Properties of Cemented Soil Fill At Liquid and Hardened States

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Abstract. Cemented soil fill is a new backfilling technology developed for the problems of narrow foundation trenches and uncompacted backfilling. It has good fluidity before solidification and higher strength and stiffness after solidification. This type of fill materials makes full use of the waste soils. The proportioning test was carried out on excavated soil on a construction site. Liquid property tests and unconfined compressive strength test was carried out. The results show that the cemented soil fill can meet the requirement of foundation trenches backfilling, which has great prospect for future applications.

1. Introduction
In recent years, the development of urban areas have continued to rise and a large number of projects have been built. Many open-cut pits in the city are generally narrow in space, and it is difficult to achieve high compaction requirements for backfill construction. This kind of backfilling project generally has the problem that the backfilled soil settles and deforms more later, and the buried pipelines and upper roads or structures are damaged due to subsidence. It affects the function of the facilities, and the repeated maintenance later causes high repair costs. Cement mixing soil can only be used for in-situ soil improvement [1, 2]. Cemented soil fill is a new type of filling materials. It consists of excavated waste soils, Portland cement, water, and possibly other waste materials and cementing agents [3, 4]. Cemented soil fill has high strength and stiffness after curing to meet the requirements of bearing capacity and deformation resistance of construction projects [5]. Although there have been some successful field trials of using cemented soil fill, its number of practical applications is still limited. In order to achieve a better understanding of the physical and mechanical properties of the material, experimental studies were carried out on the fluidity and strength of the material with varying soil, cement, and water contents.

2. Test Methods
Since the cemented soil fill is filled without rolling or compacting, it must have certain fluidity before initial setting in order to ensure that the material can fully fill various narrow spaces and irregularly-shaped spaces. If the fluidity is too small, the self-compacting effect of the material cannot be guaranteed, resulting in the holes and voids in the filled volumes. While the fluidity is too large, it will easily lead to the problems such as low strength and bleeding during or after curing [6]. This test uses the slump test to evaluate the fluidity of the cement soil, and unconfined compressive test to obtain the strength of the material.
2.1. Materials
Portland cement and excavated soil on a construction site in Suzhou were used for sample preparation. The soil is dried before the experiment, and the mix proportion is determined by cement/soil ratio and water/soil ratio. The excavated soil used in the test was silty clay, and had natural moisture content of around 28%.

2.2. Methods
The slump cylinder is used to measure the fluidity, and 70.7mm cubic samples is prepared after the fluidity measurement, which is completed within 30min to prevent hydration of cement. The cubic samples were used for the compression tests.

3. Results

3.1. Slump Results
The results show that the fluidity of the cemented soil fill increases with the increase of water consumption and decreases with the increase of cement content, as shown in table 1 and table 2. Based on our field trial, it has been found that the material at the fluid state with a slump of 120mm can be used for filling without laminating.

Table 1. Self-compacted cemented soil proportioning table with 8 % cement admixture.

| Sample Number | Water consumption per kilogram of soil (kg) | Measured slump (mm) | Curing Way |
|---------------|------------------------------------------|--------------------|------------|
| A-1           | 220                                      | 72                 | Standard   |
| A-2           | 270                                      | 123                | Standard   |
| A-3           | 310                                      | 142                | Standard   |
| A-4           | 380                                      | 195                | Standard   |

Table 2. Self-compacted cemented soil proportioning table with 10 % cement admixture.

| Sample Number | Water consumption per kilogram of soil (kg) | Measured slump (mm) | Curing Way |
|---------------|------------------------------------------|--------------------|------------|
| B-1           | 370                                      | 77                 | Standard   |
| B-2           | 410                                      | 112                | Standard   |
| B-3           | 460                                      | 160                | Standard   |
| B-4           | 500                                      | 203                | Standard   |
| W-1           | 420                                      | 123                | Water      |
| W-2           | 450                                      | 148                | Water      |

3.2. Strength Results
The samples were placed in standard curing conditions and demoulded after 3d. Unconfined compressive strength tests were carried out on 7, 14, 28 and 90 days. The results are shown in the following figure 1 and figure 2.
In order to verify the effect of the cemented soil fill curing under groundwater level on strength, two groups of samples with 10% content cement are made and the results are shown in figure 3. These samples were cured at the submerged condition under around 25°C.

Figure 1. UCS results with 8% content cement.

Figure 2. UCS results with 10% content cement.

Figure 3. UCS results curing under groundwater.
The laboratory test results show that the unconfined compressive strength of the test block with silty clay as raw material soil can reach about 0.20 ~ 0.30 MPa at 7 days, 0.37 ~ 0.46 MPa at 14 days and 0.44 ~ 0.56 MPa at 28 days; With 10% cement content, the unconfined compressive strength can reach about 0.21 ~ 0.35 MPa at 7 days, 0.41 ~ 0.54 MPa at 14 days and 0.54 ~ 0.67 MPa at 28 days. The underwater curing method has no obvious effect on the strength.

3.3. Results of Site-Collected Samples

Two groups of test samples were collected for each site filling of about 200 m³ during construction and the slump value is estimated to be 10mm. The experimental results of unconfined compressive strength at different ages are shown in the figure 4 and figure 5.

Table 3. Self-compacted cemented soil proportioning table with 10 % cement admixture.

| Sample Number | Cement content | Measured slump (mm) | Curing Way |
|---------------|----------------|---------------------|------------|
| S-1           | 8%             | 90                  | Standard   |
| S-2           | 8%             | 120                 | Standard   |
| S-3           | 10%            | 80                  | Standard   |
| S-4           | 10%            | 110                 | Standard   |

Figure 4. UCS results with 8% content cement on site.

Figure 5. UCS results with 10% content cement on site.
The results showed that the unconfined compressive strength of site samples could reach about 0.35 MPa at 7 d and 0.5 ~ 0.67 MPa at 28 d under the field conditions with 8 ~ 10% cement admixture. Its higher strength indicates a proper on-site mixing condition, where soil and cement can be mixed homogeneously.

4. Conclusions
Cemented soil fill can be used to fill narrow trenches and irregularly shaped voids by utilizing local excavated soils and other waste materials. According to the laboratory test results, the UCS should reach 0.30 MPa in 7 days and not less than 0.50 MPa in 28 days. Furthermore, the results on the field collected samples show relatively high strength, indicating a good mixing condition at the field construction.

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