Study on the Unconfined Compressive Strength Test of Liquid Soil Materials

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Abstract. Aiming at the unconfined compressive strength of the new self-flow platform backfill material which is called liquid soil, indoor tests were carried out with electro-hydraulic pressure testing machine. The effects of different water content, cement content, admixture type and admixture content on the strength of liquid soil are comprehensively analyzed. The results show: the influence of water content on the strength of liquid soil is obvious, and the function relationship of the quadratic equation is presented between them. The unconfined compressive strength of liquid soil increases remarkably with the increase of cement content, showing a trend of e-index growth. The active mineral powder has a certain increase in strength but a lower rate of increase. The water reducing agent slightly increases its strength and then slightly decreases and medium sand makes its strength increase significantly.

1. Introduction

Due to the large stiffness difference between the bridge platform structure and the embankment, the interface between the two will have a large settlement difference during operation, significantly increasing the risk of road operations. The elimination of the problem of jumping around the table back has become one of the important topics in road construction. How to improve the denseness of the post-table fill is the key to reduce the settlement of the post-table embankment and solve the settlement of the post-table back. In traditional road backfill projects, natural-graded sand and gravel or excavated earth and gravel are generally used for backfill, due to the small construction space, there is often a dead space between the backfill and the structure, resulting in the phenomenon of jumping over the backfill area and road transition. Due to the deficiencies of traditional backfill materials, new types of backfill materials have emerged. The liquid soils studied in this paper are also a new type of backfill material, the main components of which are cement, fly ash, water and additives. When using liquid soil for table backfill, the two metrics of greatest concern to the engineers were the liquid soil freshly mixed flow and 28d compressive strength. Therefore, through theoretical analysis and calculations, this paper clarifies the formation mechanism and limit values of the strength of liquid soil, and at the same time, conducts strength tests on liquid soil with different ratios to obtain the contribution laws of various raw materials and their ratios to the strength of liquid soil.
2. Mechanism of strength formation in liquid soil

2.1. Fly ash
The fly ash has a looser structure, containing 45% to 65% hollow glassy spheres, so it is less dense, it reduces the pressure of the mixture on the subsoil part of the base, thus reducing uneven settlement. Fly ash itself plays a major role in strength in the following ways.

2.1.1. Gelling
The activity of fly ash shows the volcanic ash effect, and the ability of silicate glass bodies such as SiO$_2$, Al$_2$O$_3$ and other silicate glass bodies in fly ash materials to participate in the reaction of Ca(OH)$_2$, an alkaline excitant produced by hydration of cement and lime. The production of hydrated calcium silicate, calcium aluminate and other gelling products.

2.1.2. Filling and dense action
The dense action reduces the pore volume and large voids in the mix and fills the capillary pores of the slurry, which is important for improving the strength and durability of the mix.

2.1.3. Water reduction
Fly can be adsorbed on the surface of cement particles, play the role of ball bearing or dispersion to the cement flocculation structure, thus achieving the effect of water reduction.

2.2. Cement
Cement plays two main roles in the formation of strength in liquid soils.

2.2.1. Hydration
The cement itself generates a hydration reaction to produce hydration products with the ability to glue, which are interwoven together in the fly ash pores to coat the fly ash particles, and as the hydration products increase, the mixture is gradually strengthened. This is the main source of strength of the liquid slurry.

2.2.2. Carbonation
Ca(OH)$_2$ from cement hydration can carbonate with CO$_2$ in the air and form calcium carbonate crystals. Volume expansion during calcium carbonate production can also fill and reinforce the fly ash slurry, but this effect is relatively weak and the reaction process is slow.

2.3. Mix strength formation

2.3.1. Ion exchange
After dissolving large amounts of calcium hydroxide in water, a Ca$^{2+}$-rich alkaline solution environment is formed in the fly ash. When the solution is enriched with Ca$^{2+}$, because Ca$^{2+}$ has a higher electric value than K$^+$, Na$^+$ plasma, it has a stronger attraction with the potential ions, thus replacing K$^+$, Na$^+$ and becoming the antiion, while Ca$^{2+}$ also makes the reduction of the double layer potential faster. As a result, the electric potential is reduced, the thickness of the double layer is reduced, and the fly ash is close to each other, so that the fly ash has a certain strength and stability.

2.3.2. Chemical excitation
The mineral composition of fly ash is essentially silica-aluminates, which contain large amounts of silica- and alumina-tetrahedra. In general, these minerals have a high stability, and when the pH of the medium surrounding the fly ash particles increases to a certain degree, the activity of some of the SiO$_2$ and Al$_2$O$_3$ in the fly ash is excited and reacts with the amplified Ca$^{2+}$ in solution to produce new minerals. The resulting gelling material wraps around the surface of the fly ash particles and,
together with the hydration products of cement, condenses the fly ash particles into a single unit. Therefore, the excitation of fly ash by Ca(OH)$_2$ will further enhance the strength of the liquid slurry.

3. Liquid soil strength test

3.1. Test material

3.1.1. Cement
As one of the most important raw materials for liquid soils, the main contribution of cement to liquid soils is strength enhancement. The cement used in the test is P.O. 32.5 conch composite silicate cement produced by Shanghai Conch Cement Co.

3.1.2. Fly ash
Fly ash is a volcanic ash-like mixture produced by the combustion of coal dust at high temperatures. The properties of the fly ash used in the test are shown in Table 1.

| Project                  | Parameters   | Fineness | Loss on ignition | Specific surface area | Apparent density: | The compaction density | Water content |
|--------------------------|--------------|----------|------------------|-----------------------|-------------------|------------------------|--------------|
|                          | ≤10%         | 7.9%     | ≥450m$^2$/kg     | 700kg/m$^3$           | 1150Kg/m$^3$      | 3% ~ 7%                |

3.1.3. Additives
Water-reducing admixture (The cement admixture used in this test was a nanoadhesive.) , Medium sand (The sand used in the test is sand with a full particle size of less than 5 mm and a particle content of 90% or more.) , Active mineral powder (The mineral powder can be hydrated to produce calcium hydrated silicate, which is filled in the pores of the cement concrete, substantially increasing the density of the cement concrete).

3.2. Content of the test
The liquid soil specimens are molded using a triple test mold of 100mm×100mm×100mm, and the mold is removed after 28d under standard maintenance conditions (temperature 20±2℃, relative humidity above 90%), and the unbounded compressive strength test is conducted using YA-2000 electro-hydraulic pressure tester.

4. Test results and discussion
The lateral limitless compressive strength of the liquid soil is different different water content and cement content, the lateral limitless compressive strength of the liquid soil decreases with increasing water content and increases with increasing cement content. In this paper, regression fitting of the unbounded compressive strength with moisture content and cement content was performed and the results are shown in Tables 2. and 3.

| Cement content% | 4   | 6   | 8   | 10  | 12  |
|-----------------|-----|-----|-----|-----|-----|
| Strength equation | $y=592.1ex^{-4.198x}$ | $y=330.3exp(-1.92x)$ | $y=15810exp(-9.861x)$ | $y=14000exp(-9.166x)$ | $y=18370exp(-9.218x)$ |
| R2              | 0.9834 | 0.8355 | 0.8412 | 0.9985 | 0.9104 |

| Cement content% | 43  | 45  | 47  |
|-----------------|-----|-----|-----|
| Strength equation | $y=3232x-41.46$ | $y=2320x+0.8207$ | $y=1967x+1.435$ |
| R2              | 0.9861 | 0.9863 | 0.9571 |
The following conclusions can be drawn from the fitting results.

- Liquid soil with no lateral limit compressive strength and water content satisfies the equation \( y = a \exp(bx) \), but the values of the two parameters \( a, b \) therein differ greatly. The values of \( a \) and \( b \) with different cement contents are different and there is no obvious change pattern.
- Liquid soil without side limit compressive strength and cement content of the relationship is linear, that is, \( y = ax + b \). \( a \) value with the increase of moisture content and gradually increase, \( b \) value with the decrease of moisture content and decrease.

Compressive strength data for liquid soils with different admixtures and at different dosage.

![Figure 1. Effect of additive on compressive strength.](image)

Where: Dosage 1: No additives added; Dosage 2: 1.5 per cent of solids mass for the water reducing agent group, 1.5 per cent for the active powder group and 1.5 per cent for the medium sand group: fly ash = 75:25; Dosage 3: 2.5% of solids mass for the water reducing agent group, 2.5% for the active mineral powder group, 2.5% for the medium sand group: fly ash = 70:30.

It is worth noting that the medium sand group could not be shaped without adulteration due to its low moisture content (25%), so no data for dosage 1; with the addition of medium sand, the amount of water required for forming the liquid soil decreases significantly, thus also improving its strength. It has the most significant strength enhancement effect on liquid soils. Naphthalene water-reducing agent has a strong dispersion effect on cement particles, its water-reducing effect is about 15%, the effect on liquid soil strength enhancement is still good. Active mineral powders enables the mineral powder to undergo a hydration reaction to produce calcium hydrated silicate, which fills in the pores of the cement concrete and increases the density of the cement concrete. However, in terms of test results, the strength enhancement of the active mineral powder on liquid soils did not meet expectations.

5. Concluding remarks

- In the process of strength formation of liquid soil materials, fly ash plays the role of cementing, filling and reducing water; cement plays the role of hydration and carbonization, in which hydration is the main source of strength of liquid soil.
- Liquid soil with no lateral limit compressive strength and moisture content satisfies the equation \( y = a \exp(bx) \) and with cement content satisfies the equation \( y = ax + b \).
- In the equation \( y = a \exp(bx) \), the variation of parameters \( a \) and \( b \) with cement content is not strong. In the equation \( y = ax + b \), the value of \( a \) increases with the increase of water content and the value of \( b \) decreases with the decrease of water content.

References

[1] Liu Guoyuan. (2007) Application of fluid cement fly ash slurry in table backfill.
[2] Qin Zengxue. (2003) Analysis of the causes and preventive measures of bridge head jumping [N], Artificial Times (Han).
[3] Zhang Keqian. (2003) Management of highway bridgehead jumping phenomenon of key measures [J]. Shanxi Construction, 29(17):135-136.
[4] Wang Xia. Backfill construction and quality control of the platform[J]. Shanxi Traffic Science and Technology, 2004(S1):108-109.

[5] Xiao Lijing. (2003) Application of foam mixed lightweight fill technology in solving the problem of jumping on soft embankment of high grade highways[J]. Chinese and Foreign Highway, 23(5):121-123.

[6] Ge Xisheng. & Huang Xiaoming. & Zhang Xiaoning. (2006) Study on the Application of Ceramic Fly Ash Concrete in Bridge Abutment Backfill[J], 27(11).

[7] Li Yunfei. Mechanical properties of EPS and reduction of embankment settlement [D].