Experimental Study on Subgrade Performance of Collapsible Loess Mixed with Concrete Gravel

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Abstract. Collapsible loess-like and concrete breccia is a rare special soil type in China, which is widely distributed in Baoji area. The paper preliminarily studied its collapsibility mechanism and engineering properties. The experimental results show that mixing 30% concrete crushed gravel has the best compressive effect and the best bearing ratio in California. Scanning by electron microscope found that after collapsible loess was mixed with concrete gravel, as the proportion of concrete increased, its internal structural stability increased. Concrete gravel recycling projects in subgrade engineering in collapsible loess areas have a certain feasibility, and its economic value is great. In future studies, it can be studied for higher proportions of concrete gravel.

Key words: Collapsible loess; concrete gravel; roadbed test; Baoji collapsible loess.

1. Introduction
China has a vast territory with various soil distributions, of which 6.56% of the area is covered by loess, and the area of loess distribution is relatively wide, all over the middle reaches of the Yellow River. The loess in Shaanxi Province is widely distributed, mainly in the Guanzhong Basin and the Loess Plateau north of the Qinling Mountains. There are important cities such as Xi’an, Xianyang, Baoji, Weinan, etc. in the Guanzhong Plain. Due to the complex geological structure, the development of rivers and valleys, the Guanzhong Plain has a variety of landform types, from low terraces to high terraces to loess platform sources with collapsible loess [1]. Due to the influence of geological structure and river topography, the thickness of the collapsible loess developed in the Guanzhong Basin varies greatly, and the combined structure with the lower alluvial strata also varies, and the engineering geological conditions are more complex.

60% of my country's loess has different degrees of collapsibility. The characteristic of collapsible loess is that under the combined action of overburden pressure and water immersion, the soil structure is destroyed, resulting in additional settlement deformation in addition to compression deformation, and the collapse has the inherent characteristics of sudden, strong and irreversible. Collapsibility can be divided into two types: self-weight and non-self-weight: after immersion, only self-weight produces collapsibility, which is called self-weight collapsibility; after immersion, self-weight and external load cause collapsibility and deformation, which is called non-self-weight Collapsibility. Water sensitivity is a very important feature of collapsible loess, that is, it has good strength characteristics and low compression characteristics under low water content. As the water content increases, the soil settlement deformation increases and the strength quickly dissipates [2]. The losses and technical problems
encountered in the engineering construction of the collapsible loess area are mostly caused by the water sensitivity of the loess, which seriously affects and hinders the economic development and the safety and stability of the buildings in the collapsible loess area. Metastable collapsible loess is a problem in many engineering geology and geotechnical engineering in the world.

2. Test plan

2.1. Experimental equipment
The test uses the ShearTrac-III geotechnical large-scale interface shear test equipment produced by Geocomp, USA. The device has simple structure, convenient operation, high sensitivity and high accuracy, and is widely used in shear tests on the contact surface of soil and structure [3]. The basic structure of the test instrument is shown in Figure 1. The sample size is 305mm×305mm×200mm, of which the upper shear box length×width×height is 305mm×305mm×102mm; the lower shear box length×width×height is 405mm×305mm×102mm. The shear area remained unchanged during the test. The normal force is automatically graded and applied under computer control, the shear rate ranges from 0.00003 to 15.00000mm/min, and the test data is automatically collected by the on-board software.

2.2. Preparation of loess samples
The test soil sample comes from Baoji, which is about 3m below the horizontal ground, and the loess was subjected to compaction test and static triaxial test. According to the results of compaction test, the maximum dry density of loess is 1.72g/cm³, and the optimal moisture content is 17.78%. Refer to the standard of the geotechnical test method. Pass the air-dried and ground soil through a 2mm sieve and prepare it according to the required moisture content. After sealing, let it stand for more than 24 hours and make the moisture spread evenly [4]. The specific physical and mechanical properties are listed in Table 1. In order to ensure the uniformity of the soil, when the reshaped soil sample is loaded, the soil sample is placed in a shear box and compacted in 3 layers, and a certain dry density of the soil sample is determined by measuring the thickness and mass of the added soil. After each compaction, the surface of the soil sample is shaved to ensure the integrity of the soil sample, and then the next layer of soil sample is filled. According to the static triaxial test, the cohesive force c of loess is 35.2kPa, and the internal friction angle $\phi$ is 30°. The concrete test block is made of C30 concrete. The roughness of the concrete surface is divided into two levels: rough surface and smooth surface. After 28 days of curing, the mold is removed. The particle grading curve of loess is shown in Figure 1.

| Moisture content/% | Density (g/cm³) | Dry density (g/cm³) | Liquid limit/% | Plastic limit/% | Liquidity Index | Compression factor/kPa | Collapsibility coefficient |
|-------------------|-----------------|--------------------|---------------|----------------|-----------------|------------------------|---------------------------|
| 13.52             | 1.75            | 1.35               | 31.66         | 18.96          | 1.49            | 0.27                   | 0.026                     |

Figure 1. Gradation curve of raw material loess
2.3. Preparation of loess and concrete patterns
The paper takes a certain quality soil sample, dried it, crushed it, and then passed it through a 1cm sieve; according to the pre-designed ratio (using the dry soil mass ratio as the addition standard), the ideal density model was adopted, as shown in formulas (1)-(3) Calculate the mixing quality of cement, sand, and EPS foam respectively; the purchased EPS pellets are over 3mm to obtain the EPS particles required for the test; they will be weighed according to the proportion of 10%, 15%, 20%, 25%, and 30% The concrete and loess are fully screened and mixed and stirred for 5 minutes until uniform. Add water and mix for 10 minutes until the cement soil is evenly mixed for 5 minutes until a uniform cement paste is formed.

\[
\rho = \frac{m_s + m_c + m_{sd} + m_e + m_w}{2.72 + 3.1 + 2.67 + 0.0137 + 1.0}
\]  

In the formula: \( \rho \) is the density of the lightweight soil sample, g/cm³; \( m \) is the mass, g; the angles \( s, c, sd, e, w \) represents the mixed materials dry soil, cement, sand, EPS particles.

\[
kpv = m_s + m_c + m_{sd} + m_e + m_w
\]  

Where: \( k \) is the sample preparation magnification factor, taken as 1.3; \( v \) is the volume of the ring knife used for sample preparation, cm³.

\[
m_j = m_i \delta_j
\]  

In the formula: \( \delta_j \) is the mass ratio of raw loess occupied by different mixed materials, g/kg; \( j = c, sd, e, w \).

3. Results

3.1. Unconfined compressive strength test
Prepare 5 samples in the experiment, and put the prepared samples together with the mold into a standard curing box for curing. The curing temperature is 20±2℃ and the humidity is >90%. After curing for 24 hours, the samples will be demoulded and wrapped with plastic wrap. After curing to the design age of 28 days, the strain-controlled unconfined compression tester is used for the test. The specific test steps are as follows: 1) Prepare a lightweight soil sample with a diameter of 3.9-4cm and a height of 8cm, and demould after 24h. Wrap it with plastic wrap and cure it to the design age of 28 days; 2) Turn on the power, turn the electric runner in reverse, and slowly lower it until the sample can be placed smoothly and then stop, and then cure the light soil sample for 28 days. Remove the cling film and place it on the base of the unconfined compression tester; 3) Turn on the power again, make the electric runner rotate in the positive direction, and slowly rise until the sample and the upper pressure plate are in contact with each other. Return the dial indicator of the dynamometer to zero; 4) Continue to rotate the electric runner in the positive direction, and start the stopwatch for timing, and read the axial displacement gauge and the axial dynamometer dial indicator once every 20s; 5) When demould the axial dynamometer reading reaches the peak value, record the displacement and dynamometer readings [5]. After reading the data twice, the test can be stopped; 6) After taking a photo and recording the appearance of the sample, make the electric runner rotate in the reverse direction, Remove the lightweight soil sample and describe the shape after failure on the recording paper. Figure 2 and Table 2 show the experimental results.
Figure 2. Stress test results

Table 2. Stress and strain table

| stress   | strain | stress   | strain | stress   | strain | stress   | strain |
|----------|--------|----------|--------|----------|--------|----------|--------|
| kPa      | %      | kPa      | %      | kPa      | %      | kPa      | %      |
| Plain soil | Plain soil | 10% concrete gravel | 10% concrete gravel | 15% concrete gravel | 15% concrete gravel |
| 115.26282 | 0.10411 | 115.51615 | 0.10536 | 115.76947 | 0.10495 |
| 157.06143 | 0.62469 | 157.25941 | 0.5414  | 157.45739 | 0.45811 |
| 201.39329 | 1.14526 | 201.64662 | 0.97868 | 201.89994 | 0.81209 |
| 256.49145 | 1.76995 | 262.95123 | 1.52007 | 269.41102 | 1.2702  |
| 305.88989 | 2.29052 | 312.34959 | 1.95735 | 318.80937 | 1.62419 |
| 350.85497 | 2.91521 | 358.20139 | 2.47793 | 365.54781 | 2.04065 |
| 402.15326 | 3.64401 | 409.37302 | 3.08179 | 416.59278 | 2.51957 |
| 429.38569 | 4.16549 | 442.43192 | 3.51908 | 455.47815 | 2.87357 |
| 447.75174 | 4.78928 | 468.01773 | 4.03965 | 488.28372 | 3.29003 |
| 424.9525  | 5.10162 | 479.1334  | 4.35199 | 513.4479  | 3.55972 |

| stress   | strain | stress   | strain | stress   | strain | stress   | strain |
|----------|--------|----------|--------|----------|--------|----------|--------|
| kPa      | %      | kPa      | %      | kPa      | %      | kPa      | %      |
| 20% concrete gravel | 20% concrete gravel | 25% concrete gravel | 25% concrete gravel | 30% concrete gravel | 30% concrete gravel |
| 116.0228 | 0.10453 | 116.27612 | 0.10662 | 116.52945 | 0.1062  |
| 157.65357 | 0.37481 | 157.85335 | 0.29152 | 158.05133 | 0.20823 |
| 202.15327 | 0.64551 | 202.40659 | 0.47892 | 200.12666 | 0.31234 |
| 275.8708 | 1.02032 | 282.33059 | 0.95786 | 288.79037 | 0.52057 |
| 325.26916 | 1.29102 | 331.72894 | 1.16608 | 338.18873 | 0.62469 |
| 372.89424 | 1.60336 | 392.24066 | 1.39514 | 387.58708 | 0.7288 |
| 423.81254 | 1.95736 | 471.0323 | 1.79078 | 438.25206 | 0.83292 |
| 468.52439 | 2.22805 | 528.81571 | 2.01783 | 494.61685 | 0.93703 |
| 508.54972 | 2.5404 | 564.78784 | 2.18641 | 549.0817 | 1.04115 |
| 549.82901 | 2.78878 | 597.7755 | 2.353 | 599.74668 | 1.14526 |
| 577.3317 | 3.04015 | 605.84673 | 2.51957 | 648.51172 | 1.24688 |
| 501.77464 | 3.16508 | 544.17846 | 2.60374 | 694.74351 | 1.35349 |

From Figure 2 we can get that the maximum unconfined compressive strength of plain soil is 447.7517 kPa, and the corresponding strain is 4.7893%. The best ratio is to mix 30% concrete gravel,
where the maximum unconfined compressive strength is 742.2419 kPa, and the corresponding strain is 1.6658%.

3.2. Mixture CBR test
According to the previous test results and comprehensive consideration of factors such as the indoor moulding of the sample, the mixture of loess and concrete gravel was tested with only one ratio (loess: concrete gravel = 70:30) CBR and unconfined compressive strength test [6]. The test results are shown in Table 3.

Table 3. Table of experimental results

| Soil                           | Plain soil | Plain soil + 30% concrete |
|--------------------------------|------------|----------------------------|
| Expansion                      | 3.73mm     | 2.1mm                      |
| Expansion rate                 | 3.1083%    | 1.7073%                    |
| 2.5mm pressure                 | 325.9486kPa| 595.7157kPa                |
| 5mm pressure                   | 414.0565kPa| 849.5467kPa                |
| 2.5mm force                    | 640N       | 1169.685N                  |
| 5mm acceptance                 | 813.333N   | 1665.081N                  |
| 2.5mm CBR                      | 4.0048%    | 8.5102%                    |
| 5mm CBR                        | 3.9434%    | 8.0909%                    |

3.3. SEM test
The improved soil (30% concrete gravel) with the best results of bearing ratio test and compression test was tested by SEM, and the results were compared with those of plain soil. The results of SEM found that after collapsible loess was mixed with concrete gravel, as the proportion of concrete increased, its internal structural stability increased. Figure 3 to 6 show the experimental results.

Figure 3. SEM results of plain soil (×5k)

Figure 4. SEM results of plain soil (×25k)

Figure 5. SEM results of 30% concrete gravel improved soil (×5k)

Figure 6. SEM results of 30% concrete gravel improved soil (×25k)
4. Conclusion

From the results of the three series of tests, it can be seen that for Baoji’s representative class II self-weight collapsible sedimentary loess, when other influencing factors are stable and fully mixed, when the concrete content is 15% or less, at this time, the concrete content in the aggregate has no significant effect on the strength of concrete or mortar specimens; actual verification shows that the concrete content is 30%, and the C30 and below concrete prepared according to the standard deviation $\sigma=3$ can still meet its design strength claim. Concrete crushed gravel has a certain feasibility in the recycling project of subgrade engineering in collapsible loess area. Of course, the purpose of our experiment here is not to relax the standard of concrete content in aggregate, but for Baoji, where water resources are very tight, the concrete content in aggregate must meet the current national standards or industry standards such as construction and railways. It is not easy [7]. If the tester can fully consider the influence of the concrete content when designing the concrete mix ratio, if the concrete content in the aggregate exceeds the standard, the final formed concrete can not only meet the design strength requirements, but also design an economical and suitable mix. Then, it is completely feasible.

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