Unconfined Deformation Characteristics of Collapsed Soil Based on Close-range Photogrammetry Technology

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Abstract. Benggang is a special type of landform type that exists in the hilly areas of tropical and subtropical hills in the south of China. The water and soil erosion occurring on the collapsed land is different from other types of erosion. Its occurrence and development are characterized by uncertainty and rapidity, which seriously threaten the ecological environment and human settlement security. The intrinsic geotechnical characteristics of the soil are a major factor affecting its formation and development. The unconfined compressive test plays an important part in the study of the mechanical properties and failure modes of the soil in the collapsing region. The near-sight measurement technique is now used for the unconstrained resistance. The lateral deformation of the soil samples in the pressure test was sampled and the image information was digitized using matlab. The deformation of the soil with different mechanical properties was analyzed by the displacement information of the marked points and the overall contour deformation and other information. Results showed that in the unconfined compressive strength test, there was no significant difference in the overall deformation of the different soil samples. In one sample, there were significant differences in the displacement of different markers. The close-range photogrammetry technique can well compensate for the lack of the unconfined compression test and it also has a broad space for development in the field of soil and water conservation.

1. Introduction
Benggang is a special erosive landform that occurs in the low-mountain hilly area of tropical and subtropical China, where red granite and its deep parent material are formed by caving, sliding and overturning [1]. Benggang erosion as a geomorphological process is both a trajectory of space and a function of time. High-intensity erosion and sediment production, complex and variable spatial patterns, and hydraulic-gravity composite erosion is the main features of collapsed development [2]. In the cause of the erosion of the benggang, the physical property of the soil itself is an important factor [3-6]. From the microscopic point of view, the geotechnical characteristics and the development of the collapsing erosion are inextricably linked. The shear strength of soil directly reflects the difficulty of shear deformation and failure of soil under external force [7]. It is the main index to characterize the stability of collapsed rock and soil, and also the basis for the study of the overall stability of collapse. It has an important role in the study of the mechanism of benggang erosion. Many studies in determining the mechanical properties of benggang soil have been conducted. With the continuous development of science and technology, advanced experimental equipment and research methods based on new modern equipment have emerged. Researchers also have been trying to apply new technologies and methods in other fields of the study of soil mechanics. Many scholars have applied it to the geological and
geomorphological fields such as soil erosion and landslide deformation monitoring, and analyzed the deformation of soil triaxial specimens, soil particle size distribution and dip angle. Some researchers have tried to study the deformation process of soil samples during the compressive strength experiment of soil by using close-range photogrammetry technology [8-14]. The current study is such an attempt. In the conventional unconfined compressive strength experiment, a close-range photogrammetry technique was introduced to observe the lateral deformation process of the specimen during unconfined compression. It is desirable for a more detailed description of the deformation of the soil in the unconfined compressive strength test can be made. Have a deeper understanding of the soil destruction process, explore the soil deformation characteristics, study the structural properties of the collapsed soil and explore the prospects of the application of close-range photogrammetry technology in the field of soil mechanics research. Close-range photogrammetry as a long-distance non-contact measurement technology does not interfere with the force and deformation of the specimen. It is both reasonable and feasible to apply it to the basic experiments of geotechnical mechanics. In this test, no changes were made to the conventional unconfined compressive strength test except for the marked points, which was easy to implement and popularize. In this study, the camera is selected as the image acquisition equipment to control the cost, and the whole has the characteristics of automatic processing, low cost, high precision and reliability.

2. Materials and Methods

2.1. Overview of the experimental area

The study area is located in Tongcheng County, Xianning City, Hubei Province. It is located in the southeastern part of Hubei province and the north subtropical monsoon climate zone. Due to the influence of the monsoon and landform, the spatial and temporal distribution of rainfall is uneven, and severe weather conditions, i.e. very high temperature and heavy rainfall, often occurs in summer. The soil type is characterized by red soil developed by granite parent material, and the structure is relatively loose. On the topography, there are many hilly terrains, as well as terrain such as mountains and small plains, where the south is a little higher than the north. Granite undergoes deep weathering and strong cutting in the Yanshan movement to form low mountains and hills. There are more collapsing erosion. Such climatic and topographic conditions are expected to be very suitable for the development of benggang. Therefore, the situation of benggang erosion in this area is serious, the number of active benggang is large, and the shape is different. It has typical development characteristics of granite benggang in southern China. It is precisely because of such climatic and topographical conditions that the soil and water loss in the territory is serious, especially the wide range of benggang erosion and large soil erosion modulus, which seriously affect agricultural land and economic development in the region. Samples were collected in Wuli Town, Tongcheng County. The two sampling fell posts were named as No. 1 and No. 2 benggang.

No.1 benggang: located in Wuli Community of Wuli Town (113°64'30 E, 29°13'45 N, plant species with OldWorld forked fern, Pinus massoniana Lamb, etc.), elevation of 142 meters, north-south trend, brown red soil, the structure is loose, scoop. There is one erosion gully, the collapsed backwall height is 9 meters, the average depth is 5 meters, the gully mouth width 2.9 meters. And the maximum width of the gully is 5.7 meters, the collapsed area is about 126 square meters, the channel length is 17 meters, and the side wall is 3.4 meters high.

No.2 benggang: It is located in the second group of Chengfeng Village, Wuli Town, Tongcheng County (113°43'13 E, 29°12'1 N, plant species with Castanea mollissima, etc.). Altitude elevation 164 meters, brown red soil, sand, loose structure, scoop. There is one erosion gully, collapsed wall 7.6 meters high, 20 meters deep, side wall height 7.0 meters, the average width of 9 meters, the mouth width 1.7 meters. The collapsed area is 81 square meters and the gully is 6 meters long.

According to the characteristics of vegetation roots, soil color and texture of the soil profile, the collapsed walls of the two benggang can be divided into topsoil, red soil layer, reticulated mottling
horizon and sand layer from top to bottom. The samples were in turn labelled 1-4 layers. In this study, four layers of cutting ring soil samples and aluminum box soil samples were collected from two locations.

2.2. Unconfined compressive strength test

Unconfined compressive strength test uses Model YYW-2 Strain Controlled Unconfined Compression Apparatus. The main parameters of the instrument: the maximum force is 0.6 kN, the speed is 2.4 mm/min, and the force coefficient is 2.4 N/0.01 mm. The test is measured every 0.5% strain gauge, and the test is terminated when the dynamometer reading reaches a steady value (three consecutive values remain the same) or the strain reaches 20%. The test results shall be calculated and plotted according to the following formula:

\[ \varepsilon_1 = \frac{\Delta h}{h_0} \times 100 \]  
\[ A_a = \frac{A_0}{1-0.01\varepsilon_1} \]  
\[ \sigma = \frac{C \cdot R}{A_a} \times 10 \]

Where \( \varepsilon_1 \) is axial strain (%), \( \Delta h \) is axial deformation (mm), \( h_0 \) is initial height (mm), \( A_0 \) is cross-sectional area (cm\(^2\)), \( A_a \) is initial cross-sectional area (cm\(^2\)), \( \sigma \) is axial stress (kPa), \( C \) is dynamometers calibration coefficient (N/0.01mm) and \( R \) is the number on the dynamometers (0.01mm).

With the axial stress as the ordinate and the axial strain as the abscissa, the relationship curve between the axial stress and the axial strain is drawn. The maximum axial stress on the curve is the value of unconfined compressive strength. When there is no peak value on the curve, the axial stress corresponding to 15% of the axial strain is the value of unconfined compressive strength.

2.3. Image information acquisition

The digital imaging device is the main imaging device for close-range photogrammetry. The used camera in this experiment is the Nikon D40. 6.1 megapixel (3008*2000) CCD sensor, ISO 200-1600, flash sync speed is 1/500s, continuous shooting capability is 2.5 fps, shutter speed is 30-1/4000 seconds, JPEG achieves unlimited continuous shooting, RAW Format photos can take up to 9 shots at a time. With 3-point focusing, the metering system is D-Color Matrix Metering II, which supports 75% center-weighted metering and 8% spot metering. Lens AF-S DX Nikkor 18-55mm F3.5-5.6G ED II. It uses a SD card as a storage medium and is compatible with SDHC memory cards. Other instruments used are as follows: tripod (fixed camera), LeiSe-ML-L3 remote shutter.

![Fig 1. A schematic view of the experimental apparatus](image)

Three columns of control points are marked on one the samples, and the dots are dots of 0.3 ± 0.1 mm in diameter, and the number of points is between 20-23. Try to ensure that the control points are evenly distributed on the set-up area. Adjust the camera position and focal length, make sure that the soil sample is in the middle of the screen to fill the entire screen, and ensure that the marker points can be captured. The center of the camera level was kept with the center of gravity of the soil sample. The camera is fixed after the requirements are met, and the position is fixed during the shooting. The image acquisition is synchronized with the data reading in the unconfined compressive strength test. When the
dynamometer reading is recorded every 0.5% strain, the shutter is pressed to obtain an image. According to the experimental conditions, 19-23 images can be obtained for each soil sample. A total of 24 groups and 552 experimental images were obtained.

2.4. Image processing
Check the picture quality and select the most representative group among the three repetitions of each soil sample. A total of 8 groups of pictures were screened out for further processing. The image processing software is matlab2016a. Camera Params 1-8 is obtained by inputting the corresponding correction images into each group using the Camera Calibrator toolbox. The corresponding correction parameters are used to correct the distortion of the images in the corresponding group [15]. The corrected image is processed in MATLAB to extract the coordinates of the marker points [16-20]. Eight groups of 184 marker points were obtained, with a total of 3680 x-y coordinates.

3. Results and Discussion

3.1. Basic properties of soil samples and unconfined compressive strength

| number | Moisture content (%) | Bulk density (g/cm³) | Unconfined compressive strength (KPa) |
|--------|----------------------|----------------------|--------------------------------------|
| 1-1    | 25.29                | 1.68                 | 49.66                                |
| 1-2    | 26.13                | 1.77                 | 63.46                                |
| 1-3    | 25.03                | 1.66                 | 35.71                                |
| 1-4    | 23.75                | 1.79                 | 59.78                                |
| 2-1    | 29.63                | 1.58                 | 94.60                                |
| 2-2    | 27.57                | 1.14                 | 85.36                                |
| 2-3    | 27.44                | 1.41                 | 29.20                                |
| 2-4    | 23.92                | 1.44                 | 32.40                                |

Note: the number of benggang – the layer of soil

3.2. Surface deformation characteristics of benggang soil in unconfined compressive strength test
To obtain the displacement map of marker points, read the conversion constants between the pixels and the lengths in real space from the correction information, and transformed the data by using plot function in MATLAB 2016a (Fig 2). Made a regression curve of the ordinate and the longitudinal displacement after correcting the marked points (Table 2).

- From the bottom to the top, the longitudinal displacement increased, and all the marking points have a tendency to move upward along the axial direction. This is determined by the stress direction of the instrument from bottom to top. Most of the samples met this trend and the goodness of fit was better. The samples with poor goodness of fit were analyzed, and the commonality was that the axial strain was small when the fracture surface was produced. The soil sample lost its integrity.

| number | y=kx+b                              | R²     |
|--------|-------------------------------------|--------|
| 1-1    | y = -0.0823x + 9.0618                | 0.6079 |
| 1-2    | y = -0.1103x + 9.2586                | 0.8460 |
| 1-3    | y = -0.0209x + 2.9296                | 0.4807 |
| 1-4    | y = -0.0603x + 7.0618                | 0.3451 |
| 2-1    | y = -0.0695x + 8.3851                | 0.8652 |
| 2-2    | y = -0.0987x + 11.149                | 0.8510 |
| 2-3    | y = -0.0880x + 9.7605                | 0.9467 |
| 2-4    | y = -0.0975x + 8.5707                | 0.8535 |

y: Longitudinal displacement length, x: Initial longitudinal coordinate
• From the bottom to the top, the lateral displacement of the sample without a significant rupture surface increases first and then decreases. There is an apparent rupture surface with a large displacement along the rupture surface.

• In a set of experiments, the moving direction and distance of different displacement points are significantly different. It shows that the deformation of each part of the soil sample is different, that is, in the experiment, the force of each part is different.

• Combined with the trajectory map, the larger law of displacement distance increased from top to bottom. When the trajectories of two adjacent marking points tend to be consistent, it can be considered that the soil in this area is relatively complete; when there is a large difference in the trajectory of adjacent marking points, it indicates that there is a dislocation and discontinuity between the soils, and the relative motion is more obvious. It may be the part of the rupture surface. In the special case of the figure, the marking point disappears in the middle. The reason may be that the soil where the marking point is located is dropped or the marking point is squeezed into the rupture surface, and the trajectory of the adjacent marking point is greatly different. According to the above rules, the position of the fracture surface can be inferred.

Fig 2. Marker point shift diagram

It is noted that when the three-dimensional motion is recorded by the image, it is converted into two-dimensional space, losing its spatiality. Because there is no depth information, the point showing the upward trend of the trajectory in the graph cannot be directly described as the point vertically upward. In one extreme case, when the moving direction of the point is perpendicular to the photographic plane, only one point can be seen in the image. It is quite different from the actual situation.

3.3. Surface deformation characteristics of henggang soil in unconfined compressive strenght test

In this experiment, the contour of the final shape of the soil sample was extracted when the experiment was stopped. It is noted that the contour shapes are more complex than those of plastic failure and brittle failure described in the book. The experimental results show that the contour shapes are somewhere between the two.
3.4. Precision analysis
The image accuracy is 0.03-0.06 mm. The main reasons that affect the accuracy of this experimental experiment are:

- The size and shape of the mark. Larger marking points are attached to a larger area of soil, and more are likely to be split or have a larger deformation. This can interfere with the extraction of the center coordinates of the marker points that are then performed in MATLAB.
- Self-movement of the camera and movement that occurs during the operation of the unconfined compressor.
- The photographic distance and the angle of photography (intersection angle) have a significant influence on the accuracy of close-range photogrammetry. In general, the accuracy is higher when the intersection angle is larger; the closer the photographic distance is, the higher the accuracy, so the accuracy of the experiment is also affected.
- The test site also limits the distance between the camera and the soil sample.

4. Conclusion
The most obvious rule in the displacement diagram is that the relative displacement increases in turn from top to bottom, which is determined by the pressure exerted on the soil sample by the unconfined compression apparatus. When the internal force of the soil is the same, the direction of pressure and the stress surface were not thought to affect the deformation process. However, the picture clearly disagrees with that. There are relative displacements in the soil sample, and the integrity is not good. The stress condition is complex.

In this attempt to combine close-range photogrammetry with unconfined compressive strength test, it is considered that this technique has many applications in soil mechanics research and soil and water conservation, which can help us better explore the "black box" of the soil.

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