3D Damage Identification of Soil Rock Mixture Based on Image Processing Technology

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Abstract. Soil rock mixture is a non-continuous and inhomogeneous geological material. It is significant to quantitatively analyse the internal damage features and evolution laws of destruction of soil rock mixture. The traditional rock and soil mechanics test method and analysis theory don't perform very well. Therefore, a three-dimensional identification method of internal fracture and damage is proposed which based on image processing technology. In the uniaxial compression experiments, the features' changing of the internal microstructure is extracted and analysed. According to the changing, a three-dimensional reconstruction model of the rupture of soil rock mixture is constructed. Besides, the soil rock mixture with different stone content is analysed to receive the influence result of the internal damage. Experiments prove that this method can intuitively characterize the internal damage features and evolution laws of destruction in soil rock mixture.

1. Introduction

Soil rock mixture is different from soil and rock mass [1]. It's a special, discontinuous and inhomogeneous material. Due to its non-uniform, discontinuous and nonlinear characteristics, it is difficult to analyze its deformation and destruction behavior by traditional geotechnical methods. The large-scale construction engineering facilities are increasing with the rapid development of the national economy. Thus the stability of the rock slope and the tunnel's surrounding rock is very prominent. Therefore, it is of great significance to establish the basic theory and analysis method as for the deformation and destruction of the mixture [2].

At present, there are many achievements in the study of soil and rock mixture. The scope of the research mainly includes the geometric structure of the soil rock mixture, the study of the mechanical test and the numerical simulation of deformation and destruction. In situ experiments, most of them focus on the deformation and destruction characteristics of soil rock mixtures. You X.H. et al. show that the rock content is an important index of the soil and rock mixture [3]. Its change has a great influence on the mechanical properties of the material in situ experiments. In the geometric structure, Yue Z.Q. et al. establish the plane geometric model of soil rock mixture by gray processing, increasing contrast and de-noising [4]. The three methods are facing on the digital photographs of soil rock mixtures. It reflects the heterogeneity and other mesoscopic structure of the material. Lanaro F. et al. obtain the 3D image of the gravel by scanning the gravelly soil which uses laser-scanning technology and analyzes the relevant parameters [5]. In numerical simulation, Li S.H. et al. simulate the uniaxial compression test of

the soil rock mixture using three dimensional discrete element method [6]. The results of the experiment reveal the mechanical phenomena of the heterogeneous and discontinuous medium. However, the existing studies rarely involve the three-dimensional identification of soil rock mixture fracture and damage.

In the paper, the uniaxial compression destruction process of soil rock mixture is scanned. Extracting and analyzing the internal fracture and damage process of the soil rock mixture in the process of uniaxial compression by using three-dimensional digital image processing technology, fracture recognition program and 3D model reconstruction. Proposing the characterization method of internal damage in the soil and rock mixture and analyzing the law of damage evolution of the soil and rock mixture is quantitatively.

2. Scanning Experiment

In order to study the evolution law of the mixtures' internal fracture and damage the paper caries out a scanning experiment under uniaxial compression [7]. It scanned the damage process of rock mixture with different rock rate. The mixture of soil and rock prepared in advance. Stone and plain soil are mixed into the mold according to the mass percentage. The rock and soil mixture specimens with different stone content are made by layered compaction, and two ends of the specimen are filled with 7mm soil layer. The specimens are maintained at room temperature. When the moisture content reduces to the specified value, remove the mold and obtain the specimen for compression and scanning. For the investigation of rock content's effect on the mixture, the paper designs four different stone containing rates, namely 0 (prime soil), 15%, 35% and 45%. During the uniaxial compression process, different load periods are scanned. The periods include before loading, 30% Pu before peak, 60% Pu in front of peak, Pu of peak load, 60% Pu after peak, 30% Pu after peak. When the axial pressure reaches the design load level, real-time scanning for the specimen is carried out. After scanning, continuing the load and scanning the next load level. In order to reduce the influence of end effect, the scanning is concentrated in the 1/3 height range in the middle of the specimen. The 100 1024*1024 horizontal slice is obtained at each loading stage, as shown in Figure 1.
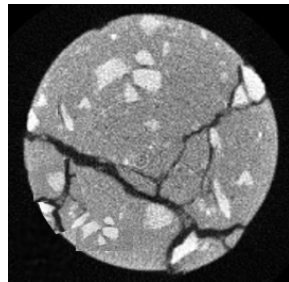

Figure 1. Original image (the stone rate of 15% as an example)

3. 3D Identification of Fracture and Damage

Computer digital image is composed of a series of pixels arranged in rectangles. For example, each pixel corresponds to an integer value of 0~255 in the 8 bit grayscale images. The value represents different gray values respectively. Therefore, using a rectangular coordinate system and a discrete function can represent an image of $m \times n$ pixel size. Pixel matrixes composed by different gray values constitute the whole image. The different gray values represent the different information contained in the image, and the pixels corresponding to each discrete data.

3.1. Image Filtering

Image filtering suppresses the noise of target image in the condition of preserving the images' details as much as possible [8]. Extracting the image obtained by the scan directly without any processing will

create many false features. It will directly affect the validity and reliability of the subsequent image analysis. Therefore, it is necessary to extract the useful information from the noisy signal.

As for digital image signal, the noise expresses as extremum, which function on the true gray value of the image pixel through adding and subtracting. So the grayscale need to be filtered before processing the image. According to the noise characteristics of the image obtained in this experiment, it use Gauss filtering algorithm to achieve the purpose of noise reduction.

3.2. Multi-threshold Segmentation

Threshold segmentation method is a kind of digital image segmentation technology based on regional. The principle is to divide pixel points into several classes according to the difference in gray characteristics. Multi threshold segmentation distinguishes and divide the target by selecting multiple appropriate gray threshold. In the paper, the original image is converted to the image that contains only three-grayscale according to formula (2).

$$f'(x, y) = \begin{cases} G_1, & f(x, y) > T_2 \\ G_2, & T_1 < f(x, y) < T_2 \\ G_3, & f(x, y) < T_1 \end{cases}$$

In the formula, $f(x, y)$ is the gray value of each pixel in the original image, and $F'(x, y)$ is the gray value of each pixel in the image after threshold segmentation, T_1 and T_2 is the gray threshold set in the original image.

When the gray value of a pixel point in the original image belongs to a certain gray range from the threshold value, the pixel is given a new gray value G_1, G_2, G_3. Figure 2 is the result of multi threshold segmentation, which contains three colors. The black represents the crack and the background, the gray represents the soil, and the white represents the stone inside the rock mixture. Figure 2 shows that there is too much white near the edge of the specimen, and some cracks have not been fully displayed. Only by multi-threshold segmentation cannot extract the cracks and stone features in the soil rock mixture very well.
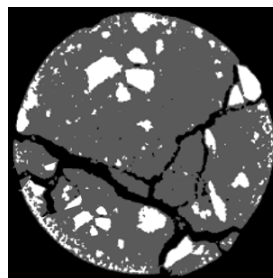

Figure 2. The result of multi threshold segmentation

3.3. Grayscale Compensation

Since the composition of the plain soil is the same and uniform, the gray value of the theoretical specimens should be the same. It can be found that there are some difference between the scanned images and the actual situation of the specimen. It is the main reason for the poor effect of multi threshold segmentation.

The paper adopts the grayscale compensation method to eliminate the influence. Firstly, the pixel values of all the plain soil are counted before loading. The gray difference of each pixel to the center of the specimen is calculated. Assuming that the scanning device's effect on each image is the same, the statistical grayscale difference is compensated to all images before multi threshold segmentation. The results of the multi-threshold segmentation are shown in Figure 3. It shows that the grayscale

compensation achieves the ideal effect. It has obvious consistency with the shape and position of the stone in the figure, and some cracks on the edge of the specimen are displayed obviously.
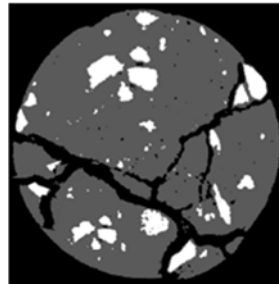

Figure 3. Gray value compensation segmentation

3.4. Smoothing Filter

In order to make the edge of the stone in the image is smoother, it is necessary to smooth the figure. Firstly, the pixel with a gray level of 255 is extracted in the image. It is saved as an image containing only stones and background. Then the median filter with appropriate parameters is adopted to smooth the stone image.

3.5. Background Extraction

The internal cracks and external space of specimen are filled with air, so the gray level of the cracks in the scanned images is close to the background gray. After the threshold segmentation, they are all black and it's difficult to distinguish. This will cause adverse effects on the reconstruction of the subsequent 3D model and analysis of the crack [9].

For this reason, the crack and the background are separated based on the geometry of the specimen and its location with the background. As shown in Figure 4, the light grey (gray value 200) in the figure is the background of the separation, which is in sharp contrast to the other parts of the specimen.
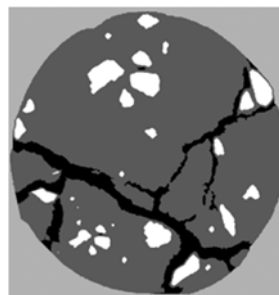

Figure 4. The processed image

4. Experiments

4.1. 3D Model Reconstruction

In order to analyze the three-dimensional space form of crack and the development law of different loading stages, the paper develops a three-dimensional reconstruction algorithm. The three-dimensional reconstruction of the scanning results is made. The Table 1 shows the internal structure evolution and cracking mode of the rock mixture with different rock content. The Pu indicates the peak load of the compression failure. In Table 1, the deep black part is the compression-cracking crack. The white part represents the stone, and the transparent gray part is the homogeneous soil.

Table 1. 3D image of soil rock mixtures' internal damage at different loading stages

	0%	15%	30%	45%
Unloaded	None	None	None	None
Peak front & 40%Pu	None	None	None	None
Peak front & 70%Pu	None	None	None	None
100%Pu	little	None	None	None
Peak behind & 70%Pu	some	some	some	some
Peak behind & 40%Pu	serious	serious	serious	serious

It can be found that before the load reaches the peak value, the cracking of the mixture under uniaxial compression is mainly along the vertical direction. Except for the original gap, there is no new crack inside the rock content test parts. When the load exceeds the peak value, there is obvious crack inside the specimens. In the mixture of low rock content (0 and 15%), there are few coarse cracks in the mixture. In contrast, there are many thin and short cracks in the mixture of high rock content (30% and 45%). The results show that the rock inhibits the expansion of larger crack inside the specimen and the deformation of soil rock mixture.

4.2. Damage Analysis

The damage value is a measure of the degree of deterioration of materials or structures. It can be intuitively understood as the percentage of the volume of a crack in the whole material. In the paper, the damage variable R is defined as the ratio of the crack area to the total area (including the crack) of a specimen. The formula is following:

$$R = S_1/S$$

Where, S_1 is the area of crack and S is the total area of the specimen.

Because the corresponding gray value of the crack is 0, the area of the crack can be obtained by counting the number of pixels of 0 in the statistical image, and the total area of the specimen can be obtained by the same reason. Therefore, in the actual calculation process, the formula is converted to the following:

$$R = N_1/N$$

Where, N_1 is the number of pixels occupied by cracks in a certain surface and N is the total number of pixels occupied by the specimen of the surfaces.

Figure 6 shows the horizontal crack morphology and the evolution of damage during the different compression stages of rock and soil mixtures with different rock ratios. R_1 to R_6 is the average damage value of all horizontal section at each loading stage, and the crack development process of the specimen at the same level of the same layer at each loading stage is given.

Table 2. Average damage values in horizontal direction of soil rock mixtures with different rock ratios

	D_1	D_2	D_3	D_4	D_5	D_6
0%	9.57×10^{-5}	8.65×10^{-5}	7.69×10^{-5}	3.68×10^{-3}	0.052	0.135
15%	7.32×10^{-5}	7.98×10^{-5}	3.67×10^{-4}	0.022	0.074	0.092
30%	3.22×10^{-3}	5.74×10^{-3}	7.95×10^{-3}	2.45×10^{-3}	0.033	0.087
45%	0.014	0.016	0.010	0.017	0.029	0.140

Table 3demonstrates the variation of average damage value in horizontal direction with strain. Table 3 shows that the damage of the rock mixture with rock content of 0%, 15% and 30% decreases with the

increase of the rock content. When the stone content increases to 45%, the damage increases with the increase of the stone content. The cause of this phenomenon may be that the rock blocks the expansion of the larger cracks in the specimen and inhibits the development of the damage as well.

Table 3. The change law of average damage in horizontal direction

	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	0.004	0.008	0.049	0.088	0.097	0. 172	0.188	0.223	0. 257
15	0	0.002	0.005	0.034	0.056	0.078	0.117	0.129	0. 142	0.185
30	0	0.001	0.003	0.009	0.039	0.068	0.075	0.083	0.108	0.122
45	0	0.020	0.030	0.050	0.130	0.165	0.207	0.249	0.272	0.295

Through the above analysis, it is found that the damage decreases with the increase of stone content when the stone content is low, and the damage increases with the increase of the stone content when it is high. The effect of rock on the damage evolution of soil and rock mixture has a critical stone rate. From this experiment, the critical rock content should be 30%~45%, and the more accurate numerical value needs further confirmation.

5. Conclusion

The paper proposes a quantitative method for the damage of soil and rock mixtures, and analyses the influence on the internal damage of the soil rock mixture with different stone content. Through the experiments and researches, we can draw several conclusions as following:

(1) In the uniaxial compression environment, the cracking of the soil rock mixture is mainly along the vertical direction. Before the load reaches the peak, there is no crack in the rock mixture. Once the load exceeds the peak, there will be obvious cracking in the interior of the soil mixture.

(2) Before the load reaches the peak, the average damage value of the horizontal direction maintains at a lower level, and does not change with the increase of the load. Once the load reaches the peak, there is obvious cracking inside the soil and rock mixture. With the increase of vertical displacement, the damage in the horizontal direction began to increase significantly and accelerate constantly.

(3) The existence of rocks restrains the deformation of the soil rock mixture and inhibits the expansion of the larger cracks in the interior of the rock.

(4) The effect of stone on the damage development of soil rock mixture is closely related to the rock content. When the rock content is relatively low, the damage decreases with the increase of stone content. When the rock content is higher, the damage increases with the increase of stone content. There is a critical rock ratio in the influence of stone on damage evolution.

It is necessary to point out that the paper focuses on the identification and analysis of the soil rock mixtures' damage based on three-dimensional reconstruction. As for the influence of rock ratio, soil types, rock types, and physical properties on the damage evolution of soil rock mixture will be studied and analysed in another paper.

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