A Quantitative Index Representing Crack Shapes and Corresponding Techniques

Junhua Wu¹,², Tangliang Kuang¹, Fangyuan Fu¹ and Jiahao Li¹

¹ College of Civil Engineering and Architecture, Nanchang Hangkong University, Nanchang, Jiangxi Province, China
² Key Laboratory of Failure Mechanism and Safety Control Techniques of Earth-Rock Dam of the Ministry of Water Resources, Nanjing, Jiangsu Province, China
E-mail: wjhchuo0791@126.com

Abstract. In order to quantificationally describe the soil cracks due to dry-wet cycles, the concept of gray level entropy is applied according to the physical significance of the information entropy to represent various shapes of cracks. Then a piece of simple and easy-to-use equipment for taking photos is used to monitor and record the crack propagation. A grayscale image and the corresponding gray level entropy are obtained automatically by a program. Test results showed that gray level entropy can quantificationally describe the shape of cracks reasonably well and evaluate the degree of crack development effectively.

Keywords. gray level entropy; crack; photograph; image processing.

1. Introduction

Desiccation cracking is an important phenomenon in soils. Bronswijk & Evers-Vermeer [1] cited several positive and negative effects of cracking on agricultural soils. The development of desiccation cracking is determined by the interaction of numerous factors, including soil mineralogy, rate of water loss, total drying time, the repeated rise and decline of underground water, repeated rain and evaporation, etc. The positive effects include improved infiltration[2], drainage[3], and soil structure[4]. Soil cracks can also help alter the pore size of soil through intermittent wetting[5], and are utilized during reclamation of high shrink-swell soils as pathways for water and salts[6]. The main negative effect of cracking on agricultural soils is stunting the growth of plants as the rapid transport of water through soil cracks results in the lack of water or higher osmotic pressure (named ‘crop water stress’ in pedology)[7]; or the rapid transport of solute through cracks results in the lack of nutrient (named ‘crop nutrient stress’ in pedology)[8]. Another negative effect of cracking on environment is that surface water contamination if transport is to a drainage system.

Desiccation soil cracking due to dry-wet cycles is commonly observed in expansive soils. As these soils dry, the collapsing layers of the clay micelles cause the soil volume to decrease. While soil swells upon imbibing water, it will result in the healing process of cracks. Soil surface cracks are formed through repeated dry-wet cycles. The shapes of cracks are influenced by numerous factors as mentioned above. In geotechnical engineering, desiccation cracks resulting from dry-wet cycles have significant effects on soil properties such as strength, deformation, permeability etc.[9]. Different crack shapes affect the soil properties differently. Therefore, it is necessary to investigate how to describe the shapes of cracks.

We know from images of cracks that the luminance at places where there are cracks is lower than that at places where there is no cracks. Due to this, RGB images are usually converted into grayscale
or binary images. The main characteristic of cracks are preserved. In this study, grayscale images are used to analyze soil cracks. A testing method and a quantitative index for describing cracks are presented.

2. Theory and Techniques

2.1. Information Entropy

Information entropy is a mathematical nonrepresentational concept in information theory. Generally speaking, information entropy can be considered as the probability of specific information. An ordered system has lower information entropy than a disordered system. The more ordered of the system, the lower the information entropy, and vice versa. In other words, information entropy is an index to describe the degree of order of a system. The grayscale system can be used to represent image information effectively. A colored image can be converted into a 8-bit grayscale image as follows:

\[
GS = \left(0.299 \times R + 0.587 \times G + 0.114 \times B\right)/255
\]

where \(GS\) = gray level ranging from 0 to 255, 
\(R\) = value of primary red color of a pixel in an image, 
\(G\) = value of primary green color of a pixel in an image, and 
\(B\) = value of primary blue color of a pixel in an image.

The gray level \(GS\) shows how close the color of a pixel in an 8-bit grayscale image to white or black. The greater gray level means the color is closer to white. When \(GS\) equals 255 it is white, while it’s black when \(GS\) equals 0. Suppose the frequency of a certain gray level \(i\) is \(P_i\), where 
\[N \sum_{i=0}^{N-1} f_i = 1\]

\(N\) is the total number of gray levels (256 for 8-bit grayscale image), and \(f_i\) is the number of pixels which \(GS\) equal \(i\). The bigger the \(P_i\), the more the number of pixels have gray level of \(i\). The information entropy for the image is defined as following:

\[
H = -\sum_{i=0}^{N-1} P_i \log_2 P_i
\]

Where \(H\) is the information entropy of a gray level image, named as the gray level entropy.

We know from the physical significance of information entropy that the greater the information entropy, the more the average uncertainty of information source, and vice versa. Thus the gray level entropy reflects the gray level distribution in a discrete manner. When the image is relatively uniform, the range of gray level is smaller and consequently the average uncertainty is small. This leads to small gray level entropy. While the gray level at places where there are cracks is lower, the range of gray level is larger and the average uncertainty increases which results in the increased gray level entropy.

3. Equipments and Techniques

As mentioned before, photographic techniques and image processing techniques, which are already mature, provide us with a new method to research soil surface cracks. First the image of cracks is taken with a digital camera. Then the information contained in the image is obtained using image processing techniques. The main equipments needed are: a digital camera (the Nikon COOLPIX L16 in our case); and a computer to operate the image processing software or program developed in-house using Visual Basic in our case. The schematic of our photography setup is shown in figure 1. In order to eliminate the effect of artificial factors, the digital camera is fixed at some distance from the soil surface with the tripod. Additionally, the camera lens and the soil surface should be in parallel and the image should be captured in the middle visual field. The image can be obtained by putting the
specimens on a pedestal. A code using Visual Basic is adopted to extract the RGB information from an image and convert to the grayscale image. Then the gray level of each pixel is calculated using Eq. [1]. Finally, the image gray level entropy can be obtained using Eq. [2] by counting the gray level distribution of the image.

![Figure 1. Schematic of the photography setup.](image)

| liquid limit | plastic limit | sand/mm | silt/mm | clay/mm | colloidal/mm |
|--------------|---------------|---------|---------|---------|--------------|
| $W_d$/%      | $W_p$/%       | 0.5~    | 0.25~   | 0.1~    | 0.075~       | 0.005~       | 0.005~       | <0.005 | <0.002 |
| 29.5         | 15.1          | 8.3     | 1.0     | 1.9     | 1.4          | 1.2          | 40.3        | 45.9     | 37.7   |

| Specific gravity | Maximum dry density | optimum water content | free swelling ratio |
|------------------|---------------------|-----------------------|---------------------|
| 2.72             | 1810                | 15.7                  | 57.5                |

### 4. Test and Verification

In order to verify the feasibility of using gray level entropy as an index to describe the shape of cracks, a series of tests on soil cracking are carried out and images of a soil surface with cracks are obtained at regular intervals. In this study, soil was obtained from the South-to-North Water Diversion Project in Xinxiang, northern Henan, China. The soil parameters are given in table 1 and table 2.

First, all the specimens and equipments are placed in the room. The photographic distance (see figure 1) is 600 mm and the resolution is set to 800×600. Pictures are taken in natural light and the water content is obtained every time a picture is taken. The images we took and the corresponding histograph of gray level are drawn in figure 2 (a)-(f). Cracks are generated and propagated due to water loss. In time, the main cracks are widened and deepened, and new cracks are generated near the main cracks. It can be seen in the images that the luminance of the cracks is higher than the luminance of other places. In other words, the gray levels of the pixels forming the crack are lower than those of pixels forming the rest of the image. We can see that the frequency distribution of gray level becomes bimodal from the initial unimodal distribution. There is one main big crack in figure 2(a), but the area is small compared to the whole. This has limited influence on the gray level distribution, and the main values of gray level still depend on the area without cracking. That means the gray level is more concentrated in a smaller range. So a unimodal distribution is shown in figure 2(b). There are two main big cracks in figure 2(c). It can be seen that the width and length of cracks are wider than that one in figure 2(a). These areas cannot be ignored compared to the whole. That means there are two
main distribution ranges of gray level here: the crack areas lower gray level contains and the rest of image higher gray level contains. The range of gray level distribution increases, mainly to the lower values. So a bimodal distribution is shown in figure 2(d). Similar results are obtained in Figure 2(f) and the range of gray level distribution increases further. Going from (a)/(b) to (c)/(d) and (e)/(f), the gray level distribution is evidently enlarged to include mainly the lower values. The peak distribution frequency reduces with crack propagation. The values of grey level entropy calculated using Eq. [3] are plotted against the corresponding water contents in figure 3. It is observed that grey level entropy increases with crack propagation. This shows that the grey level range of a soil image changes due to crack propagation. The uncertainty that one value of grey level has appeared increases greatly which results in the increased grey level entropy. From the above analysis, it can be concluded that grey level entropy is an effective index to represent and evaluate the shapes of cracks.

Figure 2. The photos and corresponding frequency distribution of gray level.
5. Summary and Conclusions

1. In order to quantitatively describe soil cracks, a simple setup for taking photos of cracks is designed in this study. According to the physical significance of information entropy, crack images are converted from RGB model to grayscale model, and the concept of gray level entropy is applied to represent various shapes of cracks. Test results showed that gray level entropy can quantitatively describe the shape of cracks reasonably well and represent the degree of crack development effectively. A sensitivity analysis of influencing factors such as photographic distance, luminance, resolution etc. has also been carried out.

2. The luminance of cracks on a soil surface is lower and gray level is lower than that at places where there are no cracks. This leads the gray level range and therefore gray level entropy to increase. Thus the gray level entropy increases with crack propagation.

Acknowledgements

This work is supported by Project (51869013) of the National Natural Science Foundation of China and Project (YK321013) of Open Research Fund of Key Laboratory of Failure Mechanism and Safety Control Techniques of Earth-Rock Dam of the Ministry of Water Resources. All opinions, findings and conclusions in this work represent the views of the authors only.

References

[1] Bronswijk J J B, Evers-Vermeer J J. 1990 Shrinkage of Dutch clay soil aggregates [J] Journal of Agricultural Science 38 175-194.
[2] Swartz G L. 1966 Water entry into a black earth under flooding [J] Journal of Agricultural Animal Science 23 407–422.
[3] Wilding L P, Hallmark C T. 1984 Development of structural microfabric properties in shrinking and swelling clays, Proc. Symposium ISSS. International Institute for Land Reclamation and Improvement, Wageningen, Netherlands 1–22.
[4] Bronswijk J J B. 1989 Prediction of actual cracking and subsidence in clay soils [J] Journal of Soil Science 148 87–93.
[5] Jalai-Farahani H R, Heermann D F, Duke H R. 1993 Physics of surge irrigation. II. Relationships between soil physical and hydraulic parameters [J] Transactions of the ASAE 36 45-50.
[6] Malik M, Amrheim C, Letey, J. 1991 Polyacrylamide to improve water flow and salt removal in a high shrink-swell soil [J] Soil Science Society of America Journal 55 1664 – 1667.
[7] Thomas G W, Phillips R E. 1979 Consequences of water movement in macropores [J] Journal of Environmental Quality 8 149 – 152.
[8] Harris, G L, Nicholls P H, Bailey S W, et al. 1994 *Factors influencing the loss of pesticides in drainage from cracking clay soils* [J] *Journal of Hydrology* 159 235 – 253.

[9] Inoue H. 1993 *Lateral water flow in a clayey agricultural field with cracks* [J] *Geoderma* 59 311 – 325.