Estimation of Unconfined Compression Test (UCT) parameters using digital image analysis

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Abstract. Digital image analysis is a method of studying digital image for obtaining significant information and has been widely used in engineering field. In this research, digital image analysis is used to estimate related parameters from unconfined compression test. Soil sample is prepared and tested until failure. During testing, vertical deformation are recorded manually, and video are captured. Static images are extracted from the video and analysis on those images are performed. The measurement from digital images are compared with manual measurement. It was found that, digital image analysis on sample produce close result when compared with manual measurement. This suggest that this method might be suitable as an alternative for manual measurement. Method for determining Poisson’s ratio using digital image is also proposed.

1. Introduction

Unconfined Compression Test (UCT) is one of the tests to determine strength and stiffness parameters of soil. Despite of its limitation compared to triaxial test and direct shear, it is used widely due to its simplicity. In order to determine the parameters, the applied force and the vertical deformation of the sample need to be measured. The measurement can be performed manually (using proving ring and manual dial gauge) or automatically (using digital transducer and data logger). However, if it is necessary to determine Poisson’s ratio, it is quite difficult to measure horizontal deformation using both manual dial gauge or digital transducer. Furthermore, physical measurement might be inaccurate, as the dial gauge or digital transducer might not located at the accurate position. In addition, manual data collection might lead to human error. Therefore, it is necessary to find alternative to those measurement methods. In this study, digital image processing is proposed as an alternative method. This method might provide more accurate measurement, and in addition, it is easy to be conducted.

Measurement of displacement during triaxial testing using laser scanning device had been developed by [1]. However, it is very expensive, as it involves sophisticated apparatus. Other researchers had developed methods that utilize digital image. Measurement of deformation during triaxial test using combination of digital photography, close-range photogrammetry and image analysis by Particle Image Velocimetry (PIV) was performed by [2]. In order to obtain deformation and strain for whole surface of the specimen, [3] combine application of camera and two mirrors. Method developed by [4] is quite similar to [3], but it involved reconstructing 3D renderings of triaxial specimens from planar images. Other work were established by [5], which used 2D images to determine volumetric shrinkage of soil that not subjected to any loading. Determination of Young’s
Modulus of clayey soil from digital image had been established by [6]. All the above-mentioned works involve complicated setup. Therefore, this work is proposed as a simpler method for determining deformation of specimen during testing.

2. Material and Methods

2.1. Experimental

2.1.1. Sample The soil sample used in this study was taken inside UiTM Pulau Pinang (coordinate 3.0696°N, 101.5038°E). The laboratory tests for particle density, particle size distribution and Atterberg Limit were performed according to [7]. The physical properties of the soil are as shown in Table 1.

| Colour          | Grey          |
|-----------------|---------------|
| Particle density [g/cm³] | 2.68          |
| Sand [%]        | 85.5          |
| Silt [%]        | 10.5          |
| Clay [%]        | 4.0           |
| Liquid Limit [%] | 50.0          |
| Plastic Limit [%] | 39.0          |
| Plasticity Index [%] | 11.0          |
| Soil classification - PSD | silty SAND (silt of intermediate/high plasticity) |

The Unconfined Compression Test (UCT) was performed in accordance to [8]. A cylindrical remoulded sample was prepared with moisture content equal to 35%. The size of the cylindrical sample is 38mm x 75mm.

2.1.2. Sample testing and video recording. The rate of displacement was 1.5mm/min. This rate agreed with suggested rate in [8], which is 2%/min. Corresponding forces were recorded for every 20s. During testing, video was recorded simultaneously. A light colour (in this study, yellow) was chosen as background, because the colour of the sample was quite dark. The purpose of choosing contrast colour for background was to ensure the edges of the sample can be easily detected during image analysis.

2.2. Image Processing

From the video that was recorded, static images were extracted for every 20s (image corresponds for recorded force). The static images were captured using HyperSnap 2.70, due to its ability to recapture images at the same region. The image equivalent to t=0s are captured and converted to binary image using MATLAB software. Table 2 shows the code for converting colour image to binary image using MATLAB.
Table 2. MATLAB Command for image conversion.

| Task                          | MATLAB Command                  |
|-------------------------------|--------------------------------|
| Read image                    | f = imread ('filename.filetype'); |
| Convert image to grayscale    | g = rgb2gray (f);               |
| Convert grayscale image to binary | h = im2bw (g);                 |

The captured colour image and converted black and white image are as shown in Figure 1. The binary representation for each pixel (black=0, white=1) were transferred to Microsoft Excel to be analysed. However, for image equivalent to t=0s, it was necessary to check the verticality of the captured image. This was due to reality that it is quite difficult to ensure that the camera was perfectly horizontal during image capturing. If the image was not vertical, it will be rotated until accepted verticality was achieved. For this purpose, Microsoft Office Picture Manager was used. Once the degree of rotation had been determined, all other images were rotated using the same degree of rotation.

![Figure 1. From left to right: a) Colour image for t=0s, b) Colour image for t=360s, c) Black and white image for t=0s, d) Black and white image for t=360s](image)

For image equivalent to t=0s, it is necessary to perform the calibration, i.e. to determine the amount of pixels corresponds to the initial dimension. This calibration was necessary, in order to determine the dimension from the binary image. Once the calibration was done, the amount of pixels that represent vertical (height) and horizontal (diameter) dimension was counted. For this study, the middle column was chosen to represent height, while the middle row for image equivalent to t=0s was chosen to represent diameter. This analysis did not consider the change of middle row (as the sample was loaded), since the horizontal deformation was quite similar for the whole height of the sample. However, if the sample was bulging, it might be necessary to count different row for different image.

The vertical and lateral strain were determined by comparing height and diameter of each image, relative to image equivalent to t=0s. From the comparison, the stress-strain curve was developed, and subsequently the strength and stiffness of the sample were determined. The Poisson’s ratio (ratio between lateral and vertical strain) of the samples was also determined.
3. Results

3.1. Stress – Strain Relationship
The stress – strain curve for both manual and digital measurement are as shown in Figure 2. From the plot, it can be observed that strain from digital measurement is slightly lesser compared to manual measurement. The parameters that can be obtained from stress-strain curve are Unconfined Compressive Strength, UCS and initial stiffness, E. Table 3 shows comparison between manual and digital measurement for both parameters.

![Stress-strain curve for manual and digital measurement](image)

**Figure 2.** Stress-strain curve for manual and digital measurement.

| Parameter                      | Manual Measurement | Digital Measurement |
|--------------------------------|--------------------|--------------------|
| UCS [kPa]                      | 135.48             | 135.48             |
| Initial Stiffness, E [MPa]     | 2.76               | 6.84               |

3.2. Poisson’s Ratio
Poisson’s ratio in compressive test is defined as ratio between horizontal (expansion) strain and vertical (contraction) strain. For Poisson’s ratio, the values vary from 0 to 0.4 throughout the test. The values also fluctuate, as shown in Figure 3. Theoretically, Poisson’s ratio value is valid for linear elastic part, i.e. the initial part of the test. However, if it is necessary to consider the whole part, linear regression of horizontal strain vs. vertical strain can be used, as shown in Figure 4.
Figure 3. Variation of Poisson’s ratio with stress

Figure 4. Linear Regression for obtaining Poisson’s ratio (\(v=0.4\))
4. Conclusion
Based on the results, this method can be applied for determining parameters from Unconfined Compression Test. Despite the accuracy might be slightly lower compared to other method that used more sophisticated equipment, this method is affordable to be applied in industry.

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