APPLICATION OF IMAGE ANALYSIS ON TUNNELLING IN GRAVEL FORMATIONS

Keh-Jian Shou Chia-Tsung Wu

Department of Civil Engineering
National Chung-Hsing University

Abstract: Gravel formations are widely distributed in Taiwan area, especially at the western terraces and foothills of the Central Ridge. The gravel formations are composed of a composite geomaterial which is mainly consisted of different sized gravels and different types of soils. Their engineering properties are quite different not only with each other but also from other soil or rock formations, therefore, the classification methods for rock tunnelling such as RMR and Q-system are not applicable. In this study, the image analysis method together with simple in-situ testing are adopted as the measurement for the engineering classification of gravel formations. This quantitative measurement can be used as the basis of support design for tunneling in gravel formations.

Keywords：gravel formations, tunnelling, image analysis

1. INTRODUCTION

Generally speaking, the engineering properties of gravel formations in western Taiwan are considered with good self-support ability for underground excavations. However, the hazards do occur from time to time due to ignoring the important influence factors such as the ground water or the lens (composed of sand or clay) within the gravel formations. In this study, a simple algorithm for gravel formation classification is proposed. According to this algorithm, simple testing, including the Schmidt hammer test and the penetration test, together with the image analysis areadopted. The image analysis method can be used to reveal not only the composition of the gravel formations (ratio of gravel to soil) but also the anisotropy properties due to the shape of the gravels and the arrangement of the gravels. The image analysis can more efficiently and economically replace the traditional seiving analysis. The main purpose of this study is to use the image analysis method together with simple in-situ testing to quantitatively classify the gravel formations in order to provide a judgement for the tunnel support design.

2. ENGINEERING PROPERTIES OF GRAVEL FORMATIONS[1,2]

Due to the cases adopted, this study will focus on the gravel formations in central Taiwan (Taichung area), even though the idea of classification could be applied to gravel formations in other area. The gravel formations are composed of a composite geomaterial which is mainly consisted of different sized gravels and different types of soils. As the diameters of the gravels, with a large volumetric percentage, are greater than 20cm, it is difficult to obtain the mechnical properties accurately due to the size effect. The large scale in-situ test provides an alternative to obtain the properties, however, the cost could to too high for projects of general magnitude. The gravel formations generally possess good ability of self support, but the ability can dramatically decrease as the change of groundwater condition due to the loss of soil between the gravels. Therefore, support systems with pumping facilities are always necessary for the excavation projects in this area. The gravels in this area are originally from quarzite with a hardness larger than 6 in the Mohr's scale and the uniaxial compressive strength of more than 1000 ~ 2000 kg/cm^2, which causes the difficulties in the excavation work.

Huang[3] investigate the laterite in the Tatu terraceand found the internal friction angle ϕ is about 37°. Wu et al.[4], based on their laboratory and in-situ testing, predict the friction in this area is about 54°. Ren and Shou[2] performed the in-situ test in the driving pit of a pipejacking project in Taichung City and found the gravel formation in the Taichung basin has cohesion C about 0.15 kg/cm^2 and internal friction angle about 48.7°. In general, the gravel formations in Taichung area possess high internal friction angle and low cohesion.

Based on the plate load tests in western Taiwan, we can find that the static deformation modulus can be greater than 9000 kg/cm^2 for larger gravel content (＞75□), on the other hand, the deformation modulus significantly decreases as the gravel content less than

60□ . Based on the site investigation results, the gravel content of the gravel formations in Taichung city is about 79□ , also due to the testing did by Lin et al.[5], the dynamic deformation modulus is about 11000 kg/cm^2 and the static deformation modulus is about 10000 kg/cm^2 in Taichung City. However, due to the size effect (the size of the plate is limited due to the capacity of the jacks) the data might not be very reliable. Lin[6], following Sung[7], study the gravel formation in San-Yi area and presented a empirical formula which predicts the deformation modulus, for different depth (1-15m) can vary between 63MPa~120Mpa.

According to a literature review on the mechanical behaviour of the gravel formations[8,9,10,11], it can be concluded: (a) If the soil between gravels increases (greater than 30% in volume), the contact effect for the gravels will be reduced and replaced by the confining effect from soil to the gravels. (b) For the condition of low confining pressure, the behavior of the gravel can be described by the concept of roughness angle given by Paton[12], which explains the ‘abnormal’ high friction angle (50°) we found. (c) For the condition of high confining pressure, the behaviour of the gravel (with a lower friction angle compared with the low confining pressure condition) can be considered as a material in a more general way. (d) The gravel formation can possess anisotropy properties due to the shapre of the gravels and the arrangement of the gravels. (e) The cementation can increase the cohesion between soil particles and between soil and gravel. (f) Groundwater affect the behavior a lot due to the breaking of cementation and the loss of soils between the gravels.

3. CLASSIFICATION OF GRAVEL FORMATIONS

The mechanical properties of the gravel formations are influenced by the behaviour of the soil, the ratio of soil and gravels, the gradation of gravels, and the shape and arrangement of gravels, etc.. As the gravels in this area are commonly with diameters greater than 20cm, it is difficult to obtain the mechnical properties accurately due to the size effect. Besides, the classification methods for rock tunnelling such as RMR and Q-system are not applicable for gravel formations. At this stage, the support design for tunnelling in this area is more in the qualitative side which is over-conservative in general. It is important to measure the mechanical properties of the gravel formations in a more quantitative way in order to design the support more properly.

3.1 The Classification Algorithm

It is essential that we consider the behaviour of the components, i.e., the soil and the gravels, separately in the first place. The behaviour of the gravel formation also somehow reflect the interaction between the components, therefore, the index reflecting the condition of interaction is necessary. Besides, the secondary contral factors, such as the lens within the gravel formations and the groundwater condition is also very important in the classification. Based on a preliminary study and analysis, an algorithm for the classification can be summarized and demonstrated in Figure 1. In this algorithm, the major control factors include the properties of soil, the ratio of soil and gravel, the properties of gravels, the shape and arrangement of gravels, etc. In this study, the image analysis method and two simple testing methods (the Schmidt hammer for the gravel and the penetration meter for the soil) are adopted as the tool to collect the indeices to reflect the control factors. The benefits of this approach are easy, efficient, and less disturbing the tunnelling work.

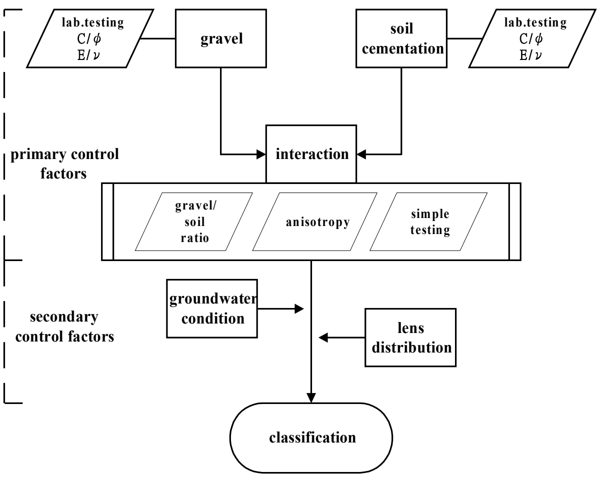


Figure 1. The algorithm for the classification of the gravel formations

3.2 The Classification Methods

The image analysis method is adopted not only to replace the traditional seiving analysis but also provide more information on the control factors. Besides, the Schmidt hammer testing on the gravel provides the properties of the gravels, and the penetration testing provides the properties of soil and the condition of cementation.

3.2.1 the Carlibration of Image Analysis

In order to carlibrate the image analysis, traditional seiving tests were executed according to ASTM code. Two test sites, one excavation site in the Taichung Basin and the other tunnelling site in the Pakua Terrace, are chosen for carlibration. In each site, two tons of the laterite were taken for theseiving analysis.

3.2.2 Schmidt Hammer Test and Penetration Test

Three 1m×1m (Figure 2) areas in the opening face are chosen. The image of the tree areas are taken by a digital camera and analyzed by computer softwares. Besides, randomly chosen gravels are tested by the Schmidt Hammer, and randomly chosen soil test points between gravels are tested by the penetration meter (see Figure 3). In each area, we take 10 tests and drop out the largest and lowest values.

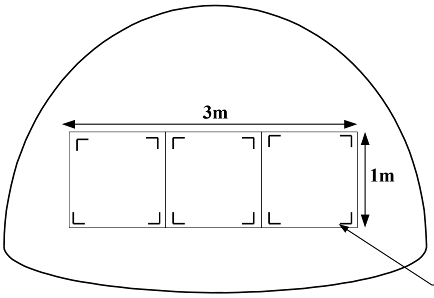


Figure 2. The three 1m×1m testing areas at the heading of a tunnel

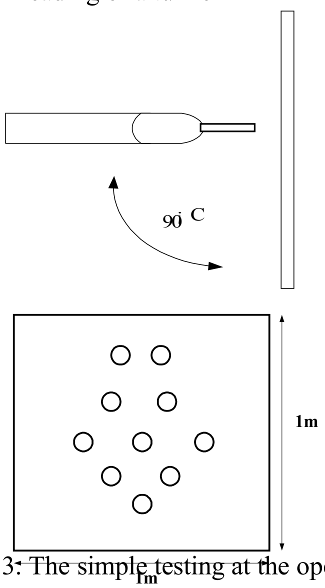


Figure 3: The simple testing at the opening

The testing results can be analyzed by the concept of the probability density function as below :

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n} (x_i - \bar{x})^2$$

$$f_x(x) = \frac{\exp\left[-\frac{1}{2}\left(\frac{x-\bar{x}}{s}\right)^2\right]}{s\sqrt{2\pi}} \quad \text{for} \quad -\infty \le x \le \infty \quad \ldots\ldots\ldots\ldots (2)$$

where x_i is the reading, nis the number of the readings, s^2 is the variance, $\bar{x}$ is the mean, $f_x(x)$ is the probability density function.

3.2.3 The Image Anaslysis

Before we take the digital image, several 10cm×10cm L-shape scales are placed at the areas(see Figure 3). The images of the three 1m×1m areas are then taken by digital camera. After we take the digital images, the Schmidt Hammer Test and Penetration Test can be performed in the same areas. The image seiving was performed by tranforming the seive to an area of circle with circumference equal to the total length of the four sides of the standard seive. Due to the resolution, the image seiving only applied to the size larger than 3/8inch in diameter at this atage.

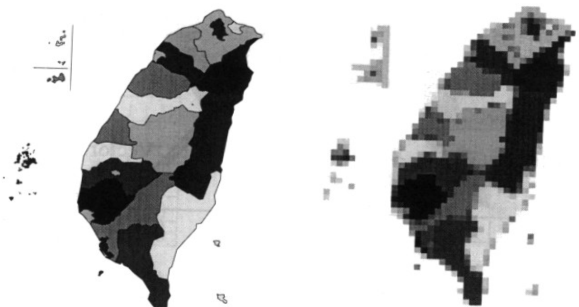
3.3 Theory of the Image Analysis 圖四 工作流程圖

The main process of the image analysis is to transfer the raster image to the vector image (see Figure 4). In the vector image, eacl coordinates, etc., such the images. On the composed of pixel with color components, it can reveal the difference in color but cannot be treated mathematically.

(a) find the boundary of gravel and soil

The images taken by the digital camera are the raster type. In order to get the information in more detail, the high resolution setting 1280 pixel/in was chosen with a more reliable .BMP type file. After we obtain the digital image, the analysis was performed by the computer softwares PhotoImpact5.0, Arcview3.0, and Arc/info. We use the PhotoImpact5.0 to find the boundaries between colors (the boundary between the soil and gravels), use the Arcview3.0 to simplify the contrast of colors, and analyze the simplified images by the Arc/info to get the useful indeices for classification. The image treat and analysis process is illuatrated in Figure 5.

(b) simplify the color contrast



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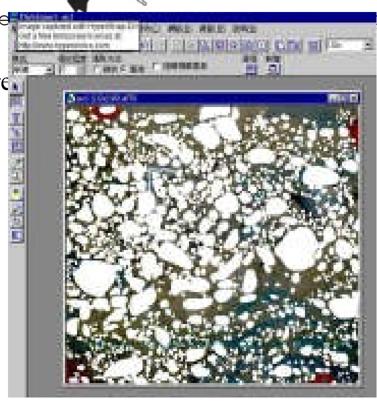
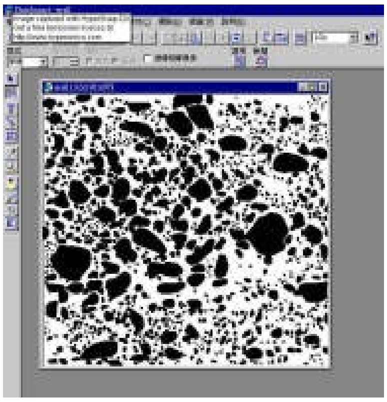
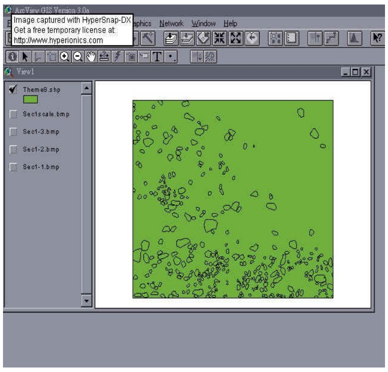


(a) testing at right angle to the surface



(b) randomly chosen test points



(c) analyze the modified image

Figure 5. The procedure of the digital image treatment

Applying the image analysis together with the simple testing at the opening face, we can obtain the indices necessary for the classification algorithm described in section 3.1. Through the evaluation processes, we can easily quantatively classify the gravel formations and provide suggestions on support design. A simple evaluation sheet is also used at the site at this moment for further development, however, the new classification method, like the other classification methods, needs more 'learning experiences' before it is good enough for engineering application.

4. RESULTS AND DISCUSSION

The results of image analysis was shown in Figure 6. We can find that the size of the gravel is larger in the Taichung Basin than the Pakua Terrace, however the gradation is smooth in both sites. The image seiving analysis is always underestimate the gradation due to the 3D effect, especially for the formation in the Taichung Basin with larger gravels. In also reveals that the gravel content is larger in the Taichung Basin, which shows that the contact effect of gravels is important. On the other hand, in the Pakua Terrace, the gravel content is lower and the contact effect is replaced by the confining effect of the soil between the gravels. The descrepencies between the image analysis and the standard seiving analysisincreases as the size increases. And this tendency becomes more significant for the formations in the Taichung Basin as the gravel size in larger in the Taichung Basin than the Pakua Terrace. Besides, the shape and the arrangement of the gravels can also be quantified as indices for classification.

The results of the Schmidt Hammer tests are shown in Figure 7, which reveals the compressive strength of the gravels in the Taichung Basin is larger than those in the Pakua Terrace. It also reflects the more contact effect in the gravels for the formations in the Taichung Basin as it has more gravel content. In the Pakua terrace, the low Schmidt Hammer test reading can be explained as the energy absorbed by the soil confining the gravels. In Figure 8, we find the compressive strength of the soils larger for the Pakua Terrace($\bar{x}$ =2.2 Kg/cm^2, S=0.8) than the Taichung Basin($\bar{x}$ =1.2Kg/cm^2, S=1.2). It also reveals that the cementation is better for the formation in the Pakua Terrace. In summary, we must be careful about the failure due to the breaking of the cementation and loss of soils especially in the Taichung Basin.

5. CONCLUSION

In this study, a simple algorithm for gravel formation classification is proposed. According to this algorithm, the image analysis and simple testings are adopted to provide the indices for classification. Beside replacing the standard seiving analysis, the image analysis method can also reveals the composition of the gravel formations in more details, such as the gravel/soil ratio, size distribution of gravels, and the anisotropy properties due to the shape and the arrangement of the gravels. Through the evaluation process, we can easily quantatively classify the gravel formations and provide suggestions on support design. However, more 'learning experiences' is needed before it is good enough for engineering application.

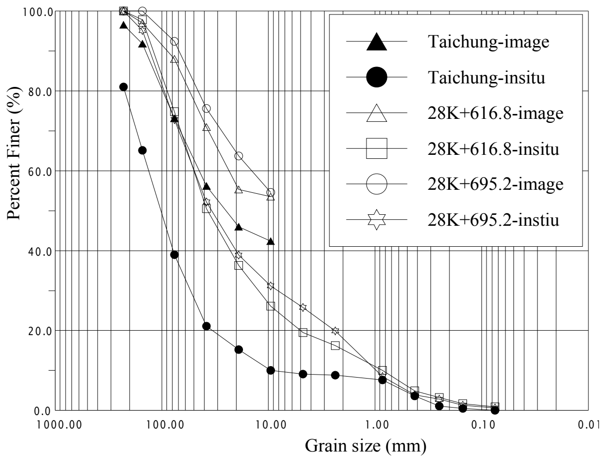


Figure 6. Comparison of the image analyses and the standard sievings

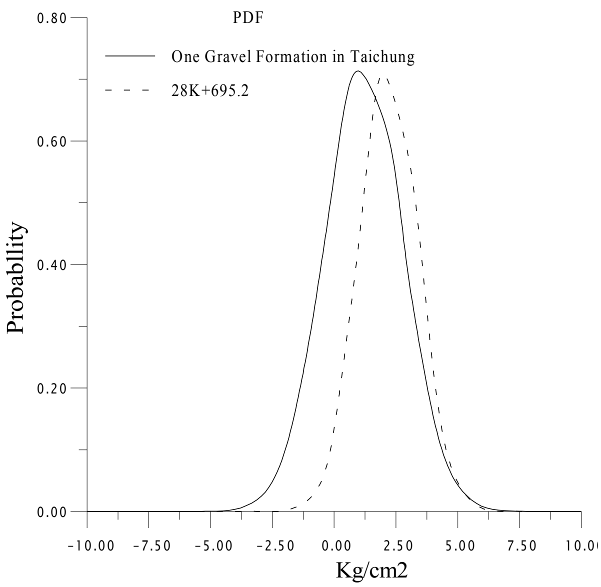


Figure 7. Results of the Schmidt Hammer testing

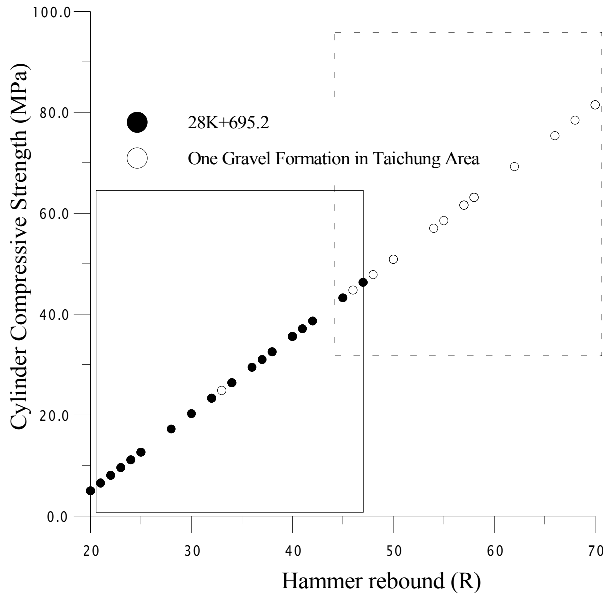


Figure 8. Results of the penetration testing

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