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Image Analysis Techniques on Evaluation of Particle Size Distribution of Gravel

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ABSTRACT: Particle size distribution of granular materials is usually evaluated by sieve analysis test. In this research, an image analysis technique using ImageJ is proposed to evaluate particle size distribution of gravels. On particular conditions, some differences of gradation curves determined by sieve analysis and image analysis were observed. Based on the results, several aspects related to image analyzing are discussed in the paper. They include appropriate evaluation of particle grain size in image analysis, minimization of shadow effects appeared in images, effects of number of particles adopted for sieve analysis and image analysis and so on. It was found that grain size in image analysis should be defined appropriately to compare the gradation curves by the two methods. Probably, due to light effects, it was also observed that black color sheets are better than white color sheets to place particles. This method can be used as an in-situ test method since this method needs only a camera and a computer.

Keywords: Coarse material, ImageJ, Image analysis, Particle size distribution, Sieve analysis

1. INTRODUCTION

Characterization of quality of materials is important to ensure good use of resources from environmental and economic perspectives. Particle size distribution of materials is one of the widely used tests in geotechnical engineering to evaluate quality of materials. Sieve analysis test has been used as the main method to determine particle size distribution of granular materials including coarse materials for many decades. Image analysis techniques are extensively used in the medical and electronics industries. In recent times, image processing techniques have also been practiced in civil engineering field [1], especially in concrete engineering [2] - [4]. Images have mainly been analyzed to study shape characteristics of particles such as elongation and angularity etc. [5] - [6]. Image analyses have mainly been conducted using 2-D images. A few researchers have discussed shape characteristics of aggregates with 3-D images too [7] - [8]. In addition to shape characteristics, size characteristics of aggregates including particle size distribution with image analysis had also been discussed in the past [9] - [14].

Particle size distribution curve is produced with mass in sieve analysis test. In image analysis, gradation curve can be produced using volume (i.e., mass based), area or number of particles. In general, image analysis uses 2-D images. However, 2-D images cannot measure volume of particles directly. Banta et al. (2003) [11] studied particle gradation curves by 2-D images of 4.75-25mm size limestone and found that image analysis gave good results. However, mass of individual particles were measured using a balance to compare gradation curves by the two methods. It was a time consuming process since mass of individual particles were measured. The method cannot be applied when there is large number of particles available.

Kwan et al. (1999) [5] used 2-D images of coarse aggregates to study particle shape characteristics. In his research, volume of particles was determined from 2-D images with some assumptions. Mora et al. (1998) [10] also compared the gradation curves determined by image analysis and sieve analysis test using 2-D images. He also determined mass of particles from 2-D images with some assumptions. The results showed that the grain size determined by image analysis overestimated the grain size determined by sieve analysis test. A size correction factor was assigned to grain size to obtain the same gradation curve as that by sieve analysis test. Therefore, it is not clear whether the assumptions made in evaluating mass affected the difference or image analysis techniques themselves had some effects on the gradation curves.

Fernlund (1998) [9] studied particle form on sieve analysis with 32-64mm size railroad aggregates using 2-D images. He also compared gradation curves determined by mass and number of particles in sieve analysis. The results showed that grain size determined by number of particles underestimated that by mass. A few other researchers also found inconsistencies between gradation curves determined by volume (i.e., mass based) and number of particles [13]. Since gradation curves determined by mass and number of particles were found to be different in sieve analysis test, it is not worthwhile to use number of particles to determine gradation curves in image analysis.

Fernlund (2005c) [12] measured three axes of particles of 10-50mm size granite while manually changing positions of particles. 2-D images of same particles were taken twice to measure dimensions of the three axes. The gradation curve determined by image analysis was compared with that obtained by Danish Box. The results showed that 2-D images, when particles placed on a stable location, gave good results. However, it was a time consuming process due to the fact that location of particles had to be manually changed twice to obtain images to measure dimensions of the three axes.

Kumara et al. (2011) [14] evaluated gradation curves of gravel using image analysis. He used area of particles to evaluate gradation curves. However, it should be noted that in sieve analysis, gradation curves is evaluated using mass of particles. Therefore, to compare gradation curves by the two methods, gradation curve should be evaluated using mass of particles in image analysis.

As mentioned in literature, usually, volume of particles has been determined using 2-D images with some assumptions or using time-consuming process where measuring mass of individual particles. It was also seen that the gradation curves determined by image analysis were different from the gradation curve determined by sieve analysis. The difference of gradation curves would have been due to several issues such as evaluation of particle grain size, shadow effects in images, effects of different number of particles used in sieve analysis and image analysis, shape of particles assumed in image analysis and so on. The issues mentioned have not been fully understood in the past. In this paper, the issues affecting gradation curves in image analysis are examined using an image analysis technique named ImageJ.

2. METHODOLOGY

Gravels of size varies from 2-19mm were used in laboratory sieve analysis test and image analysis. They are Andesite, originally produced in Yamanashi prefecture, Japan.

2.1 Sieve Analysis

Sieve analysis test was conducted according to JIS A 1204 [15]. JIS requirement for the materials used is equal to 1.5kg. To obtain high accuracy for gradation curve, additional sieves such as 6.7, 11.2 and 13.2mm were added in addition to 2, 4.75, 9.5 and 19mm sieves required by the JIS method. Sieve analysis tests were conducted with hand shaking.

2.2 Image Capturing Process

Particles were arranged manually such a way that particles stand on a stable position. Similar arrangement for aggregates of 35mm diameter had been used in [9] and [12]. In this arrangement, thickness (i.e., short axis) of particles cannot be measured directly since 2-D images measure only the long and intermediate axes. In this research, particles were arranged without touching or overlapping each other to reduce applying unnecessary image processing techniques.

Particles were placed on a transparent sheet during initial analysis (i.e., Case A-1) as shown in Fig. 1. Transparent sheets were used as lights were applied from both bottom and top of the sheet to eliminate shadow effects. The main light is back light. Top light was applied to strengthen back light effect with a reflective sheet placed as shown in Fig. 1. However, as it was difficult to apply the same light arrangement when the size of the sheets became larger with large number of particles, white or black color sheets were used. A scale was placed at the bottom of the sheet to obtain dimensions in mm since images give dimensions in pixels. This scale was used during image analysis process. Images were captured with a Nikon D7000 camera which can measure up to 16 million pixels.

In the research, image analyses were conducted in two series. In Series A, whether there is any effect due to randomly selection of particles from the main sample was examined using the sheets varying from small size to large size as discussed in section 3.1. Particles were placed on white color sheets except in Case A-1 where samples of 100 particles were used. In Series B, particles were placed on black color sheets as given in Table 2. Shadow effect on gradation curves was examined comparing the results of Series A and B.

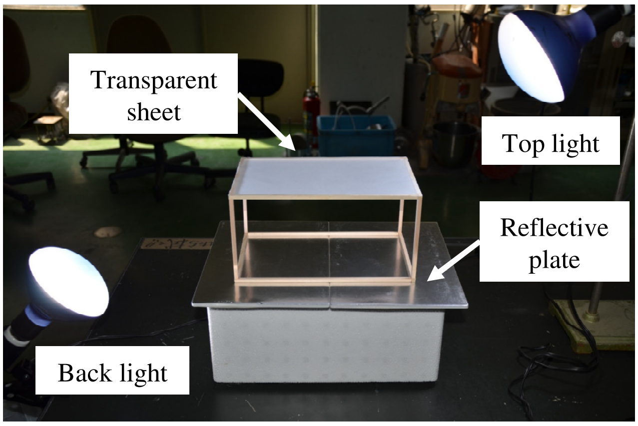

Figure 1: Image capturing process

Table 1: Image analysis - Series A

Case	No. of particles	Particle placed sheet
A-1	100 x 33 images	Transparent
A-2	1100 x 3 images	White
A-3	3300 x 1 image	White

Table 2: Image analysis - Series B

Case	No. of particles	Particle placed sheet
B-2	1100 x 3 images	Black
B-3	3300 x 1 image	Black

2.3 Image Analysis

The images analysis was done in ImageJ. ImageJ can read many image formats including TIFF, GIF, JPEG, BMP, DICOM and FITS. JPEG images were used in this research. ImageJ can calculate area and pixel value statistics of user defined selections. It can also measure distance and angle as well. It supports standard image processing functions such as contrast manipulation, sharpening, smoothing, edge detection and median filtering. More details on ImageJ can be found in [16].

In ImageJ, original images can be converted into binary images. Usually, it assumes that binary images have black objects and white background. Binary images are very important to make some process like *Erode*, *Dilate*, *Open*, *Close-*, *Fill Holes*, *Watershed* and so on. *Erode* removes pixels from the edge of black objects and *Dilate* adds pixels to the edges of black objects. *Open* performs an erosion operation followed by dilation. *Close-* performs a dilation operation followed by erosion. *Fill Holes* fills holes in objects. Due to some light effects, there might be white spots in black objects. These white spots should be eliminated using *Fill Holes*. *Watershed* separates or cuts touching particles. In this research, particles were arranged without touching or overlapping each other. More details on available image processing techniques can be found in [16].

Fig. 2 shows image analysis process conducted. As shown in Fig. 2, firstly, pixel values are converted into mm using a scale factor. The calibration of scale factor was done with the scale placed on the images as shown in Fig. 3 (a). Then, images were converted into binary images after unnecessary parts of the images were cut without disturbing particles in the images to eliminate any bad light effects at the edges of the images if there is any. Figs. 3 - 5 show some original images and their binary images of samples of 100, 1100 and 3300 particles respectively. Depending on quality of the images judged by the operator, number of steps of *Dilate*, *Fill Holes* and *Erode* process were decided. Number of steps of *Dilate* and *Erode* were always maintained equal to make sure no addition or removal of pixels from the real particles.

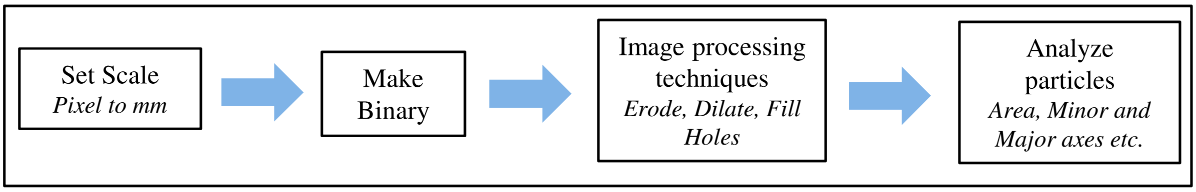

Figure 2: Image analysis process

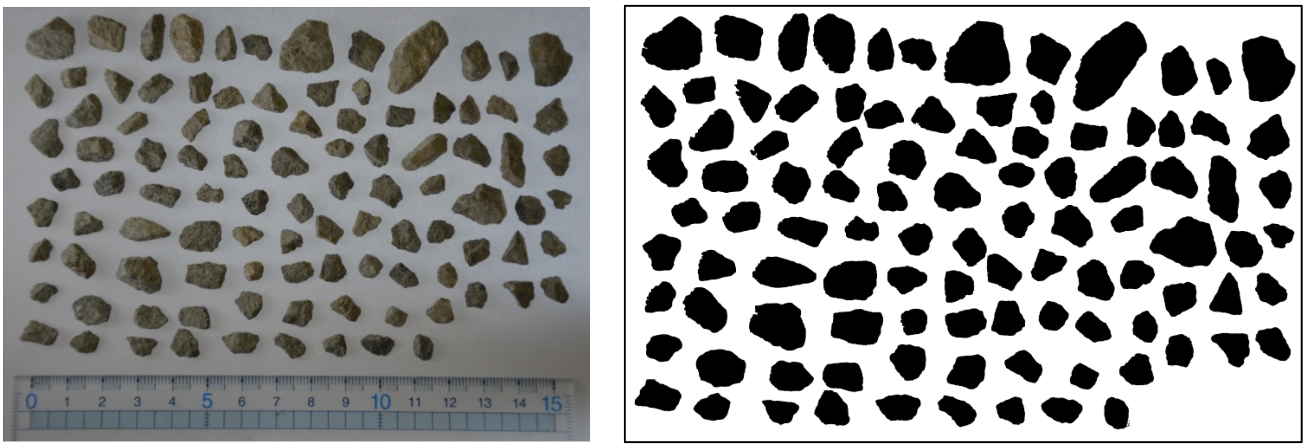

Figure 3: (a) Original image and (b) binary image of a sample of 100 particles placed on white color sheet

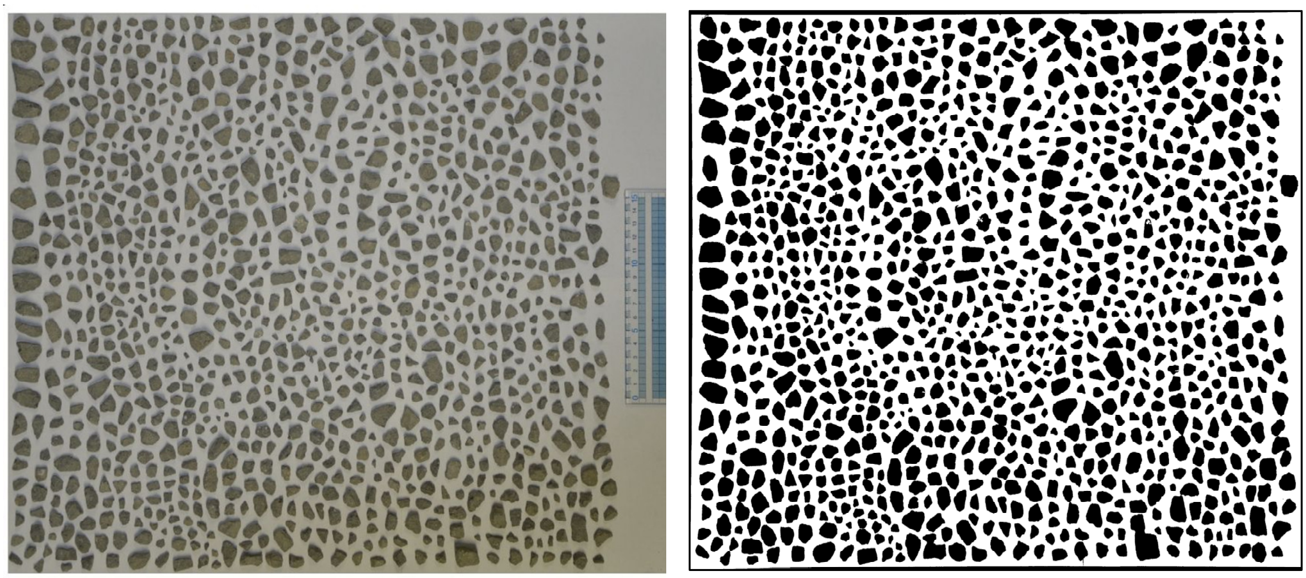

Figure 4: (a) Original image and (b) binary image of a sample of 1100 particles placed on white color sheet

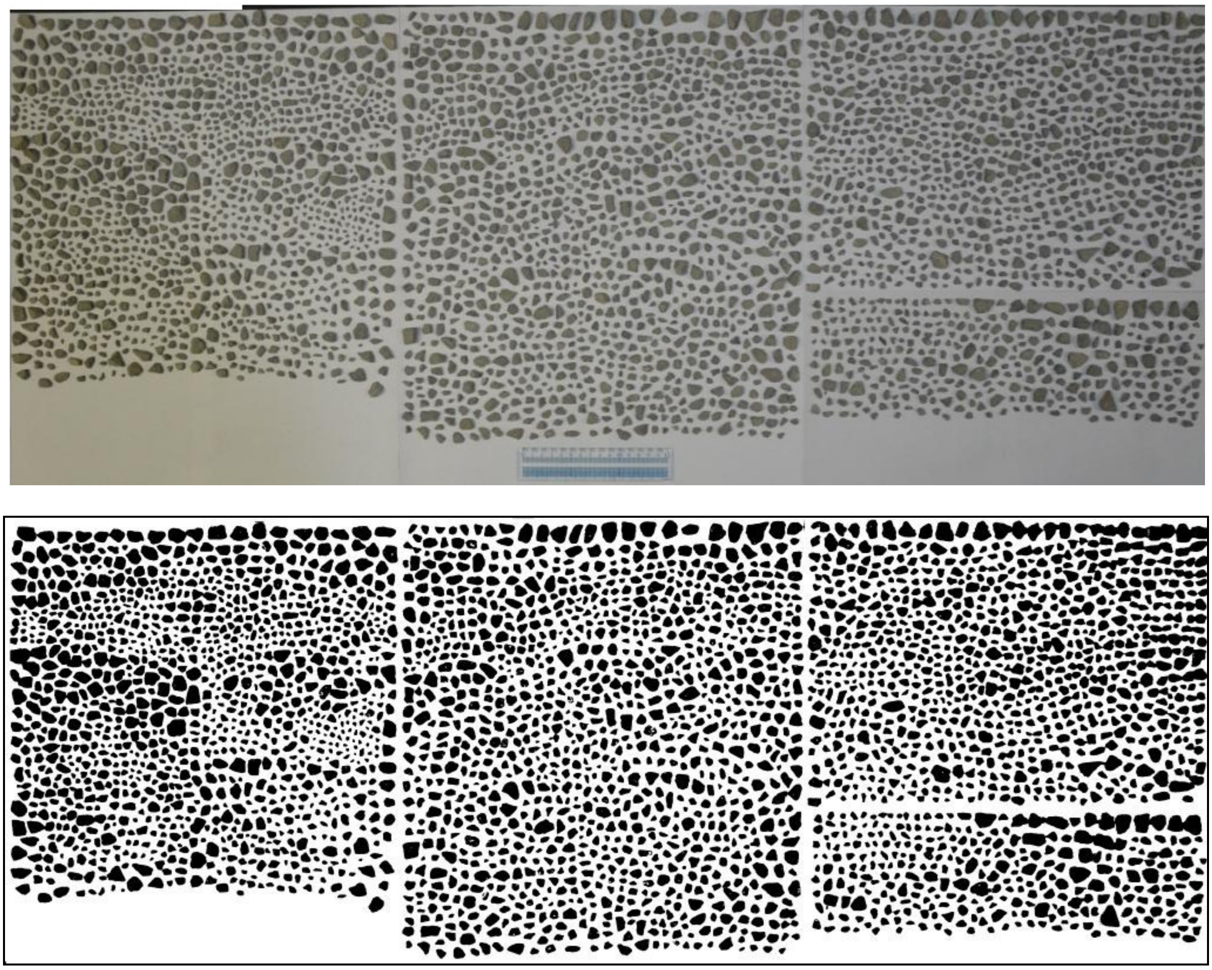

Figure 5: (a) Original image and (b) binary image of a sample of 3300 particles placed on white color sheet

Since gravel particles are in irregular shapes *Fit Ellipse* was used to find areas enclosed by individual particles. *Fit Ellipse* gives the smallest area enclosed by an ellipse. Area, major and minor axes were measured in the image analysis. Many shape characteristics including roundness, perimeter and circularity can also be measured. More details on shape parameters can be found in [16].

3. RESULTS AND DISCUSSIONS

In sieve analysis test, mass of the particles is used to obtain particle size distribution curve whereas in image analysis, either area of particles or number of particles can be used from 2-D images directly. Volume of particles can be determined from 2-D images with some assumptions.

Some researchers used area of particles directly measured from 2-D images to evaluate gradation curves [14] while others used mass determined from volume of particles with some assumptions [10] - [11]. The assumptions in determining volume from 2-D images would result in some errors. Also, if mass of individual particles are measured manually, that would be a time consuming process [11].

In this research, volume of particles was determined using the results of image analysis and measurements of gravel particles obtained using a Vanier caliper. Measurements of the long axis, intermediate axis and short axis of 50 particles were determined using a Vanier caliper before image analysis was conducted. The average value of ratio of short axis to intermediate axis obtained from 50 particles was used to determine volume of particles in image analysis.

As particles are placed on a stable position, it can be observed that 2-D images have long and intermediate axis of a particle. Therefore, it is clear that intermediate axis (i.e., minor axis of a particle in 2-D image) should be considered to determine gradation curves. Effects of major and minor axes on gradation curves have been discussed and reported that minor axis of particles in 2-D images should be used to evaluate gradation curves [8] and [12].

Kumara et al. (2011) [14] discussed effects of different shapes such as ellipse, rectangle and circle (in 2-D images) on gradation curve of gravel and found that ellipse shape gave closets gradation curves to that by sieve analysis. Therefore, in image analysis conducted in this paper, gradation curves were determined using ellipse shape for particles.

Volume of an ellipsoid, V, can be given as in (1),

$$V = \frac{4}{3}\pi \times \left(\frac{a}{2}\right) \times \left(\frac{b}{2}\right) \times \left(\frac{c}{2}\right) \tag{1}$$

where a is long axis, b is intermediate axis and c is short axis of an ellipsoid.

Area of an ellipse (placed on long and intermediate axes), A, can be given as in (2),

$$A = \pi \times \left(\frac{a}{2}\right) \times \left(\frac{b}{2}\right) \tag{2}$$

In image analysis (i.e., using 2-D images), A, a and b can directly be measured. Therefore, V can be determined as in (3). However, in image analysis, c cannot be measured directly.

$$V = \frac{4}{3} A \times \left(\frac{c}{2}\right) \tag{3}$$

Since all the particles are from the same source, it can be assumed that shape characteristics of the particles are same. Therefore, c can be determined from b as in (4).

$$c = \alpha b \tag{4}$$

where α is a constant depend on shape characteristics of aggregates.

Using (4), V can be determined as in (5)

$$V = \frac{4}{3} A \times \left(\frac{\alpha b}{2}\right) \tag{5}$$

α was determined as 0.70 using 50 gravel particles as shown in Fig. 6.

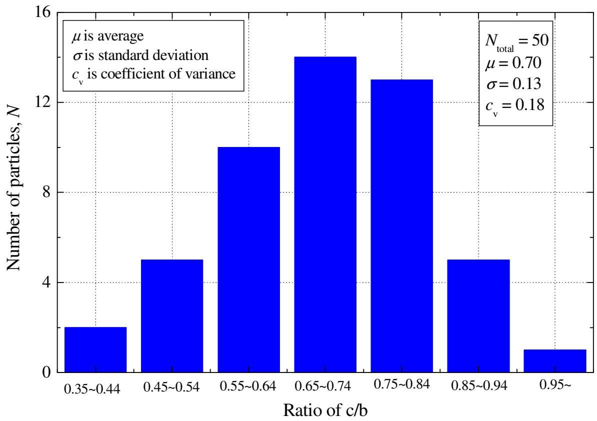

Figure 6: Histogram of c/b ratio for 50 particles

In image analysis, fine percentage passing through a sieve can be determined using (6),

$$\text{Percent passing} = \frac{\sum_i^p (A_i \times b_i)}{\sum_i^n (A_i \times b_i)} \times 100\,(\%) \tag{6}$$

where A is area of a particle, p is no. of particle passing grain size and n is total no. of particles.

3.1 Effects of Random Selection of Particles

JIS standard requires a minimum amount of materials depending on particle size of materials. JIS standard requirement for gravel is equivalent to 1.5kg which equals to approximately 3300 particles. However, when the operator takes a small sample (e.g., about 100 particles) from the main sample used in sieve analysis (i.e., about 3300 particles), it is not clear whether the operator gets a sample of 100 particles which represents the main sample appropriately. When there is large number of particles available, there might be some segregation and that might result in the operator getting coarser particles at initial stages.

Effects of random selection of particles from a sample of 1100 particles (i.e., 1/3 of the sample size used in sieve analysis) on the gradation curve were evaluated using many samples of 100 particles. Fig. 7 shows the results of gradation curves. In this case, 11 samples each of 100 particles were randomly taken from the main sample of 1100 particles without giving an attention (i.e., mixing them properly). In the image analysis here, grain size, D_1 was defined as minor axis of ellipse, b. As shown in Fig. 7, the gradation curves determined by initially selected samples overestimated the gradation curve determined by sieve analysis while the gradation curves determined by later selected samples underestimated the gradation curve determined by sieve analysis. It was also observed that the gradation curve determined by sieve analysis test stands in between the gradation curves determined by image analysis.

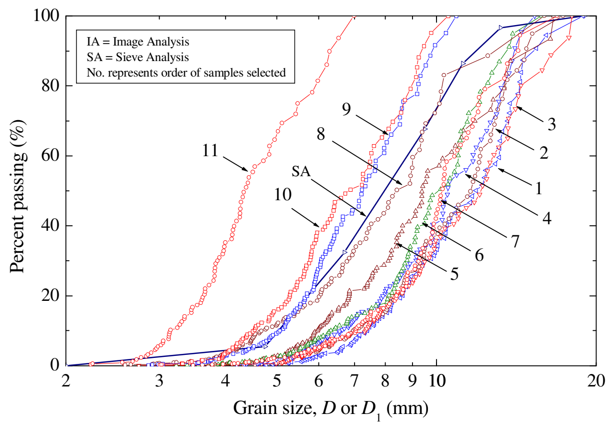

Figure 7: Effects of random selection of particles

In the next analysis, the operator intentionally tried to select samples of 100 particles appropriately to represent the main sample of 3300 particles. Initially, the main sample of 3300 particles was divided into three groups of 1100 particles each. All the particles were placed in 33 samples each of 100 particles and analyzed individually. In the selection of samples of 100 particles, the operator purposely selected samples of 100 particles with mixing particles well than unintentionally selected in Fig. 7. The purpose was to evaluate whether the operator can select a small sample which represents the main sample appropriately. Even then, there are some differences between the small samples and the main sample as shown in Figs. 8 (a) - (c).

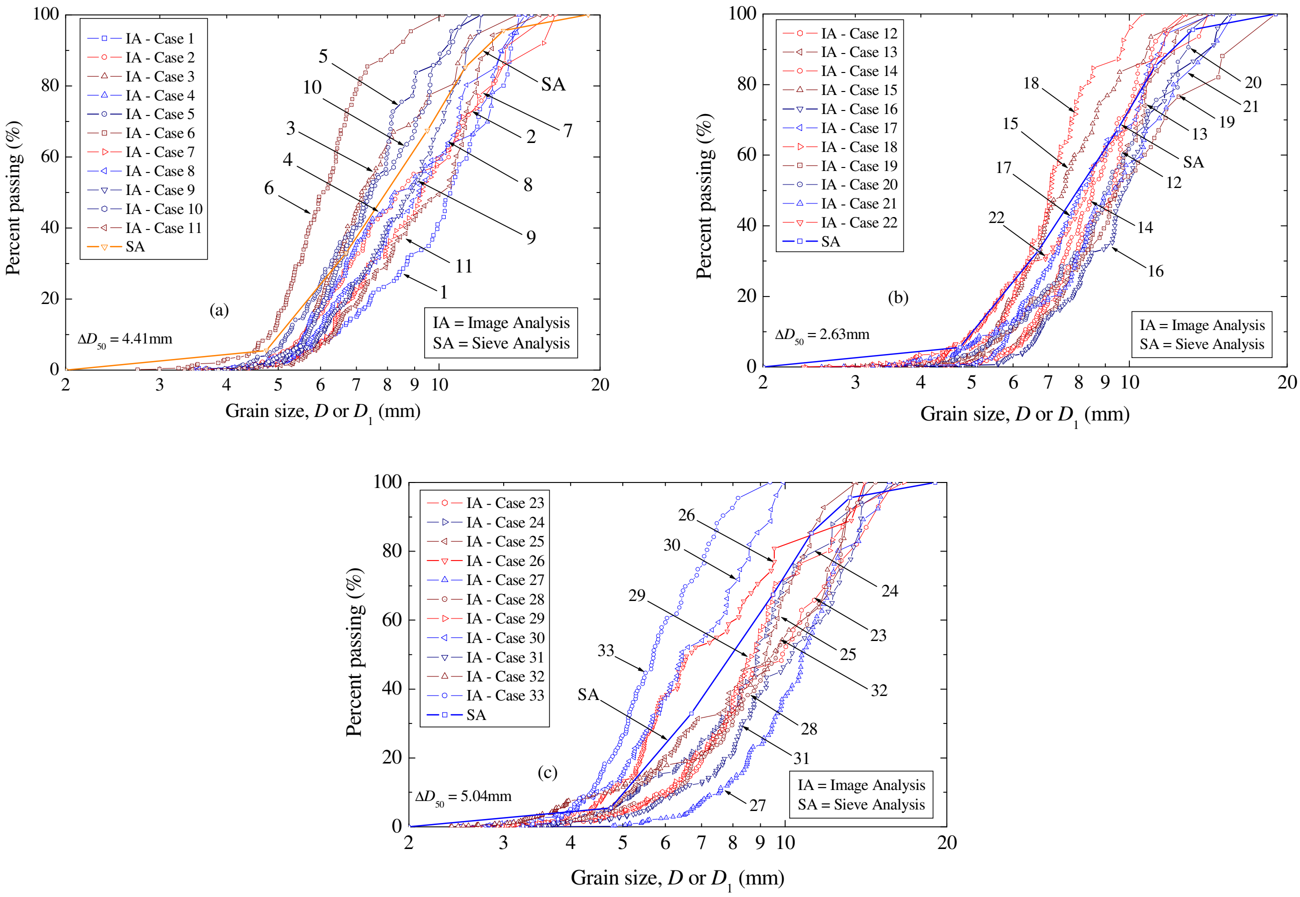

Figure 8: Effects of random selection of particles on gradation curve (a) Cases 1- 11, (b) Cases 12 - 22 and (c) Cases 23 - 33

In Figs. 8 (a) - (c), it was observed that even when the operator intentionally tries to take samples of less number of particles to represent the main sample appropriately, there is still some difference between the small samples and the main sample. However, it was also observed that the gradation curve determined by sieve analysis test stands in between the gradation curves determined by image analyses. Therefore, it could be argued that if all the particles used for sieve analysis test is considered for image analysis, results could be good. It was also observed that ΔD_{50} of the samples with the smallest and largest grain size is 5.0mm in Group 3 (i.e., Cases 23-33). Since D_{50} of the gravel is 8mm, the difference is not negligible.

Since taking many images as high as 33 to cover all the particles takes a considerable time, it was considered taking less number of images with higher number of particles. As given in Table 3, a very large size sheet is needed to cover all the particles. However, shadow effects on particles placed close to the boundary of the sheet could be a problem for very large size sheets.

Fig. 9 shows gradation curves related to Case A-2 where three images of 1100 particles each were analyzed. As observed in Figs. 8-9, scattering of data become less when number of particles in images are increased. ΔD_{50} of the samples with the largest and smallest grain sizes is only 1.2mm in Fig. 9 compared to 5.0mm observed in Fig. 8 (c).

Table 3: Details of the size of the sheets

Case	Size of sheet	No. of images
A-1	20 x 13.2 cm	33
A-2	77 x 51.3 cm	3
A-3	130 x 86 cm	1

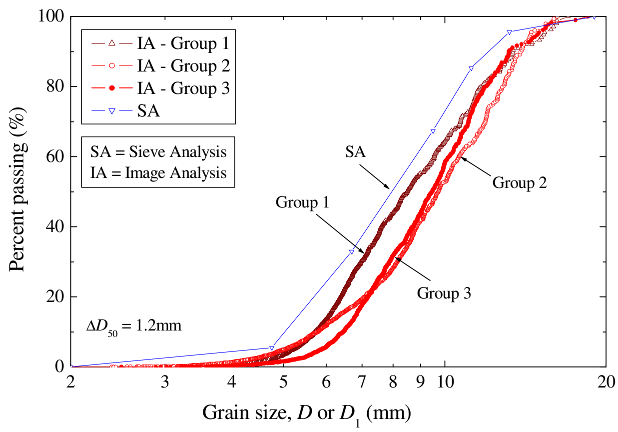

Figure 9: Gradation curves with 1100 particles

It was observed in Fig. 10 that images of 100 particles gave the closest gradation curves to that by sieve analysis. However, as shown in Fig. 10, grain sizes of all the gradation curves determined by image analysis overestimated grain size determined by sieve analysis test. It could be assumed that the overestimation of grain size determined by samples on large sheets could be due to shadow effects (i.e., colour of particle placed sheet should be examined) or due to grain size definition used in image analysis. Therefore, in next analyses, these two issues are discussed.

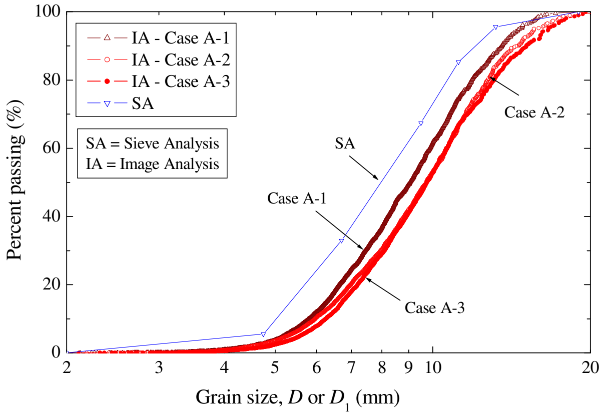

Figure 10: Gradation curves with different number of particles (Series A)

3.2 Effects of Colour of Particle Placed Sheet

It was also examined whether there is any effect of color of particle placed sheets due to light effects on gradation curves using Series A and B. Fig. 11 shows the results of gradation curves determined for particles placed on white (Series A) and black color sheets (Series B).

In Fig. 11 too, grain size of the gradation curves determined by image analysis overestimated that by sieve analysis test. However, it was found that black color sheets give better results compared to white color sheets; probably black color sheets have less effect from lights than white color sheets.

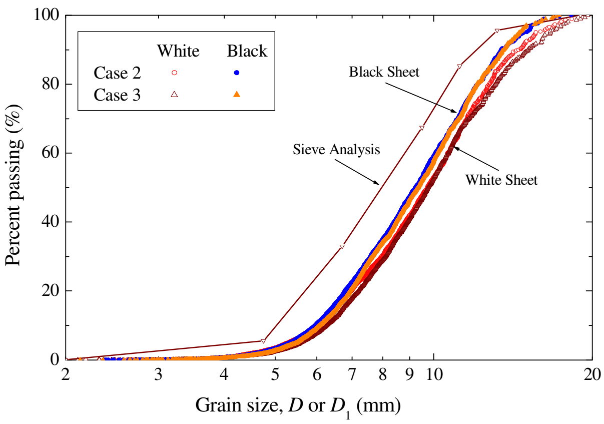

Figure 11: Effects of color of particle placed sheet

3.3 Effects of Grain Size Definition

As observed in Figs. 10 and 11, gradation curves determined in image analysis always had larger grain size compared to sieve analysis test. Therefore, in this section, it was examined effect of grain size definition on gradation curves.

Fig. 12 (a) and (b) show grain size definitions for the cases of particles pass parallel to sides of a sieve or through diagonal of a sieve respectively. If particles pass parallel to sides of sieve, grain size (i.e., D_1) should be equal to major axis of an ellipse (i.e., b). b and c are intermediate and short axes (i.e., thickness) respectively of an ellipsoid. In the case, particles pass through diagonal of a sieve, grain size is equal to D_2 and can be given as (7). Using (4), D_2 can be determined as (8). It was found that β is equal to 0.86.

$$D_2 = \sqrt{0.5\left(b^2 + c^2\right)} \tag{7}$$

$$D_2 = b\sqrt{0.5\left(1+\alpha^2\right)} = \beta b \tag{8}$$

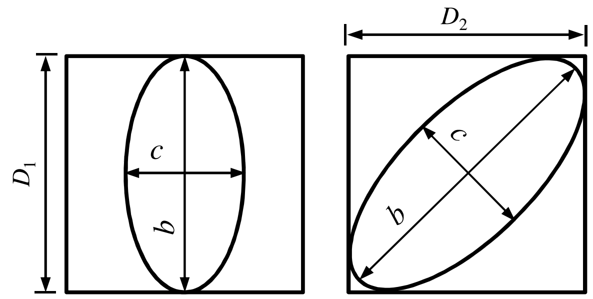

Figure 12: Particles pass (a) parallel to sides and (b) through diagonal of square sieve

Fig. 13 shows gradation curves determined using two grain size definitions shown in Fig 12. In sieve analysis, particles can pass through diagonal of a sieve. Therefore, based on that information, in image analysis, grain size should be defined as D_2. As observed in Fig. 13, when the grain size is defined such that it is equal to minor axis of an ellipse in 2-D image (i.e., intermediate axis of the relevant ellipsoid), the gradation curve is at right side of the gradation curve evaluated by sieve analysis, due to larger grain size used in image analysis. However, when grain size is defined such that it is equal to (8) and represent the case where particles pass through diagonal of a sieve, the gradation curves by the two methods are equal. Therefore, it is clear that grain size in image analysis should be defined as Fig. 12 (b) to compare the gradation curves evaluated by the two methods.

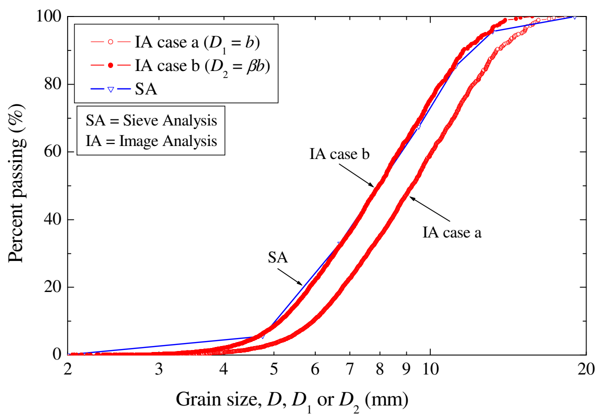

Figure 13: Gradation curves with different grain size definitions

4. CONCLUSION

Particle size distribution curve of coarse materials (2-19mm) were evaluated using the image analysis, ImageJ. 2-D images of particles were used in the image analysis. As particles were in irregular shapes, ellipse shape was used to represent them. The gradation curves

determined by image analysis were compared with that by sieve analysis.
Finally, the following conclusions were made,

1) It was found that operator tends to get a sample with coarser particles from the main sample of a large number of particles if enough attention is not given.
2) All the particles used for sieve analysis tests should be considered to obtain accurate gradation curves since taking a small sample from a large sample of particles does not necessary represent the original sample appropriately.
3) It was found that black color sheets are better than white color sheets to place particles. That's to say, shadow effects on black color sheets should be less than that of white color sheets.
4) It was also found that gradation curves determined in image analysis is always at right side of the gradation curve determined by sieve analysis (i.e., larger grain size) when minor axis of ellipse is used as the grain size.
5) It was further found that grain size in image analysis should be defined appropriately to compare the gradation curves by the two methods since particles pass through diagonal of a sieve in sieve analysis.
6) Volume of particles can easily be determined from the results of image analysis (using 2-D images) and shape characteristics measured manually for the same materials. Since this method gave same gradation curves as that by sieve analysis test, the image analysis technique used can be considered as simple and less time consuming process than sieve analysis test. This method can also be applied as an in-situ method since the method needs only a computer and a camera.

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