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Evaluation on grain size distribution of railway ballast with and without sands by image analyses

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ABSTRACT: Sand intrusions to ballast layers from underneath layers have been identified as a major problem in railway engineering. Sometimes, ballasts containing sands show large settlements, which are induced by railway traffic loading. However, degree of settlement depends not only on traffic volume but also on physical and mechanical properties of ballasts. Grain size distribution is one of the most fundamental characteristics to evaluate physical properties of ballasts especially when they are mixed with sands. In other words, whether in-situ ballasts is in dense or loose state can be affected by its change of grain size distribution.

Usually, grain size distribution of ballasts is investigated by sieve analysis in the laboratory. However, this procedure requires sampling, which makes the investigation time longer. Moreover, as numbers of samples are limited, the information is not sufficient for engineers to have an appropriate maintenance plan. Therefore, in this study,image analyses with a digital camera wasattempted to evaluate grain size distribution of ballasts with and without sands. This technique will enable railway engineers to obtain sufficient information regarding grain size distribution of ballast in the field withina short time.

In this research, gradation curves of gravel and sand were evaluated using an image analysis method with a digital camera. The image analysis method was applied to sand-gravel mixtures as well. Grain size distribution was also obtained from sieve analysis to compare results. Detailedimage analysisusing 3D shape characteristics showed that gradation curves for granular materials including fine materials can be obtained quite accurately.

1 INTRODUCTION

In railway tracks, heavy repeated train loads induce fine materials from underneath layers and also due to particle crushing. Degradation of ballasts due to fine material intrusion is a big issue in railway tracks. Deformation properties of granular soils depend on many parameters including particle size distribution (PSD). Therefore, it is necessary to understand how gradation curves change with fine intrusions.Traditionally, gradation curve of granular soilshave been evaluated using sieve analysis test at the laboratories. Recently, development of computer technology has helped to use image processing techniques in geotechnical engineering applications as well (Coster et al., 2001). In recent past, some researches have been conducted to evaluate gradation curves of coarse materials using image processing techniques (Mora et al., 1998, Fernlund, 2005 and Kumara et al., 2011). However, the methods had been limited to coarse materials. In this paper, a simple image analysis method proposed to evaluate gradation curve of granular soil including fine materials of sands is discussed. The method was also applied to binary mixture of ballast and sand samples.

In image analysis, particle size distribution can be evaluated using area of particles (Kumara et al., 2011) or number of particles (Fernlund, 1998) using 2D images. However, in sieve analysis, particle size distribution is evaluated using mass of particles. Therefore, to compare gradation curves by the two methods, volume (i.e., mass based) of particles should be determined using 2D images.

2 METHODOLOGY

Particle size distribution of gravel and sand materials were evaluated. Gravels were selected to represent 1/5 range of ballast and medium size sands (M sand) were selected to represent fine materials. Once the images of particles were captured, image analysis process shown in Figure 1 wasconducted to get the required details.

Figure 1. Image analysis process

ImageJ software was used to analysis images (Ferreira & Rasband, 2011). Images were captured using a Nikon D7000 camera. Particles were placed such that they don’t touch or overlap each other. In this arrangement, it is assumed that particles stand on their stable locations (Fernlund, 2005). In image analysis, particles were assumed to be ellipse shape as it was found in the literature that ellipse shape is better to represent granular soil materials than rectangle or circle shapes (Fernlund et al., 2007 and Kumara et al., 2011). As outputs, area, major and minor axes of particles were obtained.

3 RESULTS AND DISCUSSIONS

Though gradation curve determined by sieve analysis is based on volume of particles, 2D images cannot be used to obtain volume of particles directly. Therefore, comparison of gradation curves by the two methods is not straightforward unless volumes of particles are measured by 2D images. Volume of an ellipsoid can begiven as Equation 1,

$$V = \frac{1}{6}\pi abc \qquad (1)$$

where a, b and c are major axis, minor axis and thickness of an ellipsoid.

2D Images taken from top of the particles give a and b directly. It can be assumed that aggregates from the same source have more or less same shape characteristics (Mora et al., 1998 and Kwan et al., 1999). Therefore, mean thickness of aggregates can be determined based on the assumption given by Equation 2,

$$c = \alpha b \qquad (2)$$

where α is a parameter dependent on flakiness of particles and can be determined using Equation 3,

$$\alpha = \frac{3}{2} \times \frac{M}{\rho \sum_{i=1}^{n} A_i \times b_i} \qquad (3)$$

where M is mass of all particles, ρ is density and A is area of ellipse.

Percentage of mass passing through a sieve can be determined using Equation 4,

$$\text{Percent passing} = \frac{\sum_{i=1}^{p}\left(A_i \times b_i\right)}{\sum_{i=1}^{n}\left(A_i \times b_i\right)} \times 100\,(\%) \qquad (4)$$

where p is no. of particles whose grain size is smaller than the sieve size and n is no. of all particles.

In sieve analysis, particles can pass either parallel to sides or through its diagonal as shown in Figures 2 (a) and (b) respectively. Therefore, minor axis measured by images should be converted into equivalent sieve size to compare image analysis results with sieve analysis results as given in Equation 5,

$$\text{Equivalent sieve size} = \beta b \qquad (5)$$

where β is a size correction factor and depends on shape of aggregates.

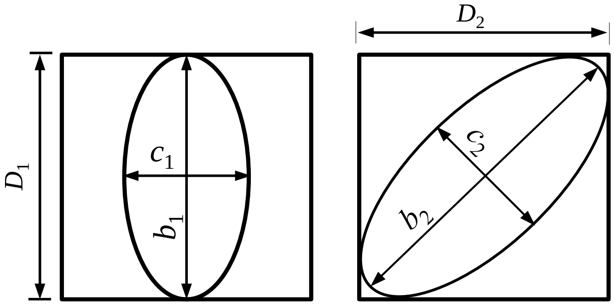

Figure 2. Particles pass (a) Parallel to sides and (b) Through diagonal of square sieve

In image analysis, gradation curves were determined using three different grain size definitions. If it is assumed that all the particles pass parallel to sides of square sieves as shown in Figure 2a, grain size should be equal to minor axis of ellipse, b_1. On the other hand, if all the particles pass through diagonal of square sieve as shown in Figure 2b, grain size should be equal to D_2 which is equal to $(0.5b_2^2 + 0.5c_2^2)^{0.5}$. Using Equation 2, grain size, in case of all particles pass through diagonal of square size, can be given as in Equation 6. Therefore, grain size, in case of all the particles pass though diagonal of square sieve, can be represented as a function of minor axis (i.e., b) once α is determined as given in Equation 6. In sieve analysis, some particles pass parallel to sides while other particles pass through its diagonal. Therefore, equivalent square sieve size determined (i.e., βb) should be in between the two limits (i.e., b and γb).

$$D = [0.5(1 + \alpha^2)]^{0.5} b = \gamma b \qquad (6)$$

where γ is a constant as given in Equation 7,

$$\gamma = [0.5(1 + \alpha^2)]^{0.5} \qquad (7)$$

Figure 3 shows a sample of 1100 gravel particles used to determine gradation curve in the image analysis. Figure 4 shows gradation curves determined using number, area and volume of particles for the gravel sample shown in Figure 3. Percentage of passing for gradation curves using number of particles were determined using Equation 8,

$$\text{Percent passing} = \frac{p_i}{n} \times 100\,(\%) \qquad (8)$$

where p and n are as given in Equation 4.

However, note that, equivalent sieve size (i.e., βb) was not used here. As shown in Figure 4, the gradation curve determined by area of particles is the closest to that of sieve analysis. Kumara et al. (2011) also reported that area of particles give gradation curves similar to that of sieve analysis for coarse materials. However, as explained above, to compare gradation curves determined by the two methods, in image analysis, gradation curves should be evaluated using volume of particles. Figure 4 also showed that the gradation curve determined by no. of particles underestimated that of sieve analysis. Fernlund (1998) also reported similar results for railroad aggregates. Therefore, gradation curves in the image analysis were determined using volume of particles in next analyses.

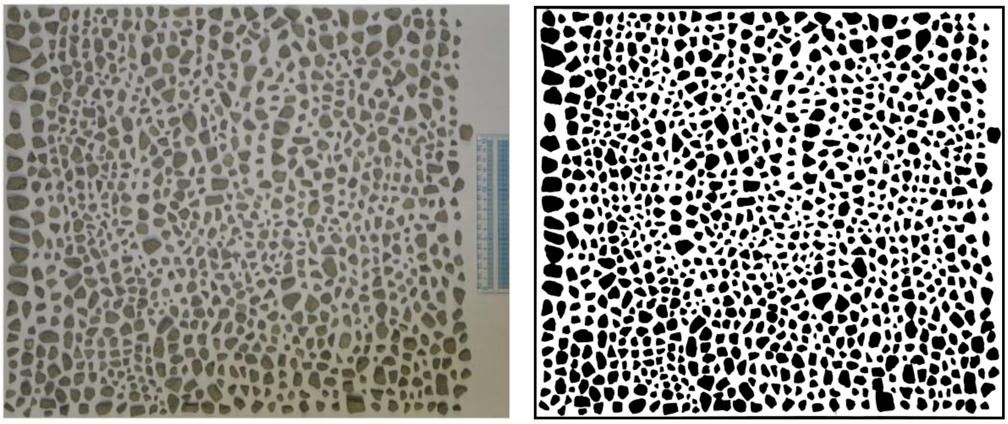

Figure 3. (a) Original image and (b) Binary image of a sample of 1100 particles

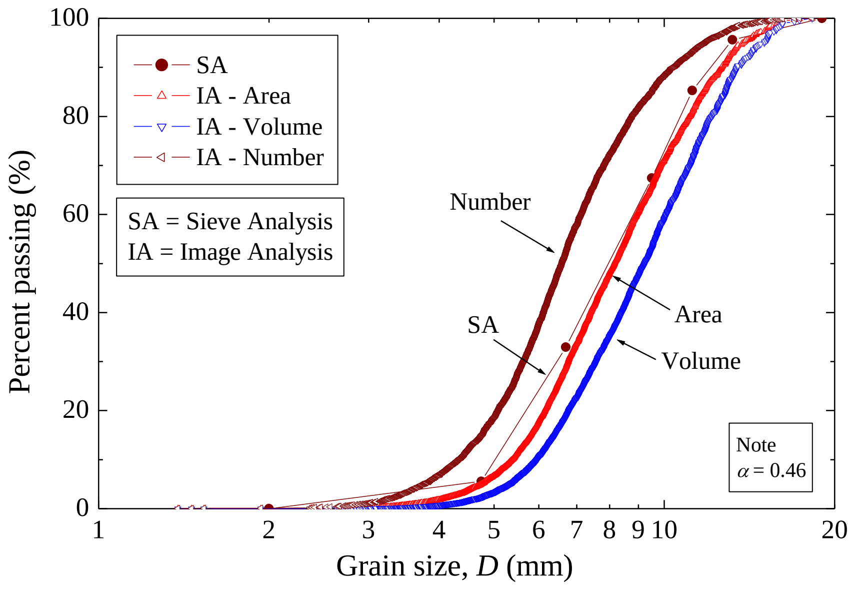

Figure 4.Particle size distribution curves determined by Number, Area and Volume of particles

Figure 5(a) shows gradation curves determined by sieve analysis and image analysis for gravel. As shown in Figure 5 (a), if grain size is equal to minor axis of ellipse, b,gradation curve determined by image analysis overestimates gradation curve determined by sieve analysis. If grain size is given by $(0.5b^2 + 0.5c^2)^{0.5}$, gradation curve underestimates that of sieve analysis as shown in Figure 5 (a). It can be observed from Figure 5 (a) results that all the particles either don't pass parallel to sides or through diagonal of square sieve. Therefore, size correction factor, β proposed in Equation 5 was determined based on "trial and error" method to fit the gradation curves by the two methods. Details of α, $\beta$and γevaluated for gravel and medium size sand are given in Table 1. Mora et al. (1998) had proposed 0.48 and 0.87-0.91 for α and β respectively for different gravel samples.

Figure 5 (b) shows gradation curves determined for medium size sand. As shown in Figure 5 (b), 0.86 of β gives same gradation curve determined by image analysis as that of sieve analysis. It was also observedthat α for medium size sand is 0.59 which is higherthan 0.46 observed for gravel. That's to say, medium size sand is less flaky compared to gravel.

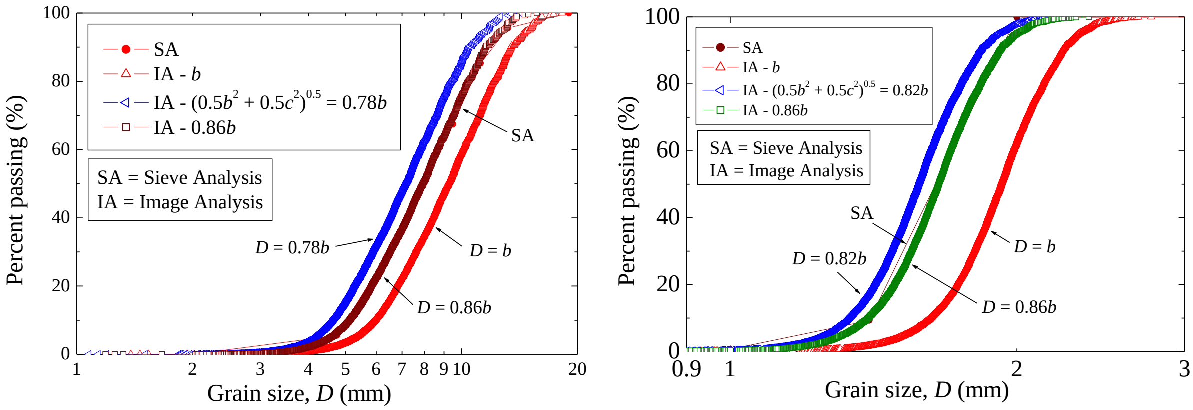

Figure 5. Gradation curves of (a) Gravel and (b) Medium size sand

Table 1. Details of α, β and γ

Material	α ($c = \alpha b$)	γ ($D = (0.5b^2+0.5c^2)^{0.5} = \gamma b$)	β ($D = \beta b$)
Gravel	0.46	0.78	0.86
M sand	0.59	0.82	0.86

Figure 6 shows gradation curves of sand-gravel mixture. Here, the sample consists of 95% gravel and 5% medium size sand. As sand has large no. of particles compared to gravel, to reduce calculations in image analysis, only 5% of sand was mixed with gravel to make sand-gravel mixture. Figure 6 also shows that PSD curves from all the methods (i.e., three grain size definitions) in fine material part are roughly same. This might be due to limited percentage of fines used (i.e., 5%) in sand-gravel mixture. Therefore, it would be better to evaluate gradation curves with large percentage of sand in sand-gravel mixtures to evaluate why PSD curves in fine material part are roughly same regardless of different grain size definitions. However, the results for coarse part clearly show different PSD curves from different grain size definitions.

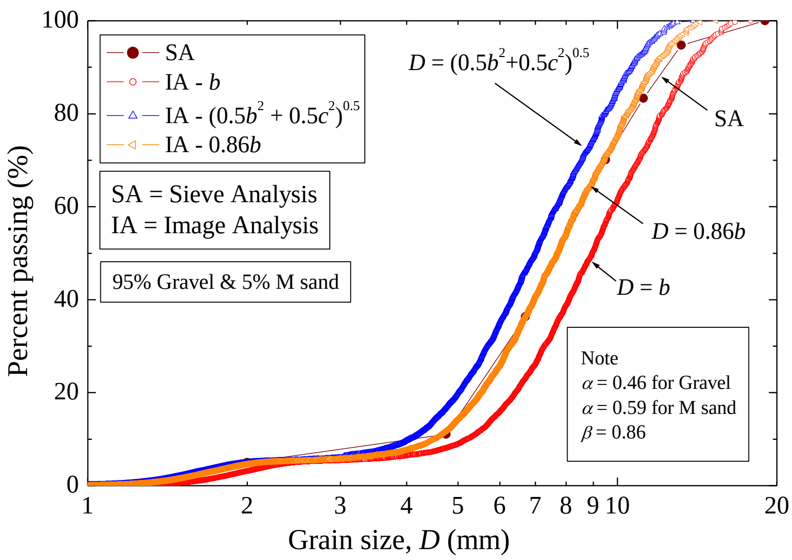

Figure 6. Gradation curves of sand-gravel mixture

4 CONCLUSIONS

The following conclusions were made;

- Gradation curves determined using no. of particles in image analysis underestimate grain size determined by sieve analysis.
- Gradation curves in image analysis should be evaluated using volume of particles to compare with those of sieve analysis. Volume of particles can be determined with some assumption from 2D images.
- Gradation curves determined using grain size equivalent to minor axis of ellipse, which assumes all the particles pass parallel to sides of sieves, overestimates grain size of sieve analysis.
- Gradation curves determined using grain size equivalent to $(0.5b^2 + 0.5c^2)^{0.5}$, which assumes all the particles pass through diagonal of sieves, underestimates grain size of sieve analysis.
- Gradation curves determined with the assumption that some particles pass parallel to sides of sieves and other particles pass though diagonal of sieves with a size correction factor, are similar to those of sieve analysis.
- The image analysis method proposed can determine gradation curves well for gravel and medium size sand. This method can also be applied to sand-gravel mixtures.

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