A Test Procedure for Particle Sizing via Digital Image Processing

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ABSTRACT

A laboratory study was undertaken to investigate the accuracy of using digital image processing to produce particle size distribution curves of road aggregate and crushed rock. The variation caused by camera angle and light source angle were tested and found to have little effect. Within the context of this investigation, it was found that manual delineation of particles produced more accurate results. Based on the results, the suitability of digital image processing for use in the engineering industry is discussed, along with a recommended testing procedure.

Keywords: aggregate, crushed rock, digital image processing, laboratory testing, particle size distribution

1 INTRODUCTION

Despite its many limitations, sieving is still considered to be the standard method for obtaining Particle Size Distributions (PSDs) for granular materials. In recent years, a new method of obtaining PSDs has been developed using Digital Image Processing (DIP). DIP works by calculating the area of a particle in a scaled image before applying a series of algorithms to convert two-dimensional data (area) into three dimensions (volume). The main advantage of DIP over sieving is that it is fast, less labour-intensive, and can be used on large particles beyond the practical size limits of sieving.

1.1 Split Desktop

Split Desktop (http://www.spliteng.com/split-desktop/) is a DIP software package developed by the University of Arizona to measure rock fragmentation. Split Desktop is considered user-assisted as it requires the user to acquire suitable images and input them onto the system, and allows the user to manipulate the images during processing. Split Desktop was chosen for this study as it achieved favourable results when tested against other software packages, such as Wipfrag and FRAGSCAN (Liu and Tran 1996, Latham et al. 2003, and Sudhakar et al. 2006).

2 STUDY METHODOLOGY

2.1 Sampling

A study was undertaken at The University of Queensland with the aim of evaluating the performance of Split Desktop, compared with sieving, of 5 mm, 10 mm, 14 mm, 16 mm, 20 mm and 200 mm aggregates sampled from the CEMEX Petrie Quarry, in South East Queensland, Australia.

2.2 Testing procedure

Each aggregate sample to be photographed was laid on a flat, black, non-reflective surface on the laboratory floor (Figure 1). Precaution was taken to avoid the overlapping of particles. Using a Canon EOS 350D digital camera, three series of photographs were taken to test the accuracy of Split Desktop, the effect of camera angle, and the effect of the light source. The PSD results obtained were compared with the results of conventional sieving of each aggregate sample.

Figure 1. Camera set up to capture images

2.2.1 Accuracy test

In this test series, the camera and lighting source were orientated at 90^o to the laboratory floor on which the particles were spread. This test was carried out for each of the aggregate samples.

2.2.2 Camera angle test

In this test series, the camera was orientated at varying angles (90 to 30^o) to the laboratory floor on which the 200 mm aggregate was spread, with the lighting source maintained at 90^o.

2.2.3 Lighting source angle test

In this test series, the lighting source was orientated at varying angles (90 to 30^o) to the laboratory floor on which the 200 mm aggregate was spread, with the camera maintained at 90^o.

3 TEST RESULTS

3.1 Accuracy

Common errors introduced by DIP, as documented by Paley (1989) and Maerz and Zhou (1998), include the effects of camera angle, lighting, sampling errors, and segregation. In the accuracy test, the camera angle and lighting were both maintained at right angles to the laboratory floor (i.e. at 90^o), to eliminate this source of error. Three images were taken for each test, and all images were processed using Split Desktop with the settings: (i) Automatic delineation – in which Split Desktop uses its algorithms to automatically delineate particles, and (ii) Manual delineation – in which the user manually delineates coarse-grained particle outlines either from scratch or by correcting the automatic delineation. Manual delineation by an experienced user can allow for the attachment of fine-grained particles to coarse-grained particles, since the automatic delineation would recognise the fine-grained particles and not the underlying coarse-grained particles, potentially leading to an overestimation of the proportion of fine-grained particles and an underestimation of the proportion of coarse-grained particles. However, automatic delineation can also fail to distinguish a cluster of fine-grained particles, seeing them as a single coarse-grained particle, leading to the reverse effect.

Reasonably good correlation is shown in Figure 2, produced by comparing PSDs from sieving against Split Desktop (average of all three images) in manual delineation and automatic delineation modes, especially for the 14 mm, 16 mm and 20 mm aggregates. The PSDs obtained by sieving are fairly consistently finer-grained than those obtained using Split Desktop. This may be due to sieving recording the intermediate dimension of angular-shaped particles, such as crushed aggregate, and allowing such particles to pass through the diagonals of the sieve openings, thus resulting in an underestimation of the average PSD. This appears to be particularly the case for the intermediate particle sizes in the aggregate samples, which explains why the sieving and Split Desktop PSDs are seen to cross-over for the 14 mm, 16 mm and 20 mm aggregates.

There was little difference between the Split Desktop PSDs obtained automatically and by manual delineation, with the automatically-generated consistently giving a slightly coarser PSD. This indicates that there was negligible adhesion of fine-grained particles to coarse-grained particles, and perhaps a failure of the automatic routine to distinguish clusters of fine-grained particles.

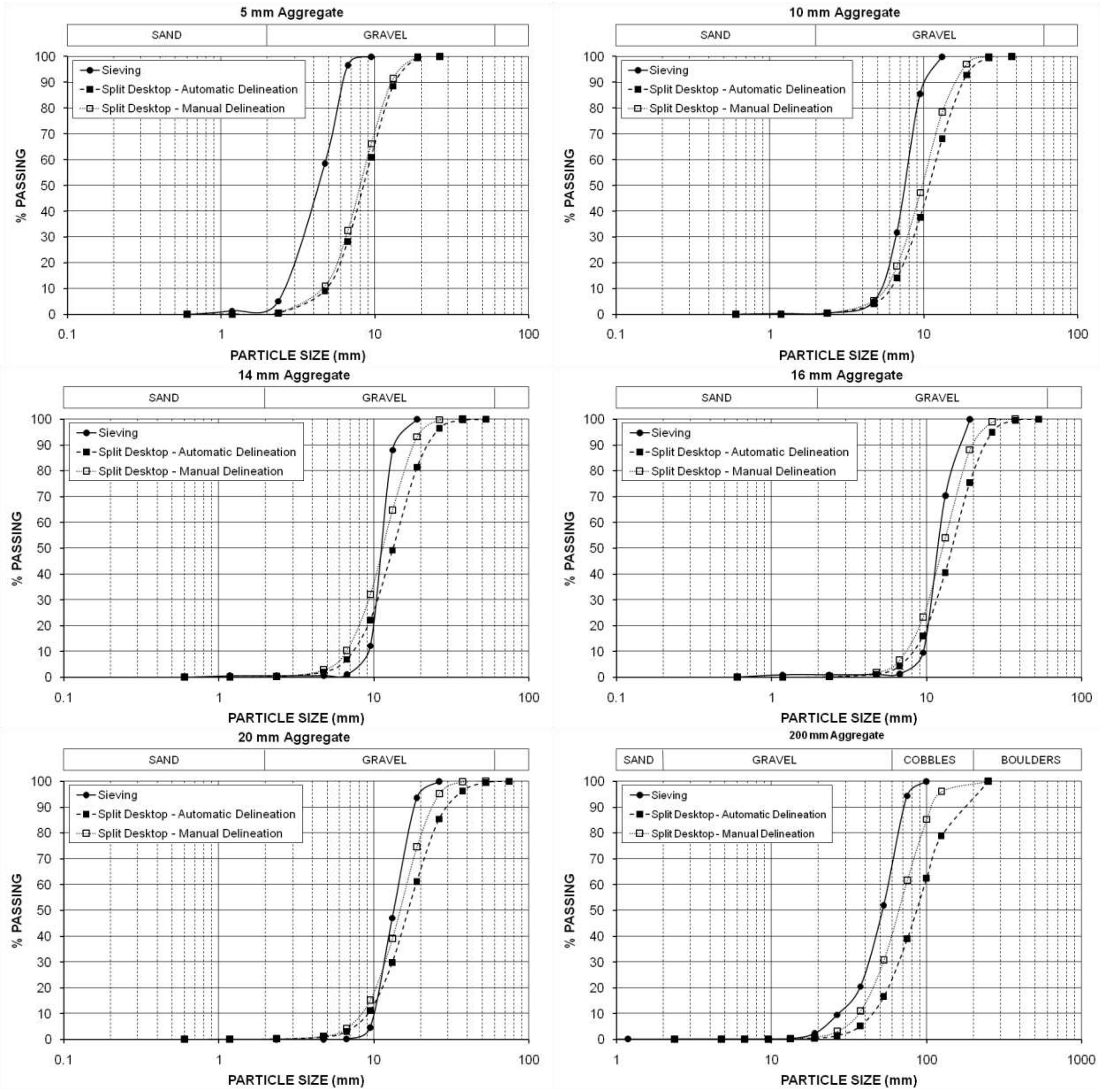

Figure 2. Split Desktop analysis results for 5 mm, 10 mm, 14 mm, 16 mm, 20 mm and 200 mm aggregate

Table 1 uses the median particle size (D_{50} or the particle size through which 50% of the aggregate passes) of each PSD to highlight the differences between the sieving and Split Desktop PSDs, and the relative differences between automatic and manual delineation of particles using Split Desktop. The results in Table 1 highlight the good agreement between the sieving and Spilt Desktop D_{50} values for the 14 mm, 16 mm and 20 mm aggregates. The poorest correlation was for the 5 mm aggregate, followed by the 10 mm and 200 mm aggregates. Comparing the automatic and manual Split Desktop D_{50} values, it is clear that manual delineation provides a better correlation, in agreement with the findings of Sanchidrian et al. (2006).

Table 1. Percentage D_{50} shift for 5 mm to 200 mm aggregates

Aggregate Size (mm)	Sieving D_{50} (mm)	Split Desktop – Automatic		Split Desktop – Manual	
		D_{50} (mm)	Difference (%)	D_{50} (mm)	Difference (%)
5	4.8	8.5	77.29	8.1	68.40
10	6.5	10.9	67.28	9.8	50.46
14	11.0	13.3	21.15	11.5	4.33
16	13.0	14.6	11.97	12.7	-2.23
20	14.5	16.9	16.44	14.8	2.09
200	52.0	86.5	66.26	69.2	33.03

Figure 3 illustrates the failure of automatic delineation by Split Desktop to distinguish clusters of fine-grained particles, with manual delineation having the potential to overcome this deficiency.

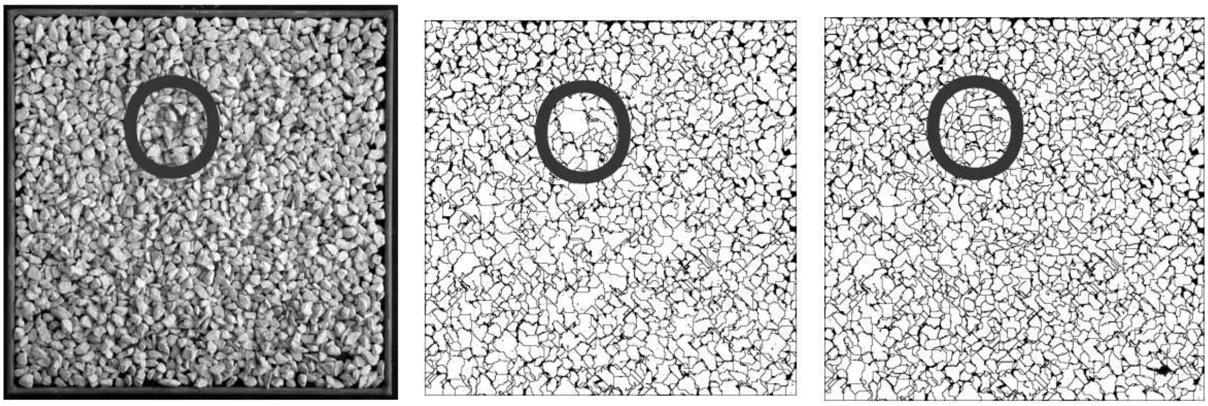

Figure 3. Comparison of the 14 mm aggregate: original image (left), automatic delineated image (centre) and manual delineated image (right) (Circle highlights an example of where automatic delineation has mistakenly grouped several particles together as one larger particle)

The accuracy of DIP appears to be dependent on the number of particles across the dimension of the image, rather than the actual aggregate size. The 14 mm, 16 mm, and 20 mm aggregate images have 40 to 30 particles across the dimension of the image. Finer-grained aggregates have many more particles across the image, making them more difficult to differentiate and making manual delineation much more time-consuming, and resulting in a poorer agreement with sieving (as seen for the 5 mm aggregate in particular, and to a lesser degree for the 10 mm aggregate. On the other hand, coarser-grained aggregates have few particles across the image, introducing more sampling error and potentially resulting in a poorer agreement with sieving (as seen for the 200 mm aggregate). Hence, images should ideally be taken to have 30 to 40 particles across the image.

3.2 Effect of camera angle

Varying the angle of the camera between 90 (at right angles to the laboratory floor) and 60^{o} had no measurable effect on the resulting 200 mm aggregate manual delineation Split Desktop PSD (Figure 4). However, increasing error was introduced as the camera angle was reduced to 45^{o} and then 30^{o}. Hence, there appears a threshold camera angle of 90 ± 30^{o}.

3.3 Effect of lighting source angle

Paley (1989) recommended that images be taken at midday, when shadowing is least profound. However, the effect of varying the angle of the lighting source on the resulting 200 mm aggregate manual delineation Split Desktop PSD was minimal, and negligible for an angle of 45^{o} or greater (Figure 5). Hence, the angle of the lighting source should be 90 ± 45^{o}.

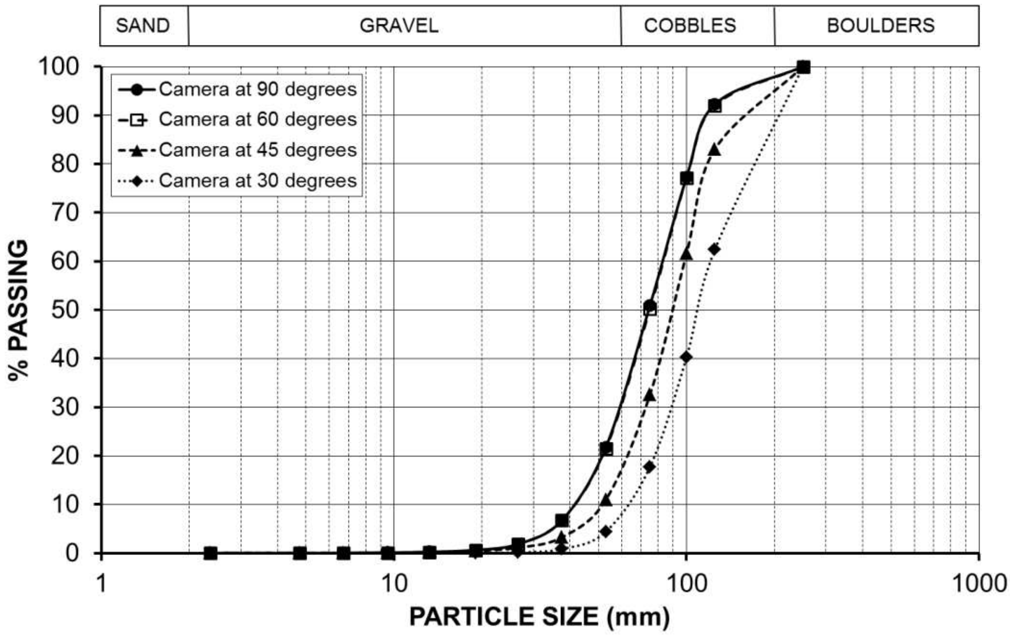

Figure 4. Results of camera angle test

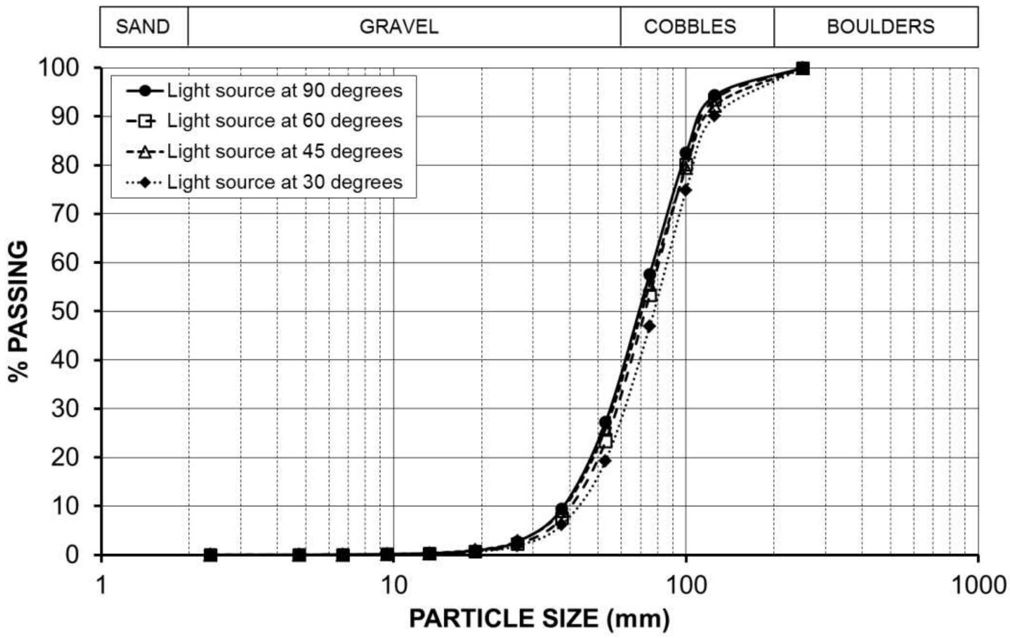

Figure 5. Results from lighting source angle test

4 RECOMMENDED TEST PROCEDURE

Based on the results of this study, the following test procedure for application to crushed aggregate is recommended:

1. Choose two circular scaling objects which are approximately 0.5 to 0.75 times the diameter of the largest particle in the sample.
2. Place the scaling objects at the top and bottom of the intended image. The dimension of the scaling object sets the scale of the particles in the image, while the difference in size of the scaling objects captured on the image is used to determine the angle of the camera, and hence the distortion of the sizes of the particles in the image.
3. Find a suitable area and dark floor covering on which to lay out the sample and take the image

4. Position the camera so that the shooting angle is approximately normal (90 ± 30^o) to the sample.
5. Set the lighting source (if required) approximately normal (90 ± 45^o) to the sample.
6. Adjust the camera zoom in order to capture 30 to 40 particles within the dimension of the image.
7. Undertake a Split Desktop analysis using manual delineation.
8. Periodically check the resulting PSDs against a PSD obtained by sieving.

5 CONCLUSIONS

The Split Desktop study described herein highlights the importance of image composition when using digital image processing. It is not intended that digital image processing replace sieving as the preferred method for obtaining particle size distributions, rather that the two methods be used in tandem. Digital image processing, combined with conventional sieving analysis for validation and calibration purposes, is a cost-effective means of determining the particle size distributions of coarse-grained materials, making the method suitable for a range of engineering applications.

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