Close-Range Photogrammetric Measurement of Erosion in Coarse-Grained Soils

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ABSTRACT: Measurement of soil erosion is difficult if the surface consists of particles whose size is of the same order of magnitude as the erosion. Close-range photogrammetry can provide high resolution in the determination of coordinates of points on the surface. With coarse-grained surfaces, a large number of points at close spacing could be observed to define the surface in terms of the size, shape, and position of the individual soil particles. However, tests showed that the experienced observer can, using far fewer observations, define an acceptable representation of the surface. The procedure requires each spot height reading to be the estimated mean surface elevation within a zone corresponding to a suitable percentage, e.g., 20 percent of the stereoplotter's field of view. This allows the overall surface to be adequately represented by measurements at spacings indicated by the macrotopographic surface roughness, rather than those associated with individual soil particles.

INTRODUCTION

CLOSE-RANGE PHOTOGRAMMETRY was used to measure soil erosion resulting from forestry activities (Sneddon *et al.*, 1984). The soils studied contained a small but significant proportion of particles of size up to 10 mm or larger. Erosion was also of the same order of magnitude, and this was about 10 to 20 times larger than the resolution of the photogrammetric measurement system. With this resolution it would have been possible to define the surface by point readings at intervals small enought to allow individual particles to be defined and sized. However, the number of observations required to define the surface by this process for a typical 2.0- by 1.5-m sample area would be have been impractical for the observer, and the size of the digital terrain model (DTM) files would have been very large. It was therefore decided to check if a reliable smoothed or meaned surface could be estimated, thus eliminating any need to consider the microtopographic surface variations associated with individual particles.

EXPERIMENTAL PROCEDURE

To obtain information on characteristic surface roughnesses, it was first necessary to carry out a seive analysis of material representative of the forestry areas under investigation. This indicated (Figure 1) a small but significant proportion of particles in the size range of 1 to 20 mm. It was therefore decided that experiments should be carried out on synthesized surface models with single-size particles of 2, 5 and 10 mm nominal size, as shown in Table 1.

Six surface models were formed in carefully manufactured molds (Figure 2) using dimensionally stable grouting cement as a bed for the stone particles. Each mold was circular (263-mm diameter) in horizontal cross section, and was machined on the upper and internal surfaces to provide smooth and reliable faces for measurement and volume computation. Internal depth was 40 mm.

For the photogrammetric measurements, control was provided by four points (Figure 2) marked on the machined top surface of the mold. These points were allocated identical elevations of 100.00 mm, with estimated standard errors of 0.05 mm. Their relative horizontal positions were determined by precise measurement of diagonals and sides of the quadrilateral which they formed. The resultant horizontal coordinates were estimated to have standard errors of less than 0.2 mm.

Photography used a Wild P32 (metric) camera (Table 2), this having been the camera used for the forest erosion study. Also, as for that study, the camera was supported (Figure 3) on a timber frame, 2.5 m above the model surfaces, with a photographic base of 1.0 m.

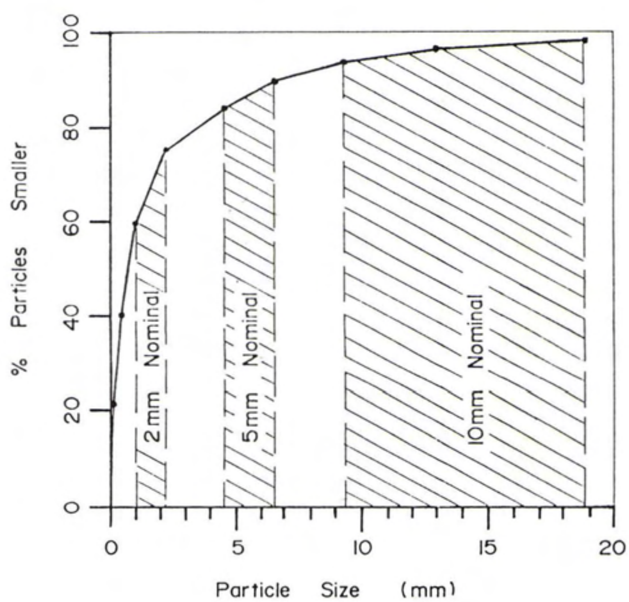

FIG. 1. Results of grain size analysis of representative surface material.

TABLE 1. PARTICLE SIZES USED FOR SYNTHETIC SURFACES

Partilce Nominal Size (mm)	Passed Seive* Size (mm)	Retained Seive* Size (mm)
2	2.36	1.18
5	6.7	4.75
10	19.0	9.5

*Australian Standard seive sizes.

A Wild BC2 analytical plotter was used to measure spot heights. Points were observed on an equilateral triangle grid of 10 mm on a side. The method of surface smoothing chosen was for each spot height to be the mean surface elevation estimate as

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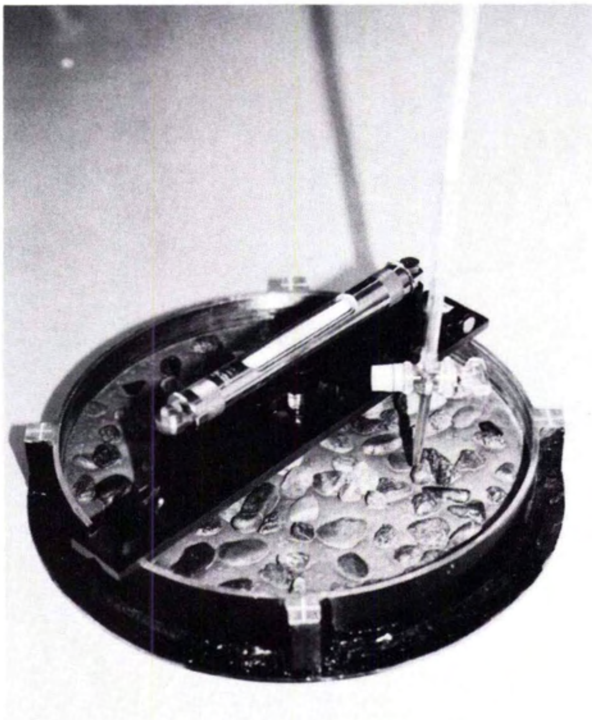

FIG. 2. Check measurement set-up.

TABLE 2. PHOTOGRAMMETRIC CAMERA DETAILS

Manufacturer and model	Wild P32
Focal length	65.77mm
Photographic format	80mm by 60mm
Focusing range	Fixed focus 2.5m
Depth of focus	350 mm at *f*8 with 50-μm circle of confusion
Photographic medium	Glass plates

seen within the central 20 percent of the field of view of the plotter. At the magnification used, i.e., 20x, the zone evaluated for each reading was approximately 60 mm in diameter. To ensure consistent results, each of the six surface models was measured at least twice as indicated in Table 3.

The procedure for assessing the accuracy of the photogrammetric measurement of erosion is indicated in Figure 2. The volume of water needed to fill the mold to the level of the top surface was determined by running carefully measured volumes of water into the mold until the water surface rose to contact the spirit level. To ensure consistent results, total water volume was measured at least twice for each surface model, again as indicated in Table 3.

One important aim of the experiments was to check how large the spacing between photogrammetric spot height readings could be without causing a deterioration in the accuracy of the erosion estimates. To do this, rows and columns were progressively eliminated from each of the 13 DTMs to provide larger equilateral triangle grids, as demonstrated in Figure 4. As a result, each DTM provided a set of four (independent) derived DTMs of 20-mm grid spacing, and sets of 16, 36, 64, and 100 derived DTMs of 40-, 60-, 80- and 100-mm grid spacing, respectively. From each of these sets of derived DTMs a standard deviation of mean depth was calculated. The two or three values thus obtained from each original DTM were then combined to provide root-mean-square (RMS) standard deviation values. These RMS values provide a basis for assessing the effect of spacing increases. It should be noted that use of widely spaced points by the elimination of intermediate points was justified by the vibrating table method of placing groundmass and particles in the molds. This ensured that the resultant mean surface was essentially free of macrotopographic variation. Any error resulting from macrotopographic variation would be expected to cause the results to be worse than for a surface free of such variation; therefore, any conclusion drawn from the experiment would be conservative.

DISCUSSION

ERRORS IN MEAN PHOTOGRAMMETRIC DEPTHS

Table 3 provides summary comparisons of photogrammetric mean depths and values determined from water volume measurements. The photogrammetrically determined values were the arithmetic mean depths determined from the 650 to 680 spot heights observed for each set of results on each surface model.

TABLE 3. COMPARISON OF PHOTOGRAMMETRIC AND WATER VOLUME DETERMINED ESTIMATES OF MEAN DEPTH TO SYNTHETIC SURFACE

Nominal Particle Size (mm) and Shape	Water Volume Depths (mm)[1] Rdg	Water Volume Depths (mm)[1] Mean	Photogrammetric Depths (mm)[1] Value[3]	Photogrammetric Depths (mm)[1] Mean	Photogrammetric Error (mm)[2]
2 rounded	10.18		10.02		
	10.12	10.13	9.46	9.74	−0.39
	10.10				
2 angular	17.38		16.76		
	17.39	17.39	16.19	16.48	−0.91
5 rounded	17.89		17.24		
	17.88	17.89	16.75	16.99	−0.89
5 angular	20.67		19.62		
	20.56	20.61	19.06	19.34	−1.28
10 rounded	20.58		19.49		
	20.56	20.57	19.53	19.51	−1.08
10 angular	21.86		21.68		
	21.91	21.85	20.77	21.33	−0.52
	21.81		21.55		

[1]Depth in mm form upper surface of mold to mean surface of material in mold.
[2]Mean photogrammetric depth - mean water volume depth.
[3]Values given are the mean depths computed from the 650 to 680 individual spot height values.

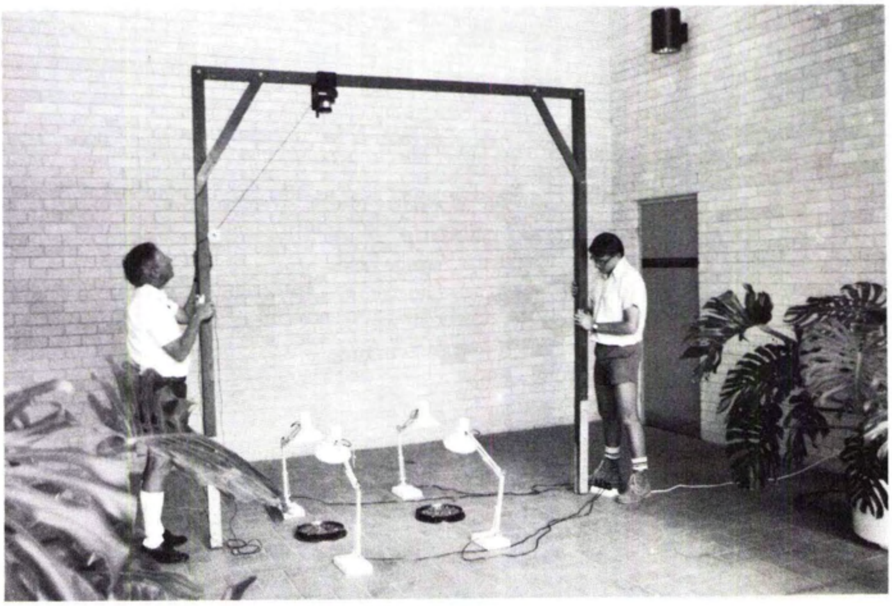

FIG. 3. Photographic set-up.

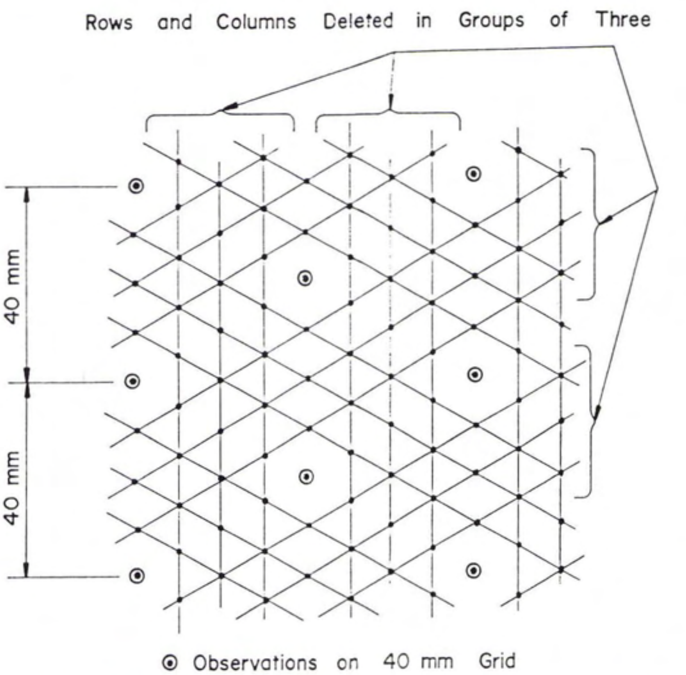

FIG. 4. Elimination of rows and columns to provide a 40-mm grid spacing.

From the variability of these results, errors of 0.5 to 1.0 mm could be expected. The water volume depths had very much smaller variability, and calculations showed that the errors in these values would be less than 0.1 mm. The errors associated with the photogrammetrically determined values were therefore determined by comparison with the water volume values, assuming the latter values to have been error-free.

Photogrammetrically determined mean depth values were in all cases greater than the water volume values, i.e., the observer appeared to consistently set the floating mark above the local mean surface. This suggests that, for a particular observer, it might be possible to improve the accuracy of the photogrammetric values by applying a personal adjustment based on similar trials.

The results for 2- and 5-mm particles showed smaller errors associated with rounded particles than with angular particles. This relationship is reversed for the 10-mm particles. It had been anticipated that the more regularly shaped rounded particles would, regardless of size, have resulted in smaller errors than those applying to angular particles. As shown in Table 3, a third photogrammetric depth determination was carried out to check the earlier results. However, this confirmed the trend displayed by the two previous sets. Several factors may have influenced this apparently contradictory result. For example:

- the larger angular particles, being characterized by large, flatter surfaces may lead to a more accurate representation by observations spaced at intervals approximating the particle sizes,
- the density of particles per unit area of surface may have been significantly different, and/or
- the macrotopographic surface variation on the 10-mm rounded particle sample may have been larger than for the 10-mm angular particles.

EFFECT OF SPACING OF OBSERVATIONS

Figure 5 demonstrates the expected result that, as the spacing of observations on the equilateral triangle grid increased from the original 10 mm to 20, 40, 60, 80, and 100 mm, the RMS standard deviations increased. In general, the RMS standard deviations for the angular particles were greater than for the rounded particles. It is interesting to note that values for the 10-mm angular particles were also higher than for the rounded particles. This result provides an interesting inconsistency with the observation made earlier about the relationship between results for the 10-mm rounded and angular particles.

The 2- and 5-mm particle sizes had RMS standard deviations which did not exceed 0.3 mm even at 100-mm observation spacing. The 10-mm particles had a larger RMS standard deviation, with a maximum value of 0.8 mm. However, this is only of a magnitude similar to the standard error of the spot height measurements achievable with this camera, plotter, and photographic configuration. Of interest also is the point that an RMS standard deviation of mean surface elevation of better than 0.5 mm would be achieved, regardless of particles shape or size

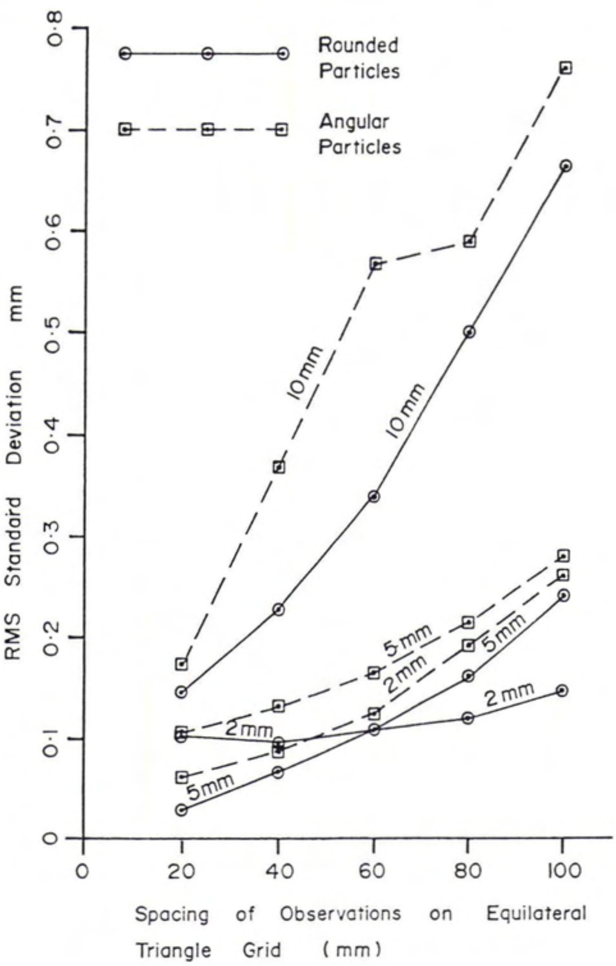

FIG. 5. Variation of standard deviation of mean depth with spacing of observations.

within the range considered, with maximum observation spacings of around 50 mm. This is a particularly useful finding as the writers' experience with the interpretation of natural surfaces using close-range photogrammetry (e.g., Sneddon and Chapman, 1988), supported by results from a progressive sampling package PROSAM (Mann and Staedtler, 1984), suggests that a 50-mm spacing would generally not be exceeded for the sampling of macrotopographic surface variations.

One matter not investigated in this study is the choice of percentage, e.g., 20 percent, of the plotter field of view over which the observer should estimate a mean surface. For example, if a sampling interval of 20 mm were dictated by the macrotopography, it would be inappropriate for the observer to attempt to mean the surface over a central 20 percent zone of 60 mm diameter. The 20 percent figure used in this study should therefore be used as a guide rather than an absolute standard. The observer should vary this figure to suit the macrotopography.

CONCLUSIONS

Reliable measurements of erosion in coarse-grained soils can be made using close-range photogrammetry. The influence of the microtopographic surface roughness caused by individual particles can be ignored. Each spot height is measured by setting the floating mark of the stereoplotter at an elevation estimated to be the mean surface of the zone corresponding to a suitable percentage, e.g., 20 percent of the field of view. Spot heights then need be measured only at spacings required by the macrotopographic surface variation.

ACKNOWLEDGMENTS

The writers acknowledge the assistance of Mr. Ian Leves, Mr. Ian Shepherd, and Mr. John MacLeod of the Civil Engineering Department, University College, University of NSW in the setting up of the various experiments reported in this work.

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(Received 4 April 1988; revised and accepted 27 September 1988)

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