

A Comparison Between Photogrammetry and a Surface Profile Meter for the Determination of Surface Topography for Micro-Erosion Measurement.

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Commission V.

Abstract:

The study of fluid flow over natural soil surfaces requires methods for describing and measuring surface micro-topography. The differences between surface topography at varying epochs can also give an indication of erosion or deposition patterns and volumes. Three methods for measuring surface topography, (metric photogrammetry, non-metric photogrammetry and a surface profile meter) were used to measure spot heights on a test area at Wagga Wagga in New South Wales, Australia, to provide data for the modelling of erosion and deposition patterns. The three methods were compared on the basis of speed and ease of use as well as accuracy and precision of the determination of the height dimension.

1. Introduction

The detailed study of fluid flow over natural surfaces generally requires methods for describing and measuring the micro-topography of the surface (Emmett, 1970). The development of mathematical models that predict soil erosion and deposition on three-dimensional catchments also requires techniques that can measure distributed soil movement to test and verify the model (Spomer and Mahurin, 1984). In order that data from one epoch to another can be compared such measurement methods should not alter the surface characteristics or flow patterns through time.

Micro-topography and the movement of soil can be determined by measuring the elevation above a datum of a series of points defining a surface. If two measurements are made at different times, the change in elevation indicates whether erosion or deposition is occurring, and the volume of soil moved. The aim of this investigation was to assess three techniques for acquiring data for the determination of surface relief and elevation. The comparison included a study of the accuracy and precision of the definition of the surface (for flow studies), and of the determination of absolute height (for erosion studies). The comparison also included an assessment of the ease and speed (convenience) of data collection and analysis. The three methods evaluated were the surface profile meter (with both manual and photographic recording of the data), metric photogrammetry using a survey camera, and non-metric photogrammetry using a medium format conventional camera.

This report is based on field work that was carried out at the Soil Conservation Service of New South Wales Research Station at Wagga Wagga in August 1987. Three independent sets of data were collected using each of the four measurement techniques.

2. Methods and Materials

2.1 The Test Site

The project area was located approximately midway along a cultivated erosion test plot measuring approximately 22 metres by 2 metres wide. The test area measured 1m square, and contained six control points. The control points consisted of brass rods which fitted into copper tubes that had been concreted into the ground. This enabled the rods to be removed between epochs so as not to interfere with the stream flow over the surface. These control points were surveyed for three dimensional position using a surveyors' level and measuring tape. Measurements of slope distance were made from each of the 6 control points to all of the other points, and height values were derived for each of the points by several independent sets of observations with the spirit level to a metal ruler calibrated in millimetres. The data were analysed using the computer program 'TDVC', (Shortis, 1987), which calculates the spatial coordinates for points based on a least squares variation of coordinates solution of a set of measurements containing a number of redundant observations. The precision of the control points following the adjustment was 0.3mm in plan and 0.5mm in height.

2.2 Equipment

2.2.1 The Surface Profile Meter

The surface profile meter (SPM) is a simple mechanical device that projects a profile of the surface into a position from which it can be measured. Metal rods or pins of the same length and a regular distance apart rest on the soil surface at known plan positions so that the tops of the rods represent a cross-sectional profile of the surface. The heights of the rods are either recorded in the field using a simple scale or they can be photographed with a 35mm camera and analysed later in the laboratory. The photographs of the backboard and rod profile are projected onto a flat-bed graphics digitiser and the profiles measured and rectified.

The surface profile meter used in this study consisted of forty one 5mm diameter rods at 25mm spacing, (Figure 1). These rods are gently lowered onto the surface, the top of the rods projecting the profile onto a gridded baseboard. The carriage on which the rods were mounted was supported on a square frame with two rails and locking positions at 25mm intervals. The frame has four threaded supporting legs and a bubble level on each edge which was used to ensure the frame was horizontal before a set of readings was taken. Two methods were used to measure the elevation of the rods, one involving reading elevations directly off the gridded baseboard in the field, and the other involving photographing the profile with a 35mm camera for later digitization in the laboratory.

2.2.2 The Cameras

The metric camera used in this comparison was a Zeiss SMK-40, with close focus rings attached to give a minimum focus distance of around 1m and a depth of field of approximately +/- 0.25m. An aluminium frame built for the task was used to support the camera horizontally above the plot (Figure 2). Monochrome glass plates (Agfa 'Agfapan 100') were used with natural lighting. The lighting was chosen to accentuate the surface without causing loss of detail in the shadowed areas. The overlap of the photographs was such that only half of the test area, containing four of the control points, could be photographed by one stereo pair.

The non-metric camera used in this comparison was a Hasselblad 500 ELM, using a Zeiss Distagon lens with a nominal focal length of 80mm. The calibrated focal length and parameters for lens distortion had previously been determined in the laboratory using photographs of a test range. Black and white roll film (Kodak Plus-X-Pan) was used, again with natural lighting. The camera was elevated 2.9m over the site using a light weight frame built for the purpose (Figure 3), and moved between photographs to obtain the stereo cover.

2.3 Experimental Procedures

The SPM, SMK and Hasselblad were used to obtain the spot heights of 205 points in a 1 metre by 0.5 metre area containing four control points. Points used for the comparison were identified by paint spots on the soil surface and were located by lowering the SPM rods on to the surface at five different positions within the test area (Figure 4).

Photographs of the five SPM profiles were taken using a 35mm camera. This was done for three independent data sets. In addition, three independent sets of elevations of the SPM rods were manually measured using the scale attached to the SPM frame. Three pairs of photographs of the surface were taken with the SMK and the Hasselblad. Between the exposure of each pair of photographs, the support frames of the cameras were removed and repositioned over the plot to ensure independent data sets.

2.4 Analytical Procedure

In order to measure the rod profiles on the SPM photographs, the black and white film negatives were projected onto a Summagraphics flat-bed digitizer. The top ends of the rods were observed, along with five control points to enable the rectification of the image. The data was processed via a simple bi-linear rectification program to obtain the reduced level of the 205 marked points for each of the data sets. (The plan positions of each of the points were known from the location of the rod carrier along the SPM frame.)

The SMK and Hasselblad stereo models were observed on a Zeiss Jena Stecometer in the Department of Surveying and Land Information, University of Melbourne.

The computer program 'STECA' (Shortis 1980) was used to orientate and scale the 205 marked points in the stereomodel onto the ground coordinate system defined by the control points. This program uses a vector solution for the collinearity condition and permits the incorporation of calibration values for lens focal length and distortion parameters. These values are known for the SMK (as supplied by the manufacturer and verified by subsequent calibrations), and were determined for the Hasselblad using multi-station photography of a targetted test range. The root mean square errors on the four control points for the solutions to the STECA adjustments for the Hasselblad and SMK are shown in Table 1. The numeral suffix denotes the data set number.

Hasselblad Model	RMSE z (mm)	SMK-40 Model	RMSE z (mm)
HAS1	0.98	SMK1	0.13
HAS2	0.72	SMK2	0.09
HAS3	0.75	SMK3	0.18

Table 1: Root Mean Square Errors on the Control Points.

2.5 Calibration of the Hasselblad Camera

The technique used for determining the lens characteristics of the Hasselblad was to observe convergent photographs of a targetted test range, and then to process these observations through a bundle adjustment. Six photographs of a test range located on the roof of the Surveying Building were taken with the lens focussed at the taking distance to be used in the field. The focal setting of the lens was noted so that the lens could be reset as closely as possible to this value. Observations to the targets visible in the photographs were then made on the Stecometer, and processed through program 'TBO'. This program, the Terrestrial Bundle Orientation, was initially developed by Earls (1981) to perform a bundle adjustment of such observations, and in the process to determine the focal length of the lenses used, and coefficients for the common expressions of lens distortion along with significance statistics of the solution. The 'TBO'

program suite has been proven on projects and tests in the past (Ogleby 1987, Shortis 1986) and the parameters computed can be accepted with qualified confidence. The values calculated by this adjustment were then input into program STECA as known parameters.

2.6 Analysis of the Heights

Two analyses of the elevation values produced by the methods under study were undertaken. A computer program was written to read in two sets of elevation data and calculate the difference in elevation for the 205 points. Comparisons were made between each of the data sets for each method to determine the reproducibility of results (within each method). The results of the comparisons are shown in Table 2. The three data sets for each technique were combined and the mean elevation of each of the 205 points was calculated. The standard deviation of the determination of elevation was then computed. These are shown in Table 3. Having determined that the SMK offered the most accurate and precise method of recording the surface, differences between the SMK and each other method were then determined to highlight the existence of trends in the results.

3. Results

In the tables the abbreviation 'MAN' is the manual record of the surface profile meter made in the field, 'SPM' is the digitized photographic records of the surface profile meter, and 'HAS' is the Hasselblad photography.

COMPARISON	Mean of Diff. (mm)	Std. Deviation (mm)
SMK1-SMK2	-0.08	0.61
SMK1-SMK3	0.16	0.58
SMK2-SMK3	0.24	0.64
HAS1-HAS2	-1.45	2.78
HAS1-HAS3	-0.30	2.47
HAS2-HAS3	1.15	2.83
SPM1-SPM2	0.77	2.13
SPM1-SPM3	0.35	1.68
SPM2-SPM3	-0.42	1.92
MAN1-MAN2	-0.44	1.14
MAN1-MAN3	0.29	1.24
MAN2-MAN3	0.73	1.11

Table 2: Comparisons Between the Three Data Sets for each of the Methods.

METHOD	Std. DEVIATION (mm)
SMK	0.413
MAN	0.815
SPM	1.385
HAS	1.902

Table 3: Standard Deviation of Elevation Measurement

	SMK1		SMK2		SMK3	
	Diff	Std.Dev.	Diff	Std.Dev.	Diff	Std.Dev.
HAS1	0.72	1.97	0.80	2.00	0.56	1.94
HAS2	-0.86	1.41	-0.78	1.42	-1.02	1.33
HAS3	0.37	2.39	0.45	2.33	0.21	2.35
MAN1	0.45	1.85	0.53	1.80	0.28	1.77
MAN2	0.00	1.99	0.80	1.92	-0.16	1.95
MAN3	0.68	1.86	0.76	1.80	0.52	1.80
SPM1	-0.94	2.29	-0.86	2.29	-1.10	2.08
SPM2	-0.13	2.07	-0.05	2.00	-0.29	1.97
SPM3	-0.60	1.97	-0.52	1.94	-0.76	1.87

Table 4: Comparison Between the SMK Results and All Other Methods.

4. Discussion

The results will be discussed on several bases: the precision, accuracy and reproducibility of measuring the height dimension above a datum; the convenience of the method in the field and laboratory; and the overall time taken for each method. The final use of the data will determine the most important of these criteria. Studies into the flow of water over natural surfaces require an accurate representation of the surface but do not need the position of the surface in space to be well defined. On the other hand, erosion and deposition studies require both an accurate definition of the surface as well as the precise position of the surface in space. This is because models from different epochs are compared and so their absolute orientation must be the same. Which method then provided the best solution?

4.1 Accuracy and Precision

The standard deviation of the differences in two data sets represents an estimate of the accuracy with which the relative elevations are known. The size of the mean differences is an indication of the precision with which the surface can be positioned in space. A large storm may remove up to 15 tonnes of soil per hectare which is equivalent to a uniform layer of approximately 1mm being removed, hence the need for the high precision and accuracy of measurement.

The results in Table 2 show the comparison between the three independent data sets for each of the three measurement techniques. These results show that the three SMK models were most consistent in the determination of the elevation of the 205 points.

Table 3 shows the standard deviation of the elevation values calculated for each of the methods. These results, along with those in Table 1, show that the SMK is capable of determining the absolute heights of the surface features better than the other methods.

Table 4 shows the results of the comparison between all the data sets and the three SMK sets. The results indicate that the standard deviation of the SPM measurements is similar in magnitude for both the methods of recording, but also that there is a consistent negative shift in the photographic recording of the SPM. This is most likely due to parallax errors introduced by the location of the camera relative to the tops of the rods, and their location with respect to the reference grid on the baseboard. Generally it would be expected that the SPM would underestimate the elevation due to the rods partially compressing the soil. The surface was hard in this experiment and little penetration appeared to occur. On soft surfaces this problem will affect the results, particularly for erosion studies, if the penetration at two epochs is significantly different. Results for the Hasselblad show a wide variation in the size of the standard deviation and the magnitude and direction of the datum shift. This is most likely a

result of random errors due to film unflatness, which in the camera/photograph configuration used here is very difficult to minimize (Ogleby, 1987). These datum shifts are a particular problem for erosion studies because a single model must be accurately located in space, and this does not appear to be possible with the Hasselblad and the analysis used here.

4.2 Convenience of Use

The photogrammetric methods were the quickest methods in the field, taking approximately five minutes per pair of photographs. The SPM requires ten to fifteen minutes to set up the base frame and one minute per row if the profile is photographed, or two to two and a half minutes per row if the elevation of the rods is manually recorded. In the laboratory, the situation is reversed. The manual SPM results are essentially completed in the field and so only need to be entered into the computer, which takes seven minutes per sample of five rows. The digitized SPM measurements took approximately fifteen minutes to observe the five rows and manipulate the raw data. The photogrammetric images took approximately thirty minutes per model (205 points plus control) to observe plus an additional fifteen minutes of transferring and manipulating the raw data. The Hasselblad calibration was time consuming (approximately ten hours) but once this is done, it may be used for all future models. Therefore the total time taken for the non-metric photogrammetry is similar to that of metric photogrammetry once the calibration parameters have been established.

All photographic methods also require time in the dark room developing the negatives. Each dozen set of SMK plates is processed in an open deep tank, and takes approximately the same time to develop and dry as a roll of 120 size Hasselblad or 35 mm film.

The total time taken for each set of 205 points for the four methods are as follows:

- SMK-40 - 50 minutes (plus developing time),
- Hasselblad - 50 minutes (plus developing and calibration time),
- Manual measurement of SPM - 28-35 minutes, and
- Photographic measurement of SPM - 30-35 minutes (plus developing time).

A major disadvantage of the photogrammetric methods is the requirement of access to a skilled observer, expensive equipment and sophisticated analytical programs. In addition a basic knowledge of the science of photogrammetry is required to run the analytical programs.

5. Conclusion

Photogrammetry is non-destructive, quick in the field and provides a permanent record of a large amount of data which can be selectively analysed. However it requires specialized equipment to analyse the photographs, a skilled operator to observe the models and the analytical skills to process the data. From the results presented here it appears that non-metric photogrammetry cannot provide the accuracy to verify models for soil erosion or deposition. In order to use non-metric photogrammetry successfully, multiple convergent photographs of the test area would be required in order to minimize the errors due to the internal instability of the camera and film unflatness. This would increase the time required for analysis to an unacceptable degree, and in the case of convergent single photographs lose the benefit of the stereomodel for interpretation.

The SPM is partially destructive, slower in the field than photogrammetry, and only records the elevation of specific points (unlike photogrammetry, which allows any number of points to be observed). If the SPM profiles are photographed, a permanent record is produced. The time required to obtain an SPM model is substantially less than for photogrammetry. The SPM is a simple, inexpensive and robust device that requires no special skills to operate. A digitizing table is advantageous as reading and recording elevations off a scale in the field is tedious and does not allow the profiles to be re-analysed at a later date.

The final choice of method will depend on many factors including the required degree of precision, the total time limitation, cost, access to photographic and photogrammetric equipment as well as the skills available to observe and analyse the data. There are basically two clear choices. The SMK will provide a high degree of precision, minimum time in the field and a permanent record but requires access to a skilled observer, expensive equipment including the camera, and analytical software. The SPM is quick, simple, cheap and fairly robust. It is limited by having a fixed point density, takes longer in the field than metric photogrammetry, is less precise and may become inaccurate if the surface is soft enough to allow penetration by the rods.

Acknowledgements

The authors wish to acknowledge the valuable assistance of Mr. Robert Straube for performing the Stecometer observations, and Mr. Sjeff Bervoets and Mr. Frank Leahy for their comments on the statistical analysis of the results.

References

- EARLS, C.J. 1981, *Self Contained Analytical Systems for Close Range Photogrammetry*. Master of Surveying Science Thesis, Unpublished, University of Melbourne, 1981.
- EMMETT, W.W. 1970 'Hydraulics of Overland Flow on Hillslopes'. *United States Geological Survey Professional Papers*, Volume 662A, 1970. 68p.
- OGLEBY, C. L. 1987 '*Applications of Non-metric Photogrammetry in Archaeometry*'. Master of Surveying Thesis, Unpublished, University of Melbourne, May 1987.
- SHORTIS, M. R. 1980, *Sequential Adjustment of Photogrammetric Models*. PhD Thesis, City University, London, 1980.
- SHORTIS, M. R. PRICE L.J. and TURNER P.J. 1986, 'Photogrammetric Monitoring of the Excavation of a Trunk Sewer Pumping Station'. *International Archives of Photogrammetry and Remote Sensing*, Volume 26 Part 5, Ottawa 1986. pp 241-250.
- SHORTIS, M. R. 1987, 'Adjustments of Survey Observations for the Computation of Universal Transverse Mercator Coordinates'. Paper Submitted to *The Australian Surveyor*, 1987
- SPOMER, R.G. and MAHURIN, R.L. 1984. Time Lapse Remote Sensing for Rapid Measurement of Changing Landforms. *Journal of Water and Soil Conservation*. November -December, 1984. pp 397-401

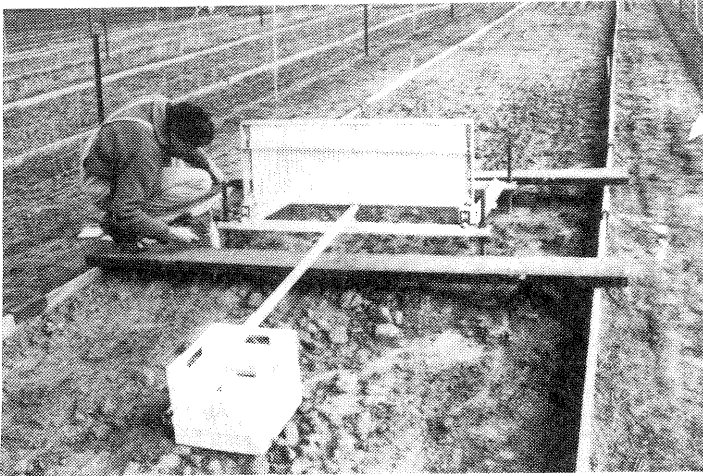


Figure 1. The Surface Profile Meter

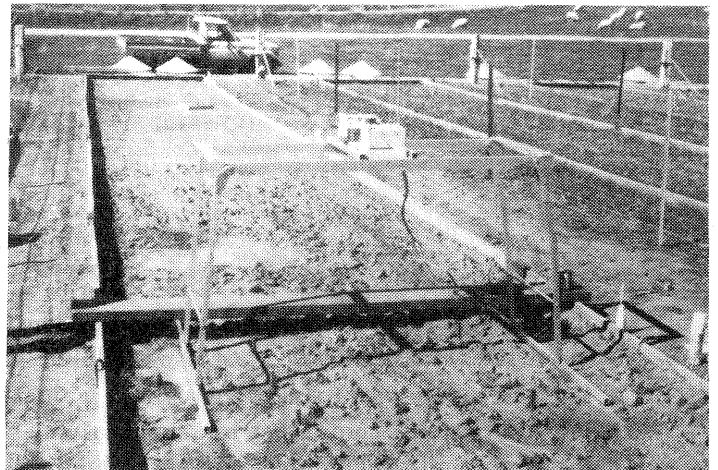


Figure 2. The SMK in Use Over The Test Site

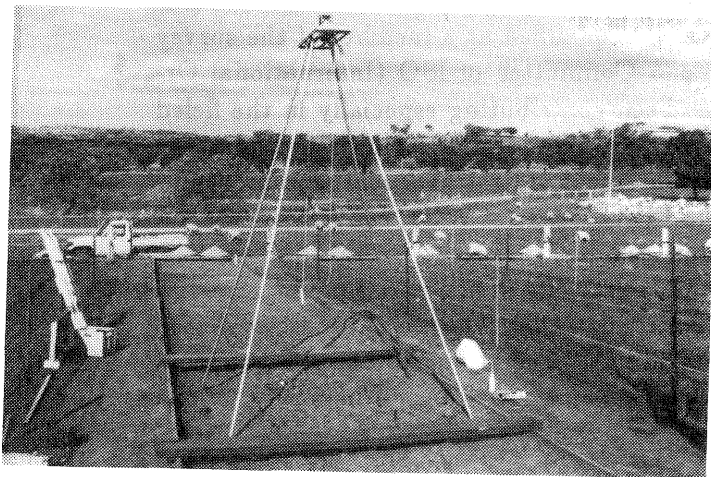


Figure 3. The Hasselblad and Support Frame

Figure 4. The Surface and Reference Paint Spots

