14TH CONGRESS OF THE INTERNATIONAL SOCIETY OF PHOTOGRAMMETRY

HAMBURG 1980

NO OF COMMISSION V

NO OF WORKING GROUP 5

INVITED PAPER

EXAMPLES OF THE USE OF TERRESTRIAL PHOTOGRAMMETRY IN HIGHWAY ENGINEERING

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ABSTRACT

Terrestrial photogrammetry has been used to make detailed plans of landslides in the mountainous areas of Colombia and Nepal. Plans were produced at scales between 1:200 and 1:10,000 with contour intervals between 0.5 and 5 metres. An analysis of cost showed that the technique permitted substantial savings to be made in time and effort compared with more conventional survey methods, particularly in the field work where cost reduction factors of 7.5 were recorded. A simplified technique involving a Hasselblad camera modified to take a reseau has been used to provide slope profiles of unstable ground. Most of the plans were produced using a range of photogrammetric plotters to provide contours but analytical techniques were used to plot the Hasselblad work and for measuring a building which had deformed due to adjacent tunnelling operations. The measurements obtained from the terrestrial photogrammetry provided a useful addition to information produced by other methods of survey.

INTRODUCTION

Much of the data on which highway designs are based is obtained from field surveys and site investigations, the effectiveness of which largely determines the future serviceability of the road structure.

This is particularly true for roads constructed in difficult terrain where poorly executed surveys can give rise to inadequate designs. These in turn can lead to road failure which may necessitate high levels of costly maintenance or reconstruction.

To avoid such costs, especially in under-developed regions where basic ground information may be lacking or where ground access presents problems, increasing attention has been focussed on developing methods to improve site investigation procedures.

One method being developed is the use of terrestrial photogrammetry to provide accurately contoured maps and plans. These are required for siting engineering works as well as providing a means for calculating the dimensions of structures, such as retaining walls, culverts etc and estimating the volumes of earthworks and sources of constructional material.

Maps and plans are usually produced by conventional theodolite, level or aerial photogrammetry survey methods. Such methods are well suited to easy terrain but often prove unsatisfactory in steep, broken ground where access may present difficulties or in circumstances where the lack of time or the unavailability of suitably skilled survey teams imposes constraints.

In such circumstances terrestrial photogrammetry appears to offer a viable alternative method of acquiring maps and plans at suitable scales for a variety of engineering applications. The terrestrial photogrammetric technique has been used to measure rock slopes, reference 1 and for mine surveying in open pits, reference 2. At the Transport and Road Research Laboratory, terrestrial photogrammetric surveys of landslides, road cuttings, road alignments and buildings have been made.

THE NEED TO SURVEY LANDSLIDES

As part of a general investigation into road building problems in the rugged terrain of Colombia a need arose to prepare detailed plans of the surface features of a large number of landslides. The landslides, distributed throughout the Colombian Andes, were located in dangerous and inaccessible terrain. The plans were required to design remedial and preventitive measures to deal with landslide problems affecting the roads. In addition the plans were needed to prepare a classification of landslide characteristics as an aid to future road design and construction in areas of unstable terrain. Traditional surveying techniques such as levelling were considered inappropriate because of the problems of access the unstable ground and the high cost of such methods.

Photogrammetry. Photogrammetry was the only survey technique which would meet the requirements. Aerial photogrammetry had to be rejected because of the very high costs of using an aircraft and also the limited landslide detail that can be seen from the air. Terrestrial photogrammetry was considered a viable alternative provided that suitable equipment could be obtained and an appropriate technique developed. The essential features of the technique were to be based on making the survey time and skilled effort as small as possible and on reducing survey costs to a minimum.

The development of the technique. The problems likely to be encountered in the field work could not be fully predicted and therefore trials were made by using the terrestrial photogrammetric technique by surveying a chalk cutting in Britain. The initial problems encountered during the early field trials were as follows;

(1) It was difficult to use a large metric camera such as the Zeiss UMK in areas of rugged terrain. Handling and transporting the equipment was considered to be an important factor when working in Colombia where site access would prove difficult.

(2) Placing survey control markers on the face of the cutting or other steep ground presented problems where personnel access was impossible.

(3) Survey accuracy was lost due to poor ground control, as a result of difficult working conditions.

(4) Finding suitable ground for the camera-theodolite baselines proved difficult. The difficulties included the obscuring effect of vegetation and the steepness of the sites.

Results from the initial trials indicated that a small metric camera with a wide angle lens, which would simplify the choice of suitable baselines, was essential. The need for extra care in making the theodolite readings for the survey control was recognised, but the problem of placing the control on the landslide was still not solved. In addition, measuring the photographs on a plotting instrument also presented problems, when for example;

(1) The large depth range of certain landslides produced a Z range outside the limits of most plotting instruments.

(2) Not having the camera base parallel to the landslide face resulted in a large Z range and also made it difficult to calculate areas and volumes from the plans.

The problems could only be solved by recourse to an analytical solution and this was developed, to be used when photographs were outside the adjustment limits of plotting instruments.

Equipment. At the time of the trials the Wild P32 metric camera had just become available. Although it was new and untried it was right for the landslide survey work in terms of operating costs, size and format. There was an expected loss of accuracy as a result of the small image size when compared with other metric cameras. See Table 1.

TABLE 1

Metric cameras suitable for field work

Camera	Relative accuracy for same, base/ distance ratio	Relative accuracy for same area surveyed	Lens Angle	Weight
WILD P30	$\pm$ 0.6	$\pm$ 1.53	44°	27.5 KG≁
WILD P31	$\pm$ 1.0	$\pm$ 1.67	60°	29 KG*
WILD P32	$\pm$ 1.6	$\pm$ 2.18	64°	15.7 KG*
ZEISS UMK	$\pm$ 1.0	$\pm$ 1.0	80°	30.5 KG*

* Camera and Theodolite
≁ Phototheodolite

SURVEY WORK IN COLOMBIA

The survey team consisted of a photogrammetrist an assistant and a labourer. Access to the sites was often difficult and normally involved walking a considerable distance with the equipment. The choice of suitable survey stations was restricted because of the dense vegetation and steep ground. The aim was to find a site that was suitable for the camera and theodolite stations although this was not always possible. Often the surveys were made looking across a valley, river or ravine, and this meant that the camera distance was not always ideal which resulted in a loss of survey accuracy. Expressed as a ratio of useful image size to usable film areas (R) from the equation

R = FILM SIZE - (B x PD/D)/LANDSLIDE IMAGE SIZE

where B = BASE
PD = PRINCIPAL DISTANCE
D = DISTANCE.

Ideally the value of R should be one.

For a sample of twenty five landslide surveys the value of R was calculated and the results provided a root mean square value of 1.29 and a standard deviation of 0.5. A high value of R, whilst resulting in a loss of accuracy, simplifies the choice of suitable survey bases for the camera. In terrain conditions where the selection of suitable survey bases is not a problem, the use of a metric camera with interchangable lenses, for example the Wild P31, would result in improved survey accuracy.

Control survey targets. The landslide control survey targets consisted of natural features such as houses, rock outcrops and fence posts. As an aid to subsequent identification and also to ensure that the targets could be seen from both camera stations, polaroid photographs were exposed from each station. As a further aid to control identification, drawings of the visible features of the control targets were made.

Photography. Colour reversal film was used in addition to glass plates for the photography. Although it was expected that the superior dimensional stability of the glass plates would allow more accurate plotting, after tests it was found that the better image detail of the colour film produced the best results.

Control measurements. Face left and right readings to each control target were made from each survey station. The fine detail of the natural feature selected as a control target was used to align the theodolite. The use of natural features as control targets presented two difficulties. The first was that it proved difficult to remember and use the same fine detail for the four theodolite readings. The second problem was that very often the fine detail used to align the theodolite from one station was obscured when viewed from the opposite station. A very careful selection of control features was essential in order to preserve the accuracy of the ground control survey. The theodolite survey base length was measured with a tape or in difficult conditions a subtense bar. Five control targets were used for each landslide survey, reference 3.

Preparation of Material. The angles measured by the theodolite from the survey base lines to the ground control targets were converted into measurements in a three axis coordinate system. A computer program was used to calculate the coordinate values from a horizontal base. The measured survey base had therefore to be reduced to a horizontal level. First the means of the face right and left readings for the horizontal circle were calculated and the angles corrected so that the base line horizontal angle was zero. All horizontal angles greater than 180° were subtracted from 360° to give the internal angles to each point. The angles in the vertical circle in the 3rd and 4th quadrants were reduced, and the mean base angles were calculated. The distances to all control targets from the left base station were then calculated. The results were drawn out on graph paper and compared with the control points marked on the polaroid photographs, as a check.

The colour film and plates were processed in small batches so that if there were any problems only a small sample of data would be affected. From the plates large scale photographs of the control features were made and the exact centre marked.

Plotting the photographs. Photographs were plotted on the Wild A40 and the Zeiss TOPOCART. In many overseas countries where terrestrial photogrammetry might be used, terrestrial plotting instruments are generally not available. Almost all countries have facilities for plotting aerial photographs. In order to investigate the suitability of aerial photogrammetric plotters a trial was made using the Wild A7 Plotter.

The P32 images were enlarged to produce diapositives with an effective PD of 150 mm. Unfortunately the survey chosen for the trial was of a landslide with a very large Z range. Only a small part of the total surveyed area was plotted on the A7. The whole area was plotted on the A40 and a segment to the A7 plan scale, was enlarged for comparison. Figure 1 shows the whole area of the Landslide at Caraza near Bogota, plotted to a scale of 1:2000 with contour intervals of 2 metres.

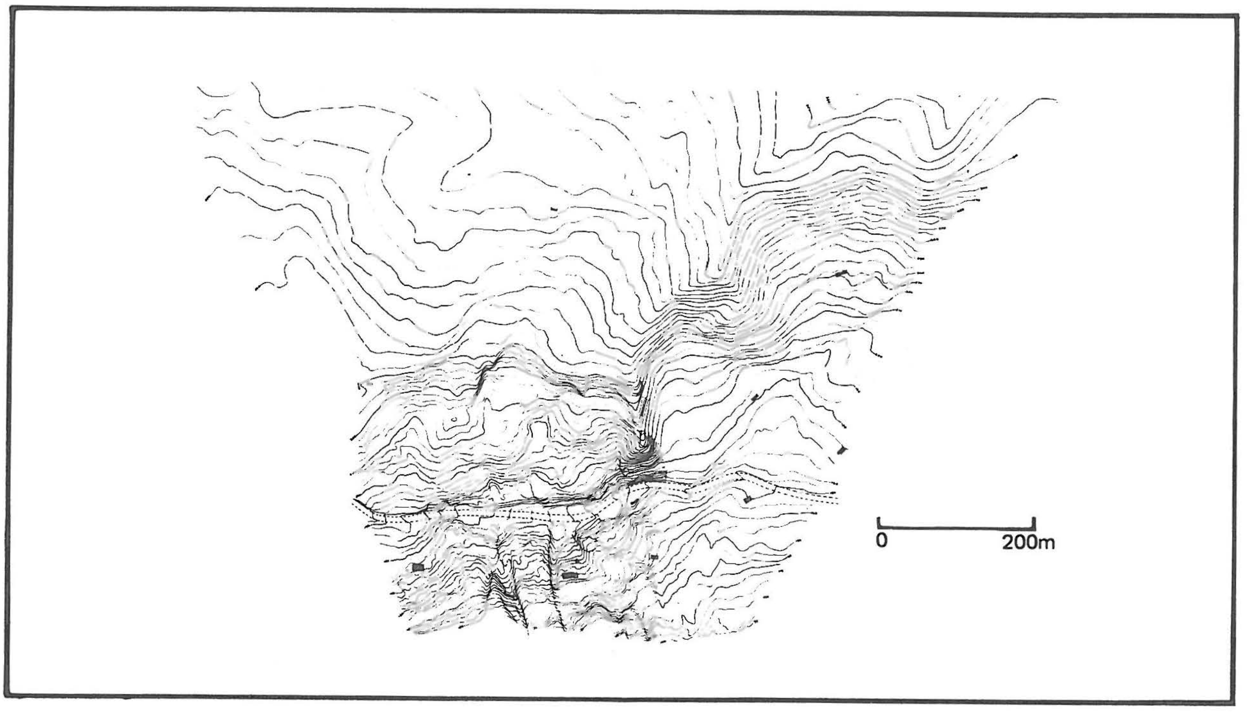
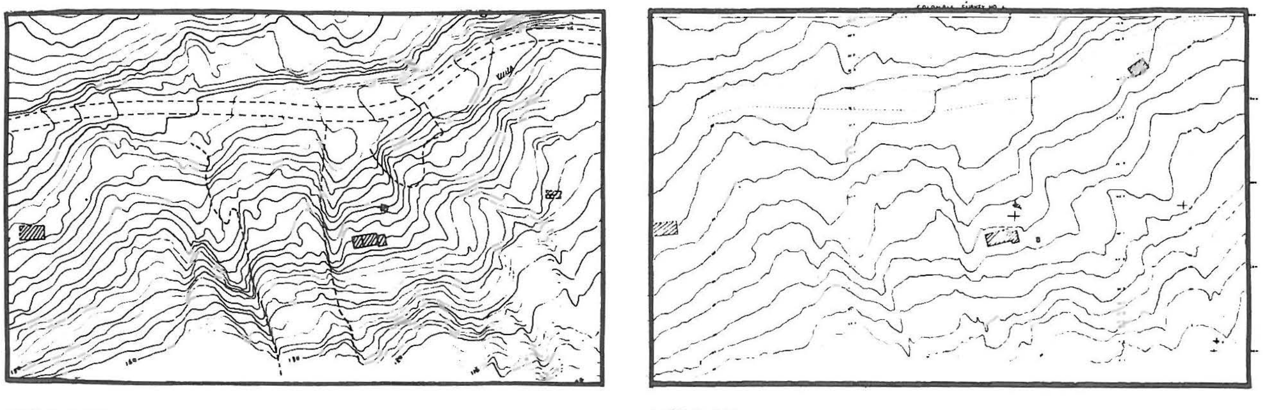


Fig. 1 CONTOUR PLAN (SURVEY No 4 CARAZA) PLOTTED ON WILD A40

Figure 2 shows an enlarged section of figure 1 to a scale of 1:500 and the plan made from the A7 plotter. Whilst the A7 is not ideal for such work it can be used to produce useful plans when other plotting instruments are unavailable.



Wild A40 Wild A7

Fig. 2 ENLARGED SECTION OF CARAZA PLAN AND A7 PLAN

Approximately eighty landslide surveys were made in Colombia and of these roughly half have been plotted. Most of the plans have been produced at a scale of 1:500 with a contour interval of 2M. Plate 1 illustrates a landslide feature and figure 3 shows the contoured plan and cross sections originally produced to a scale of 1:200 with contour intervals of 1 metre.

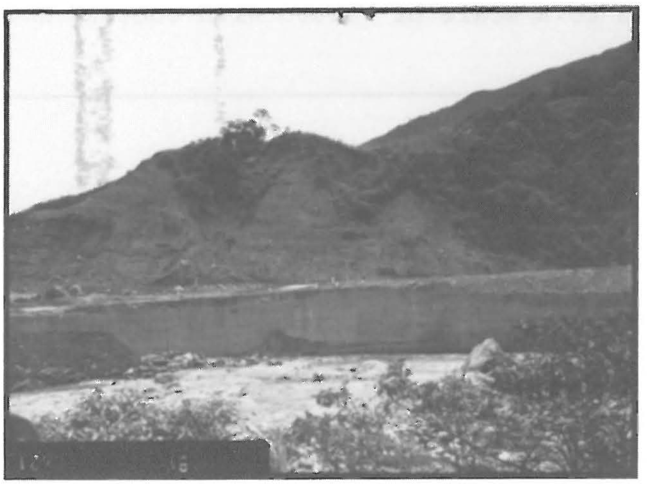


Plate 1 AREA OF UNSTABLE GROUND ADJACENT TO RIVER

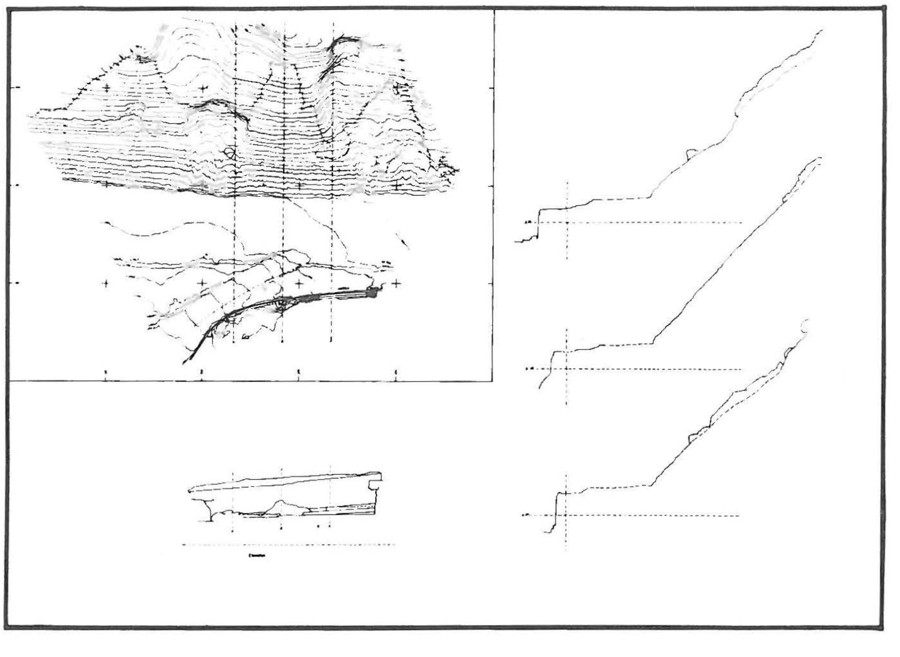


Fig. 3 CONTOURED PLAN AND DRAWING OF THE AREA SHOWN IN PLATE 1

Terrestrial photogrammetric surveys made in Nepal

The technique was used in Nepal to prepare site plans for the alignment of a new road. Surveys were made of five separate sites. Plate 2 shows the oversteepened lower slopes of a ridge through which the road alignment passes.

A photogrammetric survey involving three sets of photographs was made of the area, and these were plotted to a scale of 1:1000 with 2M contours, see figure 4. A road alignment plan had been made of the same area by conventional chain and level methods and this was used to provide a check on the photogrammetric survey plan. Part of the photogrammetric plan was enlarged to a scale of 1:500 to match the road alignment plan.

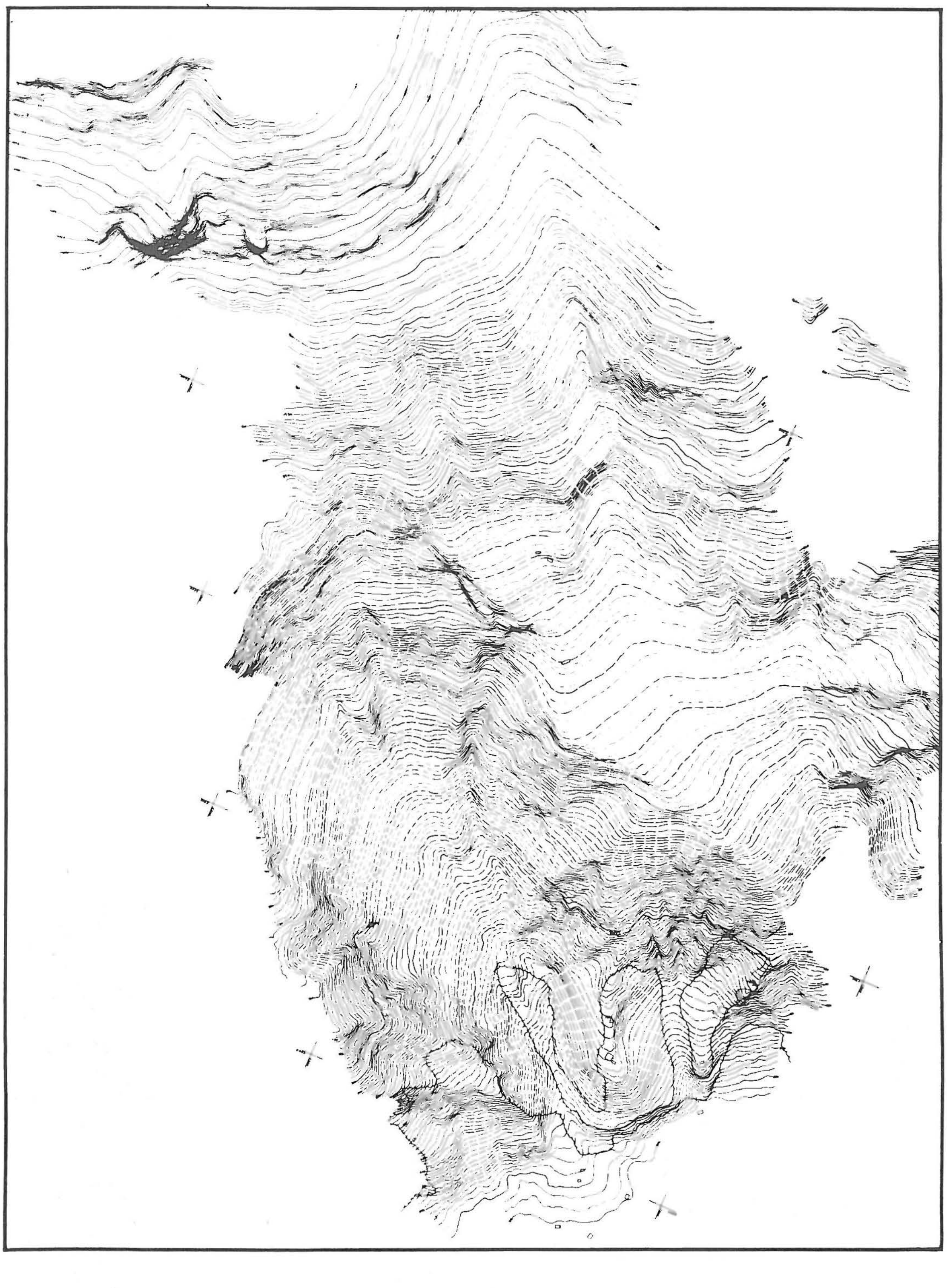


Fig. 4 PHOTOGRAMMETRIC CONTOUR PLAN, ORIGINAL SCALE 1:1000

The scaling error difference between the two plans was less than 1.5%. The fit of the bench mark references, visible on both plans, was calculated and found to be T66 = 0.5M T67 = 2M T69 = 0M T70 = 1.5M.

A relative comparison. The photogrammetric plan was divided into zones. The central zone which consists of broken contour lines is an area of uncertainty because the ground was obscured by vegetation and slopes. The comparison was based on three areas within the uncertain, broken contour zone and four areas within the well defined zone. For each area a 25M true scale, grid was drawn. Each grid contained 16 points of intersection from which comparisons of the contoured heights on both plans were made, see figure 5. The results are shown in Table 2.

TABLE 2

The results of comparison of two plans

Grid No	Mean Error (Metres)	Standard Deviation	
1	0.6	2.77	
2	0.13	1.15	
3	0.13	0.89	
4	0.65	2.37	
5	0.38	1.02	Broken Contours
6	0.56	4.19	
7	2.94	4.92	

Plate 2 PHOTOGRAPH OF PART OF THE ROAD ALIGMENT IN NEPAL

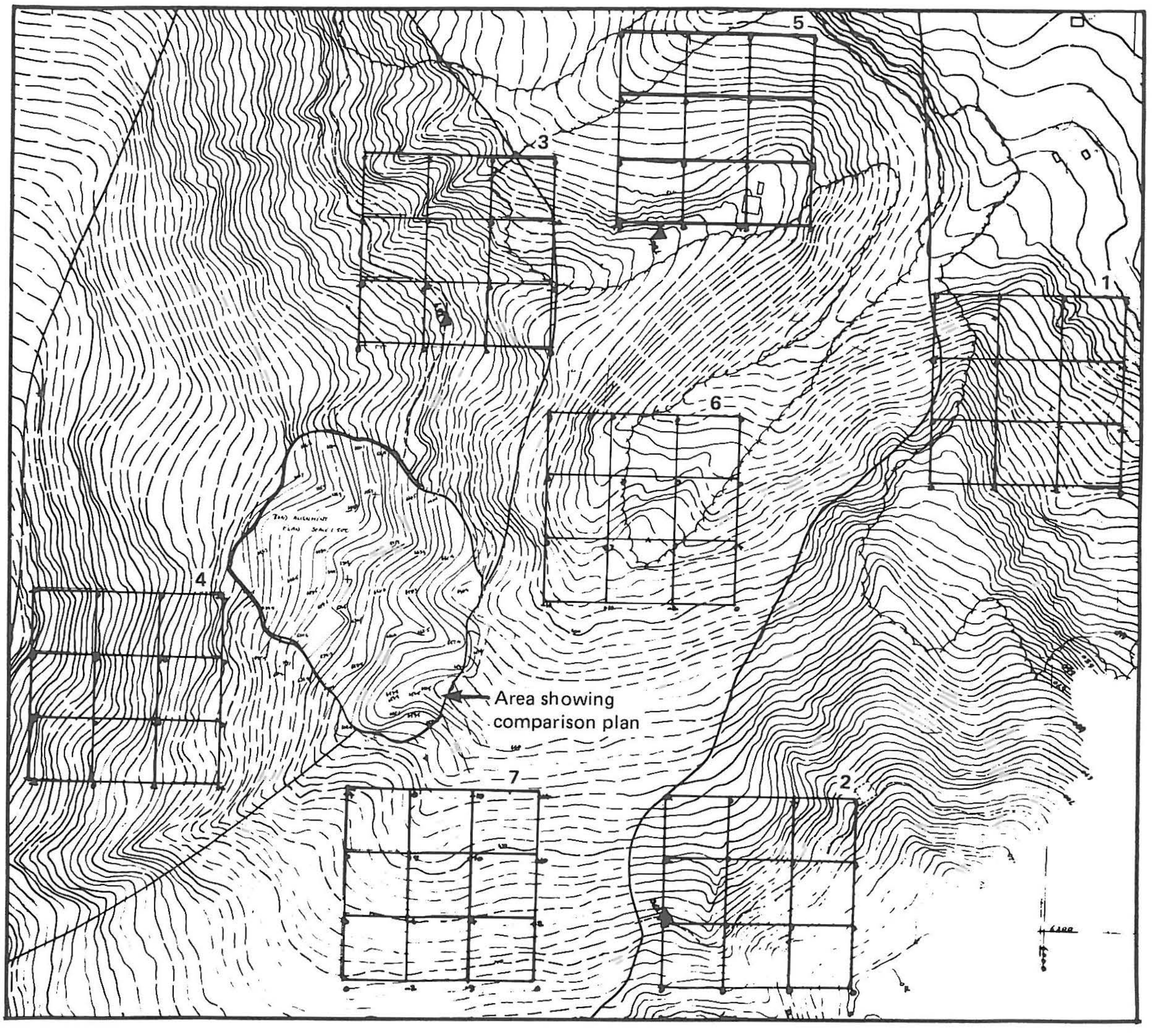


Fig. 5 PHOTOGRAMMETRIC PLAN AND CONVENTIONAL SURVEY PLAN USED FOR A CHECK ON ACCURACY

For site investigation purposes the contour plan produced by photogrammetric methods shows a good correlation to the plan made by conventional surveying. The cost effectiveness of the photogrammetric technique is indicated in the time difference to produce the two plans. One days field work and two days plotting work in the case of the photogrammetric plan, and a period of weeks for the conventional survey.

A simplified photogrammetric technique

Because terrestrial photogrammetry is a specialised technique it is only used when there are a large number of sites to survey or a single site is of particular importance. During the site investigation, small surveys are often required which at an early stage of the road building project do not justify the high costs of a special surveying team. To meet such demands a simplified photogrammetric technique has been developed. The equipment consists of a Hasselblad SW camera modified with a reseau plate in the film plane. The camera is mounted onto a rotating, graduated adapter which fits into a tribrach. A telescopic site with a graticule is mounted on the camera at 90° to the optical axis, and is used for camera alignment purposes.

The technique was used during an engineering geomorphology study of slope instability in Colombia, reference 4. One survey was of a landslide which had previously been surveyed with the P32 and a contour plan had been produced to a scale of 1:500, see figure 6. The Hasselblad

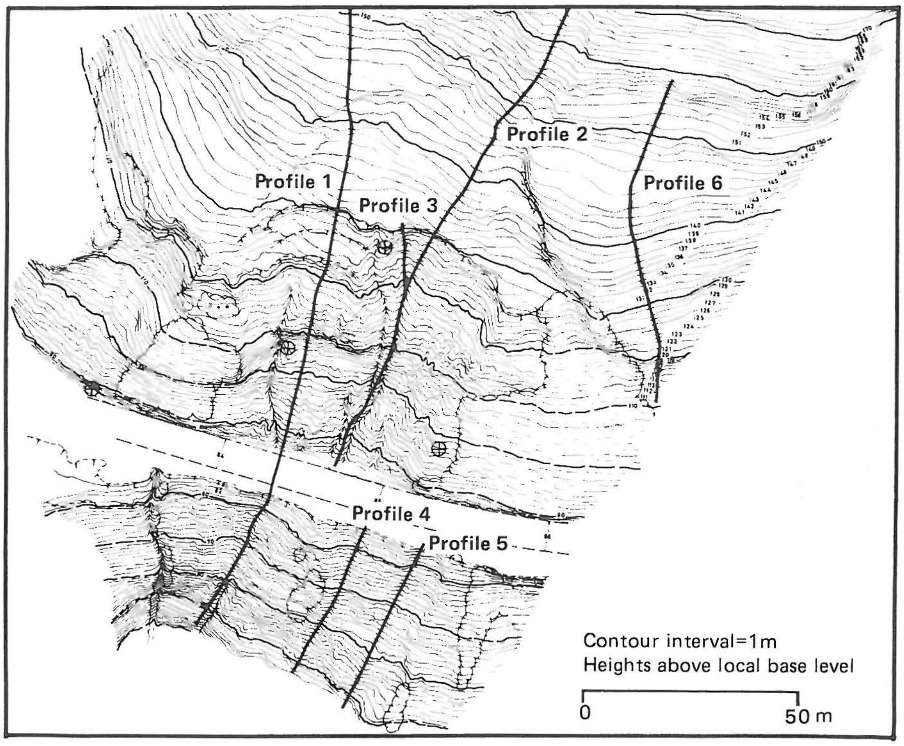


Fig. 6 WILD P32 PHOTOGRAPHY CONTOURED PLAN. PROFILE LINES TAKEN FOR COMPARISON

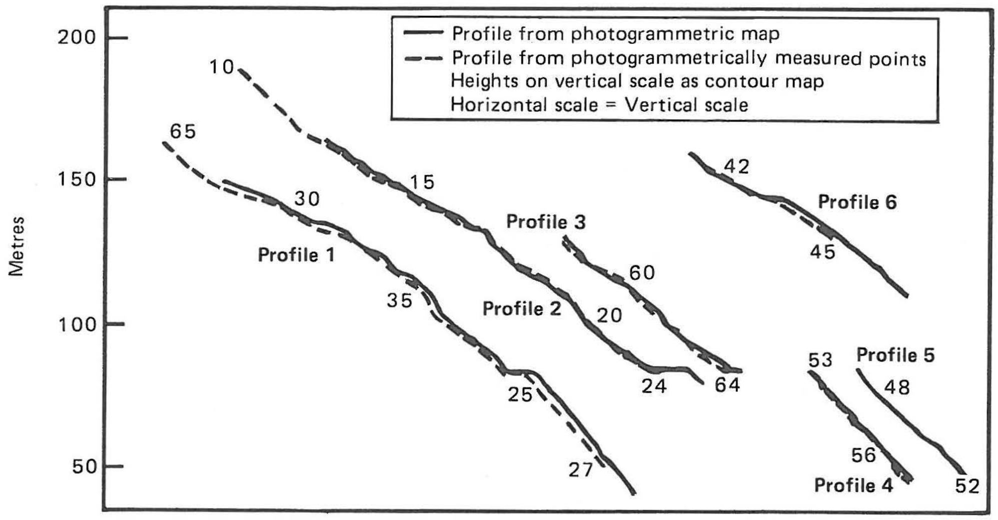


Fig. 7 A COMPARISON OF THE SLOPE PROFILES OF THE HASSELBLAD PHOTOGRAPHY (Wooding[4])

images of the same landslide were measured on the Hilger-Watts stereo comparator and the calculated slope profiles were compared with similar profiles taken from the P32 map, see figure 7. Although of a reduced order of accuracy, the Hasselblad results are adaquate for certain road design and site investigation purposes. The total cost of the equipment is less than £1000 and the weight is 5 kg.

Monitoring Movement

By taking pairs of photographs at intervals over a period of time it is possible to measure very small movements. For road engineering purposes the technique can be used to detect very small changes in the position of landslide material, or movements in buildings as a result of ground movement. The technique has been applied to the measurement of building movement which has resulted from ground movement due to tunnelling.

Precise measurements from photographs made with the Zeiss UMK camera, before, during and after the tunnelling operation were used to plot the change in shape of a building frontage, see figure 8. The images were measured on a Zeiss Stecometer and an accuracy of 1 part in 10,000 or 2mm over an area of more than 1000 M^2 has been achieved, see reference 5.

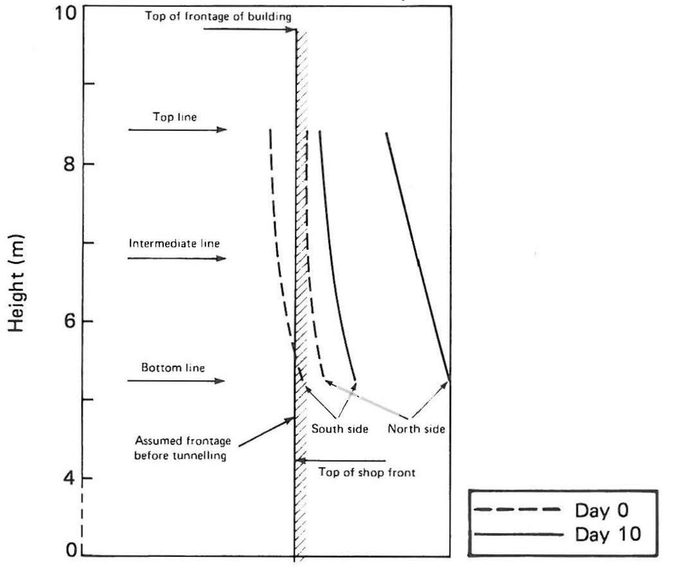


Fig. 8 PROFILES OF BUILDING MOVEMENT TAKEN FROM PHOTOGRAMMETRIC MEASUREMENTS

CONCLUSIONS

Terrestrial photogrammetry has been used for site investigation purposes in a number of difficult areas and has proved to be economic, accurate and reliable.

The versitility of terrestrial photogrammetric techniques has been demonstrated in four different applications described in this paper.

When accuracy is the prime consideration, it can be achieved to an order of 1 part in 10,000 by using large metric cameras such as the Zeiss UMK.

Conversely, if a lower order of accuracy is adaquate for the purpose, measurements made with the Hasselblad SW camera make an important contribution to site investigation work. The use of low cost equipment and simplified techniques will be an important use of terrestrial photogrammetry for engineering measurements in the future.

The economics in cost and time of surveying large sites with the Wild P32 and the good overall accuracy of the results has been demonstrated by the work in Colombia and Nepal. In many instances complete surveys cannot be achieved by terrestrial photogrammetric techniques because of dead areas where the ground cannot be seen. Such areas generally represent a small part of the total survey area, and can be completed by using traditional survey methods.

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ACKNOWLEDGEMENTS

The work described in this paper forms part of the Research Programme of the Overseas Unit (Head Mr J N Bulman) of the Transport and Road Research Laboratory and is contributed by permission of the Director. The cooperation of the Ministerio de Obras Publicas y Transportes, Colombia, Department of Roads, Nepal, and Rendel Palmer and Tritton, Consultant Engineers is gratefully acknowledged.