*Measurement of Crustal Movements by Photogrammetric Methods**

LORIN F. WOODCOCK,
Commander, USC&GS
and
B. FRANK LAMPTON,
Cartographer, USC&GS

(*Abstract on page 1047*)

INTRODUCTION

THE relative movement of points on the earth's crust in an active geologic fault area may amount to a few centimeters for pairs of points spaced a few hundred meters apart. Traditionally, precise geodetic survey methods have been used to measure these relative displacements. The Coast and Geodetic Survey is engaged in a study of the application of the methods of analytical photogrammetry to the measurement of these displacements.

This study is part of a joint effort with the University of Utah to measure changes in the relative position of points on the earth's surface in the vicinity of the Wasatch Fault, Salt Lake County, Utah. The entire program consists of four phases.

Phase I. Two short traverses are to be measured across the Wasatch Fault Scarp designed to detect local strain accumulations of small magnitudes. Civil engineering students from the University of Utah will make measurements accurate to 3 millimeters between monuments approximately 30 meters apart. The measurements will be repeated semiannually.

Phase II. The Coast and Geodetic Survey established a network of 19 first-order triangulation stations in October 1962. This network, located on both sides of the major scarp, is designed to measure strain accumulations between points several miles apart. The points in the network will be reoccupied at regular intervals. Planned accuracy of the triangulation is 1 part in 75,000.

Phase III. A triangle with sides approximately 20 miles long has been formed by permanent stations located in each of three mountain ranges surrounding Salt Lake County. The measurements between these points will be repeated to detect relative movements between distant points.

B. FRANK LAMPTON

Phase IV. This phase of the program is a photogrammetric research project designed to determine the usefulness of photogrammetry for crustal movement study. It is hoped that aerial photography and control surveys made at regular time intervals will enable the detection of movement on an areal rather than a point-to-point basis. At the same time, the repetition of this precision analytic aerotriangulation will contribute to present knowledge of attainable accuracy and replicability.

DESIGN OF PROJECT

A test site in Salt Lake City, Utah, just west of the University of Utah campus was selected for the study. The area is approximately 1,000 meters square and consists of 16 square city bocks. Figure 1 is an aerial

---

* Presented at 30th Annual Meeting of the Society, Hotel Shoreham, Washington, D. C., March 17–20, 1964.

FIG. 1. Aerial photograph of test area.

photograph covering the entire test site. The Wasatch Fault runs through the area in a northeasterly direction, and can be traced through the south-central portion by the line of heavier tree growth.

Permanent city survey monuments exist near the center of each street intersection. A Coast and Geodetic Survey field unit determined the positions and elevations of nine of these monuments by Geodimeter traverse and second-order leveling methods in a pattern as shown by the triangles in Figure 2. Elevations were also determined for the monuments indicated by crosses. Adjustment of the nets indicate a horizontal standard error of 9 mm. and a vertical standard error of 2 mm.

It was proposed that positions and elevations of monuments in the locations indicated by circles and positions of the monuments indicated by crosses be determined by photogrammetric methods; the process to be repeated annually for a period of years in an effort to detect relative horizontal and vertical displacements, particularly across the fault line.

PLANNING

Planning of photography in a project of this nature assumes great importance. Premarking of control points and points whose positions were to be determined, and the use of a glass-plate camera were obvious requirements to obtain the desired accuracy. Since the use of unorthodox aircraft seemed undesirable in a program which was intended, in part, to improve standard production techniques, the eventual limitations imposed on photography were (1) image motion, (2) minimum cycling time of the camera, and (3) the desirability of strategic placement of control on the photographs.

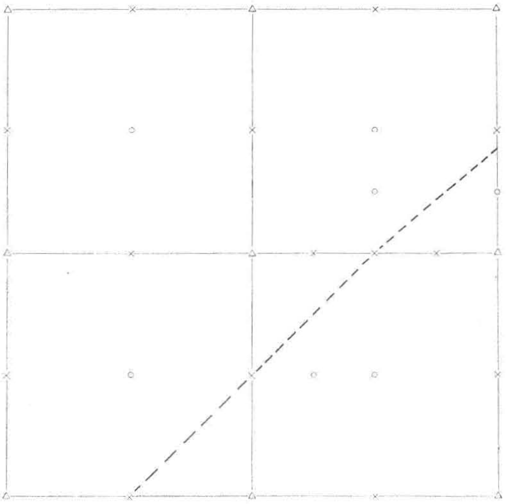

FIG. 2. Control diagram.

It was decided to photograph the area with three strips of three photographs each with 60% end and side lap. This formed a square block of nine photographs with the center photograph covering the entire test area. The relative positions and overlaps are shown in Figure 3. The photographs were to be taken by "pin-pointing" methods with a horizontal and vertical control station at the approximate center of each. A flying height of 2,800 feet above average terrain gave the desired

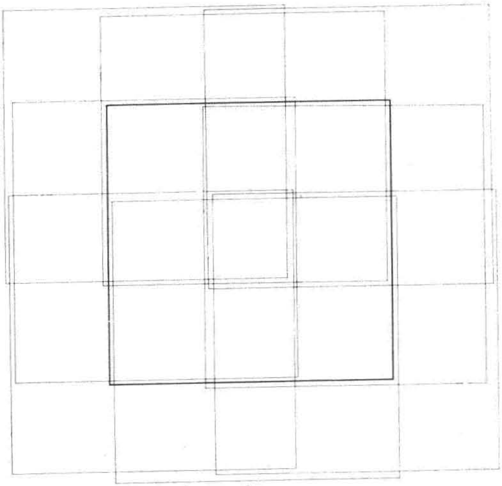

FIG. 3. Arrangement of photography.

coverage and overlap and an approximate photograph scale of 1:8,400.

It should be remarked that the adopted plan does not exploit the ultimate capabilities of the equipment used.

PROCEDURES

Prior to photography, the city survey monuments were premarked with targets designed to furnish optimum images for comparator measurements. The targets were prepared by the University of Utah, of 3′×3′ sheet metal, painted black with 12-inch white circles on the center. The white circles were precisely centered over the monuments, and the differences in elevation between the monuments and the targets determined by leveling. Figure 4 is a photograph of a typical target.

Aerial photography was accomplished in June 1963, using a Wild RC-7a automatic glass-plate camera. The photography was repeated three times to assure the desired coverage. The photographic mission must be given credit for the successful accomplishment of the photography in spite of turbulence and cross winds.

Nine of the photographs were selected in the office for measurement. Procedures followed closely the Coast and Geodetic Survey system of analytic aerotriangulation, as described in Coast and Geodetic Survey Technical Bulletin No. 21, "Analytic Aerotriangulation," by Harris, Tewinkel, and Whitten,[1] with certain refinements made possible by the 60% side-lap and optimum control.

The glass negatives from the camera were used in the bridging procedures.

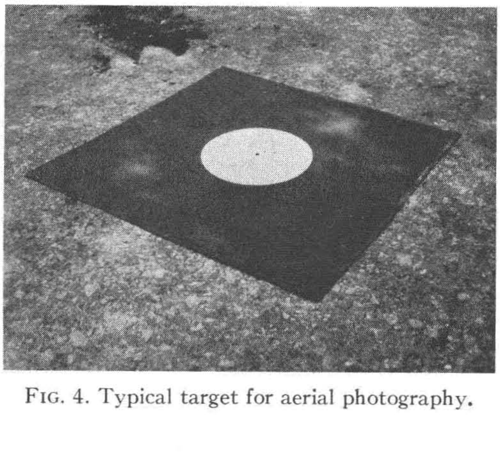

FIG. 4. Typical target for aerial photography.

Pass-points were marked using a Wild PUG-2 point transfer device. Two pass-points were marked in the vicinity of each horizontal control station, with the intention of using the station target as an additional pass-point. In the photo overlap areas beyond the center photograph, three pass-points were marked in each position as required for bridging either along flight or across flight. Marked points were transferred to all applicable photographs.

The coordinates of the marked points and the targets were measured by a Mann 422 monocular comparator, equipped with a digital readout which produces a typewritten record and a punched paper tape. Three determinations were made of each coordinate.

A brief review of the steps in the computation of analytic aerotriangulation is given in order to point out deviations from normal routine. Multiple readings of coordinates are first meaned, then corrected for lens distortion and atmospheric refraction and translated to the principal point of the photograph. The relative orientation parameters of adjacent photographs are then computed. x and y residuals are computed as a by-product of this program, giving the opportunity to evaluate and reject incorrectly marked points. In a typical strip of photographs, only the y residuals are of significance. In the present project, the 60% side lap permitted the computation of cross-strip relative orientation and the examination of x residuals.

The following program is the cantilever assembly, which attaches succeeding models to the first model and computes x, y, and z coordinates for each point of a strip. Conformal horizontal and vertical adjustments to control of the individual strips follow, to provide approximate positions for input to the final block adjustment.

Before the block adjustment, a test of the quality of the cantilever adjustment of the strips was performed. The model coordinates were adjusted to a least square fit of the nine horizontal and vertical-control stations in scale and orientation, but with no deformation of the model permitted. The strips were adjusted individually and then combined into a single block. The residuals of the fit to control after adjustment gave root-mean-square errors of 34 mm. in x, 31 mm. in y, and 19 mm. in z, or 50 mm. resultant in space. The 14 additional vertical-control stations, which were not used in the adjustment, gave a root-mean-square error in ground elevation of 39 mm.

The block adjustment was computed in several ways. An adjustment to the nine horizontal and vertical control stations was made to give the most accurate location of the unknown stations. A check on the internal accuracy was then obtained by using only the four corner control stations.

The adjustments were performed twice, first with infinite weight on the ground-control and again with weights based on a standard error of one centimeter in the positions of control stations, recognizing that the quality of the photogrammetry is approaching the quality of the ground-control. It was also desired to observe the characteristics of the block with no deformations imposed by control. This was accomplished by another adjustment to the four corner stations with no constraint from control.

The two adjustments to nine control stations permit only the observation of discrepancies in the elevations of the 14 supplemental vertical-control stations as an index of accuracy. In the adjustment with infinite weight on control, the RMS error of elevation was 36 mm. In the proportionally weighted adjustment, the RMS error was 34 mm.

The three adjustments based on four control stations permit the observation of discrepancies in horizontal position of five points and the discrepancies in the elevations of 19 points. The root-mean-square errors from the three adjustments are as follows:

With infinite weight on control—horizontal 16 mm., vertical 28 mm.
With proportionally weighted control—horizontal 18 mm., vertical 27 mm.
With no restraint from control—horizontal 21 mm., vertical 25 mm.

It will be noted from these figures that restraints upon the photogrammetric geometry imposed by ground-control cause a worsening of the vertical results. This is a corroboration of the principle that the ground-control should be given appropriate weights and not be rigidly enforced.

Figure 5 shows the pattern of discrepancies found in the elevations of the vertical check stations, with the vertical scale greatly exaggerated. The pattern was similar in each adjustment with small changes in magnitude.

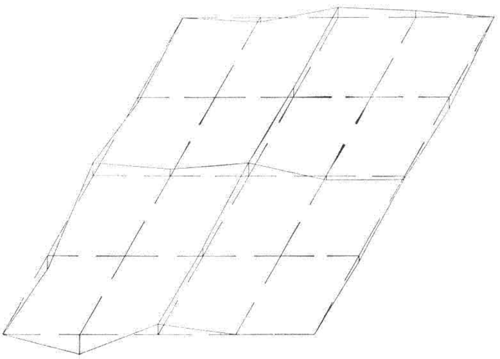

FIG. 5. Pattern of vertical deformations.

If the proportionally weighted adjustment to the four corner control stations is accepted as an accuracy index, the results may be translated into more familiar situations. With a flying height of 4,500 feet and a photograph scale of 1:13,500, one square mile would be covered by the center photograph and the positions of points could be determined with a RMS error of 1.1 inches horizontally and 1.9 inches vertically. With a flying height of 9,000 feet and a photograph scale of 1:27,000 four square miles would be covered and the RMS error of positions would be 2.3 inches horizontally and 3.7 inches vertically. In terms of the maximum distance from control, the horizontal accuracy may be stated as 1 part in 40,000 and the vertical accuracy as 1 part in 24,000.

Studies of the propagation of errors in a photogrammetric block show that the size of the block could be increased to five photographs in each direction and the peripheral control could be located in the corners of a square formed by four photographs placed edge to edge with no increase in the errors in the center of the block due to propagation of errors.[2] Thus, in a project designed to take advantage of this property, the areal coverage at any desired scale of photography could be quadrupled with no loss of accuracy.

The residuals to plate measurements from the least squares block adjustment also provide an index of precision. A typical value, derived from the adjustment to four points with infinite weight on the control, is a root-mean-square residual of 2.2 microns.

The next step of the project will be the repetition of the entire survey to demonstrate the replicability of the results. The ground survey will be repeated by methods which will provide an expected accuracy of 1 part in 300,000 or a standard error in position of 3 mm., and the test area will again be photographed this spring. The original and the new photography will be adjusted to the new control positions, and the variations in the positions of the located points will be observed.

Beyond this, new control surveys will be made and the test area will be rephotographed at regular intervals, measured, and examined for systematic changes in positions, particularly across the fault line. Any appreciable movement across the fault detected in the more frequent short line measurements of Phase I will be followed immediately by a new photogrammetric survey.

Several lines of investigation will be followed in the study of precision photogrammetric methods. The block adjustment will be recomputed, once using ground targets alone as pass-points and again using points marked by the Wild PUG alone. In a study of comparative measuring techniques, the current photographs have been remeasured using a Wild STK-1 stereocomparator, and data processing is now in progress. Another line of study is displacement due to image flare and the possible mathematical compensation thereof. Several possible modifications of operational techniques have been proposed and will be tested to determine their effect on precision.

CONCLUSION

The results of this survey demonstrate that photogrammetric methods are capable of determining the positions of points with an accuracy rivaling that of traditional ground-survey methods, and are adequate for the determination of appreciable, systematic earth crustal movements. The techniques employed will certainly find application in other fields requiring the location of a large number of points, such as cadastral surveys, highway planning, etc.

As the surveys are repeated and more refined techniques evolved, further reports on results and methods may be expected.

REFERENCES

1. Harris, Tewinkel, and Whitten, 1962, "Analytic Aerotriangulation," Technical Bulletin No. 21, Coast and Geodetic Survey.
2. Schmid, Hellmut H., "Precision Photogrammetry a Tool of Geodesy," PHOTOGRAMMETRIC ENGINEERING, Vol. XXVII, No. 5, December 1961, pp. 779–786.

---

*Infrared Geology**

JOHN L. CANTRELL,
Texas Instruments Incorp., Science Services Div.,
P.O. Box 35084,
Dallas, Tex. 75235

(*Abstract on next page*).

INTRODUCTION

It is well known that aerial photography has proved an excellent tool for collecting geologic information. Various camera configurations and multitudes of film/filter combinations have been used to take advantage of different portions of the visible, near-infrared, and ultraviolet portions of the electromagnetic spectrum. However, these systems are restricted to an extremely small portion of the electromagnetic spectrum, generally from 0.3 to 1 micron, because of the limited spectral response of film emulsions.

In the last decade, the military has been continuously developing classified infrared mapping systems using long wavelength detectors for surveillance and target acquisition purposes. It is the author's intention to show by example how longer wavelength infrared imagery could aid in geologic reconnaissance.

---

* Presented at 30th Annual Meeting of the Society, Hotel Shoreham, Washington, D. C., March 17–20, 1964.