Application of Precise Photogrammetric Methods To Right-of-Way Relinquishment Surveys

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• A METHOD which was developed in the San Francisco District Office of the California Division of Highways for obtaining right-of-way survey data using aerial photographs and simple scaling procedures has been described by Hovde (1). The measurement data obtained were sufficiently accurate to use for metes and bounds descriptions of right-of-way relinquished to local authority, such as frontage roads paralleling a completed freeway facility. This procedure offered savings over field survey methods and was conventional with this office for many years. Precise photogrammetric methods have now replaced the scaling procedures because of increased accuracies and significant reduction in man-hours of effort, which reflect further cost savings.

To provide a more complete introduction to the application of precise photogrammetric methods, a brief review of the scaling procedure described by Hovde is subsequently given. The "as built" location of a fence or other objects separating a freeway from a frontage road defines a line of reference for relinquishing right-of-way outside the freeway. The survey location of the fence is therefore important to make a realistic description of the property involved. Aerial photographs, taken at the proper scale, of a newly constructed freeway clearly show fence lines. It was from photographs of this type that the survey data were obtained.

Preliminary to taking photographs, existing construction survey points along the frontage roads were recovered and premarked with targets. Aerial photographs were then taken at a scale of 120 feet per inch and photographically enlarged for measurement purposes to the scale of 20 feet per inch. A line drawn between any two successive premarked survey points imaged on the photographic enlargement was used as the baseline for measurement of fence positions. This length of line, however, had to be compared with its known survey length to determine the correct scaling factor for adjusting all photographic measurements made within its terminal limits.

Offset measurements were made from the baseline along lines at right angle to it to selected fence posts to mathematically locate the fence. All measurements were adjusted by the scaling factor to arrive at X and Y survey coordinate values for the horizontal position of each selected fence post. From the coordinates, inversed distances and bearings were calculated to prepare a metes and bounds description, and a plot was made to document the relinquishment.

The precise photogrammetric method centers around use of the Zeiss Stereoplanigraph, model C8, an optical train photogrammetric instrument which permits determination of the X, Y, Z ground coordinates of points viewed in a stereoscopic model. The instrument is also capable of making an accurate plot of any point at the time its numerical coordinates are determined. This method requires less control, but which is of better quality, than control required for scaling from aerial photographs. The photogrammetric operation is done by the Photogrammetry Section in the Sacramento office.

RESEARCH PROJECT

As an initial project to investigate operational approaches to use of precise photogrammetric methods, and to evaluate results, a test section was chosen along a portion of State Sign Route 17 north of Santa Cruz, California. This section, about 0.9 mile

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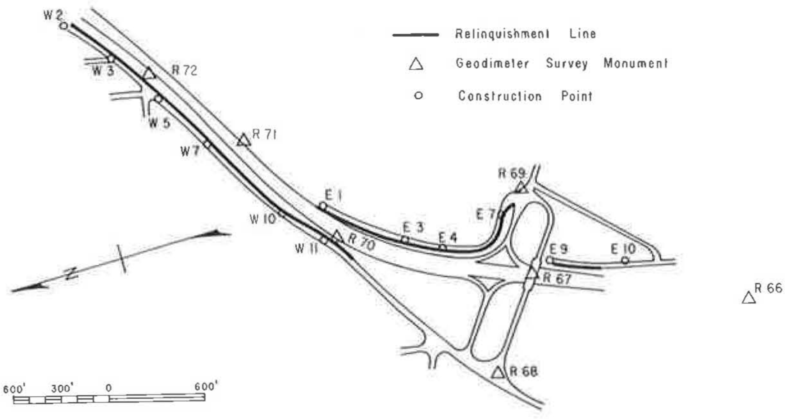


Figure 1. Layout of research project.

in length, had been previously surveyed and sufficient control existed, so further control surveying was not necessary. The layout of the project is shown in Figure 1.

Four main steps involved in conducting the investigation are described in the following sequence:

1. Selection and targeting of control points. The positions of existing survey monuments had been surveyed by Geodimeter measurement of a traverse throughout the test section within the freeway right-of-way. Supplementing monument-marked control points were construction points along the frontage roads. The survey had been made on a local coordinate system, and plane coordinate positions had been determined for each monumented control point and each construction survey point. The distribution of monumented and construction points is shown in Figure 1.

Because the monumented points position surveyed by Geodimeter were to be used to fix horizontal scale of the stereoscopic models formed by the photographs in the Zeiss C8 Stereoplanigraph, target design was considered very important to assure their accurate recovery. Figure 2 shows the target pattern and dimensions for the premarking monumented control points before photography was taken.

Each construction point was premarked with a white "arrow" target painted on the black pavement of the frontage roads, with the point of the arrow depicting the survey mark.

2. Aerial photography. A 6-in. focal length Zeiss RMK 15/23 aerial camera was used to photograph the project strip after placement of a target on each measurement point was completed. Aircraft flight-height was about 1,500 feet above the ground, which resulted in a photography scale of approximately 250 feet per inch. Cronar base aerial film was used.

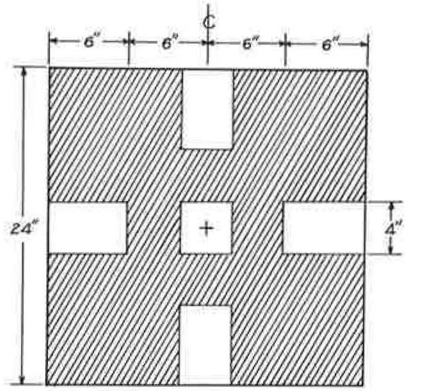


Figure 2. Target design for research project.

Photographic enlargements of alternate photographs were sent to the District Office for identification of all targeted points, and for instructions regarding relinquishment line data to be obtained.

3. Use of the Zeiss C8 Stereoplanigraph. Although a description of the Zeiss C8 Stereoplanigraph (Fig. 3) is not within the scope of this paper, a few pertinent remarks may clarify the matter of scales and measurement accuracy. There are three scales involved in numerical determinations, namely the photography scale, the measurement (stereoscopic model)

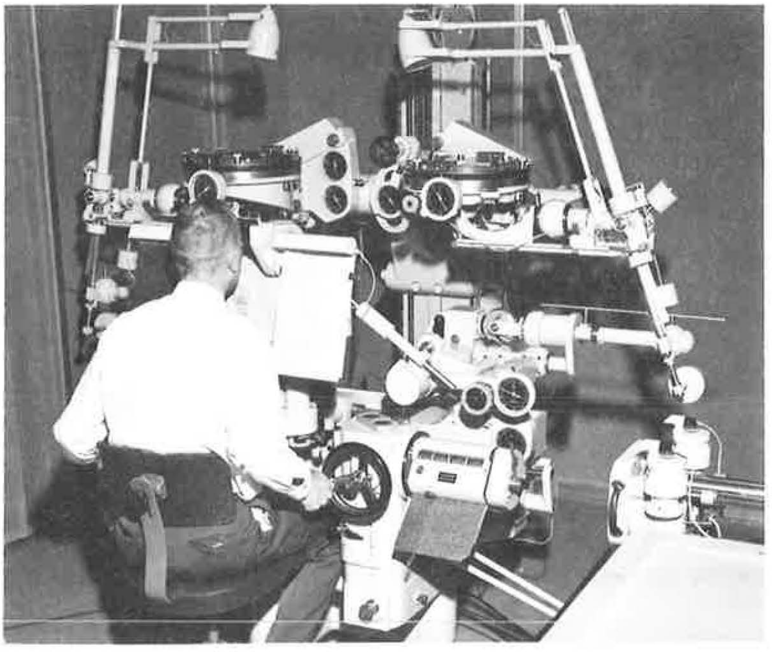


Figure 3. Zeiss Stereoplanigraph, Model C8.

scale, and the viewing scale. A fourth scale, the plotting scale, is considered only if a graphic plot is desired in conjunction with determination of numerical data regarding specific points.

At a photographic scale of 250 feet per inch the measurement scale is 125 feet per inch. The viewing scale is independent of the measurement scale and much larger. Because the measurement counter records x, y, and z measurement coordinates in increments of 0.01 mm, the equivalent X, Y, and Z coordinates, when the instrument measurement scale is 125 feet per inch, would represent 0.05 feet on the ground. This is the smallest possible measurement and, of course, is subject to random errors associated with any measurement technique.

The plotting scale can be varied mechanically by selecting gears of different ratios. It is possible to enlarge the plotting scale as much as 5 times the measurement scale (or 10 times the photography scale).

On the subject test section, six stereoscopic models covered the freeway strip. The aerial triangulation was accomplished in conformance with standard practice. The first stereoscopic model was leveled and scaled using out the best available control. When this absolute orientation was completed the photogrammetrically measured coordinates of all selected fence posts and targeted construction survey points were measured and recorded. Their positions were also plotted on mylar-base material at a scale 50 feet per inch, the same scale as the freeway construction plans.

On completion of measurements using the initial stereoscopic model, the second model was adjoined to it. The coordinates were measured photogrammetrically for all selected fence posts, construction survey points, and Geodimeter-measured control survey monument markers imaged on the stereoscopic model; their plotted positions on the map were determined in the same way as for the first stereoscopic model. Likewise, the remaining four stereoscopic models were also measured.

All photogrammetrically measured x, y, and z coordinate data were adjusted to fit only four of the seven monumented point positions which had been determined by Geodimeter surveying. The remaining three monuments could not be seen definitely in the stereoscopic models, despite precautions taken in placing the targets. It is noteworthy the the stereoscopic models were oriented to control and meas-

TABLE 1

DIFFERENCE IN PLANE COORDINATES[a]

Post	Difference (ft) X	Difference (ft) Y
8a	0.4	0.3
9a	0.1	0.3
10a	0.4	0.1
11a	0.2	0.2
12a	0.0	0.3
13a	0.1	0.4
14a	0.2	0.1
15a	0.3	0.2
16a	0.0	0.1

[a]Posts measured by use of two stereoscopic models, differences in photogrammetrically measured coordinates.

TABLE 2

DIFFERENCE IN PLANE COORDINATE[a]

Post	Difference (ft) X	Difference (ft) Y
E- 3	-0.2	0.5
E- 4	-0.3	0.1
E- 5	-0.3	0.4
E- 7	0.1	0.1
E- 9	-0.4	0.4
E-10	-0.1	0.5
W- 5	-0.1	0.2
W- 7	-0.3	0.1
W-10	-0.3	0.1
W-11	-0.3	-0.3

[a]Targeted construction survey points, differences between field and photogrammetically measured coordinates.

ured only once, and no further setups were made subsequent to the aerial triangulation and adjustment of the resultant data.

For this type of work, in which horizontal position only is desired, the Z coordinate measurement is not significant. Vertical control for orientation of the stereoscopic models was obtained from the USGS topographic maps published on a quadrangle basis of the area by assigning interpolated elevations from the contours of the maps to identifiable features on the photographs. This procedure provided elevations sufficiently accurate for the intended purpose.

4. Testing and evaluating results. As previously noted only four of the seven targeted basic control monument markers, which were position surveyed by use of the Geodimeter, were definitely visible in the stereoscopic models. Consequently the adjustment was held fixed at these four points: R66, R69, R70, R72. The photogrammetrically measured positions of 36 fence posts and 10 targeted construction survey points were accordingly determined from this adjustment in terms of X and Y coordinates on the local plane coordinate system.

Nine of the fence posts were visible in two adjoining stereoscopic models, and therefore two sets of plane coordinates were determined for each of the nine posts. Table 1 gives differences in each of the two sets of plane coordinates.

Each of the 10 construction survey points also had two sets of coordinates—the field measured and the photogrammetrically measured. Table 2 gives the differences in each of the two sets of plane coordinates.

The photogrammetrically measured coordinates were tested in the field by two different methods. Both methods consisted in measuring with a tape between a target point and some point on the fence line.

The first test involved measurements on a line perpendicular to the fence to a targeted point. The field measurement of this distance was done directly with the tape, whereas the photogrammetrically determined distance had to be inversed between the photogrammetrically measured plane coordinates of the targeted survey point and the coordinates of the normal point on the fence line. The latter had to be found by computation between photogrammetrically measured plane coordinates of fence posts either side of it. The results are given in Table 3.

The second test involved measurements along a line directly between a fence post and a targeted survey point. Here again, the photogrammetrically determined distance

TABLE 3

DIFFERENCE IN DISTANCE[a]

Targeted Point	Field Measured (ft)	Photo-grammetrically Measured (ft)	Incremental Diff. (ft)
W 2	18.6	18.5	-0.1
W 3	19.5	19.6	+0.1
W 5	18.7	18.8	+0.1
W 7	18.4	18.5	+0.1
W10	18.9	19.0	+0.1
W11	15.0	14.8	-0.2
R70	16.5	17.1	+0.6
R72	14.5	14.8	+0.3
E 1	23.5	23.7	+0.2
E 3	19.0	19.1	+0.2
E 4	19.1	18.5	-0.6
E 7	22.3	22.2	-0.1
R69	106.3	106.6	+0.3
E 9	19.3	19.8	+0.5
E10	25.3	25.4	+0.1
Corner	48.6	49.0	+0.4
		Average difference =	+0.12

[a]Right angle offset distance, differences between field measurements and photogrammetric measurements.

TABLE 4

DIFFERENCE IN DISTANCE[a]

Targeted Point	Fence Post	Field Measured (ft)	Photo-grammetrically Measured (ft)	Incremental Diff. (ft)
W 2	26b	18.8	18.5	-0.3
W 2	25b	20.2	20.0	-0.2
W 3	23b	20.1	20.2	+0.1
R72	22b	14.5	14.8	+0.3
W 5	21b	19.0	19.1	+0.1
E 1	1a	27.7	28.8	+0.4
E 5	8a	19.1	19.6	+0.5
E 7	14a	22.3	22.2	-0.1
E 9	17a	48.1	48.3	+0.2
E 9	18a	19.4	19.8	+0.4
E10	Corner	23.9	24.3	+0.4
			Average difference =	+0.16

[a]Between field measurements and photogrammetric measurements.

had to be inversed between the photogrammetrically measured coordinates of the fence post and the targeted survey point for comparison with the field measured distance. The results are given in Table 4.

Sources of error should be identified to evaluate properly these results. The arrow-type design of the target for construction survey points presented an indefinite shape in the stereoscopic model. The well-known halation phenomenon override of photographic images of white objects onto images of dark areas tended to make the targets appear too large. This in turn introduced some error in recovery of the survey point. On considering other sources of error, magnitude of such an error is probably not significant.

The most important source of error was undoubtedly caused by the fence post, because it is an "object" and not a "point." Hence, the "pointing" in the stereoscopic model cannot be exact, and the recorded measurement may not apply to the center of the post. Furthermore, the "lean" of the post, especially if brush obscures its base, contributes to position error. Another factor is the sun angle and resulting shadows. Posts of a chain link fence are particularly difficult to position in the stereoscopic model if their shadows fall in line with the fence. The differences given in Table 1 are undoubtedly attributable mainly to these sources of error, although they are of minor importance for this type of survey. (Subsequent projects photographed immediately on completion of construction have demonstrated a post newly set in concrete can be seen very clearly on the stereoscopic model, thus eliminating some of these sources of error.)

It has been reported test measurements made in the field may not be as reliable as desired. This comment is based primarily on the fact it was difficult to accurately locate the center of posts and normal points on fence lines. Although the results recorded in Tables 3 and 4 are considered entirely adequate for this type of survey, some measurements containing the larger differences should probably be rechecked in the field.

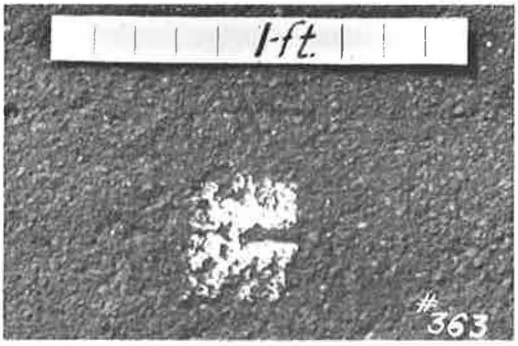
In any event, the fence line is not the line of relinquishment but only a reference to it. The question therefore resolves into whether or not photogrammetrically measuring the position of a fence is (a) of sufficient accuracy to serve as reference for mathematically determining a metes and bounds description of relinquishment property, and (b) cost savings attained thereby justify use of such measurement methods.

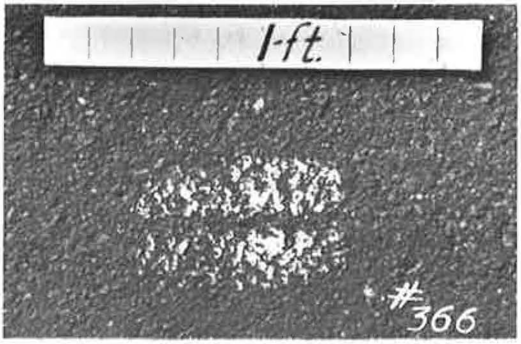
With respect to (a), accuracy of the precise photogrammetric method of measuring is unquestionably superior to scaling procedures using an engineer's scale on semi-controlled aerial photographs, and also probably superior to measuring by routine field surveys. By holding only to Geodimeter-measured control for aerial triangulation using the precision photogrammetric instrument, fence positioning is completely independent of ties to construction survey points. The differences given in Table 2 are believed mainly caused by inconsistency in field values rather than in photogrammetric values.

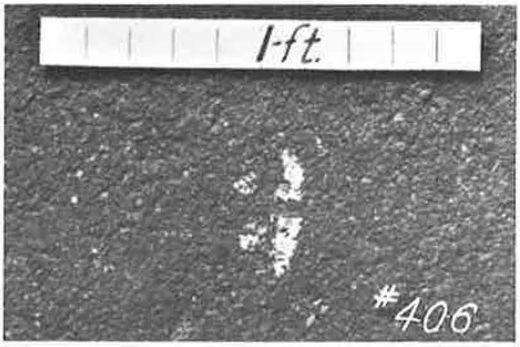
With respect to (b), costs savings were difficult to assess on the research project. Costs, however, were analyzed on three subsequent projects and definite savings were realized, ranging from 50 percent for a rural highway project to 70 percent for each of two urban highway projects.

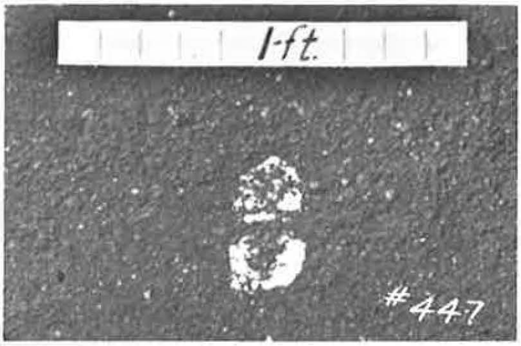
FURTHER INVESTIGATIONS

A particularly interesting operational project was recently completed which offered an excellent opportunity to investigate further the accuracies of photogrammetric methods of measuring by use of the Zeiss Stereoplanigraph, Model C8. This project was located on the Pacific Coast Highway (State Sign Route 1) on the east boundary of the newly established Point Reyes National Park. Survey records were not available for this road, and it became necessary to provide "as-built" location and right-of-way information in connection with establishing the Park boundary.









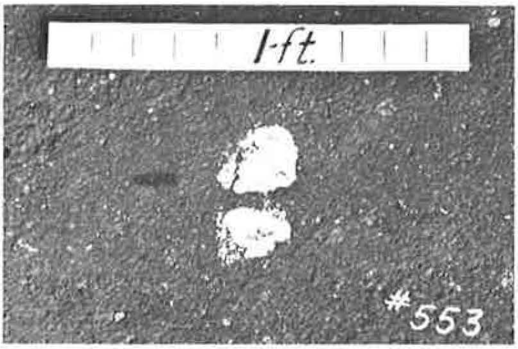


Figure 4. Example of centerline "cat-track" marks taken with a 35-mm camera from a distance of 4 feet. Note the 1-ft scale divided into 1/10ths for an estimate of size.

With respect to photogrammetric procedures, this project was handled in the same way described for relinquishment surveys. A control traverse was measured with the Geodimeter paralleling the highway for the length of the survey project, and ties were made to station markers in the California State plane coordinate system. The monument markers of points in the traverse were located roughly 1,000 feet apart, and were targeted before photography using targets similar in design to the target illustrated in Figure 2. No other control points were used, except for a few points position measured with the Geodimeter which were situated at broad intervals transverse to the main traverse to provide stereoscopic model scaling bases for accomplishing the aerial triangulation.

Aerial photography on cronar base film was taken with a Zeiss RMK $^{15}/_{23}$ aerial camera from a flight-height of 1,500 feet. Resultant scale of the photography was 250 feet per inch.

When the stereoscopic models were viewed in the Stereoplanigraph, it was noticed centerline "cat-track" markings were actually visible on new sections of asphalt pavement. These marks served as suitable targets for photogrammetrically measuring coordinates where they were not obliterated by centerline strips. On older sections of pavement where only centerline stripes existed, measurements were made on the ends of stripes. Spacing of these coordinate measured points was approximately 50 feet, depending on the centerline markings.

Because of the finite size of the "cat-track" marks a field check was made of their photogrammetrically measured positions. It seemed expedient simply to measure between them for a comparison of photogrammetrically measured distances with field-measured distances. Figure 4 shows how these marks actually appeared on the pavement.

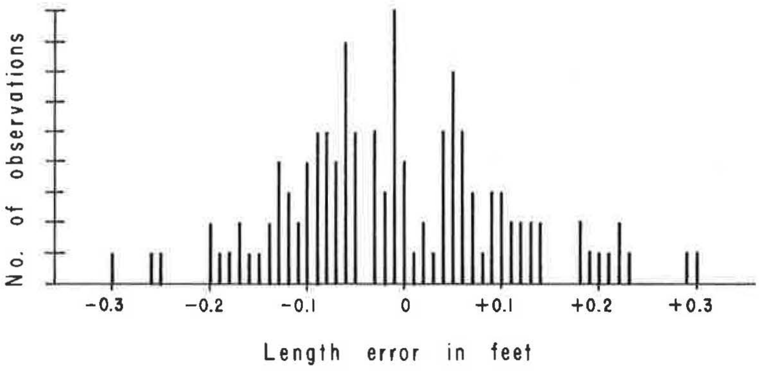
Because the marks were not centered on a survey point, an estimate was made as to the probable point of measurement by the operator of the Stereoplanigraph according to density or concentration of paint. This probable point was indicated with lumber crayon for reference in making measurements with a tape. A total of 123 measurements were then made between the crayon points for checking inversed lengths determined from photogrammetrically measured coordinates of the "cat-track" marks. Resultant errors in the photogrammetrically measured distances were, as follows: consecutive distances (123 measurements) (Fig. 5a); arithmetic mean, -0.009 feet (or -0.01 feet); and root mean square error, ± 0.11 feet.

Because the distances were measured consecutively, apparently a natural balancing effect was inherent in these results. Therefore, errors in alternate lengths were analyzed with the following results: alternate lengths, group A (62 measurements) (Fig. 5b); arithmetic mean, +0.007 feet (or +0.01 feet); root mean square error, ± 0.11 feet; alternate lengths, group B (61 measurements) (Fig. 5c); arithmetic mean, -0.027 feet (or -0.03 feet); and root mean square error, ± 0.11 feet.

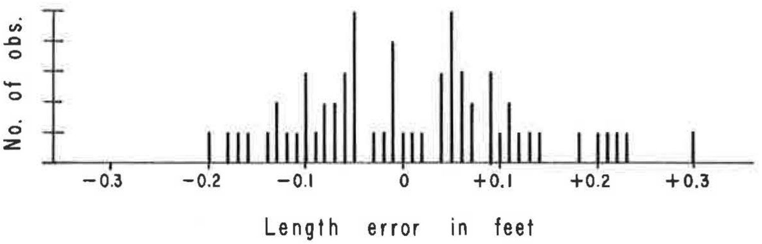
A rational analysis of errors indicates they are independent of distance measured. Even though the distances involved were about 50 feet, the same range of results would be expected if they were 900 feet (the airbase of a stereoscopic model formed by use of photographs taken at a scale of 250 feet per inch). Expressed in conventional terms of proportional accuracy, differences between exact measurements and these photogrammetrically made measurements should approach 1 part in 10,000 or smaller difference as the magnitude of the distance measured increases with the limits of a stereoscopic model. Because measured plane coordinates are being dealt with, however, perhaps errors should be expressed in terms of variation of coordinates, or "Absolute" accuracy rather than proportional accuracy.

Notes About Targets

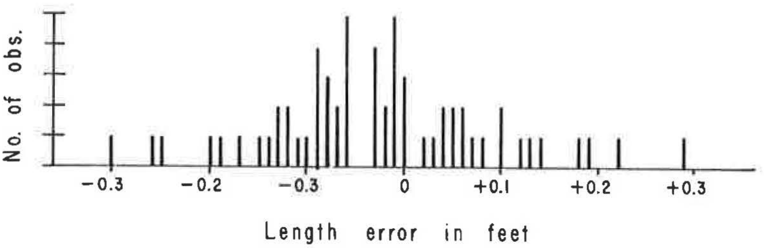
Aerial survey targets for placement before photography on control points or points for which plane coordinates are to be measured must be carefully considered for accurate work. The targets used for the projects reported in this paper have not been completely satisfactory. Most of these targets were printed on 10-point waterproof paper with printer's ink for attaining high contrast. Nevertheless they were not always distinctive in the stereoscopic models.



a. 123 consecutive measurements



b. 62 alternate measurements



c. 61 alternate measurements

Figure 5. Distribution of errors.

Figure 6 shows two targets of similar design but of different size and material. The right target is printed on waterproof paper, and the left target is printed on muslin cloth. It is readily noted the paper causes considerable reflection of light, whereas virtually no reflection occurs from the cloth. According to experience to date, the cloth target is far superior.

The cloth target size is 45 inches by 45 inches square. The crossarm width is 4 inches, and the white center is 4 inches square. The distance between the edge of the center square and the beginning of a crossarm is 7 inches. A target of this design provides a high proportion of black area to white area, which helps to balance halation caused by the white portions. The center square is easily visible on stereoscopic models in the Stereoplanigraph which are formed by using photography of a scale of 250 feet per inch

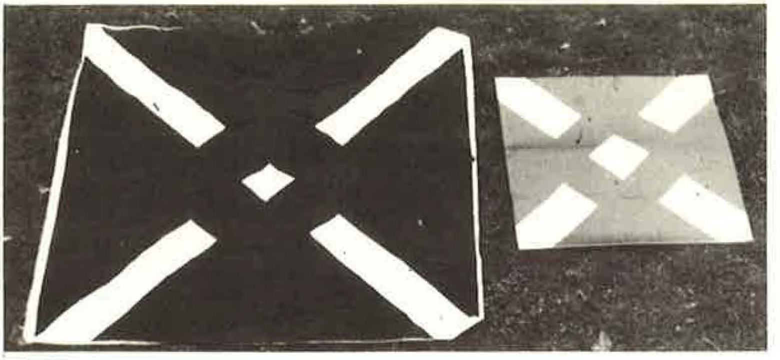


Figure 6. Aerial survey targets. Note the gray cast of target on right caused by light reflection.

and, under good conditions it is visible when the photography scale is 500 feet per inch. For any right-of-way or other type of cadastral surveying, it is necessary for the center of a target to be seen for making accurate measurements. The crossarms merely serve as reference identification for the center.

CONCLUSIONS

Results of investigations reported in this paper suggest precise photogrammetric methods can be adapted to making right-of-way and other cadastral surveys where high accuracies are required. Proper attention must be given, as in use of any other measurement technique, to particular phases of the entire operation if superior results are to be expected.

It is important that horizontal control points be position surveyed by use of the Geodimeter or other electronic distance-measuring equipment, and be targeted properly for absolute location on the stereoscopic models. Aerial photography should be taken using a scale stable base film with a cartographic camera of high resolution characteristics. High-quality photogrammetric instrumentation and procedure should be carefully considered. An electronic computer program for adjustment of photogrammetrically measured data is extremely helpful. And last, but not least, the photogrammetrist responsible for photogrammetric instrumentation must be thoroughly trained and skilled.

REFERENCE

1. Hovde, E. E., "Semi-Controlled Aerial Photographs as a Right-of-Way Surveying Tool." HRB Bull. 354, pp. 51-60 (1962).