Use of the Zeiss Stereotope for Highway Engineering Purposes

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The need to evaluate a third order photogrammetric instrument for general use to procure data for highway engineering promoted the idea of testing the Zeiss stereotope. To determine whether the stereotope would meet better than third-order accuracy requirements, a comparative study of first and third order photogrammetric instruments was made at the Ohio State University. This paper reports an evaluation of the stereotope in terms of the accuracy requirements set for procurement of cross-section data used in computing earthwork quantities.

The comparative study consisted of two parts. The first part was a calibration test of the stereotope to determine the feasibility of using it for large-scale mapping and cross-section data procurement. The second part consisted of evaluating it in terms of spot-height accuracy and earthwork quantity measurements of final-pay quantities. To evaluate the accuracy of its measuring of spot heights, the latter were compared with those read by means of the Wild A-7 autograph.

The photography of a 1-mi section of interstate route had been taken for determining final-pay quantities on an interstate highway improvement project constructed in 1960 by the Ohio Department of Highways.

It was found that with normal ground-control data and aerial photographic operations the stereotope would be an instrument as satisfactory as the Kelsh plotter for procuring cross-section data for final-pay quantity measurements, provided that care is taken in performing the parallax measurements, using either dimensionally stable plastic-base print film or glass diapositives.

• ACCURACY of the large-scale maps required in the highway applications of photogrammetry in the past has made necessary the use of second and higher order plotting instruments. In general, the higher order, the more expensive instruments, are not within the financial grasp of highway departments of the county level of government or of most underdeveloped countries. Therefore, there is the need to determine if a third order instrument would be satisfactory. This need promoted a comparative study at the Ohio State University. First and third order photogrammetric instruments were used to determine cross-section data. The spot-height measurements of discrete points along the profile and cross-sections of a roadway were used in the evaluation of instrument accuracy.

Information was not available on the Zeiss stereotope's capability in large-scale mapping or in spot-height measurement of elevations for determining cross-sections. However, Quinnell (30), in 1959, tried the instrument for reconnaissance survey data and found that it afforded a simple but economical method of obtaining engineering data by means of photogrammetry.

This paper reports the results of the study to establish what use can be made of the instrument in highway engineering. The study was performed in two parts. The first

part was to determine the feasibility of using the stereotope for measurements of cross-section data for use in earthwork volume calculations. An instrument calibration experiment was set up. Figures 1 and 2 show the stereotope as used for spot-heighting measurements. Bastian (19), in 1960, determined that it was feasible to use it to determine cross-section data for earthwork volumes.

The second part of the study determined its accuracy, again using the performance of the Wild A-7 autograph as the standard. Sahgal (29), in 1961, found that because the third order instrument performed well to produce accurate cross-section data, the stereotope could be used in many phases of highway engineering applications of photogrammetry.

CALIBRATION TEST

Procedure

The camera was set up and leveled 23 ft from the mock-up of a cut-fill roadway section (Fig. 3). The camera stations were designated from left to right as north base and south base, respectively (Fig. 4). The point of intersection of the line of sight of the telescope axis and the plane of the surface of the mock-up was marked with a small cross consisting of masking tape, the exact point of intersection being marked on the tape with a horizontal and a vertical pencil line. The camera was turned toward the south base for the tilt angles. Points on the mock-up were designated 0, 1, 2, 3, 4, and 5 to represent the principal points of photographs for the 0^0 to 5^0 of tilt (Fig. 5). Four reference points were marked on the floor to locate each camera station exactly, inasmuch as no plum system was available. The optical axis of the instrument was lined in first direct, then reversed, and the angles to the principal points were re-read to eliminate orientation errors. The maximum difference between orientation angles

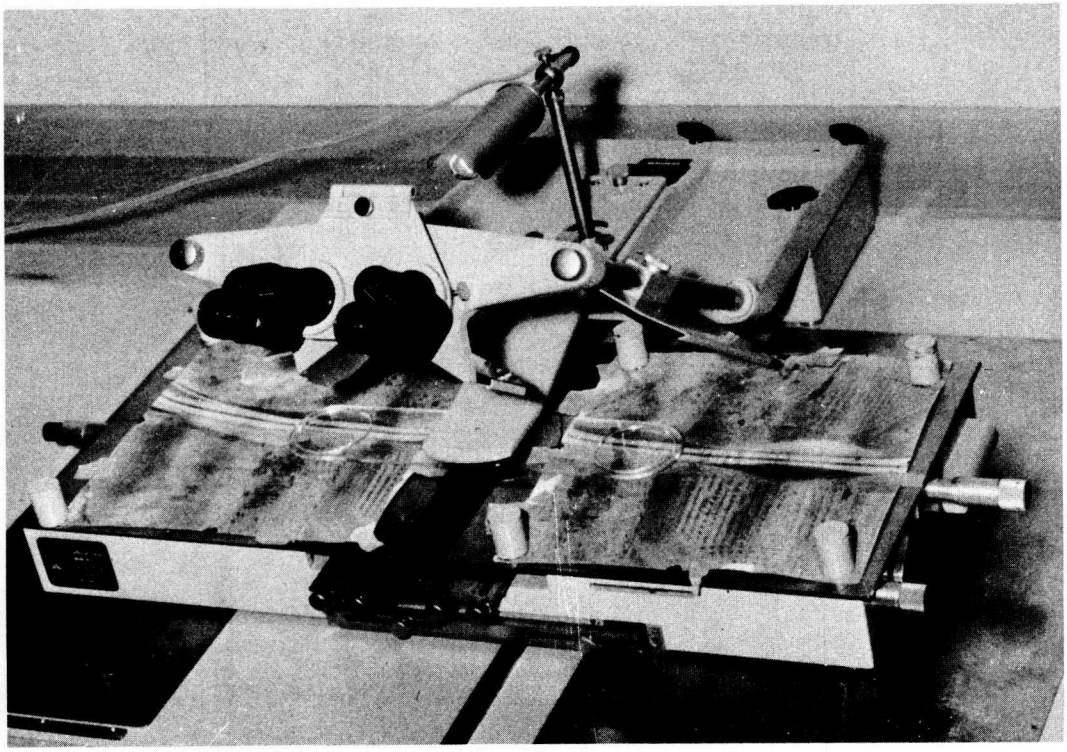

Figure 1. Zeiss stereotope used at Ohio State University (1960-61).

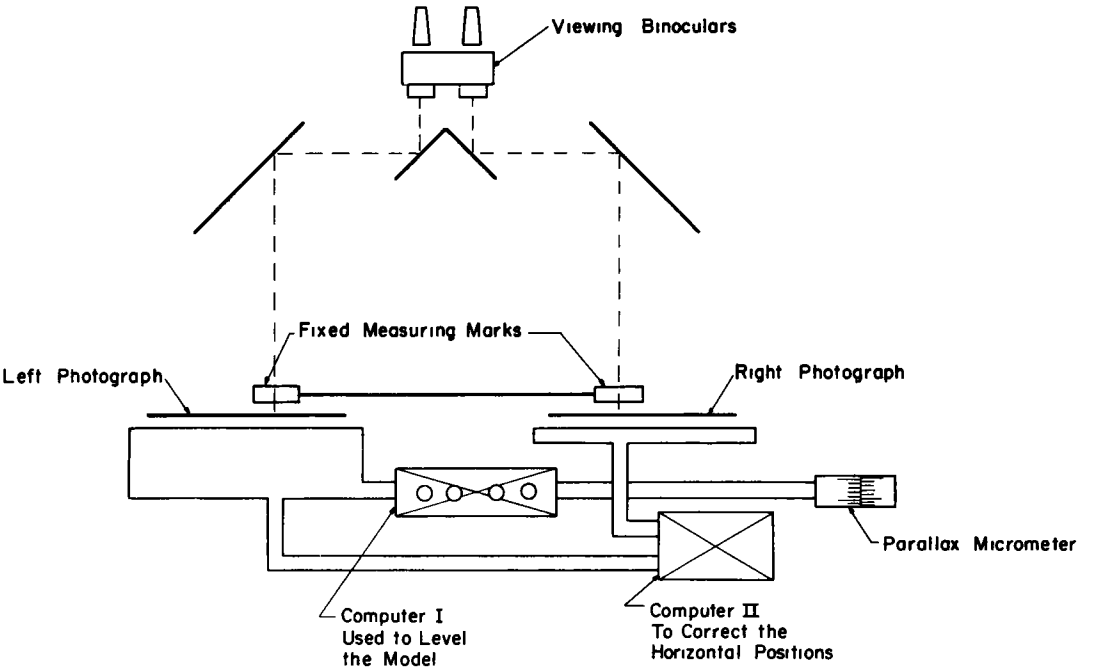

Figure 2. Schematic diagram of Zeiss stereotope showing arrangement of photographs for viewing and parallax measurements (after Bastian, 19).

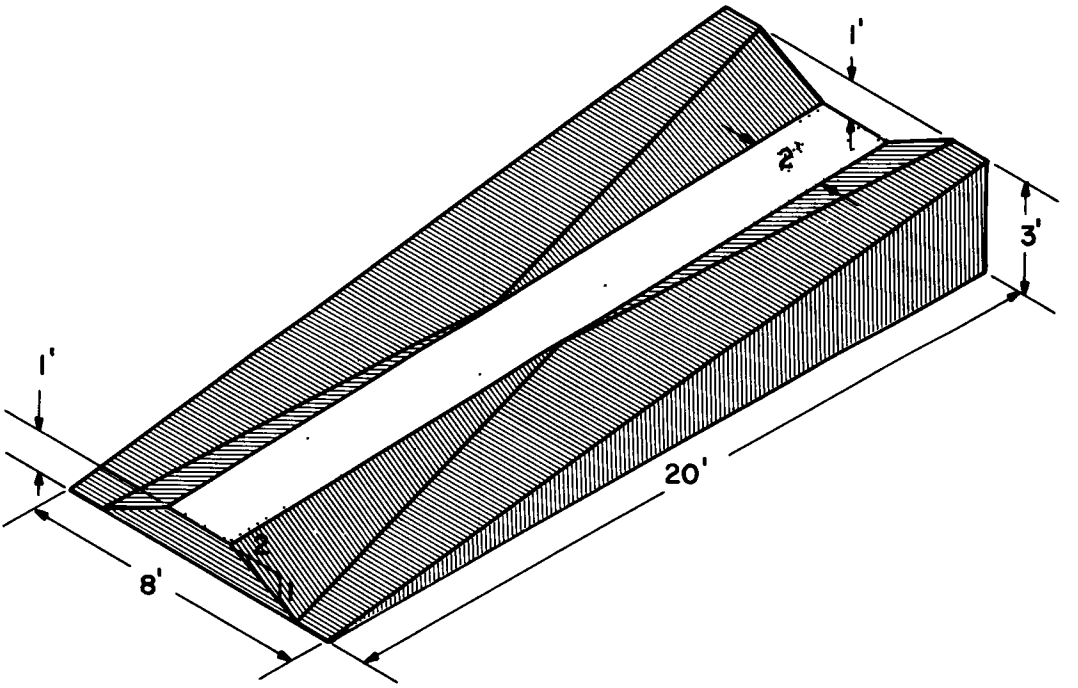

Figure 3. Illustration of cut-fill roadway mock-up section photographed and measured using Zeiss-stereotope calibration test (after Bastian, 19).

was less than 30 sec, representing a linear distance of only 0.0037 ft, which was considered accurate within the experimental limits. Direct and reverse readings did not differ by more than 0.001 ft. A level rod was read to determine the height of the instrument. The north base line of sight was 0.018 ft below the south base, and this was taken into account.

Six glass-plate negatives were made with the camera pointing at the marked principal points from each base. Before dismantling the camera equipment, measurements were taken with a steel tape between machined surfaces on the camera mount in position as a check on the camera base test. The distance (15.672 ft) between north and south bases compared exactly with the measurement determined later between the camera stations, and the distance between the 0° principal-point marks on the mock-up, corrected for the 5 percent slope, was within 0.001 ft of the base distance (Fig. 6).

A Wild T-2 theodolite was set up and accurately sighted on the stations defined by the four control points. Three or four sets of angles were taken at each station, reading

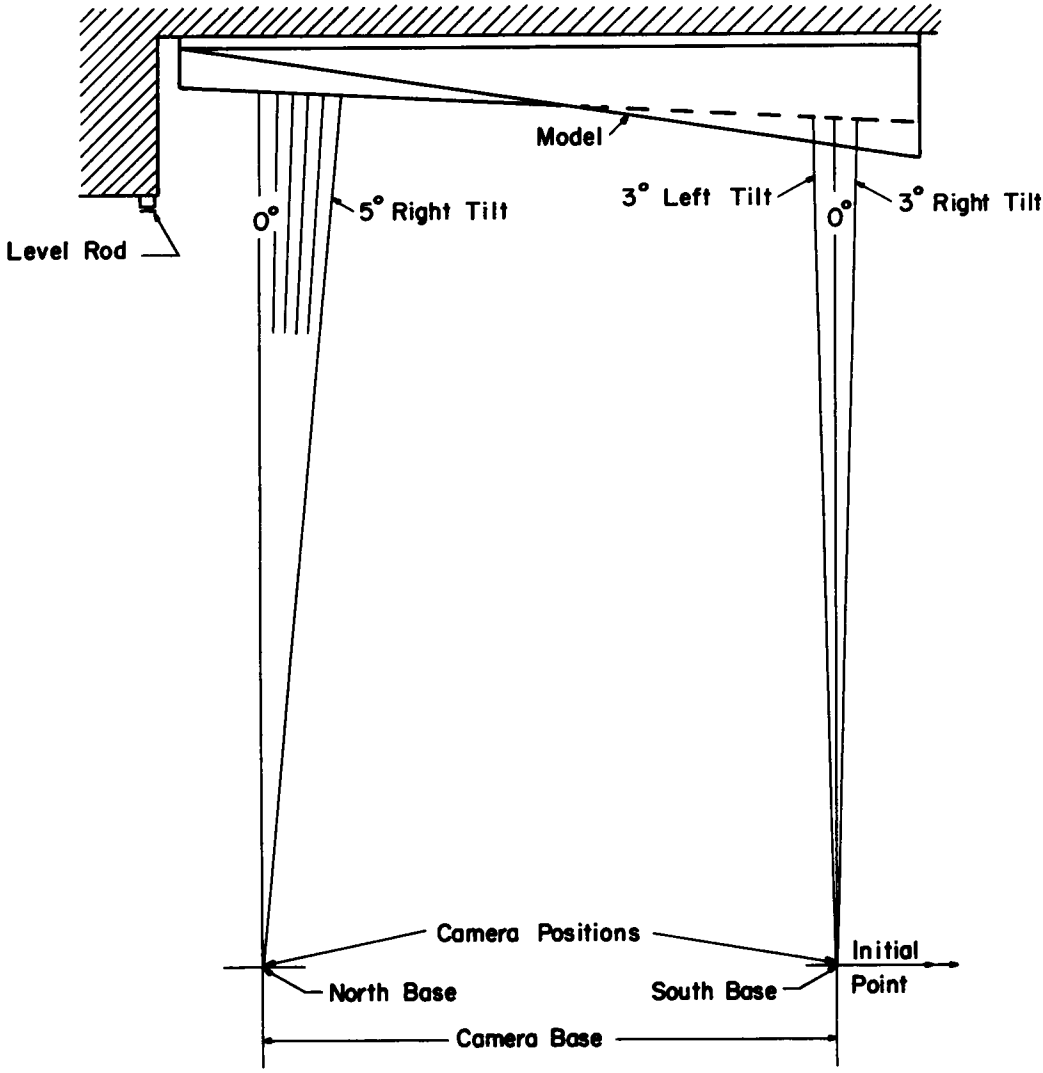

Figure 4. Camera station arrangement when negatives were exposed for calibration test (after Bastian, 19).

both the horizontal and vertical angles of the control points, W, X, Y, and Z. The mean errors in the horizontal and vertical angles were 3.19 and 2.63 sec, respectively, representing an elevation difference of only 0.0006 ft which was disregarded.

The glass-plate negatives, on which the photographs had been exposed using (an f:32 aperture) distortion-free lens, were oriented in the Wild A-7 autograph, and the elevations of each point determined. These elevations, determined to 0.001 ft, were used as the true elevation of each point and the results obtained with the stereotope were compared with them. Figure 7 shows one set of stereophotographs used in the experiment.

One of the sources of error in the measurements obtained with an instrument like the stereotope is inherent in the photographic positive print material. The errors inherent in paper print material are significant. DuPont "Cronopaque" print film on Cronar

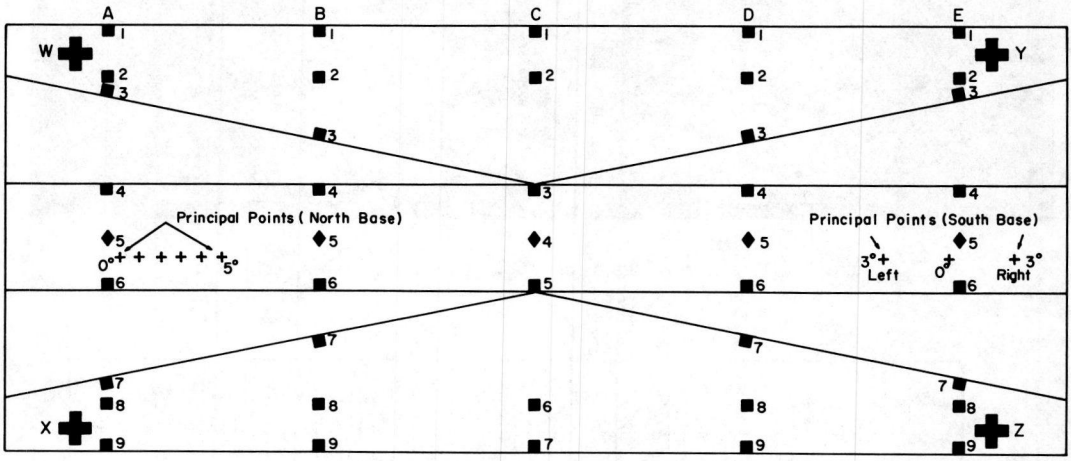

Figure 5. A, B, C, D, and E identify cross-sections, with 1 through 9 indicating spot-height points; crosses in left center indicate principal points for tilted photographs (after Bastian, 19).

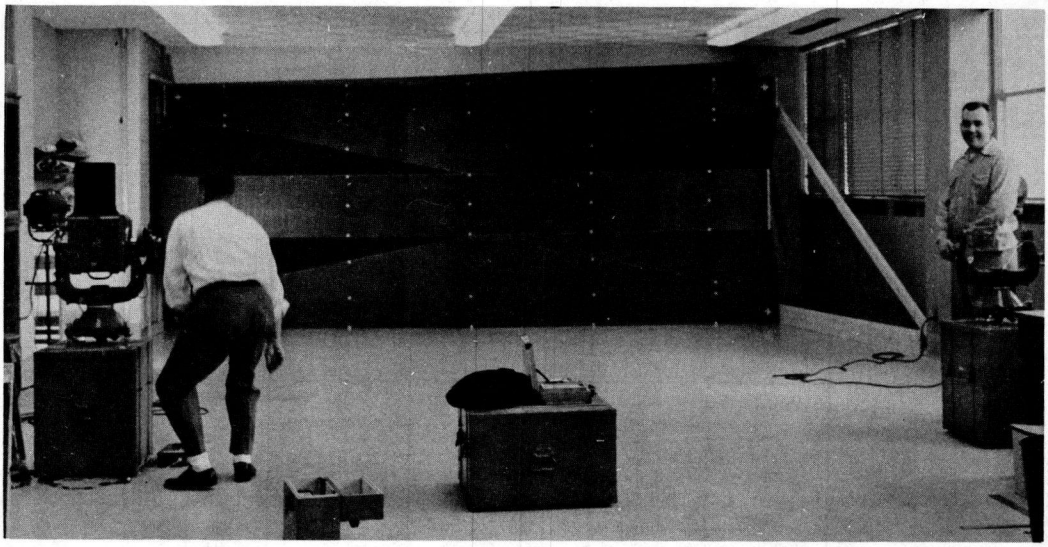

Figure 6. Camera in position at north base.

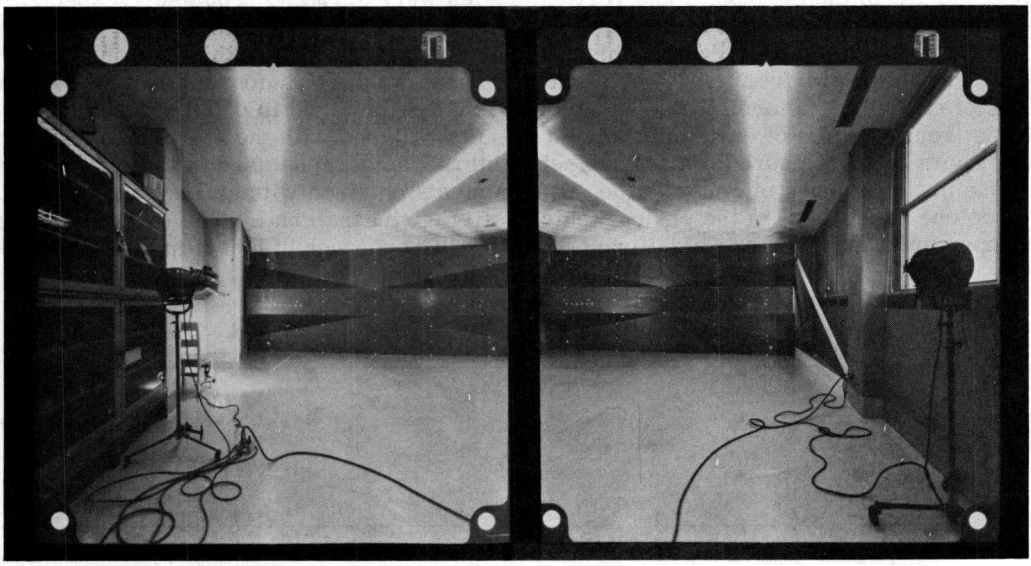

Figure 7. One set of stereophotographs used in experiment.

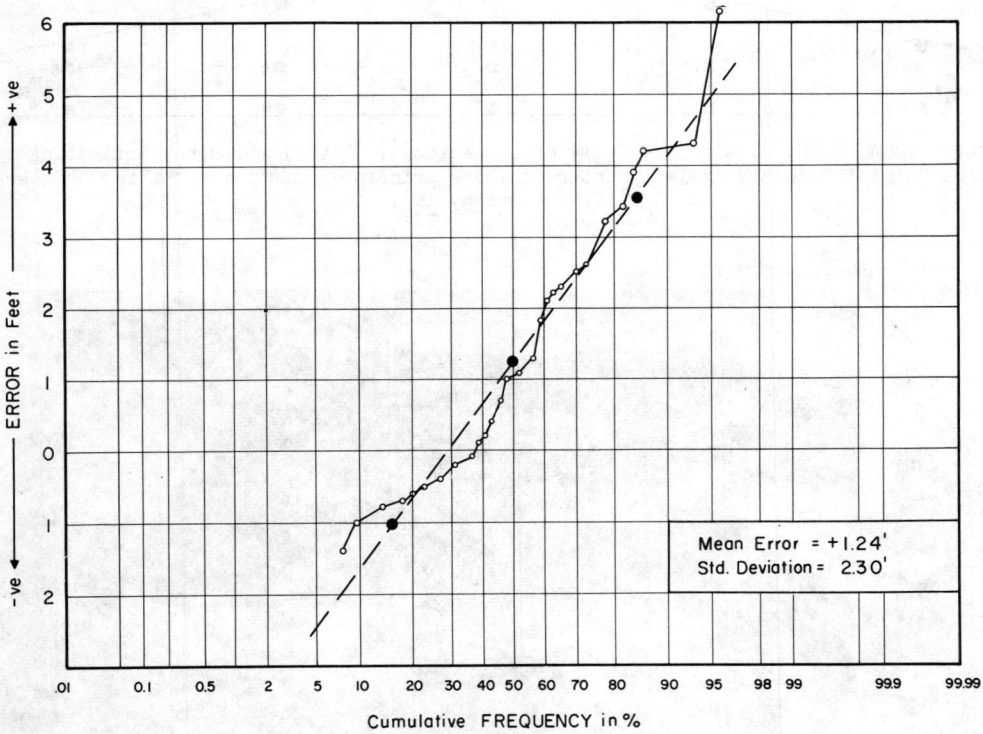

Figure 8. Error plotted against cumulative frequency for spot-height elevations read on paper prints.

polyester photographic film base holds size, is flexible, and is easy to handle in the instrument. For a 30-in. length of Cronopaque film a change in length from 0.008 to 0.1 in. occurs for a 20° increase in temperature, and a 20 percent increase in relative humidity causes a change of 0.007 to 0.01 in. in a 30-in. length of film. Thus, under the calibration test conditions and later the accuracy test conditions, the Cronopaque film was assumed to be dimensionally stable. A comparative test of the accuracy of spot-height values was obtained first on ordinary single-weight print paper, then on Cronopaque print film. The mean error and standard deviation gave a means of evaluating the magnitude of the error for ordinary print paper. Figures 8 and 9 show the error plotted against cumulative frequency in percent. For this special case, the standard deviation for the measurements made on the Cronopaque film was about one-fourth that for single-weight print paper. The mean and standard deviation of error can be reduced appreciably using a stable print film such as DuPont Cronopaque.

After the model was oriented in the stereotope, three micrometer readings were taken at each of the pre-selected spots in cross-sections A, B, C, and E. The readings were averaged and the value of the parallax constant, C, added to obtain the parallax of each point. Elevations of the points were computed from parallax values in the conventional manner. The elevation of each point was compared to the elevation determined with the Wild A-7. The differences in the elevations given by the Wild A-7 and the stereotope were considered errors.

After the control data were numerically set on the stereotope computers, the floating dot was set at the proper position of each control point, the right photo was shifted, and the model was oriented. Then the dot was set on each point and micrometer readings recorded for use in calculating the parallax. The corresponding spot elevations were

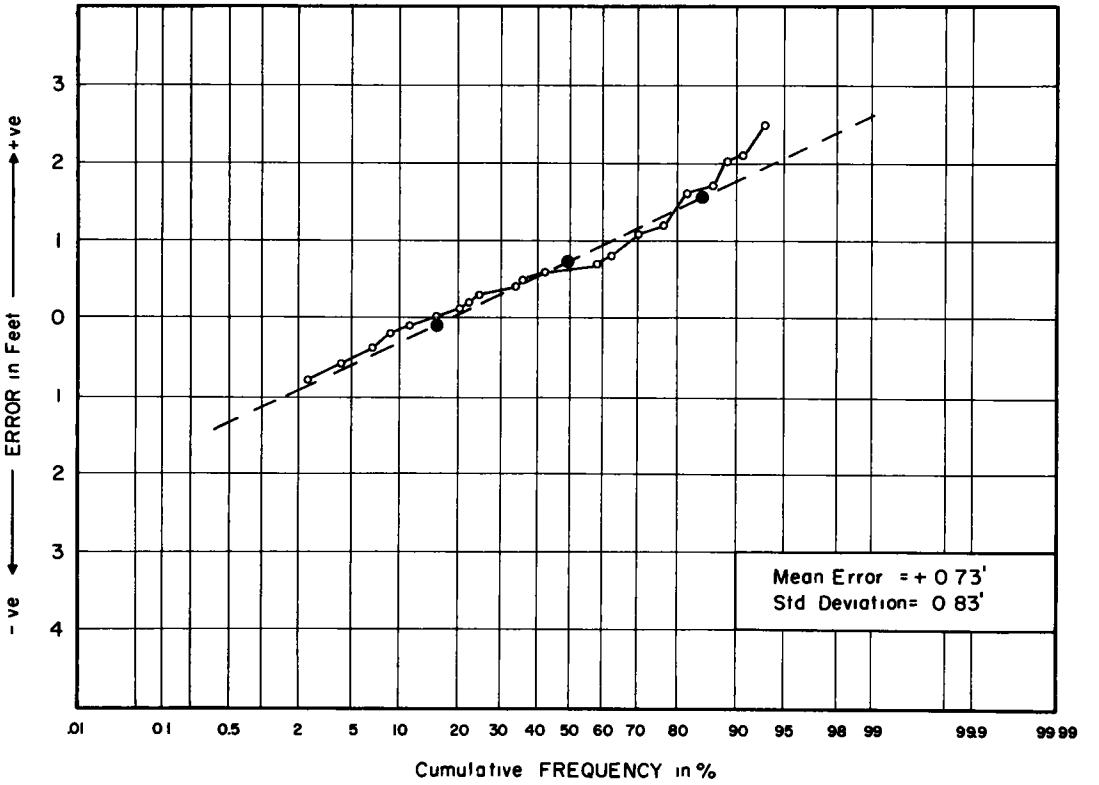

Figure 9. Error plotted against cumulative frequency in percent for spot-height elevations read on Cronopaque film prints.

calculated in the conventional manner: Given a micrometer reading of 17.538 mm an average of three readings on point A, adding to this the parallax correction, C = 59.446, there is then parallax P = 76.984 mm. Using the parallax formula there is

$$h = H - \frac{bf}{P} = 25.000 - \frac{15.683 \times 114.81}{76.984} = 1.607 \text{ ft},$$

the value of the height of point A from datum. The development of the parallax formula is given elsewhere (15).

TABLE 1

SUMMARY OF RESULTS OF CALIBRATION TEST[a]

Cross-Section Point	Wild A-7 Elevation	Stereotope Elevation Differences* (degree of tilt)**					
		Zero	1 Left	2 Left	1 Left, 3 Right	2 Left, 3 Right	3 in Both
A1	0.779	-0.003	+0.014	***	-0.003	-0.009	+0.004
2	0.764	+0.003	+0.012	+0.009	+0.009	+0.001	+0.003
3	0.760	-0.003	+0.013	+0.005	+0.009	+0.008	+0.001
4	1.546	-0.001	+0.008	+0.010	+0.067	+0.051	+0.070
5	1.545	0.000	+0.009	+0.014	+0.058	+0.051	+0.071
6	1.540	+0.009	+0.009	+0.009	+0.057	+0.052	+0.071
7	0.734	+0.003	+0.013	-0.003	+0.015	-0.006	+0.008
8	0.733	+0.004	+0.008	-0.001	+0.016	-0.007	+0.001
9	0.737	0.000	+0.009	***	+0.012	-0.017	+0.003
B1	1.362	+0.007	+0.075	+0.141	-0.098	-0.098	+0.033
2	1.355	+0.006	+0.071	+0.147	-0.087	-0.040	+0.035
3	1.337	+0.007	+0.074	+0.148	-0.084	-0.037	+0.036
4	1.733	+0.008	+0.072	+0.147	-0.053	-0.017	+0.060
5	1.728	+0.006	+0.072	+0.144	-0.051	-0.026	+0.063
6	1.726	+0.010	+0.074	+0.144	-0.035	-0.029	+0.063
7	1.322	+0.007	+0.062	+0.148	-0.083	-0.044	+0.041
8	1.306	+0.009	+0.067	+0.145	-0.072	-0.060	+0.041
9	1.303	+0.013	+0.059	+0.139	-0.070	-0.043	+0.041
C1	1.930	+0.008	+0.073	+0.192	-0.117	-0.046	+0.047
2	1.934	+0.003	+0.090	+0.183	-0.117	-0.046	+0.042
3	1.920	+0.004	+0.096	+0.184	-0.112	-0.044	+0.047
4	1.916	+0.010	+0.097	+0.189	-0.110	-0.044	+0.051
5	1.911	+0.006	+0.089	+0.179	-0.107	-0.047	+0.052
6	1.905	+0.004	+0.072	+0.177	-0.105	-0.048	+0.046
7	1.911	+0.004	+0.080	+0.177	-0.109	-0.046	+0.044
D1	2.533	+0.001	+0.064	+0.139	-0.060	-0.044	+0.030
2	2.555	-0.002	+0.061	+0.144	-0.074	-0.044	+0.036
3	2.524	+0.001	+0.065	+0.140	-0.071	-0.030	+0.037
4	2.123	-0.008	-0.075	-0.155	-0.078	-0.036	+0.023
5	2.113	+0.008	+0.077	+0.151	-0.089	-0.031	+0.029
6	2.118	+0.007	+0.073	+0.148	-0.079	-0.048	+0.024
7	2.519	+0.005	+0.078	+0.148	-0.067	-0.034	+0.036
8	2.529	+0.005	+0.077	+0.140	-0.066	-0.042	+0.029
9	2.503	+0.012	+0.073	+0.144	-0.063	-0.035	+0.035
E1	3.123	+0.007	+0.009	***	+0.007	+0.006	+0.003
2	3.114	+0.007	+0.017	+0.024	+0.009	+0.012	+0.009
3	3.117	+0.007	+0.014	+0.024	+0.009	+0.009	+0.011
4	2.314	+0.007	+0.029	+0.057	+0.009	+0.013	+0.003
5	2.306	+0.010	+0.039	+0.053	+0.011	+0.013	-0.002
6	2.313	+0.003	+0.036	+0.046	+0.007	+0.003	+0.003
7	3.119	+0.006	+0.024	+0.018	+0.001	+0.011	+0.007
8	3.121	+0.007	+0.013	+0.016	-0.000	+0.009	+0.008
9	3.106	+0.007	+0.009	***	+0.005	+0.017	+0.009

[a]After Bastian (19).
*Difference equals Stereotope elevation less A-7 elevation.
**Refers to tilt in left and right photographs, respectively.
***Not legible—ink on photograph.

Results of Calibration Test

A summary of the results obtained with stereotope compared to the elevations determined with the Wild A-7 is given in Table 1. A plus difference indicated that the elevation determined with the stereotope is higher than the elevation determined with the Wild A-7. The various stereoscopic models are designated by the amount of tilt present in the left and right photograph. The tilted model 1° in the left and 0° in the right photo refers to the north base photograph having the camera optical axis tilted 1° toward the south base. The tilt angle is to the right from north base toward south base in the positive X direction.

The elevations of the four control points obtained by both plotting instruments compared closely. For these points, the maximum errors of the Wild A-7 and the stereotope were, respectively, 0.002 and 0.003 ft. This comparison indicates that the accuracy with which the models were oriented in each instrument was comparable.

For the photographs with no tilt, the errors appear to be random, but with a predominance of positive values. There is an indication that the operator had a tendency to read the elevations high. It was observed during the calibration test that the instrumentation reported herein lends itself to testing operator acuity and efficiency.

The C-factor was found for the non-tilted model. The error was no greater than 0.0102 ft for 90 percent of the points and the "flying height" was 23.00 ft. These values give a C-factor equivalent to 2,230.

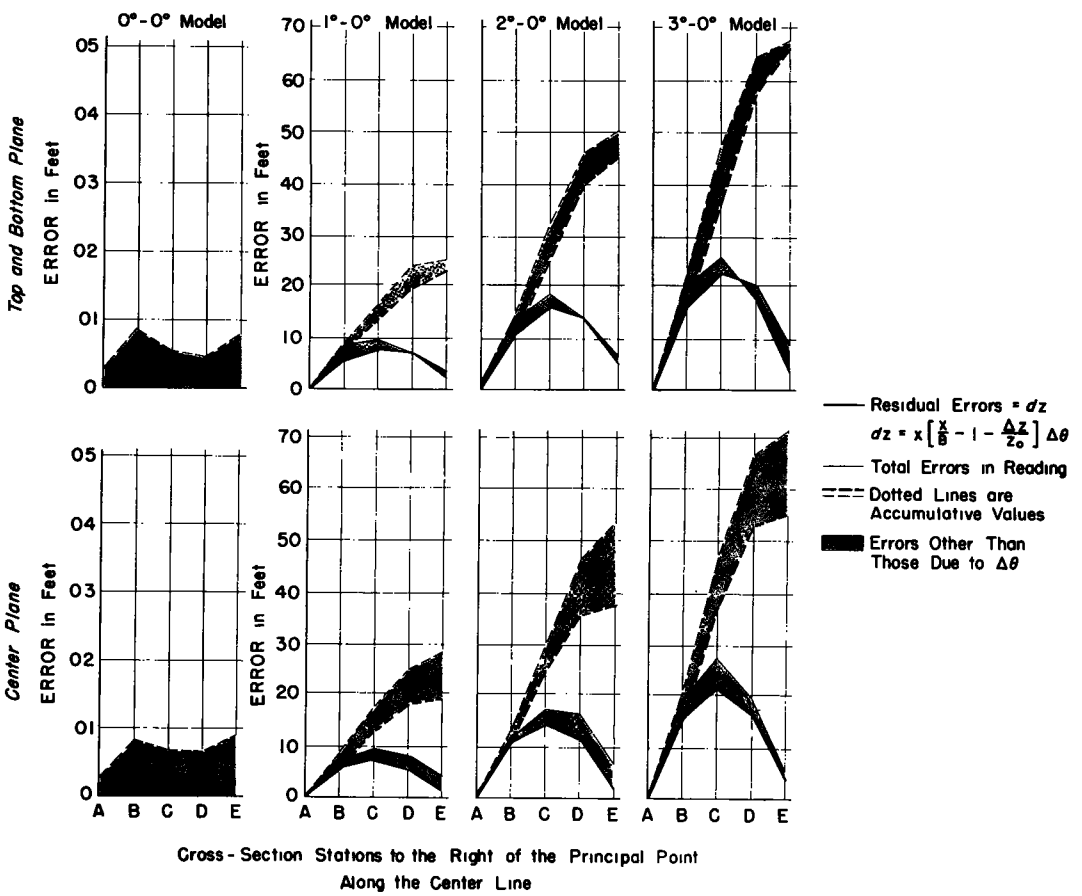

Figure 10. Error plotted against position of cross-section as related to principal center of photograph.

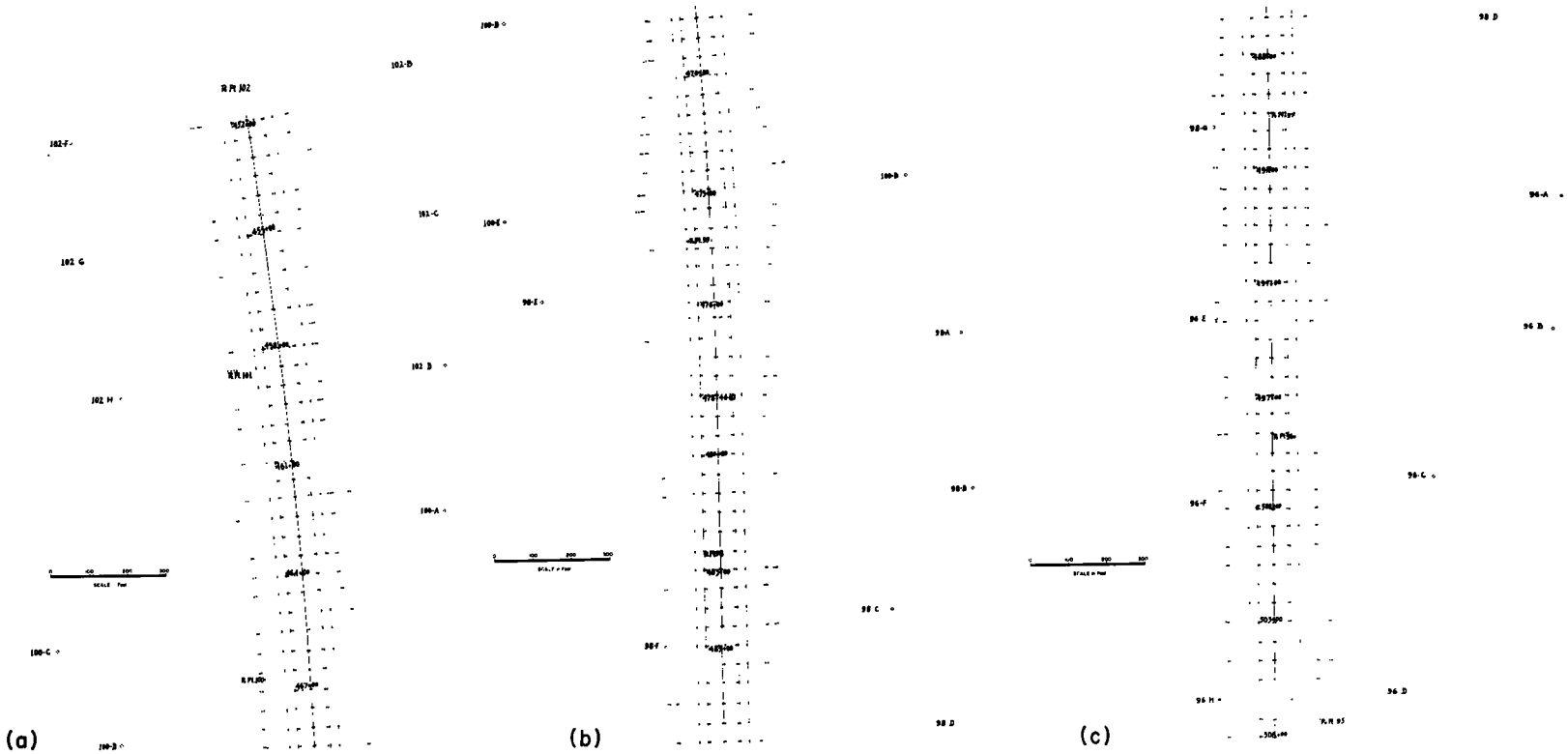

Figure 11. Photographs (a), (b), and (c) taken of US 62 for final pay quantity measurements controlled by pavement station marks; these stations, the other control stations, and cross-sections to be measured were plotted on manuscript as shown in these diagrams (after Sahgal, 29).

The mean error of the spot-height elevations was 0.0059 ft and the probable error was 0.0039 ft. Expressing these errors in terms of the "flying height,"

$$\text{mean error} = \frac{0.0059}{23.00} = \frac{1}{3,900} \text{ of "flying height"}$$

and

$$\text{probable error} = \frac{0.0039}{23.00} = \frac{1}{5,900} \text{ of "flying height."}$$

There were sizeable errors in the elevations measured in the tilted models. The largest portion of any error is probably due to the tilt that cannot be entirely eliminated with the stereotope computers. The maximum error of the tilted (2° to 0°) model was about 1/125 of the flying height.

Funk (7) found that in practice the profile of a constructed section of roadway is usually accurately determined and the known profile elevations can be used to adjust the remaining cross-section elevations. The suggested adjustment was applied to the cross-sections of the 0°-0° model, reducing the mean and probable errors respectively from 0.0059 to 0.0037 and from 0.0039 to 0.0025 ft. But similar adjustments to the centerline profile data in tilted models did not give good results.

Figure 10 shows the error plotted against distance from the principal point across the mock-up from section to section. The error of greater magnitude was always near the center of the neat model. This confirms what was noted by Funk (9) in 1958.

ACCURACY TEST

Description of Photogrammetric Procedure

There were seven models of the photography which had been flown by the Ohio Department of Highways at an altitude of 1,650 ft above the average terrain providing a plotting scale of 1/2,400 for the stereotope and a manuscript plotting scale of 1/625 for the Wild A-7 autograph. The photographs were printed on 0.13-in. glass plates and on dimensionally stable Cronopaque film. As the work with the stereotope was carried out in an air-conditioned room, for the 9- by 9-in. format the effect of dimensional changes due to temperature and humidity variation was neglected for the Cronopaque film. There were 45 vertical control points spread over the seven stereomodels, including 20 points fixed on the pavement edge.

To identify the cross-section lines to be measured in each instrument, the cross-

TABLE 2

SUMMARY OF STANDARD DEVIATIONS AND ARITHMETIC MEANS FOR STEREOTOPE[a]

Model No.	No. of Observations	Results Before and After Adjustment[b], Standard Deviation (ft)		Arithmetic Mean (ft)	
		A	B	A	B
96/96	306	±0.75	±0.81	+0.38	-0.30
96/97	262	±0.90	±0.98	+0.42	-0.44
97/98	275	±0.90	±0.86	+0.13	-0.26
98/99	291	±0.94	±0.67	+0.08	+0.09
99/100	294	±0.58	±0.59	+0.03	+0.12
100/101	323	±0.54	±0.65	-0.20	-0.19
101/102	291	±0.57	±0.58	-0.29	+0.02
Total	2,042	±0.76	±0.74	+0.07	-0.13

[a]After Sahgal (29).
[b]Col. A=initial stereotope readings; Col. B=adjusted stereotope readings.

section lines were marked on each Cronopaque print. These prints were placed emulsion-side down on top of a light table and the corresponding diapositives, emulsion-side down, were then placed on top of the respective prints, using the fiducial marks as guides. The position of cross-section lines were marked on the clear side of the diapositives with a China marking pencil while being viewed orthogonally from the top. These cross-section lines were used as the guide lines for the plotting of the manuscript in the Wild A-7 autograph operation.

The interior, exterior, and absolute orientations were executed in the Wild A-7 autograph in the conventional manner. The scaling of the models was carried out numerically by reading the machine coordinates of the stations, computing the distance between them and comparing the model distances with corresponding true ground distances. The leveling of the model was then carried out by reading the elevations on vertical control points which had been measured to 0.01 ft in the field survey. Then, after the absolute orientation and the plotting of the planimetric position of each point, the spot-height readings of 2,042 points were taken and recorded. Along with these values the horizontal distances to the left or the right of centerline on the cross-sections were scaled off from the manuscript and recorded. Also, height readings were taken at the principal points of each photograph and recorded for later use in the stereotope orientation.

The planimetric positions of the cross-section stations at 50-ft intervals and all control points were plotted on Mylar film manuscript by means of the Wild A-7 autograph. Figure 11 shows the manuscript identification of the stations and cross-section points used in spot-heighting operation. The numbers 96 to 101 are the photo print numbers in sequence. The stations, 467+00 to 485+00, identify the route alignment.

In the case of the stereotope, there was only an "interior orientation" which constituted the correct positioning of the left-hand and the right-hand photographs of every model in sequence. The photographs were positioned on their respective photo carriers, in the manner described next. The principal and conjugate points were located and transferred in the conventional manner to establish the line of flight or the X-axis of the measurement system. The photocarriers, mirrors, and ocular viewers were adjusted for comfortable stereovision. Displacements in the Z and Y directions were affected by the large mirrors and the small mirrors, respectively. The two measuring marks held in reticules were brought on top of the two engraved crosses on two photo carriers, with the computers being set at a value of 10.0 (which is the zero setting). Then the parallax value recorded at the X-parallax measuring thimble was checked. This value

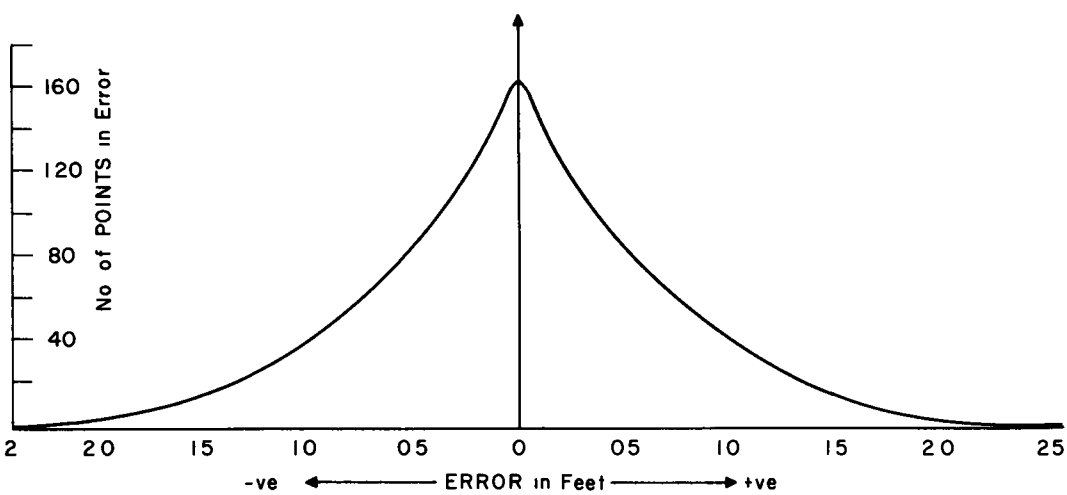

Figure 12. Normal curve showing distribution of errors for unadjusted stereotope data (after Sahgal, 29).

should be 15.00 mm in this position; otherwise, there is some zero error in the micrometer setting. The "zeroing in" must be taken care of before operating the stereotope.

The photographs, with X- and Y-axes denoted, were then fixed on their respective carriers with magnets and tape. The coordinate axes were then matched with the engraved lines on the photo carriers.

After the preceding procedure, the "leveling" of the stereomodel was done using the stereotope computers. Aerial photographs are seldom vertical and, due to distortion characteristics of the taking camera lens, the height value read in the instrument's operation has a small systematic error; therefore, it was necessary to level the model carefully. The true parallax values at the vertical control points were set by the computers in each case. Then the photo carriers were adjusted to correspond to the respective values read at the X-parallax micrometer. Further details on the orientation procedure for the instrument are given elsewhere (3, 16, and 17). Each model was observed to determine the planimetric and parallax position of the 2,042 points to establish the cross-section data for the earthwork volumes.

Results Using Interstate Project Photos

For the spot-height elevation data obtained, this study derived the standard deviation, the arithmetic mean, developed a comparison of the frequency distribution with the theoretical error or probability curve, and calculated the C-factor as derived from the theoretical contour interval that would comply with the specification requirement "that 90 percent of the points tested must be within one-half contour interval." The 90 percent value is derived from the error frequency distribution. In addition the accuracy of earthwork volumes calculated from the cross-section data were evaluated.

The measurements taken by means of the Wild A-7 autograph were used as the standard of comparison. Spot-height elevations for the cross-sections were taken using each of the instruments. There were more than 100 sections measured. The number of discrete points (2,042) was considered satisfactory as a statistical sample. To determine a measure of the vertical accuracy of the stereotope, spot-height elevations were obtained conventionally by means of the parallax readings. These elevations were compared with the corresponding values computed from data given by the Wild A-7 autograph operation. The differences from the standard were classified as

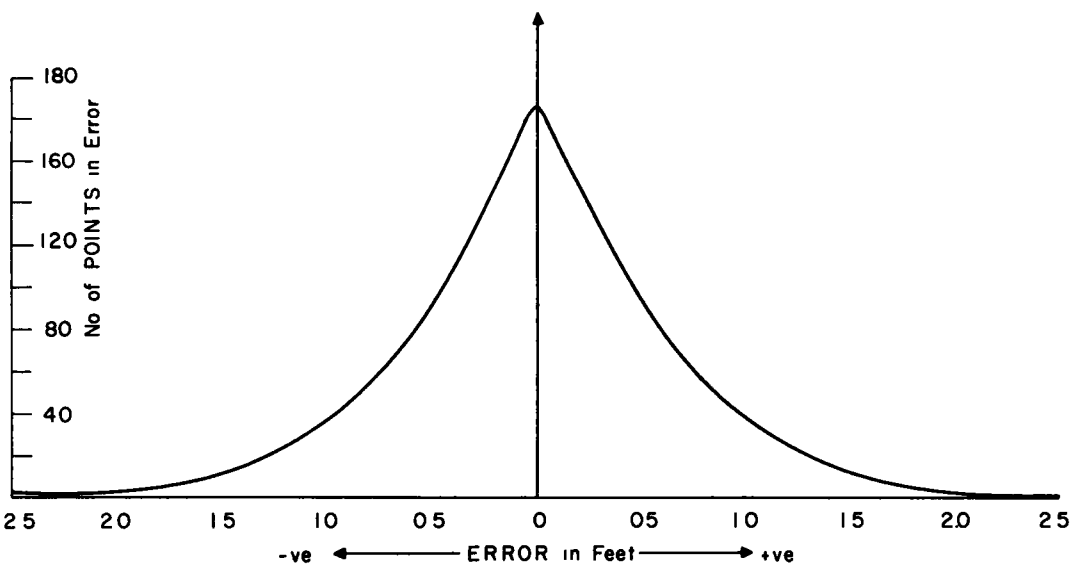

Figure 13. Normal curve showing distribution of errors for adjusted stereotope data (after Sahgal, 29).

errors. The residual or difference between the standard value and that given by the stereotope was considered either a random or systematic error, or it was a blunder.

The standard deviation of errors in the spot-height measurements of all 2,042 points was found to be ± 0.76 ft with an arithmetic mean of + 0.07 ft. The standard deviation varied from a low of ± 0.54 ft to a high of ± 0.94 ft, with a corresponding arithmetic mean varying from -0.20 to +0.08 ft, respectively, and from model to model. Table 2 gives the summary of standard deviations and arithmetic means for all models.

In 1959 Funk (9) indicated that in Kelsh plotter operations to obtain cross-section data for earthwork-volume computations there was an improvement after adjusting the height readings to the data from the field-measured centerline profile. A similar adjustment was made for the cross-section data obtained using the stereotope, but the improvement was only slight; in fact, for some models the adjusted-to-centerline values produced poorer results. The over-all standard deviation reduced from ± 0.76 to ± 0.74 ft, although the arithmetic mean degraded from ± 0.07 to - 0.13 ft. Table 2 gives the results in all models before and after adjustment.

Figures 12 and 13 show the distribution of the errors in the form of a "normal curve." The "normal" curve found in this study was not bell-shaped but had similar characteristics as in the normal curve. Figures 14 and 15 show the cumulative frequency distribution plotted with the abscissa scale graduated according to the area under the normal curve. Any line of this graph passing through a point defined by an elevation error of zero at a cumulative percentage error of 50 would correspond to the normal curve. Dotted lines on these figures represent the normal distribution of errors. The cumulative percentage distribution agreeing with the position of dotted lines would meet with the National Map Accuracy Standards for a contour interval of 2.0 ft. The continuous lines shown in Figure 15 indicates the degree of agreement or disagreement of the results of the stereotope operation with the Accuracy Standards requirement.

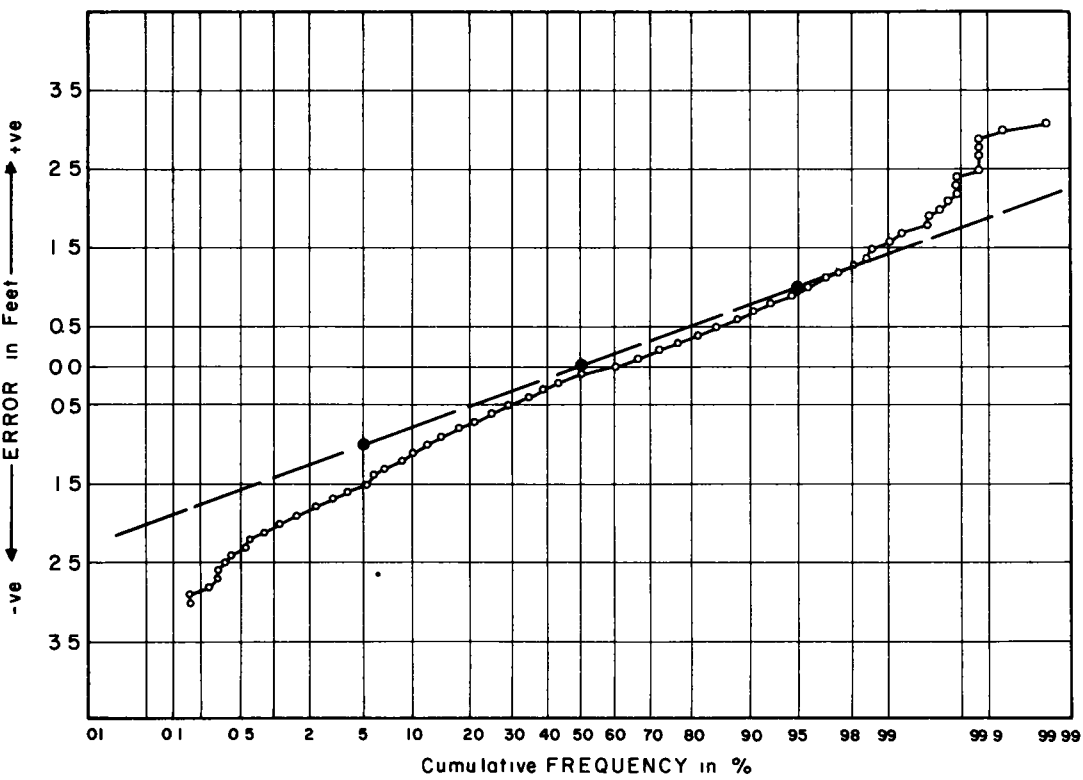

Figure 14. Errors in unadjusted stereotope data plotted against cumulative frequency distribution (after Sahgal, 29).

The C-factors computed for the cross-section data, with the contour intervals corresponding to the National Map Accuracy Standards, were read from figures of cumulative percentage distribution of errors. For the stereotope 90 percent of the discrete points were found to be within ± 2.4 ft and 3.0 ft for the unadjusted and adjusted stereotope cross-section values. With a flying height of 1,650 ft, the following C-factors were computed: stereotope unadjusted, 688; stereotope adjusted, 550.

A further accuracy test was devised in determination of the precision of the parallax readings within a given model. This test was carried out using 32 points in one model selected at random; i.e., along the median, slopes, top of pavement, top of buildings, and on ground areas. The floating dot was placed on the image always from above. The "true reading" for any point was taken as the arithmetic mean of the ten readings on each point. The errors were computed for the ten readings in terms of the standard deviation for the 320 readings taken with each instrument. For the stereotope the standard deviation was found to be equal to ± 0.02 mm of X-parallax, which is equivalent to ± 0.32 ft of ground height. One may speculate that the error is explained as a combination of the following: (a) inherent error in the stereotope, (b) the photographic quality (poor image contrast), and (c) erratic visual acuity of the operator. Comparing this error of 0.32 ft with the over-all standard deviation of 0.76 ft, one may speculate that the balance of the error is primarily random. For the Wild A-7 autograph the corresponding error in reading precision was found to be equivalent to ± 0.21 ft.

Earthwork Computations

Another measure of accuracy of the stereotope was based on earthwork quantities. Both the adjusted and the unadjusted values observed in the instrument's operation were again compared with the Wild A-7 autograph measurements. The computations were made on the IBM 650.

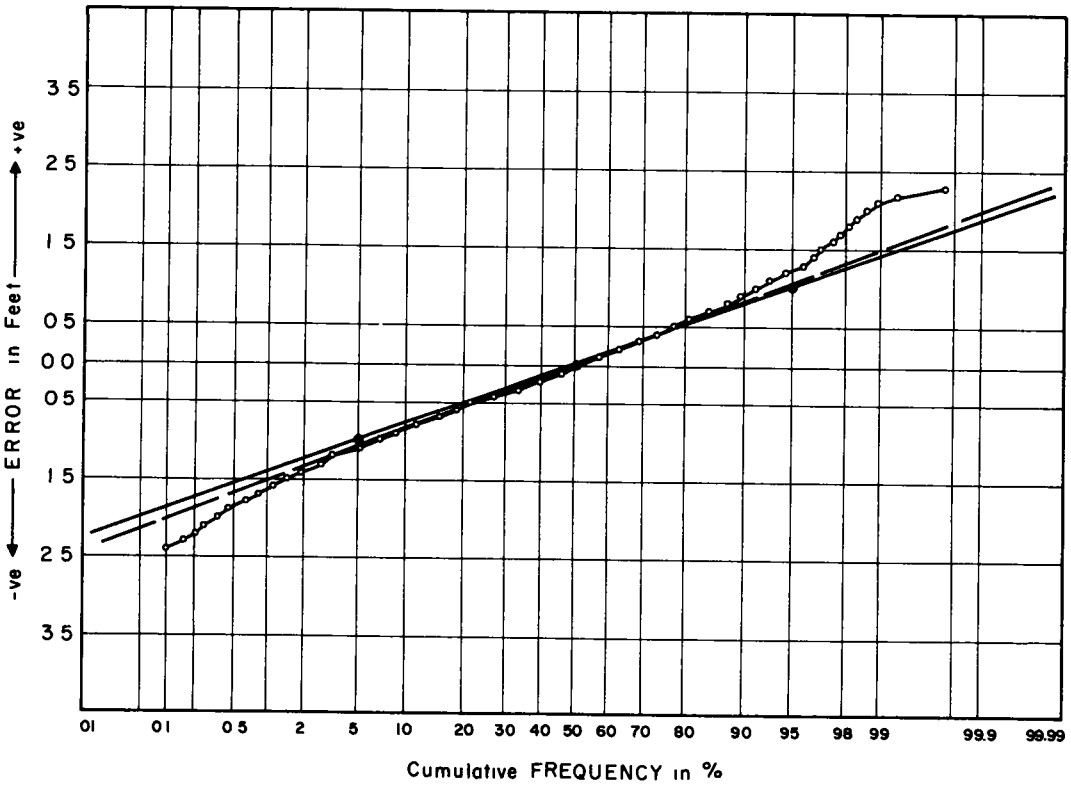

Figure 15. Errors in adjusted stereotope data plotted against cumulative frequency distribution (after Sahgal, 29).

To facilitate the card-punching for volume computations, the earthwork cross-section data were tabulated for presentation on profile-grade data forms. The cross-section data were recorded in the conventional method used in field surveys.

There were several sets of cross-section data prepared as input for earthwork computations: (a) unadjusted sections from the stereotope, (b) adjusted sections from the stereotope, and (c) the original ground line sections.

The earthwork program instructed the electronic computer to use the original and final cross-section data and by means of the conventional end-area method to determine the earthwork volumes for each set of instrument cross-section readings.

Table 3 shows that the excavation volumes contained the largest errors. When adjustment to centerline profile was made, the accuracy of the earthwork volume data did not improve; i.e., it degraded from +1.4 to -3.8 percent, thus verifying the calibration test.

Results Using Kelsh Plotter

Comparing the spot-elevation accuracy of the stereotope with that of the Wild A-7 autograph gives one picture of instrumental performance that can be expected. However, how well a third order instrument performs in comparison with a second order instrument in general use in the United States is of interest. Therefore, this study also included evaluating the spot-height accuracy of the Kelsh plotter. The same photography was used and all the accuracy tests enumerated above were applied to the data procured by the plotter. For all models and 2,042 readings, the values for the standard deviation for a given arithmetic mean were ±0.94 and ±0.05 ft, respectively, but when adjusted to the true elevation of the centerline profile, the standard deviation improved to ±0.69 ft and the arithmetic mean was -0.06 ft. The C-factor was computed to be 550 initially; however, with adjustment, the C-factor improved to 750. The earthwork volume error was +1.4 percent before and -1.1 percent after data adjustment. Furthermore, the precision of readings or spot-height pointing error was equivalent to ±0.36 ft. It can now be observed that the stereotope performed with similar results to those of the plotter to procure cross-sections data for earthwork volume calculations.

EVALUATION OF ZEISS STEREOTOPE

The comparison of the stereotope, a third order instrument, with a first order instrument may hardly seem worthwhile. Most highway engineers would be reluctant to make such a study. And the results of this study will be seriously questioned by photogrammetrists. Yet there is value in learning that under certain conditions the stereotope compares favorably with, at least, second order instruments, such as the Kelsh plotter. The primary comparison is one of accuracy of spot-height elevations. Using

TABLE 3

EARTHWORK QUANTITIES IN TERMS OF ERRORS BASED ON COMPUTATIONS OF EXCAVATION AND EMBANKMENT VOLUMES[a]

Unadjusted Stereotope				Adjusted Stereotope				Over-all Error (%)	
Volume (cu yd)		Error (%)		Volume (cu yd)		Error (%)			
Fill	Cut	Fill	Cut	Fill	Cut	Fill	Cut	Unadj.	Adj.
14,285	3,134	+19.6	-25.7	10,238	5,439	-14.3	+29.0	+44.3	-39.1
10,929	2,467	+14.3	-37.5	6,951	5,225	-27.3	+32.4	+50.7	-69.3
22,980	3,019	+ 6.7	+ 0.6	19,936	4,057	- 7.4	+35.1	+ 7.7	-14.3
99,097	2,338	+ 1.9	+ 9.7	98,385	2,036	+ 1.2	- 4.7	+ 1.7	+ 1.3
116,056	2,902	- 1.3	- 6.3	118,274	2,819	+ 0.6	- 9.0	- 0.4	+ 0.9
2,767	13,236	- 3.15	+11.0	3,146	13,399	-22.2	+12.3	+32.8	+30.0
16,916	5,270	- 8.4	+ 9.6	18,442	4,791	- 0.1	- 0.4	-14.7	0.00
283,033	32,366	+ 0.96	+ 2.3	275,382	37,766	- 1.8	+14.0	+ 1.4	- 3.8

[a]After Sahgal (29).

the standard of comparison (the Wild A-7 autograph), it was learned in the first part of the study that the cross-section elevations read with the stereotope on dimensionally stable print film made from non-tilted negatives exposed by a distortionless lens in close-up type photography had a mean and probable error equivalent to 1/3,900 and 1/5,900 of the "flight height," respectively, the "flight height" being 23 ft. These findings justified the second part of the study; i.e., to determine the use of the stereotope in highway engineering, large-scale mapping-type photogrammetric practice.

The results compared with those from the autograph, used as the standard of accuracy, indicated that errors in the results from the stereotope operation have a standard deviation of ±0.76 ft (for 2,042 points in eight models) with an arithmetic means of +0.07. As a measure of accuracy, the earthwork volumes calculated from cross-sections measured by the stereotope were in error by +1.4 percent. The C-factor calculated for the stereotope was 688. Because its accuracy was of a similar order to the Kelsh plotter, it can be stated that use of the former for data processing for highway engineering is warranted; i.e., for earthwork quantity and other large-scale mapping measurements having similar accuracy requirements.

When the idea of testing a third order photogrammetric instrument for highway engineering large-scale mapping purposes first was initiated in 1958, it was thought that the stereotope was a competitively priced instrument at about $2,500. Currently it is available for about $4,500. The increase in price is partly due to the higher value of the West German mark relative to the dollar that has occurred in the past year. With the Kelsh plotter at $6,500 and the Balplex at $5,000, one wonders if the stereotope is price-competitive, even though it has met the accuracy tests with favor.

Three highway departments have this instrument currently in use. There are eight government agencies, eight educational institutions, and nine private firms that have one in operation in the United States. It is believed that this instrument is used, in the latter cases, primarily for small-scale mapping.

CONCLUSIONS

The results of this two-part study have brought forward some interesting, although not absolutely conclusive, ideas:

1. Under controlled conditions, such as distortionless, non-tilted, close-up photography printed on stable film, vertical accuracies with mean and probable errors of 1/3,900 of flight height, 1/5,900 of flight height and C-factor of 2,230 respectively can be expected.
2. Errors are greater in tilted photographs and affect the spot-heights of cross-sections falling within the central portion of the neat model. The maximum error could be as high as 1/125 of the flight height.
3. In practice, the spot-height measurements of cross-sections by means of the stereotope can be expected to have similar accuracies to those made with the Kelsh plotter.
4. The adjustment of stereotope-measured cross-sections to known centerline profile data does not increase the vertical or earthwork-quantity accuracies.
5. The volumes of earthwork quantities computed by means of stereotope-measured cross-sections have reasonable errors of less than 5 percent.
6. The C-factors for data procured by means of the stereotope and the Kelsh plotter proved to be much lower than expected, an observation that leads to the conclusion that further study of both instruments is in order.

RECOMMENDATIONS FOR FURTHER STUDY

The calibration-test photography, data, and instrumentation have interesting possibilities; i.e., the vertical photography would be useful in testing operator accuracy, acuity, and efficiency. The effects of various lighting on the subsequent surface texture and to effects on photogrammetric measurements would be a useful study.

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