Comparative Accuracies of Field and Photogrammetric Surveys

LEWIS A. DICKERSON and PETER E. WARNECK, Lewis-Dickerson Associates, Watertown, New York

Data resulting from the examination of surveys made by photogrammetric and by conventional field survey methods for highway design are compared. The greater part of the data presented compares the accuracy of elevations on one highway survey project for design of a section of Interstate highway approximately 7 mi long. The results of one evaluation indicate that the frequency and magnitude of differences between two field parties are approximately the same as those between either field party and the photogrammetric approach. Data from a less extensive examination of three other projects are also analyzed and compared.

Both field and photogrammetric methods can be used to make surveys and compile maps for highway design, as far as elevations are concerned. Either method may produce errors in elevation, and the field survey method is likely to cause the larger ones. However, in both cases, the errors are of little consequence during design and construction. Elevation measurements made by photogrammetric methods are sufficiently accurate for computing volumes of earthwork, both for design and for payment purposes.

Basic field survey control is necessary for horizontal measurements made by either conventional field or photogrammetric surveying methods. Aside from this, and to the extent horizontal measurements are shown by plotted positions, photogrammetric methods result in better local and overall horizontal accuracy. Both methods, however, are adequate for the purposes of highway design and construction.

•IT IS the purpose of this paper to present data resulting from the examination of surveys made by photogrammetric methods for the design of highways. Since the principal means of determining accuracy is by comparison with measurements accomplished by conventional field survey methods, pertinent data on these field surveys were also secured and are presented. Most of the data given concerns the accuracy of elevations on one extensive highway survey project. Data from less extensive examinations on three other projects and a very small amount of data on comparative accuracies of horizontal positions are given.

BACKGROUND

In the course of making surveys by photogrammetric methods, many queries are received as to the accuracies to be expected from such methods. Although practicing photogrammetric engineers obtain in the course of their work many indications of accuracy, these tend to be somewhat qualitative and are seldom in a form suitable for conclusive presentation. With one exception known to the authors, there is no con-

Paper sponsored by Committee on Photogrammetry and Aerial Surveys.

clusive factual data published on the accuracy of photogrammetrically made measurements and field surveys as applied to large-scale topographic mapping for highway design purposes. The exception is a paper recently published by L. L. Funk after completion of the data given here. In the course of their work, the authors have collected the results of several tests and comparisons, and it was felt these would be of value to others and serve to answer the queries encountered concerning accuracy of surveys made by photogrammetric methods.

The bulk of the data given here was obtained from one Interstate highway survey project. As the project work moved on through design and into the construction stage, it became convenient to secure the results of the pre-construction field-measured profile and cross-sections from the supervising engineer, as well as the cross-sections he plotted using the photogrammetrically made measurements. None of the engineer's original work of plotting cross-sections, based on the photogrammetrically made surveys, was checked for horizontal positioning, interpolation of elevations from the contours, or plotting. This work provided a mass of data which could be used to evaluate the accuracy of the photogrammetric work for the original design. It then developed that the contractor on the job had also measured pre-construction cross-sections and was willing to make his data available for study. This then provided an opportunity to compare field surveys against one another as well as against surveys made by photogrammetric methods.

As the results of the comparative examination became available, the need for examining other projects was indicated. Without undertaking costly field work for this purpose, two other projects were on hand where some limited comparison of field survey and photogrammetrically made measurements could be made. These comparisons were made and studied along with the more extensive data already referred to; the resulting data are being presented herein. Data from a fourth project are also presented. These resulted from a vertical accuracy test performed under circumstances which necessitated only a minimum of field survey cost.

It should be noted that the data given are largely comparative and leave unanswered the question of absolute accuracies. It would have been desirable to settle that question in the case of the first project mentioned but by the time need for such a comparison became evident, construction was under way and the original ground was no longer available for re-survey. Cost considerations ruled out further field survey test work on two other projects. It is felt, however, that the data gathered are still of considerable value even though the absolute accuracy question still remains unanswered.

SCOPE

The first project to be examined was about 7 mi of highway route surveyed by photogrammetric methods for design of a section of the Interstate Highway System. The photography was taken during the fall flying season from a height of 1,500 ft. A K-17 camera equipped with a 6-in. wide-angle Metrogon lens was used. The maps were compiled using Kelsh stereoscopic plotters at a scale of 1 in. = 50 ft with contours at an interval of 2 ft. Except for one section of rough topography, approximately 2 mi long, the topography was generally rolling and the land was under cultivation or in pasture. Some scattered stands of light to medium hardwood cover were encountered. The rough area contained heavy stands of hardwood timber and medium stands of conifers which were particularly dense in the drainage ways.

On completion of the photography, examination indicated that the vegetative cover presented no problem to mapping by photogrammetric methods except in the rough area. It was obvious that field survey work would be required to complete the maps for the sizable areas scattered throughout the rough topography section where the ground was invisible. During the photogrammetric phases of the survey work, contours were measured and delineated in all but these areas. Copies of the photogrammetrically compiled manuscripts were then taken to the field to be used as plane table sheets; the contours were completed in the missing areas by plane table and alidade surveying methods.

Following design of the highway and as construction approached, the supervising engineer established the centerline on the ground, staking it while using normal survey procedures. He also measured cross-sections across the route using the normal on-the-ground survey procedures. His field notes of the cross-sections became the source for positions and elevations of the points used in making the comparison reported herein. Also, before any construction work on the highway, the contractor on the job had the original ground cross-sections independently measured by his engineering staff. The contractor did not establish an independent centerline but used as a base the centerline previously staked by the supervising engineer. The contractor used normal procedures in his cross-section measurement work. These cross-sections, as measured and plotted by the contractor, were the second source of data subsequently reported.

With a rather unlimited amount of data on hand, it became apparent that all the information available could not be analyzed and some selection would have to be made which would constitute a fair sampling. It was determined that it would be appropriate, as a first comparison, to examine the centerline profile from one end of the survey project to the other. It was realized this approach would tend to show the field work in a favorable light because both field parties had the advantage of measuring elevations at the same horizontal point, whereas at the time of map compilation, information was not available as to where the centerline would be established.

It was then determined that if the cross-sections were examined, the comparison of Party A to Party B would have no advantage of horizontal positioning except at the base line. It was impractical to examine each cross-section in its entirety for the entire project, so an arbitrary decision was made to examine, as a second comparison, a complete cross-section at each interval of 1,000 ft throughout the length of the survey project.

In the data collecting phases, it became apparent that one portion of the rough wooded territory, previously mentioned as requiring plane table survey, was producing gross differences in all possible comparisons. In view of the magnitude and frequency of the differences uncovered, it was decided to treat one part of this area separately. A segment some 1,900 ft long, containing about 1,100 ft of plane table work, was isolated and examined separately. The data examined in this area are not included in the two sets of data previously mentioned, but are considered in a third comparison. The area mentioned was not completely surveyed by plane table because the area requiring such work had a random outline and generally followed the gullies.

It was then decided as the fourth and final analysis of Project 1 to examine a segment of designed highway completely in cut or fill. An arbitrary segment length of 1,000 ft was selected as being a representative sample. Subsequent investigation of the construction plans revealed that in only one place was the condition satisfied and the area involved was entirely in cut.

FACTUAL DATA

The first examination of data was made of the centerline profile. Here the engineer established the centerline and staked it at a stationing stake interval of 50 ft. Elevations were extracted from his field survey records for the stations. The contractor's data were extracted and recorded on the same basis. The map elevations were taken from the cross-sections measured from the topographic maps and plotted on separate sheets by the engineer during the design phases of the highway engineering work. Comparisons were made between the contractor's and the engineer's data, between the map and the contractor's data, and between the map and the engineer's data. When the engineer's data were involved in comparison, it was held as a base and the deviations found indicate the departure of the other set of data from the engineer. When comparison was made between the contractor's data and map data, the contractor's data were held as the base. This basic procedure was followed for all projects examined. A portion of the plotted base line profile is shown in Figure 1 and the results of the comparison are given in Table 1. It is pertinent to note that in each of these comparisons there were 10 differences greater than 2 ft.

The second examination of data consisted in analysis of each elevation along each cross-section at even intervals of 1,000 ft for 7 mi. The engineer's cross-section point distances from centerline and elevation measurements were taken directly from

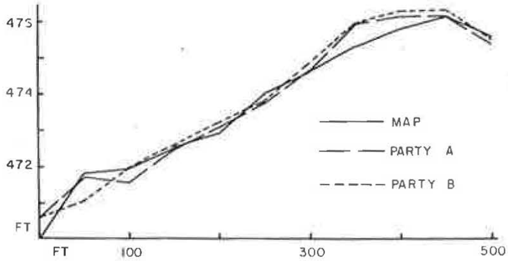

Figure 1. Typical segment of base line profile.

his field survey notes. The contractor's elevation measurements were taken from his plotted cross-sections, interpolating where necessary, using points the same distance from the centerline as the engineer's. The elevations for the map were taken from cross-sections measured from the map and plotted by the engineer, but again the engineer's field measured distance to each elevation point was considered to best portray the surface of the ground. It should be noted that the sepa-

TABLE 1

COMPARISON OF ELEVATIONS, PROJECT 1

Data Source	No. Points	Arith. Mean of Diff.[a]	Avg. Diff.	Std. Dev.	Maximums
(a) Along Staked Centerline[b]					
Party A to B	532	+0.04	0.23	0.75	-70.0 to +10.6
Map to Party A	532	+0.05	0.59	0.93	-10.1 to +5.9
Map to Party B	532	+0.02	0.61	1.13	-10.1 to +10.6
(b) For Complete Cross-Sections, 1,000-Ft Intervals Throughout Project[b]					
Party A to B	227	+0.03	0.50	0.98	+3.9 to -7.5
Map to Party A	227	+0.10	0.67	1.07	-4.0 to +7.5
Map to Party B	227	+0.08	0.65	0.961	+4.3 to -4.1
(c) Along Every Cross-Section for 1,900 Ft of Centerline[c]					
Party A to B	465	0.0	1.1	2.2	-10.5 to +13.9
Map to Party A	465	-0.1	1.6	2.8	-16.8 to +15.3
Map to Party B	465	0.0	1.8	2.9	-14.4 to +11.3
(d) Along 1,000-Ft Segment of Highway in Cut					
Party A to B	171	-0.03	0.29	0.48	-2.0 to +1.6
Map to Party A	171	+0.2	0.4	0.53	±1.7
Map to Party B	171	+0.2	0.4	0.44	±1.2

[a] Disregarding sign.
[b] Plane table surveyed areas excluded.
[c] In rough wooded area, mapping partially by plane table method.

rate distances from base line to points selected by the engineer for elevation measurement on each cross-section are not necessarily the same points selected by the contractor or, as could normally be expected, selected based on map content alone. It is pertinent to note that in each comparison there were 13 elevations differing by more than 2 ft. The results of the comparison of the three sets of elevations are given in Table 1 and samples of plotted cross-sections are shown in Figures 2 and 3.

The third set of data compared consisted of elevation data along each highway segment for 1,900 ft of centerline in a rough wooded area. The mapping of approximately 1,100 ft of this area was accomplished by plane table surveying methods. The three sets of elevations were analyzed and comparison results are also given in Table 1. Figure 4 shows a plotted cross-section in this area. It should be noted that all gross map differences occurred in areas where plane table surveys were performed and differences encountered where surveys were made by photogrammetric methods fell in the same general range as encountered elsewhere in this paper.

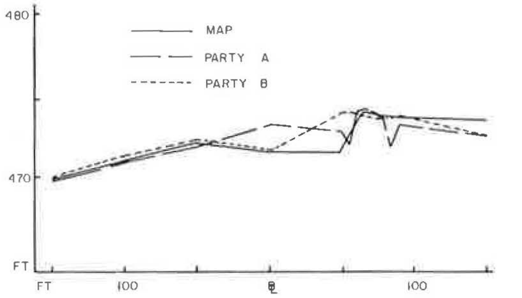

Figure 2. Typical section, average terrain.

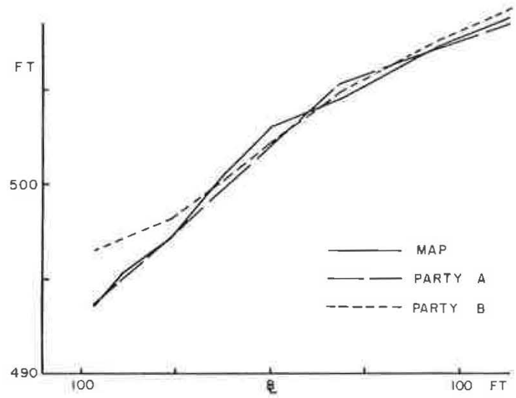

Figure 3. Typical section, average terrain.

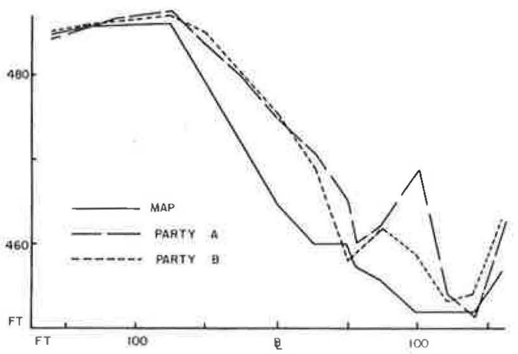

Figure 4. Typical section, rough wooded area.

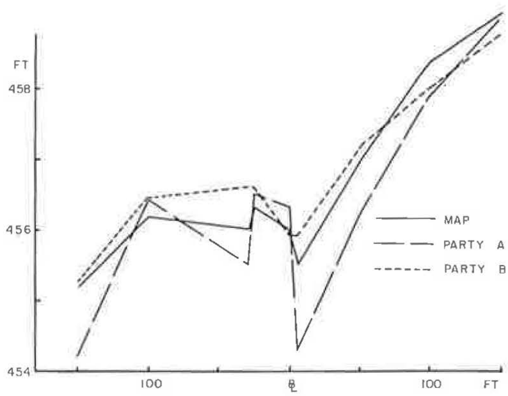

Figure 5. Typical section, cut area.

The fourth set of data examined on this project consisted of the 1,000 ft of highway designed to be completely in cut. Here again the engineer's data were considered to be datum and for elevation comparison purposes his distances from centerline to elevation measurement points were assumed to be the best representation of the ground. The engineer established the staked centerline as well as grade stakes 150 ft right and left of the centerline. The contractor had these stakes to provide horizontal positioning 150 ft left and right of the centerline as well as a measurement line along each cross-section. The map elevations were taken from cross-sections measured from the map and plotted by the engineer and appropriate elevations were taken from the contractor's plotted cross-sections. The results of the analysis are given in Table 1 and a typical cross-section is shown in Figure 5.

In addition to analyzing the data as in the previous three cases, earthwork volumes were also computed using the design templates for this section of highway. The engineer's and contractor's were both data taken directly from their field survey records. This is not the case in the previous studies where it is assumed that the contractor's distances from centerline to elevation measurement points on each cross-section were his best evaluation of the ground surface and should be used. Map elevations were taken from the cross-sections measured from the maps and plotted by the engineer. Volumetric data were computed electronically and the following values were found:

Based on engineer's data, 98,640 cu yd;
Based on contractor's data, 98,628 cu yd; and
Based on map data, 100,235 cu yd.

The difference between map data and field data was +1.62 percent. The average depth of cut was 20 ft, of which 2 to 4 ft were overburden and the remainder was rock. A typical cross-section is shown in Figure 5.

The second project to be examined was about 1,800 ft of a highway project where mapping by photogrammetric methods overlapped mapping by conventional field survey methods. The aerial photography was taken during the fall flying season from a height of 1,200 ft. A precisionized K-17 camera equipped with a 6-in. wide-angle Metrogon lens was used. The maps were compiled using Balplex stereoscopic plotters at a scale of 1 in. = 50 ft with a contour interval of 1 ft. The topography was generally rolling and the land consisted of cultivated fields or pasture. No additional field topographic information was required in the area of this study.

Field data were obtained from cross-sections plotted from the original survey. Ground elevations from the maps were obtained by measuring the profile of the original base line plotted on the maps compiled by photogrammetric methods. The cross-section lines were then erected perpendicular to the centerline and elevations were interpolated from contours on the maps at the same distance from the centerline as recorded for elevation measurement points in the field survey cross-section notes. The results of the study are given in Table 2.

In plotting the field measured cross-sections on the map, it was discovered that where the cross-sections were on curves and one cross-section line crossed the plotted position of another, field surveyed elevations on the different cross-sections fell very close to each other. Vertical differences in the neighborhood of 2 ft were observed in several places. The horizontal accuracy of this project is discussed in this paper.

The third project to be examined was 1½-mi segment of mapping on a 10-mi survey project. The photography was taken during the spring flying season from a height of 1,200 ft. A precisionized K-17 camera equipped with a 6-in. wide-angle Metrogon lens was used. The maps were compiled using Balplex stereoscopic plotters at a scale of 1 in. = 50 ft with a contour interval of 1 ft. The topography was generally flat and the land was under cultivation and pasture. Although some field survey elevation data were required to supplement photogrammetrically obtained data in several other areas, none was required here. For comparison purposes, the field survey data were taken from the field survey notes prepared by the organization which photogrammetrically compiled the maps. A second-order base line survey had been made through the project, and side base lines, established by second-order survey methods, were also established on several intersecting streets. Station marker monuments were established at intervals of approximately 500 ft along these base lines for which elevations were measured by third-order levels. Positions for profile measurements were established by stadia methods at intervals of about 50 ft along the base line. Using a Wild N-2 level, a series of unchecked side shots were made to establish the elevation of the profile points. The base line was plotted on the maps, and using field measured distances, elevations were interpolated from the contours of the maps. The results of the analysis are given in Table 2.

TABLE 2

COMPARISON OF ELEVATIONS, OTHER PROJECTS

Proj.	No. Points	Arith. Mean of Diff.	Avg. Diff.[a]	Std. Dev.	Maximums
2	136	+0.61	2.3	1.51	+6.4 to -9.4
3	145	-0.02	0.18	0.26	+0.5 to -1.2
4	28	-0.02[b]	0.29[b]	0.37	-0.9 to +0.5

[a]Disregarding sign.

[b]Here differences classed as errors because positive horizontal and vertical position assured.

The last project to be examined was a segment of an 11-mi section of mapping performed for design of the Interstate Highway System. The photography was taken during the spring flying season at a height of 1,500 ft. A precisionized K-17 camera equipped with a 6-in. wide-angle Metrogon lens was used. The maps were compiled using Kelsh stereoscopic plotters at a scale of 1 in. = 50 ft with a contour interval of 2 ft. The topography was generally rolling. Most of the mapped area was under cultivation or was in pasture. In several areas, light to medium hardwood timber covered the land. No additional field work was required to supplement the photogrammetric work in the wooded areas. On completion of the mapping, the centerline of the northbound land was staked on the ground. Using a Wild N2 Precise level, a closed line of levels was measured over two portions of the line, each about ½ mi in length. Stations on the centerline at intervals of 200 ft were turned through, these points were plotted back on the 1 in. = 50-ft maps, and elevations were interpolated for the appropriate stations. Approximately 40 percent of the points tested were in the woods. The analysis of the errors is given in Table 2. This is the only test reported here in which positive horizonal and vertical positions are assured.

DISCUSSION

It might be wise here to consider the causes of errors that affect topographic mapping by photogrammetric methods. L. L. Funk states that major errors in the photogrammetric system stem from either large systematic errors or blunders. He also states that random errors together with small systematic errors, which may be impossible to eliminate, determine the basic accuracy of the system. Inasmuch as the magnitude of the small systematic error is in the range of 0.20 ft or less, it is not felt that this type of error will noticably affect map accuracy. Large systematic errors together with small random errors, however, would have an effect on map accuracy. By maintaining tight control over the field and map compilation phases, these errors and blunders can be kept to a minimum. Random errors, some large systematic errors and blunders will, however, escape detection and appear in the completed map. As long as the frequency of this type of occurrence remains low, highway design will not be materially affected.

It is also appropriate to mention some of the advantages and disadvantages of the stereoscopic model. Vertically, the least elevation measurement that can be repeatedly read on the instrument is about 1/7,500 of the flight height. In other words, if a surveyed project was photographed from a flight height of 1,500 ft to prepare a map, the best possible measurement reading of a known elevation on the ground would be ±0.1 ft. To set up the stereoscopic model, at least three known elevations are required and four should be used in best practice. The stereoscopic model is leveled to these field-surveyed points to within ±0.1 ft; when this is done, the model is brought to scale by means of at least two known horizontal positions. An area about 2,000 by 900 ft is then prepared for mapping. The photogrammetric instrument operator moves his measuring mark through the stereoscopic model delineating planimetry and contours in separate phases. Inasmuch as the entire area is fixed horizontally and vertically, the instrument operator must measure and delineate something that he cannot see if he is to make a mistake. He can, however, still be guilty of an omission or carelessness. In actual practice every movement of the tracing table, while measuring and delineating contours, is measuring and connecting spot elevations. The process then takes an infinite number of spot elevations which the instrument operator connects together as he moves the measuring mark over the spatial model. At any one time he may be a little above or below the ground. This type of error can be expected to be within the range of less than one-half the contour interval. Vertical errors in excess of this amount are caused by the inability of the operator to see the ground or to blunders or carelessness.

In comparison to field survey methods then, we have combined the observing, measuring and plotting phase into one operation and have eliminated two possible sources of error.

It is also appropriate to examine the field survey procedures that would be used to gather similar data. In all probability, mapping by field survey methods stems from a base line which may or may not be closed on itself, let alone being tied to high order control surveys established by governmental agencies. This then is the first place that errors can occur in the field work, and although solar observations may tie down azimuth, there may be no check made on distance measurements. After base line staking at stations and ground line breaks, it is the usual practice to measure a base line profile and gather cross-section data. Considering only the vertical aspect for a moment, elevations along the base line and the cross-sections will be measured by use of a series of backsights and foresights. Each one of these separate elevation measurements is unchecked and subject to question. Although an occasional wild reading of the level rod will not materially affect highway design, it is certainly not desirable.

The horizontal positioning of all cross-section points for which elevation measurements are made and all other data to be plotted is open to suspicion. Although both field survey parties worked from a staked base or centerline and were supposedly measuring ground point data on the same cross-sections, differences of from -10.5 to +13.0 ft did occur in one of the tests. Although the measured elevations were unchecked single measurements, it is difficult to assume that the differences all stem from poor leveling. It is more reasonable to assume that different cross-sections were actually measured with the only common point being at the centerline. In one of the other sets of data presented, Party B had the advantage of having a centerline stake and a grade stake set 150 ft right and left of the centerline. In several instances, elevations measured for the same grade stakes varied as much as two ft between the work of two field survey parties. Obviously in this case the differences were caused by poor leveling procedures.

In comparing maps compiled by photogrammetric methods with those compiled from field survey data, it has been observed that horizontal positioning of lineal features at the base or centerline is usually good. It is very common to observe large differences appearing, however, as the distance from the centerline increases. Figure 6 is illustrative of this. Fence and building positions and size were measured from the maps prepared from field survey data and maps compiled by photogrammetric methods. Both of these were then overlaid and the discrepancies became obvious. Field investigation proved that the map compiled by photogrammetric methods was correct. At this point, it is impossible to determine whether or not the surveying instrument measurements were incorrectly read or recorded, whether a right deflection was recorded as a left deflection or whether the data were just plotted wrong. This type of horizontal error has been found with fences, houses, the centerline of intersecting roads, railroads and all other planimetric detail. The authors have never tied into adjoining maps prepared by field methods without finding at least one such discrepancy. It must be pointed out that while this gross type of horizontal error is not likely to be found in photogrammetric work, it is impossible by the photogrammetric approach to provide absolute dimensions of features. It is possible, however, to assume that good photogrammetric work in making measurements and compiling topographic maps of a built-up area would overlay identically a good map prepared using data obtained by field survey methods, for the drafting tolerances would be the controlling factor.

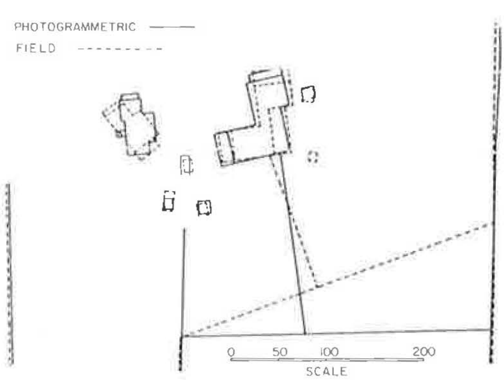

Figure 6. Comparison of horizontal positions.

It is vitally important to remember this horizontal weakness in evaluating all the vertical comparisons included in this paper. In only one case can it be said that a test has been applied to the mapping; the rest of the data is presented as comparisons only. While these comparisons tend to indicate someone is wrong, no proof has been presented to identify which one is wrong or how much each one is wrong.

An overall look at the first project examined indicates that the maximum differences in all cases, be it Party A to Party B or either party as compared to interpolated elevations from the maps, are large, but all maximums for any one examination are in the same range. The original data tend to indicate that gross type differences were made by all parties concerned. In fact, all comparisons for any single test are of the same general magnitude. The one place where the comparison of data indicated that the field parties were producing better results between themselves than either did with the maps was in the computation of the standard deviation. Even here, however, in two cases, a lower standard deviation was obtained by comparison of the map elevations with measured elevations of one field survey party than between elevations measured by the field survey parties themselves.

In the test where 1,000 ft of centerline was designed to be in cut, the arithmetic mean of the comparison of photogrammetrically compiled map data with either field survey party data indicated that the contours of the maps were 0.2 ft above datum. Subsequent volume determinations bear this out. The field survey parties had greater maximum differences between themselves, but their overall results appear to be more uniform.

A comparison of the volumes computed from cross-section data of the engineer and of the contractor indicates that for a planned excavation of some 99,000 cu yd, their cross-sections produced a volume difference of 13 yd and the maps indicated a difference from the measurements by either field survey party of 1,606 cu yd. This amounts to a difference of 1.63 percent, and both the engineer and the contractor felt that, in this case, such an amount was negligible. Had the cut been shallower, however, this percentage could have risen to a point of significance.

The real test of a map prepared for highway design and construction lies not in statistical data but in how well the job can be done. That the highway discussed has been designed and constructed and both the engineer and the contractor feel only the usual number of modifications were made in the construction phases prove the topographic mapping done by photogrammetric methods was as satisfactory as if the mapping had been done by conventional field survey methods.

The results of the second project examined tend to indicate that the datum of the topographic mapping done photogrammetrically was high by about 0.6 ft. It should be noted on this project that data have been presented which prove the cross-section measurements were in error and, in addition, proof has been presented to show errors also occurred in the horizontal measurements.

The data of the third project tend to indicate topographic mapping was very good, which was all that could be hoped for. The only explanation which can be offered for the small differences shown in this project, where the elevations are all of the unchecked nature, is that the field survey work was under control of the mapping organization and the work was carefully done. It is a little incongruous to make this statement when all previous statements made condemn loose field surveying techniques. Once again it should be emphasized that although the field survey data were gathered after the mapping was completed, it is considered a comparison and not a test.

The last project examined was a test and is positive proof the arbitrary line, as staked, produced errors of the indicated magnitude. The size of the sample is small, but the distribution of points is reasonable and the accuracy in all types of cover was tested.

CONCLUSION

Both field and photogrammetric methods can be used to make surveys and compile maps for highway design, in as far as elevations are concerned. Either method may produce large errors in elevation with the field survey method likely to cause the large ones; but in both cases, such errors are of little consequence during design and construction. Elevation measurements made by photogrammetric methods are sufficiently accurate for computing volumes of earthwork, both for design and payment purposes.

With respect to horizontal measurements, we must recognize that the basic field survey control is necessary in surveys made by either conventional field or photogrammetric methods. Aside from this, and to the extent horizontal measurements are shown by plotted positions, photogrammetric methods result in better local and overall horizontal accuracy. Both methods, however, are adequate for the purposes of highway design and construction.