Photogrammetric Measurement of Final Pay Quantities in Highway Construction

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INTRODUCTION

Photogrammetry is being used in the location and design of highways to achieve a saving in time, manpower, and cost. Considerable interest has been expressed in extending its use to achieve a similar saving in the measurement of highway final pay quantities. The acceptance of photogrammetric methods for the determination of final pay quantities, however, is contingent upon their applicability in this respect and the accuracy which can be obtained for each type of measurement.

This paper reports an attempt to apply photogrammetric methods to the determination of several final pay quantities and to evaluate its accuracy by comparison with quantities determined by normal field procedures. The final pay quantities concerned were earthwork, concrete pavement and appurtenances, paved side ditch, sodding, curbing, guard rail, and guide posts. The photogrammetric plotting study, performed on a newly constructed section of highway approximately 10,000 feet in length, was accomplished with a standard six-inch focal length Kelsh plotter at a scale of 1 inch = 50 feet.

Photogrammetric spot elevation readings for the final roadbed cross sections and field survey notes furnished by the State Highway Department for the original terrain cross sections were used in combination to determine the earthwork quantities. Comparisons were analyzed on the basis of volumes for individual sections, for individual plotter models, for various classifications of excavation and embankment, for urban and rural classifications, and for the entire project. Although payment is made on the basis of excavation quantities only, embankment quantities were also considered, because they would aid in the evaluation of earthwork quantities in general. Computation of the earthwork quantities was accomplished with an IBM 650 electronic computer.

Since vertical accuracy is of great importance in the determination of earthwork quantities, a statistical analysis of vertical accuracy was undertaken by comparing photogrammetric centerline elevations with the corresponding elevations from the field survey.

Non-earthwork final pay items were delineated on the photogrammetric manuscript, and the quantities were determined by scaling or planimetering, which were compared with corresponding quantities determined by normal field procedures.

PRESENT METHODS

The present practice in Indiana regarding final earthwork quantities is to make payment on the basis of cubic yards of excavation as measured in the original position by taking cross sections before excavation is started and again after it is completed. Volumes are computed by the average end-area method. If the cost of excavation is specifically included in the payment for any item of work, the final cross sections are taken at the finished surface of the work. Payment for embankment is not ordinarily made on a unit volume basis, but is included in the various pay items of the contract, such as spreading and compacting of embankment material, labor and equipment.

Other final pay quantities such as payment, curbing, paved side ditch, guard rail, and sodding are measured when complete in-place and accepted, with payment being made on a contract unit price per lineal foot or square yard.

PHOTOGRAMMETRIC METHODS

The proposed procedure for determining earthwork quantities photogrammetrically is a direct analogue of the field survey method. Cross section lines are drawn on the photogrammetric manuscript at right angles to the centerline. Spot elevations along the cross section lines are read directly from the photogrammetric plotter or the elevations may be interpolated from photogrammetrically established contours on the manuscript. For final pay measurements, it is generally agreed that spot elevations are more desirable since they can be made with at least twice the precision of the interpolated readings. The coordinates of each reading are written on the manuscript at the position of the reading.

The ease and facility of reading elevations from the plotter, as opposed to the laborious and time consuming field methods, motivates the measurement of more cross sections and more elevations per cross section. This is highly desirable since the accuracy of the terrain representation is a function of the density of elevation readings.

In connection with the measurement of non-earthwork quantities, it may be said that the physical dimensions of any object identifiable to its full extent in the plotter model can be measured. The measurement of these qauntities is not always in the horizontal and vertical system of coordinates, a condition which calls for special allowances when making photogrammetric measurements since direct measurements from the plotter are always horizontal and vertical.

STUDY LOCATION

Several factors were considered in the selection of a section of highway on which to perform the investigation. The study site had to be recently completed construction and of sufficient length to provide an adequate statistical base for accuracy evaluations. The topography, land use, and proximity to Lafayette were deemed desirable considerations, but not necessarily of a controlling nature.

The newly constructed section of SR 27 beginning at Liberty, Indiana and extending northward about five miles was selected as a suitable location for the study. A portion of the study area, showing the overall terrain, is illustrated in Fig. 1.

The construction on SR 27 was primarily of a relocation nature although some of the highway was rebuilt to higher standards in the same position as before construction. Construction was completed in the fall of 1958, and the actual study was performed on a 9,643 foot length of this section beginning at Westcott Street in the town of Liberty, and proceeding northward. About 800 feet of the study section may be assigned an urban land use classification, because it is within the city limits of Liberty.

The terrain may be described as rolling, although there are some flat reaches, and some of the excavations and embankments were relatively large as would be expected in terrain of this nature.

QUANTITIES MEASURED

It was decided in the study that quantities which could possibly be measured were earthwork, concrete pavement, concrete pavement appurtenances, paved side ditch, sodding, guard rail, guide post, and curbing. Only items which would be identified and delineated from air-photos were considered. Payment for such quantities had to be

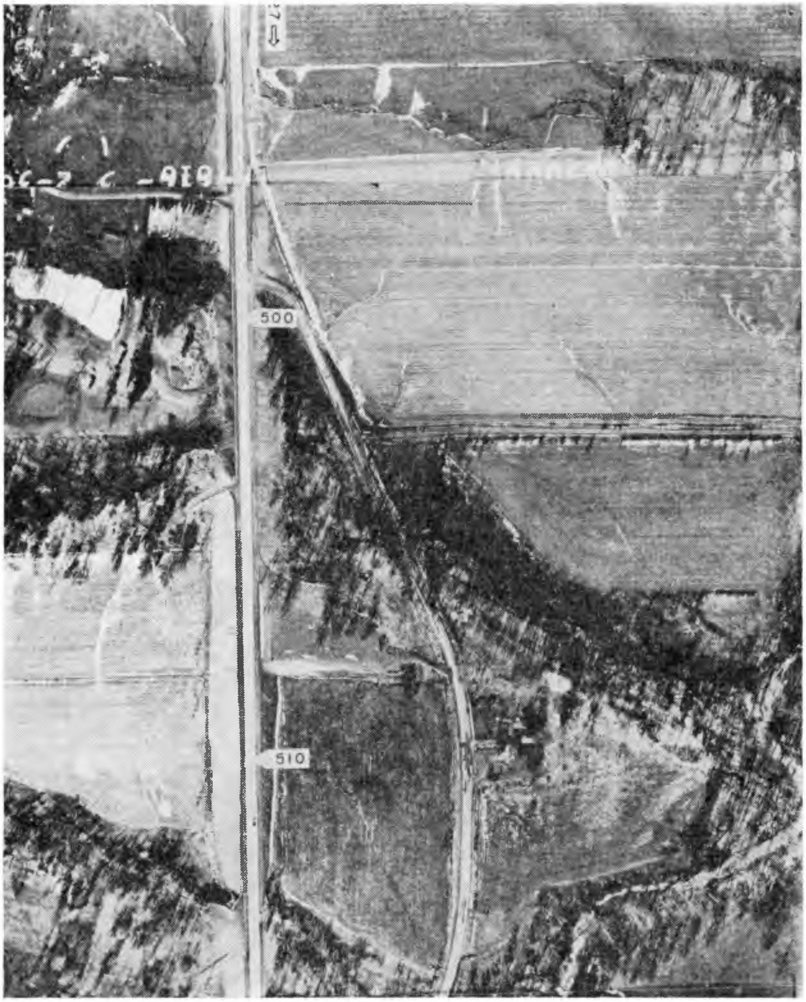

Fig. 1. A section of recently constructed highway used in the investigation.

on the basis of dimension measure rather than weight measure. On this premise, a quantity measurement such as seeding would not qualify for photogrammetric measurement since payment for this item is on the basis of weight measurement of seed, fertilizer and straw mulching. Nor would base course materials lend themselves to photogrammetric measurement since these quantities are not visible from air-photos.

PROCEDURES

The photography was flown at an altitude of 1,500 feet above average ground elevation by the State Highway Department, and this altitude provided a contact scale of 1 inch = 250 feet and a manuscript plotting scale of 1 inch = 50 feet. The diapositives were made of .06-inch sensitized glass plates printed emulsion side up. The photography and diapositives were, in general, of high quality. The corners of some photos were slightly under-exposed, but as most cross section plotting was near the center of the photos, only the observation of elevation control points in the darker corners was adversely affected.

The planimetric outline of the pavement was first drawn on the manuscript by plotting points about one inch apart to delineate the centerline and edges. These points were then connected by using a straight edge or highway curves on the curved portions.

Cross section lines were drawn at right angles to the centerline at the proper centerline stations as indicated by the highway level books. Correct positioning of the cross section stations was achieved by referencing permanent station marks, which were stamped on the pavement at 500 foot intervals, to the horizontal ground control.

Spot elevations were read to 0.1 foot along the cross section lines at the centerline station, pavement edges, and at significant changes in the profile of the cross section line. The elevation readings were extended far enough on either side of the centerline to include any terrain which indicated earthwork movements. The position of the reading point was marked on the cross section line, the elevation and the scaled distance of the point from the centerline were recorded on the right and left of the point respectively as shown in Fig. 2.

Special borrow pits were plotted in the same manner, except that cross section lines were referenced to a base line rather than the centerline of the highway.

The planimetric features of other final pay items were delineated on the manuscript by guiding the tracing table so that the floating mark and plotting pencil followed the feature being compiled. The dimensions of these items were not recorded on the manuscript at the time of plotting but were measured and tabulated later upon the completion of each model. Large irregular-shaped areas, such as sodding, were planimetered several times and averaged to increase the accuracy of measurement. Areas of more constant dimensions were subdivided into simple geometric shapes for scaling and computation. Paved side ditch, guard rail and curbing were measured in the linear direction only. Guide posts were outlined and counted.

Cross sectional areas for earthwork quantities were determined by a combination of photogrammetric and conventional methods. The

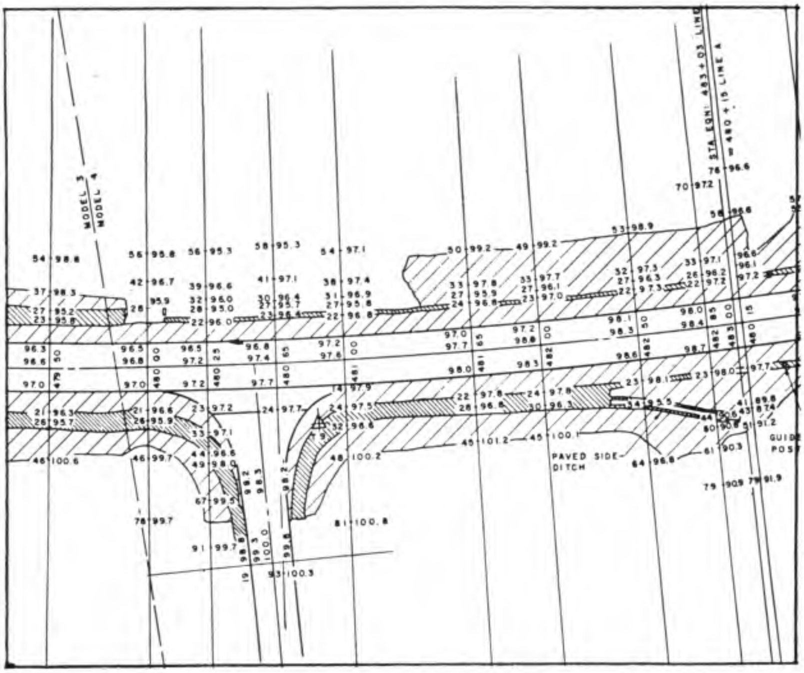

Fig. 2. Section of photogrammetric manuscript.

original cross sections of the terrain before construction were procured by field survey methods; whereas, the template sections or, cross sections of the finished road bed, were procured by photogrammetric spot elevation readings. Field level books from the highway department supplied the data for the original cross sections. Although it would have been possible, and perhaps desirable, to determine the initial terrain data by photogrammetric methods, the time interval from staking of the centerline to completion of construction would have precluded such a procedure for this study.

Studies conducted in California (2, 3) indicated that accuracy of photogrammetric earthwork quantities could be considerably improved by adjusting cross section elevation readings to an accurate centerline profile. It was decided that this procedure should be included in the study along with the method of determining earthwork quantities without adjustments. Accordingly, all template sections were raised or lowered by an amount equal to the error at the centerline station, and the resulting earthwork quantities were also compared with the quantities determined by normal field methods. The three general cross sections are shown in Fig. 3.

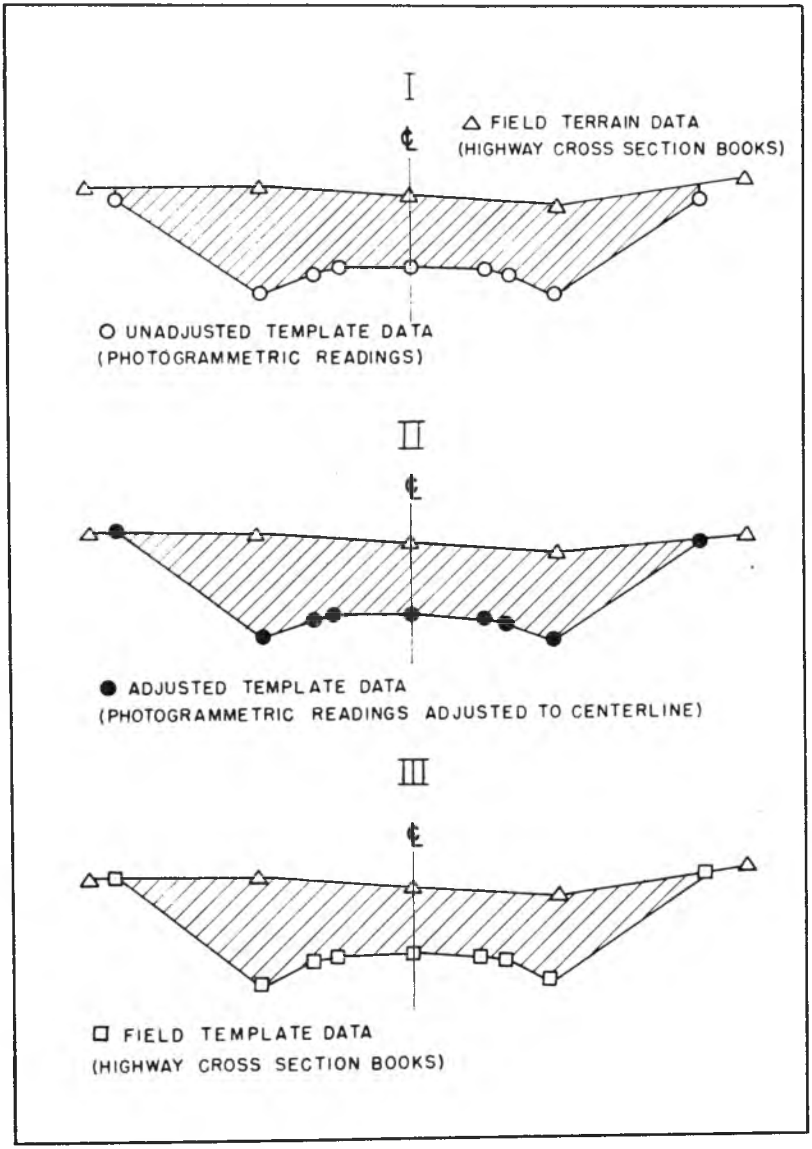

Fig. 3. General cross sectional data combinations.

RESULTS

Figure 4 illustrates graphically the results obtained in measuring non-earthwork quantities.

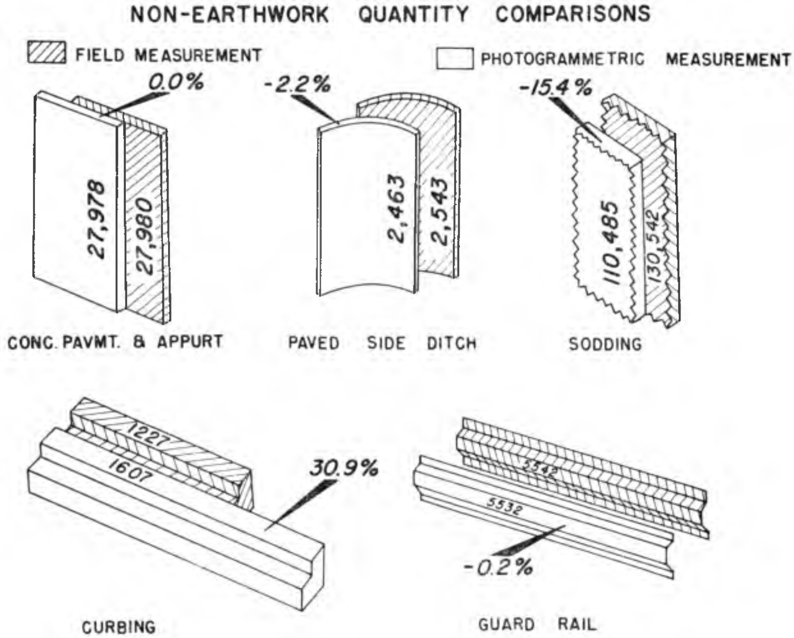

Fig. 4. Results of non-earthwork quantity measurements.

CONCRETE PAVEMENT AND APPURTENANCES

The photogrammetric measurements of these quantities were combined and compared with the field measurements in accordance with the quantity subdivisions of the construction record. A total of 21 sections were measured. No slope corrections were made because the grades were very small. The combined error in measurement was essentially zero and the error range was from 0 to -3.7 per cent. The largest error of -18.8 square yards or -3.7 per cent was made in determining the area at a street intersection within the urban section.

Separate comparisons, not on Fig. 4, of eight private drive entrances also showed good agreement between the photogrammetric and field measurements. The combined error was a -2.2 per cent, or 2.8 square yards, with the error range from 2.4 to -8.3 per cent.

PAVED SIDE DITCH

Measurements were made along the length of the paved side ditch, and corrected for slope. The construction record listed 15 sections of paved side ditch; but, due to unmelted snow in shadow zones, only 13 were observed and measured in the stereo model. Snow, silt and debris near the ends of the sections caused errors in identification as well as measurement. A better indication of photogrammetric measurement was obtained by omitting the two unidentified sections. The difference between photogrammetric and field quantities was then only 16 feet or 0.7 per cent. This error is deceptive since it results from the compensation of one large plus error and several small minus errors. The elimination of the large plus error caused by silt cover and snow results is a total error of 27.5 feet or 1.5 per cent. Errors in identification must be taken into account as they can be expected to occur.

SODDING

Ninety-four sections of what were considered to be sodded areas were measured and compared. Slope corrections were applied in both the longitudinal and transverse directions. Primarily errors in identification occurred because the photographs were obtained in the winter months, but a few small errors in measurement also occurred. The combined error was a -15.4 per cent but the errors ranged from 33.1 to -60.4 per cent. A difference of a few inches in a narrow band of sodding caused a large percentage error. This type of error was unavoidable since measurements could be made only to the nearest 0.5 of a foot.

CURBING

Poor agreement was obtained between field and photogrammetric quantities of curbing because it was impossible to distinguish between newly placed curbing and curbing which existed in the urban area prior to construction. Of the nine sections compared, the combined error was 30.9 per cent with an error range from 0 to 17 per cent.

GUARD RAIL AND GUIDE POST

Relative good agreement between the field and photogrammetric quantities was obtained in the guard rail comparisons. Eleven sections were measured for a total error of only a -0.2 per cent, or -11.0 feet with the range in errors of 0 to -0.7 per cent. Because of the small grades, no slope corrections were applied.

Guide posts were counted in 12 different groups. Three of the 12 groups were in error from the construction record. It was impossible to distinguish between posts placed prior to construction and new posts; therefore, the photogrammetric count gave 54 and the field count 46. Eight posts were counted in an 80-foot section in which no guide posts were listed by the construction record. In another section, two posts were counted in the stereo model for which the construction record listed only one. It may be that the construction record was in error on this count since these posts were definitely on newly constructed fill.

EARTHWORK QUANTITIES

Figure 5 illustrates graphically the results in measuring earthwork quantities over the entire length of line. A total of 238 sections of earthwork were compared to include excavation, embankment

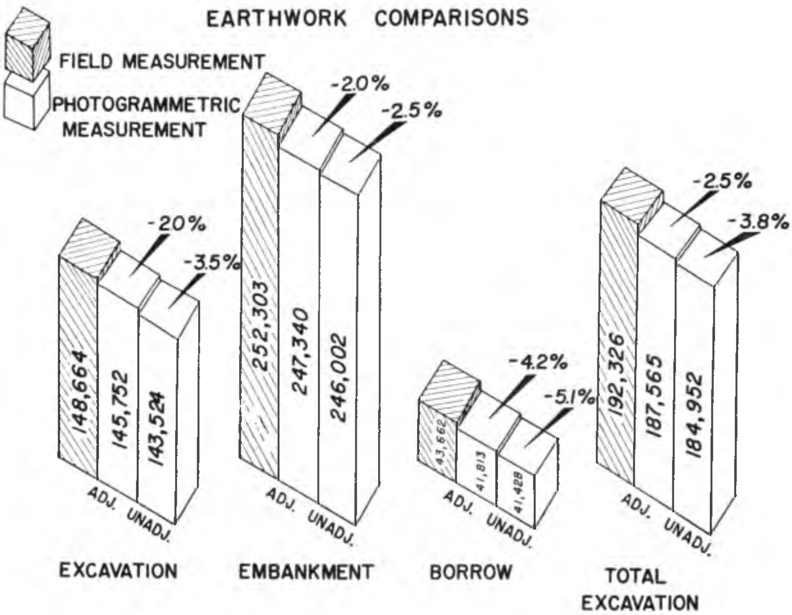

Fig. 5. Earthwork quantity comparisons.

and borrow. Only excavation quantities were compared to the construction record. The unadjusted quantities were compared, and a correction or adjustment was made to the centerline datum as measured in the field and a comparison was made.

In excavation, the unadjusted quantities were in error from field measurements by a -3.5 per cent and the adjusted quantities only a -2.0 per cent. Errors ranged from 0 to incalculable values on those sections in which the field measurements for excavation were 0. In comparison to the construction record, the error for the unadjusted photogrammetric quantity was -11.3 per cent and -9.9 per cent for the adjusted quantities. The poor comparison between the construction record and the field and photogrammetric quantities in excavation is due in part to the shortened cross sections which had to be used in many places to allow machine computation. The original field terrain data did not extend to an intercept with the photogrammetric final cross section and therefore some sections were fore shortened as shown in the top diagram in Fig. 2.

Borrow pit quantities by field methods amounted to 43662 cu. yd. The unadjusted photogrammetric quantities were in error a -5.1 per cent and the adjusted quantities a -4.2 per cent. The errors ranged from 0 to a -24.1 per cent.

Total excavation quantities for the unadjusted photogrammetric sections were in error from the field quantities by a -3.8 per cent and the adjusted quantities were in error by -2.5 per cent.

The percentage errors used in making the comparisons of earthwork quantities may be very misleading if not interpreted with any consideration for the size of the quantities involved. This is especially true of very small quantities where an error of a few yards can result in a very large percentage error. In many instances where the quantities used as a basis of comparison were zero, the resulting percentage errors were incalculable.

On the other hand, very large quantities, such as the total yardage for the entire project, may show a low percentage error and yet have a yardage error that might be considered undesirably large for pay purposes. Although the percentage error method has this inherent defect, it is the only method available for evaluating earthwork quantity comparisons.

Large percentage errors were generally associated with small earthwork quantities and, conversely, small percentage errors were generally associated with large earthwork quantities.

Seven groups of individual earthwork sections were classified according to various depths of excavations and embankments and compared with the corresponding field quantities. The selection of sections for each depth of classification was made on a relative basis by stereoscopic study of the aerial photographs for the entire length of the project. These classifications included shallow, medium, and deep cut and medium and deep fill.

The percentage errors for the various cut and fill classifications ranged from 20.5 per cent for an unadjusted quantity of shallow cut to 0.4 per cent for an unadjusted quantity of deep fill. The percentage errors generally followed an inverse relationship between the depth of the earthwork and the magnitude of the percentage error.

STATISTICAL ANALYSIS OF VERTICAL ACCURACY

In addition to the actual comparison of final pay quantities, a statistical analysis of vertical accuracy was undertaken. Vertical accuracy is perhaps one of the most critical considerations in the determination of earthwork quantities, and it is also an important factor in the determination of slope corrections for other quantities. There are no accepted standards by which to judge the vertical accuracy of spot elevation readings; however, the standards for vertical accuracy of contour mapping are well established and may be used as an indication of the precision with which spot elevations may be read. Certain statistical measures may also be used as an indication of precision.

The analysis was accomplished by a comparison of field centerline and baseline elevations with corresponding photogrammetric elevations. The difference or "error" in the 239 elevation readings tested was treated as a random sample from the population of possible centerline and baseline elevation readings. The mean, variance, standard deviation, and range of the errors were computed, and the type and distribution of errors was investigated on the means and variances of the individual models and on the variances within a single model.

Figure 6 shows the frequency distribution plotted in cumulative form with the abscissa scale graduated according to the area under a normal distribution curve. The points were plotted on the basis of cumulative per cent less than the class boundaries of the errors starting with the minus values. The distribution of the elevation errors is in close agreement with the normal distribution function which is shown by a broken straight line. The importance of this distribution is emphasized by the fact that such a distribution will have a compensating effect on the total error.

Approximately 90 per cent of the points tested fall within the error range of $\pm$ .45 feet as estimated from the cumulative frequency distribution of Fig. 6. According to the National Map Accuracy Standards, this would allow a usable contour interval of 0.9 foot. At a flying height of 1500 feet, the calculated C-factor is approximately 1670.

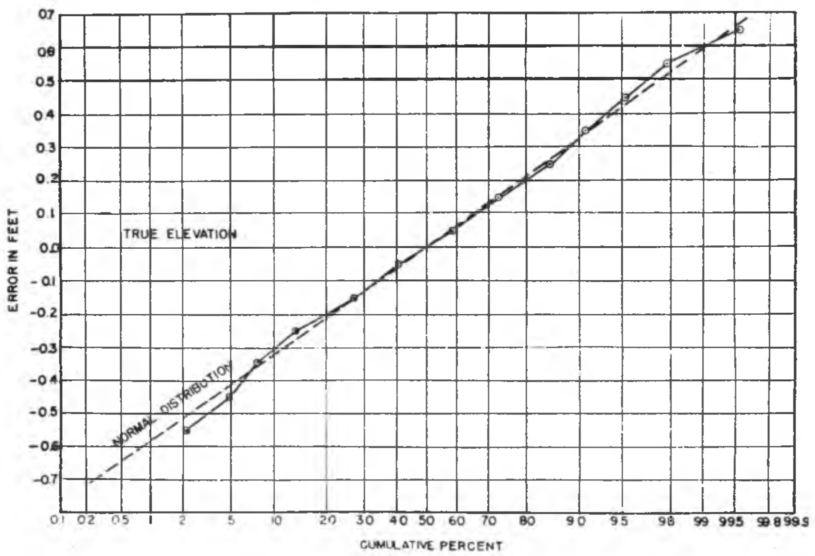

Fig. 6. Cumulative frequency distribution of elevation errors.

The centerline and baseline elevation errors were processed to yield values of the mean, variance, standard deviation, and range for the entire project and for individual models and borrow pits. This subdivision of the data was used because each model was independent of all other models in the study. Differences in accuracy might be expected since each model was separately oriented and the quality of the diapositives varied from model to model.

The means for the individual models ranged from -.144 feet to .257 feet and the standard deviation ranged from .120 feet to .314 feet. The mean for the entire project was .009 feet with a standard deviation of .252 feet. The range in errors was 1.3 feet.

Analysis of variance indicated that the mean error for the entire sample was not significantly different from zero at the five per cent level of significance, but the mean errors for most of the models were significantly different from zero. Since the range of errors would indicate that no serious blunders were made, these tests would seem to indicate that systematic errors were operative from model to model. It appears that the systematic errors compensated each other in such a manner that the mean of all errors was practically zero.

To test the precision of elevation readings within the model, repeated elevation readings were made at nine points selected at random from nine subdivisions of a single model area. Ten independent readings were made at each point. The variances were computed and analyzed by the Bartlett test. Again, the variances were found to be significantly different at the five per cent level.

The results of this test would seem to indicate the variation in the precision of elevation readings is dependent not only upon the model but also upon the point at which the reading is made within the model. This would tend to coincide with actual plotting experience in which it was observed that elevations of some points were more difficult to determine than others, because of the varying degree of ground cover, image clarity, and the lack of contrast in tone and terrain.

SUMMARY AND CONCLUSIONS

In conducting this study, an attempt was made to approximate typical conditions and situations. It must be recognized, however, that no section of highway can be classified as typical. Variations in terrain, land use, and physical features of highways make this an impossibility. Nor can the equipment or procedures which were employed be classified as representative. A wide variety of photogrammetric plotting instruments, flying heights, and plotting procedures could be used in an undertaking of this nature. Caution must be exercised, therefore, in any generalization of the results and conclusions of this particular study.

From experience gained in this study, it may be concluded that photogrammetric methods and procedures are applicable, with *limited* regard for accuracy, to the measurement of the following final pay quantities: earthwork, concrete pavement and appurtenances, paved side ditch, sodding, curbing, guard rail, and guide posts.

From analysis and results of the accuracy comparisons, it may be concluded that:

1. There was good agreement between the photogrammetric earthwork excavation quantities and the corresponding quantities computed electronically from the data in the field cross section books.

2. The photogrammetric embankment quantities also showed good agreement with the corresponding quantities computed electronically from data in the field cross section books.

3. Adjustment of the photogrammetric earthwork quantities to an accurate centerline profile generally improved accuracy.

4. The relatively large errors of some of the individual sections of earthwork compensated to yield a smaller error for the total earthwork.

5. The percentage errors generally varied inversely with the depth and size of the earthwork quantity.

6. The photogrammetric measurements of concrete pavement and appurtenances were in close agreement with the construction record measurements, and the percentage error was, for all practical purposes, zero.

7. Due to the compensation of a few large errors, the photogrammetric measurements of paved side ditch showed fairly good agreement with the construction record, where the photogrammetric measurements were in error by -3.1 per cent.

8. Poor agreement was obtained in the comparison of photogrammetric quantities of sodding with the corresponding construction record quantities, and the error was -15.4 per cent.

9. Poor agreement was obtained in the photogrammetric and construction record comparisons of curbing, with an error was 30.9 per cent.

10. The photogrammetric measurements of guard rail were in close agreement with the construction record measurements. The photogrammetric quantities were in error by -0.2 per cent.

11. The photogrammetric count of guide posts did not agree well with the construction record count. The construction record listed a total of 46 guide posts compared to the photogrammetric count of 54.

As a corollary to the above conclusions, it may be stated that photogrammetric techniques described definitely provide accuracy and reliability of a nature that would *warrant their use in the location and design phases of highway construction.* This is true not only for the preliminary stages but also for the final stages of location and design as well.

REFERENCES

1. Johnson, R. R., "Photogrammetric Measurements of Final Pay Quantities in Highway Construction," *Thesis,* MSCE, January 1960, Purdue University, Lafayette, Indiana.

2. Funk, L. L., "Adjustment of Photogrammetric Surveys," *Bulletin 228,* Highway Research Board, No. 688, pp. 21-27, January 1956.

3. Funk, L. L., "Terrain Data for Earthwork Quantities," *Bulletin 228,* Highway Research Board, No. 688, pp. 49-65, January 1959.