EVALUATION OF PHOTOGRAMMETRIC CROSS SECTIONS FOR EARTHWORK PAYMENT

Vernon H. Schultz, Division of Highways, Wisconsin Department of Transportation

Earthwork quantities were compared on four projects by using both photogrammetric final cross sections and conventional field-measured final cross sections. Original cross sections had been taken by conventional field procedures. On one project elevations were also compared. It must be recognized that any system of cross sectioning (field or photogrammetric) used to obtain earthwork quantities is an approximation. Therefore, the comparison made here is a comparison between two approximations. It was found that for dual roadway sections involving 7,500 cu yd or more per station the difference between photogrammetric and field-measured yardage was 2 percent or less. On those roadway sections involving 12,000 cu yd or more per station, the difference was less than 1 percent. In all cases the photogrammetric yardage was greater than the field-measured yardage. When interpolated photogrammetric elevations were compared to field elevations, it was observed that the average mean difference showed the photogrammetric to be 0.15 ft lower than the field. It was concluded that the difference in earthwork quantities was within the range of possible error because of the average end area method of computation, and therefore the photogrammetric method will produce an accurate estimate usable for payment.

•EARTHWORK quantities computed from conventional field surveys by using elevations determined by spirit levels have been used as the basis of payment to contractors for many years. Although this procedure has consistently produced accurate results, since the advent of freeway construction with heavier grading and wider cross sections, the cost of conventional surveys has steadily risen. Also, since the general public has become more involved in matters of design detail and because of the apparent need for greater analysis by the engineering staff of environmental conditions, conventional field surveys may no longer be the most efficient way of obtaining the data required for this new concept of maintaining design flexibility.

A research program was undertaken by the Wisconsin Division of Highways to determine whether sufficiently accurate results could be obtained from photogrammetric cross sections such that they could be used for pay quantities. Of particular emphasis here was that the investigation determine accurate results under typical production situations.

It was felt that there was adequate documentation of the basic theoretical research in this area and that the problem was one of determining whether these basic theories could be implemented on a production basis with sufficient results.

DESCRIPTION OF PROJECTS

Four construction projects were used in the analysis. The selection was based on availability of data within the time period, variability of field personnel and working conditions, and, to some extent, terrain. A special effort was made to select projects in different districts in order to determine the effectiveness of the method while working

Sponsored by Committee on Photogrammetry and Aerial Surveys and presented at the 50th Annual Meeting.

with many different people. It was felt that, with more people being involved, a greater variety of potential procedures and problems could be analyzed.

Only final cross sections were used in the tests. Yardage computations for both the photogrammetric method and the conventional method were made by using conventionally measured original cross sections to define the original ground.

US-14, Oregon-Madison Road, Dane County

This test section was 3 miles of a four-lane, divided freeway through rolling countryside. Cross sections varied from 250 to 465 ft wide with maximum elevation differences on any one section ranging to 60 ft. There were no interchanges involved on this test section, but there was variable median width throughout and independent reference lines for earthwork computation in some areas.

Photographs were taken on December 7, 1968. The subgrade was bare; the granular subbase placement had not yet begun. Grass cover was almost nonexistent on the slopes inasmuch as they had been seeded only a short time before.

US-10, Amherst Junction-East County Line, Portage County

This test section was 1 mile of two-lane, undivided highway through a flat-to-rolling area. Cross sections varied from 120 to 210 ft wide with maximum elevation difference on any one section ranging to 47 ft.

Photographs for original sections were taken on April 11, 1969, but because the contractor had already commenced clearing, grubbing, and removing topsoil it was decided not to use this for comparison. Photographs for final sections were taken on August 20, 1969. Because the pavement was already in place, "blue-top" elevations were substituted for the subgrade readings for the yardage computation. Grass cover on the slopes was minimal.

Wisc-15, Beloit-Milwaukee Road, Waukesha County

This project involved 3 miles of four-lane, divided freeway through gently rolling area. Only a partial analysis was done on this project because complete field sections were not available. Eleven random cross sections were field-checked, and one borrow pit immediately adjacent to the roadway was completely checked. Cross sections varied in width from 250 to 400 ft with maximum elevation differences of up to 30 ft. One diamond interchange and one directional interchange were included in the project.

Granular subbase placement had already commenced at the time of photography in August 1969. Thus, the "blue-top" elevations were substituted for subgrade readings for the yardage computation. Grass cover was at a minimum on new slopes.

US-53, Chippewa Falls-North County Line Road, Chippewa County

This test section involved 2.5 miles of four-lane, divided freeway through generally level terrain but with one 80-ft high river escarpment. Cross sections varied from 225 to 440 ft in width with maximum elevation differences on any one section ranging to 60 ft. There was one partial directional interchange involved. The subgrade was bare, and the slopes had a minimum of grass cover. Photographs were taken October 29, 1969.

EQUIPMENT AND TECHNIQUES USED

Conventional field cross-sectioning techniques were used to obtain field data. These consisted of establishing the stationing with a transit and steel tape, using a right-angle prism for "squaring out," and using a cloth tape for measuring distances from the reference line. Locke shots were used beyond the limits of the automatic level setup.

Prior to aerial photography, targets were placed by district survey personnel on the reference line at 500-ft intervals. Targets were made of white muslin 12 in. wide by 3 ft long in the shape of a cross. On the US-10 project where concrete pavement had been recently placed, targets made of heavy, dark brown paper were used. These contrasted very well with the brilliant white of the new concrete.

On the US-53 project, wing-point targets were used in lieu of image point control as was done on the other projects. These wing-point targets were placed at distances of 400 to 500 ft from the reference line and were roughly "square-out" from those targets on the reference line.

Photographs were made with a Zeiss RMK-A, 6-in. focal length camera from an altitude of 1,500 ft. On those projects where wing-point targets were not used, wing-point image control was designed in the photogrammetric unit, and field work was done by district survey personnel.

A reference line layout with a scale of 1 in. equal to 50 ft was prepared on vellum by drafting. Shown on this layout were the alignment stationing, target locations, target elevations, and locations where cross sections were desired. On the US-53 project, additional care was taken in the preparation of this layout by first computing the coordinate position of the various reference line targets and then by plotting these points by coordinate position. Thus it was found that, in interchange areas where several reference lines are used for cross sections, the relative position of each reference line was far more accurate.

By using the Kelsh Model 5030 stereo plotter, we scaled and made horizontal the stereo model by using the reference line layout and picture point control. Using an automatic scaler and digitizing equipment, the operator proceeded to take cross sections.

ANALYSIS AND EVALUATION PROCEDURES

Two methods of analysis and evaluation were used to compare the results of conventional field cross sectioning with the photogrammetric cross sectioning. First, it was desired to compare the ability of the stereo plotter operator to duplicate the elevation data obtained in the field; and, second, it was desired to compare the earthwork quantities.

It should be emphasized that any system of cross sectioning (field or photogrammetric) used to obtain earthwork quantities is an approximation. Therefore, the comparison made here is a comparison between two approximations, not between an approximate earthwork quantity and a correct one.

Almost all of the data used were generated by conventional production procedures, both in the field and photogrammetrically. Additional care and precision were used only in test cases to determine the effectiveness of the analysis procedures.

An analysis was made between the field elevations and interpolated photogrammetric elevations on about half of the cross sections of the US-14 project. On each cross section generally twice as many photogrammetric spot elevations were obtained as were field elevations. Thus it was felt that a valid comparison could be made by interpolating an elevation from the photogrammetric data at the specific distance of the field elevation. A test area was selected to determine the validity of this procedure. The results are given in Table 1. Where photogrammetric elevations were taken at the same dis-

TABLE 1

COMPARISON OF PHOTOGRAMMETRIC AND FIELD DATA USING INTERPOLATED ELEVATIONS

Elevation Location	Excavation			Embankment		
	Field	Photo-grammetric	Percent Difference	Field	Photo-grammetric	Percent Difference
Same distance from reference line	151,101	151,641	+0.4	5,622	5,686	+1.1
Different distance from reference line	151,101	151,796	+0.5	5,622	5,989	+6.5

Note: Length (8 stations) was 800 ft and number of points was 194 for each elevation location; average difference was -0.06 ft at same distance and -0.16 ft at different distance; and root mean square was 0.38.

tances from the reference line as field elevations, the mean of the average difference was -0.06 ft. When the photogrammetrist was allowed to select points at significant breaks in the ground, the mean of the average difference was -0.16 ft. Those figures for different distances were obtained by using interpolated photogrammetric elevations. There is a close comparison in the earthwork quantity.

The difference between the figures given in Table 1 can be attributed to two factors. One is that two different photogrammetrists did the interpretation. The second is the result of the error in the interpolated elevation caused by horizontal displacement. From this test we concluded that the method of using interpolated photogrammetric elevations would give sufficiently accurate results.

As the data were being compiled it became apparent that there were obvious blunders in both the field points and the photogrammetric points. As such, it was decided that any elevation comparison showing a difference of 1.0 ft or greater would be excluded from the study. Studies have shown conclusively that the photogrammetrist can interpret the ground elevation within ±0.25 ft; therefore, our elimination of obvious blunders of 1.0 ft or more may be rather conservative. A similar study by the Texas Highway Department eliminated all differences of 0.6 ft or more. The following table gives the distribution of points on the US-14 project for various elevations. Only 3.2 percent of the 1,598 points were eliminated as obvious blunders.

Elevation	Number of Points Compared
0.0 to ±0.5	1,323
±0.6 to ± 0.9	224
±1.0 and higher	51

We divided the US-14 project into various categories of grading and alignment. This was done to determine whether there were any significant differences in the results that might be attributed to the character of the highway design. The division between heavy and light grading was 15 ft at the reference line. The division between tangent and curve was 0 deg 30 min, where curves 0 deg 30 min and under were considered tangent sections and curves 0 deg 30 min and over were considered curved sections.

DISCUSSION OF RESULTS

Table 2 gives comparisons of the photogrammetric and field methods on the US-14 project. The average difference varied from -0.11 to -0.22 ft with the average for the

TABLE 2

COMPARISON OF PHOTOGRAMMETRIC AND FIELD DATA ON US-14 PROJECT

Section Type	Length (ft)	Number of Points	Average Difference[a]	Root Mean Square	Earthwork		
					Field	Photo-grammetric	Percent Difference
Heavy fill, tangent	500	117	-0.14	0.34	61,400	60,954	-0.7
Light fill, tangent	1,500	321	-0.22	0.39	72,148	70,055	-3.0
Light cut, curve	1,200	216	-0.15	0.35	37,496	39,850	+6.3
Heavy cut, curve	1,800	420	-0.20	0.38	267,092	270,825	+1.4
Heavy cut, tangent	2,664	435	-0.11	0.30	508,621	513,305	+0.9
Light cut, tangent	700	89	-0.15	0.23	63,039	64,185	+1.8
All special sections		1,598	-0.15	0.33			

[a]Includes sign.

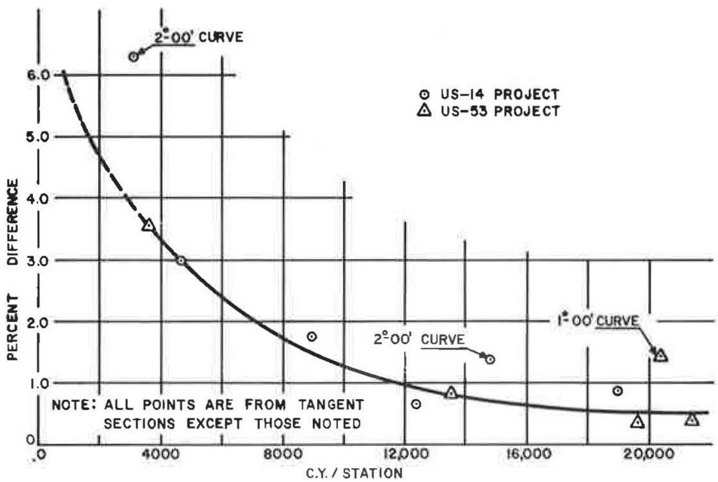

Figure 1. Percent difference between photogrammetric and field-computed earthwork quantity.

entire project being -0.15 ft. The yardage varied from -3.0 to +6.3 percent with the total for the project being +1.2 percent for excavation and -2.4 percent for embankment.

Several observations can be made from these results. There is no apparent correlation among the average differences, the root mean square, and the yardage differences. The percentage of yardage difference is more a function of the amount of grading and the depth of cut and fill. Figure 1 shows the amount of yardage per station and the percent difference between photogrammetric and field-computed yardage. With heavy grading, less than 1 percent difference can be expected. With light grading, minor absolute differences make substantial percentage differences. (Table 3 gives the results of the yardage comparison of all four test projects.)

The US-10 project produced a better correlation than did the US-14 project. The major difference in procedure here was that the "blue-top" elevations were used in the yardage computation. This was necessitated by the fact that the pavement had already been placed when the photographs were taken. This led to the conclusion that, on all photogrammetric final cross sections, the "blue-top" elevations as the project engineer has set them in the field should be used. These elevations are readily available, and their use will eliminate some of the coordination required to get photographs of bare subgrade.

The borrow pit on Wisc-15 had an excellent yardage correlation. In addition, there were 11 random field cross section checks made on this project to verify the photo-

TABLE 3

COMPARISON OF EARTHWORK QUANTITIES ON ALL PROJECTS

Project	Length	Excavation			Embankment		
		Field	Photo-grammetric	Percent Difference	Field	Photo-grammetric	Percent Difference
US-14	12,900	925,747	936,519	+1.2	721,941	704,922	-2.4
US-10	5,400	107,333	107,988	+0.6	58,107	56,795	-2.2
Wisc-15	1,250	86,175	86,434	+0.3			
US-53		1,077,709	1,089,960	+1.1	1,320,998	1,304,476	-1.2
Main line	12,180	1,064,742	1,076,177	+1.1	781,819	773,753	-1.0
Ramps	12,000	12,967	13,783	+6.3	539,179	530,723	-1.6

TABLE 4

COMPARISON OF EARTHWORK QUANTITIES BY TYPE OF GRADING SECTION ON US-53 PROJECT

Station	Section Type	Earthwork Field	Earthwork Photo-grammetric	Earthwork Percent Difference
61+00 to 71+00	Heavy fill, tangent	197,999	197,167	-0.4
71+00 to 78+00	Light fill, tangent	26,983	26,070	-3.4
86+00 to 109+88	Heavy cut, curve	480,758	487,401	+1.4
143+00 to 157+00	Heavy cut, tangent	543,891	546,366	+0.5
170+30 to 179+77	Heavy fill, tangent	131,145	130,169	-0.8

grammetric final sections. Although yardage could not be computed from these random sections, the end areas were compared. The field end area came to 35,700 sq ft, and the photogrammetric end area came to 35,614 sq ft, a difference of 0.2 percent.

On the US-53 project, evaluation was again made on several types of grading sections to determine the percent difference related to the volume of earthwork per station. Results similar to those of the US-14 project were obtained and are given in Table 4. Again we found a greater difference in the area of the 1-deg curve than was found on tangent sections.

Figure 1 shows that three points are well above the curve. The data for these points came from curved sections of highway. All of the other points represent data from tangent or slightly curving alignments (0 deg 30 min or less). Although we do not have any apparent reason for this particular phenomenon, we do believe that there is no difference in the photogrammetric procedure that could account for this.

Many leading textbooks indicate that the average-end-area method of computation will produce errors of up to 2 percent in earthwork computations. Thus it would appear that, by using this 2 percent figure as a guide, we could duplicate field-computed earthwork quantities with photogrammetric cross sections any time the grading involved about 7,500 or more cu yd/station on divided highways. This 7,500 cu yd/station would be represented by a uniform 10-ft cut for one station.

Translating the curve shown in Figure 1 into absolute values of difference per station, we find that it varies from about 100 to 150 cu yd per station. In other words, one might expect a difference of this amount regardless of the depth of grading for a dual roadway section. For a single roadway, a difference of maybe 50 to 75 cu yd per station might be expected.

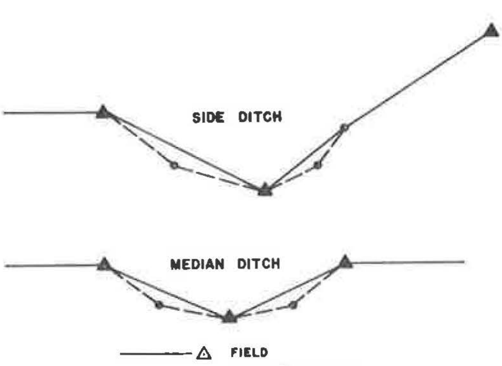

Figure 2. Difference between photogrammetric and field section.

When overlaying the two types of cross sections, we frequently observed one area of difference. Although this was relatively small it may have contributed to the fact that the photogrammetric excavation quantity was always higher than the field-measured quantity. In ditch bottoms the greater number of readings taken photogrammetrically would produce a more rounded section than that produced from field data. An example of this is shown in Figure 2. The quantity involved in this might run anywhere from 20 to 50 cu yd for the dual roadway section. It might be reasonably concluded that, by the use of twice as many points, there will be a truer approximation of the cross section. Likewise, any blunder in the field method will produce twice the impact because of fewer points.

We agree with Dickerson and Warneck (2) that there are fewer sources of blunder in the photogrammetric method. With field sections, three sources of blunder appear: the person who observes the numbers on the level rod and tape; the one who records these observations; and the operator who punches these observations into cards. The photogrammetric method, on the other hand, combines all these operations into one by automatically recording and keypunching the data. Further, the stereo plotter operator does not observe numbers as does the field instrument man but merely places a measuring mark on the ground.

Early in our development of the photogrammetric cross section capability it was discovered that the accuracy of the reference line layout had an important bearing on the accuracy of the output. The more accurate the layout was, the more accurate the cross section was. This is especially true in interchange areas or where wide medians are used. This layout should be prepared to an accuracy of $\frac{1}{40}$ in. Thus, any particular dimension should scale within 1 ft of its true, on-the-ground distance.

Such things as paper shrinkage and poor drafting lead to scale errors. On the US-53 project, all reference line targets were plotted by coordinate position on stable-base drafting film. This method produced an excellent layout.

CONCLUSIONS

1. The percent of yardage differences between photogrammetric and conventional cross sections was more a function of the amount of grading and depth of cut and fill than of the average differences in elevations.
2. On all final photogrammetric cross sections, "blue-top" elevations as set by the project engineer should be used in lieu of photogrammetric elevations of the subgrade.
3. Photogrammetric cross sections should be subject to fewer blunders than conventional field-measured sections.
4. Earthwork quantities computed from photogrammetric final cross sections will produce an accurate estimate usable for payment.

REFERENCES

1. Merrill, R. L. Determination of Accuracies in Earthwork Quantities From Photogrammetrically Made Surveys. Texas Highway Dept., May 1968.
2. Dickerson, L. A., and Warneck, P. E. Comparative Accuracies of Field and Photogrammetric Surveys. Highway Research Record 109, 1966, pp. 49-58.
3. Turner, F. W., and Kassis, A. W. Earthwork Quantities by Photogrammetric Measurements—Foothills Parkway Project 862. Aerial Surveys Branch, Bureau of Public Roads.
4. Meyer, C. F. Route Surveying, 3rd Ed. International Textbook Co., Scranton, 1968.
5. Bouchard and Moffitt. Surveying, 5th Ed. International Texbook Co., Scranton, 1966.