Adjustment of Photogrammetric Surveys

L. L. FUNK, Photogrammetric Engineer, California Division of Highways

PHOTOGRAMMETRIC surveys are subject to systematic errors, variable in size and difficult to eliminate. Such errors, if they fail to compensate, can cause serious discrepancies in earthwork quantities even though the surveys may comply with mapping specifications and with National Map Accuracy Standards. A previously reported experimental project (4) by the California Division of Highways indicated that the accuracy of earthwork quantities could be greatly improved by adjusting photogrammetric surveys to an accurate field profile.

To test this method under actual field conditions three sections of photogrammetric mapping, totaling 10.7 mi in length, from three construction projects were selected for study. Conditions on all of the projects were ideal for photogrammetric mapping with ground cover being almost negligible in each case. Data concerning the accuracies of the mapping, as measured by field profiles, are shown in Figures 1, 3, and 5. The method used in analyzing map accuracy has been discussed in a previous article (3).

In each case earthwork quantities for design and advertising the construction contracts had been obtained by taking terrain cross-section notes from the 2-ft interval contour maps. The terrain notes and corresponding roadbed notes were then processed by electronic computers. Field cross-sections for determining pay quantities of roadway excavation had been taken as the projects were slope staked for construction.

The field cross-sections were taken either with an engineer's level or by reading vertical angles with a transit. Right angles were determined with a 90 deg prism for the cross-sections taken with a level. A few individual points on the project on IX-Mno-23H were read with a hand level. While no definite statement can be made as to the absolute accuracy of the field surveys on these projects, it is believed they are slightly less accurate than the F1 survey of the experimental section (4) but somewhat better than the accuracy of the F2 survey.

EXCAVATION AND EMBANKMENT QUANTITIES

In developing comparisons of quantities the same stations were used for cross-sections from both field and photogrammetric surveys. In general, the cross-section interval was 50 ft. Results were screened for large, obvious blunders in the area of individual cross-sections. Adjustments of the photogrammetric surveys were made by raising or lowering the entire terrain at each cross-section by an amount equal to the difference in elevation from the field survey at centerline.

For purposes of comparison the three projects were divided into 10 segments each approximately 1 mi in length. Differences between field and photogrammetric survey quantities, both before and after adjustment, are shown in Table 1. The differences in excavation quantities, before adjustment, for the 10 segments ranged from 0.3 percent to 5.4 percent with an average of 2.5 percent. After adjustment the differences ranged from 0.0 percent to 1.8 percent with an average of 0.5 percent. Corresponding differences for embankment quantities were 0.9 to 9.7 percent with an average of 3.1 percent before adjustment and 0.1 to 1.8 percent with an average of 0.6 percent after adjustment.

Difficulties have been previously encountered on several projects where large localized errors in photogrammetric surveys caused serious imbalance in earthework quantities. These occured even though the projects as a whole balanced fairly well. Comparisons were therefore developed to determine the effect of the adjustments on 14 individual cuts and fills which showed serious differences between field and photogrammetric survey quantities. These comparisons are shown in Table 2. It will be noted that the differences, before adjustment, ranged from 0.7 percent to 10.2 percent with an average of 5.2 percent. Adjustment of the photogrammetric surveys to a field profile reduced these differences to a range of from 0.0 to 1.3 percent with an average of

TABLE 1

COMPARISON OF EARTHWORK QUANTITIES FROM FIELD AND PHOTOGRAMMETRIC SURVEYS

Project Sta. to Sta.	Excavation					Embankment				
	Field Survey Quantity (cu yd)	Photogrammetric Survey				Field Survey Quantity (cu yd)	Photogrammetric Survey			
		Difference (cu yd)		Difference (%)			Difference (cu yd)		Difference (%)	
		Before Adjust.	After Adjust.	Before Adjust.	After Adjust.		Before Adjust.	After Adjust.	Before Adjust	After Adjust.
ASC 188-IX Mno 23H										
283 to 340	50,121	+2,016	+ 887	4 0	1 8	44,039	-4,398	-145	9.7	0 3
340 to 390	87,661	-2,638	+ 369	3.0	0.4	67.894	-3,209	+481	4 7	0 7
390 to 440	15,658	- 667	+ 9	4.3	0.1	27,960	+1,671	+192	6.0	0.7
440 to 491	81.024	+4,123	+1,145	5.1	1.4	86,657	+2,281	-585	2.6	0.7
Total	234,464	+2,834	+2,410	1 2	1.0	226.550	-3,655	- 57	1.6	0.0
ASC 135-V SLO 33B										
92 to 150	83,535	+ 316	- 5	0.4	0.0	130,356	-2,175	-866	1.7	0.7
150 to 208	136,321	+7,306	- 237	5.4	0 2	23,120	- 447	+411	1.9	1 8
Total	219,856	+7,622	- 242	3.5	0.1	153,476	-2,622	-455	1.7	0.3
ASC 192-VI Ker 58D										
220 to 280	303,664	+2,744	+2,060	0.9	0 7	356,359	-5,006	+535	1.4	0.2
280 to 330	356,445	+1,230	+ 145	0.3	0.0	397,553	+3,500	+867	0.9	0.2
330 to 390	586,841	+4,326	+4,073	0.7	0.7	1,251,489	+14,371	+851	1.1	0.1
390 to 460	977,477	+10,690	-1,183	1.1	0.1	752,711	-7,172	+2,042	1.0	0.3
Total	2,224,427	+18,990	+5,095	0.9	0.2	2,758,112	+5,693	+4,295	0 2	0.2

0.5 percent. The wide variation in the arithmetic mean of the centerline profile in these 14 cuts and fills illustrates the variability of systematic errors in the mapping.

COMPARISONS OF TOTAL DIFFERENCES

The effects of adjustment on the total differences and the equivalent vertical differences for the ten 1-mi segments are shown in Table 3. The total difference is the difference in cubic yards between the terrain as depicted by the contour maps and the terrain as developed by the field survey. For a project designed for balanced cut and fill the total difference would, therefore, represent the imbalance caused by errors in the

TABLE 2

EFFECT OF ADJUSTMENT ON LARGE ERRORS IN INDIVIDUAL CUTS AND FILLS

Project Sta. to Sta.	Arithmetic Mean of Centerline Profile (ft)	Field Survey Quantity (cu yd)	Photogrammetric Survey Difference			
			Cubic Yards		Percent	
			Before Adjust.	After Adjust.	Before Adjust.	After Adjust.
ASC 188-IX Mno 23H						
363 to 378	-0.75	62,891 exc.	4,497	584	7.1	0.9
447 to 460	+0.31	80,648 exc.	4,106	1,017	5.1	1.3
287 to 320	+0.53	36,855 emb.	3,771	125	10.2	0.3
377 to 385	+1.45	46,682 emb.	3,899	382	8.3	0.8
459 to 491	-0.45	48,792 emb.	3,285	651	6.7	1.3
ASC 135-V SLO 33B						
180 to 200	+0.74	120,022 exc.	7,712	171	6.4	0.1
133 to 155	+0 20	113,554 emb.	1,538	55	1.4	0.0
ASC 192-VI Ker 58D						
391 to 416	-0.22	723,816 exc.	5,014	297	0.7	0.0
422 to 430	+0.91	114,805 exc.	6,091	3	5.3	0.0
439 to 449	+1.79	138,373 exc.	10,402	835	7.5	0.6
220 to 230	+1.03	48,012 emb.	4,625	234	9.6	0.5
275 to 288	-0.35	481,148 emb.	4,629	1,016	1 0	0.2
330 to 356	-0.52	657,624 emb	12,789	3,680	1.9	0.6
446 to 460	+1.28	502,201 emb.	8,402	337	1.7	0.1

TABLE 3

RELATION OF MAP ACCURACY TO DIFFERENCES IN EARTHWORK QUANTITIES

Project Sta. to Sta.	Centerline Profile: No of Points	Within ½ C.I. (%)	Arithmetic Mean (ft)	Standard Deviation (ft)	Total Difference (cu yd): Before Adjust.	After Adjust.	Equivalent Vertical Dif. (ft): Before Adjust.	After Adjust.
ASC 188-IX Mno 23H								
(1) 283 to 340	113	89	+0 30	0.61	+6,414	+1,032	+0.35	+0.06
(2) 340 to 390	100	80	+0.04	0 90	+ 571	- 112	+0 03	-0.01
(3) 390 to 440	100	93	-0.15	0.61	-2,338	- 183	-0 16	-0.01
(4) 440 to 491	103	88	-0.12	0.68	+1,842	+1,730	+0.09	+0.09
Total	416	88	+0.03	0 75	+6,489	+2,467	+0.09	+0.04
(4A) 440 to 460	40	90	+0.38		+5,115	+ 937	+0.52	+0 10
(4B) 460 to 491	63	87	-0.43		-3,273	+ 793	-0.32	+0.08
ASC 135-V SLO 33B								
(5) 92 to 150	110	90	+0 05	0 61	+2,491	+ 861	+0.11	+0.04
(6) 150 to 208	110	86	+0.26	0.67	+7,753	- 648	+0.30	-0.03
Total	220	88	+0 16	0.64	+10,244	+ 213	+0.21	0.00
ASC 192-VI Ker 58D								
(7) 220 to 280	118	79	+0.28	0.83	+7,750	+1,525	+0.19	+0.04
(8) 280 to 330	99	86	-0.05	0.88	-2,270	- 722	-0.07	-0.02
(9) 330 to 390	123	58	-0.46	1.45	-10,045	+3,222	-0.21	+0.07
(10) 390 to 460	146	62	+0.44	1.08	+17,862	-3,225	+0.32	-0 06
Total	486	70	+0.07	1.13	+13,297	+ 800	+0.08	0.00

photogrammetric survey. The equivalent vertical difference was calculated by dividing the total difference in cubic feet by the area between the slope stakes in square feet. In effect, it is the mean vertical difference between the average of the terrain as represented by the contour map and the average of the terrain from the field survey. It is, therefore, a one-dimensional variable which is directly related to the difference in earthwork quantities.

It will be noted in Table 3 that the equivalent vertical differences of the ten 1-mi segments ranged from -0.21 to +0.35 ft before adjustment of the photogrammetric surveys. The average (without regard to sign) for these 10 segments was 0.18 ft. The adjustment reduced the equivalent vertical differences to a range of -0.06 to +0.09 ft with an average of 0.04 ft.

To further study the effect of adjustment on imbalance of quantities the total differences were calculated in 1,000-ft

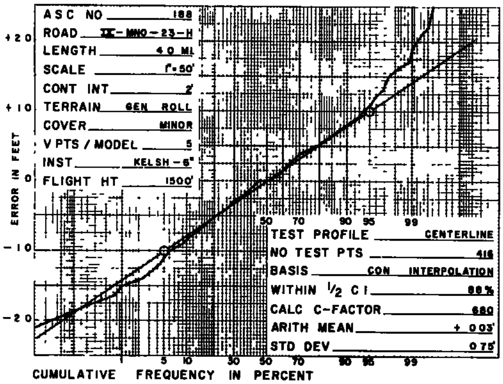

Figure 1

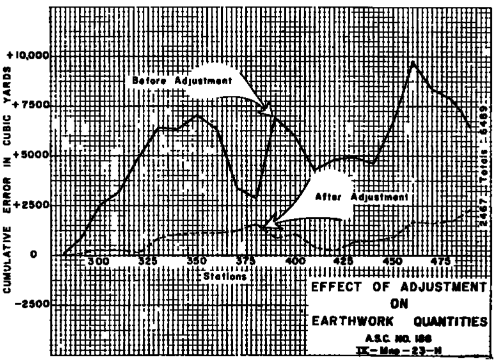

Figure 2

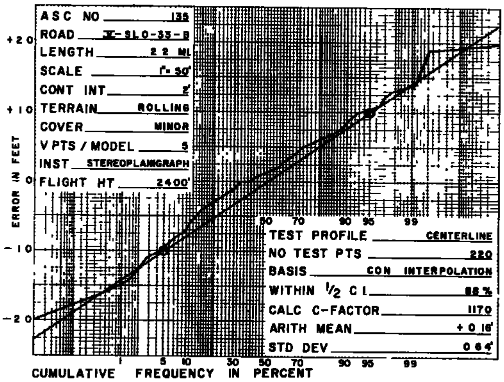

Figure 3

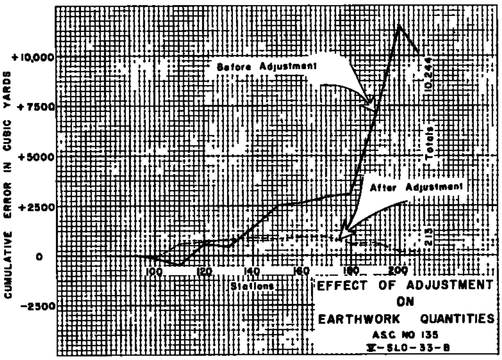

Figure 4

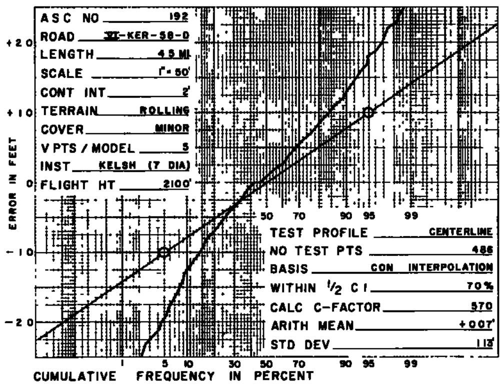

Figure 5

segments for the three projects. Cumulative total errors (differences) before and after adjustment were then plotted as ordinates with centerline stations as abscissae. The resulting curves in Figures 2, 4, and 6 show the imbalance in quantities caused by errors in the photogrammetric surveys. They also illustrate the dampening effect of adjustment of the photogrammetric surveys on errors in earthwork quantities. The only evidence of serious discrepancies in the after adjustment curves is between Stations 330 and 370 on the VI-Ker-58-D project shown in Figure 6. These discrepancies were probably caused by large individual blunders in either the field or photogrammetric surveys.

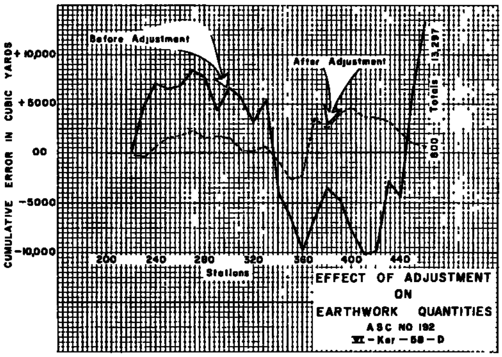

Figure 6

RELATION OF MAP ACCURACY TO EARTHWORK QUANTITIES

The National Map Accuracy Standards are the basis for most photogrammetric mapping specifications. For vertical accuracy the requirement is, in effect, that 90 percent of the points shall be within one-half contour interval of their true elevation. One of the objectives of this study was to determine if this or any specification for map accuracy can be directly related to the resulting accuracy of earthwork quantities.

As previously noted the equivalent vertical difference is a one-dimensional measure of the accuracy of earthwork quantities. The equivalent vertical differences before adjustment and the percentage of points on the centerline profile within one-half contour interval are both shown in Table 3. A comparison for the various segments of the mapping shows little, if any, relation between these two values. For example, the portion of the project on IX-Mno-23-H from Stations 340 to 390 has the lowest percentage of points within one-half contour on this project (80 percent) and also has the lowest equivalent vertical difference (+0.03 ft). Similarly, of the three projects, the one on VI-Ker-58-D has by far the lowest percentage of points within one-half contour interval (70 percent) and also has the lowest equivalent vertical difference (+0.08 ft) as compared to +0.09 ft and +0.21 ft for the other two projects. The mapping on V-SLO-33-B was very good by conventional map accuracy standards, having 88 percent of the points tested within one-half contour interval and a standard deviation of 0.64 ft, and yet the equivalent vertical difference before adjustment of +0.21 ft is the highest of the three projects.

The lack of relationship between National Map Accuracy Standards and accuracy of

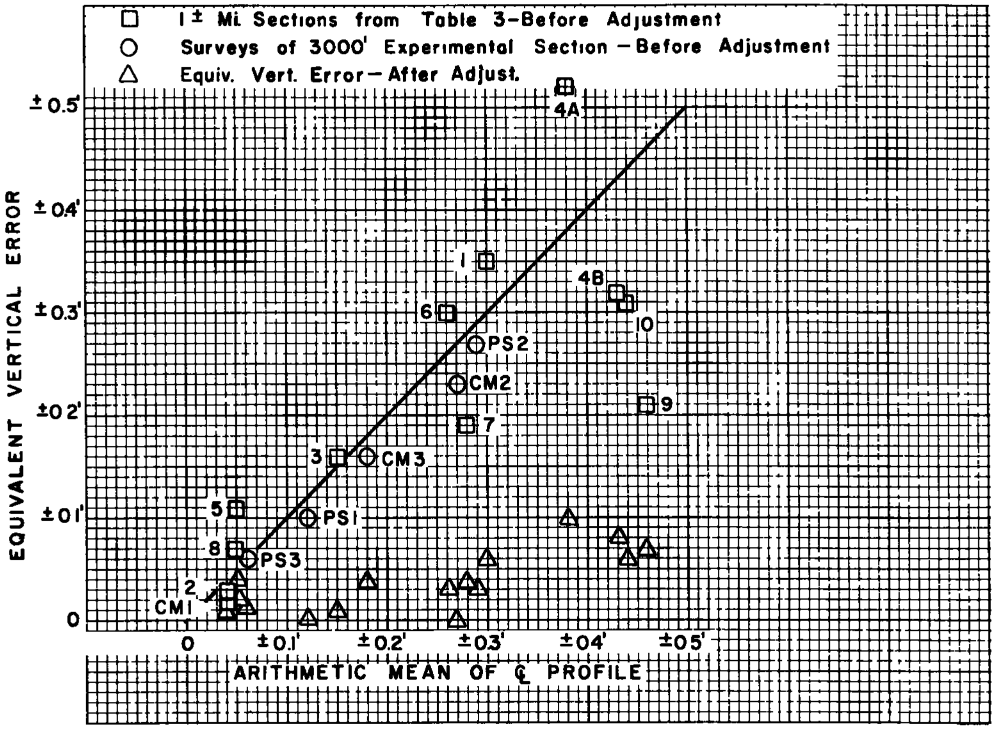

Figure 7

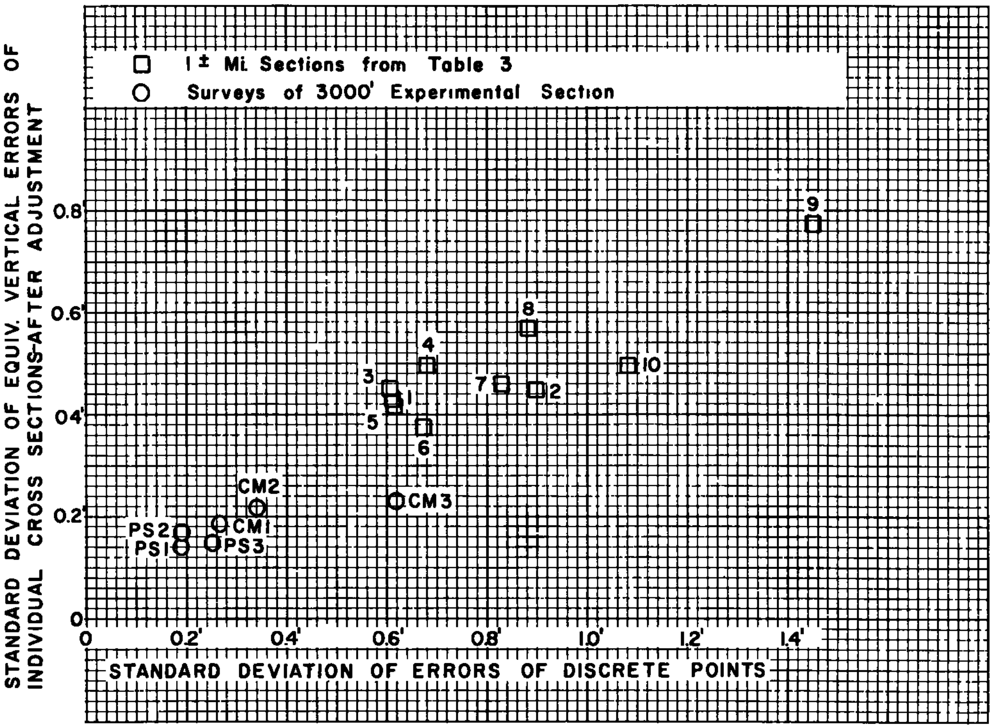

Figure 8

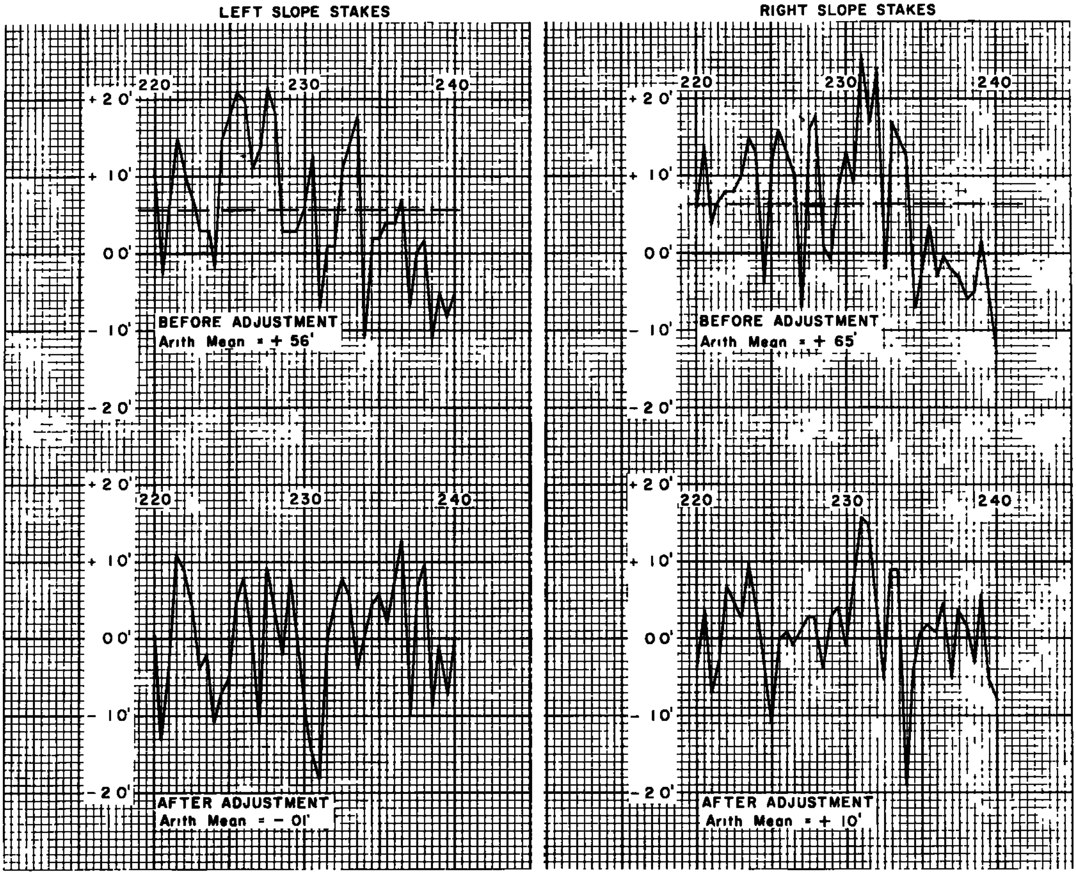

Figure 9. VI-Ker-58-D, effect of adjustment on slope stakes.

earthwork quantities is due, of course, to the serious effect of relatively small systematic errors on earthwork quantities as compared to the relatively minor effect of much larger random errors. This has been previously pointed out by Miller in connection with photogrammetric measurements for earthwork quantity determination (1).

In a previous article (4) the close relationship between the arithmetic mean of a centerline profile and the accuracy of earthwork quantities was noted. In comparing the arithmetic mean of the field profiles with the equivalent vertical differences before adjustment for the 1-mi segments, as shown in Table 3, a similarly close relationship is apparent for 7 of the 10 segments. The exceptions are shown in Lines 4, 9, and 10. For the segments shown in Lines 9 and 10 the less direct relationship is probably due partially to the large variation in width between slope stakes in the rough terrain and partially to blunders in the field and photogrammetric surveys. For the section from Station 440 to Station 491 of IX-Mno-23-H, shown in Line 4, the arithmetic mean of the centerline profile is -0.12 ft, as compared to an equivalent vertical difference of +0.09 ft. As shown by Lines 4A and 4B this apparent discrepancy is caused by averaging 2 segments having widely different systematic errors.

The relationships between the arithmetic mean of the centerline profiles and the equivalent vertical errors (differences) for the various segments of Table 3 and for the six photogrammetric surveys of the experimental section (4) are shown graphically in Figure 7. These data indicate that a field profile will furnish an excellent guide to the probable accuracy of earthwork quantities. They lead to the conclusion that mapping specifications should include a limitation on the arithmetic mean of points tested if the mapping is to be used as a source of terrain data for earthwork quantities.

If adjustment of photogrammetric surveys to a field profile tends to greatly reduce systematic errors the remaining discrepancies in earthwork quantities should be largely due to random errors. In this case the accuracy of earthwork quantities after adjustment should be proportional to the standard deviation of the random errors and inversely proportional to the number of points tested or the number of cross-sections. To determine whether any such relationship could be developed, the equivalent vertical differences for each individual cross-section of the three projects were calculated. The standard deviations of these individual equivalent vertical differences were then computed for each of the ten 1-mi segments. In only three of the ten cases were the equivalent vertical differences after adjustment, as shown in the last column of Table 3, greater than the standard error of the mean for the number of cross-sections involved. In all cases they were well within the limits of a normal distribution.

The standard deviations of the equivalent vertical errors (differences) for the 1-mi segments are shown as ordinates in Figure 8 with the standard deviations of the centerline profile from Table 3 plotted as abscissae. Corresponding values are shown for the 6 photogrammetric surveys of the experimental section (4). The resulting pattern gives strong indication of a straight-line relationship between the two values. If this is verified by further research it will provide a means of estimating the accuracy of earthwork quantities from adjusted photogrammetric surveys in terms of probability.

Further evidence of the effect of adjustment on systematic errors is illustrated by Figure 9. The graphs show the errors in the left and right slope stake points before and after adjustment for the section from Station 220 to Station 240 on the VI-Ker-58-D project. The adjustment reduced the arithmetic mean of the left slope stakes from +0.56 to -0.01 ft and of the right slope stakes from +0.65 to +0.10 ft. The reduction in the equivalent vertical difference for this 2,000-ft section was from +0.58 to +0.06 ft. It will be noted that there is no appreciable change in the magnitude of the random errors.

CONCLUSION

The results of this study have generally confirmed those developed by the previously reported 3,000-ft experimental section. The slightly greater differences between field survey quantities and photogrammetric survey quantities both before and after adjustment were anticipated. They can be attributed partially to the fact that the photogrammetric mapping was obtained under actual working conditions. More important, however, is the probability of less accuracy of the field surveys which were used as a yardstick. For this reason the term "difference" rather than "error" has been used in most instances in this report.

The most important conclusion which can be drawn from the study is that adjustment of photogrammetric surveys by means of accurate field profile will:

1. Materially reduce large localized errors in earthwork quantities; and
2. Result in over-all quantities which are within limits generally considered tolerable for purposes of payment.

REFERENCES

1. Miller, C. L., "Digital Terrain Model Approach to Highway Earthwork Analysis." M. I. T. Photogrammetry Laboratory, Publication III (August 1957).
2. Miller, C. L., and Kaalstad, T. H., "Earthwork Data Procurement by Photogrammetric Methods." M. I. T. Photogrammetry Laboratory, Publication 115; also HRB Bull. 199 (1958).
3. Funk, L. L., "Photogrammetric Map Accuracy." Photogrammetric Engineering (June 1958); also HRB Bull. 199 (1958).
4. Funk, L. L. "Terrain Data for Earthwork Quantities." HRB Bull. 228 (1959).