Results of U.S. Forest Service Stereotriangulation Bridging on Virginia Highway Photogrammetric Test Project

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The Forest Service of the U. S. Department of Agriculture is constantly striving to improve the quality of the surveys it makes by photogrammetric methods. The tests described in this report were conducted using the usual methods and procedures. The report pertains to four basic factors which affect the quality of photogrammetrically made measurements: (a) identification of ground control (horizontal and vertical) points on the aerial photography, (b) movement of the aerial camera during negative exposure, (c) scale of the aerial photography, and (d) quantity of ground control.

Included are tabulations showing results of the bridges (extension of basic ground control by photogrammetric methods) using vertical photography taken with two different aerial cameras, two types of control identification, four scales of photography, and various spacings of ground control. These results are based on the photogrammetric measurement and electronic computation of 50 bridges.

Also presented is an outline of procedures to be followed for the location and design of highways based on surveys accomplished by photogrammetric methods, as well as conclusions based on these tests.

•IT IS IMPERATIVE that the Forest Service seek new methods of control extension by photogrammetry. Normal mountainous topography and short field survey season make it mandatory that photographs be used for inventory purposes, mapping, and engineering measurements. Aerial photographs to be used for making measurements by photogrammetric methods require some kind of ground control. Ground control is based on the U. S. Coast and Geodetic Survey (USC and GS) national network, with 1929 sea level datum for elevations and North American 1927 datum for horizontal control (with the geodetic positions converted to the State Plane Coordinates for each zone of application) inasmuch as this control is the most accurate and economical in the long run.

From 1947 to 1957, the Forest Service photogrammetrically extended vertical and horizontal control by the use of two scales of photography; i. e., field control was established for points on small-scale photography and, in turn, by photogrammetric use of this photography elevations and horizontal positions were established for selected points on larger scale photographs by use of common image points between the two scales of photography. The horizontal control was extended by the use of a stereo-templet triangulation plot. The stereo-templets were made by projection from the Kelsh stereoscopic plotter using the small-scale photographs. The Kelsh stereoscopic models were than reset (using position and distances determined by the stereo-templet triangulation plot) and vertical and horizontal control for the large-scale photographs was established from the stereoscopic models formed from the small-scale photographs.

From 1957 to the present, the Forest Service has been extending the horizontal and vertical control with the Zeiss Stereoplanigraph, Model C8. This method of control extension is called "bridging." (Wherever the word "bridging" is used in this paper it

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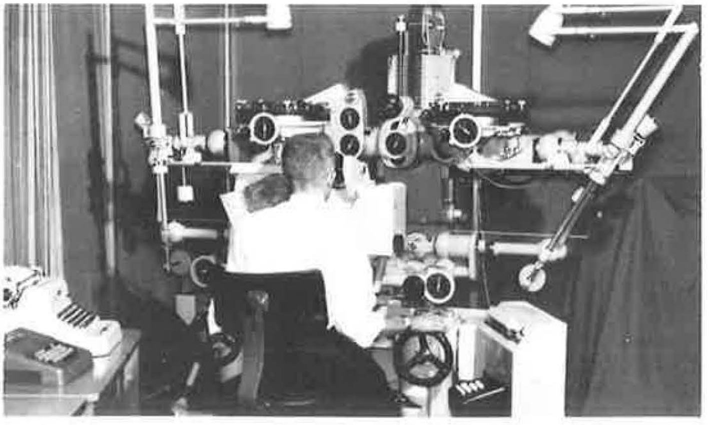


Figure 1. Zeiss Stereoplanigraph, Model C8.

means measurement by photogrammetric methods (stereotriangulation) and electronic computer adjustment of the measurements to establish both horizontal and vertical supplemental control for selected image points on the aerial photography between points on the ground and seen on the aerial photographs for which basic horizontal and vertical control has been surveyed on the ground.) By use of the C8, the photographs (printed as transparencies on glass) are cantilevered from the first model, with ground control through seccessive models to the end of the strip of photographs. The C8 has a system of optics and mirrors which allows one photograph to remain stationary while the next photograph is added to the stationary photograph. The "end product" of the C8 bridge is a stack of IBM cards with X, Y, and Z coordinates of identified points (control, pass points, center of each photograph and any other point). In other words, the Stereoplanigraph is an analogue computer that will take photographs of unknown scale, tip, tilt, and swing, and put them into a continuous strip of photographs with constant scale (horizontal and vertical) and on one datum. This statement is oversimplified, but it is in general what is being accomplished. The set of instrument-measured coordinates is computed with a digital computer to obtain the best least square fit on the ground coordinates. This paper gives the results of a series of tests on bridging by photogrammetric methods using aerial photography taken by two different aerial cameras, two types of control identification, four scales of photography, and various amounts of ground control within one strip.

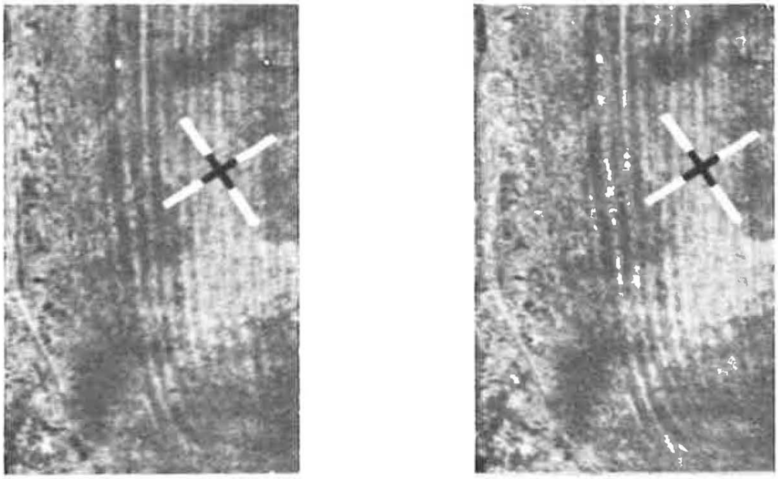
In early 1959, the Forest Service cooperated with the California Division of Highways in testing stereotriangulation bridging. The results of this test were inconclusive due to the few models available, and it was evident that further tests were needed.

In September 1959, the Virginia Department of Highways, U. S. Bureau of Public Roads, and the U. S. Forest Service agreed on a cooperative photogrammetric test project. The Virginia Department of Highways agreed to obtain aerial photography, establish horizontal and vertical control, set targets, identify "image" ground control points, and evaluate the bridging results. The Bureau agreed to plan the target placement, help set the targets and make stereotemplet bridges, using its three-projector Kelsh instrument. The Forest Service agreed to make stereotriangulation bridges with its Zeiss Stereoplanigraph, Model C8 (Fig. 1).

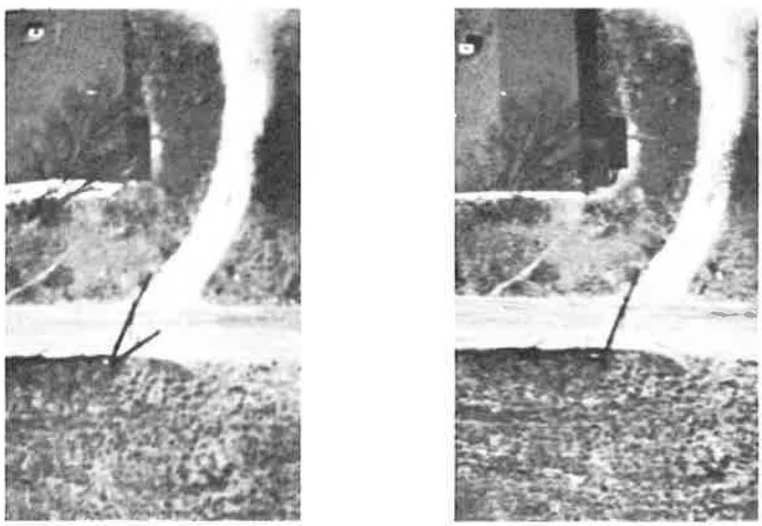
The area selected for the test is a preliminary survey segment of I-66 in Fairfax County, Virginia. Ground cover ranged from open farm land to wooded hills, and from a few roads and buildings to urban developments.

THE PROBLEMS

The Forest Service's part of the tests was planned for study of four problems in bridging to establish supplemental control for photogrammetric compilation of topographic maps and measurement of profile and cross-sections for highway design. The



This target is 27 feet long (9 ft white, 9 ft black, 9 ft white) and 23 in. wide.



The utility pole, with its shadow crossing the road, is an example of an image point.

Figure 2. Stereograms of a target and an image point. These photographic enlargements (8X) are at the same scale as viewed by the Stereoplanigraph operator.

tests must be considered a study of photogrammetric bridging methods and not basic research. These problems include:

1. Are targets required on control points for bridging or will natural images (picture points) suffice? (Fig. 2.)
2. Is the shutter speed on the aerial cameras a major source of error in bridging?
3. Can photogrammetric control be established from photography 2, 3, or 4 times smaller in scale than the design mapping photography and still be usable to measure

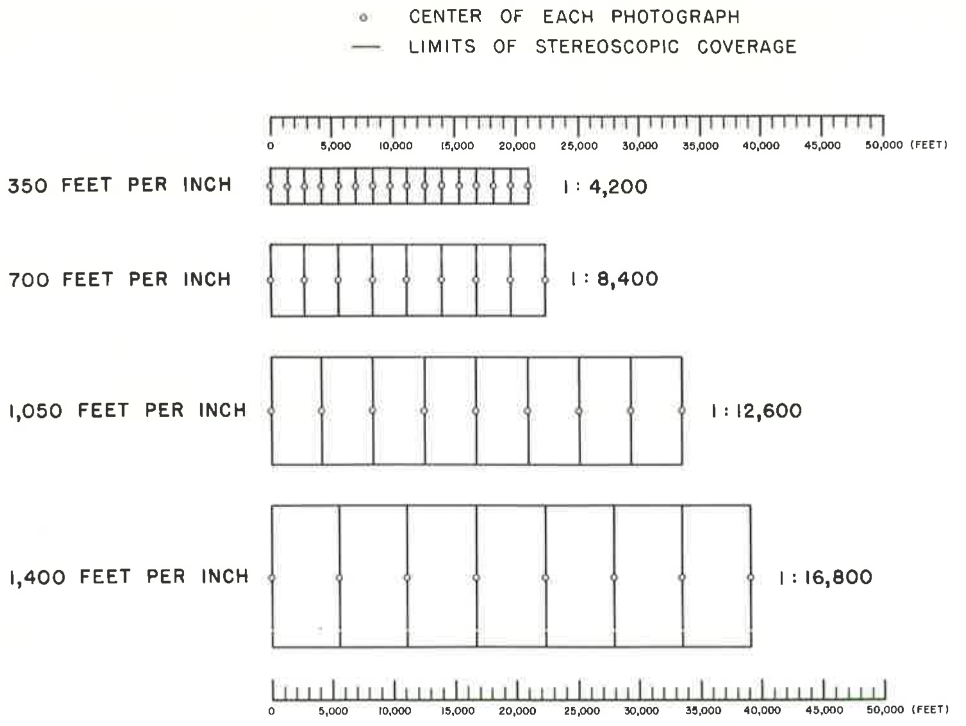


Figure 3. Scales of photography.

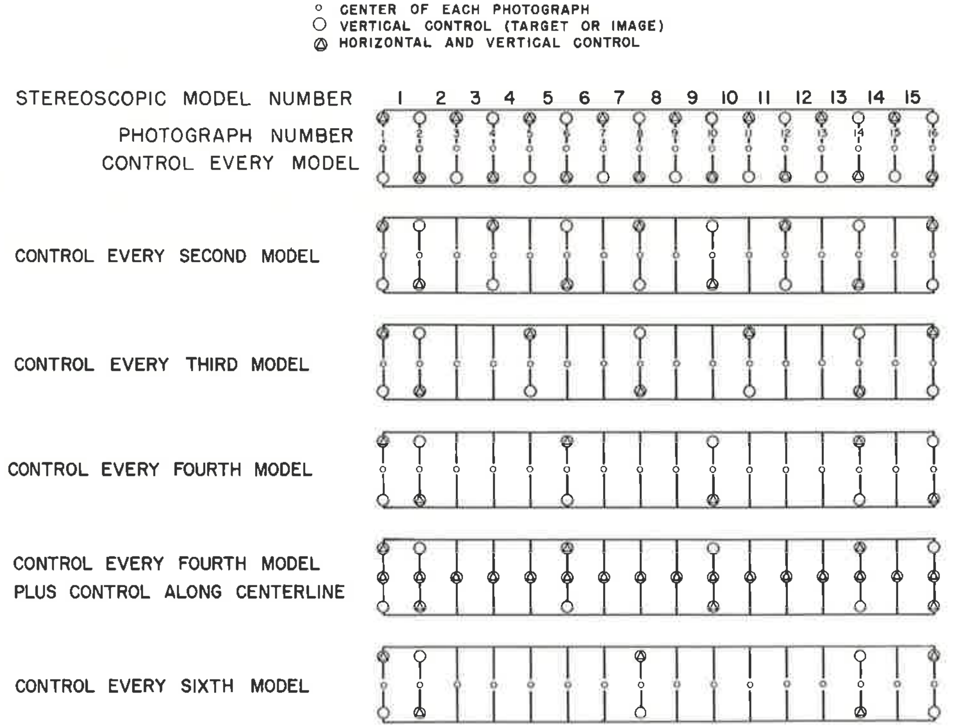


Figure 4. Control spacing for photography of 350 ft/in. scale.

and delineate planimetry and contours, and to measure profile and cross-sections? (Fig. 3)

4. Is field surveyed control required every 2nd, 3rd, 4th or 6th stereoscopic model used for bridging? (Fig. 4)

BRIDGING RESULTS USING THE 1959 PHOTOGRAPHY

The test area selected had been photographed by the Virginia Department of Highways (VDH) in the spring of 1959 with its Wild, 6-in. focal length aerial camera, equipped with a shutter which could be operated at a speed as fast as $\frac{1}{300}$ second To start the tests, this photography was used to measure and compute bridges with varying amount of image point control Tables 1 and 2 (with comments) give the results. At the time these bridges were measured and computed, the electronic computer programs were in two parts: (1) computation of the horizontal position of the bridge-measured points, and (2) computation of the vertical (elevation) position of bridge-measured points, using results from the electronic computer program for computing the horizontal bridge.

TABLE 1

HORIZONTAL BRIDGING RESULTS OF 1959 PHOTOGRAPHY[1]

Points (No.)	Largest Error (ft)	Least Error (ft)	Avg. Error (ft)	Standard Deviation (mean sq. error)	Total Error (ft)
			Test Points		
48	2.244	0.102	0.927	1.056	44.508
47	2.360	0.098	0.818	0.968	38.467
47	2.887	0.022	1.027	1.199	48.264
46	2.640	0.045	0.886	1.052	40.778
44	2.304	0.106	0.828	0.955	36.452
38	2.304	0.120	0.882	1.002	33.519
12	2.140	0.530	1.174	1.684	14.088
			Control Points		
3	0.104	0.041	0.083	0.088	0.248
4	0.311	0.041	0.144	0.177	0.576
4	0.120	0.030	0.071	0.079	0.282
5	0.368	0.061	0.192	0.230	0.959
7	0.683	0.141	0.359	0.397	2.516
13	0.582	0.188	0.380	0.399	4.945
39	1.153	0.136	0.585	0.689	22.799

[1] Horizontal results of the Forest Service Stereoplanigraph, Model C8, bridging of 12 stereoscopic models (stereotriangulation) using 1959, 6-inch focal length Wild camera photography at a scale of 350 feet per inch (1:4,200) which was taken at a shutter speed of $\frac{1}{300}$ second. The photogrammetrically measured bridge made using image point control was computed using the U.S.C. & G.S. horizontal bridging program in an IBM 650 electronic computer.

TABLE 2

BRIDGING RESULTS USING IMAGE POINTS

Bridging No.	Points (No.)	Largest Error (ft)	Least Error (ft)	Avg. Error (ft)	Standard Deviation (mean sq. error)	Arithmetic Mean (ft)	Total Neg. Error (ft)	Total Plus Error (ft)	Total Error (ft)
					Test Points				
1	115	+4.85	0.00	1.109	1.479	0.554	95.61	31.95	127.56
2	113	+6.11	0.01	0.681	0.840	0.523	8.93	68.04	76.96
2A	113	+6.04	0.00	0.666	0.832	0.057	34.41	40.84	75.25
2B	113	+6.22	0.00	0.815	1.041	0.038	43.93	48.17	92.10
3	111	+5.58	0.00	1.104	1.455	0.535	31.60	90.94	122.54
4	107	+3.37	0.00	1.041	1.378	0.146	47.88	63.47	111.35
5	95	+2.72	0.06	1.010	1.357	0.385	29.70	66.29	95.99
6	82	+3.57	0.00	1.011	1.345	0.122	36.46	46.45	82.91
					Control Points				
1	6	-0.07	-0.02	0.038	0.041	0.038	-0.23	0.00	0.23
2	8	+0.62	+0.14	0.358	0.401	0.010	1.47	1.39	2.86
2A	8	+0.26	+0.03	0.133	0.153	0.035	-0.39	0.67	1.06
2B	8	+0.20	+0.01	0.114	0.144	0.046	-0.27	0.64	0.91
3	10	+1.96	-0.20	0.914	1.123	0.035	-4.76	4.41	9.17
4	14	+2.12	-0.07	0.814	1.068	0.055	-6.08	5.31	11.39
5	26	-2.31	+0.03	0.963	1.164	0.048	-13.15	11.89	25.04
6	39	-2.97	-0.01	0.976	1.196	0.047	-19.96	18.12	38.08

Table 2

Results of the Forest Service Stereoplanigraph (C8) bridging of vertical control on 12 stereoscopic models (stereotriangulation), using image point control on 1959, 6-inch focal length, Wild camera photography taken at a scale of 350 feet per inch (1:4,200) with a shutter speed of $\frac{1}{300}$ second, were computed using the U. S. C. and G. S. vertical bridging program in an IBM 650 electronic computer.

Control Points.--Bridging no. 1 gives computed results using six control points: two at the west edge of the first stereoscopic model, two near the middle, and two at the east edge of the last model. Bridging no. 2 gives computed results using eight control points: two at the west edge of the first stereoscopic model, and two each near the fourth, eighth, and twelfth models. Bridging no. 2A gives computed results using eight control points, as in bridging no. 2, but three control points were changed; the horizontal control is along the flight centerline. Bridging no. 2B gives computed results using the same eight control points as in bridging no. 2A but with the horizontal control in the pass point area. Bridging no. 3 gives computed results using ten control points: two each on the first, third, sixth, ninth, and twelfth stereoscopic models. Bridging no. 4 gives computed results using fourteen control points: two each on the first, second, fourth, sixth, eighth, eleventh, and twelfth stereoscopic models. Bridging no. 5 gives computed results using twenty-six control points: four on the first and two for all other stereoscopic models. Bridging no. 6 gives computed results using thirty-nine control points spaced throughout the strip.

BASIC MATERIAL

Four scales of photography were obtained in the spring of 1961 (before the deciduous trees had leafed out): 350, 700, 1,050, and 1,400 feet to 1 inch. The photography scales selected were for compilation of topographic maps by use of a Kelsh stereoscopic plotter at a 7-diameter projection ratio (the ratio used by the Virginia Department of Highways; Forest Service uses a 5-diameter projection ratio). By use of the 7-diameter projection ratio, maps can be compiled at scales of 50, 100, 150 and 200 feet to 1 inch, respectively, using photography of the scales at which taken.

All four scales of photography were obtained with two precision 6-in. focal length cameras: the Virginia Department of Highways Wild camera with a shutter speed of $\frac{1}{300}$ second and a Zeiss camera with a shutter speed of $\frac{1}{1,000}$ second. Besides using photography taken at the four scales with the two cameras, the test project area was also photographed on clear and overcast days, with and without filters. In all some 43 flights of photography were obtained.

The U. S. Bureau of Public Roads and Virginia Department of Highways set the targets before any flights were made for taking the test project photography. The spacing of the targets on the photographs as taken did not agree exactly with plans, but was as good as could be expected on a production project. After the photographs were obtained, the Forest Service selected and circle identified image points and requested the Virginia Department of Highways to measure horizontal and vertical control positions for each of these images. As a whole, the results of this method were satisfactory. In one case, however, an image point was circled on the 1,050 feet per inch scale photography, described as a "fence corner," and the field party surveyed the position of the fence corner. Actually, the circled image was on a ditch crossing of the fence line, which was about 0.004 inch away (on the contract printed photograph) from the fence corner. Such misidentification of images is one of the pitfalls in using image points for horizontal control.

Photography image control points (common image points) were selected and circle identified on all scales of photography from both cameras before the bridging work was started. In other words, natural image points were selected for correlation of position between the 350 feet per inch scale photography and the photography of 1,400, 1,050, and 700 feet per inch scales. This procedure became a compromise in point selection which was necessary in order to do bridging with the photography of 350 feet per inch scale using image points for which control had been bridged using photography of the three smaller scales.

The Virginia Department of Highways furnished the horizontal and vertical control required for bridging with the 1,400 feet per inch scale photography. Control for the other scales was withheld by VDH until the Forest Service finished the bridges using photography of the 1,400 feet per inch scale and forwarded results to the VDH. The bridges were computed on the IBM 650 using basic formulas published by the U. S. C. and G. S. (1, 2).*

TARGET OR IMAGE POINTS

The test area selected in Northern Virginia is better than average for the selection of natural images. More image points are required for the same number of control points when natural images are used than when targets are placed on station markers because the identification of a triangulation station which is not targeted requires use of at least two nearby image points. This means that two bearing and distance measurements are needed for the identification of one station, where a target over the actual station marker would not require additional field measurements.

The use of image points for vertical control is sound because a flat area can be misidentified horizontally by several feet and still not impair the accuracy of the point. The actual field survey measurement of the elevation on an image point has a good chance of being accurate within 0.1 or 0.2 foot.

The use of image points for horizontal control is not sound. Further study is required, however, to determine the best size, shape, and color for targets, and the materials most suitable for their construction.

Most of the advantages of targets are lost if the photogrammetric instrument operator is unable to measure accurately both horizontally and vertically on the point.

The field surveyed positions of image points are not finite and the position of good image points may be in error by 0.5 foot. Control surveyed to second order accuracy is recommended, plus or minus 0.1/foot, so results from bridging will not be degraded by poor quality in the field surveyed control.

AIRCRAFT MOVEMENT DURING EXPOSURE

Two cameras were used on this test—a Wild with a shutter speed of $^1/_{300}$ second and a Zeiss with a shutter speed of $^1/_{1,000}$ second. At 120 mph, the aircraft with the Wild camera traveled 0.59 foot and the Zeiss 0.18 foot while the shutter was open. According to these figures, the Zeiss camera would be expected to enable achievement of better results, but the test showed bridging results were the same, regardless of which camera was used. The only way such an equality in results could be rationalized was to study the resolving power of the two cameras be-

*The Forest Service has been bridging with the Stereoplanigraph since 1957 and is now using the basic formulas of the U. S. Coast and Geodetic Survey. The horizontal and vertical control electronic computer programs were combined and a "borrow" feature added. This feature allows the borrowing of photogrammetrically measured control points from one strip and the use of them on an adjacent strip, which is a form of a modified block adjustment. While not used on the test project, the production bridging program has a horizontal and vertical rejection limit; i.e., the program is loaded to reject horizontal points with X foot error. For example, if a rejection horizontal error of two feet and vertical error of one foot are desired and if there are 18 horizontal control points and 28 vertical control points, the procedure would be as follows:

The horizontal portion of the formulas are computed first to get a printout (storage) of the least square fit of the 18 horizontal control points. The point with the largest error (if over 2 feet) is rejected and a printout (storage) with the least square fit of the 17 remaining points is obtained. This process continues, rejecting the largest error, one point at a time, until the remaining control points have less than two feet of error. The same process is repeated with the vertical control, except this time points with an error of over one foot are rejected, one point at a time; i.e., a fit with 28 points, a fit with 27 points, etc. After the rejection limit has been satisfied, the correction coefficients are applied to all points in the bridge. This program was not used on the Virginia Highway test, because it was for testing all elements of bridging, not just control. For this reason, it is believed better results can be obtained on a production job than on this test.

cause camera movement, the same as poor resolving power, would appear as fuzzy images.

Because there is no international test for cameras, the manufacturer's report was used to compute the number of lines per millimeter times the percent of the 9- × 9-in. format. For example, from the center of the lens out five degrees, approximately 1 percent of the 9 × 9 in. is covered. This percentage multiplied by the lines per millimeter, for both radial and tangetial resolution, gives the number used to compare the cameras. The Wild camera had approximately 15 percent better resolving power.

ESTABLISHING CONTROL IN PHOTOGRAMMETRY

It is difficult to say that horizontal and vertical control can be established from control photography two, three, or four times smaller in scale than photography taken for mapping purposes without some kind of a common denominator. The scale of some strip topographic mapping for design purposes is 40 feet per inch, another may be 200 feet per inch, and the contour interval may range from one foot to five feet. To establish a common denominator, the photography flight height divided by the average error was used. For example, if the average error was 0. 6 foot and the flight height was 4, 200 feet, the factor would be 1:7, 000; in other words, an error of one foot in vertical measurement can be expected for each flight height increment of 7, 000 feet.

About fifty bridges were measured and adjustment computed using a combination of the four scales of photography of 350, 700, 1, 050 and 1, 400 feet per inch taken separately with two aerial cameras (Wild and Zeiss); two types of control identification (image points and target) and two different spacings of the control (one with control every fourth stereoscopic model, and the other with control every fourth model plus horizontal and vertical control about 1, 400 feet apart along the centerline of the high-

TABLE 3

BRIDGING RESULTS FOR CHECK POINTS[1]

Camera	Control Identification	Scale of Photography (ft/in.)							
		Horizontal Results				Vertical Results			
		350	700	1, 050	1, 400	350	700	1, 050	1, 400
Control Every Fourth Model									
Zeiss	Picture point	1:1926	1:3853	1:3000	1:4389	1:4487	1:4773	1:5385	1:5156
Wild	Picture point	1:1944	1:3307	1:2800	1:3676	1:4516	1:5676	1:4598	1:5519
Avg.	Picture point	1:1935	1:3580	1:2900	1:4032	1:4502	1:5224	1:4992	1:5388
Zeiss	Target	1:2143	1:3529	1:4809	1:3992	1:4200	1:4200	1:6774	1:3406
Wild	Target	1:2658	1:3784	1:3462	1:3676	1:5000	1:6462	1:5040	1:3987
Avg.	Target	1:2400	1:3656	1:4135	1:3834	1:4600	1:5331	1:5905	1:3696
Avg. Total		1:2168	1:3618	1:3518	1:3933	1:4551	1:5278	1:5449	1:4517
Control Every Fourth Model Plus Along the Centerline of the Highway									
Zeiss	Picture point	1:2354	1:4343	1:6087	1:4819	1:4667	1:5250	1:6709	1:8580
Wild	Picture point	1:2515	1:4316	1:4828	1:5237	1:5357	1:5357	1:5620	1:6931
Avg.	Picture point	1:2434	1:4330	1:5428	1:5028	1:5012	1:5916	1:6164	1:7756
Zeiss	Target	1:2300	1:4375	1:5727	1:5138	1:4286	1:5250	1:7167	1:7939
Wild	Target	1:2482	1:4730	1:4609	1:5166	1:5541	1:6491	1:5375	1:6195
Avg.	Target	1:2391	1:4552	1:5168	1:5152	1:4914	1:5870	1:6271	1:7067
Avg. Total		1:2413	1:4441	1:5313	1:5090	1:4963	1:5894	1:6218	1:7411

[1] Results of the aerotriangulation by the Stereoplanigraph (bridging), using horizontal ground positions and elevations as check points. The control used to compute the bridges is not included in the tabulation.

way). The following comments and Tables 3 through 5 summarize results of these bridging tests.

In Table 4, results are given for the same bridges as compared in Table 3, but in Table 4 the flight height is related to the error on the ground control used to compute the bridges. For example: On the 350 feet per inch scale Wild (photography) target (control), control every fourth model shows 1:2, 658 (Table 3) while the control used to compute the bridge shows 1:7, 500 (Table 4). It should be noted from Table 4 that results are very erratic when control is used in every fourth model. When as few as

TABLE 4

BRIDGING RESULTS FOR CONTROL POINTS

Camera	Control Identification	Scale of Photography (ft/in.) Horizontal Results				Vertical Results			
		350	700	1,050	1,400	350	700	1,050	1,400
Control Every Fourth Model									
Zeiss	Picture point	1:6364	1:89362	1:78750	1:125373	1:5676	1:17500	1:71590	1:64615
Wild	Picture point	1:9130	1:127273	1:57273	1:254545	1:16154	1:56000	1:21000	1:30000
Zeiss	Target	1:7500	1:52500	1:63000	1:105000	1:14000	1:13548	1:42000	1:27097
Wild	Target	1:7500	1:62686	1:94029	1:105000	1:12353	1:42000	1:42000	1:20000
Control Every Fourth Model Plus Along the Centerline of the Highway									
Zeiss	Picture point	1:3281	1:6774	1:6560	1:80000	1:6364	1:10220	1:8720	1:10500
Wild	Picture point	1:3962	1:6462	1:5620	1:5833	1:7143	1:9550	1:10700	1:9130
Avg.	Picture point	1:3621	1:6618	1:6090	1:6917	1:6754	1:9885	1:9710	1:9865
Zeiss	Target	1:3621	1:6462	1:7780	1:7568	1:7692	1:9550	1:12350	1:8155
Wild	Target	1:4545	1:8077	1:5430	1:6087	1:9091	1:10780	1:12350	1:8235
Avg.	Target	1:4083	1:7269	1:6605	1:6827	1:8392	1:10215	1:12350	1:8195
Avg. Total		1:3852	1:6944	1:6347	1:6872	1:7572	1:10025	1:11030	1:9005

TABLE 5

BRIDGING RESULTS FROM COMMON POINTS WITH THE PHOTOGRAPHY, 350 FEET PER INCH SCALE, AS A BASE

Control Identification	Scale of Photography (ft/in.) Horizontal Results			Vertical Results		
	700	1,050	1,400	700	1,050	1,400
Bridging With Control Every Fourth Model						
Picture point	1:3621	1:3728	1:2675	1:9333	1:5294	1:4398
Target	1:3889	1:4375	1:4541	1:8077	1:6300	1:6269
Average	1:3784	1:4091	1:3485	1:8700	1:5833	1:5316
Bridging With Control Every Fourth Model Plus Along the Centerline of the Highway						
Picture point	1:5316	1:4286	1:3443	1:8571	1:5833	1:6043
Target	1:6176	1:5294	1:6087	1:11053	1:7241	1:11507
Average	1:5833	1:4884	1:4565	1:10000	1:6632	1:8235

three control points are used (as was done in using photography of 1,400 feet per inch scale for horizontal bridging) the bridge adjustment fits the control almost exactly and the ratio, flight height to error, is unbelievable. To prove this, the horizontal bridging done using Zeiss camera photography of the 1,400 feet per inch scale was recomputed using 5 control points (3 in the 1st stereoscopic model) instead of 3 (one every 4th model). The ratio decreased from 1:105,000 to 1:15,556 (present thinking is 1:8,000 to 1:12,000) which is still too accurate, but does show an average measurement is not obtained when too few control points are used.

To evaluate the results of establishing horizontal and vertical control points photogrammetrically, the average value obtained by use of photography of 350 feet per inch scale was used, with control every fourth stereoscopic model plus control along the centerline of the highway as a base. In other words, the position and elevation of the points established by using photography of 350 feet per inch scale were used to check the elevation and horizontal position of the same points obtained by separately using the other three scales of photography.

Table 5 gives the bridging results related to flight height, using natural image point and target marked control in photography used from the two cameras (Wild and Zeiss) combined.

All common points between the four scales of photography were used in the tabulation. The photogrammetric instrument operator had to select "compromise image points" on photography of one scale to get image points which would be common to photography of all four scales. It is believed that better results would be obtained if only two scales of photography were involved.

By using all common points, with no rejects, the tabulations appear to be erratic. One point on the photography of 1,400 feet per inch scale, included in the tabulation, had a 10-ft horizontal error. If this test project were an actual bridging and mapping project (with just two scales of photography to be used) selection of the best images for use as bridging points could be made.

Table 7 is a different approach to the question: "Can supplemental horizontal and vertical control be established photogrammetrically from small scale photography for control of large scale photography to photogrammetrically compile topographic maps?"

For such bridging previous tests showed small differences occurred between using photography from the Wild and Zeiss cameras, so for this test only photography from the Wild camera was used. In order for this test to be considered as being accomplished on a "production methods" basis, the control established photogrammetrically

TABLE 6

GUIDE LINES FOR PHOTOGRAPHIC SCALES[1]

Control Identification	Scale of Photography (ft/in.)					
	Horizontal Control			Vertical Control		
	700	1,050	1,400	700	1,050	1,400
Bridging With Control Every Fourth Model						
Picture point	2.3	3.2	6.4	0.9	2.6	4.4
Target	2.0	2.7	3.3	1.1	2.0	2.6
Average	2.1	2.9	4.8	1.0	2.3	3.5
Bridging With Control Every Fourth Model Plus Along the Centerline of the Highway						
Picture point	1.7	3.2	5.7	0.9	2.3	2.9
Target	1.2	2.2	2.7	0.9	1.7	1.6
Average	1.4	2.7	4.2	0.9	2.0	2.2

[1] Tentative guidelines in planning photography for bridging control and for topographic mapping. Accuracy (in feet) to be expected for 90 percent of the points for which horizontal position and elevation are established by bridging using the three scales of photography.

TABLE 7

BRIDGING RESULTS USING IMAGE POINTS COMMON TO ALL PHOTOGRAPHY AND THE GROUND SURVEYED CONTROL AS CHECKS[1]

Photo Scale (ft/in.)	Check or Control Points (No.)	Error (max.)	Error (min.)	Total Error	Avg. Error $\left[\frac{\text{Total Error}}{\text{No. of Points}}\right]$	Algebraic Arithmetic Mean $\left[\frac{\text{Algebraic Sum}}{\text{No. of Points}}\right]$	Standard Deviation $\left(\sqrt{\frac{\Sigma d^2}{N}}\right)$	90 Percent Within (1.65 × S.D.)	B Factor $\left[\frac{\text{Flight Height}}{\text{Avg. Error}}\right]$
					Horizontal				
700	70[2]	3.4	0.1	63.1	0.9	-	1.06	1.75	4,667
	18[3]	2.4	0.1	13.9	0.8	-	0.9	1.48	5,250
1,050	70[2]	4.0	0.3	84.4	1.21	-	1.36	2.24	5,207
	19[3]	3.7	0.4	27.4	1.4	-	1.6	2.64	4,500
1,400	70[2]	5.0	0.1	110.85	1.58	-	1.78	2.94	5,316
	19[3]	6.4	0.2	36.5	1.9	-	2.4	3.96	4,444
					Vertical				
700	121[2]	6.2	0.0	60.5	0.5	0.1	0.8	1.32	8,400
	18[3]	1.1	0.0	73	0.4	0.1	0.5	0.82	10,000
1,050	121[2]	5.7	0.0	128.9	1.1	0.7	1.3	2.15	5,727
	19[3]	1.8	0.0	12.2	0.6	0.0	0.8	1.32	10,000
1,400	121[2]	7.1	0.0	143.5	1.2	0.1	1.6	2.64	7,000
	19[3]	1.4	0.0	8.9	0.5	0.0	0.6	0.99	16,800

[1] Evaluation of aerotriangulation (bridging) with the Stereoplanigraph C8, using the Wild camera photography at a scale of 350 feet/inch. The control used for measuring and computing these bridges was established by photogrammetric bridging using Wild camera photography at the scales at 700, 1,050, and 1,400 feet/inch, which in turn, was controlled by use of ground surveyed control every fourth stereoscopic model.
[2] Check points.
[3] Control used.

consisted of image points. Common points were selected between the four scales of Wild camera photography, and horizontal positions and elevations were obtained from the bridges using control in every fourth model. The 350 feet per inch scale Wild camera photography bridges were computed using control established from bridging done by use of Wild camera photography of the scales of 700, 1,050, and 1,400 feet per inch. To check results obtained from the bridging accomplished using these three separate photography scales, all ground control appearing on the photography of 350 feet per inch scale was tabulated.

Results are erratic. Here again compromise image points were used in order to get conjugation of images on all four scales of photography. Often rejection of one or two points would improve results considerably. This is done on production jobs when two scales of photography are used, rather than four scales as in this test.

On a whole, these results are better than those shown in Table 6. The main differences occur with respect to bridging done using photography of the 1,400 feet per inch scale.

SPACING OF CONTROL FOR BRIDGING

All of the previously described bridges which were measured photogrammetrically were computed with surveyed control in every fourth stereoscopic model or every fourth model plus centerline. The Wild camera photography of 350 feet per inch scale used for this test contained 17 exposures for 16 stereoscopic models. Table 8 summarizes results of varying the surveyed control from every stereoscopic model to every sixth model.

It should be noted that surveyed control spacing has a very small influence on bridging results. In other words, 75 percent of the ground surveyed control could have been eliminated and results would have been the same.

Bridging results shown in Table 8 are better than those in Tables 1 and 2, which were obtained using photographs taken in 1959. The only reason for this difference is that the image points were selected by the Stereoplanigraph instrument operator and the field survey crew established horizontal position or elevation for these office selected image points.

An evaluation of Tables 7 and 8 shows that use of smaller scale photography for bridging gives better results when compared with the flight height. This is caused by "built-in" errors such as camera movement during negative exposure and field surveying errors in measuring control point positions (horizontal and vertical).

From these tests and other production projects, it is recommended that surveys for highway location and design by photogrammetric methods should proceed along the following lines:

TABLE 8

BRIDGING RESULTS FROM DIFFERENT CONTROL SPACING[1]

Control Spaced Every:	Check or Control Points (No.)	Error (max.)	Error (min.)	Total Error	Avg. Error $\left[\frac{\text{Total Error}}{\text{No. of Points}}\right]$	Algebraic Arithmetic Mean $\left[\frac{\text{Algebraic Sum}}{\text{No. of Points}}\right]$	Standard Deviation $\left(\sqrt{\frac{\Sigma d^2}{N}}\right)$	90 Percent Within (1.65 × S.D.)	B Factor $\left[\frac{\text{Flight Height}}{\text{Avg. Error}}\right]$
					Horizontal				
Model	50[2]	2.2	0.1	39.2	0.78	-	0.91	1.52	2,692
	19[3]	0.8	0.1	8.5	0.45	-	0.49	0.81	4,667
Second model	59[2]	2.0	0.0	44.0	0.75	-	0.87	1.43	2,800
	10[3]	0.7	0.2	4.4	0.44	-	0.46	0.76	4,773
Third model	61[3]	2.0	0.1	44.3	0.73	-	0.84	1.39	2,877
	8[3]	0.7	0.1	3.6	0.45	-	0.48	0.79	4,667
Fourth model	62[2]	2.1	0.1	48.1	0.78	-	0.89	1.47	2,692
	7[3]	0.5	0.1	2.5	0.36	-	0.38	0.63	5,833
Sixth model	63[2]	2.0	0.1	48.1	0.76	-	0.86	1.42	2,763
	6[3]	0.5	0.1	1.9	0.32	-	0.34	0.56	6,563
					Vertical				
Model	72[2]	1.4	0.0	31.5	0.44	0.04	0.58	0.96	4,773
	48[3]	0.8	0.0	13.0	0.27	0.03	0.33	0.54	7,778
Second model	103[2]	1.6	0.0	45.7	0.44	0.02	0.58	0.96	4,773
	17[3]	0.6	0.0	3.5	0.20	0.05	0.27	0.45	10,500
Third model	107[2]	1.5	0.0	47.8	0.45	0.08	0.58	0.96	4,667
	13[3]	0.4	0.0	2.2	0.17	0.05	0.20	0.33	12,353
Fourth model	109[2]	1.5	0.0	45.8	0.42	0.01	0.56	0.92	5,000
	11[3]	0.3	0.0	1.7	0.15	0.05	0.19	0.31	14,000
Sixth model	111[2]	1.5	0.0	46.5	0.42	0.08	0.55	0.91	5,000
	9[3]	0.2	0.0	1.3	0.14	0.06	0.15	0.25	15,000

[1] Evaluation of aerotriangulation (bridging) with the Stereoplanigraph C8 using the Wild camera photography at a scale of 350 feet/inch. The amount of ground control used to compute the photogrammetrically measured bridges was varied from every model to every sixth model. Total number of horizontal control points available was 69. Total number of vertical control points available was 120.
[2] Check points.
[3] Control used.

1. Outline the area for location of highway route alternatives on topographic maps which are published on a quadrangle basis.

2. Plan aerial photography flights to obtain photographic coverage of the outlined area and existing horizontal control. For example, if photography at a scale of 1,400 feet per inch is planned, photographs of the usual 9- by 9-in. format will cover a strip area width in excess of two miles for the length of the flight. On some projects, there will be a sufficient number of horizontal control stations to control the bridges; if not, additional horizontal control will have to be surveyed.

3. Set targets on the ground before photography for each horizontal control point. These targets should be in the shape of a cross (plus mark) each leg of which should be 14 feet long on the ground (0.01 inch long on the photography) and 3 feet wide (0.002 inch on the photography). The center 7 feet of the plus mark should be made of dull black material and the four tips (3.5 × 3 feet) of dull white material. The plus mark should be oriented so the legs will be parallel and normal to the photography flight line. Besides control identification, these targets will afford a check on camera motions during exposure and flight-line placement.

4. Obtain the planned 6-in. focal length "distortion free" photography at the scale of 1,400 feet per inch.

5. Identify both existing and essential additional vertical control by selected natural image points for controlling the bridge with two vertical control points in every fourth stereoscopic model (approximately 4 mile spacing along the photography strip).

6. Measure and compute the bridges. Plot the bridging results at a scale of 200 feet per inch and photogrammetrically compile the topographic maps, with contours at a 10-ft interval, of the route band outlined on the small scale quadrangle size topographic map.

7. Project proposed highway centerlines on these 200 feet per inch scale topographic maps and decide on the best alinement location.

8. Stake on the ground and monument a control survey base line, which will be near the proposed location of the highway centerline. This survey base line will be used to control topographic mapping to be done photogrammetrically for highway design and preparation of detailed highway construction plans.

9. Plan photography flight lines to obtain photographs of the proposed highway location corridor. For example, plan for taking photography at a scale of 350 feet per inch which will provide a width of photography coverage of more than 1,400 feet on either side of the flight line.

10. Set targets on the control survey (step 8) at an interval of about 1, 000 feet along the base line. These targets would be in the form of a plus mark (like those for the 1, 400 feet to one inch scale photography) 3. 5 feet long (0. 01 inch on the photography) and 0. 7 of a foot wide (0. 002 inch on the photography) with the center black and the tips white.

11. Obtain 6-in. focal length "distortion free" photography as planned in step 9.

12. Identify image points common between the photography of 1, 400 feet per inch scale and the photography of 350 feet per inch scale. Reset the 1, 400 feet per inch scale photography in the Stereoplanigraph and establish horizontal position and elevation for each of the common points which will be near the edges of the 350 feet per inch scale photographs.

13. Measure and compute the bridges using photography of 350 feet per inch scale and control from the control survey and control established for the image points common to both scales of photography by use of the 1, 400 feet to one inch scale photography. Plot the bridged control points on a manuscript at the scale of 50 feet per inch and compile the topographic maps with contours at a 2-ft interval, or measure profile and cross-sections.

14. Design the highway based on the maps or stereoscopic model measured cross-sections.

15. Using the control survey as positioning origin, compute a description of the centerline of the designed highway and stake it on the ground for construction.

CONCLUSIONS

Stereotriangulation bridging for highway location and design is feasible and economical. It will improve the quality of each photogrammetrically made survey because the plotted position of bridged control points will result in a better individual solution for each stereoscopic model.

Targets will improve the accuracy of horizontal control bridging but may not improve the accuracy of vertical control bridging. Continued research on materials for, and colors, shapes, and placement of targets is needed. Being able to see a target on a contact printed photograph is a long way from making an accurate measurement when it is magnified eight or ten times in the view provided by the Stereoplanigraph for the instrument operator. Most of the usefulness of precise measurements for the horizontal and vertical position of targets is lost whenever the targets do not provide clear definite patterns of good contrast.

Use of photography taken with a camera having an efficient fast shutter should give better bridging results than photography taken with a camera having an efficient slower shutter. Camera movement during exposure causes a fuzzy appearance in the images, and poor lens resolution will also produce fuzzy images; therefore, in order to take advantage of a fast shutter, the resolving power of the lenses (with slow and fast shutter) should be approximately equal. The test results were approximately equal for the two speeds of shutters.

The use of multiple scales of photography for control extension is feasible and will give "by-products" that will more than pay for the photography. Tables 6 and 7 show results to be expected for three different scales of photography.

The spacing of field surveyed control required for stereotriangulation is somewhat nebulous but, at this time, one horizontal and two vertical control points every fourth stereoscopic model will produce results consistent with the photography quality, targets used, and field surveyed control usually obtained.

REFERENCES

1. Harris, W. D., "Aerotriangulation Adjustment of Instrument Data by Computational Methods." U. S. C. and G. S., Tech. Bull. No. 1.
2. Harris, W. D., "Vertical Adjustment of Instrument Aerotriangulation by Computational Methods." U. S. C. and G. S., Tech. Bull. No. 10.