Aerotriangulation Research to Reduce Ground Control Requirements

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Aerotriangulation research conducted by the Wisconsin Department of Transportation to determine the minimum control configuration that would yield accurate photographic control with error-detection capability is described. A new aerotriangulation program package developed for the department's photogrammetry system was used. Conclusions are based on the results of four projects in which 1:3000-scale photography was used at a flying height of 457 m (1500 ft). In the test procedure, an adjustment that used all available control was taken as a basis of comparison in determining a minimum control standard, with redundancy, to allow for detection of single and multiple errors. Accuracies were determined based on the standard deviation of discrepancies among withheld-control points and pass-point movement. The relation between analytical instrumentation, control configuration, and program capabilities has resulted in standards that produce equal adjustments to different projects. The results indicate that the bridging distance between successive vertical wing points and successive horizontal picture points can be as much as six models and all control points can be in double-overlap areas. The new program package has greatly reduced field survey time and increased design flexibility.

An aerotriangulation computer program package has been developed specifically for the analytical photogrammetry system used by the Special Services Section of the Wisconsin Department of Transportation (DOT). This program package consists of integrated computer programs that can perform either fully analytical or semianalytical control extension by using a least-squares simultaneous adjustment of blocks of photographs and several editing routines.

Research was conducted to determine the capabilities and limitations of the new aerotriangulation system and the reduction of ground control allowed in 1:3000-scale photography with a 152-mm (6-in) focal length camera and a flying height of 457 m (1500 ft).

RESEARCH OBJECTIVE

The objective of this research was to determine the minimum ground control configuration required to produce accurate photographic control, in accordance with 1968 Federal Highway Administration standards (1), in 1:3000-scale production projects. Another objective was to determine the ability to detect single and multiple errors in photogrammetric measurements and ground control surveys at various ground control configurations.

SELECTION OF TEST PROJECTS

Four test projects were selected from among projects that had recently been processed by using analytical sequential strip formation and a polynomial strip final adjustment. Since these projects contained many more ground control points than it was believed the new program package would require, they provided an abundance of ground control for use in testing different control configurations and completing the research objectives.

Every attempt was made to select representative projects. Prime consideration was given to such variables as (a) the length of photographic strips, (b) multiple strip configuration, (c) the quality of analytical instrumentation, and (d) the quality, configuration, and type of ground control.

TESTING PROCEDURE

A basis of comparison was needed to test the results of the four production test projects. An overabundance of the ground control required for a simultaneous adjustment made it possible to withhold many ground control points from various adjustments for use as test points.

An adjustment in which all available ground control was used became a basis of comparison with all subsequent test runs for determining a minimum control standard. Control points were withheld from each solution to determine the accuracy of the adjustment. "Pass-point" movement was also determined to indicate the adjusted coordinate strength of pass points used in compilation (a pass point is a photographic control point that is mechanically produced in the analytical process and is usually not identifiable on the ground). A root-mean-square error was calculated for discrepancies among points at which control was withheld and differences of pass-point positions based on a comparison of coordinates for total control adjustments and minimum control adjustments. Additional tests were made by using a vertical ground control point in the center of each model because the policy of the Special Services Section requires these points for stereoplotter indexing.

The capability to detect single and multiple ground control errors was also tested and incorporated into the final control standards for horizontal and vertical control. Analysis of error-detection tests yielded several guidelines that were used to help determine the minimum control configuration. The magnitude of detectable error appears to be 0.18 m (0.6 ft) in coordinates X, Y, and Z. This type of error, however, does not always show up at the point itself within the polynomial or simultaneous adjustments.

RESULTS

Projects

Each of the four projects tested contributed to the development of control standards for production projects that use 1:3000-scale photography:

1. Project 1 (see Figures 1-4)—Three strips were run to form a block configuration of 21 models representative of most flight designs covering a highway corridor. All ground control points were targeted.
2. Project 2 (see Figures 5 and 6)—Two cross-flight strips were run to form a block configuration of 14 models representative of highway interchange areas. Ninety percent of ground control points were targeted.
3. Project 3 (see Figures 7 and 8)—One long strip of 25 models was selected to test the strength of strip formation orientation and simultaneous adjustment. Ninety percent of ground control points were targeted.
4. Project 4 (see Figures 9 and 10)—This 17-model strip was tested because it appears to be the optimum length for maintaining strong analytic orientation during strip formation. This strip was considered to have weak analytic orientation compared with the other three projects tested.

The root-mean-square discrepancies at the control points and pass points for the four projects tested are given in Table 1.

Standards

Figure 11 shows samples of the ground control standards determined by the Wisconsin DOT for 1:3000-scale photography. These standards are summarized below.

Horizontal Control

1. All horizontal control points may be double overlap.
2. Each strip must contain four horizontal points for redundancy.

Figure 1. Total control configuration: project 1, run A.

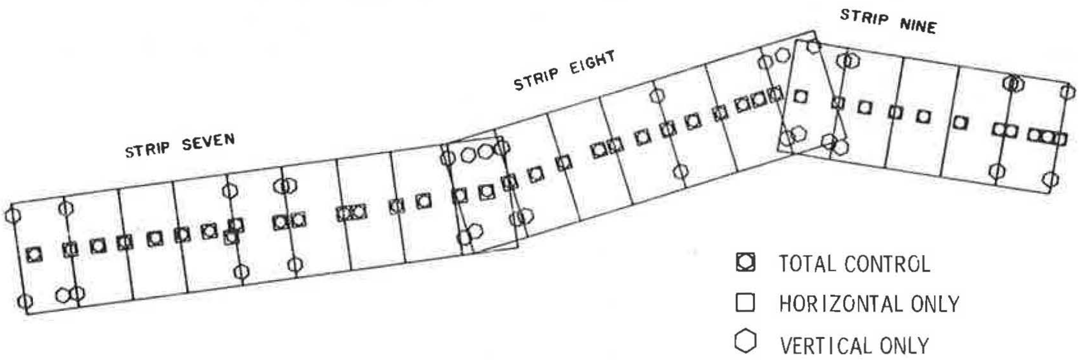


Figure 2. Minimum control without vertical index points and without redundancy: project 1, run B.

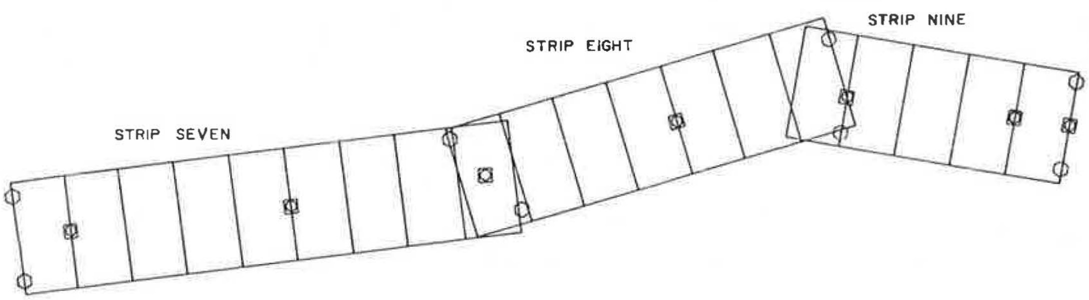


Figure 3. Minimum control with vertical index points and redundancy: project 1, run C.

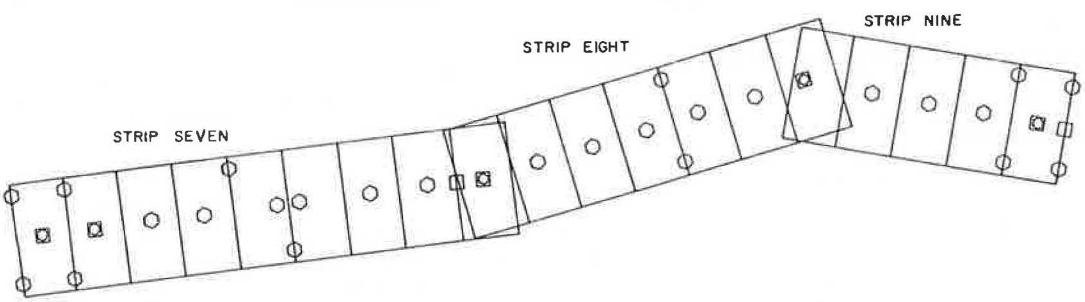


Figure 4. Minimum control with vertical index points and redundancy: project 1, run D.

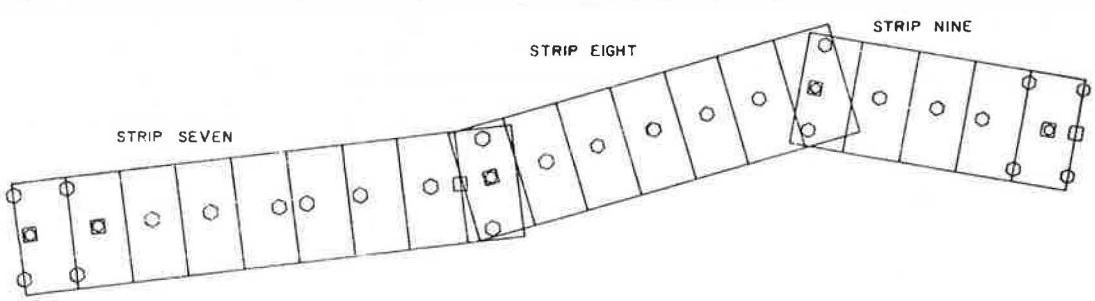


Figure 5. Total control configuration: project 2, run A.

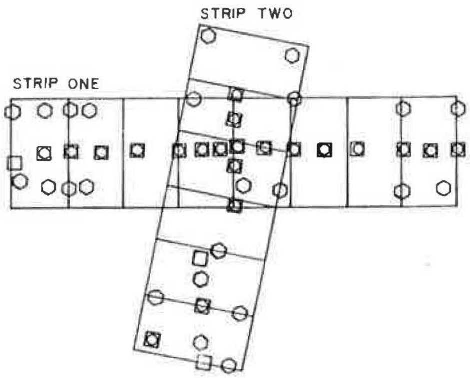


Figure 6. Minimum control with vertical index points and redundancy: project 2, run B.

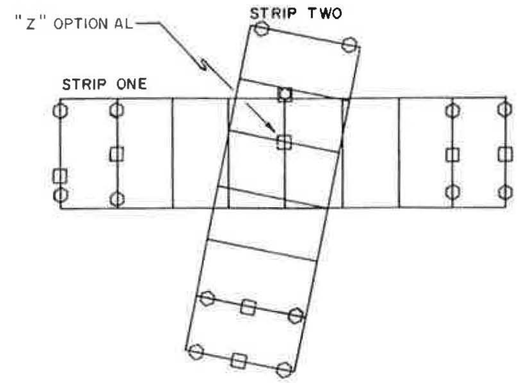


Figure 7. Total control configuration: project 3, run A.

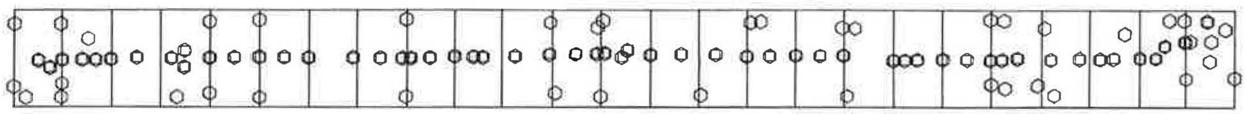


Figure 8. Minimum control with vertical index points and redundancy: project 3, run B.

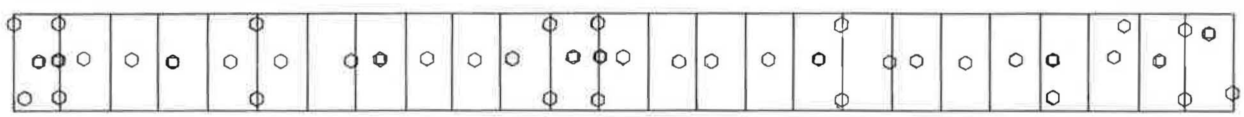


Figure 9. Total control configuration: project 4, run A.

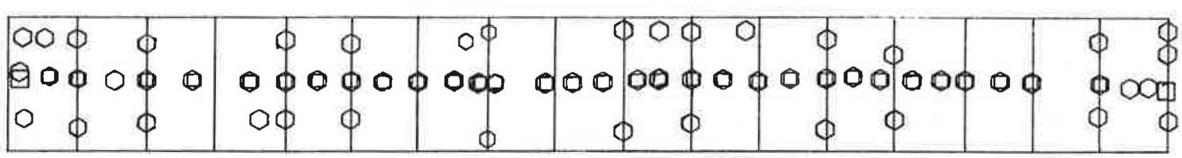


Figure 10. Minimum control with vertical index points and redundancy: project 4, run B.

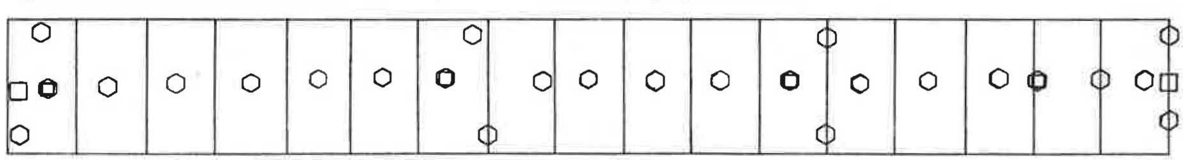
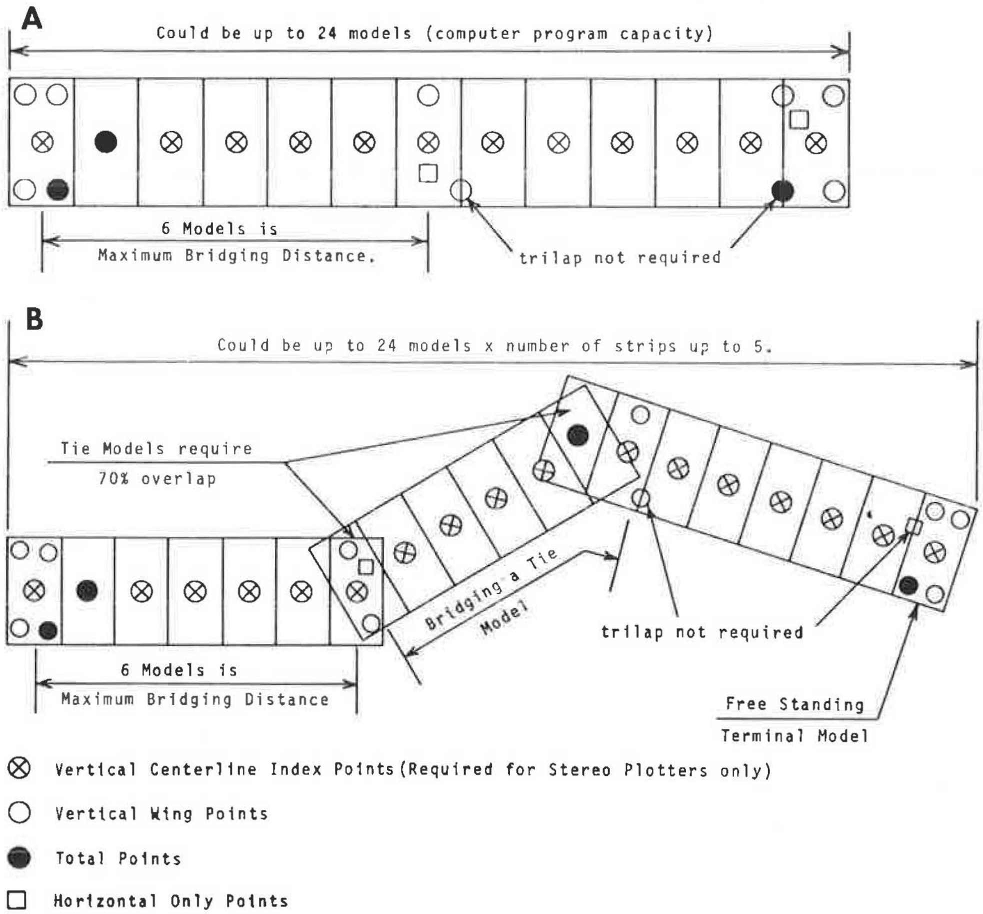


Table 1. Root-mean-square error of control and pass points for coordinates X, Y, and Z.

		Root-Mean-Square Error (m)								
		Control Held			Control Withheld			Pass-Point Movement		
Project	Run	X	Y	Z	X	Y	Z	X	Y	Z
1	A	0.018	0.020	0.027						
	B				0.043	0.030	0.048	0.035	0.025	0.034
	C				0.043	0.043	0.043	0.025	0.027	0.021
	D				0.044	0.044	0.039	0.026	0.026	0.019
2	A	0.016	0.028	0.031						
	B				0.024	0.056	0.038	0.022	0.041	0.026
3	A	0.028	0.026	0.037						
	B				0.033	0.037	0.048	0.019	0.026	0.028
4	A	0.032	0.026	0.029						
	B				0.063	0.043	0.051	0.053	0.038	0.036

Note: 1 m = 3.28 ft.

Figure 11. Ground control points required (a) for single strips and (b) for multiple strips.



3. At least one horizontal point is required in each terminal model of each individual strip of a block solution.

4. The horizontal control-point spacing may be as much as six models or seven triple overlaps (trilaps).

5. "Tie" models (points of overlap between strips) within a strip block type of adjustment must contain at least one horizontal point.

6. All horizontal points may be placed along the centerline of a flight strip or may coincide with wing-point placement (a wing point is a picture point on either side of a strip of photographs, usually surveyed for only vertical control).

Vertical Control

1. All vertical control points may be double overlap.

2. The free-standing terminal models of a strip block type of adjustment must contain total wing-point design and one centerline index point for redundancy.

3. The vertical control-point spacing may be as much as six models or seven triple overlaps when centerline index points exist.

4. Wing points should be located as far out from the center of the model as is physically possible.

5. The flexibility in vertical control design provides the ability to bridge tie models between strips in a block configuration and incorporate this area within the six-model wing-point spacing.

6. The length of individual strips is limited to 17 models because of a deterioration of interior orientation during strip formation, which is not offset by the simultaneous adjustment without use of additional control. Strips that exceed 17 models in length may be split without using full terminal control by treating them as a tie model.

CONCLUSION

Aerotriangulation research conducted by the Wisconsin DOT has been successful in determining new ground control standards for use in large-scale highway mapping and determining pay-quantity cross sections on highway construction projects. The need for sufficient redundant control was incorporated into the standards to make it possible to detect errors during aerotriangulation. These standards for ground control have resulted in a substantial reduction in field work and increased flexibility in the placement of control points.

In the aerotriangulation system developed by the Wisconsin DOT, the average horizontal positional error distribution of photogrammetric control has a standard deviation of approximately 1 part in 10 000 of the project flying height. The error in vertical position has only a slightly larger standard deviation than that in horizontal position. The accuracies obtained are the result of good survey procedures and ground control, properly calibrated analytical equipment, and a simultaneous aerotriangulation adjustment program.

REFERENCE

1. Reference Guide Outline Standards: Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways. Federal Highway Administration, U.S. Department of Transportation, 1968.

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