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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOLOGIC MAPPING OF TUNNELS USING PHOTOGRAMMETRY--CONTROL-POINT CONFIGURATION

by

Jeffrey A. Coe and Keld S. Dueholm

Open-File Report 90-37

Prepared in cooperation with the
U.S. Department of Energy
(Interagency Agreement DE-AI08-78ET44802)

Denver, Colorado
1991

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GEOLOGIC MAPPING OF TUNNELS USING PHOTOGRAMMETRY--
CONTROL-POINT CONFIGURATION

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ABSTRACT

A photogrammetric method has been developed by the U.S. Geological Survey and the U.S. Bureau of Reclamation for use in geologic mapping of tunnels (drifts). The method requires photographing the tunnel walls and roof with a calibrated small-format camera to obtain stereo pairs of photos which are then oriented in an analytical stereo plotter for measurement of geologic features. The accuracy of the mapping depends, in part, on the control configuration used to orient the photos.

Accuracy experimentation using a block of 16 small-frame-stereoscopic models was performed. Systematic control configurations were tested, using bundle adjustment calculations, to determine the effect on the absolute accuracy of point measurements in oriented blocks of photos. Surveyed targets and camera-station coordinates were used as control. Fifteen control targets produced reliable and robust-orientation results with RMS coordinate errors less than 3.0 mm. Four control targets, combined with 20 camera stations, produced equally good results.

INTRODUCTION

A photogrammetric method for underground geologic mapping of tunnels (drifts) is being developed by the U.S. Geological Survey and the U.S. Bureau of Reclamation. The mapping method consists of: 1) placement of control-point and tie-point targets on tunnel walls (ribs) and roof (back), 2) surveying the three-dimensional coordinates of control-point targets, 3) photographing tunnel walls and roof with a calibrated small-format camera from positions along the tunnel centerline to obtain blocks of overlapping stereo photos, 4) orienting the blocks of stereo photos to the surveyed control-point coordinates in an analytical stereo plotter, and 5) stereo measurement of geologic features in the analytical plotter (i.e., digital three-dimensional point collection and calculation of geologic structural parameters). The accuracy of the mapping depends, in large part, on the control configuration used to orient the photos.

Our intention in this paper is to describe and present the results from an experiment designed to evaluate absolute cartographic accuracy as a function of the number and position of control points used to orient the photos. From the results of the experiment we define one or more control configurations that minimize the number of control points (surveyed targets), thus, reducing time spent underground, while maintaining acceptable accuracy. Absolute cartographic accuracy, as used here, refers to the degree of conformity of point measurements, gathered by photogrammetric means from an oriented block of stereo photos, to the ground coordinate system being used. We express absolute cartographic accuracy in terms of root mean square coordinate errors (RMS) for each configuration tested.

Photos and Targets

All configurations tested consisted of 20 photos and 45 targets configured according to principles described by Coe and Dueholm (1990). Target placement and photography took place in G-tunnel on the Nevada Test Site. Photos were taken using a Rollei 6006 camera with a 40-mm lens. Nine targets appeared in each photo so that six targets occurred in each 60 percent stereo-model overlap, and three occurred in each 20 percent sidelap (fig. 1). All targets were surveyed. Therefore, any target could be used either as a control point or a tie point in bundle adjustment calculations. Under production conditions the same number of targets would be used, but only targets designated as control points would need to be surveyed (i.e., tie-point targets will be positioned but not surveyed).

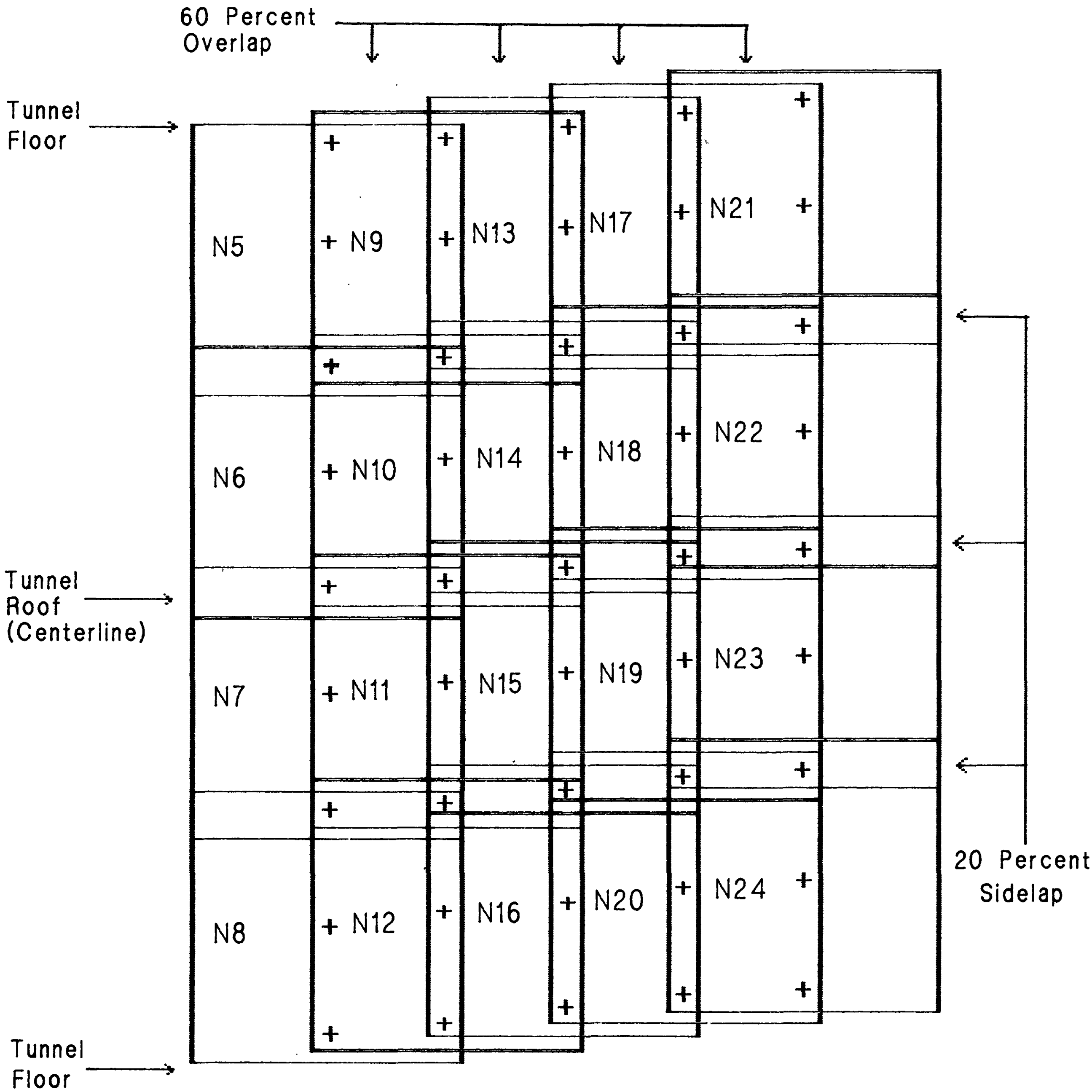


Figure 1. Photo and target configuration in the test tunnel (shown in full periphery projection equivalent, ie, projected onto the theoretically defined tunnel walls and then unfolded). + = targets

Photos were developed and printed on two 8-X-10-inch film positives called templates. Each template contained alternating left photo, right photo, columns and "reseau-like" marks ("template tick marks") in each corner (fig. 2). The pair of templates covered a linear distance of approximately 6.4 m in the "down" tunnel direction of the test area. The tunnel was approximately 6.4 m wide by 4.3 m high.

Camera-Station Coordinates

Camera-station coordinates were used as additional control in combination with some of the selected control-point configurations. This was done to determine how the additional control would effect the absolute accuracy and the control-point requirements in case it is practical to survey the location of each camera station in the tunnel. Addition of camera-station coordinates is a way to further strengthen the adjustment and(or) reduce the number of control points. As camera stations were not surveyed in the field, their coordinates were photogrammetrically resected from the surveyed targets (see Measurements and Adjustments).

Orientation and Adjustment Methods

Template registration and target measurements were made on the USGS Micro-Vax II computer/Kern DSR11 analytical stereo plotter system utilizing the multi-model software package (Dueholm, 1990) called ORIPROGRAM in this report.

Template registration is divided into two parts, template orientation and orientation of individual photos on each template. Templates are oriented in the DSR11's plate coordinate system by measuring the location of the template-tick marks (fig. 2) on the stage plates of the plotter. This procedure establishes plate to template transformation matrices. Orientation of individual photos is based on calibrated camera reseau mark coordinates supplied by the camera manufacturer (Rollei). Each photo is oriented by measuring a minimum of 4 reseau marks, transforming the measurements to template coordinates, and calculating template to photo transformation matrices. Each individual photo orientation defines a reference coordinate system (photo coordinates) which is used for subsequent measurements. This two-step registration process makes it possible for all of the photos on each template to be oriented as a group.

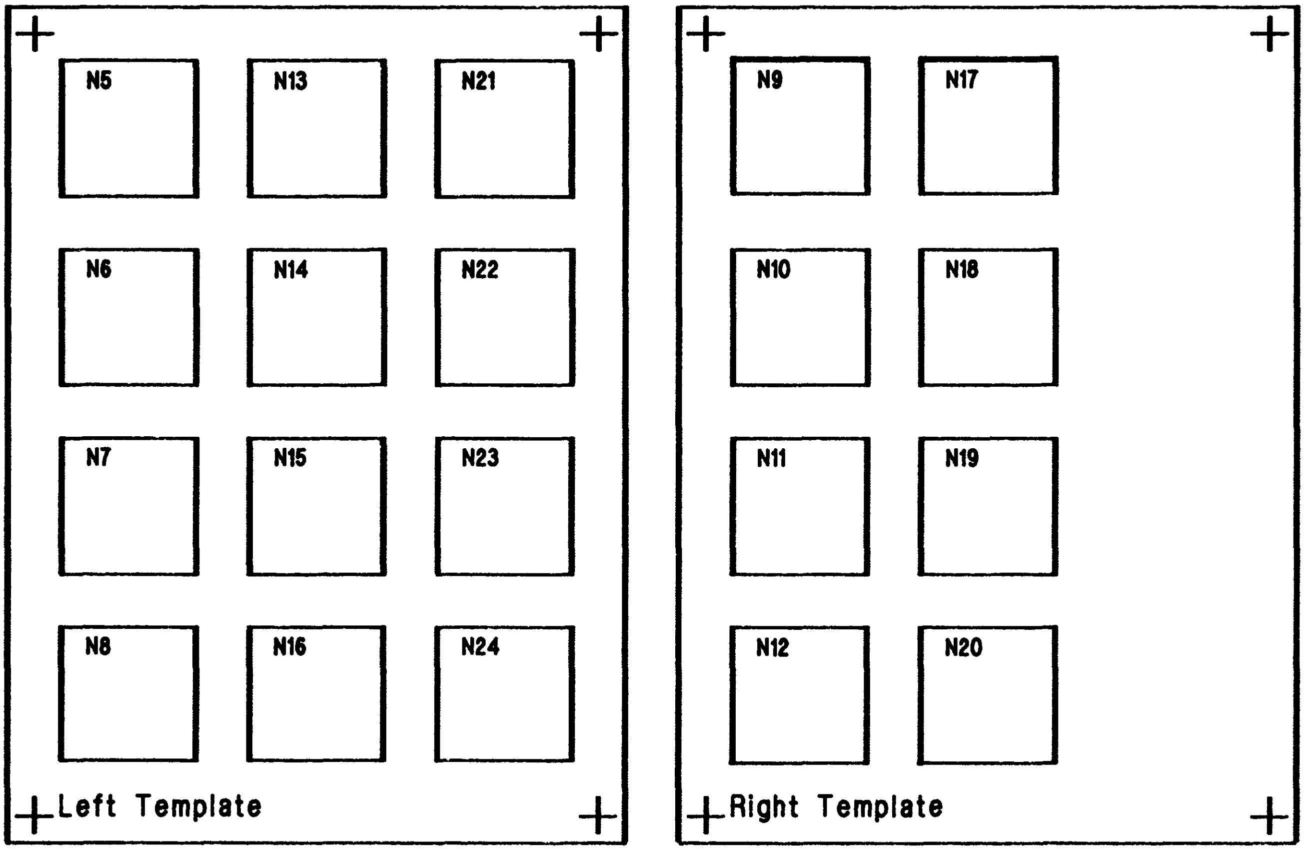


Figure 2. Diagram showing the placement of photos on left and right templates used in the analytical plotter. Crosses in the corners of each template are template tick marks used for template registration. Photo numbers are the same as in figure 1.

Residuals between the calibrated reseau coordinates and the measured (transformed) coordinates from our individual photo orientations were inconsistent, ranging from 1 to 21 micrometers in the X direction and from 1 to 13 micrometers in the Y direction. Typically, residuals on metric camera fiducial marks or reseau marks are from 3 to 5 micrometers. The higher standard deviation in this experiment may be due to some instability in the Rollei camera. An investigation of the camera by the manufacturer is currently (September 1989) underway.

Photo coordinates of the targets were measured monoscopically in the DSR11. Targets that were difficult to see in single images were measured stereoscopically. Depending on the configuration tested, measured targets were used as control or tie points in the ORIPROGRAM exterior orientation calculations.

The Generic Bundle Adjustment (GBA) module (Dueholm, 1989) of ORIPROGRAM was used to calculate the exterior orientation of the photo block using different control-point configurations. A bundle-block adjustment reduces the number of control points needed for photo block orientation as compared to the number needed when single stereo models are oriented individually. Adjusted values for control points and tie points calculated by the GBA were compared to the corresponding surveyed target coordinates. Differences in X, Y, and Z values at each point were used to calculate overall root mean square error (RMS) values, systematic errors, and maximum differences in X,Y, and Z for each configuration tested.

MEASUREMENTS AND ADJUSTMENTS

Calculating Standard Deviations

The GBA performs a weighted adjustment of photo and surveying observations to determine an exterior orientation for the block of photos. The GBA uses the inverse square of an a priori error value to weight each observation. The a priori error value is determined by the GBA from the observation standard deviations entered by the user. The two types of observations in this experiment were photo and survey measurements.

The standard deviation of photo measurements was computed by running the GBA using two XY control points and three Z control points. All other targets were used as tie points only. This configuration created no redundancy in the control-point coordinates, thus, the resulting standard error unit weight was a measure of the "correctness" of the applied a priori error on photo measurements. The standard deviation was modified after successive GBA runs until the standard error unit weight computed by the adjustment was equal to 1.0. In this manner, the photo measurement standard deviation was found to be 7 micrometers. The Kern DSR11 instrument precision is 1 to 3 micrometers and the operator's repetition error is 2 to 3 micrometers, which should result in a photo measurement standard deviation of 4 micrometers or less. The high value of 7 micrometers found in this experiment may reflect the capability of the Rollei camera and coincide with the reduced accuracy results obtained on the reseau cross measurements.

The standard deviation of the surveyed targets coordinates was determined by running the GBA using all 45 targets as control points in a GBA calculation with the photo measurement standard deviation set to 7 micrometers. The standard deviation of the surveyed coordinates was modified after successive GBA runs until the standard error unit weight was equal to 1.0. In this manner, the standard deviation on surveyed target coordinates was found to be 1.8 mm, which is in accordance with the accuracy estimated by the surveyors.

From the same adjustment calculation as described above (using 45 control points) the individual camera station coordinates were calculated. As the camera stations were not surveyed in the tunnel, this provided the most accurate camera-station coordinates available. The computed standard deviations on camera-station coordinates varied from 0.9 mm to 3.0 mm. The mean value was 1.6 mm which is less than the 1.8 mm standard deviation on surveyed target coordinates. Therefore, experimental results using these camera-station coordinates in addition to control-points (configurations 15B-4B, described in Control-Point Configurations) should be relatively reliable.

Addition of Tie Points

No surveying or photo measurement blunders were detected. However, target 11 in photo N21 was covered by hanging electrical wires in the tunnel. To replace the missing target a natural tie point was measured in images N21 and N17.

Control-Point Configurations

Selection of the control-point configurations that were tested was controlled by the need for ease of underground surveying and symmetrical control-point distributions to minimize systematic errors. Skipping entire target columns was preferred for the ease and quickness of surveyor setups. Also, configurations that contained control points around the periphery of the block of photos were necessary to avoid uncontrolled error propagation along the edges of the block.

Seven configurations (appendix A: 45A, 37A, 27A, 15A, 9A, 6A, 4A) were tested using from 45 to 4 targets as control points. Four configurations (appendix C: 15B, 9B, 6B, 4B) were tested using the 20 camera station X,Y,Z coordinates as additional control. Finally, single control points were systematically dropped out from the most feasible configuration to determine the robustness of the block if points were missing. These configurations (appendix B: 14A, 14B, 14C, 14D, 14E, 14F) were based on the 15A configuration with 1 control point dropped out at each symmetrically possible location.

RESULTS

A computer program was implemented that read the adjusted coordinate values (Xa, Ya, Za) from the GBA output file and compared them to the surveyed coordinates (Xs, Ys, Zs). RMS values (Mx, My, Mz) and systematic errors (Sx, Sy, Sz) were calculated according to the following formulas:

$$Mx = \sqrt{\sum_i (Xa_i - Xs_i)^2/n}$$

$$My = \sqrt{\sum_i (Ya_i - Ys_i)^2/n}$$

$$Mz = \sqrt{\sum_i (Za_i - Zs_i)^2/n}$$

$$Sx = \sum_i (Xa_i - Xs_i)/n$$

$$Sy = \sum_i (Ya_i - Ys_i)/n$$

$$Sz = \sum_i (Za_i - Zs_i)/n$$

where $i = 1, n$

The maximum errors in X, Y, and Z were calculated and their target numbers were identified. Table 1 contains the RMS, systematic, and maximum error results from all configurations tested. Figures 3, 4, and 5 show RMS values plotted as a function of the configuration for 45A-4A (appendix A), 14A-14F (appendix B), and 15B-4B (appendix C), respectively.

CONFIGURATION	RMS (meters)			SYSTEMATIC ERROR (meters)			MAXIMUM ERROR (meters)					
	X	Y	Z	X	Y	Z	X	Pt. #	Y	Pt. #	Z	Pt. #
45A	0.0013	0.0016	0.0014	0.0000	0.0000	0.0000	0.0032	44	0.0034	38	0.0037	32
37A	0.0014	0.0018	0.0014	0.0000	0.0000	-0.0002	-0.0038	17	-0.0041	11	0.0034	32
27A	0.0015	0.0018	0.0015	-0.0001	0.0001	0.0002	-0.0039	17	0.0037	35	0.0053	32
15A	0.0019	0.0027	0.0019	0.0000	-0.0001	-0.0006	-0.0052	38	0.0067	38	-0.0052	40
9A	0.0021	0.0032	0.0030	-0.0001	0.0006	-0.0019	-0.0071	38	0.0088	8	-0.0078	40
6A	0.0022	0.0032	0.0029	-0.0004	0.0011	-0.0018	-0.0074	38	0.0091	8	-0.0074	40
4A	0.0053	0.0059	0.0026	0.0039	-0.0041	-0.0001	0.0085	42	-0.0109	4	0.0075	32

Configurations 45A-4A (see Appendix A)

CONFIGURATION	RMS (meters)			SYSTEMATIC ERROR (meters)			MAXIMUM ERROR (meters)					
	X	Y	Z	X	Y	Z	X	Pt. #	Y	Pt. #	Z	Pt. #
14A	0.0020	0.0027	0.0019	-0.0003	-0.0001	-0.0007	-0.0052	38	0.0067	38	-0.0052	40
14B	0.0019	0.0027	0.0019	-0.0002	-0.0001	-0.0006	-0.0052	38	0.0067	38	-0.0051	40
14C	0.0019	0.0027	0.0019	-0.0001	-0.0002	-0.0005	-0.0051	38	-0.0067	44	-0.0051	40
14D	0.0019	0.0027	0.0018	-0.0001	-0.0001	-0.0005	-0.0052	38	-0.0067	44	-0.0049	40
14E	0.0019	0.0027	0.0019	0.0000	-0.0001	-0.0008	-0.0052	38	-0.0068	44	-0.0052	40
14F	0.0019	0.0027	0.0019	0.0000	0.0000	-0.0006	-0.0052	38	0.0067	38	-0.0052	40

Configurations 14A-14F (see Appendix B)

CONFIGURATION	RMS (meters)			SYSTEMATIC ERROR (meters)			MAXIMUM ERROR (meters)					
	X	Y	Z	X	Y	Z	X	Pt. #	Y	Pt. #	Z	Pt. #
15B	0.0018	0.0025	0.0018	-0.0001	0.0001	-0.0005	0.0048	44	0.0064	38	-0.0051	40
9B	0.0020	0.0027	0.0020	-0.0002	0.0006	-0.0006	-0.0056	38	0.0074	8	-0.0059	40
6B	0.0021	0.0027	0.0020	-0.0004	0.0008	-0.0004	-0.0058	38	0.0076	8	-0.0057	40
4B	0.0022	0.0026	0.0019	-0.0004	0.0007	-0.0001	-0.0054	38	0.0071	8	-0.0053	40

Configurations 15B-4B (see Appendix C)

TABLE 1. RMS values, systematic errors, and maximum errors from all configurations tested.

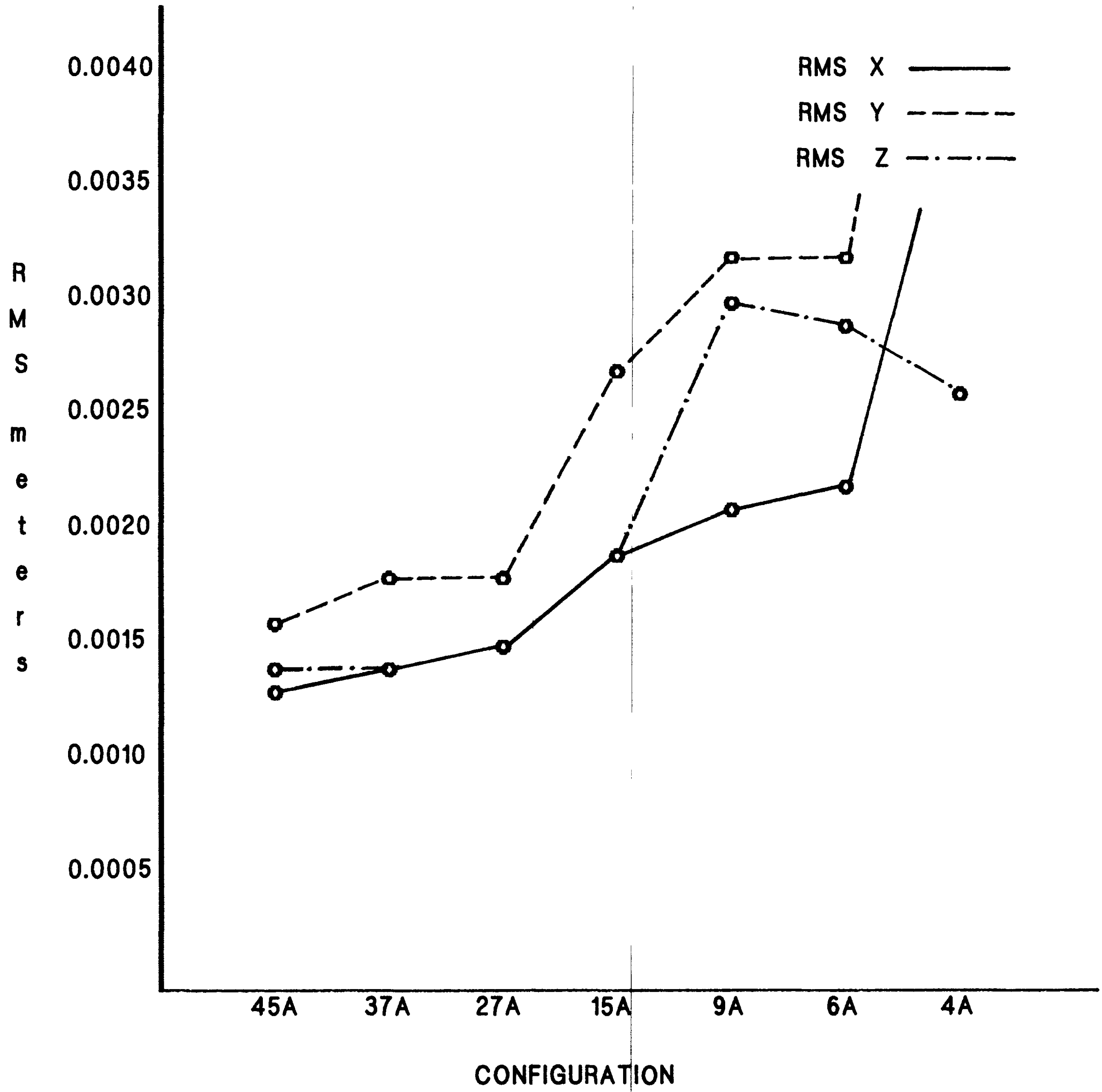


Figure 3. RMS values plotted as a function of configurations 45A-4A.

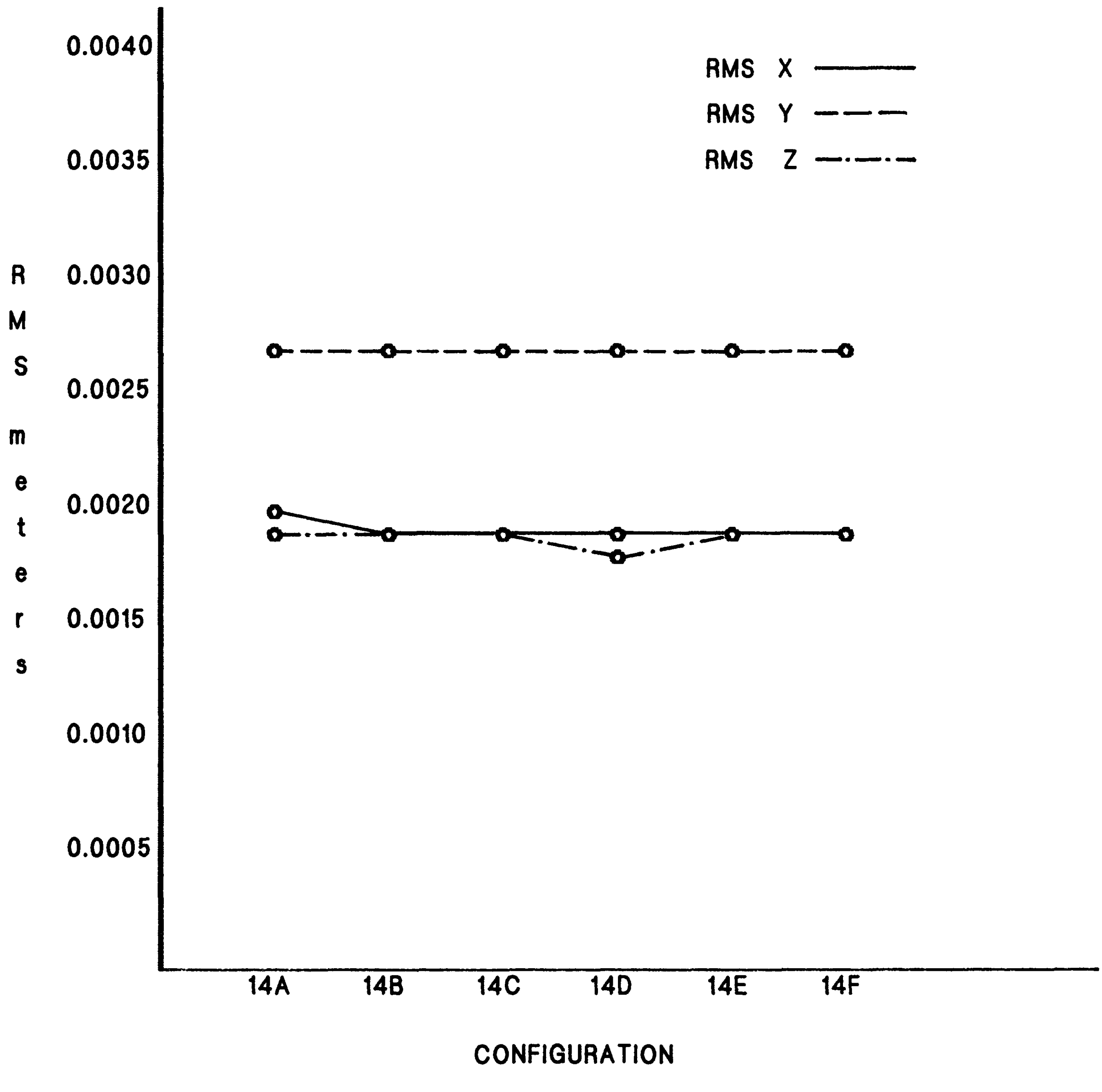


Figure 4. RMS values plotted as a function of configurations 14A-14F.

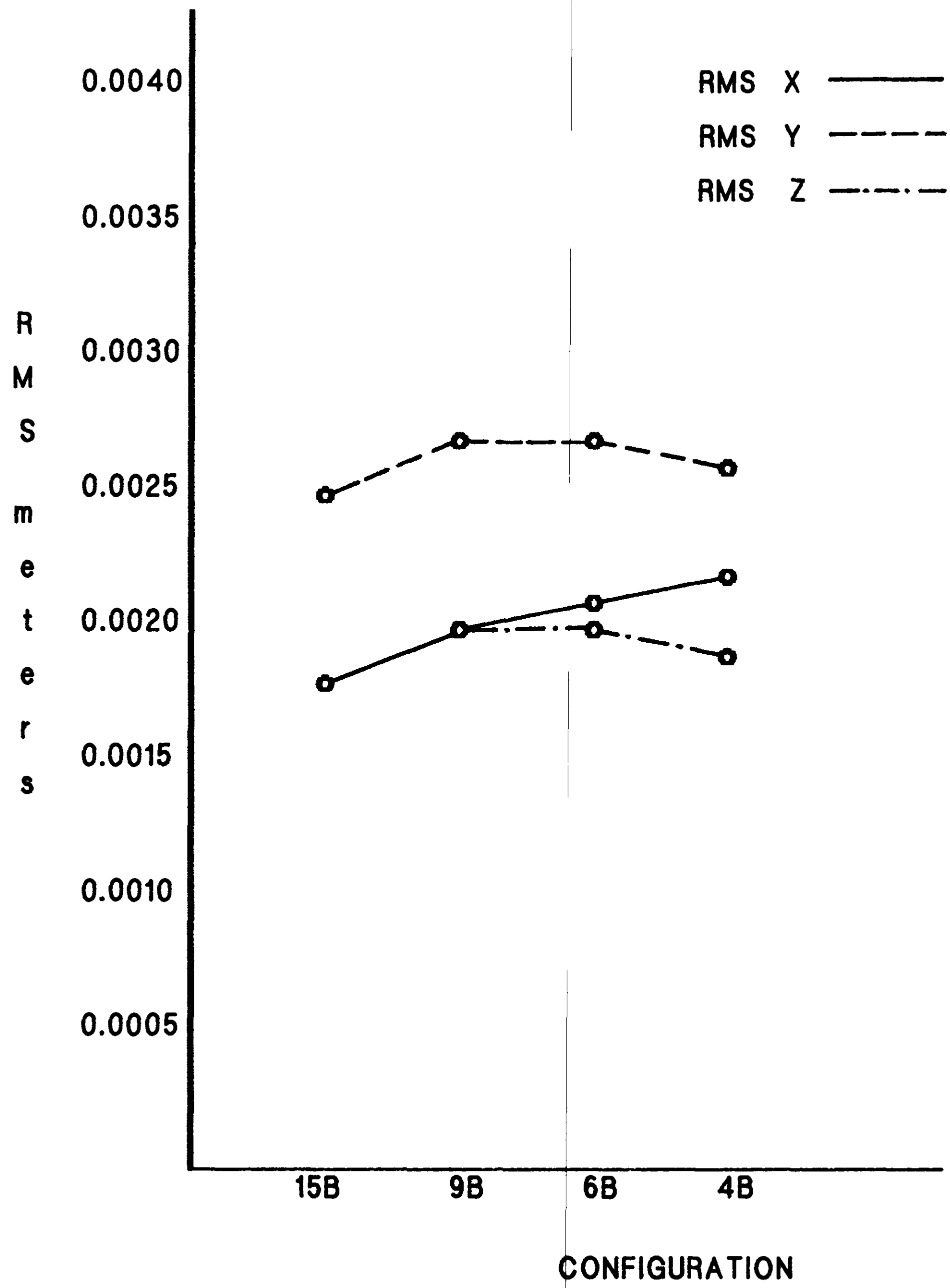


Figure 5. RMS values plotted as a function of configurations 15B-4B.

Configurations using Surveyed Targets only

The maximum accuracy achievable using all surveyed targets as control points is shown by the results from the 45A configuration. As seen in table 1 and figure 3, the RMS values from the 45-point configuration were less than 1.8 mm in the X, Y, and Z directions. Systematic errors were negligible and the maximum error values were within tolerance (less than three times the RMS values). From configurations 45A to 6A, RMS, systematic, and maximum error values gradually increased. At the 4A configuration all errors jumped dramatically, with very high systematic errors in the X and Y directions, indicating an unstable configuration. Until the 4A configuration, RMS values on all coordinates were less than 3.5 mm. However, the 9A and 6A configurations had relatively high systematic errors in the Z direction showing some instability. This indicates that the 15-point configuration (appendix A, 15A) is the most feasible. The 15A configuration results (table 1 and fig. 3) show RMS values less than 3.0 mm in all coordinates and acceptable low systematic errors. In addition, as configurations 9A and 6A produce relatively good results, a reasonable safety margin seems to exist for the 15A configuration. Results from 14A-14F configurations support this safety margin assessment. Table 1 and figure 4 show that no significant change in error values occurs between the 14A-14F configurations and the original 15A configuration. This indicates that one point could safely be dropped out at any location in the 15A configuration and the same accuracy would still be maintained.

Configurations using Surveyed Targets and Camera-Station Coordinates as Control

Using the camera stations as additional control significantly strengthened the adjustment and enhanced the accuracy results (see 15B-4B in table 1 and fig. 5). In general, the fewer control points used, the larger the difference in results when camera-station coordinates were added. When comparing the 15B-4B results to the 15A-4A results (table 1 and fig. 3) the most noticeable difference is in the 9-4 point configurations. The 9B and 6B point configurations are 0.5 to 1.0 mm better in X and Y RMS values compared to 9A and 6A. The 4B configuration is stable and achieves about the same accuracy results as the 15A configuration. Systematic errors are acceptable for 9B-4B, where they were not for 9A-4A.

SUMMARY

Fifteen surveyed targets (appendix A, 15A) should be used as a minimum requirement to achieve a reliable orientation result for a block of 20 photos. The 15A configuration uses every other target, in every other column, starting in the first column at the tunnel floor, as control points. This configuration produced RMS coordinate accuracy of less than 3.0 mm (table 1 and fig. 3). The 15A configuration will maintain the same accuracy if one point is dropped from any location in the block (14A-14F, appendix B, table 1, and figure 4).

Including all 20 camera stations as additional control information significantly strengthens the block to the point where only four surveyed targets are needed. Four surveyed targets, one in each corner of the block, combined with surveyed camera stations; or 15 targets alone, give equally good results (see 4B and 15A in table 1). It is a matter of surveying convenience which is chosen.

If additional columns of photos are added to the block being oriented and the number of photo and target columns is even, instead of odd, as in this experiment, the same general control point configuration as used in 15A, supplemented with five additional surveyed targets in the even numbered column, is recommended (fig. 6).

The relatively high photo-measurement standard deviation of 7 micrometers obtained in this experiment reflects the present capability of the Rollei camera. A different camera may further reduce the need for surveyed targets and may slightly increase the accuracy.

ACKNOWLEDGMENT

This experiment was funded by the U.S. Department of Energy (Interagency Agreement DE-AI08-78ET44802).

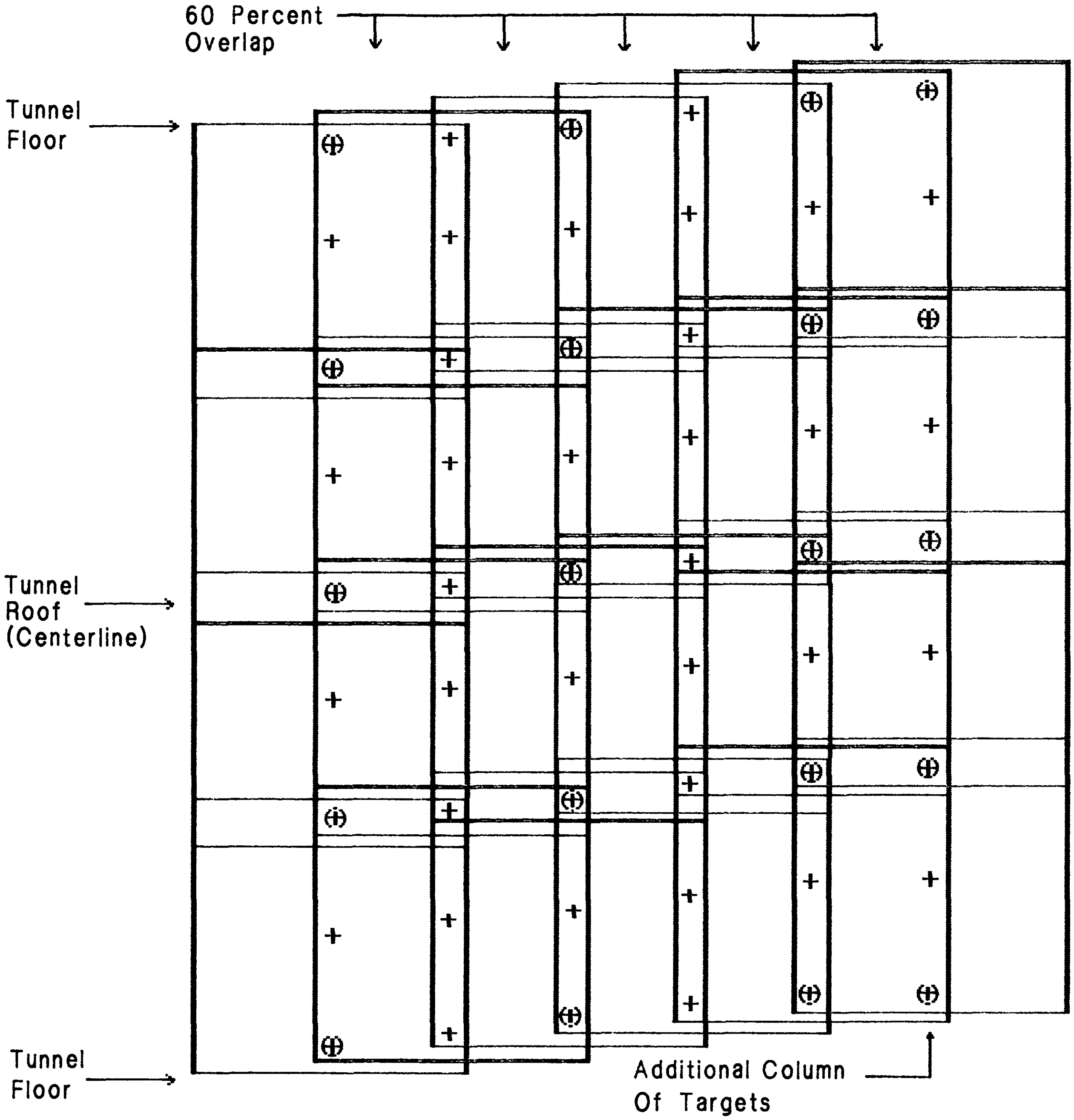


Figure 6. Possible control configuration if one additional photo/target column is added to the block. ⊕ = targets used as control points, + = targets used as tie points.

REFERENCES CITED

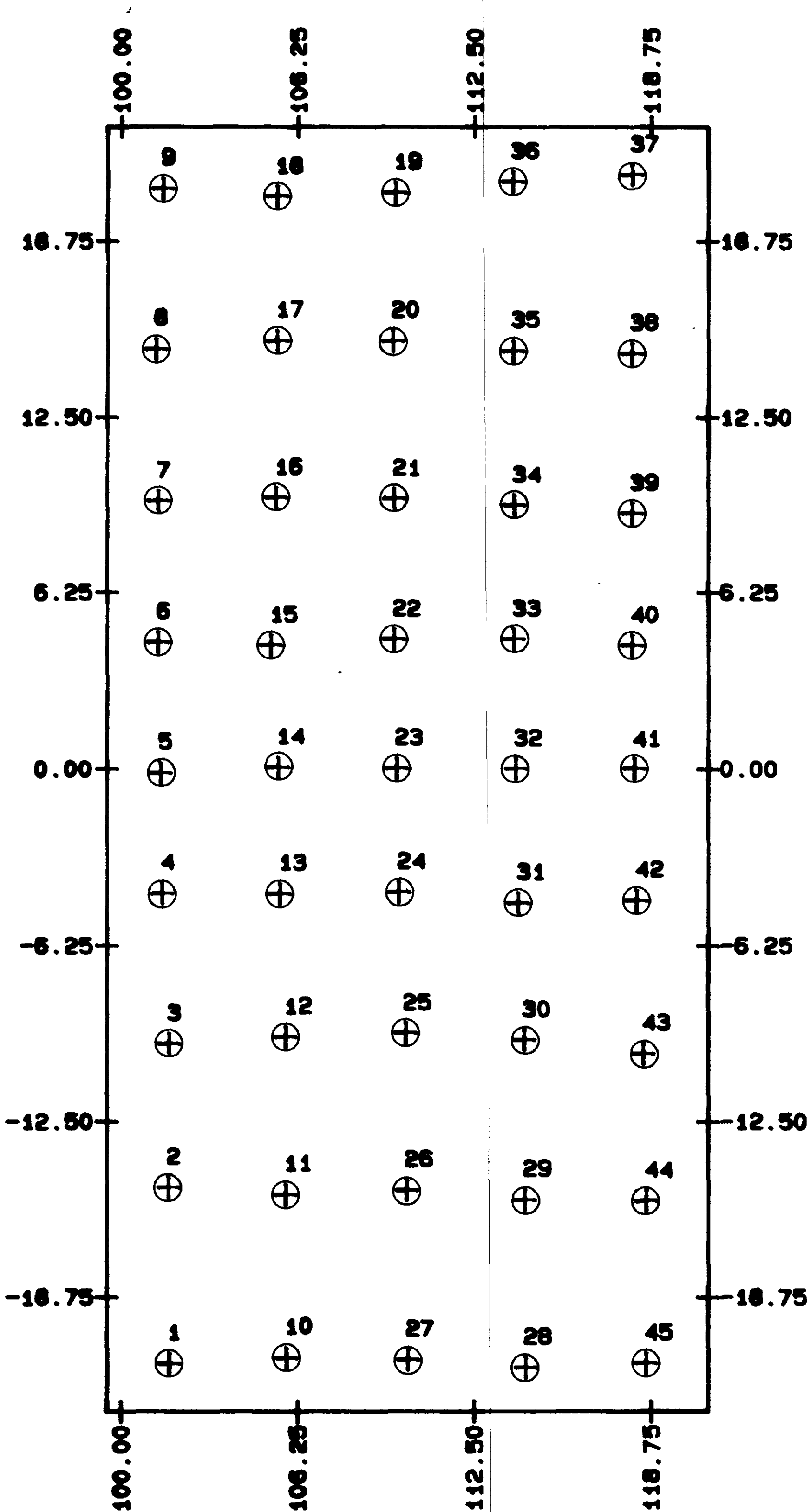
Coe, J.A., Dueholm, K.S., 1990, Geologic mapping of tunnels using photogrammetry--target and camera positioning, U.S. Geological Survey Open-File Report 90-49, 15 p. NNA.901031.0002

Dueholm, K.S., 1989, Generic Bundle Adjustment, U.S. Geological Survey Open-File Report 89-185, 73 p. NNA.901022.0057

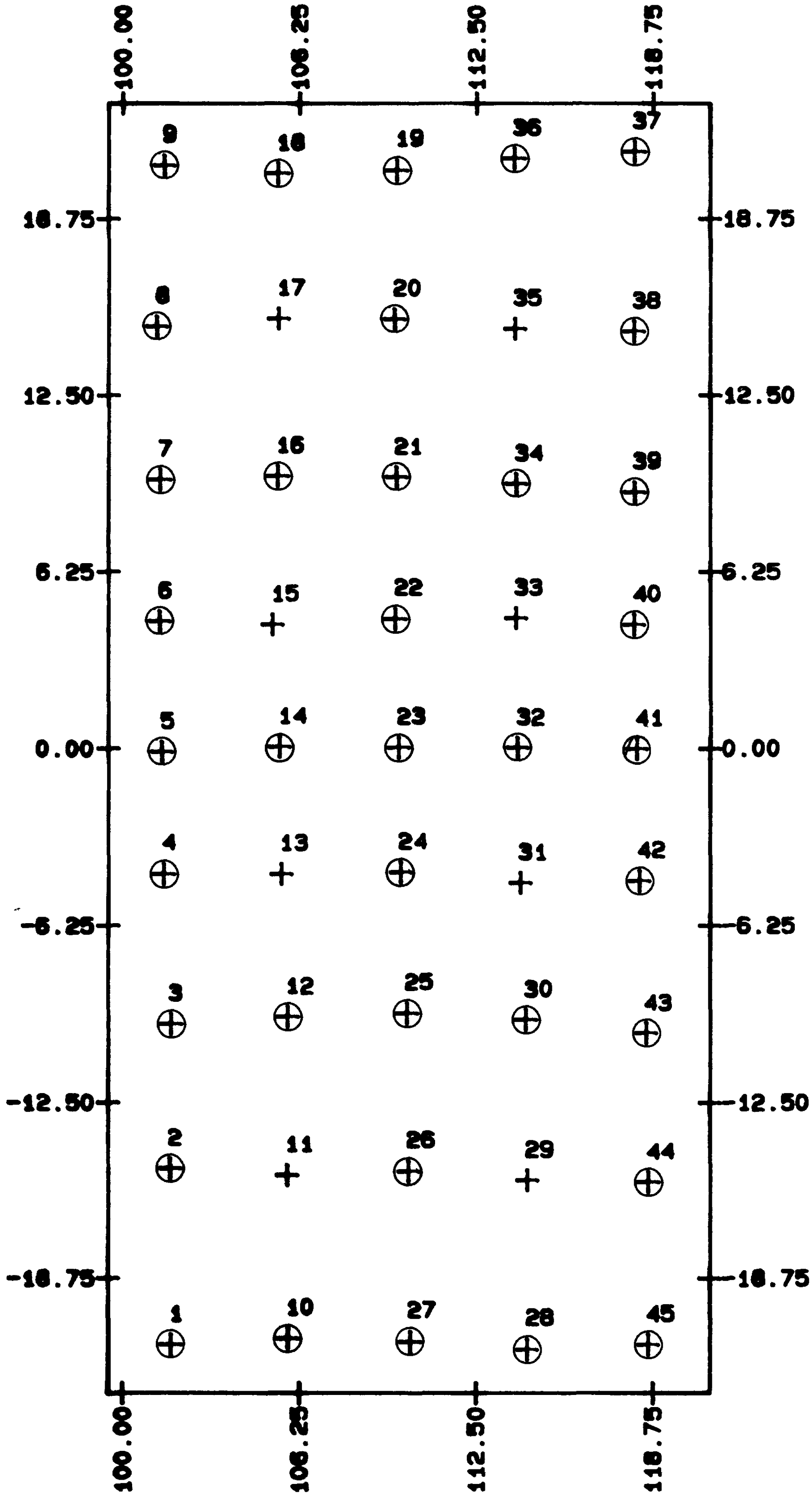
Dueholm, K.S., 1990, Multi-model stereo restitution: Photogrammetric Engineering and Remote Sensing (in press).

APPENDIX A

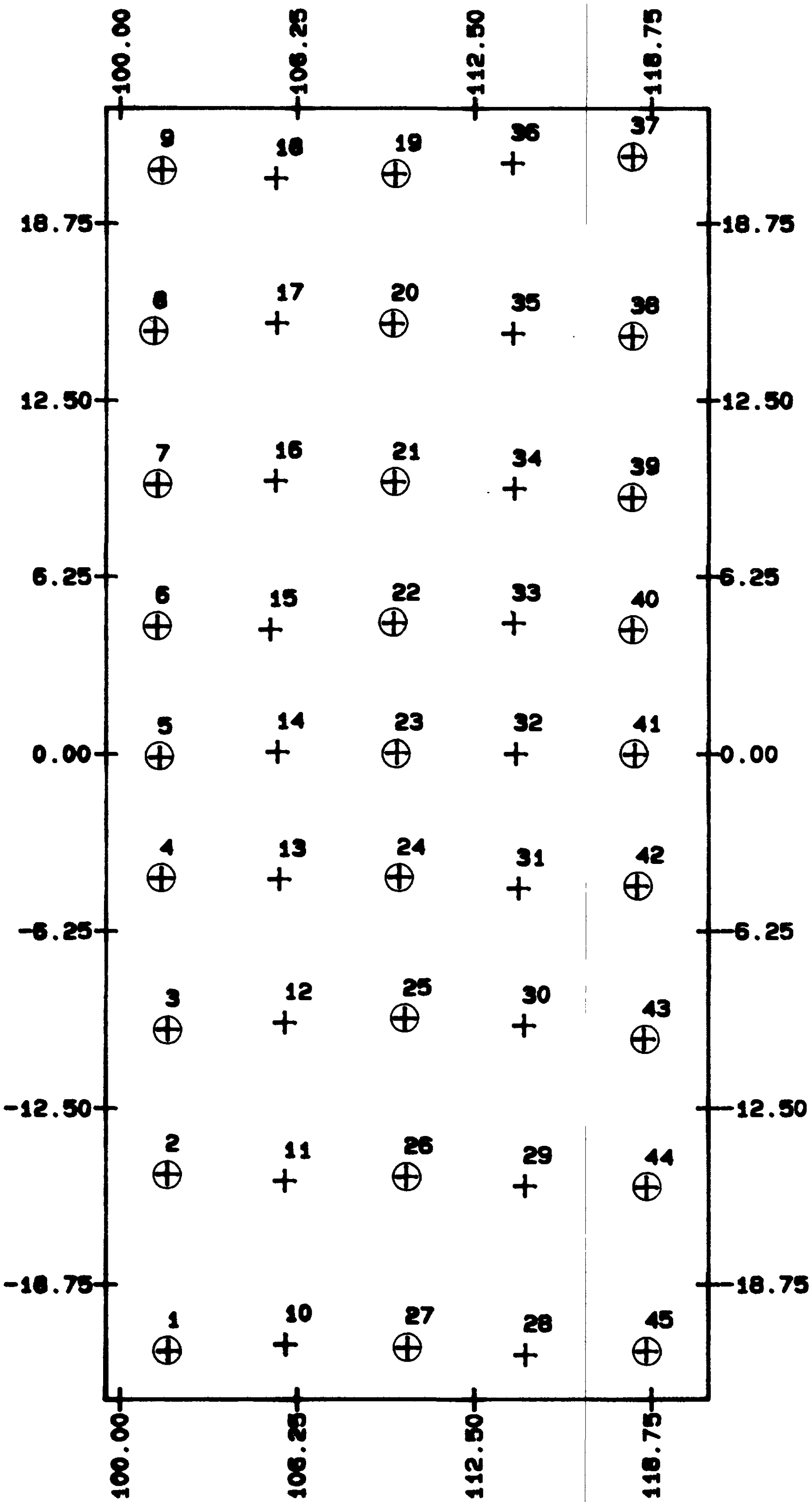
Configurations 45A-4A shown in full periphery projection at a scale of 1:75. 0.0 is the tunnel centerline. Units are feet. ⊕ = targets used as control points, + = targets used as tie points.



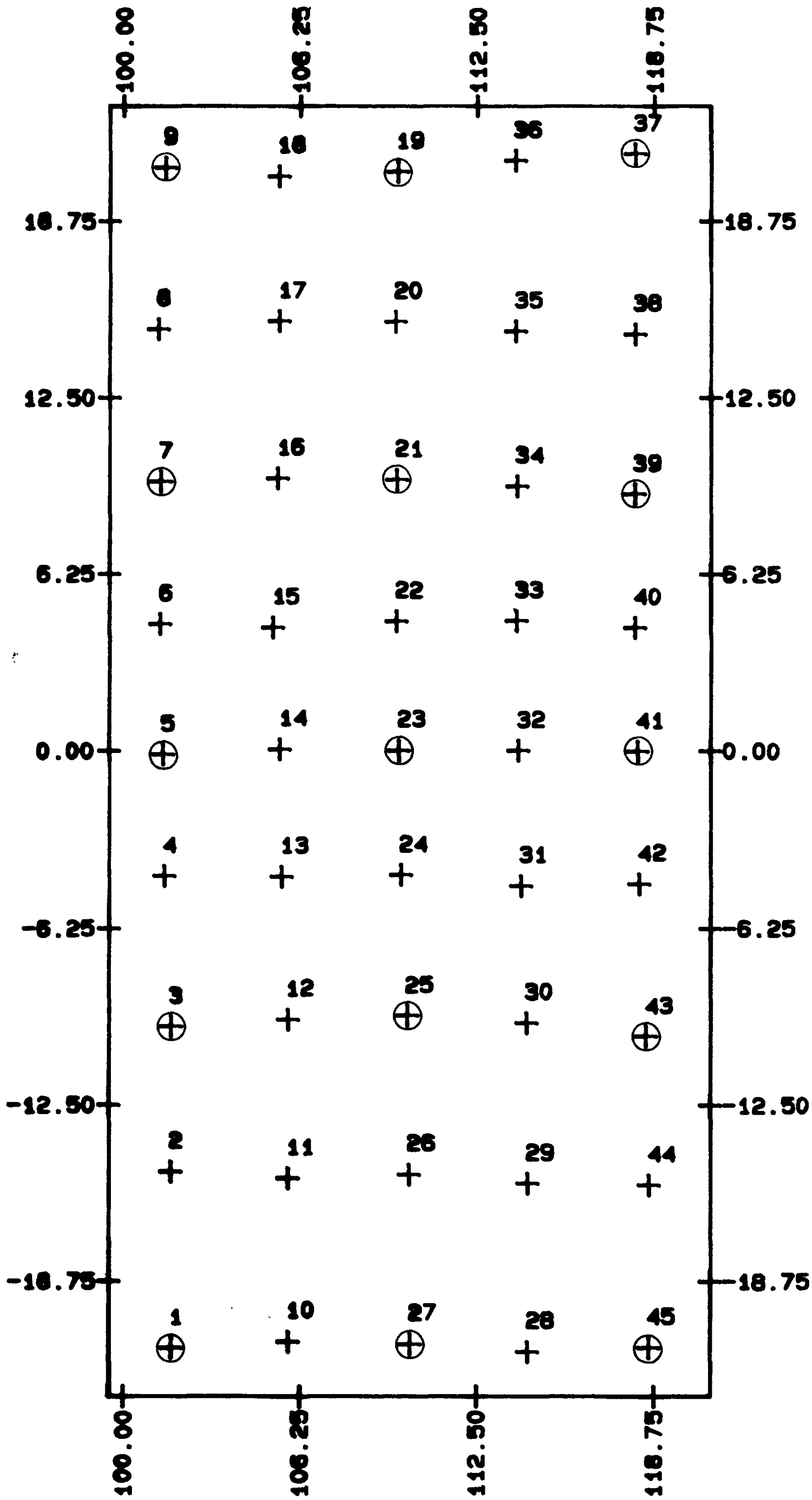
Appendix A, Configuration 45A



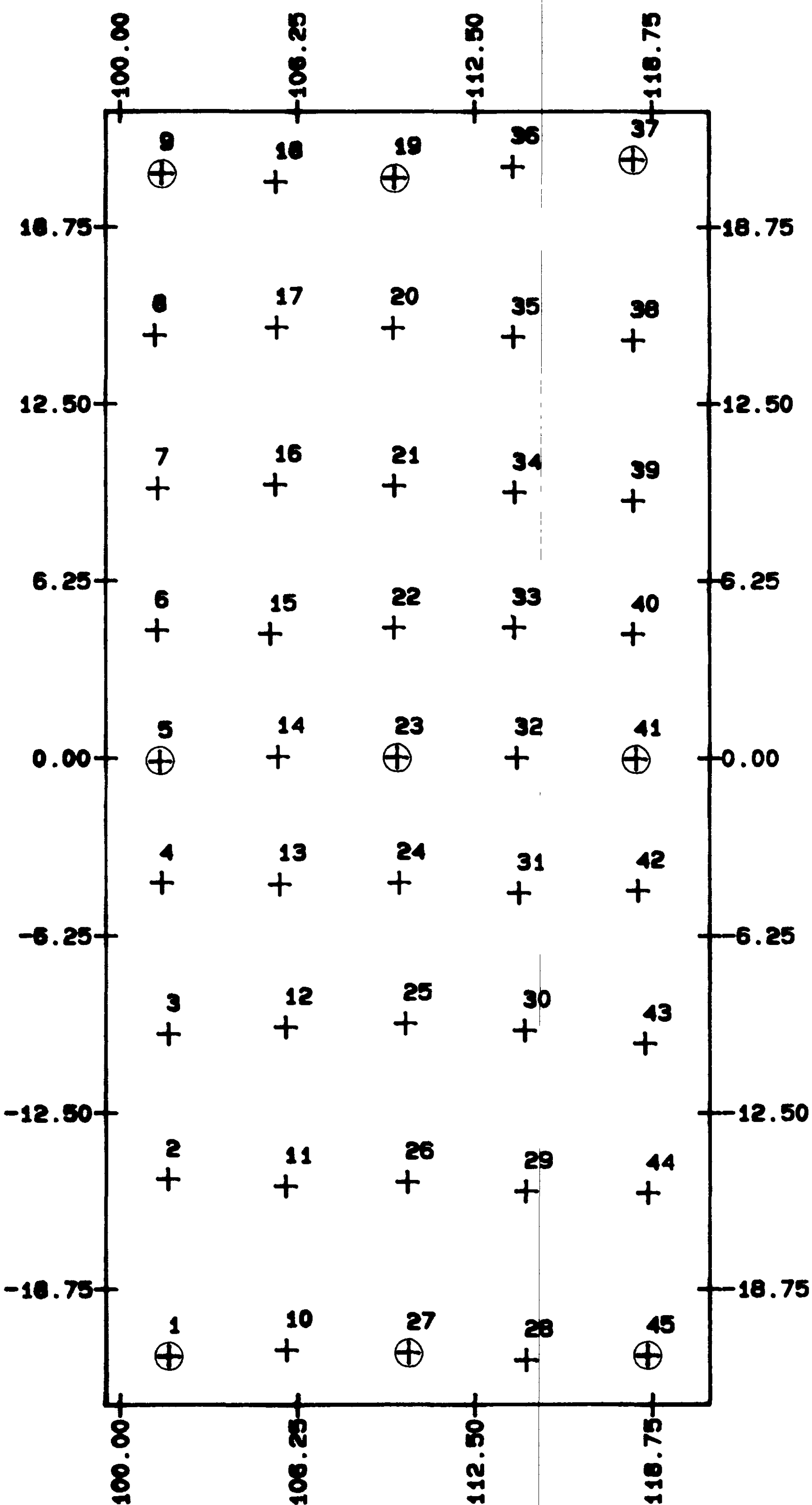
Appendix A, Configuration 37A



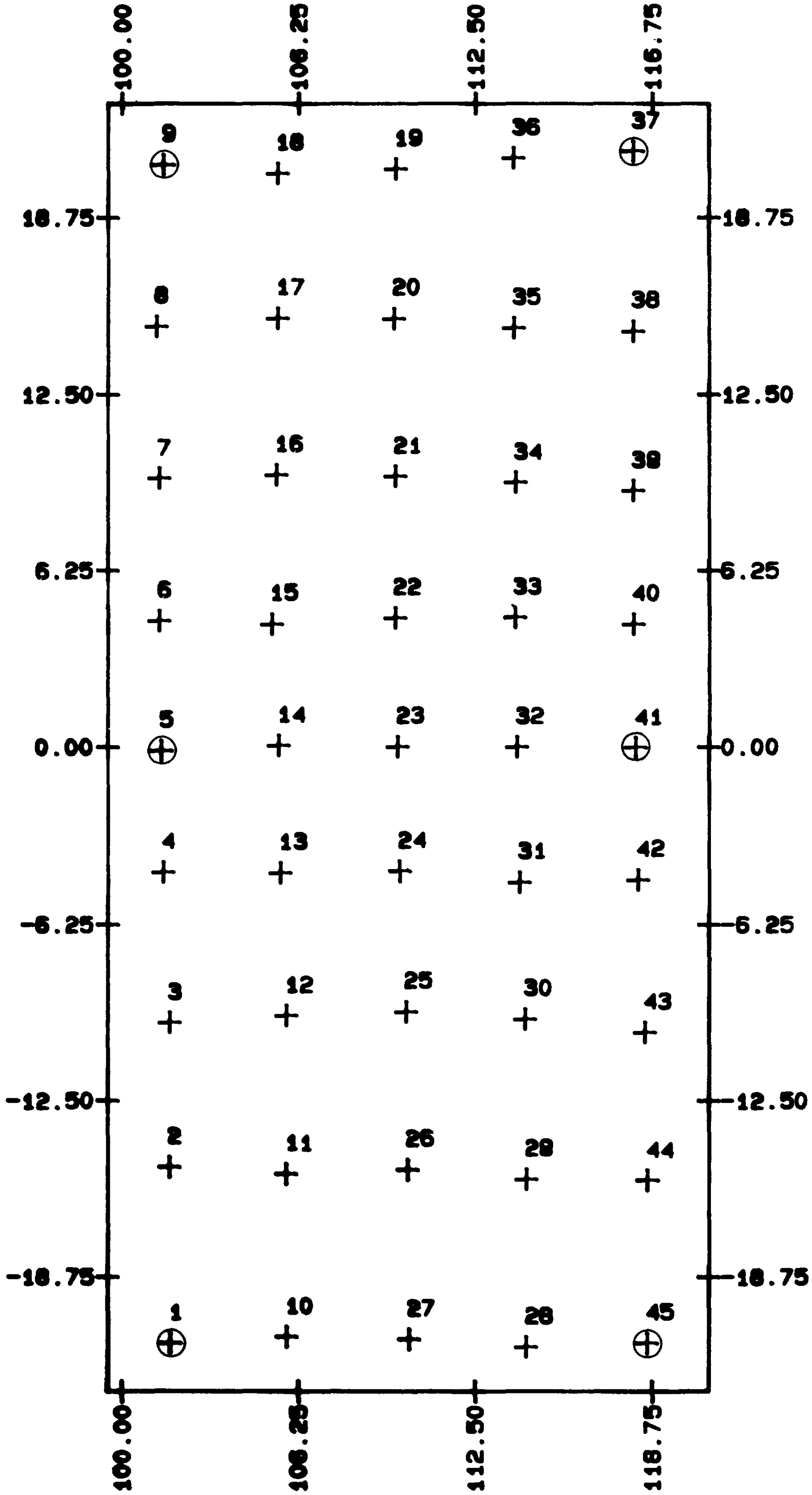
Appendix A, Configuration 27A



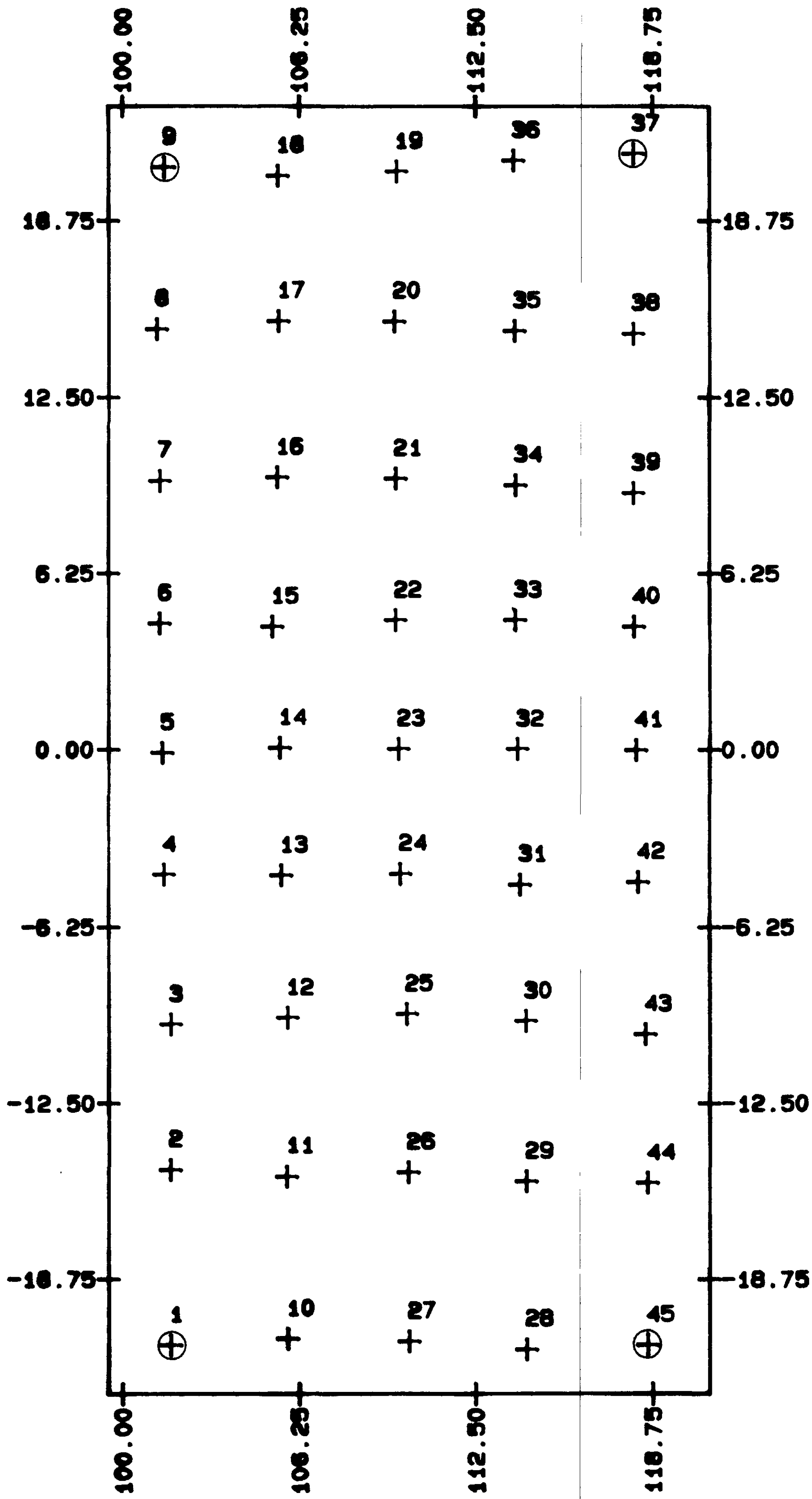
Appendix A, Configuration 15A



Appendix A, Configuration 9A



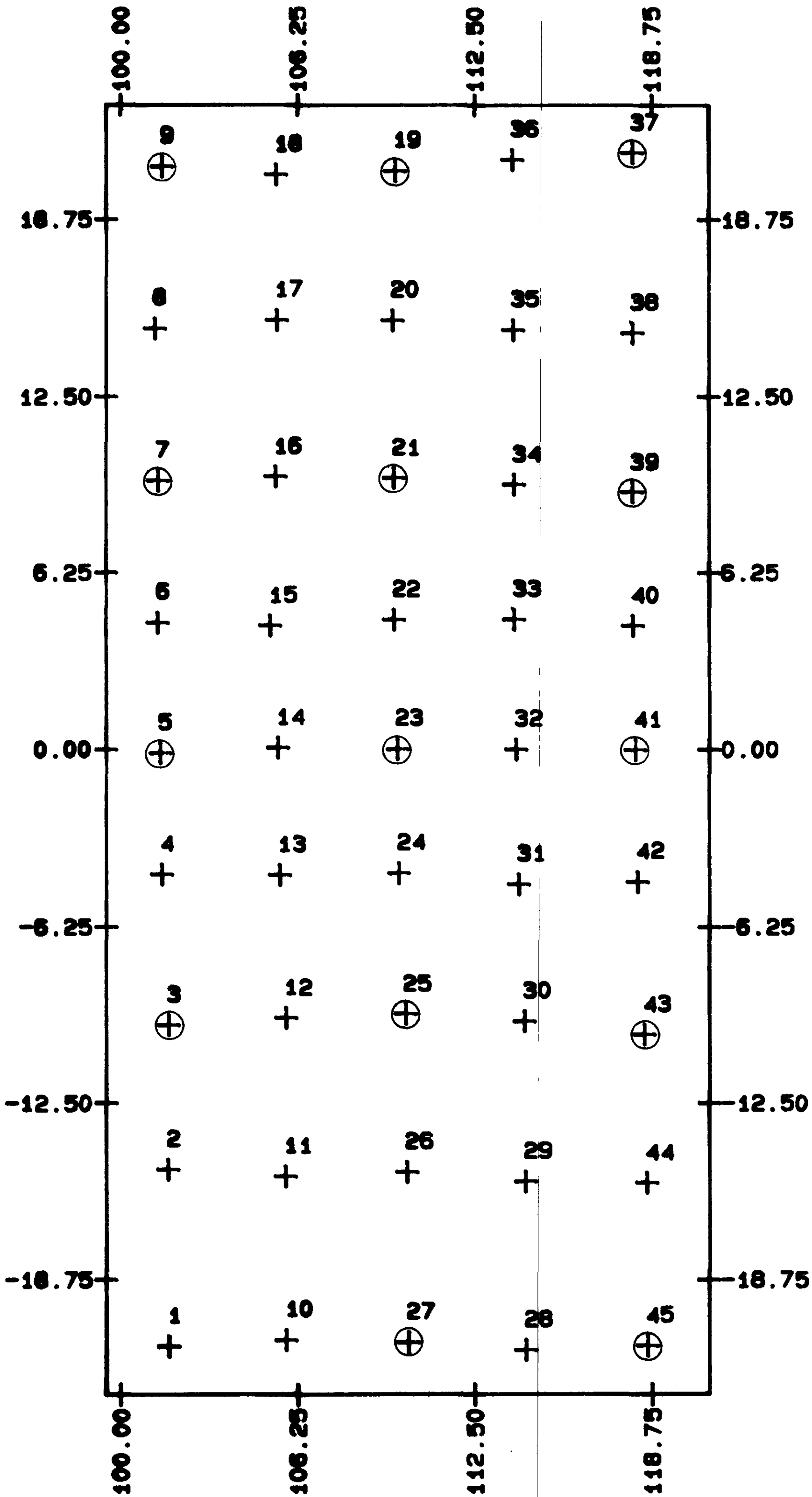
Appendix A, Configuration 6A



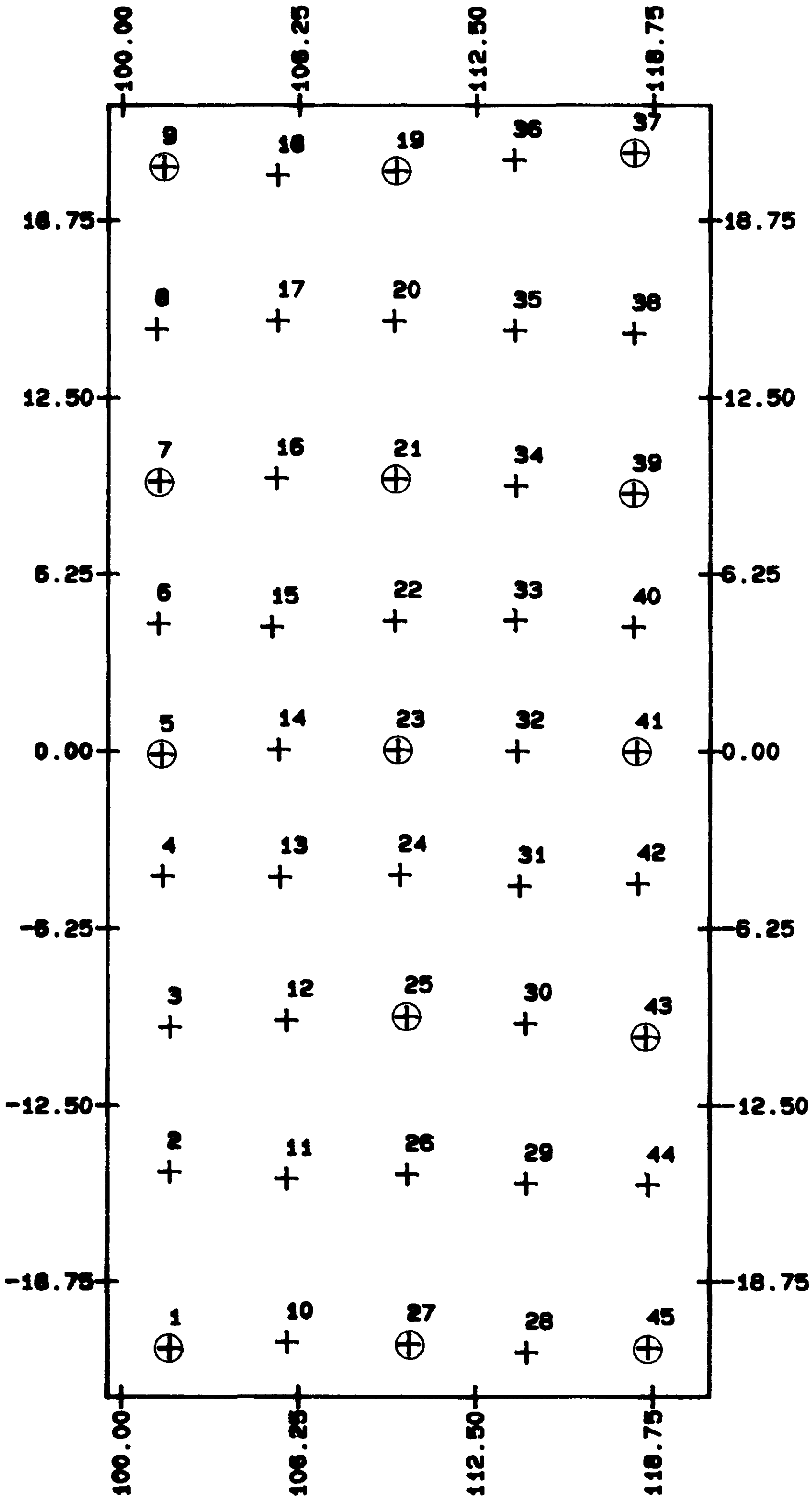
Appendix A, Configuration 4A

APPENDIX B

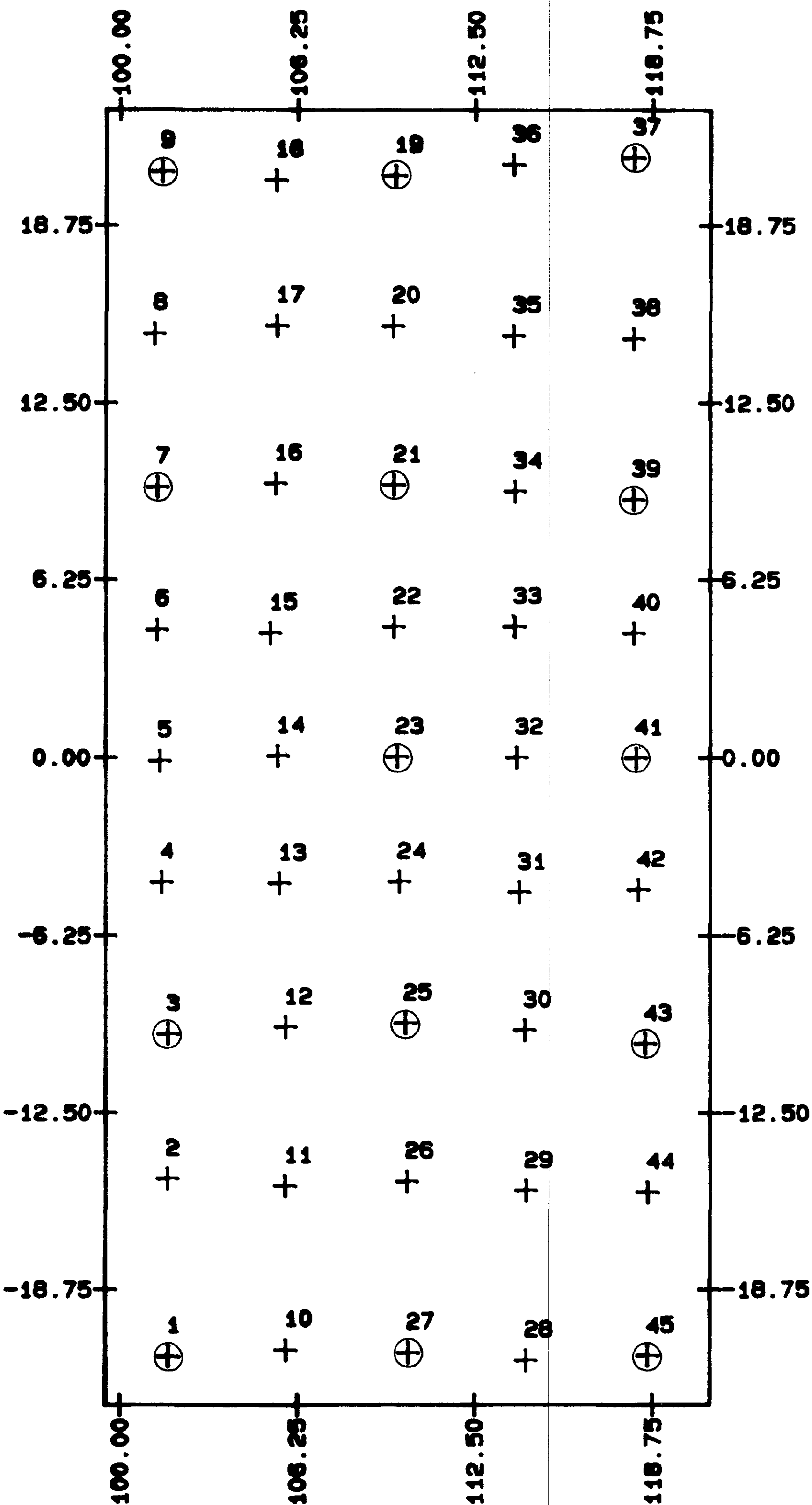
Configurations 14A-14F shown in full periphery projection at a scale of 1:75. 0.0 is the tunnel centerline. Units are feet. ⊕ = targets used as control points, + = targets used as tie points.



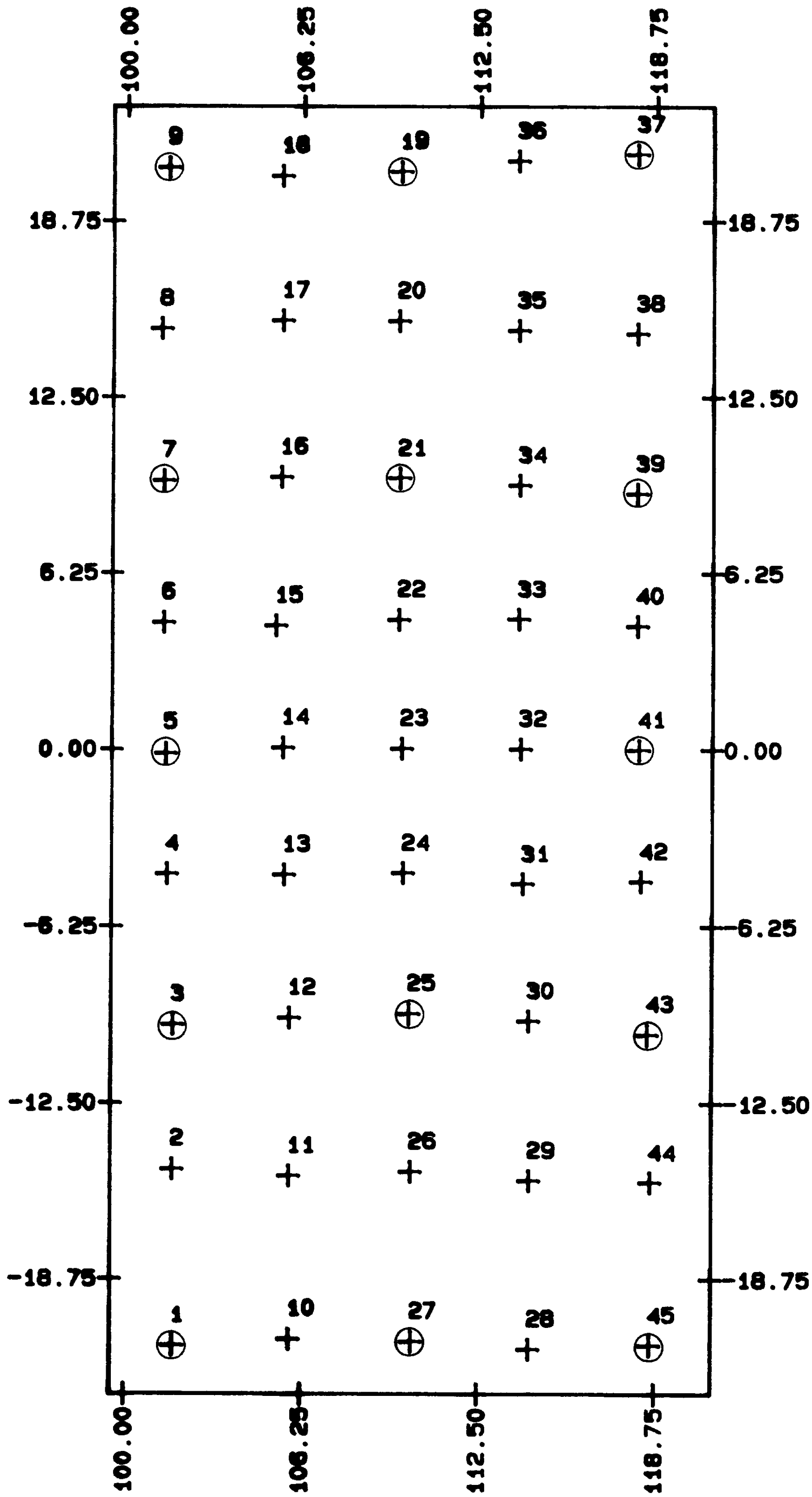
Appendix B, Configuration 14A



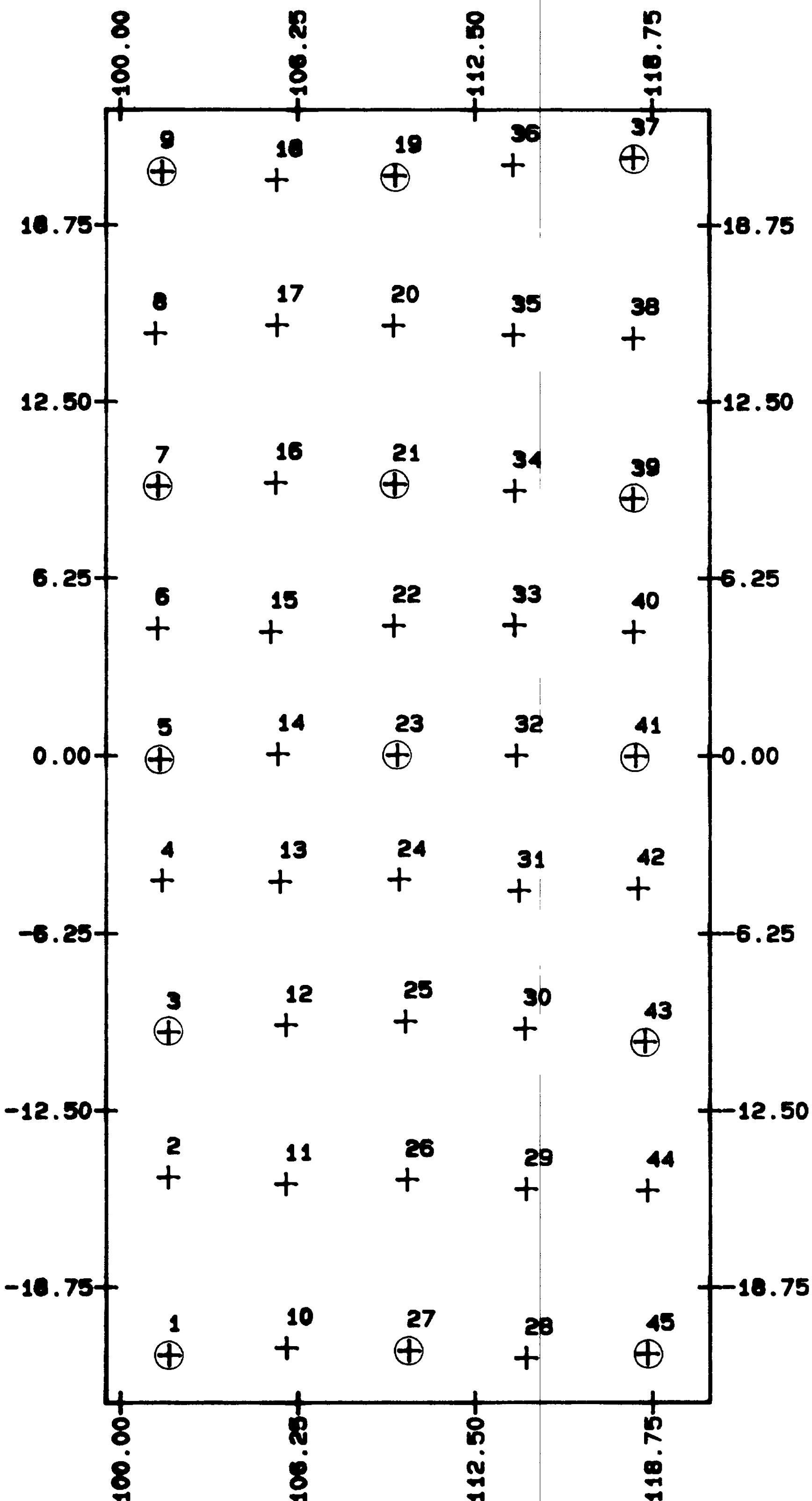
Appendix B, Configuration 14B



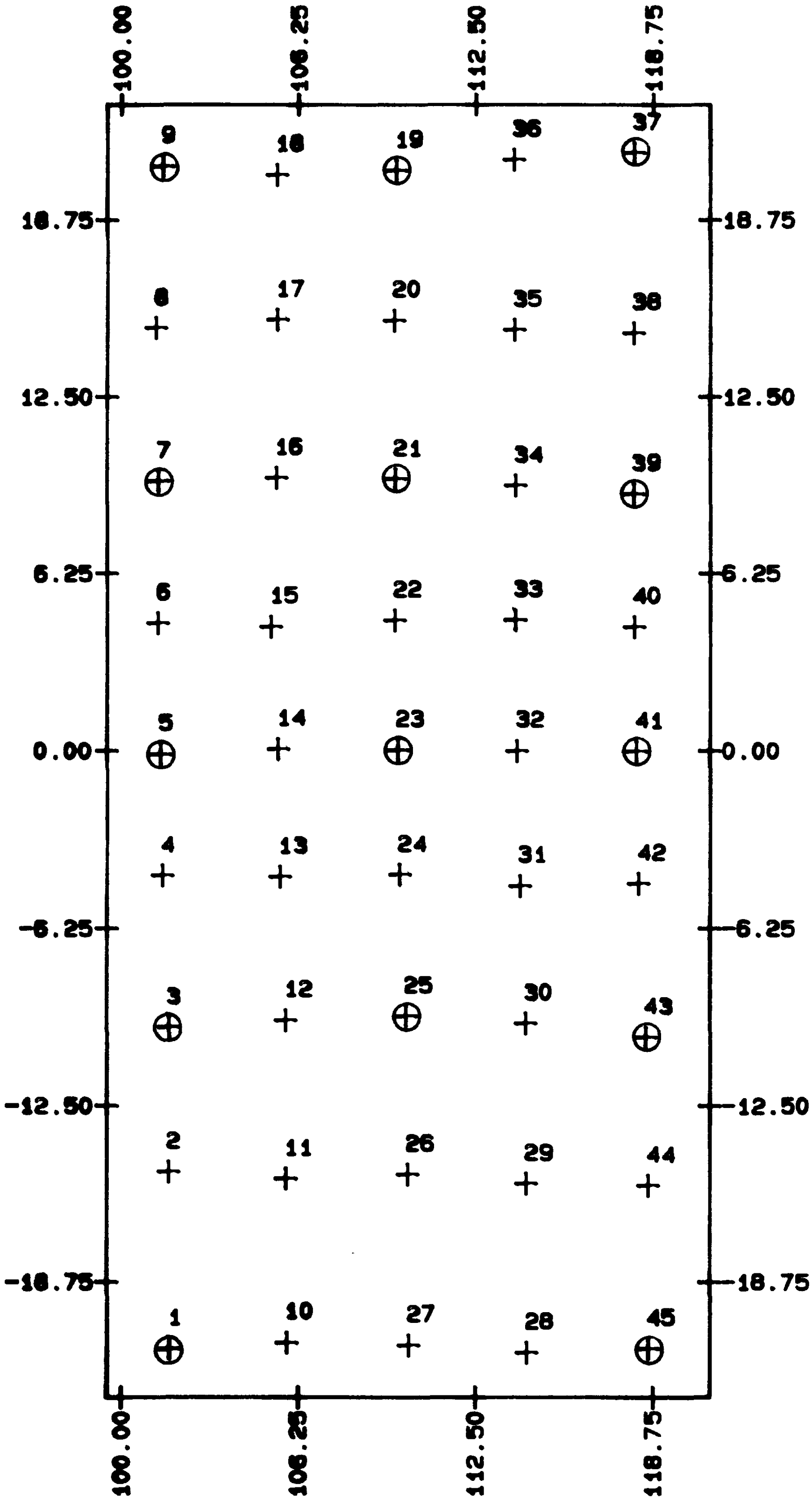
Appendix B, Configuration 14C



Appendix B, Configuration 14D



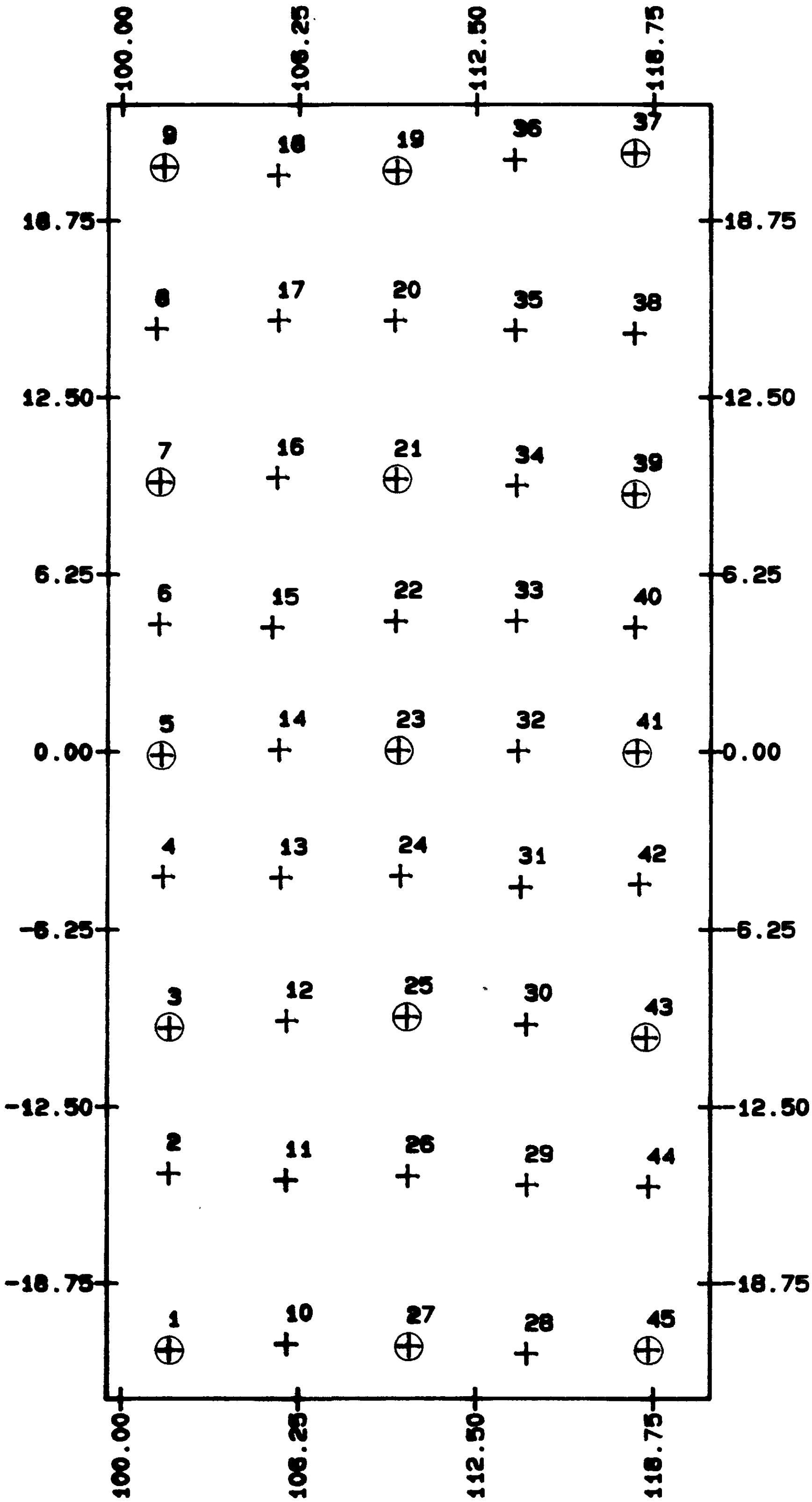
Appendix B, Configuration 14E



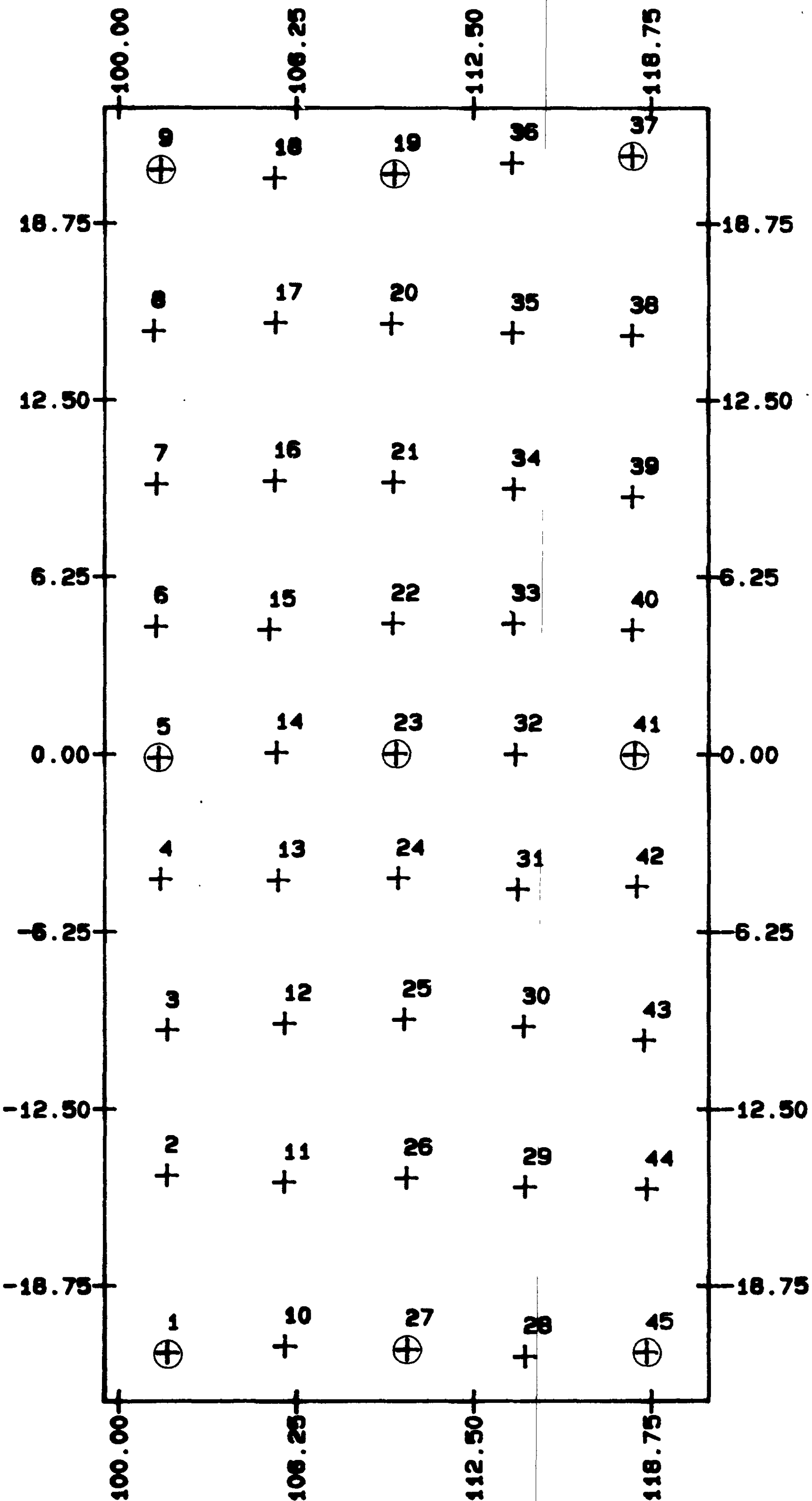
Appendix B, Configuration 14F

APPENDIX C

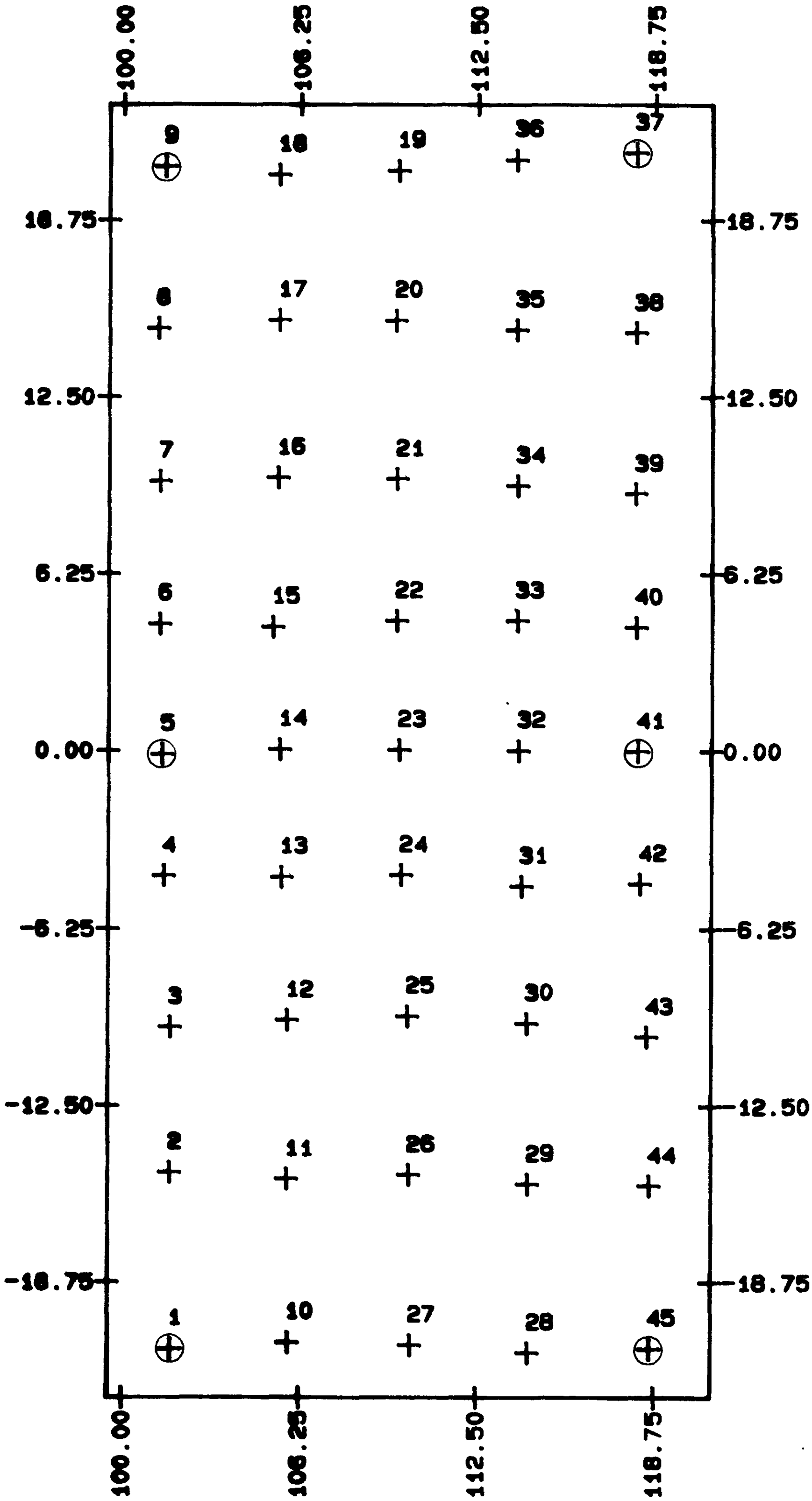
Configurations 15B-4B shown in full periphery projection at a scale of 1:75. 0.0 is the tunnel centerline. Units are feet. ⊕ = targets used as control points, + = targets used as tie points, camera stations are not shown.



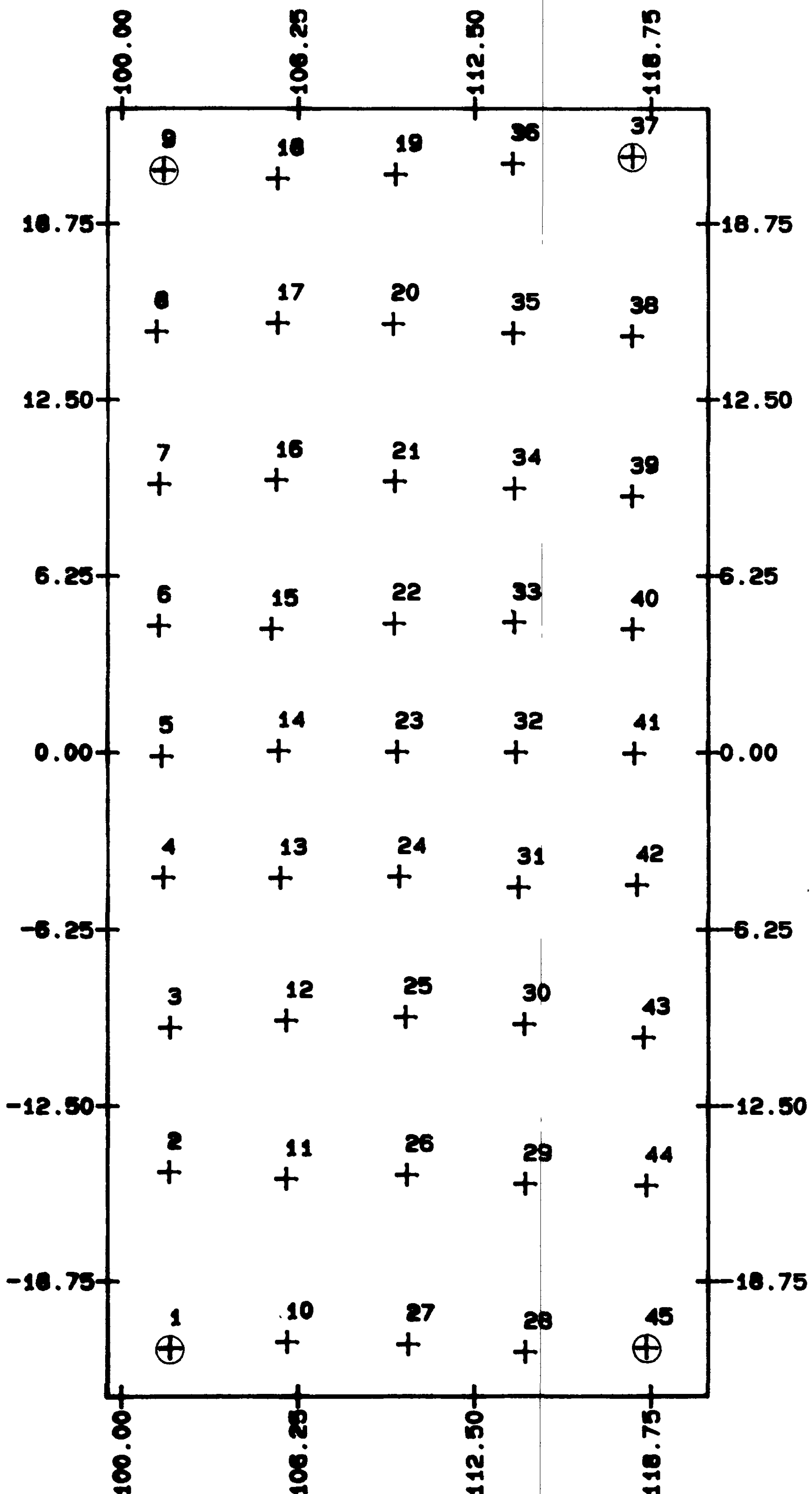
Appendix C, Configuration 15B



Appendix C, Configuration 9B



Appendix C, Configuration 6B



Appendix C, Configuration 4B

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