THE SLOTTED TEMPLET METHOD

For controlling maps made from aerial photographs

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The Slotted-Templet Method For Controlling Maps Made From Aerial Photographs

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INTRODUCTION

Aerial photogrammetry is new, and the technical problems involved in the making of maps from aerial photographs are by no means easy of solution. Moreover, there is no ideal method universally applicable to all kinds and conditions of mapping. The results desired are, of course, the first consideration; but even after the standards which the finished map must meet have been set up, there are still varying ideas as to the correct approach to the solution of the mapping problem.

Much experimentation has been done, and several of the systems developed have been standardized to the point where a presentation of the practical application of these systems is timely, so that the advantages of each may better be understood and a correct choice of method for a particular purpose simplified.

In the construction of planimetric maps from aerial photographs, the primary problem is to secure the horizontal control necessary to place the photograph centers in their correct positions on the map grid and to obtain the correct orientation of the photographs, and then, with this accomplished, to eliminate the errors of position of all other points as they appear on the photographs—these errors being the result of displacement of each ground point on the photo-

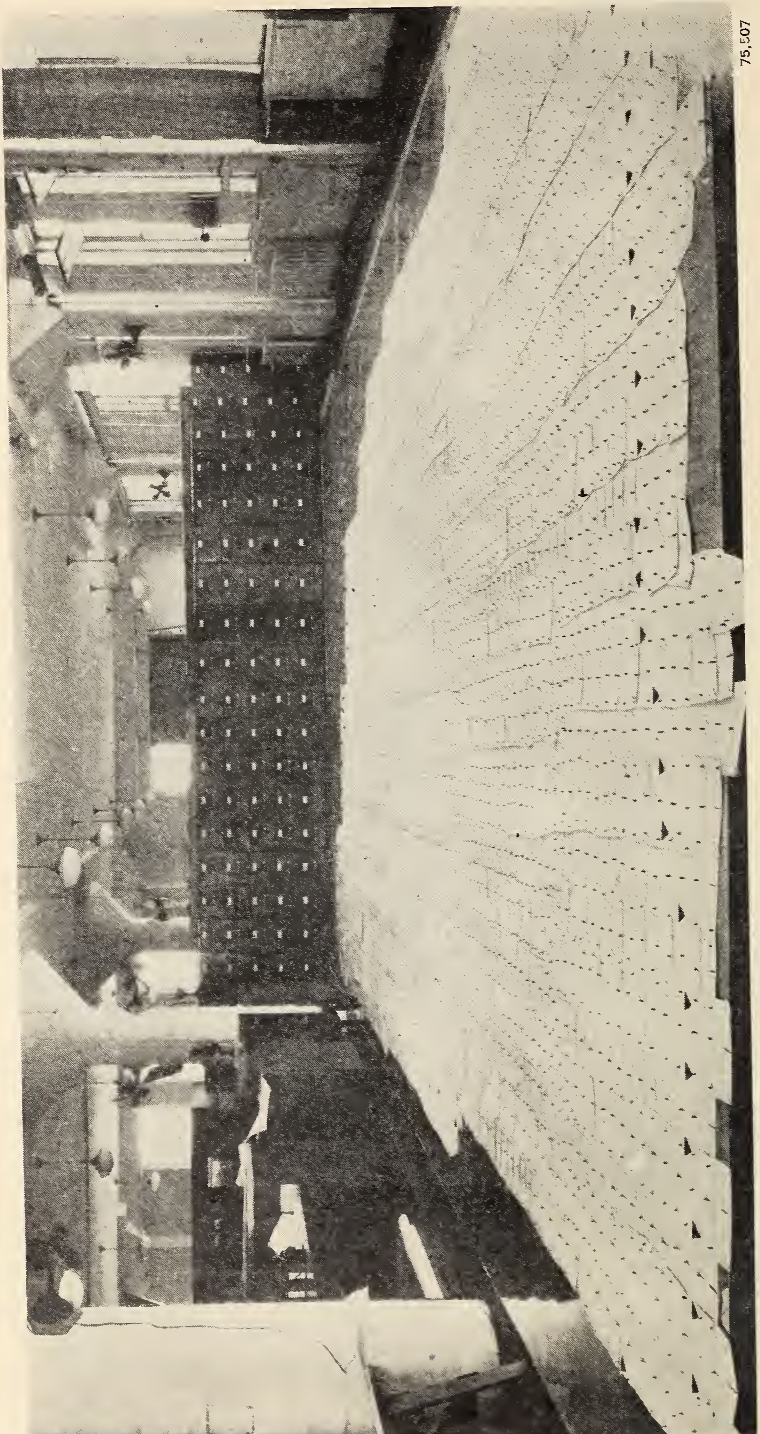

FIGURE 1.—An area of 4,400 square miles, covered by 2,700 photographs. This was laid (for test purposes) with ground control only around the perimeter of the area. Control is indicated by black triangles.

graphs from its correct position, due to the relief of the ground. Of course, in practice, lens distortion, tilt, and paper and film shrinkage are factors which may introduce additional errors.

If previously located ground positions obtained by triangulation or traverse are sufficiently numerous that several appear on each photograph, then the compilation of planimetric maps from these photographs is a comparatively simple matter; but this ideal situation, unfortunately, seldom exists. In fact, in terms of usual single-lens photographs, such control is often 50 to 100 photographs apart.

It is, therefore, necessary to break down this control spacing to a degree sufficient that a number of points can be located on each photograph. This may be done by triangulation, by traverse, or by plane table. But since all of these methods are expensive and slow, and under certain conditions are completely unfeasible, one of the major problems of photogrammetry has been to find a workable method of carrying forward the control through the photographs themselves. Various systems have been devised to accomplish this. Costs and accuracy resulting from the use of these systems vary and there are limits to which each particular system can be carried in dispensing with ground control.

No matter what system is used, the true position of each photograph center must be obtained; and so effort has been directed also to reducing this cost by cutting down the number of photographs required. This may be done in a number of ways.

If the flying altitude is doubled, then four times the area will be included in each photograph; but to double the usual flying altitude of about 13,000 feet above the ground requires planes and equipment which up to the present have not ordinarily been available; and furthermore, by doubling the altitude, the scale is reduced to one-half and all photographic detail reduced accordingly.

The use of a wide-angle lens in the camera will increase the covering power, and a larger plate size can be covered at the same flying altitude. This, of course, decreases the necessary number of photographs to cover a given area. With such a type of lens, however, there is considerable distortion of physical features near the edges of the resulting photograph, since image displacement, due to relief, increases with the distance from the photograph center. This tends to limit the general usefulness of the wide-angle photograph, particularly in rugged country, to mapping purposes only, in which the increased displacement may be no disadvantage—in fact, it may for some purposes actually be of material benefit, provided there is no masking out of ground detail by the relief.

Multiple-lens cameras furnish another approach to the solution of this problem of reducing the number of photographs covering a given area. The most successful development along this line is the nine-lens camera of the United States Coast and Geodetic Survey. Using lenses of 8¼-inch focal length, the camera produces a photograph covering 124 square miles for a photographic scale of 1:20,000, as compared with 8 square miles covered by the 9″ x 9″ single-lens camera with lens of the same focal length. The negative is 23 inches square, and the composite photographic print produced from it is 35 inches square, so that it is somewhat unwieldy in ordinary use. The camera with equipment, weighing nearly 800 pounds, is quite bulky, and the average plane used in photographic work cannot be equipped to carry it. Special printing equipment also is necessary, since the resulting composite print requires transposition and rectification of the wing components.

Consideration of the advantages and defects of the various types of mapping cameras thus briefly discussed, together with the fact that about 2 million square miles of the United States already have been covered with vertical photographs produced by single-lens cameras with lenses of 8¼-inch focal length on plate sizes 7″ x 9″

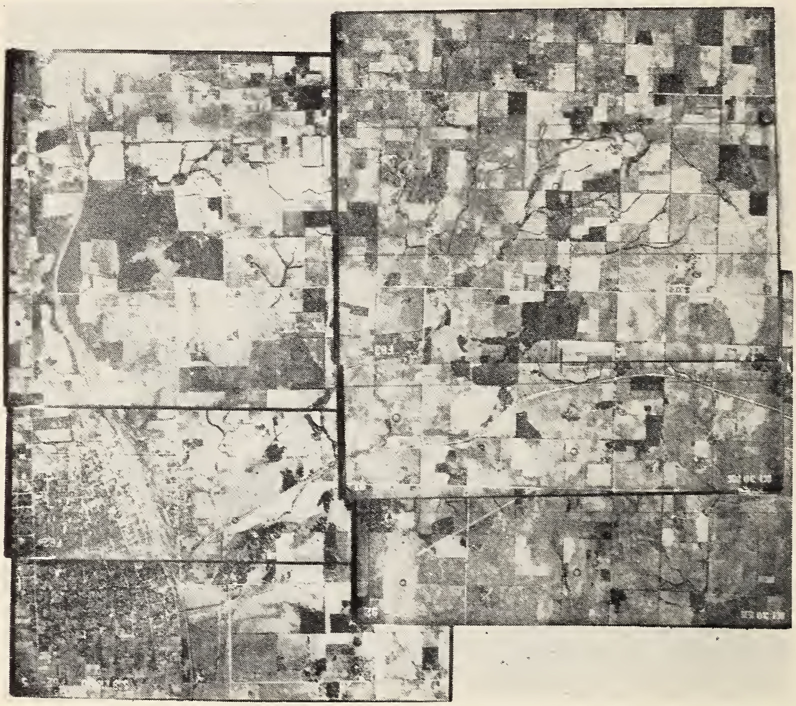

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FIGURE 2.—Average photograph overlap. Note that with this overlap every ground point will appear on at least two photographs in line of flight.

or 9″ x 9″ on a scale of 1:20,000, and the desirability, in the interest of practical economy, that photographs should be usable for other than map-making purposes, have tended to direct experimentation, in the Soil Conservation Service, toward the solution of the problem of securing the necessary horizontal control for accurate planimetric maps through the development of a system that would advantageously use the existing photographs.

Figure 2 gives a general idea of the appearance of such photographs. Flying specifications of the Service require an overlap in line of flight of approximately 60 percent and a side overlap of 25 to 30 percent, also that the photographs shall be at approximately the correct scale, and with small allowable departure from the true horizontal plane.

The work of the Service calls for large-scale (usually 1:15,840) planimetric maps of country where the amount of existing control is generally sparse. Reasonable accuracy on this large scale at reasonable cost is the prime requisite.

The result of the experimentation has been the development of the "slotted-templet method." It was invented by Charles W. Collier, while with the Soil Conservation Service, and since then has been perfected through improvements made in the Cartographic Division of the Service and elsewhere. It is designed to meet all ordinary requirements for planimetric maps of any desired accuracy, by increasing, as needed, the density of the ground control.

Interest in the use of slotted templets for securing map control has been growing steadily, yet most people are completely unfamiliar with the details involved. This publication discusses these details, and also compares the method with the hand-templet method, of which this new development is an outgrowth.

An effort has been made to avoid discussion of the theoretical work that preceded the development of the method. Instead, the publication gives the practical results that have been obtained, and discusses in detail the office practices that have proved effective in securing the best results.

No attempt is being made here to prove that the slotted-templet method is theoretically perfect. The results of the tests which have been made illustrate the accuracy that can be obtained with it, using differing amounts of accurately located ground control. The method is in no way limited to the use of photographs taken with cameras equipped with normal-angle lenses, but all the tests included here were made using single-lens photographs taken with standard $8\frac{1}{4}$-inch lens.

STANDARDS OF ACCURACY AND ADDED CONTROL

In making comparison of various means of reaching a desired degree of accuracy on the finished map, attention is directed to the fact that with one system of compilation more ground control will be needed than with another. Also, as will be developed later, every system has a very definite break-down point below which density of control cannot be reduced with any regard for accuracy.

No final standards of map accuracy have as yet been adopted by the Federal Board of Surveys and Maps. However, a tentative standard has been set up for general-purpose maps, which specifies that for the highest class of such maps, designated as Class "A", the planimetric detail must be of such accuracy that 90 percent of all well-defined cultural and drainage features will be in correct horizontal coordinate position within $\frac{1}{40}$ of an inch (0.6 mm.) at the publication scale. The Board further decided that general-purpose maps shall be planned for publication at 1:31,680 or a smaller scale.

The results of the tests of the slotted-templet system which are included in this publication demonstrate that when the regularly available photographs (1:20,000 scale) are used and the work compiled at the Soil Conservation Service 1:15,840 scale, the finished product, when reduced to 1:31,680, easily meets the requirements for Class "A" maps. Furthermore, the results indicate that with sufficient ground control the specifications for the highest class of general-

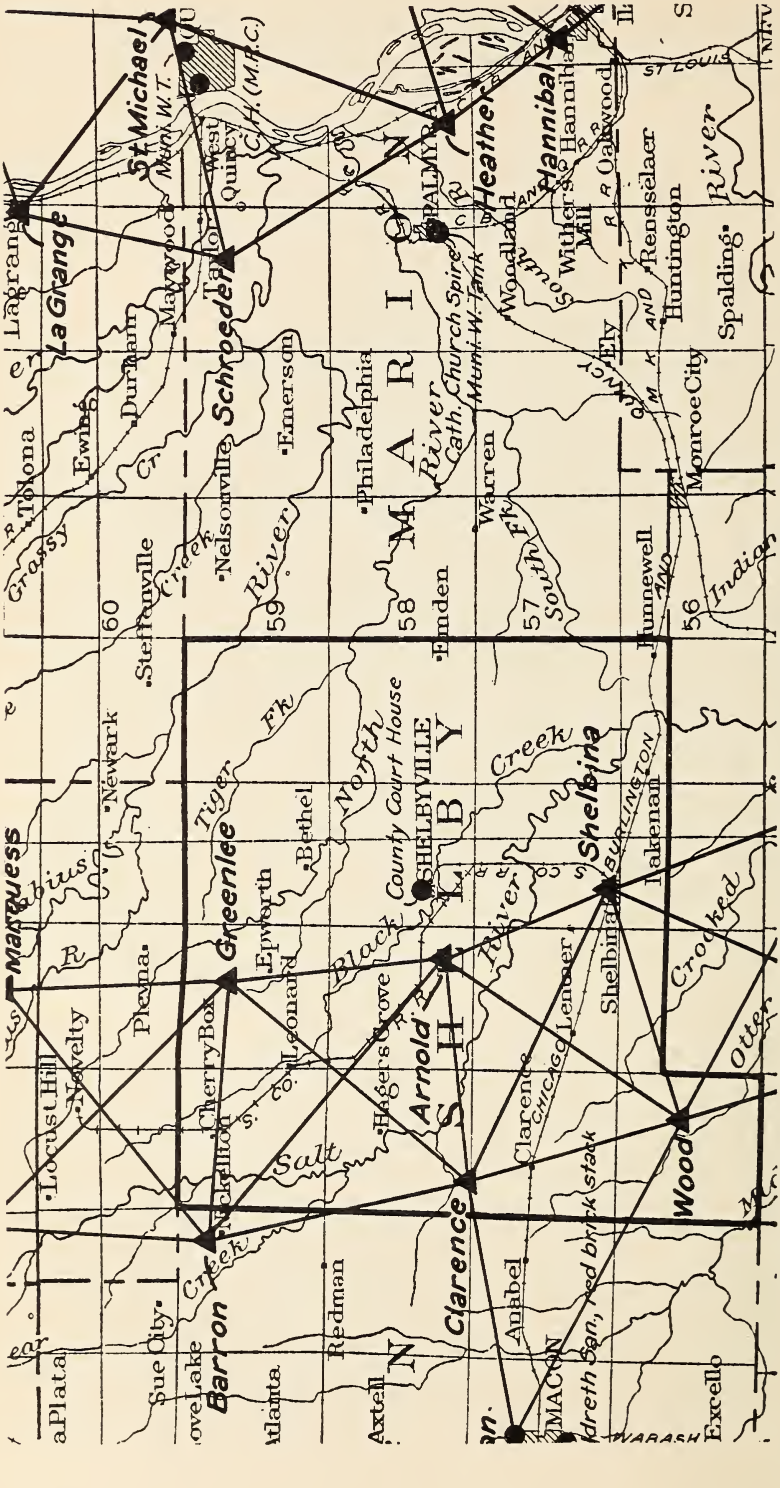

FIGURE 3.—Example of average control spacing, as established by the U. S. Coast and Geodetic Survey.

purpose maps probably can be met even if the publication scale is the same as that of compilation.

Test No. 4 (fig. 17) on the Beltsville, Md., area clearly shows this. Here the photographs were made on a scale of 1:12,000 and the map compiled at that scale. If this map is published at a scale of 1:24,000 (one-half of compilation scale), 98 percent of all points fall within $\frac{1}{50}$ of an inch (0.5 mm.) of correct position. The test demonstrates that, using the slotted-templet method, satisfactory accuracy can be obtained with a reasonable amount of ground control. The test also offers a basis of comparison with other systems as to the amount of control necessary to produce comparable results.

To meet a high accuracy map standard, more ground control is needed than is usually available. The necessity for adding to existing control is illustrated in figure 3, which depicts a portion of the State of Missouri and on which is shown the present triangulation established by the United States Coast and Geodetic Survey. We may assume that we wish to map Shelby County.

The county is approximately square and has an area of 509 square miles. The density of control shown is better than average for most parts of the country. It can be seen that there are six triangulation stations covering the west half of the county, spaced about 10 miles apart. (This triangulation was run for the general benefit of the country and its cost cannot appropriately be charged against the single mapping project of Shelby County.)

If a control system could be worked out that would require no more known positions, and still hold desired mapping accuracy over the entire county, then by such a system the cost of the field control would be nothing. In order to compete, another system would have to cut office cost sufficiently to balance this advantage. Using the slotted-templet system, the amount of control already established in Shelby County is insufficient to make an accurate planimetric map, and additional triangulation or traverse must be run. (The cost of this field work is a part of the cost of mapping the county by this particular method.)

Figure 4 shows an average area on which control was obtained by the slotted-templet method. It illustrates the amount of control that was added to the original control available, in order that the resulting map might meet the standards of accuracy referred to in this chapter. The area is approximately 1,200 square miles, laid at a scale of 1:15,840, with templets made from vertical photographs taken at an approximate scale of 1:20,000.

Fourteen triangulation stations (shown by white triangles) had been previously located in this area. From the best available maps of the region, traverses were planned between these stations to augment the control to a point where office work could be substituted for field work. The traverses, as executed in the field, resulted in the addition of 160 accurately located ground control points (black triangles).

The outer traverses approximate the boundaries of the area to be mapped. It will be noted that the positions obtained are, where possible, in the overlap areas between flights. The number actually obtained is more than needed; but if traverse control is run, a point on each flight crossed might as well be secured. Furthermore, in

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FIGURE 4.—Slotted-templet assembly. The scale is: 4 inches equal 1 mile.

average country, the roads are winding and seldom fall where most desired, thus more than the theoretical amount of traverse is nearly always necessary.

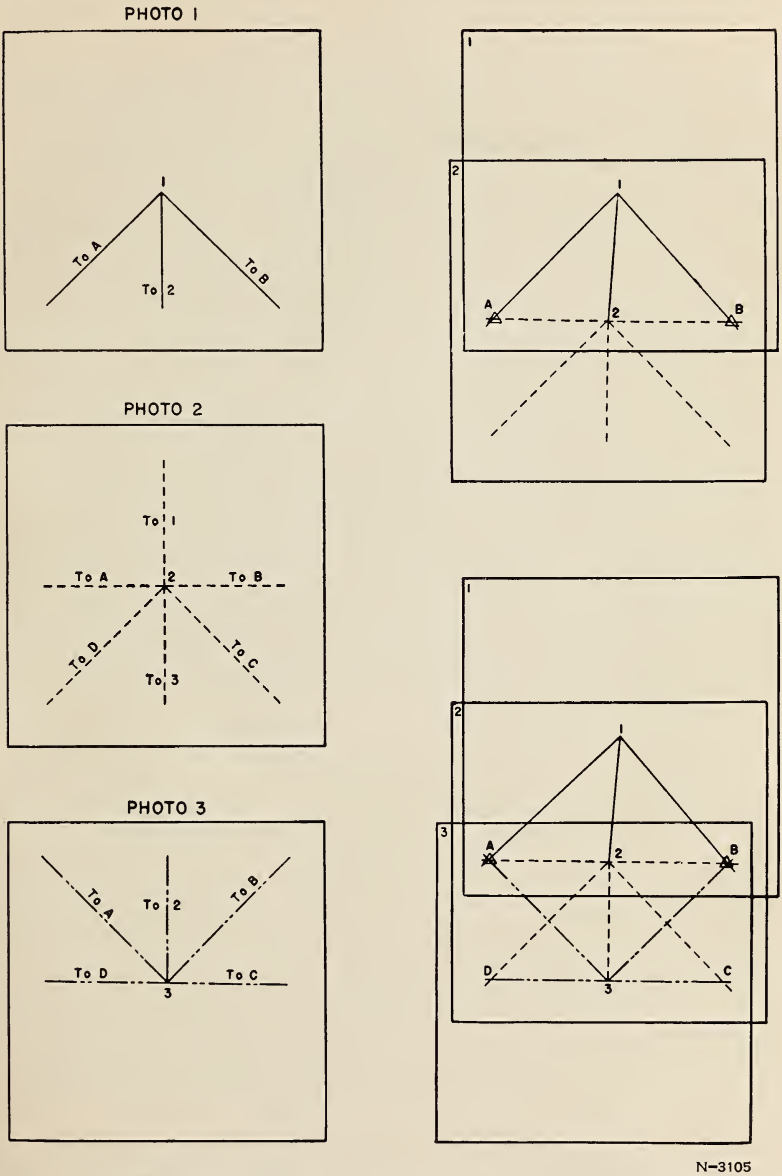

FIGURE 5.—Diagrammetric sketch of extension of control by radial triangulation.

After the additional ground control was plotted upon the base sheet in the office, radial triangulation was performed graphically to secure a known position for every picture point. Figure 5 makes plain this method for the extension of control. Approximately 2,000 points (fig. 4, black buttons or studs), or about 140 times the amount of the original control, were obtained in this manner. (The cost of securing the necessary radial triangulation is a proper charge against the cost of the map.)

If the planimetric detail between these control positions is delineated with a plotting machine, then these 2,000 positions will probably, for this size area and this scale map, be sufficient to enable the construction of a map of good accuracy. However, if a plotting instrument is not used, additional points are cut in, using the photographs, oriented to correct position by the radial control, so as to reduce even the small distances between the control points shown in figure 4; after which the detail is secured by projecting the photographic image between each set of adjacent control points, adjusting the scale until the points on the photograph match the correct ground positions as shown by the plotted points on the base sheet; and then the detail is drawn in. The required intensity of supplemental points, obtained as described above, depends largely upon the roughness of the terrain.

THE HAND-TEMPLET METHOD

An early attempt to meet the conditions suggested in the introduction was made with what is called the hand-templet method. It is based upon the simple principle that, provided the aerial photograph is taken with the horizontal axes of the camera parallel to the ground, all angles radiating from the principal point of the photograph, through the image points as identified on the photograph, remain constant angles, irrespective of scale change or relief.

In practice, the method consists of reducing each photograph to a transparent templet on which the picture points are represented by lines radial to the principal point, and then assembling these templets so that all the radials common to each identified position intersect, the intersection being the true location of the point.

The limitations of this system early became apparent. They include the fact that templets of transparent cellulose acetate or nitrate are subject to considerable distortion, due to humidity and temperature change. Limitations in drafting cause a certain amount of error to accumulate. If tilt is present, the radials will not intersect but will form triangles of error, and the elimination of these is a matter requiring considerable experience and, at the best, is largely a matter of personal judgment and compromise.

However, if there are a number of control stations on each photograph, then this system will allow very rapid assembly of the templets; but such a condition is rare in ordinary practice. The problem in map control is not how to fit a large amount of control to the photographs, but how to use the sparse existing ground control with as little addition in new work as possible.

Since the slotted-templet method is directly a development from the hand-templet method, although eliminating the features which limited the scope of the latter, a description of the hand-templet method is worth while. The steps in its operation, as well as a direct comparison of the two methods, are included herein.

The hand-templet method for the extension of radial control works as follows: The first step in the preparation of the photographs is to locate the principal point on each print. This may not be identifiable, and it is better to pick a definite image nearly coinciding with it than to attempt to locate an indefinite principal point, since the point must be transferred to the succeeding photograph. The point selected should never, however, be more than one-eighth of an inch

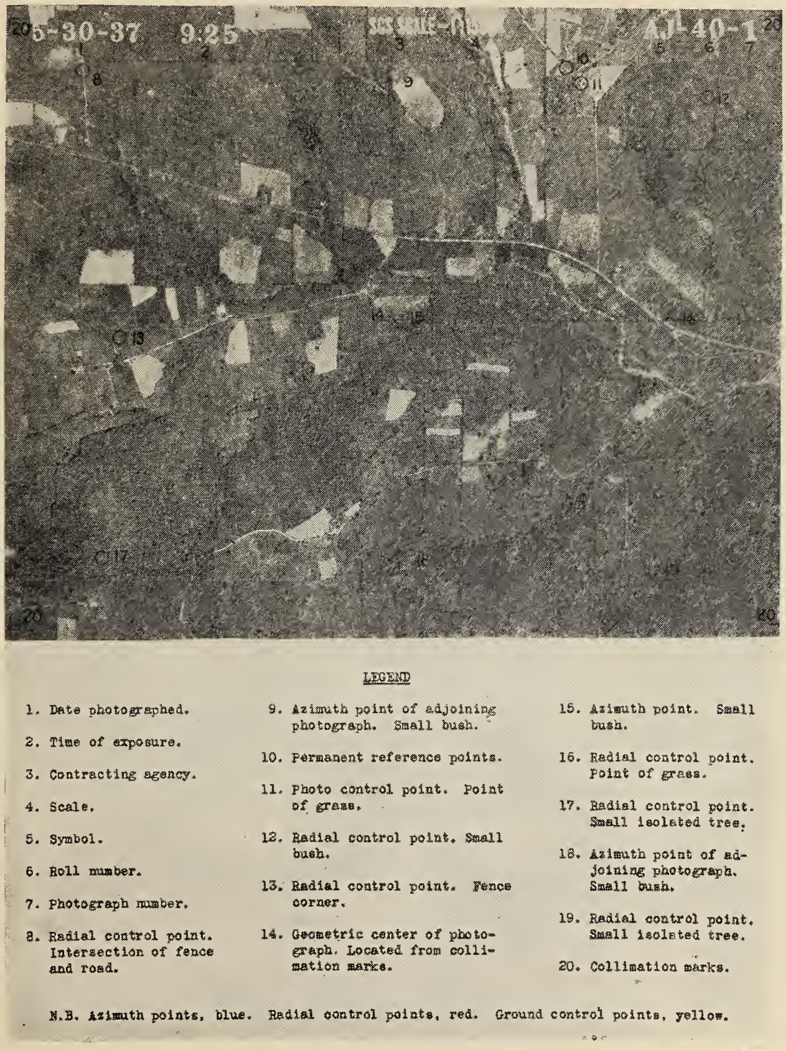

FIGURE 6.—Typical aerial photograph with essential data completed.

from the true principal point. This variance will introduce no plottable error in the angles between the picture points, as measured from the selected point instead of from the true principal point.

Under a stereoscope, this point is transferred to the succeeding picture and, as ordinarily there is a 60-percent overlap in line of flight, three azimuth points (fig. 6) will thus appear on each photograph. At least three additional picture points (radial control points), approximately parallel to the line of flight and opposite these plotted centers, are picked on each side, in the overlap area between the lines of flight. They should be of such character that they can be identified and transferred, stereoscopically, to the photographs in the adjacent flights. This gives at least nine picture points on every photograph. Usually, at least three or four more than this minimum are selected and marked.

In practice, the points are located by pricking fine holes through the photograph and encircling them with small circles, red for the radial control points and blue for the azimuth points, approximately three-sixteenths of an inch in diameter. Ordinary drawing ink is quite suitable for this purpose.

In advance of the office work, the ground control points have been identified stereoscopically on the photographs in the field. They are marked by pricking a fine hole with a needle through the photograph and encircling the hole on the back of the photograph with a small penciled circle. It is advisable not only to number these, but to add a brief description of each point, together with a small sketch, at the time of identification. These points are now marked on the face of the photograph with small yellow circles, and are transferred stereoscopically to all overlapping photographs on which they appear, and on which they can be identified.

When all of the photographs are thus prepared, the next step is to make a templet for each photograph. For this purpose clear, transparent cellulose acetate is used. This can be obtained either in sheets or rolls. A thickness of 0.0075 inch is very satisfactory. It should be cut into rectangles approximately 1 inch larger on each side than the corresponding dimensions of the photograph. This allows the photograph to be taped face down on the templet, using removable crepe-paper adhesive tape along the edges. The assembly is then turned over, the center point marked with a small black circle, and radial lines from that point drawn through the other picture points appearing on the photograph. (See fig. 7.)

It is preferable to etch the lines, and fill them with an opaque substance such as graphite. In this manner, very fine, distinct lines are obtained.

The azimuth lines are extended from the center, but the radials are merely drawn through the points, with about one-half inch of line on each side of the actual point. This is long enough to take care of ordinary relief differences of average country, on photographs made with normal-angle lens. It takes care, as well, of slight scale changes between individual photographs. However, if it is desired to make a map upon a scale differing from the scale of the original photographs, it is necessary to make a larger or smaller templet and extend the radials a proportionate distance out from the center, corresponding to the difference in scale desired.

The picture number is inked on the templet alongside the azimuth point, with the same orientation as on the photograph. (See fig. 6.)

The photographs are now stripped from the templets, and need not be referred to again in the establishment of the auxiliary radial control net unless some error is found in the templets. Where this occurs, it is generally due to misidentification of points. The templets are stacked by flights in numerical order, and are ready for assembly.

The base upon which the assembly is made may be of any material, but until recently, the practice has been to use transparent cellulose acetate. The size of the area having been previously determined, the material is cut to the required size, and in the event that the area is of sufficient size to require more than one width, the strips are overlapped and taped together to form a continuous sheet. Since the centers of a flight line may fall close to the edge of such a strip, the

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FIGURE 7.—Drawing the radials on a transparent hand templet.

practice has been to overlap the sheets sufficiently that the centers may be transferred to the succeeding strip. Transparent cellulose tape is a satisfactory means of taping the overlapping edges.

On this base sheet is constructed the projection (map grid) upon which it is desired to lay the assembly. It should, of course, be of the type best suited to the size and shape of the area.

The United States Coast and Geodetic Survey has established a system of State plane coordinates for every State and is publishing the plane coordinate, as well as the geodetic positions of their triangulation stations. This system is rapidly coming into use throughout the country for surveys of areas of reasonable size and, of course, simplifies construction of a grid.

Upon the grid, which is etched on this cellulose base, are accurately plotted all of the known ground control positions that have been identified on the aerial photographs.

In order to start the assembly of hand templets, it is necessary to locate definitely the positions of the exposure stations of two successive photographs. This is usually done by a graphical solution of the three-point problem. Two templets in the same flight, on the common overlap of which appear at least three picture ties, preferably so placed so that they approximate an equilateral triangle, are selected. The two templets are then placed upon the base sheet so that the radial lines to these picture points pass through the plotted positions of the points, and so that the azimuth lines on the two templets coincide; and they are then fastened down to the grid with adhesive tape. These now establish additional positions by a system of radial triangulation, the distance and direction between the positions forming the base from which additional templets can then be laid, carrying the control forward along the flight line.

As each templet is laid it is taped to the grid sheet and the preceding templet by small pieces of adhesive tape. This procedure is repeated until the flight is tied in to the next control points.

In spite of all possible care, it is seldom that a correct assembly, even of a single strip, will be made the first time. The difference which is found at the end of the line is proportioned through the whole distance by picking up and re-laying the templets to a smaller or larger air base (the distance between two consecutive exposure stations). Personal judgment is of great importance, since ordinarily, the first problem which presents itself is how closely to hold to the azimuth lines when triangles of error are found in the intersection of the radials.

When one strip is apparently satisfactorily adjusted, the next strip is laid, when additional adjustments must usually again be made in order to bring points common to both strips into coincidence. From this trial and error procedure, however, an average result is finally arrived at; and the time that it will take depends very largely upon the skill of the operator. As the number of templets increases, the slight errors accumulate and the proportioning out of these becomes increasingly difficult, and beyond a certain point, impossible.

After the assembly has been completed, if a transparent base has been used, the simplest method of transferring the intersections of the radials to the base is to turn the whole assembly over and mark the positions by small black circles on the back of the base. The use of a transparent base is quite advantageous also in the succeeding phase of map compilation, but cellulose acetate is very unsatisfactory from the basis of accuracy, since it is practically impossible, under ordinary working conditions, to prevent a considerable amount of distortion. As a result, it is usual to take off only a small portion of the data at one time, evening up any distortion within each grid rectangle.

The use of any rigid material is, therefore, from this standpoint alone a very distinct advance. In the development of the slotted-templet method by the Soil Conservation Service, aluminum sheets have been found quite satisfactory, since transparency is not essential, due to the use of a different method of recording intersections. The use of aluminum sheets will be discussed further under the description of slotted-templet method.

A comparative test between the hand-templet method and the slotted-templet method, described near the end of this publication, gives an indication of the relative accuracy of the two methods and the point at which the hand-templet method tends to break down.

THE SLOTTED-TEMPLET METHOD

In this system, the radial line on the templet is replaced by a radial slot, in which a close-fitting round stud is inserted, free to slide along the longitudinal axis of the slot. Since the slot takes the place of the line, the templet material need not be transparent, and therefore can be made of stiff material not subject to distortion to the same degree as the flexible cellulose sheets used for hand templets. The rigidity of templet material is one of the vital factors in the method as it permits the laying of all of the templets having cuts to the same common point, over the stud representing that point, and since the stud and the templets are of rigid material, motion is possible only along the longitudinal axes of the slots. Thus the templets will tend to adjust themselves into theoretically perfect positions.

In practice, this method is subject to certain mechanical limitations. If the templet material is soft, the stud may tend to dig into the side of the slot instead of forcing the templet to move. If the tolerance between studs and the slots is too great, the resultant accuracy of position is decreased. Moreover, friction cannot be eliminated absolutely between studs and slots or between the templets, themselves, irrespective of what materials are used. Furthermore, in the strictest theory, and assuming perfect conditions, it should not be possible to introduce into this general assembly any templet made from a photograph in which any degree of tilt, whatever, is present.

As the rigidity of the studs and templet material is increased and the allowable tolerance in size between the studs and the slots is decreased, the amount of possible play decreases; consequently photographs with less degree of tilt can be laid into the general assembly. In practice, it is found that any large degree of tilt becomes immediately apparent, and that the templet or templets in which such tilt appears will not fit into the assembly, or will tend to buckle. This does not prevent extending the control around such photograph or number of photographs on which excessive tilt is present, and then covering this area by averaging in the tilted photographs or rectifying those photographs and making new templets.

Preparation of the photographs for making slotted templets is practically the same as for hand templets. It consists of the selection of the center point (a definite image so nearly coinciding with the principal point as to introduce no appreciable error through its use), the selection of the radial control points of the density and location required by the particular job at hand, and the addition of all picture ties the geographic positions of which are known. Excluding such picture ties, a minimum of eight slots and a center hole will appear on each templet, two representing the radials to the preceding

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FIGURE 8.—Slotted templets. The shafts of the studs are pierced, as shown, so that the position of the center of the stud can accurately be recovered.

and succeeding photographs' centers, and six representing the radials (three on each side) to points in the overlap area between flights (fig. 8).

For small areas and limited production, a portable hand slotter ordinarily is used. First, photographs are taped, face upward, to the templet material. Four-ply Bristol board is very satisfactory. This is commercially available in sheet sizes up to 22″x30″. With a fine needle or pricker point, the radial points and picture points then are punched through the photograph onto the templet. The photograph is then removed, the points circled with pencil, and the number of the photograph marked alongside the principal point, with its correct orientation to correspond with the line of flight. If the map is to be laid at approximately the same scale as the photographs, this is all that is necessary; but if the scale is to be materially changed, radials from the center are drawn with fine lines through the points

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FIGURE 9.—Punching center hole.

which have been established, and on these lines are set off approximate enlargement or reduction of distances to take care of the desired change.

The center of the templet is then punched out with a small hand punch (fig. 9) which makes a hole the same size as the diameter of the studs used in assembling the templets. The templet is then placed over a metal stud of the same diameter, sliding in a groove on the hand cutter, and the templet rotated on this pin and pushed in or out until the center of the die approximates the position of a marked picture point. The lever is pressed down (fig. 10) and a slot, whose longitudinal axis should correspond to the radial line from the principal point through the picture point, is punched in the cardboard templet.

The length of the slot (1½ to 2½ inches has been used) is sufficient to take care of slight scale differences in the individual photographs as well as relief.

There has been developed (fig. 11) and put in use in the Soil Conservation Service, a templet cutter which materially decreases the cost of the work. With this cutter, the photograph is placed upon a turntable; the templet of cardboard or other material is inserted below the table top; and a small lever, which also cuts the center hole

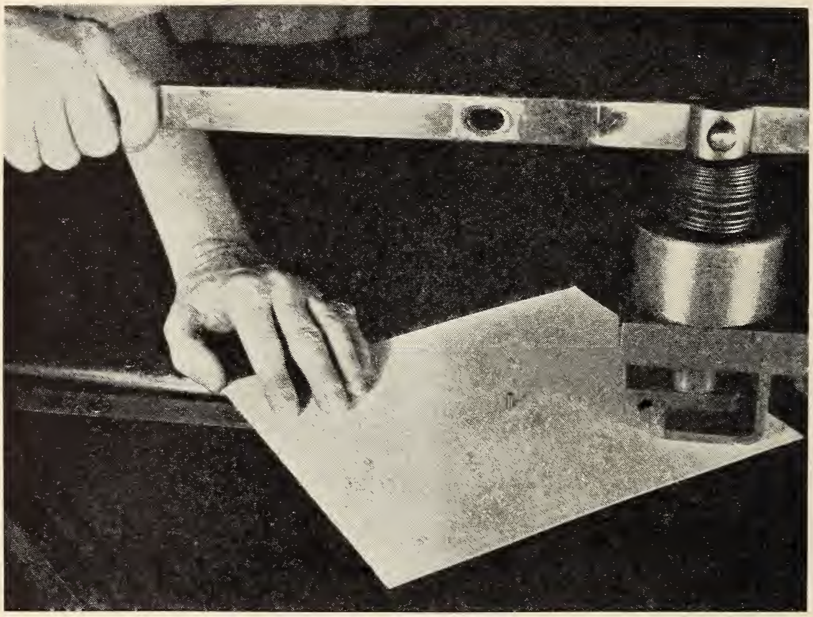

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FIGURE 10.—Cutting templets with hand cutter.

at the same time, clamps the templet in position, so that it rotates with the photograph when the turntable is swung. A small pointer moves in and out from the photograph center, through the use of a small handwheel located on the front of the machine. When the turntable is so swung as to bring a picture point on the photograph into position along the axis of motion of the pointer, and the pointer so placed that it is directly over the picture point, a foot lever is depressed, cutting a slot in the templet.

This machine also is so arranged that it can be set for variations in scale, so that a templet from one-half-diameter reduction to two diameters enlargement can be made by setting the ratio scale on the machine. The machine combines the various operations described in the paragraphs on the hand cutter, and not only effects a reduction of approximately 40 percent in the time required, but cuts more accurate templets. An efficient operator can turn out 20 or more templets per hour on this cutter.

As a medium upon which to lay slotted templets, the use of aluminum in sheets has been found to be very satisfactory. The aluminum used is 15 one-thousandths of an inch in thickness. Sheets 5 by 10 feet, which are about as large as can be conveniently handled, are abutted and taped together with transparent tape, and the outer

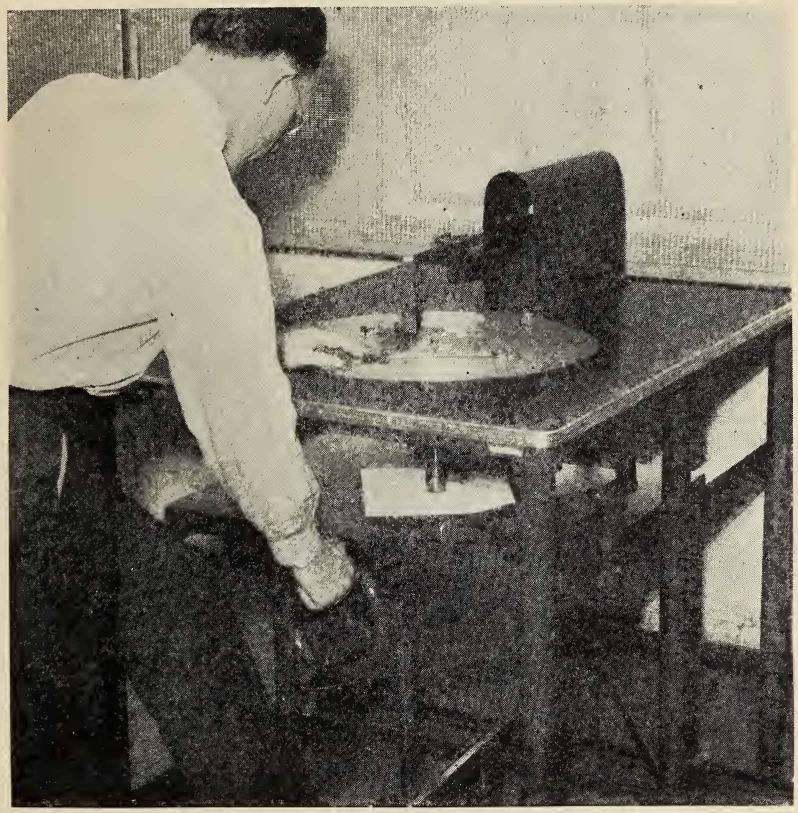

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FIGURE 11.—Improved templet cutter. This machine can be set automatically to change scale between photographs and templets.

edges of the sheet junctions soldered together. This has been found to work very satisfactorily. The largest area that has come under the writer's experience is the one to which reference is made later in this description, an area consisting of approximately 4,400 square miles, laid on a scale of 1:15,840, and requiring a base approximately 25 by 35 feet.

The grid is etched on the aluminum as a very fine line, after which the control positions are carefully plotted, and a metal templet stud cemented to the aluminum sheet at each control point. This is a very simple procedure. The bottoms of the studs are coated with an aluminum cement; the studs placed over a fine pin with the same diameter as the hole through the shaft of the studs; the point of the pin centered over the plotted position (fig. 12); and the stud then

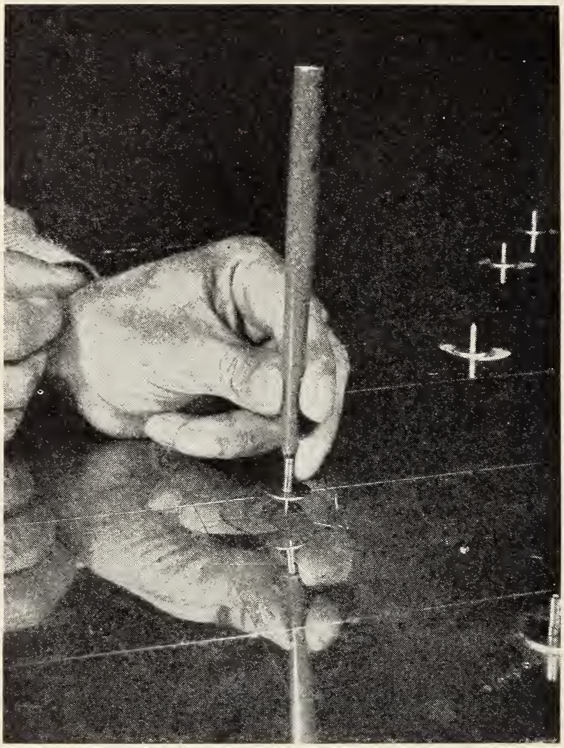

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FIGURE 12.—Placing the control studs in position. This also illustrates size and shape of studs.

carefully dropped on the aluminum. The operation avoids the necessity of nailing through the base, a decided advantage, as it was found that, even with care, the nails or pins so driven tend to work away from correct position.

As a simple check on the accuracy of placement of the studs, when they are scraped off the aluminum sheet after the assembly is completed, the bottom of the stud will be found to bear a distinct impression of the cross that was etched on the aluminum base to locate the plotted position of the point, and these lines should clearly quartersect the small hole in the stud.

The cement may easily be cleaned from the stud by immersing in an acetone solution for a few minutes.

After making the templets and etching the grid base, the next step is the assembly of the radial control net. It is not necessary to have three known control positions, as with the hand-templet method. The assembly can be started from any single picture tie and with any flight, although it is preferable to pick out a good flight strip, and, if possible, a templet with two or more picture ties. Ordinarily, the flight strip will be laid in its entirety, just as is done with transparent templets. However, when the next control is reached, if a slight scale adjustment is necessary, this is easily accomplished by squeezing together the whole assembly or stretching it out slightly along the line of flight, as may be required.

As stated before, to be theoretically perfect, the slotted-templet system requires perfect fit between the slots and the studs and a minimum of friction both between studs and templets and between the templets, as well as a templet material sufficiently rigid to resist any distortion under the forces applied. The use of sheet aluminum

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FIGURE 13.—Laying templets in alternate flights.

for templets indicates that they slide slightly better than untreated cardboard. However, they are higher in cost, are more difficult to cut with a clean slot edge, and the edges of the templets themselves are quite sharp, so that they require considerable care in handling.

It will be noted in the photographs of the templet assemblies that the templets are not square or rectangular. This is due to the fact that the edges are trimmed off to avoid interference on overlapping flights. This irregularity of outline would add to the problem of knifelike edges on thin aluminum templets. Waxing the cardboard templets will materially decrease friction, and increase the accuracy of adjustment.

If no difficulty is encountered in making the assembly, then the procedure under which each adjacent flight strip is laid in turn, is usually the easiest. However, alternate flights may be laid (fig. 13), or the templets may even be built up across the lines of flight.

Where difficulty in laying a certain portion of the area is encountered, the work can be carried around this portion, and eventually the templet or templets causing the trouble will be segregated.

Laying the assembly at approximately the same scale as the photographs means that picture points on 9″ x 9″ photographs are never over 5 inches away from the center. Consequently, a small amount of tilt will cause no appreciable error in the assembly, since the angular amount that it will displace a picture point at that distance will not ordinarily be beyond the usual tolerance limit of good drafting. A templet from a photograph with a large amount of tilt cannot be laid, unless the attainable accuracy of the system is reduced through the use of slots with too great a tolerance between the diameter of the studs and the width of the slots or unless the material used for templets is of such weak consistency that the studs will indent the side of the slot at the least binding. The condition of the slots at the end of the assembly will show whether this last situation exists.

In practice, the small errors which result in small triangles of error on hand templets and cannot be worked out but must be averaged in, are taken up in the differential between practical accuracy and theoretical perfection.

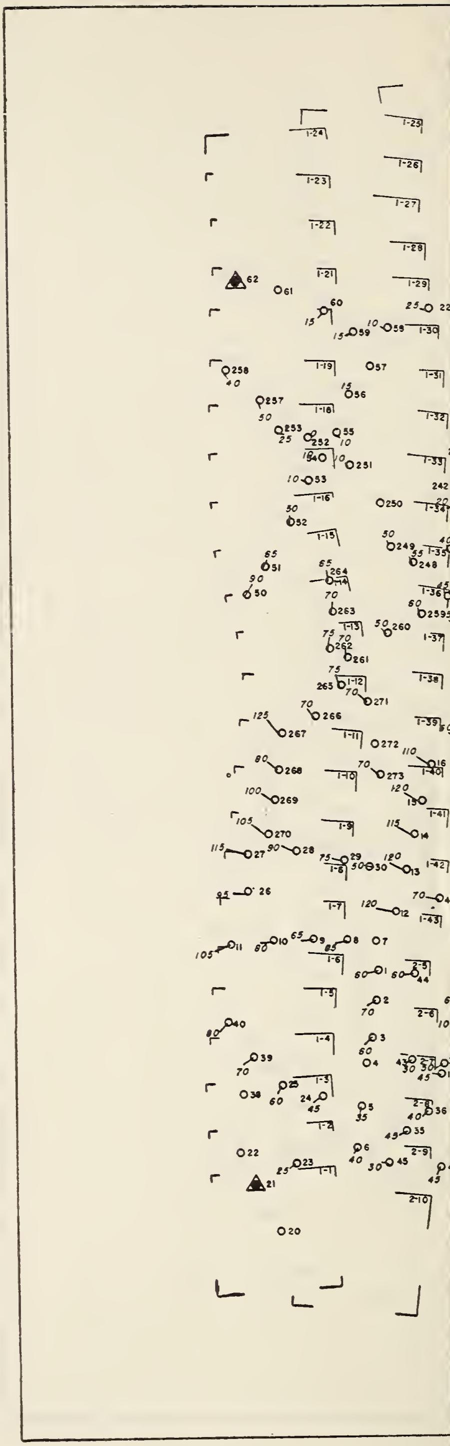
SLOTTED-TEMPLET TESTS

As an initial proving ground for tests of the slotted-templet system's accuracy, an area was selected which had been covered by aerial photographs of average quality and where an accurate and dense system of control points had been established. This was found at Beltsville, Md., where, in a roughly rectangular area of 155 square miles of rolling country, with a maximum elevation difference of approximately 200 feet, 273 ground control points were available. These points were established for test purposes under the direction of the U. S. Geological Survey with position accuracy of 1:7,500. Two hundred and thirty-three photographs, size 9″ x 9″, on a scale of 1:12,000, cover the area in 12 flights, averaging 19 photographs each with approximately 60 percent overlap in line of flights and 30 percent side overlap.

Low-shrink paper was used for the photographic prints. The 273 picture points, which had been located on a set of field prints, were transferred, and the azimuth and radial control points identified and added.

A polyconic projection with 1-minute grid, scale 1:12,000, was constructed upon two sheets of 26-gage aluminum, size 3′ × 8′ each, abutted, taped, and riveted together with aluminum strips to form a single sheet. The projection was tested for accuracy before and after completion of the work. Upon this projection, the 273 control points established were carefully plotted.

A sheet of opaque paper was then placed over the entire projection, leaving visible only the control points actually held to in each individual test. Thus, in the first test in which four control points, one in each corner of the area, were held to, these were the only control points visible, so as to avoid influencing, in any way, the placing of the templets.



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Cum. percent
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25 feet

Four-play Bristol board was used for templets. More than ordinary care was taken in their handling to avoid damage to the sides of the slots; and the same set of templets was used throughout. At the end of the test, they were still in good condition.

Tests were made in the order as numbered. Diagrammatic sketches, showing the result of each assembly, are included, giving for each point tabulated, the approximate azimuth and distance from the true geographical position. A small percentage of points where the intersection of the radials was very flat or where points fell too near the centers of the photographs to be of any use were not recorded.

Flights were numbered from west to east, beginning at "1."

Discussion of Assembly No. 1

Four picture points only, one located in each corner of the area, were used for this assembly (fig. 14). This gave control at the ends of the first flight with 21 photographs between, and control at the ends of the 12th flight with 19 photographs between.[1]

The distance between control points was approximately 12 miles along the line of flights, and 13½ miles across flights.

This test alone demonstrates the value of the slotted-templet method. The assembly was loose and could be moved to an appreciable extent in any direction, except near the control points. Nevertheless, an assembly was accomplished with this extremely scant control in which the average error of absolute position was less than 50 feet, which on this scale is one-twentieth of an inch. The relative error in distance between adjacent control-point positions as plotted by this templet assembly averaged 25 feet, or only half as much.

Discussion of Assembly No. 2

An additional point to the four located in the corners was added in the middle of the area (fig. 15), thus breaking the square down into four triangles approximately 10 miles on each side, with control on each corner.

The additional point strengthened the assembly only slightly. The assembly could still be moved at the outer edges between control, but the errors were reduced appreciably in the vicinity of the additional control point. The general error of assembly, which had been without definite pattern in assembly No. 1, swung from a northwesterly direction to a more southerly one.

Discussion of Assembly No. 3

Eight control points were held (fig. 16). This gave control on flights 1, 6, 7, and 12 with additional control points on flights 1 and 12 at points midway on these flights. As located, this reduced the number of photographs between control points to a minimum of 10 and a maximum of 16.

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[1] In counting the number of photographs between control on this and subsequent tests, the rule was established to include only the number of photographs between such control positions sufficient that an intersection of two radials would be made on each control point.

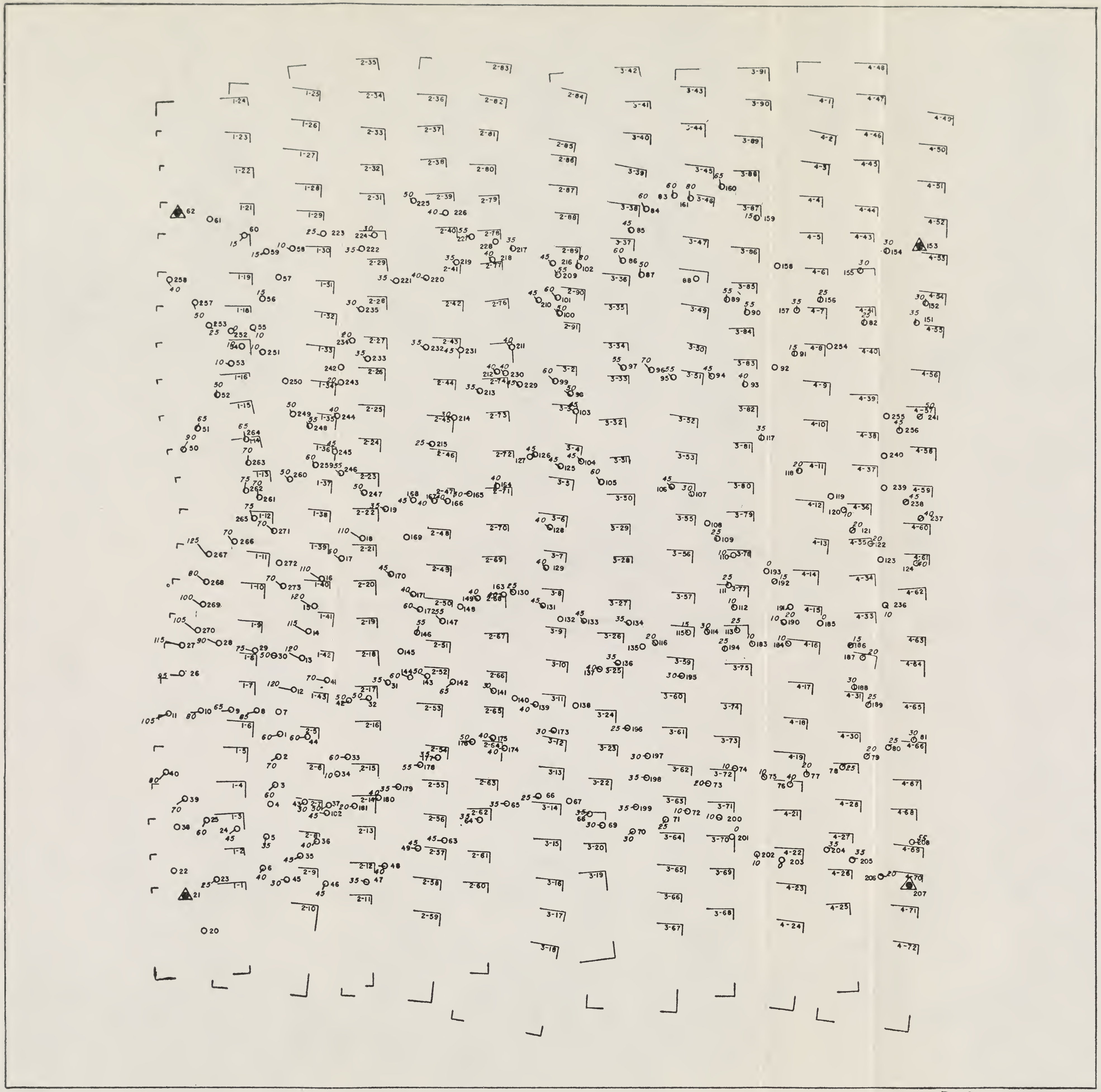


Figure 14.– Results of radial triangulation by the slotted-templet method, assembly No. 1, Beltsville, Maryland, Demonstration Area.

Legend

Scale of assembly – 1 inch = 1000 feet

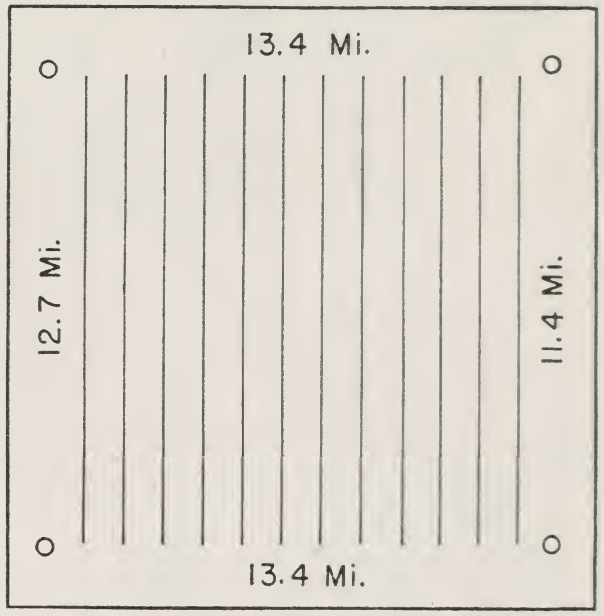
4-30 – picture number and location

○ 207 – picture point position by traverse

▲ – picture point controlling assembly

○–50 – azimuth and distance from geographic position to the position obtained by radial triangulation.

Control distribution



Breakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0	5	2	
10	18	8	10
20	21	9	19
30	36	15	34
40	53	22	56
50	40	17	73
Over 50	64	27	100

Average error of all positions recovered is 43 feet, maximum error is 125 feet

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Sheet 1

This amount of control was sufficient to eliminate any movement in the assembled templets.

Discussion of Assembly No. 4

Thirty-one picture points (fig. 17), one in each corner of the area, one in the common overlap of each flight at each end, two intermediate along flight 1, and three along flight 12, were held.

This test approximates the result that might be obtained by breaking down the original triangulation control into 15-minute quadrangles, and traversing across the ends of the flights from one triangulation station to another. Since with such traverses it is necessary to cover all of the flights anyway, it is customary to secure a picture point in the overlap between each flight while making such traverses. Furthermore, it is always desirable to have one or two points along the outer flights to prevent bowing in or out of the templets.

While the maximum error was reduced in this test to a considerable extent over test No. 3, the average error was reduced but very slightly.

This test indicates that with present materials and with this amount of control, the probable accuracy limit is approached. It also indicates clearly the point beyond which the cost of obtaining additional control should be closely balanced against the required accuracy of result.

Discussion of Assembly No. 5

It has been found in practice that with the slotted-templet method of control, the accuracy of the system breaks down very rapidly outside of control points. However, conditions might arise in which it would be necessary to carry the mapping to a considerable extent outside of control. For this reason, a test was made with control normal to the lines of flight at one end of the desired area, only.

Test No. 5 (fig. 18) extended the templets for 12 miles from such a base, using control points in the overlap area of each successive flight. The maximum error on this assembly was, of course, on the outer fringe of the photographs and amounted to 380 feet. It is probable that this error would have been materially reduced if one or more azimuth lines had been secured from the control base.

Discussion of Assembly No. 6

Assembly No. 5 was repeated except that only seven templets were laid from the control base. The general pattern of error remained the same but the error was greater at the outer edges than at the same distance from the control base in assembly No. 5.

Discussion of Assembly No. 7

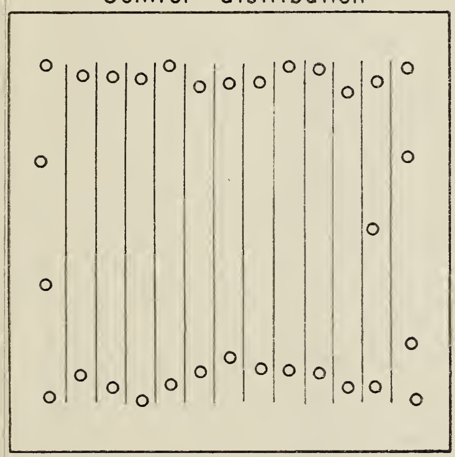
This assembly (fig. 19) was made with control along an outside line of flight, only. The maximum error was nearly four times as great as on test No. 5.

'igure 17.— Results of radial
iangulation by the slotted-templet
ethod, assembly No. 4, Beltsville,
aryland, Demonstration Area.

Legend

cale of assembly - 1 inch = 1000 feet
-30 - picture number and location
) 207 - picture point position by traverse
- picture point controlling assembly
50 - azimuth and distance from geographic position to the position obtained by radial triangulation

Control distribution



reakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0	50	24	
10	44	21	45
20	62	30	75
30	32	16	91
40	14	7	98
50	4	2	100
ver 50	0		

verage error of all positions recovered
s 15 feet; maximum error is 50 feet

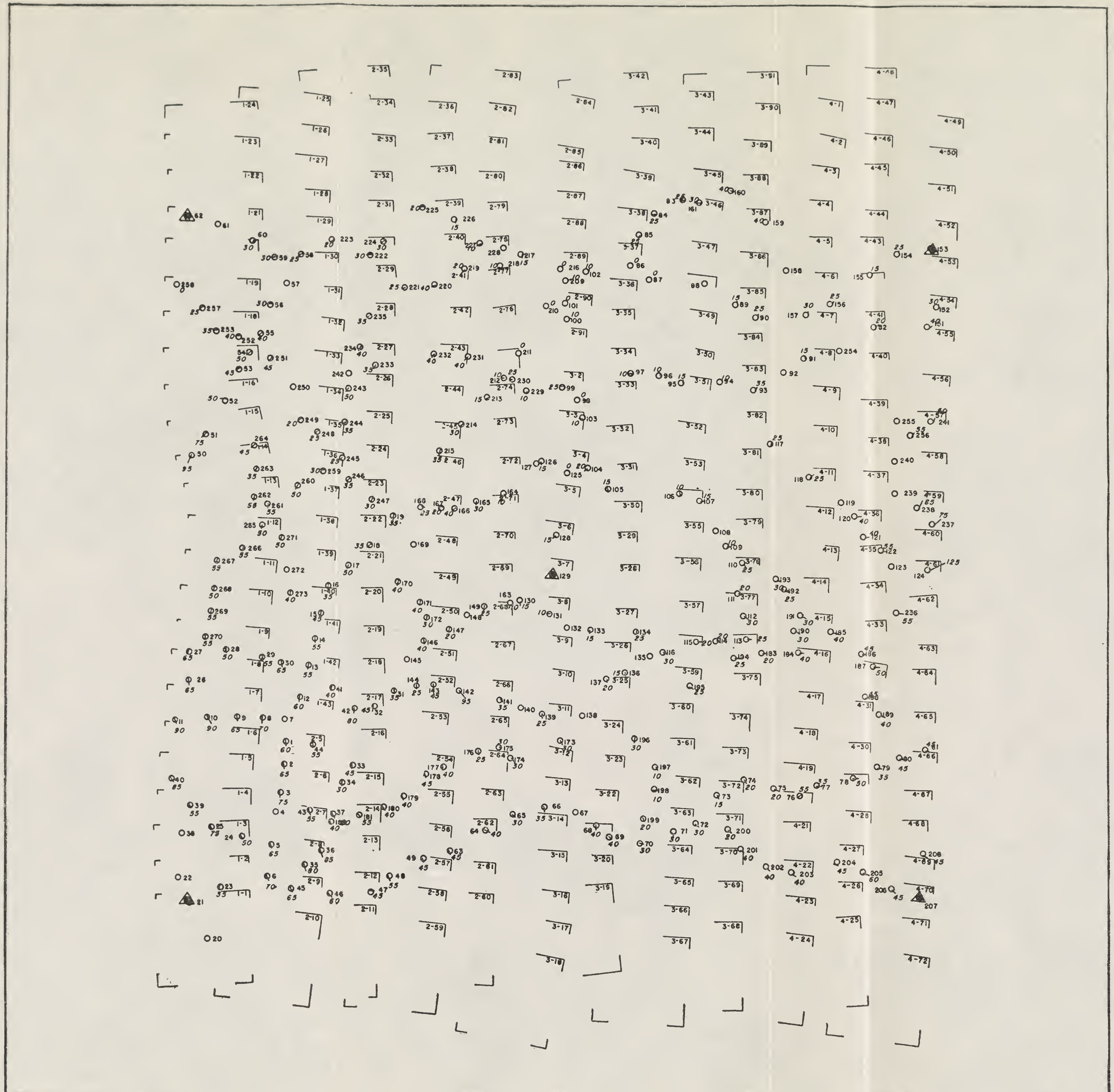


Figure 15.—Results of radial triangulation by the slotted-templet method, assembly No. 2, Beltsville, Maryland, Demonstration Area

Legend

Scale of assembly – 1 inch = 1000 feet

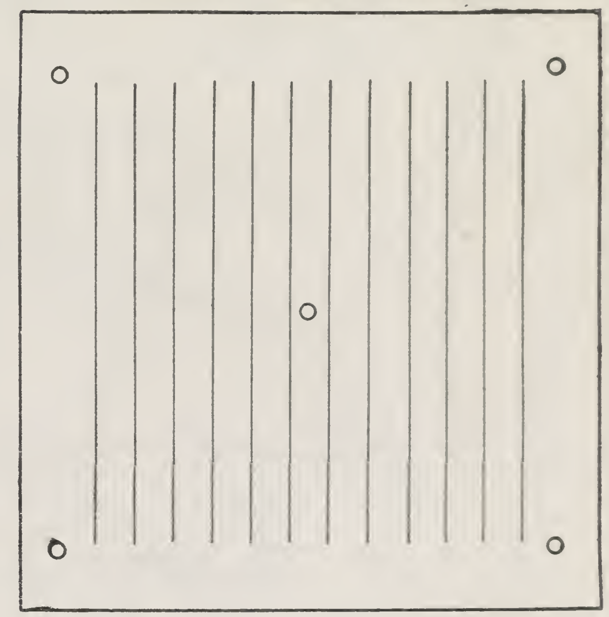
4-30 - picture number and location

○207 - picture point position by traverse

▲ - picture point controlling assembly

○50 - azimuth and distance from geographic position to the position obtained by radial triangulation

Control distribution



Breakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0	9	4	
10	18	8	12
20	32	14	26
30	53	22	48
40	47	20	68
50	31	13	81
Over 50	46	19	100

Average error of all positions recovered is 36 feet; maximum error is 125 feet

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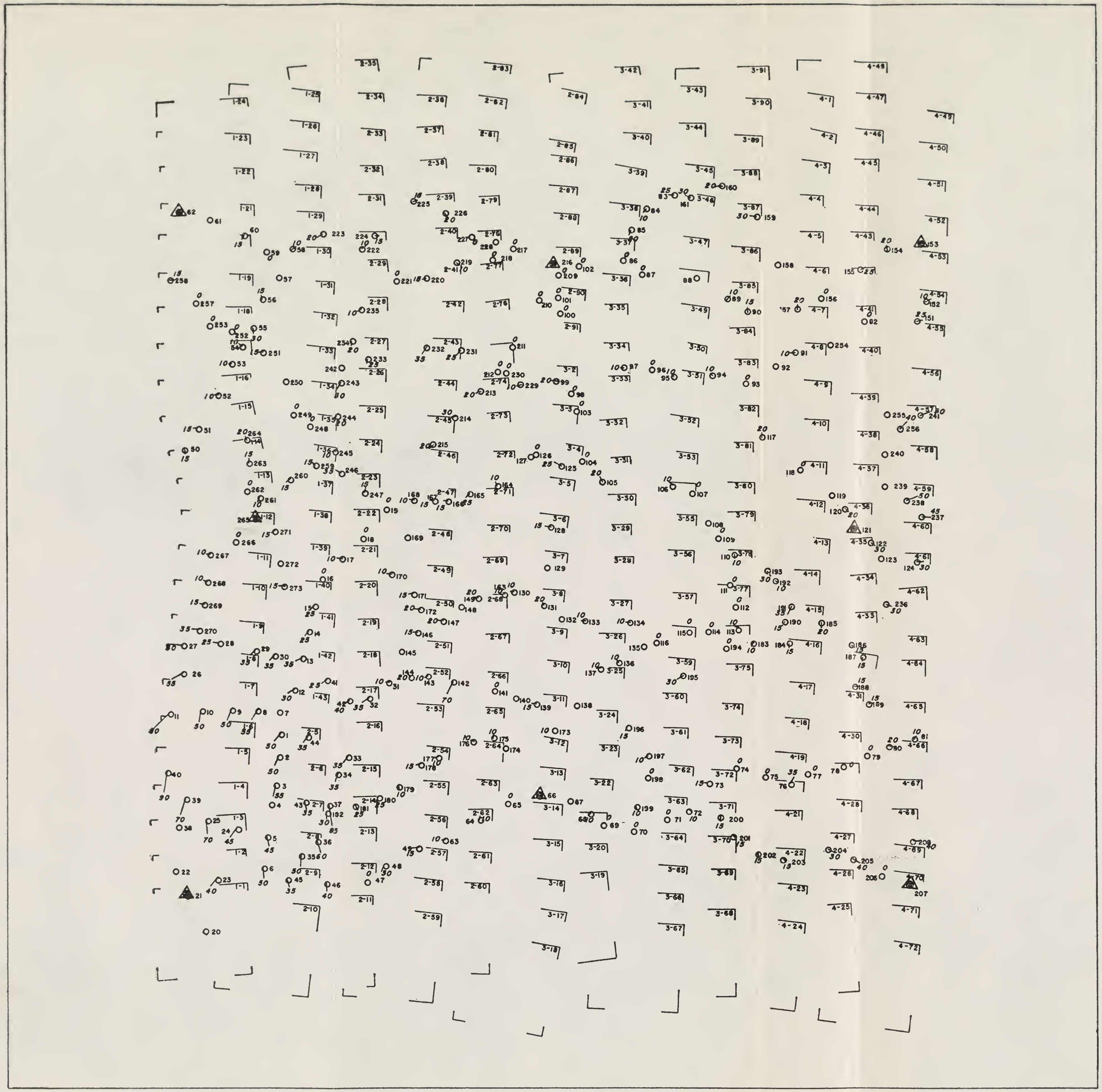


Figure 16.– Results of radial triangulation by the slotted-templet method, assembly No. 3, Beltsville, Maryland, Demonstration Area.

Legend

Scale of assembly – 1 inch = 1000 feet

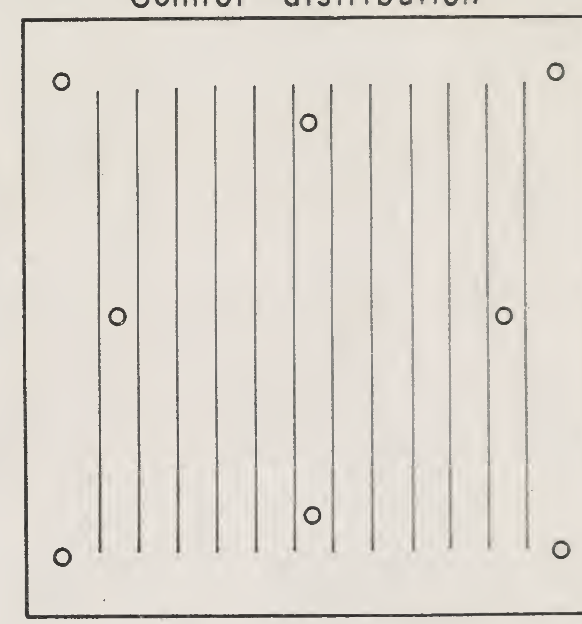
4-30 – picture number and location

○207 – picture point position by traverse

▲ – picture point controlling assembly

○–50 – azimuth and distance from geographic position to the position obtained by radial triangulation

Control distribution



Breakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0	55	24	
10	49	21	45
20	59	25	70
30	27	12	82
40	20	9	91
50	12	5	96
Over 50	10	4	100

Average error of all positions recovered is 18 feet, maximum error is 90 feet

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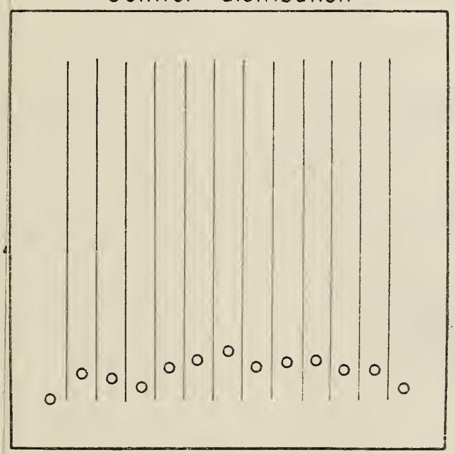
igure 18.– Results of radial
angulation by the slotted-templet
ethod, assembly No. 5, Beltsville,
aryland, Demonstration Area.

Legend

:ale of assembly – 1 inch = 1000 feet
30 – picture number and location
207 – picture point position by traverse
△ – picture point controlling assembly
50 – azimuth and distance from geographic position to the position obtained by radial triangulation

Control distribution



reakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0	38	18	
10	23	11	39
20	30	14	43
30	22	10	53
40	11	5	58
50	7	3	61
Over 50	82	39	100

Average error of all positions recovered
s 60 feet; maximum error is 380 feet

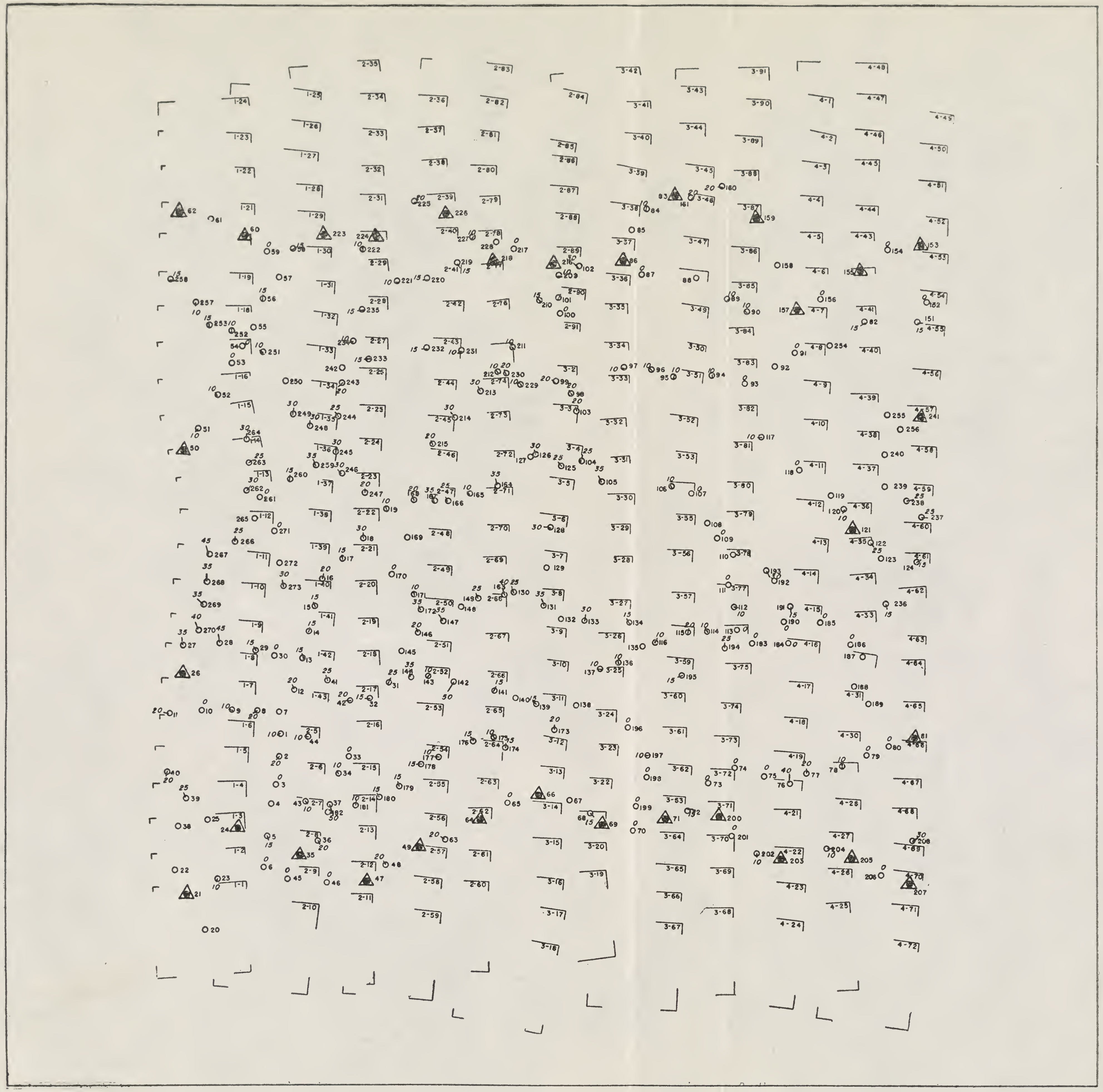


Figure 17.—Results of radial triangulation by the slotted-templet method, assembly No. 4, Beltsville, Maryland, Demonstration Area.

Legend

Scale of assembly – 1 inch = 1000 feet

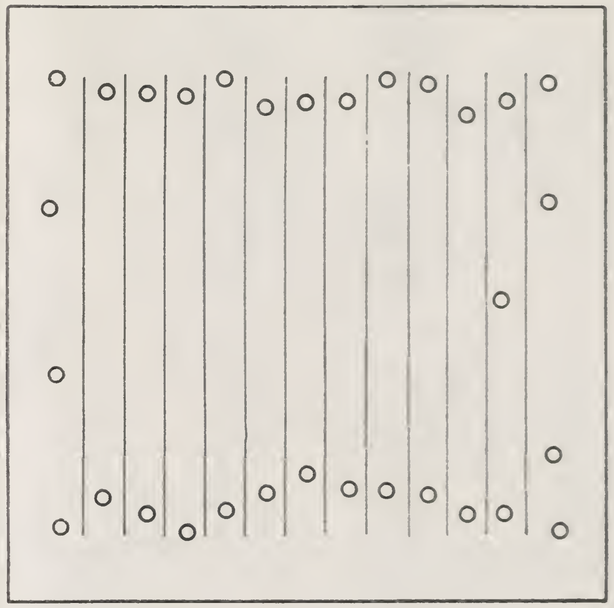
4-30 – picture number and location

○ 207 – picture point position by traverse

▲ – picture point controlling assembly

○ 50 – azimuth and distance from geographic position to the position obtained by radial triangulation

Control distribution



Breakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0	50	24	
10	44	21	45
20	62	30	75
30	32	16	91
40	14	7	98
50	4	2	100
Over 50	0		

Average error of all positions recovered is 15 feet; maximum error is 50 feet

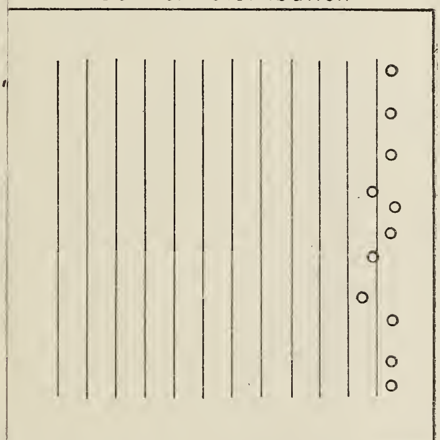
A.S. 100131 P-3104 sheet 4

'gure 19.— Results of radial
angulation by the slotted-templet
ethod, assembly No. 7, Beltsville,
aryland, Demonstration Area.

Legend

1300— ale of assembly - 1 inch = 1000 feet
30 - picture number and location
1200— 207 - picture point position by traverse
1070 - picture point controlling assembly
-50 - azimuth and distance from
geographic position to the position
obtained by radial triangulation

Control distribution



eakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0	18	8	
10	2	1	9
20	9	4	13
30	4	2	15
40	8	3½	18½
50	8	3½	22
/er 50	178	78	100

verage error of all positions recovered
350 feet; maximum error is 1300 feet

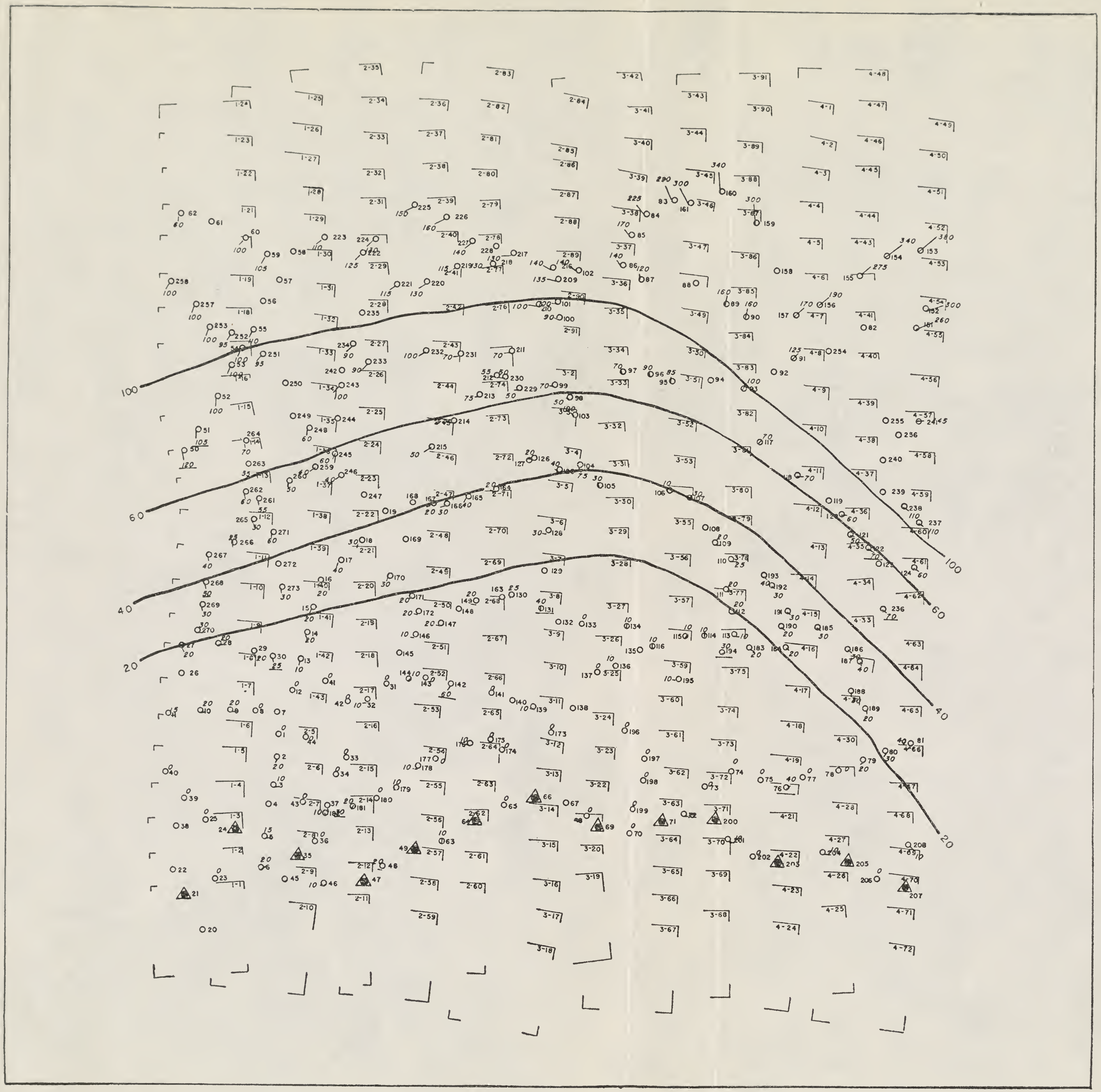


Figure 18.– Results of radial triangulation by the slotted-templet method, assembly No. 5, Beltsville, Maryland, Demonstration Area.

Legend

Scale of assembly – 1 inch = 1000 feet

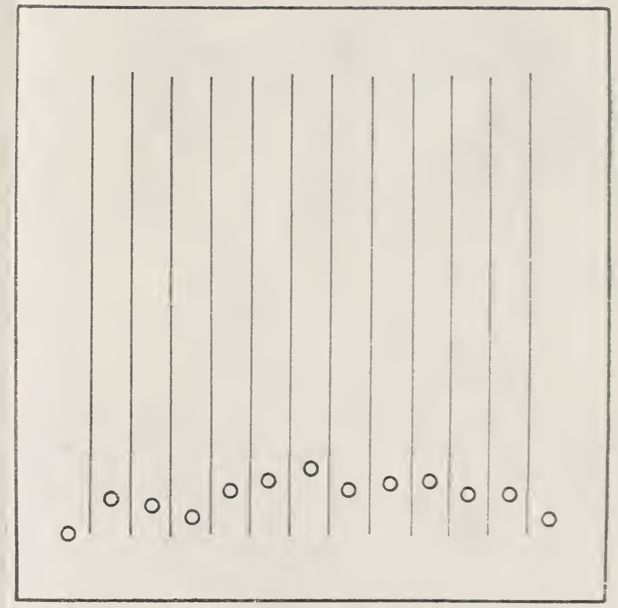
4-30 – picture number and location

○ 207 – picture point position by traverse

▲ – picture point controlling assembly

⊖ 50 – azimuth and distance from geographic position to the position obtained by radial triangulation

Control distribution



Breakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0	38	18	
10	23	11	39
20	30	14	43
30	22	10	53
40	11	5	58
50	7	3	61
Over 50	82	39	100

Average error of all positions recovered is 60 feet; maximum error is 380 feet

A.S. 100132

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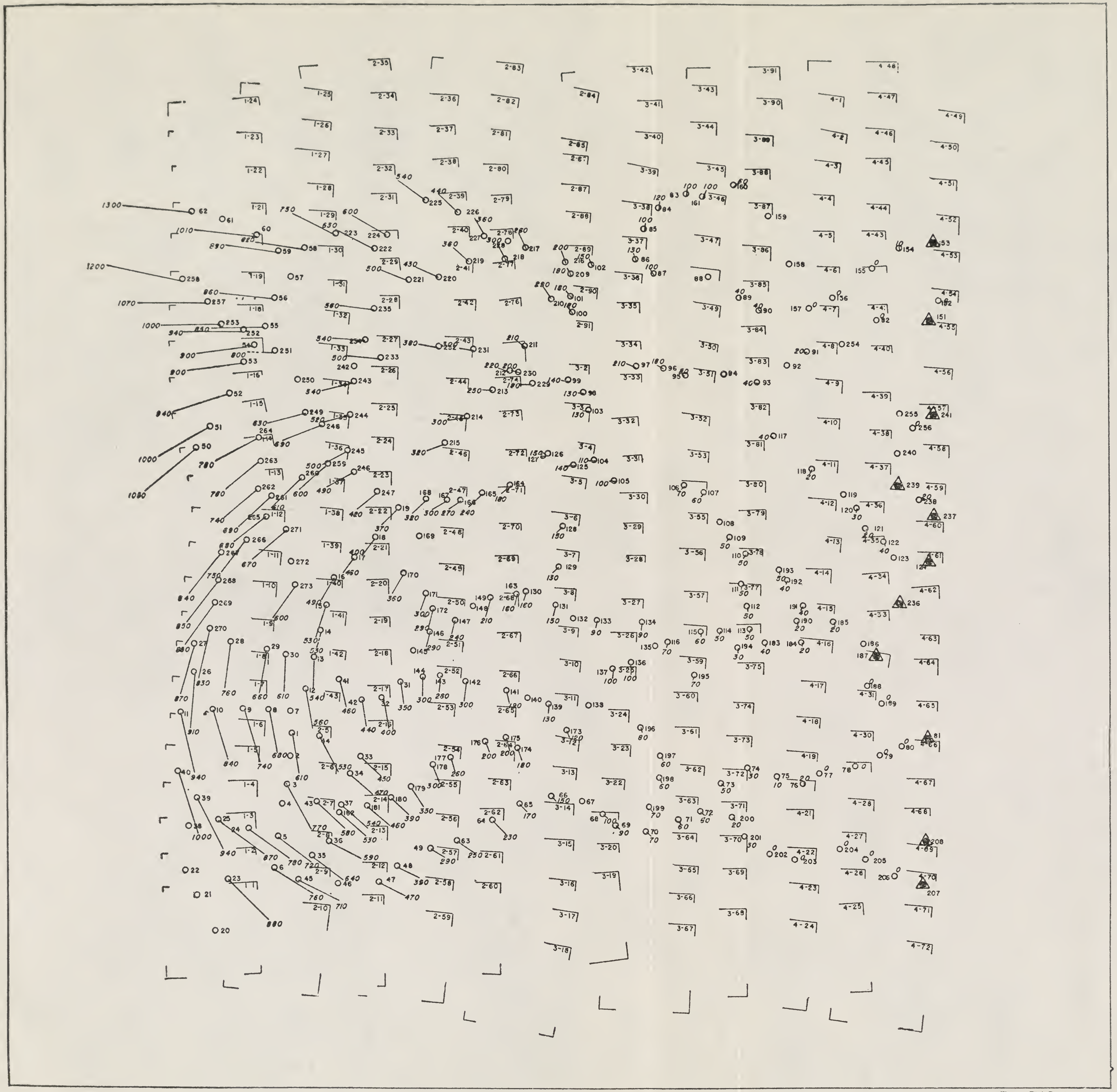


Figure 19.—Results of radial triangulation by the slotted-templet method, assembly No. 7, Beltsville, Maryland, Demonstration Area.

Legend

Scale of assembly- 1 inch = 1000 feet

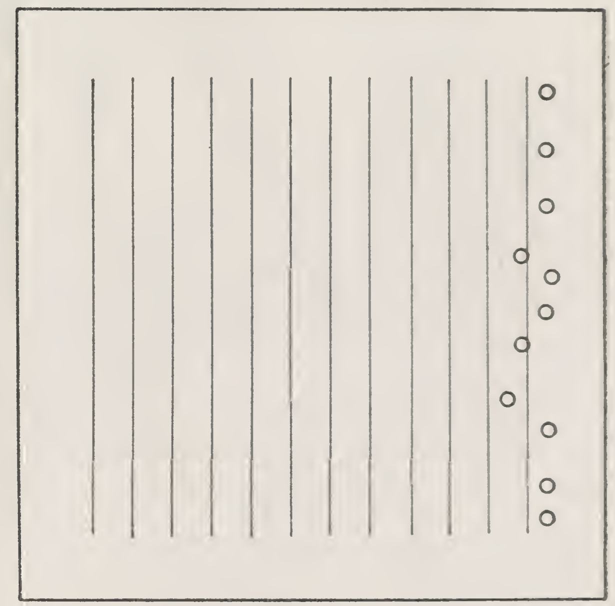
4-30 - picture number and location

○ 207 - picture point position by traverse

▲ - picture point controlling assembly

○— 50 - azimuth and distance from geographic position to the position obtained by radial triangulation

Control distribution



Breakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0	18	8	
10	2	1	9
20	9	4	13
30	4	2	15
40	8	3½	18½
50	8	3½	22
Over 50	178	78	100

Average error of all positions recovered is 350 feet; maximum error is 1300 feet

A.S.100134

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Comparative Tests Between Hand-Templet and Slotted-Templet Methods

In an attempt to compare the two systems, hand templets were made from the same photographs used for the slotted-templet tests at Beltsville, Md.

As test No. 4 had established the point at which very good accuracy could be obtained by the slotted-templet method, the amount of control used in that test was established for this hand-templet test. The original aluminum base sheet was used, and all except the bands of control on the North and South and points on the edges were covered with a sheet of opaque paper.

It became apparent, as soon as the assembly was started, that the number of radials was insufficient for the hand-templet method; and approximately 20 percent more points were selected on the photographs and cut on the templets.

A diligent effort was then made to lay the templets, but without success; and eventually, eight more control points were added, stretching across the center of the flights. This was in line with previous experience which indicated that under average conditions the maximum gap that could be bridged successfully with hand templets usually would not exceed 10 photographs. It must, of course, be understood that this refers to areas and not to a single strip of photographs. The final assembly, with this additional control, was within the usual specifications for templet assemblies and may be classified as good.

The result was not as accurate as that obtained from assembly No. 4, using slotted templets. The summation of percentages of error is shown in figure 20 so that a direct comparison can be made.

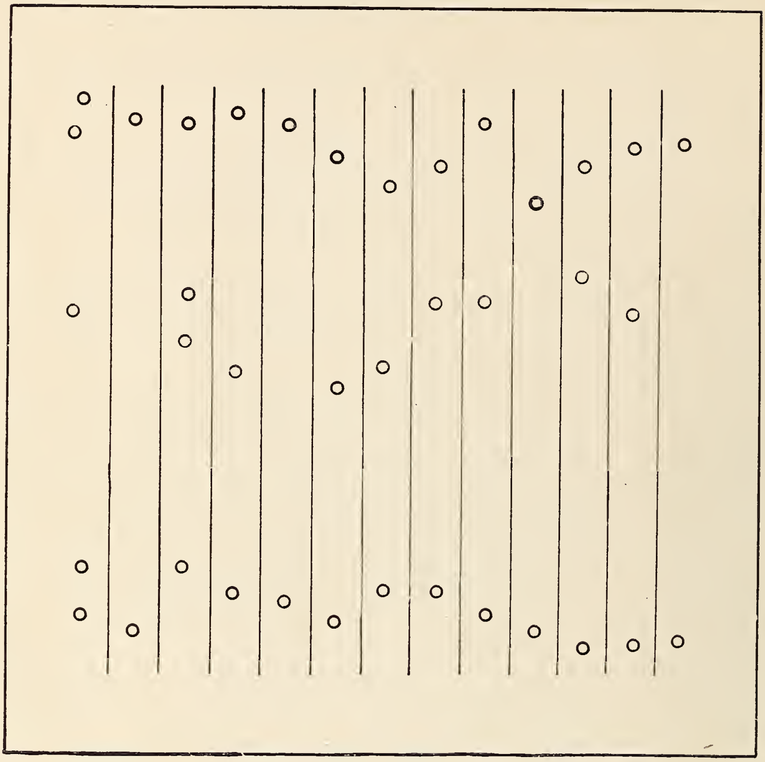
The results of the hand-templet assembly test clearly indicate the limits to which this method may be extended. If the available control is more widely spaced than as used in this test, it usually must be supplemented by additional ground control.

Additional Slotted-Templet Tests

The Beltsville test gave no indication that the limit to which slotted-templet control could be extended, had been reached. The assembly, even with the minimum control used for test No. 1, was easily made. A considerably larger area, therefore, was selected for the next test. This was Carter and Murray Counties, Okla., covering an area of 1,200 square miles of comparatively flat country. The area covered is shaped somewhat like a T-square, with an average of 20 photographs between control in the western part of the area and 40 photographs between control in the eastern part. The control held to was spaced around the perimeter of the area. Fifty-five check points gave an average error of 55 feet and a maximum error of 130 feet.

Considerable difficulty was experienced in moving the mass of templets into adjustment, indicating that without further development this was probably the limit to which this method of obtaining control could be extended. Moreover, distances between control stations, as used on this test, are not the maximum required to bridge the spacing between established triangulation nets in all parts of

Control distribution



Breakdown of points into error classifications

Error	No. of points	Percent	Cum. percent
0			
10	66	40	40
20	42	25	65
30	40	24	89
40	11	7	96
50	7	4	100
Over 50	1		

Average error of all positions recovered is 21 feet; maximum error is 65 feet.

P–3103–2

FIGURE 20.—Results of radial triangulation by the hand-templet method, test for comparison with slotted-templet assembly, Beltsville, Md., demonstration area.

this country. To meet these two conditions, the simple expedient of waxing the templets in order to reduce friction was resorted to in the next larger test.

This test was on an area of 4,400 square miles included in the Bird and Caney watersheds in Kansas and Oklahoma (figures 1 and 21). Two thousand seven hundred templets on a scale of 1:15,840, made from negatives taken on a scale of 1:20,000, covered the area. As with the previous test, control was held to only around the edge of the area, thus giving the maximum distance possible between control. The distance along the line of flight averaged 93 miles with 108 templets. Across flights, the average distance was 51 miles, covered

75,509

FIGURE 21.—Laying out projection for the 4,400 square mile area in Bird and Caney watersheds in Kansas and Oklahoma referred to in the tests. The sponge-rubber pads shown are an important aid in assembling large areas. They can be laid over the studs without disturbing the assembly and can be walked on without discomfort.

by 25 flights. Eighty-seven control points were held to, as shown in the frontispiece. Table 1 gives the number of check points and percentage of error. The total number of points checked for error was 192. The maximum error was 140 feet and the average error, 45 feet.

TABLE 1.—*Check points and percentage of error for test on area of 4,400 square miles in Bird and Caney watersheds in Kansas and Oklahoma*

Error (feet)	Number of points	Percentage	Cumulative percentage	Error (feet)	Number of points	Percentage	Cumulative percentage
0	11	6		70	15	8	83
10	14	7	13	80	17	9	92
20	21	11	24	90	6	3	95
30	23	12	36	100	1		95
40	34	18	54	110	7	4	99
50	22	11	65	120	1		99
60	19	10	75	140	1	1	100

No difficulties were experienced in making the assembly, and the average and maximum errors, while maintaining the same relative ratio as indicated by previous tests, were considerably less than was anticipated. Waxing the templets made a shifting of the mass of templets possible, so that they could be pulled into adjustment with other flights. In addition, much more correct general adjustment was obtained.

TEST DEDUCTIONS

In general map work, using 7″ x 9″ or 9″ x 9″ single-lens photographs, and with a control situation approximating the conditions of the Beltsville, Md., and the additional tests discussed, that is, bands of reasonably closely spaced control normal to the lines of flight at definite intervals and with a number of control points along the sides of the assembly sufficient to hold the azimuth of the outside flights, we may expect the following:

1. The errors of position as a percentage of maximum error will approximate the graph shown in figure 22.

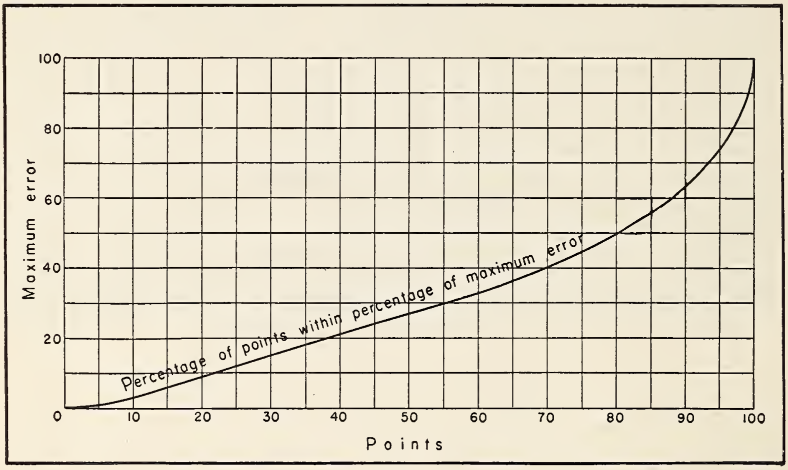


FIGURE 22.—Error distribution indicated by test templet assemblies.

2. For maps made from photographs taken at a scale of 1:20,000 and compiled at a scale up to 1:15,840, the average error in feet should not exceed the average number of photographs between control, and (as shown in figure 22) the maximum error should not exceed three times the average error.[2]

CONCLUSION

The Beltsville, Md., and additional tests reported, it is believed, allow a fair evaluation of the worth of the slotted-templet method in making possible the mapping of country where ground control is exceedingly sparse.

[2] The proportional errors in the Bird and Caney test are materially less than this.

They clearly demonstrate that the limitations of the system would in no way prevent its use in making an aerial planimetric map of any portion of the United States, using only the existing control and the type of photographs at present available, since the spacing of the control used for the Bird and Caney test exceeds the maximum spacing of the triangulation nets already established.

Furthermore, they give a good idea of the degree of accuracy that could be expected with a small amount of control, and indicate the increase of accuracy obtainable by adding additional control, so that, considering the purpose of the desired map, the cost of the additional control can be correctly weighed against the resulting increase in accuracy.

Finally, these tests indicate equally clearly the point beyond which additional control—using this method—adds little to the accuracy of the finished map.

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