Aerial Photography in Right-of-Way Acquisition: A Symposium

Semi-Controlled Aerial Photographs as a Right-of-Way Surveying Tool

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With ever-increasing survey costs, it becomes necessary to develop techniques and methods of acquiring information that reduce these costs and still retain accuracies that are acceptable. To use aerial photographs as a satisfactory surveying tool and map substitute, it is necessary that the photographs be enlarged precisely. To obtain precise photographic enlargements, adequate targets must be set on the ground before photography, within the area to be photographed, to obtain both an enlargement factor and scaling factors.

It has been experienced in working with aerial photographs enlarged to a scale of 20 ft to 1 in. that the determination of the dimensions of areas, such as frontage roads, that are to be conveyed to other political subdivisions saves a great deal of office and survey time. The results obtained have been found as accurate as those normally obtained by conventional survey methods on the ground.

Planimetry can be located with sufficient precision for most of the work to be acceptable. This can be done at a lower cost, covering a greater area, and with better detailed coverage, than by conventional survey methods.

The merit of using semi-controlled aerial photographs lies in the fact that the method is fast, inexpensive, and has acceptable accuracy as compared with conventional survey methods. In addition, the number of mistakes or errors is reduced and these errors are readily isolated.

• THE USE of aerial photographs for obtaining quantitative information is not new, as this procedure has been used for many years. Over the years the use of photographs has been expanded and techniques refined, so that they are now used for many more things than originally contemplated. Aerial survey is a form or refinement of the use of the aerial photographs, and without the vision of its potentials the techniques that are now used in aerial work probably would never have been developed.

Experience by the San Francisco Office of the Division of Highways has been primarily in the use of enlarged aerial photographs for the determination of fence lines for relinquishment purposes, and for obtaining horizontal positions of planimetric features associated with other right-of-way problems. There are other uses for which this tool can be used, but this paper is primarily based on the experiences in these two fields.

In California, areas in frontage roads, relocated streets, etc., which are not part

of the freeway proper but which have been constructed or reconstructed as part of a freeway project, are turned over to the local political subdivision by relinquishment; that is, the State gives all of its rights to the county or the city concerned. Between the freeway proper and the frontage roads, there is normally a fence which becomes in most cases the line of demarcation for the relinquishment. Records indicated that costs of conventional surveys were very high for determining the fence line location with the accuracy desired.

As a means of reducing costs and speeding up the work, it was felt necessary to develop techniques and methods that would reduce the time and effort being spent in determining and preparing relinquishments. The use of aerial photographs suggested itself as a possible solution to the over-all problem.

After considerable investigation and experimentation, techniques for using large-scale enlargements were developed which permit the location of these fences with greater over-all accuracy than was normally obtained by conventional survey methods. This is particularly true for fence lines that have large radius curves, and fences with many angle points.

GENERAL REMARKS

To obtain photographic enlargements that will produce the information wanted with the accuracy desired, it is necessary to develop field control for the aerial photographs. The process is to set targets on the ground before photography so that a minimum of three targets will appear on each photograph. If the photography negative scale is to be approximately 120 ft to 1 in., the targeted points should be set at an interval of about 350 ft within the area or along highway route zone to be photographed. These are located by any method that will permit their plane coordinates to be determined and the distance between any two points calculated. In areas where there is a known base line but not in the position that is wanted for the aerial photographs, it is necessary to establish additional targeted points within the area concerned. Thought should be given in positioning the separate target points on the ground so that the resulting control lines between target points are within close proximity of the wanted planimetry. The closer the wanted planimetry is to the control line, the greater the accuracy of the information obtained.

It is important that the aerial photographer be given a sketch map with suggested flight lines shown thereon. This procedure becomes particularly important when the photography flight is to be made so as to attain a vertical photography scale of about 120 ft to 1 in. The lateral displacement of the flight line can be such that the information wanted is not centered in the photographs. As with all aerial photographs, the information in the center portions of each vertical photograph contains less radial displacement of images due to ground relief, and also it is the area on the photographs where lens distortions are smallest. Therefore, care should be used to plan each photography flight line to center approximately on the information desired.

After the contact prints have been obtained, the targeted points are identified and marked on each print (Fig. 1). The points are indicated on the back of the contact prints with a sketch of each target. The exact survey point with respect to the target must be indicated as well as the ground distance between points. For instance, with a triangular-shaped target, the point of the triangle used as the survey point on the ground is shown for each target, and each measured or computed distance between these points is indicated on the back of the contact print for use in the photographic laboratory.

Figure 2 is the reverse side of the contact print shown in Figure 1 and shows the information furnished to the photographic laboratory. Target points are shown with the ground distance between targets, along with the dimension in inches that should be obtained on the photographic enlargement. This information provides the dark-room photographer with the necessary data to produce photographic enlargements of the vertical photographs which will be reasonably close to the desired scale. In all cases of further reference, scales as stated are approximate scales because the accuracy of any photographic enlargement is affected by such causes as relief displacements,

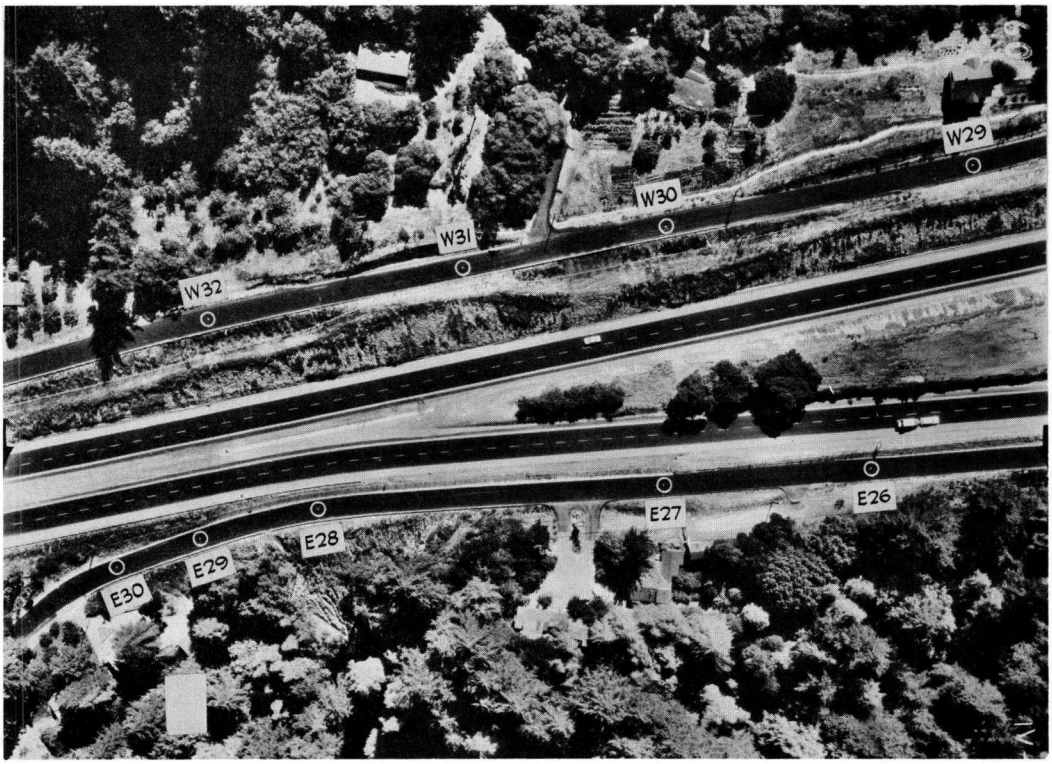

Figure 1. Target points marked on photograph.

inexact rectification, and differential paper shrinkage. In practice, the causes affecting accuracy are accounted for by resorting to scaling factors

SCALING FACTORS

Scaling factors are numbers used to adjust scaled distances. The factors are derived for each control distance to show the variation between the desired scale and the actual scale of the photographic enlargement for the distance concerned. Because of the different causes of scale variation (relief displacements, inexact rectification, differential paper shrinkage, etc.) the factor applies only to that portion of the photographic enlargement which lies in the immediate vicinity between the two target points defining a control line. Thus, there are as many scaling factors as there are separate control lines on any one enlargement.

To illustrate the derivation of a scaling factor, the following example is given, using the control line W29-W30 (Fig. 2): desired scale of enlargement, 20 ft to 1 in.; actual scale between W29-W30, 15.03 in./297.7 ft = 1/19.8 ft which is 19.8 ft to 1 in.; scaling factor, 1 in./20 ft ÷ 1 in./19.8 ft = 19.8/20 ft = 0.99. A more direct approach is as follows: field-measured distance, W29-W30, is 297.7 ft; distance measured on the photographic enlargement with engineer's scale is 300.8 ft; scaling factor = 297.7 ft/300.8 ft = 0.99.

Consequently, all other distances measured on the enlargement in the immediate vicinity of control line W29-W30 are adjusted by multiplying such distances by the scaling factor, 0.99.

In rolling topography or in sidehill topography in which the difference in elevation between the target line and the area being determined is appreciable, it may be necessary to establish additional points laterally in order to refine the scaling factors. For example, Figure 1 has frontage roads on both sides of a freeway which are at different

elevations. It was necessary to establish points on each frontage road in order to determine a control line on each frontage road at approximately the elevation of the dimensional data wanted. Points E26 to E30 are in effect lateral points with respect to the control line established through points W29 to W32. In this case and in similar cases, it is normally desirable to order two separate photographic enlargements, one centered over control line W29 through W32, and the second centered over control line E26 through E30. In this way, reliable scaling factors may be determined for each frontage road, thus effectively eliminating large-scale differences between the roads.

Usually, it is not possible to use a single factor for the whole enlargement. Determination of factors between each targeted point results in better scaled information and, in addition, draws immediate attention to any error or deviation that might be encountered. This permits the isolation of error in the mathematical or survey location of any of the targeted points as variations from the expected factors normally indicate that there has been an error. This is not true however, on the extreme edges of the photographs where a certain amount of lens distortion will contribute to variations in

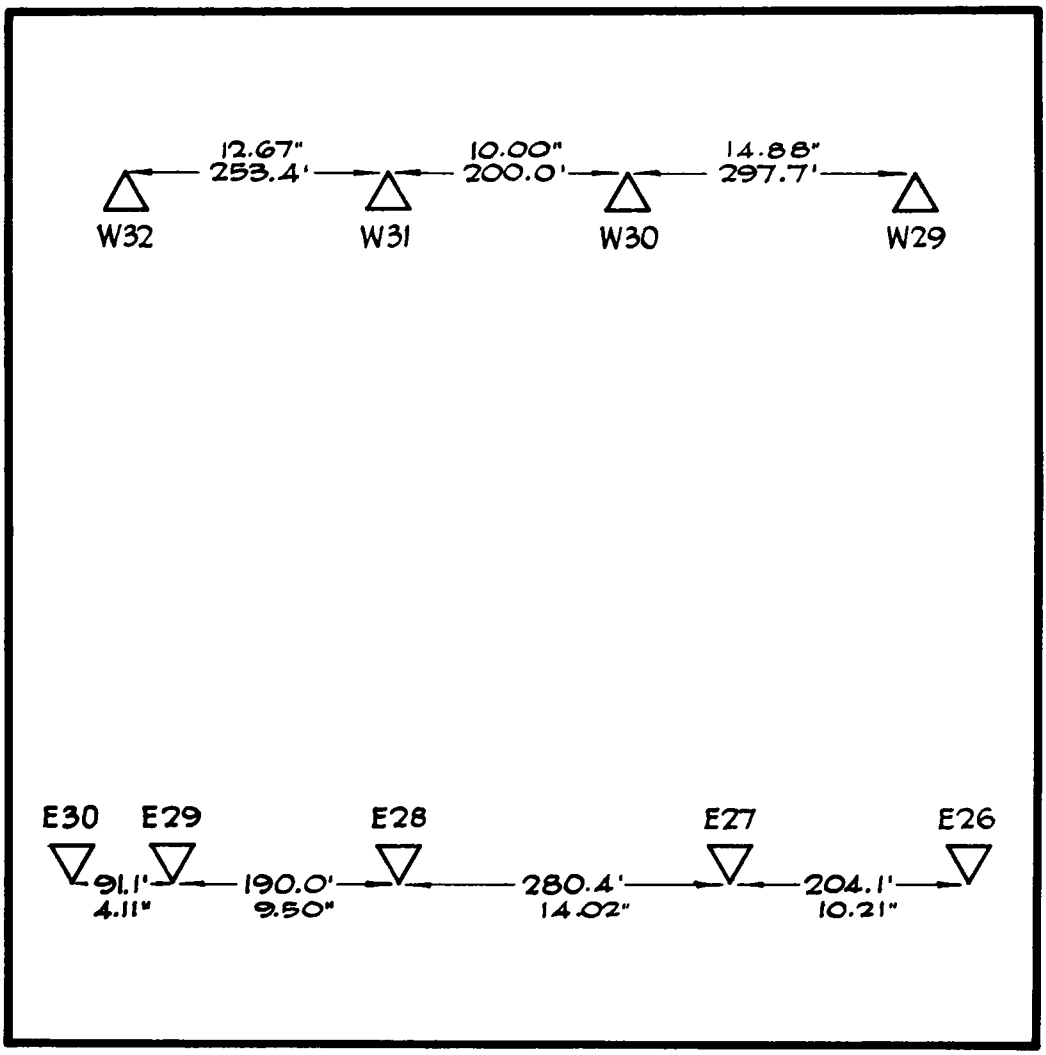

Figure 2. Reverse side of contact print shown in Figure 1.

excess of the expected factors for the main portion of each vertical photograph. It has been found that 90 percent of each photographic enlargement is sufficiently free from distortion for the purposes of scaling when the aerial photographs have been taken with a 12-in. focal length lens.

It is not feasible for the photographer to enlarge to an exact scale as there are variables over which he has little or no control. Rectification along a control line is determinable and can be taken care of, as well as lateral rectification, whichever is needed. However, there is shrinkage in paper and sometimes this shrinkage is not uniform throughout any one enlargement. As a consequence, some latitude must be given in acceptance of the enlargement. The necessary dark room equipment consists of a rectifying enlarger, such as a Saltzman projector with a tilting easel to permit adjustments for uniform slope about both the X and Y axes.

It has been demonstrated that the scaling factors obtained on the enlargements range from approximately 0.99 to 1.01. (The California Division of Highways obtains the enlargements by contract under specifications a portion of which is, "When more than 2 premarked control points are provided, the variation in relative scales between any 2 points in a single enlargement shall not exceed one half of one percent except for variation in relative scale caused by relief displacement due to non-uniformity of slope. The variation in scale on any one enlargement shall not exceed 2 percent of the average scale specified.") These factors are easy to work with, for it is apparent that a deviation of 1 percent from unity in the factor can be applied easily to any scaled dimension. In most cases, it is no greater than the error of scaling with an engineer's scale.

Deviations caused by non-uniform slopes cannot be eliminated by rectification, and enlargements of segments of the aerial photograph are therefore required. Two or more photographic enlargements from each film negative result in scale factors closer to unity. Two or more photographic enlargements should always be obtained and used where there is non-uniformity of ground slope. This is contingent on having sufficient target points set or identified with their plane coordinates within each image area on the photograph to have adequate control lines to determine factors within the specific photographic enlargement area of concern. If the slope between the east and west frontage roads shown in Figure 1 were uniform, rectification about both axes would result in factors close to unity.

Continuing with this thought, it is easily seen that in those cases where rolling topography is encountered, sufficient points set laterally from the target line may be required to facilitate the determination of additional factors at different distances from this control line. This would be particularly applicable along highway locations where there is a large area for which planimetric positions are needed. By setting additional targets laterally from the main target line, additional factors can be determined so that scaling of planimetry is more accurate.

For level ground, the factor determined for the control or base line can be applied to short lateral distances with the same accuracy as distances along the control line. Over rolling ground, however, or where there is a difference in elevation of considerable amount between the target line and the planimetry desired, the scaling factor will be affected, and it is necessary in this situation to establish control points in the area where dimensional data are wanted. It is not necessary to run lines but only to determine point location. The easiest field method available is the one which should be used.

Errors of point location are easily detected on a photographic enlargement if the error is of any magnitude. The location of the point in error can be re-surveyed if necessary and another factor determined for use on the enlargement.

OBTAINING FENCE LINE LOCATIONS

The limitation on the amount of photographic enlargement, before appreciable fuzziness occurs, seems to be about 6 diameters. That is, an aerial film negative exposed at a scale of 120 ft to 1 in. is limited to an enlargement of 6 diameters to a scale of 20 ft per in. In general, on a 50-ft-per-in. scale photographic enlargement, scaling should be within 1 ft of true position; thus, on a 20-ft-per-in. scale enlargement scaling is usually correct to within 0.3 ft and nearly a certainty not to exceed 0.5 ft of true

position. All points will not necessarily fall within this range but nearly all will be within these limits unless there are relatively large changes in elevations. Relative positions of the scaled points will be better and more certain if additional targets are set and additional control lines with factors are determined.

On receipt of the photographic enlargements, each target point is identified with its survey designation, and the control lines between the exact survey points defined by the targets are carefully drafted on the enlargements as shown in Figure 3. The survey distances and bearings for these control lines are either available from completed field work, or must be computed by inversing between established plane coordinate values of the survey points. The corresponding distances are also scaled on the photographic enlargements for determination of the scaling factors as previously discussed.

Figure 3 is a portion of the enlargement of Figure 1, being part of the west frontage road, and is used as an illustration. For purposes of this illustration, the fence post shadows in the figure have been deliberately darkened. In actual practice, the density of shadow in the enlargements is adequate and sufficient to define the fence line from the post shadows.

On this photograph only points W30, W31, and W32 are shown. The ground distance between points W30 and W31 is 200 ft, whereas the scale distance is 199.6 ft, which results in a scale factor of 1.002. Between points W31 and W32 the ground distance, 253.4 ft, scales 252.0 ft, resulting in the scale factor of 1.006. The portion between W30 and W31 is used as an example.

The corner of the fence, point 4, which is the end of the curve labeled 2, is determined by scaling the distances A and B. These scale distances are then multiplied by 1.002 and a coordinate determined for the location of this point on the fence. For determining the tangent (the line labeled 1) distances C and D, and also E, are scaled as shown in Figure 3. The scaled distances are adjusted by multiplying by the scale factor, and plane coordinates for the points on the tangent are computed. The curve is determined by trial on the photographic enlargement by use of transparent curves to obtain the best fit. The tangent line is prolonged to assist in determining the tangential point

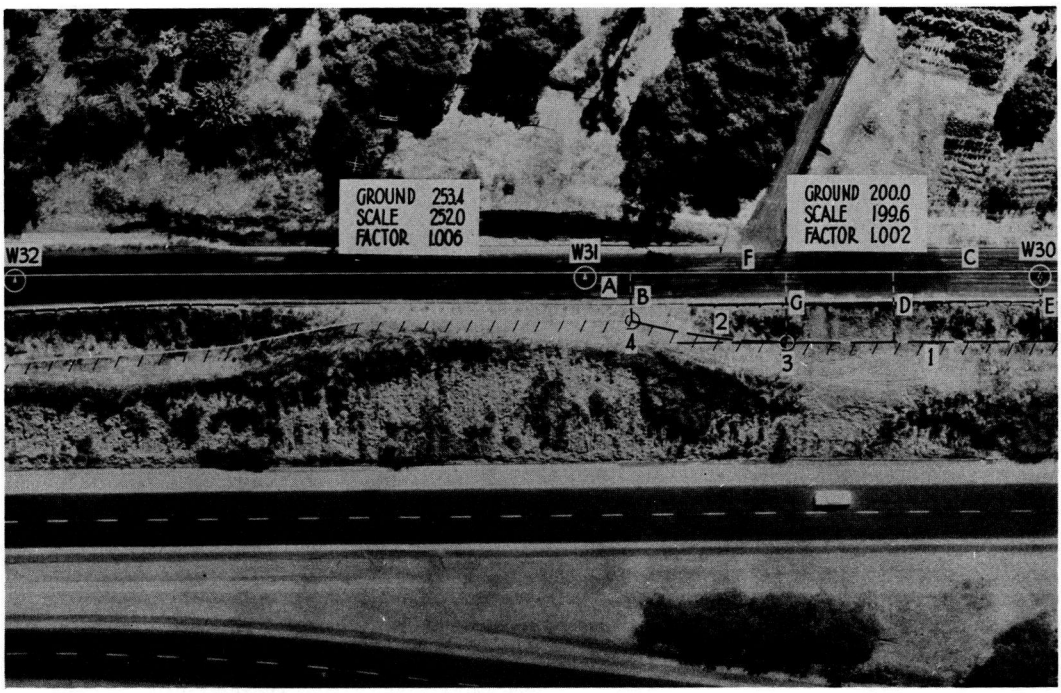

Figure 3. Portion of Figure 1.

of the curve. The location of the beginning of curve, point 3, is reasonably close. After the radius has been determined, the curve is computed to obtain the true position of beginning of curve and rechecked on the photographic enlargement for fit. With the plane coordinates for points 3 and 4, and the plane coordinates of points on the tangent line 1, having been determined, the bearing and distance for the tangent and the curve data can then be computed.

The same process is used throughout the project for locating the fence both on the portion shown in Figure 3, and also for the remainder on both the east and west side frontage roads on their respective enlargements. The photographic enlargement readily shows a multitude of points available for the location of relinquishment fence lines and as much scaling as needed can be done to average the errors of scaling and the errors in the photograph. All the required work for determining curves and tangents is done in the office by scaling, using transparent curves and making such calculations as are needed.

The aerial photographs are taken soon after the fence is built and before development of brush cover, thus precluding trouble from heavy shadow in the vicinity of the fence lines. If the image areas of concern have heavy shadows in critical areas, a certain amount of additional but minor field work would be required.

The development of agreements with the political subdivisions involved with relinquishments sometimes create cut-off lines that are not normal. There are times when a traffic island in a channelization is used as a control for the cut-off line. Precise location of all points of the islands is not usually determined, and there are occasions when the cut-off point in the channelization is changed from the point originally proposed. It is a simple matter to make this change on the photographic enlargement by rescaling and recomputing any portion of the changed relinquishment line. If conventional survey methods for making ties to planimetry are used, additional ties are usually necessary to obtain the information wanted.

The advantage of having a complete vertical photograph of the channelization has additional merit in the use by others for corrections of improper traffic functioning of the intersection or for the study of drainage problems that might develop.

In the field it is difficult at best to determine minor variations in the fence particularly in those cases where the angular deflections are small. These are not always visible to the eye without actually sighting down a fence, and even then the exact point of deviation is not always determinable. Additional ties are then required if the survey is done by conventional methods to be certain that the point of intersection is bracketed. This is necessary to locate definitely the two tangents, so that their intersection can be determined with reasonable accuracy.

Curves with exceedingly long radiuses result in lines that appear as tangents on the ground, thus requiring a great many field ties to determine a curve that will fit accurately and be closely allied with the actual curvature of the fence. Fence lines may vary from the anticipated pattern shown on the design plans due to obstructions or the necessity of modifying the location of the fence during the construction stages. These resultant variations which do not appear to be correct from the plot of survey notes require a field check to ascertain that the deviation is as shown in the field notes. The photographic enlargement, however, clearly shows the small angular deflections, tangents, long curves, and a complete picture of the fence. The graphical determination of the tangent and curves is easily and accurately obtained from the photographic enlargement. There is also the advantage of being certain that there have been no errors in survey and that the dimensional data obtained are correct.

OBTAINING OTHER PLANIMETRIC DATA

The techniques used with photographic enlargements for determining the location of planimetry, other than fence lines, is not a great deal different from that used for relinquishments, as it is necessary to determine the position of target points. It usually differs only in the width of the band for which planimetric information is needed.

Figure 4 shows a typical example of a large area in which planimetry is required. The control base line is shown by points A, B, and C. After the vertical photographs

had been taken, it was found that more planimetric information was needed in this area; therefore, points D, E, and F were located by ground survey methods subsequent to the receipt of the enlarged photographs.

To use this method, it was necessary to determine points within the photograph that can be physically located and defined on the ground and on the enlargement. Point D is the intersection of the driveway and the walk, and the location of this point is easily found and its plane coordinate position obtained by survey on the ground. Point E is the outside intersection of the painted lines of the school ground for the basket ball court, and point F is the intersection of the road gutter and the driveway return. Additional points could be used as there are many points within the area which can be identified and defined with reasonable accuracy.

With the addition of points D, E, and F, which have been indicated with squares in Figure 4 to differentiate them from the original points A, B, and C, indicated with circles, additional control or base lines are computed, such as lines AD, DB, DF, CF, EC, and AE. These new control lines permit the determination of additional scaling factors. The required planimetry can then be scaled using the same techniques described for the fence line in Figure 3.

Photographic enlargements can be made to any scale desired. Most right-of-way work is done at the scale of, 20 ft to 1 in. for relinquishments and the scale of 50 ft to 1 in. for planimetry. By enlarging the vertical photographs to a scale of 50 ft to 1 in., the planimetry can be traced from the enlargement to the hard copy tracings for design control.

A plane coordinate grid can be superimposed on the photographic enlargement if desired, as plane coordinates for the various targeted control points are known and this plane coordinate grid with the scale factors can be used in the same manner any other similar grid is used. Slight shiftings of the tracing would of course be required to accommodate for the scale factor, and adjust for non-uniformity of ground slope. (The plane coordinate grid, as constructed on the enlarged photograph, will be imperfect with respect to square shape and uniformity of distance between the grid lines and will not coincide with map grids because of the scale factors.) The resultant tracing would be satisfactory for the location of the planimetry for appraisal purposes.

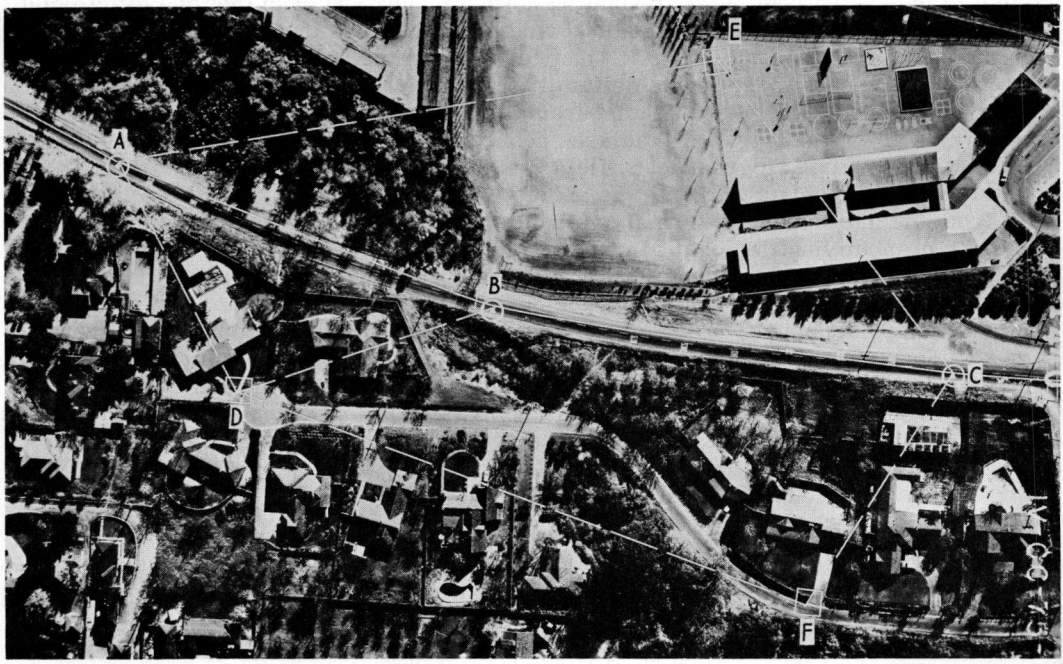

Figure 4. Example of area in which planimetry is required.

If it is necessary to know the location of a corner of a building with an exactitude that is greater than could be obtained from the photographic enlargement, a field survey tie to the controlling building is usually required.

The photographically enlarged aerial vertical photograph serves well in obtaining planimetric information needed for any particular purpose. In addition, the location of the possessory lines of ownerships of various properties are easily seen and the probable lines of ownership are reasonably well delineated along with the culture of the area.

A study of the school grounds in Figure 4 shows some of the information that can be obtained from photographic enlargements. The school ground is suggested for study as it is relatively open and has painted courts, fences, buildings, and trees.

If it is necessary in the determination of the planimetry to know the overhang of eaves and porches, a minimal amount of field survey work will be required. There will also be field survey work required when the buildings are located under heavy, dense shadows that overhang the lines of the buildings. This supplemental survey does not normally entail a complete or new survey but only field checking with notations on the photographic enlargement in order to clarify and furnish the additional information when this information is of importance.

CONCLUSIONS

Precise location of any single point is not obtained from a photographic enlargement, but for the location of planimetry and the determination of fence lines for relinquishment and allied purposes the use of such enlargements is an inexpensive, time and labor saving device. The use of this method should be considered wherever this media will be advantageous.

District IV of the Division of Highways, which is the San Francisco Bay area, has been using 20 ft-per-in. scale photographic enlargements for determining the relinquishment areas for about four years. During this time, relinquishment lines for about 100 mi of road have been determined. This work has all been done by the use of aerial enlargements in lieu of conventional ground survey methods.

By working with the construction forces, control points are preserved for targeting, thereby reducing the amount of additional control survey required for making the photographic enlargements. In one instance, on a 5-mi stretch of road in the Santa Cruz mountains, the additional survey required for the additional targets was completed with one survey party in one day. It was estimated that a conventional survey would have taken six weeks for a survey party to make the necessary field ties to the fence and that the office work would have been quadrupled.

In determining planimetry, the savings are primarily dependent on the density of cultural development. On a 3-mi portion of road with planimetry of medium density, it was estimated that there were savings of three weeks of a six-man survey party and savings of office time in the plotting of the notes on a hard copy of an additional three man-weeks.

The potentials in savings in dollars and in manpower is to a large extent dependent on the complexity of the area in question, whether it be for relinquishment or for the obtaining of planimetric information. In all cases, it has been found that the office work is reduced by one-half to three-quarters by the use of the enlargements over conventional survey methods.

Aerial photographs enlarged to scale are used in the office in conjunction with property determination and are of great value to the right-of-way engineer. A plot of the properties, as determined by the right-of-way engineer on the photographic enlargements, gives reassurance that the location of the properties is ascertained within reasonable limits. This permits the work to be done more quickly and eliminates a certain amount of mistakes in judgment. The use of photographic enlargements defines and locates errors that may occur through misinterpretation of available information or possible errors in mathematics.

The author does not believe that this method will do everything that is done by ground survey methods. It does not give accuracies that are adequate for the determination of

property lines. Proper field ties to the property corners and monuments that might be in existence within the area must be made. The potential deviation in scaling a distance of as much as 1 ft on a 50-ft-to-1-in. scale photographic enlargement results in the location of property lines from aerial photographs with error differentials that are too great to be tolerable.

For those areas of low land value, perhaps the accuracies obtained by this method would be acceptable for property line locations. In these areas, however, the properties are usually large and the number of survey ties required is relatively small. In areas where land values are high, the tolerances that would be acceptable in the location of properties would not be met by the use of photographic enlargements. As a consequence, it is necessary to make field survey ties to property corners and lines, in order to determine their most probable location and to eliminate the possibility of paying for land more than once.

The use of large-scale photographic enlargements facilitates the work of the right-of-way engineer and produces the information desired at low cost. The author does not consider that the enlarged aerial photographs will satisfy all survey requirements. It is not a cure-all but a tool to be used in conjunction with conventional survey methods of acquiring essential data. Considerable savings are possible with the use of photographic enlargements with adequate control, and the results are comparable with those normally obtained by usual ground survey methods where the precise location of points is not a necessity.

Preparation of Right-of-Way Plans from Aerial Mosaics

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• WITH THE expansion of the National System of Interstate and Defense Highways and the acceleration of completing plans and construction, the acquisition of the right-of-way is a very important facet of the over-all program.

The Commonwealth of Pennsylvania, in conjunction with the Bureau of Public Roads, has adopted the policy that construction cannot start before condemnation and clearing of the right-of-way has been completed.

The former procedure was to do the property investigation and then negotiate after the plans were signed by the Governor. This is in compliance with the condemnation law in the Commonwealth of Pennsylvania. The same plans were prepared for condemnation and construction. This naturally hindered the operation of the Right-of-Way Department with the result that valuable lead time was lost to complete the necessary work involved in property acquisition.

At the inception of the Interstate Program in Pennsylvania the Right-of-Way Department could foresee that additional measures would have to be taken to facilitate this standard method of right-of-way acquisition.

Because a great deal of preliminary work had to be done and it was necessary to obtain values for programing, it was decided that certain right-of-way information should be acquired in the preliminary design stage.

The original contracts provided that "Transparent right-of-way maps and aerial mosaics, both 24 by 48 in., should show the highway right-of-way lines, property lines and property owners between and for a distance of at least 100 feet beyond the right-of-way lines, and the approximate acreage to be acquired from each owner." A copy of the pertinent deed for each property owner indicated was to be furnished.

During the early part of the preliminary design for Interstate 80, known as the Keystone Shortway, the Right-of-Way Department, in close cooperation with one of the consulting engineers, developed a more refined and workable method for producing the requirements of the Department.

The Keystone Shortway is a completely new route, approximately 300 mi of new