PHOTOGRAMMETRY SPECIFICATIONS AND PRACTICES FOR THE USE OF AERIAL SURVEYS*

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AERIAL photography applied to mapping is not particularly new but recent years have seen phenomenal development, largely because older methods of mapping have proved too slow and expensive to meet certain present day needs. The highway engineer, faced with demands for surveys and plans expanding at a rate much greater than could be met by expansion of conventional methods and organization, has turned to aerial photogrammetry for help. We have found that aerial mapping methods, modified to suit the needs of the highway engineer and properly combined with conventional ground surveys, will permit us to develop plans more rapidly and at a substantial saving in cost over older methods.

The success of aerial surveys applied to highway engineering depends upon the highway engineer's understanding of the possibilities, as well as the limitations, of photogrammetry. Conventional photogrammetric methods must be properly combined with conventional ground survey methods and the selection of the best combination of methods must include consideration of the problems and requirements of the particular highway engineering job.

CALIFORNIA PRACTICES

In California we have developed certain practices which appear to have outstanding value, and it is proposed to devote this paper to those practices to the exclusion of others which may be either better known generally or less important in our experience.

The effect of these developments has been to tie photogrammetric mapping to highway surveys, with the result that on suitable terrain we can now complete preliminary surveys with a large part of the work done from the air. The combination of old and new methods in their proper relation has developed great savings of time and cost in the planning and design.

The most important developments in our practice may be summarized as follows:

(1) Control surveys are made to modified second order accuracy generally tied to California Coordinate System with control net extended for highway use.

This must be carefully planned by the highway engineer and it will generally include control not essential for strictly mapping use.

(2) Permanent points in the control net. These may be either key property corners, existing monuments, or new points selected for later use.

(3) Complete notes of observation and adjustment furnished by the mapping organization to the highway engineer.

RESULTS OBTAINED

These developments in practice have given us maps from which it has been possible to project a located line with computed ties to points of known position in the control net, complete design, compute quantities, write deed descriptions

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for right of way, and go to contract with a minimum of additional field survey work. In some cases the located line is not being run in the field until the right of way itself has been purchased and completely cleared. With key property corners and other permanent monuments selected by the highway engineer tied into the primary control net of the survey, and the entire survey tied to the California Coordinate System, the located line as finally run in the field has closed without difficulty.

One of the most obvious advantages to us in the use of these methods is the possibility of completing the survey and design with a minimum of disturbance to the local community.

CONTROL BASED ON MAPS

During the past two years the California Division of Highways has awarded contracts for topographic maps from aerial photographs for over 200 miles of highway. The type of highway facility to be located or designed from these maps ranges from two-lane secondary roads to four-lane divided freeways through urban areas. Map scales have been 400, 100, and 50 feet per inch with contour intervals of 10, 5, and 2 feet. On several of the projects it is planned to acquire the rights of way and award the construction contracts on the basis of these maps supplemented by a very minor amount of ground surveys by the division.

Successful use of aerial contour maps, particularly their use in the final stages of design, requires careful planning, adequate specifications, and a reliable mapping contractor. The planning must be done by a highway engineer who is familiar with all phases of location and design, and has sufficient knowledge of photogrammetry and its limitations to specify what is required without incurring excessive costs. Mapping contractors are usually willing to assist in the planning of a project but their knowledge of highway engineering is limited, and in the final analysis it is the highway engineer who must decide what he wants for each specific project.

SUITABILITY OF PROJECT

As the first step in planning it is necessary to determine the suitability of the project for this type of mapping and the purpose for which the maps are to be used. For reconnaissance studies and the evaluation of alternate routes satisfactory maps for almost any project can be made by aerial surveys. A high degree of accuracy is not required and, unless the ground is obscured by very tall timber, a specification that the contours be within half the height of the ground cover should result in maps which are adequate for preliminary studies. The specifications for horizontal and vertical control should be broad enough to allow the contractor to take full advantage of his equipment in bridging control across several models.

Where a strip of topography wider than one-half mile is required it will frequently be more economical to obtain a preliminary map at 400 feet per inch with 10-foot contours for the initial studies, to be followed by a larger scale map of a narrow strip along the selected route for use in final location and design. For maps at 400 feet per inch a single strip of photographs will generally cover a width of $2\frac{1}{2}$ to 3 miles.

SEVERAL LIMITATIONS

Where contour maps from aerial photographs are to be used for final location and design work, there are several limitations which must be known and considered. Most important of these is the extent of the ground cover and its effect on aerial mapping. If the ground is completely obscured the best that can be expected from the stereoplotting equipment is that the contours will be within half the height of the cover. If greater accuracy is required, and it usually is for design work, it must be obtained by supplemental field surveys. The extent to which these field surveys are required will usually determine the suitability of the project for aerial mapping. If the mapping contractor is required to undertake field completion surveys in certain areas where the ground is obscured the extent of this work must be clearly defined in the specifications.

USE OF AERIAL CONTOUR MAPS

A second limitation is the extent to which an existing highway is to be used as a part of the proposed facility. It is obvious that aerial contour mapping is not suitable for a widening project and it follows that its greatest usefulness is on entirely new locations. It will, however, prove satisfactory for some reconstruction projects where a four-lane divided facility is proposed which utilizes the existing highway for two of the lanes, provided the median has sufficient width that tight grade controls are not required.

It is doubtful if the cost of an aerial contour map would be justified across flat terrain where drainage conditions control the grade line to within a few tenths and where earthwork quantities are very light. With this type of terrain in urban areas a large scale planimetric map from aerial photographs has been obtained at a lower cost than a contour map. Another solution is the use of rectified aerial photographic enlargements at 50 feet per inch. These could be tied together for control by a ground survey and used in the field for obtaining spot elevation at road connections, drainage channels, etc. Cultural detail could be traced on the construction plans from the enlargements.

STANDARDS OF ACCURACY

Having determined that aerial contour maps are practicable for a specific project, the next step is the determination of scale and contour interval and the standards of accuracy to be specified. Our experience in California indicates that for complex highway facilities such as multilane, divided freeways, or expressways where traffic interchanges, ramps, frontage roads, and other features are involved, a scale of 50 feet per inch and a contour interval of 2 feet are the most advantageous. This is particularly true where construction contracts are to be awarded on the basis of the topographic maps without making a final location survey in the field. In such cases the only field survey work prior to award of the construction contract will be for the location of underground utilities, additional property corner ties if required, and elevations to the nearest 0.01 foot where connections are made to improved streets.

IN MOUNTAINOUS TERRAIN

For the location and design of less complex highway facilities and through undeveloped or mountainous terrain we are generally using a scale of 100 feet per inch and a contour interval of five feet. Here again only a minor amount of field survey work will be required prior to award of the construction contract provided the ground is not obscured to the extent that accurate contours cannot be plotted from the photographs. On projects where aerial contour mapping at 50 feet or 100 feet per inch is obtained we have previously selected the route of the highway facility within rather narrow limits either from small scale aerial photographs, U.S.G.S. quadrangle sheets or other available maps combined with field reconnaissance. Consequently the contour maps are confined to a width sufficient to allow for minor adjustments in location and to permit the layout of traffic interchanges, road connections, etc. This width generally ranges from 600 feet to 2,000 feet as compared to the 200 feet to 500 feet usually obtained from ground surveys.

REQUIREMENTS

Our most recent specifications conform to the National Standards of Map Accuracy which have been adopted by the major governmental mapping agencies. These standards require that 90 per cent of the contours be within one-half the contour interval and that 100 per cent be accurate to the full contour interval. For horizontal positions of well defined features they require that 90 per cent be within one-fortieth inch and all be within one-twentieth inch of their true position at the final map scale. With detailed topographic maps to these accuracies and covering a strip 600 feet to 2,000 feet in width, the designer has far more information at his disposal than is available from conventional field surveys, and he can develop the final position of the highway and its appurtenances with assurance that no possibilities are being overlooked.

GROUND CONTROL SURVEY

One of the most important factors in the planning and preparation of specifications for a satisfactory aerial mapping project is the ground control survey. Several types of stereoplotting equipment in use today are capable of bridging horizontal control across several photographic models. The mapping contractor will naturally wish to take advantage of this feature to reduce the extent and costs of the ground control surveys. However, a spacing of several miles between monumented control points will not allow the highway engineer to realize the full potential value of the mapping even though it may comply with the specified standards of accuracy. Additional monuments are required for future staking of the projected center line and right of way lines, for making ties to property and subdivision corners and for obtaining various other information during the course of design work.

MONUMENTS IMPORTANT

In California we have found it generally advisable to specify such monuments at intervals of 1,000 to 2,000 feet in urban areas and not more than one-half mile in rural sections. The location of these monuments must be carefully planned by the highway engineer to avoid additional and unnecessary survey work in the future. Their location is usually indicated on maps accompanying the contract and specifications. The monuments may be set as arbitrary points for future use or they may be existing property corners or street or subdivision monuments.

Figure 1 shows a section of map as delivered by the contractor in which just this has been done. Not only are the subdivision monuments shown, but property lines may also be confirmed by the fence lines and fragments of fence lines.

On several projects in urban areas we have indicated a sufficient number of property corners to be tied in by the mapping contractor so that deeds may be prepared without additional survey work on our part. In such cases it will not be necessary to run the projected center line in the field until buildings and other obstructions have been cleared from the right of way immediately prior to construction. The value of an adequate number of properly positioned monuments as an adjunct to the aerial survey cannot be too strongly emphasized.

SPECIFICATIONS

Where the aerial contour maps are to be used for design work we specify that the contractor's primary survey network shall be based on and adjusted to first or second order triangulation stations of the U. S. Coast and Geodetic Survey, and that they shall be made by second order triangulation or by modified second order traverse. We further specify that the surveys shall be adjusted by standard methods and that horizontal positions of all monuments shall be based on adjusted data and expressed in rectangular coordinates of the California state-wide system of plane coordinates. Control points, monuments, and coordinate grid lines are shown on the maps with an accuracy to the nearest 0.01 inch.

In addition to the horizontal position of all monuments, the contractor is required to furnish the original field notes of his ground control surveys, together with a tabulation showing all measured and adjusted bearings and distances. As a result we have, in addition to the maps, an accurate well-monumented survey network which can be used as the basis for all future survey work on the project.

Figure 2 (which is the same section as that illustrated in Figure 1) shows the survey coordinate grid, to which the highway centerline is referenced, added to the base map. The ties between monuments on the ground and the "*L*" line are made in just the same way that ties are made between the "*P*" and "*L*" lines in ordinary route surveys.

VERTICAL CONTROL

The extent of vertical control to be established will vary with the individual project. Quite frequently a level line of the U. S. Coast and Geodetic Survey is parallel or closely adjacent to the project. In such cases a specification requirement that all vertical control points set by the contractor shall have an accuracy of one-tenth the contour interval is considered sufficient.

In view of the wide variety of stereoplotting equipment used by reliable mapping organizations, it is not considered desirable or feasible to require specific equipment or to write a rigid specification as to methods of procedure. In lieu of this we prefer to specify the accuracies required in the final maps and give the contractor wide latitude as to the method of producing them. As a means of evaluating proposals submitted by different mapping firms and to have some measure of control over the contractor, we require that each proposal be accompanied by a statement showing experience in similar work, equipment proposed for the project and scales, operating ratios, and methods of procedure to be used in various phases of the work. This statement also includes the extent of horizontal and vertical control proposed in addition to the monuments we have specified.

TABULATION OF EQUIPMENT

The following tabulation shows the equipment, scales and operating ratio proposed by four reliable nationally known mapping organizations for various large-scale mapping projects in California within the past two years. The number and variety of proposals shown for the 100 feet and 50 feet per inch scales are sufficient to be considered a resume of current mapping practice at these scales.

EQUIPMENT AND SCALES FOR AERIAL CONTOUR MAPPING

Stereoplotting equipment	Flight height	C factor	Flight scale	Map compilation scale
Maps at 1″=50′ 2′ contours				
Stereoplanigraph	2,450′	1,200	1″= 400′	1″= 50′
Kelsh Plotter	1,500′	750	1″= 250′	1″= 50′
Kelsh Plotter and/or Wild A-5	2,000′	1,000	1″= 333′	1″= 67′
Kelsh Plotter	2,000′	1,000	1″= 333′	1″= 70′
Maps at 1″=100′ 2′ contours				
Kelsh Plotter and/or Wild A-5	2,000′	1,000	1″= 333′	1″= 67′
Kelsh Plotter	2,000′	1,000	1″= 333′	1″= 70′
Stereoplanigraph	2,450′	1,200	1″= 400′	1″= 50′
Maps at 1″=100′ 5′ contours				
Kelsh Plotter and/or Wild A-5	5,000′	1,000	1″= 833′	1″=167′
Kelsh Plotter	3,000′	600	1″= 500′	1″=100′
Stereoplanigraph	4,900′	1,000	1″= 800′	1″=100′
Kelsh Plotter	5,000′	1,000	1″= 833′	1″=167′
Maps at 1″=400′ 10′ contours				
Kelsh Plotter and/or Wild A-5	10,000′	1,000	1″=1,667′	1″=333′
Kelsh Plotter	10,000′	1,000	1″=1,667′	1″=350′
Stereoplanigraph	9,800′	1,000	1″=1,600′	1″=200′

ADVANTAGES

The advantages most frequently cited for the use of contour maps made from aerial photographs in highway location and design are savings in time, money, and manpower, and the added width of the band of topography at the disposal of the designer. The latter feature enables the engineer to see possibilities which might otherwise have been overlooked and could very easily result in either savings in construction costs or an improved facility, or both. This is particularly true of superhighways where interchange facilities and frontage roads are involved in the design.

As a measure of cost comparison, the following tabulation has been prepared to show the contract price on a number of recent aerial mapping projects in California.

REPRESENTATIVE COSTS OF AERIAL SURVEYS

Map scale	Contour interval	Terrain	General width of mapping	Miles	Average cost per mile
1″= 50′	2′	Semi-urban—rolling	600′–1500′	15	$1,630
1″= 50′	2′	Rural—rolling	700′–1300′	11	1,410
1″=100′	2′	Rural—rolling	700′–1500′	12	1,210
1″=100′	5′	Rural—rolling	500′–1600′	9	935
1″=100′	5′	Rural—rolling to mountainous	1000′–2000′	60	930
1″=400′	10′	Rural—rolling	5000′–9000′	15	485

FIG. 1. Section of map as received from contractor. Original scale 1 inch equals 50 feet.

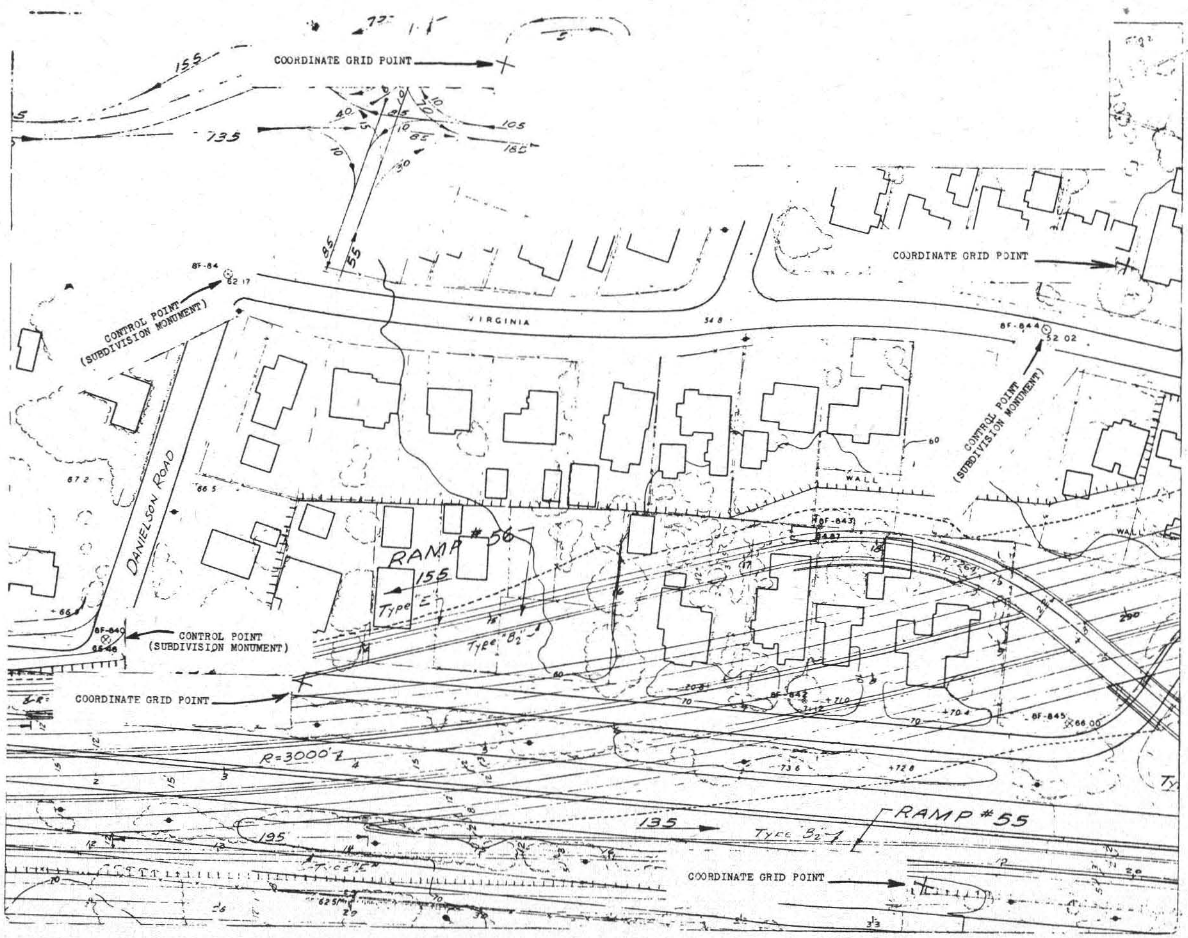

FIG. 2. Section of map after adding freeway lines. Property lines have been added by ties to subdivision monuments which are also used as reference points when freeway is staked.

REPRESENTATIVE COSTS

The costs shown in the tabulation can be considered representative of contracts totaling 20 miles or more in length. Frequently costs can be reduced by combining several short highway projects in one mapping contract. The saving in time is dependent on the work load of the various mapping contractors and the urgency of the project. A premium price is usually paid for a rush job and results are not always satisfactory. As a general rule, if a project is over five miles in length, and if only one survey party is available, a saving in time can be made by using aerial surveys. The time saving will increase rapidly with the size of the project.

As previously discussed, the shortage of engineering manpower will probably outweigh the other advantages afforded by aerial survey methods for several years to come. Any highway organization confronted with this problem should give serious consideration to a wider use of aerial photographs and aerial survey methods.