As for excavation quantities, a large-scale topographic map with 2-foot contours to National Map Accuracy Standards will provide ample accuracy for all practical purposes in rolling or mountainous terrain. In level terrain the California method of using a map with photogrammetric spot elevations will provide the same accuracy as photogrammetric cross sections. Horizontal or vertical accuracy to fit tight controls is another matter. Such controls might be the location of the edge of a vertical cliff or a costly building or other improvement or the elevation of a railroad track. Controls such as these are relatively infrequent and it is doubtful whether the required accuracy can be supplied by photogrammetric methods. It is also doubtful if the average conventional field survey will supply it. When the experienced designer recognizes such a control, he will call for a check measurement regardless of whether his original information came from photogrammetric data or from conventional field surveys. The added accuracy of photogrammetric cross sections as compared to a topographic map does not appear too important.

The labor involved in taking cross section notes from the contour maps is relatively minor. On an average project, two trainees or technicians can take off terrain notes at the rate of a mile a day or better. It would, of course, be worth-while to save this labor if it could be done without sacrifice of other elements essential to the design. As large-scale contour maps rather than cross sections are considered essential for determination of the final line and fast, efficient design of the project, it would be uneconomical and time-consuming to reset the models in the plotter and take the time of the plotter and operator to produce cross section notes which can be taken from the map by technicians.

Principal advantages of the method used in California are that it saves time in the preliminary stages of project planning and that by obtaining the large-scale mapping before staking the centerline in the field, it provides the designer with the maximum of detailed information for determination of the best possible line. When these various factors are given full consideration, we cannot help but wonder if photogrammetrists and highway engineers are not overselling each other on the advantages of photogrammetric cross sections.

*Obtaining the Optimum Value from Photography and Photogrammetry in Highway Engineering**

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AERIAL photography and photogrammetry have been proved conclusively to be useful tools to the highway engineer in expediting highway projects. In the application of these tools time has been saved, engineering manpower conserved and great economies achieved—all without sacrificing accuracy.

Once the usefulness of a device has been proved and accepted, the next logical step is to determine its optimum value; rather, obtain its optimum value. In accomplishing this with aerial photography and photogrammetry—as in obtaining the optimum value from any device—they must be given the widest possible applica-

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tion. Specifically, the optimum value of these useful tools to the highway engineer can be obtained by applying them to all phases of highway engineering: location, design, right-of-way construction and operations.

Location

In determining highway location through the use of photography and photogrammetry, small-scale photography and U. S. Geological Survey topographic maps are the initial aids. They are used to make a reconnaissance survey of a broad area, which provides a comprehensive basis upon which all feasible routes may be carefully compared—allowing the consideration of all factors affecting location, including design standards.

Subsequently, larger scale photography (1-inch = 800 feet) is provided to allow a closer study of one or more of the preferred alternate locations. Finally, a 200 feet to 1-inch topographic map with 5-foot contours is prepared for detailed study of the chosen location—or even for alternates, where selection cannot be readily made. In flat terrain the topographic map would not be needed; however, in built-up urban areas a planimetric map may be necessary.

With the aid of this map (200 feet to one inch, 5-foot contours) and photography the engineer can pin-point the center of the proposed location; prepare profiles; establish grades; study soils conditions, land use and drainage; determine work limits, and prepare reasonably accurate estimates.

Other products of aerial photography which are useful in determining line are: a photo mosaic with the proposed line superimposed; aerial obliques, enlargements of built-up areas; and an artist's concept of the finished highway drawn realistically on an aerial photograph.

Since in some States final determination of the location of a new facility is by law subject to public scrutiny of engineers' proposals, certain products of aerial photography are invaluable aids in winning public acceptance. The adage "a picture is worth a thousand words" applies: It has been proved that such visual aids as a photo mosaic showing the proposed line or an aerial photograph replete with artist's rendering of the proposed new facility, lend immeasurable assistance to the engineer in his task of justifying the proposed line to the lay public.

Design

Aerial photography and photogrammetry, when applied to the design phase, provide planimetric maps, cross-section data, and site plans—considerably speeding up the production of all three.

Since it is always necessary to stake and reference a centerline and establish benchmarks prior to construction, it should be done at this stage to provide control for the aerial survey to be used in design. The line is signalized every 300 feet on actual centerline stations, benchmarks are established and elevations taken on centerline at each station. In placing control for the wing points for this survey, careful consideration should be given for its possible use for photogrammetry after completion of construction.

Staking the centerline at this time not only insures accuracy of the survey but permits taking soil samples at an early date, permits negotiators to make early contact with property owners, and enables engineers to review location on the ground and make field inspections during design. Other advantages of staking early are: the same survey crew locates property lines that cannot be identified in the photos and obtains the names of owners; the survey crew also obtains information relative to underground drainage, utilities, etc., not observable from the air.

The flight for the survey to be used in design provides photography from which a planimetric map 50 feet to one inch is compiled. This map is traced on cloth and becomes the line sheet for detailed construction plans.

Concurrently with plotting the topoggraphy, necessary information for cross sections is taken from the photogrammetric plotter. These cross sections are obtained by reading the elevation of a definite point to the nearest 0.1 foot and not by interpolation from a contour map. The sections are taken at true right angles to centerline and are extended well beyond the right-of-way limits. This permits some shift of centerline during design without putting the models back into the plotter.

(The Ohio Department of Highways is now using an attachment to the Kelsh plotter, developed as a research project, that permits the operator to record and print automatically on punch cards pertinent data such as station, elevation and distance from centerline to the nearest 0.1 foot along a cross section. This device conserves manpower and increases accuracy. Previously, these data were plotted on a manuscript: the distance out from centerline was then scaled and read along with the recorded elevation to someone plotting the cross section.)

The punch cards with design data are then sent to the electronic computer for computation of earthwork quantities, slope stakes, etc.

Maps of sites for structures and interchange areas are prepared at a scale of 50 feet to one inch, with 2-foot contours while the models are in the plotter for the planimetric map and cross section. This map is copied in the photo laboratory to a scale of 20 feet to one inch for the convenience of the bridge design engineer and is traced on cloth for the site plan.

Design then proceeds in the conventional manner except that the engineer has much more information available from the maps and photographs than he could possibly have from ground surveys.

Controlled scale photography alone has proved to be very useful in flat or level country, particularly so for widening and resurfacing projects. For this control the centerline is staked and signalized every 300 feet including points on curves and the points of intersection.

Photography taken at a scale of 200 feet to one inch is enlarged to 50 feet to one inch. With the aid of a tilting easel the photography is rectified when projected to fit the control. The final picture is made on water resistant paper having suitable dimensional stability. The planimetry is then traced from the photograph on cloth for the line sheets of the construction plan.

Right-of Way

The acquisition of right-of-way, one of the many items to be considered in expediting any highway construction program, can also be greatly aided by the application of aerial photography and photogrammetry.

The photographs and maps prepared for location studies can be used for right-of-way estimates, which are needed for determination of location. Work limits can be determined from the map to permit early preparation of right-of-way plans and establishment of taking limits. Property lines that are visible in the photography can be provided to the plotter operator and can be indicated on the planimetric map or line sheet, thereby expediting right-of-way plans.

Having the centerline located in the field and the right-of-way limits established at an early stage, the traverse, bearings and parcel areas can be computed by the electronic computer and actual negotations can be underway before design is completed.

Enlargements to scale of 1-inch = 50 feet of the photography used in design plus the artist's rendering of the proposed project are proving very helpful to the negotiators in securing right-of-way.

Oblique photography, enlargements of vertical photography and in some instances maps are valuable in appropriation cases to acquaint the judge and jury of the actual condition.

Certain photos taken during construction are helpful to right-of-way personnel in settlement of cases that have not been settled prior to construction and in settlement of damage claims due to construction.

Construction

Aerial phography is useful in the construction phase in that it provides a pictorial account of the progress of special or unusual projects or projects of particular-interest to the public.

Final cross sections are taken by aerial photogrammetry with the information being placed on punch cards automatically from the Kelsh plotter. These cards are then sent to the electronic computer to compute earthwork quantities for final payment accurately and quickly.

If the control points for the design photography were wisely chosen they can be used for the photography for final cross sections. Only the finished centerline need be signalized. This photography can be taken in the summer as the area has been cleared by construction, thereby providing photographic and photogrammetric work for a season that is normally considered slack in the aerial survey business.

The available maps and photography are useful to the contractor as there is much more detail in the photos than is shown on the plan sheets. The topographic map and overlapping photos are helpful in observing soils, locating borrow pits and classified embankment material. They are also used in preparing bids, prosecuting the work and publicizing the contractor's achievements.

Operations

Photography of the completed project is an aid to the maintenance engineers in observing pavement and roadway conditions, erosion and drainage problems. This photography is also studied by the design engineer to observe any deficiencies in the design.

The traffic engineer can use aerial photos in traffic studies of roadway facilities and the movement of traffic on the facilities. An overall view can be obtained of traffic movements and the physical conditions which affect those movements in the area surrounding a point where traffic is experiencing difficulty.

Photos can be used to show the relative use of roads in the vicinity of large generators of traffic. The location of points of congestion, the time at which congestion occurs, and apparent causes of congestion can be identified from the aerial photos.

Delay at specific points of congestion—both total delay to all vehicles and maximum and average delay to each vehicle—can be determined from the movement of vehicles as shown on photos taken at regularly-spaced intervals.

Where construction plans are not available or not up to date, a condition diagram can be made from the photos.

Limited and controlled access projects can be photographed to compare the access at one date to that of a later date.

Many Uses

Many uses for photography and photogrammetry in highway engineering have been cited and no doubt there are many other applications. As has been stated, there is no question any more as to their usefulness in expediting highway projects, conserving engineering manpower and achieving economies—all without sacrificing accuracy. Now with the integration of aerial photogrammetry and electronic computers their importance as tools for the highway engineer is greatly increased.

To gain acceptance of these tools by the engineers it was necessary to supply their needs without changing the procedures for planning, surveying and design wherever possible. Now that these tools have been accepted and considerable sums of money have been invested in them, attention should be given to operating them efficiently.

To obtain the most from aerial photographs and photogrammetry much thought must be given to scheduling since aerial photography can be taken only at certain times and under certain conditions to provide the quality of photos necessary for interpretation or the desired maps. Perhaps more thought should be given to clearing and grubbing contracts to permit taking of aerial photography for design purposes in densely wooded areas and at times when foliage would interfere with the photography.

To obtain the most from the integration of photogrammetry and electronic computers it may be helpful to revise our specifications as to methods of payment, measurement of quantities, etc., also our method of design and preparation of construction plans. This of course could be done only by maintaining a high level of design and construction.