*Aerial Surveys and Photogrammetric Methods for Highways**

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ACCOMPLISHMENT OF the highway program provided by passage of the Federal-Aid Highway Act of 1956 is requiring the expenditure of enormous sums of money. Most highway departments find that unprecedented demands are being placed on available engineering manpower.

Utilization of more economical and expedient methods of accomplishing highway location and design problems is an absolute necessity for a highway department if it is to keep abreast of time schedules without appreciably enlarging its engineering staff —an almost impossible task in itself. Replacement of standard ground survey and location methods with photogrammetry and aerial surveys—methods which are no longer new to many highway engineers—has been accepted by more and more highway departments as the best solution to the problem of increasing production without increasing manpower and without lowering the accuracy standards of the department. Aerial Surveys will not eliminate the work of the highway engineers. They will, however, greatly reduce the work required of the engineer on a project. At the same time, they will provide more information and data when and where needed, at the same or less cost than was provided by old survey methods.

Photogrammetry has provided valuable aid in many fields. In topographic mapping, the cost and manpower requirements have been reduced tremendously—to 10 per cent of what was earlier required. At the Society's Semi-Annual Convention in Los Angeles in 1955 Mr. Rex H. Fulton, Senior Highway Engineer, California Division of Highways presented a report on California's use of photogrammetry in highway work; this report should be sufficient to convince almost any highway department that their methods should be used.

California started utilizing photogrammetry and aerial surveys to a limited extent nearly 30 years ago. About five years ago an expanded highway program developed mapping problems faster than the available supply of engineers could handle them by using conventional ground survey methods. It was then the State made its greatest strides in the use of photogrammetry and aerial surveys. Now, the California Division of Highways has completely discontinued using plane-table surveys for map compilation. This surveying method has been found to be much less accurate and more costly than that of photogrammetry.

California contracts all its photogrammetric work to photogrammetric firms. Its aerial survey organization is the minimum required for administration and for checking completed work. Mr. Fulton has estimated a savings of about 75 per cent in the cost of mapping by photogrammetric methods over conventional ground methods. Also as a result of contracting the Department's mapping work to photogrammetric firms, there has been a savings of 80 per cent in manpower. The coverage obtained by aerial surveys is much wider than that obtained by ground methods, with the result that location advantages are not apt to be overlooked.

Many States are now using essentially the methods that are now used by California. They thereby ease their mapping demands and at the same time make available more information and data than were previously obtainable from earlier survey methods. Connecticut, Virginia, North Carolina, Wisconsin, Montana—States with widely differing conditions and problems—are a few of the states that have had great success with the products obtained by contracts negotiated with photogrammetric firms.

The use of aerial surveys and photogrammetric methods for highways does not begin with the compilation of maps, nor is this the end. Mr. William T. Pryor, Chief

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of Aerial Surveys, Bureau of Public Roads, advocates application of aerial methods to highway location and design in four sequential stages. These stages begin after terminal points have been determined and traffic data are analysed, and end when a project is ready for construction.

During the *first stage*, a reconnaissance survey is made of a broad area between terminal points to determine feasible route alternatives. The width of the area should be 40 to 60 per cent of the length between terminal points or intermediate controls. The reconnaissance is accomplished by stereoscopic examination of small-scale aerial vertical photographs of the entire area. The scale of the photography for the reconnaissance survey may range from 5,000 to 500 feet to one inch, depending on the general character of the topography and the intensity of land use throughout the area of survey. The smallest scale photography practical in any particular area will be the most advantageous, since the smaller scale decreases the number of stereoscopic pairs required to cover an area, thereby decreasing the cost of the work in terms of both time and money.

The *second stage* carried the reconnaissance survey through a second phase—comparison of alternate routes for selection of the best route for preliminary survey, in the third stage. In some cases the small scale photographs used for the first stage work are not adequate for detailed analysis of each of the alternate route locations. Should this be true, the alternate route bands may be photographed to a larger scale. This scale may range from 1,000 feet to one inch for rural areas where topography is rugged and land use small, to 200 feet to one inch for urban and suburban areas where land use is intense and more detailed comparative data are required for proper evaluation of each route.

Comparison of alternate routes may sometimes be facilitated by the preparation of reconnaissance-type maps. Such maps, varying in scale from 1,000 to 400 feet to one inch, will allow more accurate comparison than is obtainable through an evaluation of sets of aerial photographs and the use of available small-scale maps—2,000 feet to one inch and smaller-supplemented by field checks on the ground.

The reconnaissance use of aerial photographs in two stages has developed a route location in which considerably greater confidence can be placed than when only ground reconnaissance methods are used. In the past, to establish that a route location determined by ground reconnaissance was the best route, it was necessary that each engineer involved in the location and design go through the same laborious and time-consuming task of acquainting himself with the entire area of reconnaissance and the route selected—just as was necessary for the locater of that route. Through using stereoscopic coverage of an area, the engineer making the route reconnaissance can easily demonstrate that every feasible alternative has been determined and fully considered. The aerial photographs of the area on which the route reconnaissance lines have been drawn are available for stereoscopic viewing by anyone with two good eyes. The information and data required to justify selection of routes are available for a study and review in the office by all concerned.

The *third stage* work consists of a detailed preliminary survey of the best route, design of the location on this route, and the preparation of highway construction plans. When aerial methods are being employed, it is in this stage that photogrammetrically compiled maps replace plane-table or other types of maps made by using ground-survey methods. Large-scale photography of the selected route is used for mapping a band of topography one-tenth to one mile wide along the route. From this same photography, a wealth of qualitative information—information which cannot easily be symbolized and placed on maps—may be obtained by photographic interpretation, and is readily available to the design engineer for his consideration as he makes use of the quantitative data supplied by the maps.

Map scales and contour intervals commonly required in this third engineering stage range from 400 feet to one inch with a 10-foot contour interval to 50 or 40 feet to one inch and 1-foot contour interval. In lieu of topographic maps, particularly in areas of little relief, planimetric maps may be compiled with the relief dimension obtained from spot elevation measurements of the profile along the center line of the route, and of cross sections across the route for a sufficient width to insure that the best location possibilities have been covered. This procedure is particularly advantageous when electronic methods are

to be employed in computing grading quantities for design purposes or for the payment of excavation on construction contracts.

The *fourth stage* is the first stake-setting stage whenever aerial surveys are employed from the beginning. The design has been completed in the third stage and the centerline and rights-of-way boundaries have been indicated on the map. Rights-of-way descriptions can be based on coordinates of the properties as determined by the aerial survey. If laws and procedures permit, right-of-way procurement may precede the staking of the designed centerline on the ground, and the centerline may be staked later when construction is programmed.

Aerial survey methods, then, permit determining all feasible routes, comparing them and selecting the best one, making a preliminary survey of the selected route, completing the design and preparing construction plans, and procuring right-of-ways—all of this is done well in advance of construction programming. Because numerous ground surveys need not be made to select the best route, there is eliminated much unnecessary excitement of property owners and the public. Also this tends to prevent speculation resulting in increased right-of-way costs.

Highway engineers who plan using, or are responsible for using aerial methods in their departments must have a sound understanding of the subject of photogrammetry. The extent to which personnel must be trained will depend upon the procedure to be used in the department.

If, as in Ohio, the State plans to set up a complete photogrammetric section, considerable time and effort for training will be involved to become qualified to fly its own photography, to develop and print photographs, make mosaics, and prepare photogrammetrically compiled maps. Even when the photogrammetric work is to be accomplished by contract with photogrammetric firms, as in California, the highway engineer must have sufficient understanding of aerial survey methods and photogrammetry to recognize fully what services the photogrammetric firms are capable of providing, the accuracies that can be expected of their product, the economy of specifying certain scale-contour-interval combinations for photogrammetrically compiled maps, and so forth.

In the field of photographic interpretation, the proper procedure for training interpretation specialists is to train men who already have the professional background for a special field, but who lack previous photographic interpretation experience. This is preferable to attempting to train men who have had previous photographic interpretation experience in one field or another, but who lack the professional background. The same is true in the highway engineering field. It is not practical to hire a photogrammetrist for a highway department and expect him to be immediately productive. He must first learn the principles of highway engineering, and obtain practical experience in highway location, design, and construction.

The present staff of highway engineering personnel may best be trained in the use of photogrammetry and aerial surveys by the in-service or on-the-job training method. Mr. Pryor, whom I mentioned as advocating the four-stage procedure just discussed, has been conducting training courses for State and Bureau personnel since 1950 when the first of the courses was presented at Denver, Colorado. Since that time there have been other schools, 11 in all, in such places as Sacramento, California; Madison, Wisconsin; Seattle, Washington; and Lincoln, Nebraska. A 12th school is scheduled to be held this November in Fort Worth. In addition to these courses which are conducted in the field, similar courses are conducted by Mr. Pryor in the Aerial Surveys Office of the Bureau in Washington. State and Bureau personnel are temporarily assigned for training as well as highway engineers from other countries who are in the United States under I.C.A. sponsorship.

These courses include the basic principles and theory of photogrammetry, and practices in their application to the making of surveys for the solution of highway engineering problems. Some of the principles, theory, and practices covered are:

(1) Stereoscopes and the various photogrammetric instruments now in use
(2) Types of aerial photographs and their geometry
(3) Stereoscopy, determination of parallax from stereoscopic pairs, computation of differences in elevation and determination of grades from parallax measurements

(4) Preparation of uncontrolled mosaics, and the use of mosaics in the solution of location problems
(5) Principles of a radial plot, and its application to preparation of controlled mosaics and topographic and planimetric maps
(6) Photographic interpretation
(7) Use of stereoscopic pairs in making route reconnaissance surveys and comparison of route alternatives
(8) Relationships in contour interval, scales, and stereoscopic plotting instrument usage.

The in-service training courses as conducted in the field by Mr. Pryor are now scheduled for a three-week period. At some of these schools, Mr. P. C. Smith, Assistant Chief, Soils Branch, Bureau of Public Roads has presented a special course for soils engineers which is particularly applicable to aerial photographic interpretation of soil and ground conditions. Although it is impossible in a three-week period to give the engineers attending these courses more than a basic training in theory and practice, the courses are conducted with the hope that with that basic training the engineers will continue to acquire knowledge and experience through application within their own organizations.

Formal training in photogrammetry and photographic interpretation at both the undergraduate and graduate levels is available in some universities and colleges. Professor Arthur J. McNair, Cornell University, reported on "Education in Photogrammetry" at the 1956 Semi-annual Meeting of the Society in Denver. A few of the facts Professor McNair had to report are these: "Undergraduate instruction in photogrammetry is conducted in the United States primarily at schools of civil engineering and usually in the surveying course . . . there are altogether too many schools teaching civil engineering which give little or no instruction in the fundamental principles of photogrammetry . . . a substantial number of schools of civil engineering have eliminated completely or substantially the teaching of surveying to their students. . . . About 75% of the students in the country who are required to take a course or sequence of courses in surveying are exposed to photogrammetry, (but) this exposure varies all the way from one 50-minute lecture to as much as 3-credit hour courses for one semester."

Even if a highway department should be fortunate enough to hire an engineer fresh from the university who has had training in photogrammetry, that engineer should not be expected to be a skilled photogrammetrist any more than the engineer fresh from the university should be expected to be a skilled locating engineer. However, with a background of training in the underlying theory, and enough on-the-job training in practice, so that the engineer understands the uses to be made of the theory, he can quickly develop his skills.

Two excellent references are available to highway departments seeking information about photogrammetry. One, and undoubtedly the most comprehensive coverage of the subject available anywhere, is the "MANUAL OF PHOTOGRAMMETRY" published by and available from the Society. The other, which contains a wealth of material directly applicable to highways, is the "*Reference Guide Outline*—Specifications for Aerial Survey and Mapping by Photogrammetric Methods for Highways —1956." This reference was prepared by the Photogrammetry for Highways Committee jointly sponsored by The American Society of Photogrammetry and The American Congress on Surveying and Mapping. It has been published by and is available from the United States Government Printing Office.