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Photogrammetry and Aerial Surveys
A Symposium

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Introduction to Photogrammetry and Aerial Surveys

WILLIAM T. PRYOR, Chief of Aerial Surveys
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● IN the present stepped-up program of highway construction, highway engineers face the reality that the usual survey methods on the ground are too slow for keeping abreast of time schedules without making large increases in the size and number of survey parties. Furthermore, such increases are virtually impossible to make because of the acute shortage of personnel with adequate training and experience. New ideas and methods are being sought to alleviate this situation. But before acceptance in highway engineering, new ideas or methods must pass the tests of feasibility, adaptability, reliability, and universality of application and economy. Anything new in surveying for highways receives extra scrutiny and tests throughout a long period of time. This has been especially true with respect to photogrammetry and aerial surveys—methods new to many highway engineers.

A pioneering few are always blazing new paths ahead in preparation for anticipated needs and for the satisfaction of making improvements and new developments. This has been done in photogrammetry and aerial surveys for highway engineering purposes. So, fortunately, new methods are available. And now that the expanded highway program is in effect, an increasingly wider acceptance of the usefulness, accuracy, and thoroughness of photogrammetry and aerial surveys is occurring. Among the major forces bringing about this current and rapid acceptance are the magnitude of the new highway program, the shortage of engineers, and the speed with which the engineering work must be done to get the construction under way and accomplished on schedule. Fortunately, the new survey methods are proven and ready to supersede a majority of surveys on the ground and to supplement the remainder. Aerial surveys will greatly reduce the work of highway engineers while making such work easier, but they will not eliminate it. Properly used, however, they enable the engineer and the other specialists to do their work to the best of their abilities. Such surveys provide the right kind and amount of information and data when and where needed. Thus, the scope of their effectiveness and use are seemingly boundless.

In the highway field, however, photogrammetry and aerial surveys have been largely confined to supplying a set of aerial photographs and to compiling maps photogrammetrically, usually large scale topographic maps for preliminary survey purposes. This limited use of methods has been caused by lack of mutual professional and technical knowledge between highway engineers and photogrammetric engineers. This situation should not continue any more than adherence to conventional methods of surveying should continue, since an expanded and improved use of the new methods will make it possible for the available highway engineers to keep pace with stepped-up schedules and to do better engineering than ever before.

Highway organizations can now take advantage of developments and improvements, made by federal agencies and private firms, in photogrammetric instruments and in techniques of their use. In the future, these organizations can accomplish new developments and improvements through both use and research, while they focus on the attainment of better highway engineering and better highways through full use of the improved methods.

The essentials for attaining such worthwhile objectives are full knowledge of the principles and procedures of application, as well as knowledge of uses of photogrammetry and aerial surveys. In the immediate future, highway engineers who do not have this knowledge will need to obtain it. They can obtain it the "hard way" through experience, or by receiving in-service training and schooling from those who possess such knowledge. For the engineers of the future, this knowledge should be obtainable in our engineering schools.

Through the years, highway departments have worked very closely with engineering schools, both in education and in research to solve highway problems. Now the scope of this cooperation must be broadened, to include aerial surveys for highways and rapid methods of utilizing data obtained by such surveys, such as use of electronic digital computers.

Photogrammetry and its essential companion, a national network of basic ground control surveys, are given recognition in the Federal-Aid Highway Act of 1956. The Act stipulated an expanded program for construction of the primary and secondary highway systems and extensions within urban areas, and for the National System of Interstate and Defense Highways. This program affords the near-perfect opportunity for highway engineers and their working associates to advance photogrammetry and aerial surveys, both professionally and technically, and to advance use of the national network of basic ground control established by the U. S. Coast and Geodetic Survey. First, this can be done through the cooperation of all state highway departments, the Bureau of Public Roads and other federal agencies, engineering and construction firms, interested national and state societies and institutions, and colleges and universities—the type of cooperation which has proven effective in every phase of highway engineering and con-

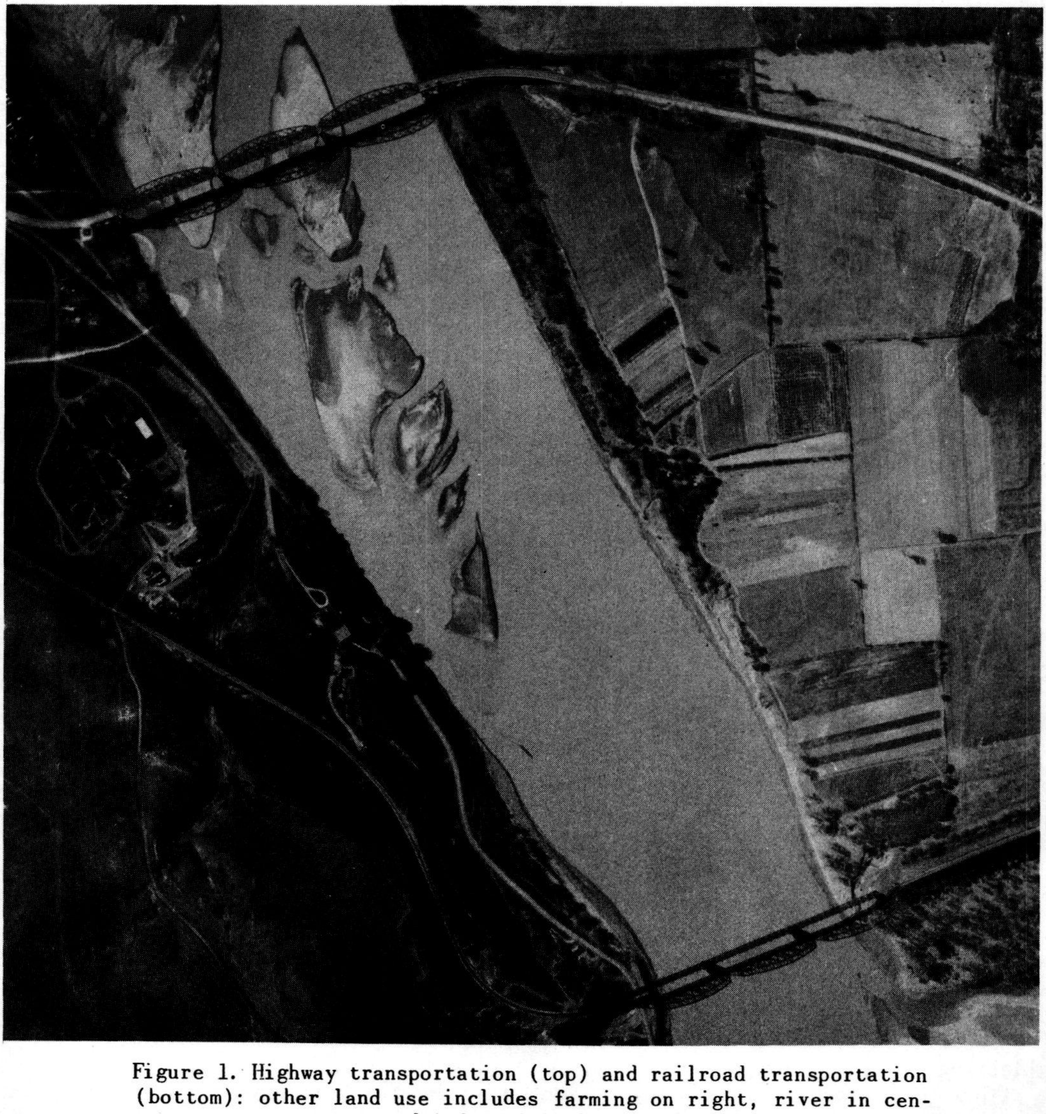


Figure 1. Highway transportation (top) and railroad transportation (bottom): other land use includes farming on right, river in center, and industrial plant on left.

Figure 2. Ground structure.

struction efforts since the first federal-aid law of July 1916. Second, the services of photogrammetric engineering firms and consultants should be engaged by negotiation on the basis of qualifications, reliability, and economic performance. Third, satisfactory performance on the part of the engaged firms is equally essential in the professional advancement of these relatively new survey methods. Finally, highway engineering organizations should fully use the photographs, the photographic mosaics, and the photogrammetrically compiled maps and measured dimensions supplied by the photogrammetric engineering firms.

DEFINITIONS AND APPLICATIONS

In planning for and in using these modern methods in making surveys for the location and design of highways, it is well to keep in mind four terms, their definition, and their usual applications. The first is photographic interpretation; the second, photogrammetry; the third, aerial surveys; and the fourth, highway location and design.

Photographic interpretation is the recognition, identification, and analyses of visible photographic images of the ground, and of objects and features on the ground, and, from visible photographic images, determination of the existence or likelihood of existence of hidden objects and features and their probable composition. Photographic interpretation obtains the needed qualitative information about the topography, vegetative ground cover, drainage, soils, ground structure, erosion, and uses of the land by nature and by man (Figures 1, 2, and 3). Such interpretation has to do with ascertaining type or form, composition, characteristics, condition, prevalence and intensity, relationships, scope, influence, importance, adaptability, feasibility, and value or worth. In most photographic interpretation, the principles and techniques include the recognition and analyses of location or site, shape, relative size or area, image patterns and relationships, image texture and color tone, shadow, land form, and land use. Mentally, all of these are interrogated individually and collectively as the photographic images are examined—usually by stereoscopic methods—and while, in this procedure, the images are quickly or slowly recognized, their analyses are accomplished in step-by-step processes of selection or elimination. Thus, to perform photographic interpretation successfully, one must have the proper abilities (including the physical ability to see stereoscopically), knowledge, and objectives or purposes for undertaking interpretation.

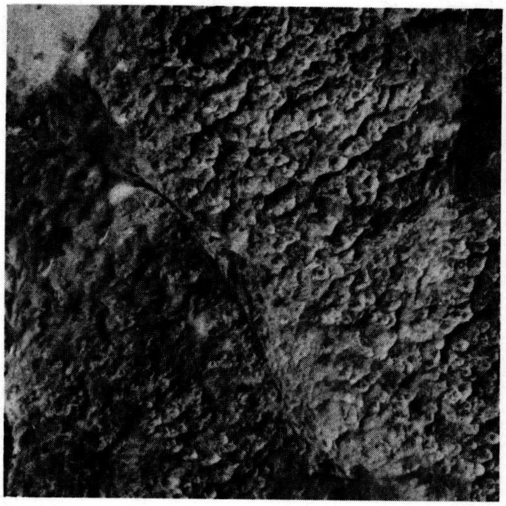
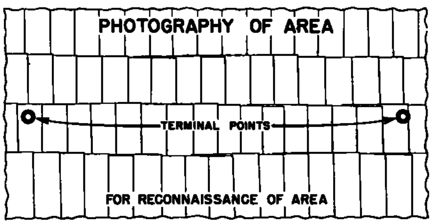


Figure 3. Sand dunes retarded in movement by vegetation; such wind erosion characteristics are easily determined by examination of aerial photographs.

Photogrammetry is the science or art of obtaining reliable measurements by means of photography, oriented as necessary by ground control surveys. Photographic interpretation is applied to the extent necessary in measuring position, direction, and size, or area, volume, or number, and in delineating shape. Measurements by photogrammetric methods are made to obtain quantitative data (dimensions) to the accuracy required. Instruments or measuring devices of some kind are used in conjunction with the photographs and ground control surveys. The result of such an application of photogrammetry is usually a map on which the horizontal position, shape, and size of features are represented to scale and the vertical dimensions are delineated by contours or are recorded as spot elevations and as profile and cross-section dimensions. Included are property lines, all essential land use and other planimetric features, and all vital topographic details.

Aerial surveys are the use of photography to obtain by photographic interpretation and photogrammetry the qualitative information and the quantitative data needed in the solution of engineering and other problems.

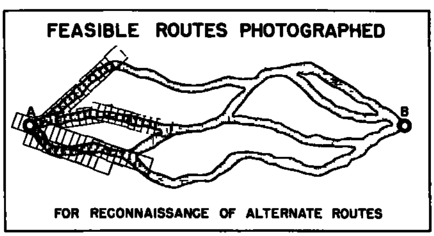
Highway location and design are the use of essential qualitative information and quan-



FIRST STAGE

RECONNAISSANCE SURVEY OF THE ENTIRE AREA BETWEEN TERMINAL POINTS

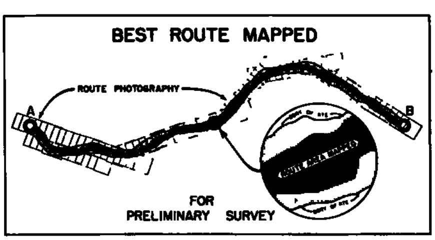
1 STEREOSCOPIC EXAMINATION OF SMALL SCALE AERIAL PHOTOGRAPHS OF THE AREA, SUPPLEMENTED BY AVAILABLE MAPS
2 DETERMINATION OF CONTROLS OF TOPOGRAPHY AND LAND USE
3 LOCATION OF FEASIBLE ROUTES ON THE PHOTOGRAPHS AND MAPS



SECOND STAGE

RECONNAISSANCE SURVEY OF FEASIBLE ROUTES·

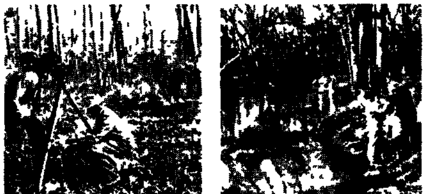
1 STEREOSCOPIC EXAMINATION OF LARGE SCALE AERIAL PHOTOGRAPHS OF EACH ROUTE
2 DETERMINATION OF THE DETAILED CONTROLS OF TOPOGRAPHY AND LAND USE
3 PREPARATION OF ROUTE MAPS BY PHOTOGRAMMETRIC METHODS WHEN NECESSARY
4 LOCATION AND COMPARISON OF FEASIBLE ROUTES ON PHOTOGRAPHS AND MAPS
5 SELECTION OF THE BEST ROUTE



THIRD STAGE

PRELIMINARY SURVEY OF THE BEST ROUTE

1 PREPARATION OF LARGE SCALE TOPOGRAPHIC MAPS USING ROUTE PHOTOGRAPHS AND PHOTOGRAMMETRIC METHODS, OR
PREPARATION OF LARGE SCALE TOPOGRAPHIC MAPS BY GROUND SURVEYS, GUIDED BY BEST ROUTE LOCATION MADE ON PHOTOGRAPHS IN SECOND STAGE
2 DESIGN OF THE PRELIMINARY LOCATION
a–USING TOPOGRAPHICAL DIMENSIONS OF THE LARGE SCALE MAP,
b–WHILE STEREOSCOPICALLY EXAMINING THE ROUTE PHOTOGRAPHS
3 PREPARATION OF HIGHWAY CONSTRUCTION PLANS



FOURTH STAGE

LOCATION SURVEY STAKING OF THE RIGHT-OF-WAY AND OF THE HIGHWAY AND STRUCTURES FOR CONSTRUCTION

Figure 4. Aerial surveys determine the best highway location. Four progressive survey stages are employed. These methods are being used in locating and designing the national system of interstate and defense highways.

titative data to determine the best location for the highway and to prepare plans in sufficient detail for construction.

ENGINEERING STAGES

The engineering stages of highway location and design by use of aerial survey methods are four in number, beginning after traffic surveys are completed and fully analyzed,

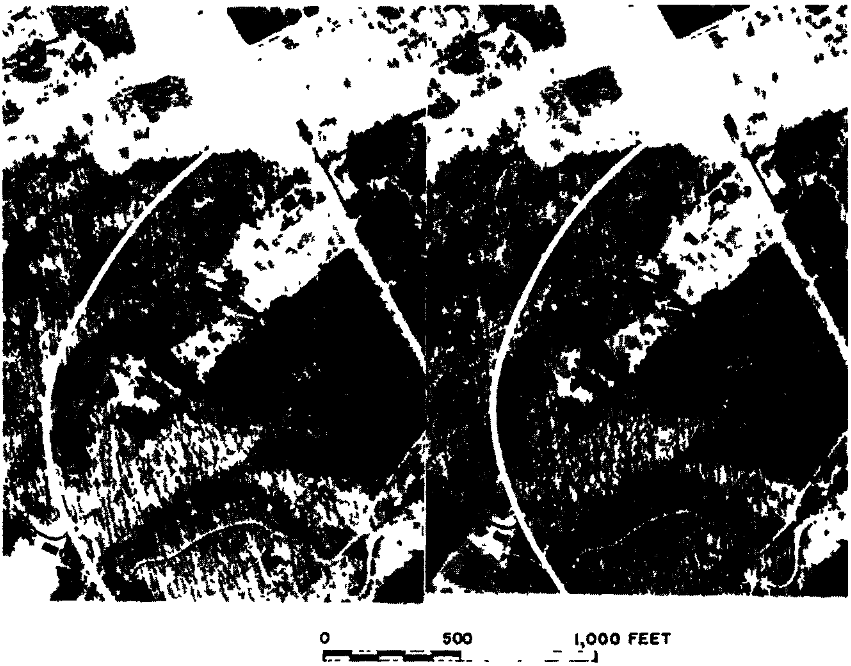


Figure 5. Stereogram of portion of highway route located in Stage 1 and selected in Stage 2 for preliminary survey in Stage 3. To examine a stereogram stereoscopically either of two methods may be employed—a lens-type stereoscope or the unaided eyes. To examine a stereogram with the unaided eyes, look at the left photograph with the left eye and the right one with the right eye. To make this easy, place a 10-in. card between the eyes from the face to the line between the pair of photographs of the stereogram. By this means, one is prevented from looking first at one photograph and then the other. With the card in place, look into the distance—like seeing through the paper on which the photographs are printed—until the three-dimensional picture is seen beyond the pages of the book. After a little practice, the card can be eliminated.

and terminal points are selected or are designated, and ending when construction can be started (Figure 4). Briefly stated, these stages are as follows:

Stage 1 is the reconnaissance survey of a broad area to determine the feasible route alternatives. The width of the area is usually four-tenths to six-tenths as wide as the airline distance between the terminal points or between the major intermediate objectives. In this stage, every route alternative is determined which will fulfill alignment, gradient, and cross-section requirements, and which will serve the traffic for which the highway is to be constructed.

Stage 2 is reconnaissance survey of the alternate routes, comparison of the routes, and determination of the best route for the highway. This reconnaissance survey is accomplished by thorough examination of a band of topography which is usually one mile

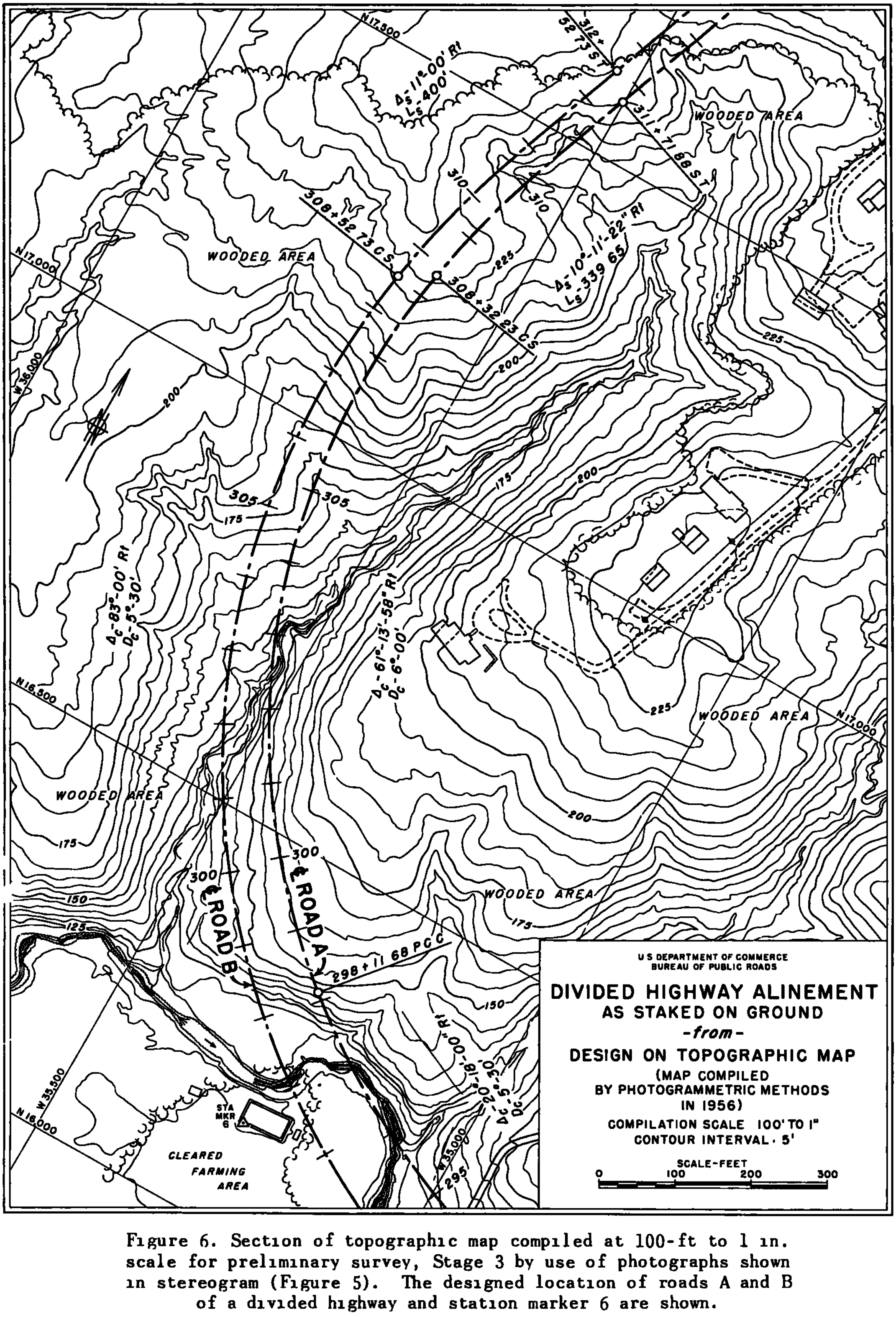
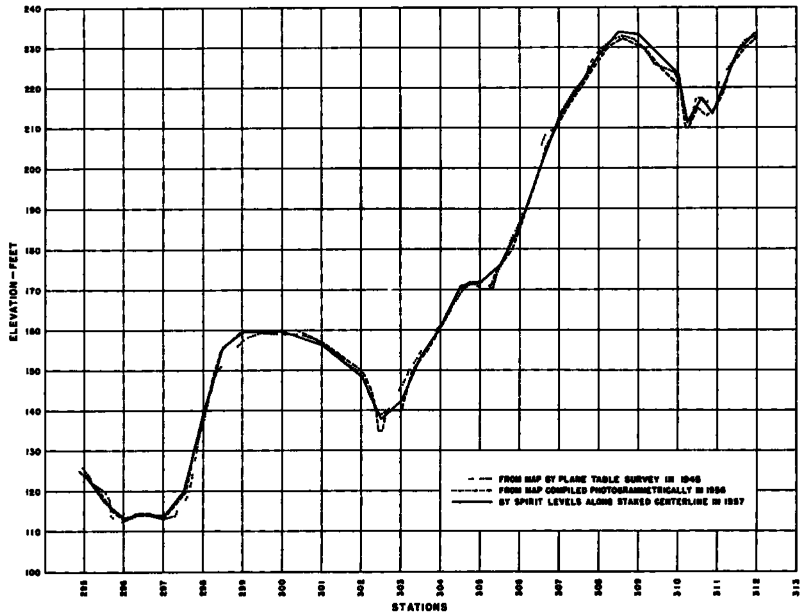
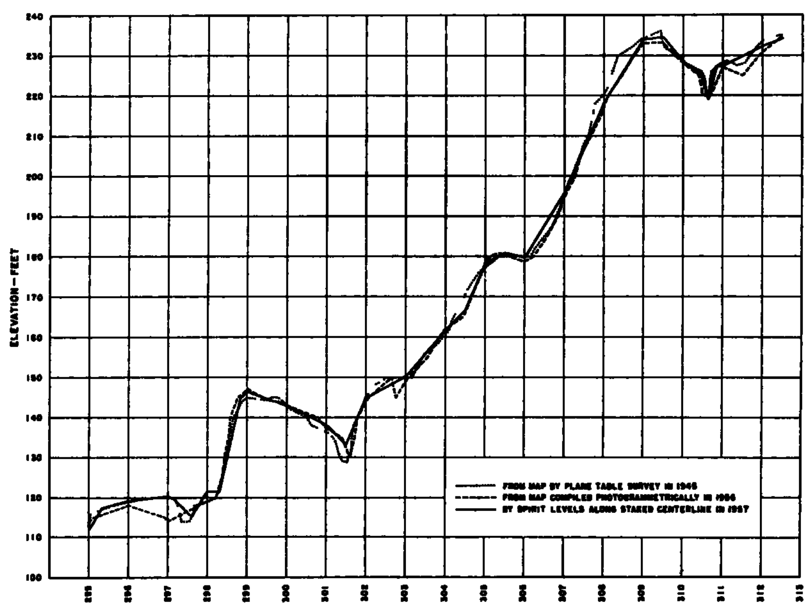


Figure 6. Section of topographic map compiled at 100-ft to 1 in. scale for preliminary survey, Stage 3 by use of photographs shown in stereogram (Figure 5). The designed location of roads A and B of a divided highway and station marker 6 are shown.



COMPARISON OF PROFILES ON CENTERLINE OF ROAD A



COMPARISON OF PROFILES ON CENTERLINE OF ROAD B

Figures 7 (above) and 8 (below). These comparisons were made to show the relationship between three separate profiles on the centerline of the two roads of a divided highway. Profiles measured by spirit levels on the ground contain plotted points of rod readings largely at station and half station points, intermediate breaks being ignored because these readings were made for slope staking purposes only. The initial mapping by plane table was insufficient in width for this project. Consequently, the same area was mapped by photogrammetric methods to attain continuity and for comparison purposes while the additional required width was mapped; hence the availability of three profiles.

to three miles wide along each feasible route (Figure 5). Mistakes made in this stage or in the preceding stage cannot be corrected in the subsequent stages. Consequently, the character of the highway and its general location are set by the highway standards and the survey and design accomplishments in these two stages. Every factor of comparison is considered and evaluated in terms of quality, dimensions and quantities, and service. These factors include distance, direction, rise and fall, travel time, comfort convenience, safety, and costs of rights-of-way, construction, vehicle operation, and maintenance. They also include the serviceability and the benefits of the highway.

Stage 3 is preliminary survey of the best route, design of the best location on this route, and preparation of highway construction plans. This survey usually includes the use of qualitative information obtained by photographic interpretation and large scale quantitative data obtained by mapping a band of topography about one-tenth or one-quar-

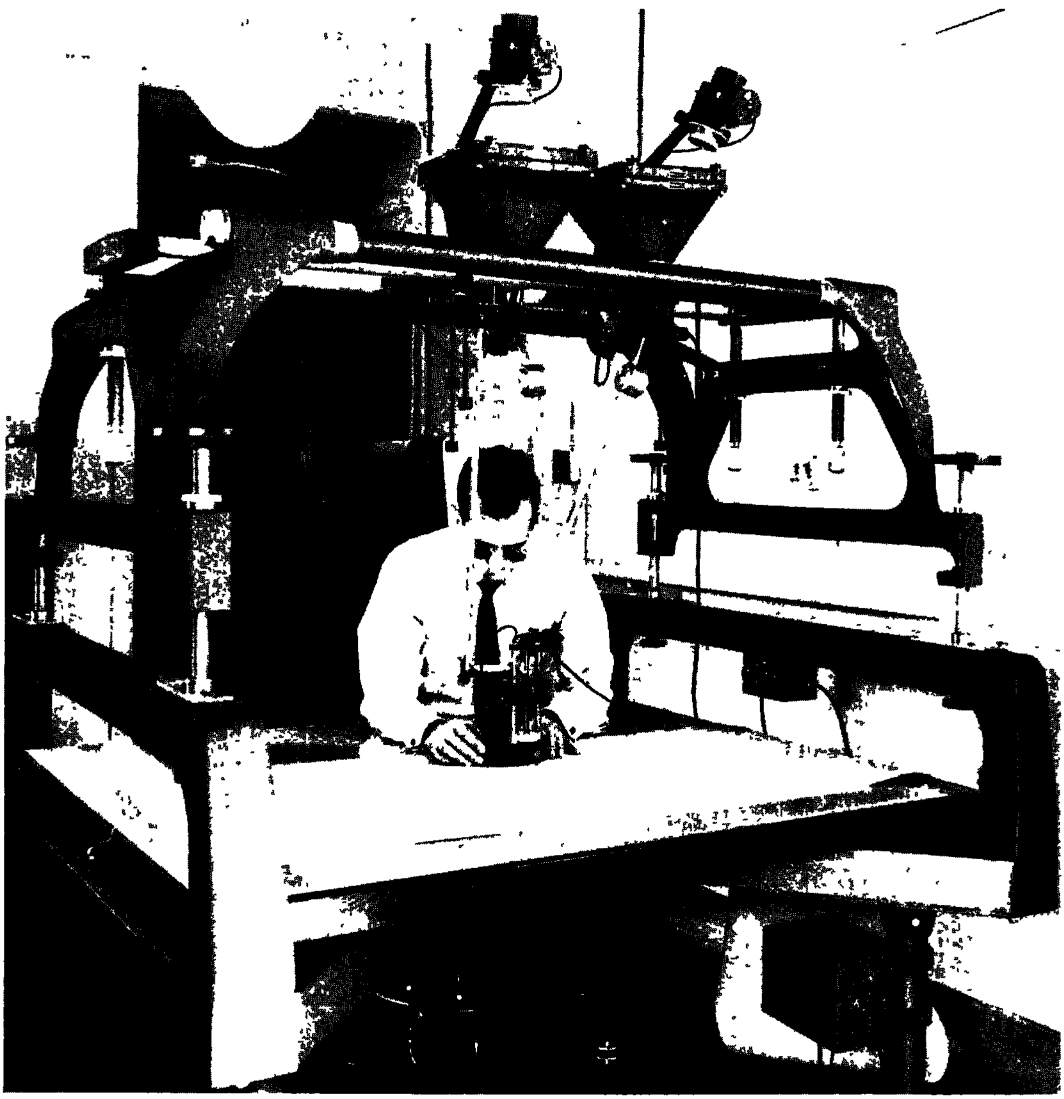


Figure 9. A Kelsh stereoscopic plotter, one of the types of precise photogrammetric instruments used for large-scale topographic and planimetric mapping by photogrammetric methods in the preliminary survey stage. Map in Figure 6 was compiled with this instrument.

ter mile to one mile wide along the route. The mapping scale is governed by the ruggedness of the ground, the intensity of land use, and the class of highway being surveyed. Usually, the largest scale and the smallest contour interval are required where land use is intense and the topography is smooth to rolling, and the smallest scale and largest contour interval where the topography is rugged (mountainous) and the land use is small or nil. Map scales in feet to one inch, and contour interval in feet, commonly required are: 400 to 10, 200 to 5, 100 to 5 or 2, 80 to 2, 50 to 2 or 1, and 40 to 1 (Figures 6, 7, and 8).

In lieu of topographic maps, planimetric maps may be compiled and the third dimensions obtained by measurement of profile along the center of the route and measurement of cross-sections across the route for sufficient distance (width) to include the best location possibilities (Figure 9). This procedure is especially advantageous wherever the ground is smooth and flat, nearly level, and whenever electronic methods are to be employed in computation of grading quantities for design purposes or for payment of excavation on construction contracts.

Stage 4 is the location survey staking of the designed highway on the ground in readiness for its construction. This staking includes the centerline with its circular curves, transition spirals, and joining tangents, the cross-sections, right-of-way, and all structures. The location staking is guided by all that has been accomplished in the preceding stages. This is the first stake-setting stage whenever aerial surveys are employed from the beginning, and it is necessary because the construction forces require guidance in their work on the ground.

Subsequent engineering is construction, maintenance, and reconstruction. The construction surveys are made to replace stakes of the location survey which are knocked out during construction operations, and to set stakes for finish-grading and other finishing operations. This survey work is guided also by the engineering accomplishments in the first three stages of highway location and design.

USES OF AERIAL PHOTOGRAPHS IN HIGHWAY SURVEYS

In each of the stages of highway surveys, aerial photography (both vertical and oblique) can be used in many ways. Use begins in a general way on an area basis in Stage 1, and from there becomes progressively more detailed, accurate, and specific throughout Stages 2, 3, and 4. Such range in use applies to photography as single photographs printed as reductions, contacts, or enlargements; as groups of photographs assembled to form photographic mosaics of the uncontrolled, semi-controlled, controlled, and precise types; and as stereoscopic pairs whether photographically printed on opaque paper or on transparent film or glass to reduced, contact or enlarged size (Figures 10 and 11).

Photographs used singly and as photographic mosaics are effective for illustrative purposes, as substitutes for planimetric maps when or wherever precision in orthographic accuracy is not essential, and for certain types of photographic interpretation. The orthographic accuracy of a mosaic is improved to the extent horizontal position control is used in assembling and matching the photographs. Photographs and photographic mosaics also serve as before, during, and after records when properly and specifically taken for such purposes; thus, whenever necessary, they readily refresh memories about situations, conditions, and circumstances. They are especially effective for display and illustration of alternatives at public meetings, and for representing rights-of-way in condemnation proceedings.

Photographs in stereoscopic pairs provide every two-eyed user with a three-dimensional model of the ground and all things on it. The details seen in this model will depend upon the scale and photographic quality of the photographs and the visual acuity of each person who examines them stereoscopically. In stereoscopic pairs, aerial photographs are effective for illustrations, for making photographic interpretations, and for making measurements photogrammetrically, whether to a reconnaissance degree of accuracy or to the preciseness required in the preliminary survey stage. Stereoscopic pairs contain both the qualitative information and the quantitative data needed by highway engineering staffs. Procuring these photographs to the proper scale and getting from

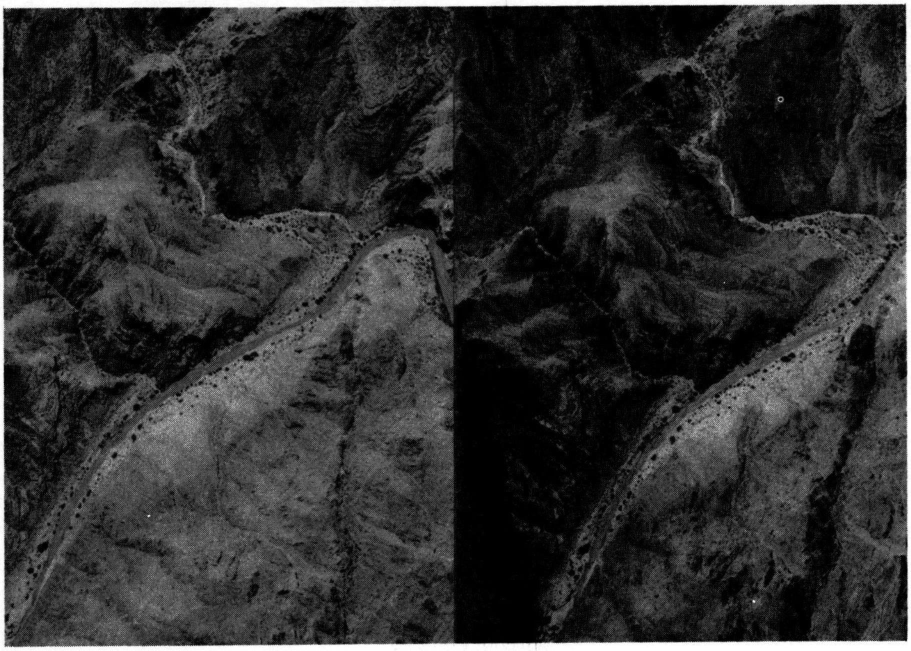


Figure 10. Vertical photography stereogram of rugged region eroded by river.

Figure 11. Low oblique of same section of river seen in the vertical photography stereogram of Figure 10.

the stereoscopic models they provide the information and data needed in usable form are the problems. The usable scales expressed in feet to one inch for each survey stage range from small to large scale as follows: Stage 1, 5,000 to 500; Stage 2, 1,000 to 200; and Stage 3, 500 to 40.

Photogrammetric engineering firms can provide the photographs; assemble, copy, and print the photographic mosaics; make essential project ground control surveys; and, by using the photographs, their instruments and ground control can photogrammetrically compile the maps and measure profile and cross-sections. It is the responsibility, however, of each highway engineering staff to perform the highway engineering in each stage of the location and design. Consequently, all aerial photography and photogrammetry systems used for highway purposes are to serve highway engineering staffs. The systems require intelligent direction—what is needed must be fully and exactly specified. It cannot be emphasized too strongly that highway engineers must know what is required, know what can be furnished or done, and know when specified materials have been delivered and specified work has been accomplished. Thus, aerial surveys are the qualitative-information and quantitative-data furnishers, and highway engineering staffs are the users.

ACCURACIES BY PHOTOGRAMMETRIC METHODS

Wherever the surface of the ground can be seen or interpreted in stereoscopic pairs of aerial photographs being used to make measurements and do mapping by photogrammetric methods, certain accuracies are attainable and can be reasonably expected. These apply to contours, to the horizontal position of planimetric and topographic features on the maps, and to spot elevations.

Contours on topographic maps should have an accuracy sufficient for 90 percent of the elevations determined from the contours to not vary from true elevation by more than ½ the contour interval and the remaining 10 percent by not more than 1 contour interval.

Horizontal position accuracy, in relation to true coordinate position at map scale, of features on the maps should be 1/40 of an inch or better for 90 percent of the features tested, and should be not less accurate than 1/20 of an inch for the remaining 10 percent.

Spot elevations on topographic maps should have an accuracy of at least ¼ the contour interval, and spot elevations of profile and cross-sections measured while planimetric or topographic maps are compiled should have an accuracy of at least 1/200 the scale of the map expressed in feet to the inch.

REQUIREMENTS

To gain as much as possible from the advantages of aerial surveys for highways, and to overcome their disadvantages and limitations, certain requirements should be provided for or met. Aerial surveys should be planned and conducted in a series of coordinated steps within each highway engineering stage.

As applicable to his work, each specialist should make full use of the appropriate photogrammetric instruments and aerial surveys in performance of the work in his specialty, and in cooperation and coordination of his work with that of others.

Photogrammetric engineering firms should be apprised of the needs and requirements of highway engineers in each of the successive stages of highway engineering, and should make every effort possible to fulfill those needs in the quality and to the accuracy commensurate with the requirements.

In planning for and undertaking every aerial survey project, time must be allowed for photography when leaves are off deciduous trees, with anticipation of interferences especially by weather and ground conditions, for making project ground control surveys as necessary, for the mapping, for testing the completeness and accuracy of the surveys and maps, and for performing essential completions and corrections to make the surveys and maps fully usable.

Specifications prepared by highway engineers for aerial surveys should be written so as to attain at reasonable cost in time and money, in sufficient detail, and to accuracies required, all that is needed for the solution of highway engineering problems in each survey and design stage.

To attain effective and efficient use of photogrammetric methods in topographic mapping for the preliminary survey of highways, there is a relationship that should be adhered to between map scale and contour interval. This relationship may be stated in two ways. The denominator of the scale of the topographic maps, when the scale is expressed as a representative fraction, should not exceed 1,600 times the contour interval in meters, or not exceed 480 times the contour interval in feet. Under certain conditions this denominator should not exceed 1,000 and 300 times the contour interval in meters and feet, respectively. In other terms, the map scale in feet to one inch should not exceed 40, and, according to conditions and photogrammetric instruments used, the scale might preferably be as small as 25 times the contour interval in feet.

All mapping should be based on the state system of plane coordinates in the area of survey, and before the mapping is started the plane coordinates of the basic ground control should be adjusted for scale and elevation above sea level so as to apply correctly at the average elevation of the survey project. These adjustments, which are easy to make, are necessary in order that distances measured on the maps will agree by scale with distances measured on the ground. Otherwise, every distance on the maps would have to be multiplied by a correction factor before such distances would agree with horizontal distances on the ground. It is easier and more economical to make a few adjustments in the beginning before the mapping is done than it is to make an almost unlimited number after the mapping has been completed and while the maps are being used.

To have an accurate and direct means of "tying" map position to ground position (especially the designed and mathematically described centerline of the highway with its circular curves, transition spirals, and joining tangents, and the description of each parcel of land comprising the highway right-of-way), permanent station markers should be set and accurately surveyed while the project ground control surveys are under way. The plane coordinates of each station marker should be marked in proper position and recorded on the applicable map sheet. Then for staking purposes, it will be easy to determine mathematically the bearing or azimuth and the distance between such markers and staking points on the highway centerline and on its right-of-way lines. Accuracy of origin for all location survey staking will thus be assured.

Vertical photography taken with 8¼-in. focal length precision aerial cameras is especially useful for photographic interpretation purposes and for mapping rugged areas where the ground cover consists of tall trees which are not so close together as to fully obscure the ground. Six-inch focal length vertical photography is useful for mapping rolling to nearly smooth ground wherever the ground cover is not tall and is not dense, and 6-in. focal length photography which is convergent (oblique) 15 or 20 degrees in line of aircraft flight is especially useful for mapping gently rolling and smooth (nearly level) ground wherever vegetation is not tall or dense enough to cause blind spots resulting from perspective "lay-over." For similar photography scales, both types of 6-in. focal length photography increase the accuracy of contour delineation and spot elevation measurements under the conditions described as compared to the 8¼-in. focal length photography. But the longer focal length is superior where topography and ground cover combined will hide the ground on the shorter focal length photography.

ADVANTAGES OF AERIAL SURVEYS

In highway engineering the advantages of aerial surveys are almost legion, for the scope of their effectiveness and their usability are seemingly boundless. For emphasis and to make a reference record, some of these advantages are enumerated, as follows:

They provide ample qualitative information pertaining to topography, soils, drainage and land uses.

They are the means whereby the required quantitative data can be measured and shape delineated for all topography, for drainage areas, for property boundaries, for man-made objects, for sites of construction materials, and for all facilities that will be affected by the future highway.

They provide a useful means of correlating to the type and intensity of land use the land-use and traffic-generation factors as developed from origin and destination traffic studies. Traffic forecasts involve anticipated future land use, and the aerial surveys are especially useful in ascertaining what the land use might be from time to time during the forecast period. Thus, traffic forecasts can be made with reasonable certainty and adjusted as necessary. Moreover, by correlation with previous patterns and rates of development, future changes and developments in land use can be estimated by thorough stereoscopic examination of aerial photographs taken periodically.

They are an ever-ready method which will save man-days on surveys and on design. In addition, they will release professional highway engineers from performance of routine, repetitive tasks, and will allow them to devote most of their time to their professional duties.

They make inaccessible areas accessible. They fill in details where it is not physically practicable or legally feasible to go on the ground in making numerous surveys, and in locating and comparing alternate locations.

They reduce, if they do not eliminate, the excitement of property owners. This is accomplished through elimination of the need of on-the-ground flagging of routes in the reconnaissance survey stages and of staking P-lines in the preliminary survey stage. Thus, no lines need be staked on the ground for design purposes. Only one L-line need be staked in the location survey stage after all alternatives have been determined and compared, the best location has been ascertained, and construction plans have been completed.

Full use of aerial surveys eliminates any need for cutting trees and other vegetation for reconnaissance survey purposes and for staking P-lines and measuring profiles and cross-sections through vegetation-covered areas in the preliminary survey stage. Route areas covered by vegetation can be cleared after an "initial" design is made. Then new route photographs can be taken and precise mapping of the route zone accomplished where the highway is to be constructed. New control surveys will not be required for this mapping as the control established for the first mapping can be utilized the second time. This procedure will also assure uniform accuracy and completeness of design detail throughout the full length of the proposed highway.

Aerial surveys permit the completion of designs and establishment of the location for years-in-advance procurement of rights-of-way. Thus, the costs of right-of-way will be reduced while continuity is attained along each highway location from one terminal point or intermediate objective to another, and inconsistencies which usually result from a piecemeal approach are avoided.

All of the specialists on the highway engineering team can use aerial surveys in their work and in correlating their contributions toward attainment of the best highways possible according to need.

Once the aerial photographs are taken and the essential ground control surveys are completed, all survey and design work can proceed without interference from the weather, or, if need be, the time of day.

Aerial surveys make seeing the whole and the parts possible while the work proceeds, such as seeing "where you were, where you are, and where you are going" all at the same time. Thus, all concerned can see and evaluate the problems, and fit the proposed highway to the topography and to the land use so it will best serve both traffic and occupants of the land. This is reduction of the engineering problems to size and continuity.

They improve the possibilities of reducing or eliminating interference with present land use by avoiding severences and using the less valuable lands.

They serve as a reliable guide for location of section lines and property lines, and for tying rights-of-way lines and other property lines together by description in the use of plane coordinate ties to ground survey markers.

They provide pictorial records in usable and permanent form for study, analysis, review, and demonstration of accomplishments whenever necessary. Thus, no factor of importance need be omitted, overlooked, or ignored.

They provide in usable form the dimensions for use in the efficient and effective, man-power saving, electronic methods of computation (1) to ascertain excavation and embankment quantities and other quantities required in design and preparation of plans, and (2) to determine pay quantities on contract construction.

They illustrate effectively problems of right-of-way, drainage, soils, grading, access and interchange, and also their proposed solutions, and the finished results.

They reduce time-consuming reconnaissance surveys on the ground by enabling engineers to bring the topography and land use into the office for intensive and extensive examination and evaluation.

They make determination and comparison of feasible route alternatives easy to accomplish in a reliable and factual manner. This is also true for alternate locations along the band of topography comprising the best route. Such accomplishments are possible because the location and design engineers are supplied with the means for obtaining a three-dimensional concept, including the alignment, profile, cross-sections, and directionality, of all highway location possibilities all along each feasible route.

They assure that the best route and the best location on that route have been determined through full consideration of every aspect of the controls of location and design presented by the topography, soil and ground conditions, drainage, erosion or the possibilities of it, directionality, length, rise and fall; costs of right-of-way, construction, maintenance, and vehicle operation on the proposed highway; and service to traffic and occupants of the land.

Every highway engineering organization, through the impetus of the expanded highway program, now has greater interest in and more willingness to accept and use aerial surveys than ever before. Reasons for this favorable situation are the realization that the usual and outmoded survey methods on the ground are inadequate, slow, require more surveyors and engineers than available, and lack the scope of coverage and detail essential for attainment of all that is desired. Aerial surveys when properly and fully used are the means to overcome the difficulties of such circumstances.

Aerial surveys are effective and efficient methods of making condition and inventory surveys.

Results attained by full use of photogrammetry and aerial surveys are much better than those attained by ground surveys only.

DIFFICULTIES

Although the future is bright for these relatively new methods of surveying, there are some difficulties yet to be overcome. The photogrammetric engineering firms will be affected by a shortage of engineers with sufficient training and experience to do their surveying and to operate their photogrammetric instruments. Some highway departments now lack engineers with enough training and experience in the use of aerial surveys to utilize fully the services of qualified photogrammetric engineering firms. The national network of basic ground control surveys needs expansion, and it will take time for the U. S. Coast and Geodetic Survey to extend this network near and along the national system highways. Mistakes will probably be made, as all aerial surveys undertaken will be performed by people and instruments, and both are not yet infallible.

Equipment, Methods and Standards of Accuracy Applicable to Aerial Surveys

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This paper is a discussion of the various methods of using aerial surveys and maps compiled by photogrammetric methods in highway engineering investigations. Scales of photographs, mosaics, and maps for different purposes are discussed, along with horizontal and vertical accuracy requirements.

The paper briefly reports on an investigative study that is being made for the State Highway Department of Indiana to develop directly from large-scale aerial photographs bridge site topographic maps at a scale of 30 ft per in. Equipment considerations are presented for a proposed photogrammetric system which will include an aerial camera, processing laboratory, and photogrammetric plotters.

● THE purpose of this paper is to give thought to, with a view to purshasing, accepting or adopting aerial surveys for different purposes. In these considerations it is necessary to discuss equipment, methods, and standards of accuracy as well as the purposes for which the aerial surveys are to be used.

Aerial surveys are used for many purposes, but for the highway engineering profession they may be grouped under three major headings: Reconnaissance of area to determine feasible route alternatives, reconnaissance of alternate routes to ascertain the best, and preliminary survey of the best route for design of the location and preparation of construction plans. Under each of these headings the product of the aerial survey, the aerial photograph, a perspective projection and/or the photogrammetric map, an orthographic projection compiled by photogrammetric methods, has many uses, such as, land use studies, soil studies, drainage studies, right-of-way studies, and geometric design studies, which would include earth-work computations. The techniques of how to make these various studies are beyond the scope of this paper, as innumerable articles are available in technical journals of the American Society of Photogrammetry, the American Congress on Surveying and Mapping, the American Society of Civil Engineers, and the Highway Research Board. Highway engineers should research these articles and determine the techniques that are applicable within their field of interest.

AERIAL SURVEYS

Aerial surveys are considered to be of three types: (1) individual photography, including vertical and oblique; (2) photographic mosaics, including uncontrolled or controlled; and (3) topographic maps with contours at 1-, 2-, and 5-ft intervals, and also planimetric maps and large-scale cross-sections for design and preparation of plans.

There are three methods available for making such aerial surveys. One method is by contracting with photogrammetric companies for the particular type of survey desired. This method requires the compilation of a set of specifications for the end product desired—aerial photography, photographic mosaics, and topographic maps or planimetric maps with profile and cross-sections, or any combination of the three. To assist the highway engineer in specification writing, the Committee on Photogrammetry for Highways sponsored by the American Society of Photogrammetry, and the American Congress on Surveying and Mapping, have prepared a Reference Guide Outline, which may be obtained at nominal cost from the Superintendent of Documents (1). This method has the advantage that it, in effect, increases the productivity of a highway department without increase in personnel.

A second method for obtaining aerial surveys is to contract for the photography and preparation of mosaics, and within the framework of a preliminary engineering section of the highway department to photogrammetrically prepare the maps desired. Production is controlled by the ability of the highway department to plan projects so that advantage can be taken of seasonal conditions to secure all the necessary photography for six to eight months of operation.

The third method is to have an aerial engineering section fully equipped with an airplane, camera, photographic processing facilities and photogrammetric instruments to perform the complete operation. This method has the advantage that the highway department has complete control over the procedures. Production is limited by the number and type of photogrammetric instruments and the availability of trained personnel.

Area Reconnaissance

Most of the state highway departments use aerial photographs in the various steps of area reconnaissance to determine route alternatives. A practical combination is to use Department of Agriculture photographs at an approximate scale of 1: 20,000 in conjunction with the 7½-min National Topographic Quadrange Series of maps enlarged to the scale of the photographs. The only equipment necessary for area reconnaissance using available aerial photographs is a simple lens stereoscope or, if preferred, a mirror stereoscope with binocular attachment. Uncontrolled photographic mosaics of a large area can be assembled by matching vertical photographs in a flight line for use in area reconnaissance, and the seeable portion of each individual photograph in this mosaic, when matched with and oriented to the auxiliary stereoscopic mate photograph, is easily observed by use of the lens or mirror stereoscope.

If the existing governmental photography of the area of survey is over 6 to 10 years old it would be advisable to obtain for the area reconnaissance survey new photography of the area of interest. This new photography should be obtained at a scale ranging between 1,500 to 2,500 ft per in. Since land use, drainage, urban areas, and general topography are the major controls and since these vertical photographs would not be used for topographic mapping in making the area reconnaissance survey, the photographs could be obtained with a 12-in. focal length camera if desired. Such long focal length photography is especially useful of rugged mountainous regions and large cities where the streets are narrow and buildings are tall.

To assist in area reconnaissance, especially in areas that are deficient in topographic map coverage of the 7½-min series, it would be practical to purchase two sets of stereoscopic photography coverage, one for the development of uncontrolled photographic mosaics using 7½- min quadrangle as the size, and the other for stereoscopic examination. The mosaics could be prepared at an approximate scale of 1: 20,000 by using available governmental photography and existing ground control. Mosaics would be assembled from the strips of photographs by using the effective coverage of each individual photograph fitted on flight-line to the adjacent photographs, and then scale adjusting each strip in line of flight. The mosaic would then be copied photographically and printed to a scale of 1: 24,000. It probably would not be possible to obtain scale-ratioed photographs from the governmental agencies for development of controlled mosaics, but even without the ratioed prints a good uncontrolled photographic mosaic for area reconnaissance survey purposes could be assembled if local relief is not too great.

Such mosaics would be invaluable in all phases of engineering in both area reconnaissance and reconnaissance of alternate routes. Watershed areas and land use could be determined with ease. Urban and rural land use would be shown in detail, and the mosaics would be an invaluable aid in determining feasible highway routes in a minimum of time, while the other set of photographs is thoroughly examined stereoscopically.

These photographic mosaics could be prepared very economically, because fairly recent photographic coverage is available of most areas. Experienced assistants, after proper training, could be used by the highway department to prepare these mosaics, or photogrammetric engineering firms might be interested in preparing the mosaics on a state-wide basis. The cost of this mosaic preparation could be recovered by sales to other interested parties.

The uncontrolled photographic mosaics would not be maps, as all photographic images not on a level plane are displaced perspectively from an orthographic position; this displacement is especially large in areas of high local relief. The mosaics should be annotated to show plane coordinate grid lines, and the grid should be plotted to an accuracy of 1/50 in. or better at the scale of the mosaic. Position of photograph images should be accurate to at least 1/5 in. of true coordinate position. Accuracies of this type enable the highway engineer to select the controlling points of various alternate routes for a highway in moderate relief to within practical working limits on a reconnaissance survey basis.

Preliminary Survey of Best Route

Medium-scale aerial photographs of the highway route, the uncontrolled photographic mosaics, and topographic strip maps are required for the preliminary survey and design of the location. The general practice in rural areas is to have route photographs taken at a scale of about 1,000 ft per in. with a 6-in. focal length camera or 800 ft per in. with an 8¼-in. focal length camera. In commercial practice the 6-in. focal length is generally used. Vertical photographs at these scales are used in the photogrammetric plotter to map at a manuscript scale of 200 ft per in. annotated with contours at a 5-ft interval. In highly developed areas, the accepted practice is to obtain photographs at a scale of 500 ft per in. or 400 ft per in. with 6-in. or 8¼-in. focal length cameras, respectively. The topographic map then may contain a strip of terrain up to ½ mi wide at a scale of 100 ft per in. annotated with contours at a 2-ft interval.

It should be understood that the various photogrammetric plotters in this country are usable for mapping at manuscript scales ranging from three to ten times the scale of the photography—the scale enlargement. The scale enlargement combined with the contour interval desired determine, to a large extent, the taking scale of the preliminary survey route photography. Negative scales smaller than 1,000 ft per in. do not provide the detail that is needed by the engineer in making the preliminary survey, especially in urban areas, even though these smaller scales may be used on some photogrammetric plotters to prepare an accurate topographic map with contours at a 5-ft interval. If only the topographic map is to be used in the preliminary survey and design of the location, then the scale of the photography is controlled by the photogrammetric compilation system. In highway engineering, both the maps and photographs are needed in making the preliminary survey; therefore, the taking scale of the photographic negative is an important item. Often it is desirable to take the photography at scales of 600 or 800 ft per in., compile the maps at a scale smaller than 200 ft per in., and then by scale enlargement techniques reproduce the map for use at the 200 ft to 1 in. scale.

In preliminary survey and design it is advisable to secure low oblique photographs in conjunction with vertical photography. Low oblique photographs should be secured at a ratio of 5:1 or 10:1 with respect to each vertical along the line of flight. The low obliques taken from the nose of the aircraft should be secured with a 12-in. focal length aerial camera. They will present a perspective view that will assist greatly in analysis of the preliminary survey location, and in presentation of data, especially in highly developed areas or at proposed interchanges.

Aerial vertical photographs for stereoscopic examination and for compilation of strip topographic maps at a scale of 200 ft per in. or 100 ft per in. in the preliminary survey stage should be secured with a precision cartographic camera of the proper focal length. The distortion characteristics of the camera lens should be known, and, if necessary, compensating distortions should be designed into the photogrammetric plotter to reduce all distortions to an absolute minimum. These items would not be important to the highway department that contracts for all photogrammetric work, but to the highway department that buys photography these items can make or defeat the over-all photogrammetric system. The specifications for photography in this case should include maximum and minimum values of distortion or a description of the distortion correction system, and require a Bureau of Standards or other testing agency report to compare the systems. If the camera used for photography has different distortion characteristics than can be compensated by the photogrammetric plotter, a delay will ensue while corrections are made to the plotter.

The accuracies of aerial photographs, photographic mosaics, and topographic maps compiled by photogrammetric methods with an appropriate contour interval for the preliminary survey are sufficient for the highway design, and the maps are as accurate as maps compiled by any other methods, and are all within practical working limits. The general accuracy requirement for contours is that 90 percent of the elevations determined from the solid line contours shall not vary from true elevation by more than one-half contour interval. The remaining 10 percent should not vary more than a full contour. In heavily wooded areas the contours should be dashed, and their accuracy should be such that 90 percent of the elevations determined from the dashed-line contours would be correct to one contour interval or one-fourth the average height of the ground cover, whichever is the greater (1). In dense wooded areas it would generally be necessary to survey by field methods especially in coniferous regions. The State plane coordinate grid, adjusted to result in true distances at the average elevation of the survey project by scale without need for any correction, should be an essential part of the map and should be accurately plotted to within 0.01 in. of true grid value. Selected horizontal control points measured in the field also should be accurately plotted to within 0.01 in. of true position. Planimetric details should be within 0.02 in. of true position when measured to the nearest grid, and spot elevations on the map should be accurate to one-fourth the contour interval.

Ground control is an essential part of any survey made photogrammetrically. Horizontal and vertical control monuments should be placed at intervals along the route survey so that they may be recovered by field crews. The interval for horizontal control should be about 1,000 ft for preliminary surveys, and points should be referenced to the state plane coordinate system adjusted to apply at the average elevation of the survey project. These points should be advantageously located so that the designed center line (L-line for the highway) can be located on the ground to within a few feet of true position. The lateral tolerance used on the Ohio Turnpike was 10 ft (4). With good ground control a mathematical solution of the location can be developed for preliminary staking in the field, with final adjustment made by the field location engineer.

The Designed Location

The application of photogrammetry and aerial surveys to design of the highway location is the ultimate development for which highway engineers are searching. This requires the accurate measurement of all possible details for preparation of construction plans, including estimation of earthwork quantities, final measurement of earthwork quantities (if necessary), and procurement of right-of-way. In some cases, certain phases of this ultimate utilization of aerial surveys have been reached, as reported in California, Ohio and Pennsylvania (4, 5, 8, and 12).

One method of developing the preliminary design of the highway location is to survey in the field the center line as determined by the preliminary survey at 200 ft to 1 in. scale, as discussed previously. Center line profiles are obtained after necessary adjustments are made to fix the positions of tangent intersections. If ground detail is insufficient, control points along this line are then signalized by the use of cloth, lime, paint or other contrasting material that will photograph from the air. A flight line to produce route photography at a scale of 250 or 200 ft per in. for 6-in. or 8¼-in. photography, respectively, is made. Glass diapositives made from this photography are used to plot planimetric maps along the preliminary center line at a scale of 50 ft per in. These same diapositives are then used to develop spot elevation information for use in plotting cross-sections. Under ideal conditions when vegetation is low or nonexistant, it is reported that photogrammetric spot elevations are accurate to ± 0.2 ft (3). Under average conditions the vertical accuracy is ± 0.5 ft, even though the photogrammetric readings are interpolated and recorded to 0.1 ft of elevation using a foot-reading plotting table. Horizontal accuracies are of the order of 1 to 2 ft measured at a map compilation scale of 50 ft to 1 in.

The L-line location is then resolved by making a paper location using the planimetric map, contact prints of the photographs, and cross-sectional information. This location is made to fit the natural ground and cultural conditions, and other geometric considerations. The large scale of these items enables the engineer to select the controls for this L-line, construction plan location of the highway. Frequently the scale of this paper projected location is then reduced, using a process camera, to a scale of 100 ft to 1 in. and traced to produce road plans.

In some cases the preliminary location is not surveyed in the field, but is used only as a flight plan to secure large-scale photographs for preparation of topographic maps at a scale of 50 ft per in. with contours at 1- or 2-ft intervals. In this case, the engineer uses these large-scale topographic maps to refine further the location before it is actually staked on the ground. This method does not necessarily require the measurement of spot elevations for cross-sections. Various location alternatives are projected on the maps and are studied by measuring cross-sections from the contours or by drawing the proposed grading contours of cuts and fills and measuring volumes of the horizontal slices, pyramids, and wedges produced. Approximately the same accuracies are achieved by this method as before, and both methods should produce earthwork estimates within 2 to 5 percent of the estimates determined by normal field procedures.

Another application of aerial surveys and photogrammetry to highway design is in the field of site plan preparation. Stream crossings, grade separations, interchanges and other items requiring site plans at scales of 20 to 50 ft per in. fall in this category. These site plans are prepared with contour intervals of 1 or 2 ft. The minimum ground control necessary for surveys of this type is four vertical control points and two horizontal control lines for scale for each stereoscopic pair of aerial photographs. A rapid method of determining the horizontal control is by the use of a 2-meter subtense bar and a second-reading theodolite.

Some agencies prepare these site plans at scales of 40 or 50 ft per in. in photogrammetric plotters and then enlarge these photographically to scales of 20 ft per in. In this manner map compilation and drafting inaccuracies are increased by the amount of the enlargement.

The Indiana State Highway Department generally prepares site plans at a scale of 30 ft per in. The Joint Highway Research Project at Purdue University is investigating the possibility of preparing these maps from aerial photographs secured at a scale of approximately 150 ft per in. with a 6-in. Metrogon precision mapping camera. For this project the photography and diapositive plates were secured by contract.

The glass diapositives 0.06 in. thick are printed emulsion to emulsion for projection with the emulsion side up, and are projected in a Kelsh stereoscopic plotter at a 5-diameter enlargement for map compilation at a map manuscript scale of 30 ft per in. Most of the models developed in the Kelsh stereoscopic plotter at these scales appear to be of excellent quality, and the image motion that was expected has not necessarily occurred. Photography of this type requires a very slow flying speed (80 to 100 mph), fast shutter speed, and rapid rewind cycle. Image motion greater than 0.01 in. can normally be detected, and in all probability would prohibit accurate measurements. Some difficulty has been encountered due to the inability of the vacuum system to take hold in the extremely short time between exposures. The negative is therefore not flat during the exposure cycle. This can be corrected by shortening the rewind cycle of the camera. This project is in its infancy, but at a later date it is expected that an analysis will be made of several site plans to determine vertical and horizontal accuracies.

EQUIPMENT

In consideration of equipment, it is advantageous to present the experience of the State Highway Department of Indiana as an example. The author has worked extensively with the Department in determining needs and type of equipment for the proposed development of the complete photogrammetric system. The Department has available an airplane of the twin engine type that is suitable for conversion into a photographic plane. Equipment considerations, therefore, revolved around the aerial cartographic camera, the photographic processing laboratory, and the photogrammetric plotters.

Aerial Camera

The first consideration is the focal length of the camera lens desired. The lens should be of a type that has high resolving power under the operating conditions planned and either be distortion-free or have a narrow range of distortion that can be compensated for or removed in the photogrammetric mapping system. Focal lengths may vary from 4 in. to 12 in. or more. In general, large angular field, as obtained in the shorter focal length systems, is desired because of less flying, fewer photographs, less ground control, and a higher mapping accuracy due to the larger angle between intersecting rays which indicate parallax. The 6-in. camera, as mentioned previously, is the one generally used by the photogrammetric mapping companies. Photography taken with the 8¼-in. or longer focal length lens is better for preparation of mosaics and for photographic interpretation; it is also advantageous for mapping heavily timbered areas.

The next consideration is the cycling time. Most of the work of the Department is going to be very large scale photography which requires cycling times of 2 to 3 sec at aircraft speeds of 80 to 150 mph. Most cameras recycle in 3 or 6 sec.

The cameras considered were the government surplus cameras designated K3B, K17B, K17C, and T5, and the new Fairchild T11 (11). The first three are charting cameras that must be converted to precision mapping cameras. The last two are precision topographic cameras. The information available on these cameras indicated that only the K17C 6-in. camera was equipped to re-cycle in less than 2 sec (11). This camera has a re-cycle time of 1¼ sec which would enable higher aircraft speeds for more stable flight. It was decided that the K17C converted to a 6-in. Metrogon precision mapping camera and tested for distortion characteristics by the Bureau of Standards would fulfill the expected needs of the Highway Department. Auxiliary equipment for the camera included the camera mount, extra magazines, intervalometer, dynamotor for converting to 24-v electrical system, electrical cables, and equipment for producing a vacuum for film flatness control.

Processing Laboratory

The processing laboratory is considered as a three phase system with separate darkroom facilities for film processing, print processing, and enlarging. The important pieces of equipment are film developers, film dryers, water jacketed film processing units, large stainless steel sinks and water temperature control devices for the film processing room. The print processing room requires such items as large stainless steel sinks and trays, electronic printers to control density of diapositive plates, 10-in.-by-10-in. contact printers, 4 by 5 enlarger, 40- to 60-in. diameter print washers, and large matte and gloss print dryers. The enlarging room requires large stainless steel tanks and trays, rectifying enlarger for aerial roll film 9½ in. wide, and a 24- or 36-in. process camera for copying mosaics and enlarging or reducing maps compiled by photogrammetric methods. Miscellaneous supplies for the laboratory would include diapositive plate hangers, various sizes of graduates, and 10- to 50-gal. storage tanks and mixing crocks. It is estimated that the equipment would require about 1,000 sq ft of floor area, and cost about $18,000 with some items being rebuilt units or surplus.

Actual selection of the various manufactured models of the items mentioned is naturally an economic study. Compromises are made to fit immediate needs, availability of space, and available electric current supply. This last item can be a considerable cost item in an already overloaded electric system.

Photogrammetric Plotters

There are numerous photogrammetric plotters, and each has particular advantages or applications for surveying purposes. Private photogrammetric mapping organizations or the federal mapping organizations may have a series of plotters with certain types of mapping planimetry, others topography and still others bridging control to name just a few of the applications. A few of the photogrammetric plotting instruments are listed in Table 1 along with some of the reported "C-factors" for contours and for spot elevations.

The "C-factor" is the ratio of contour interval on the topographic map to the flight

TABLE 1

PARTIAL LISTING OF PHOTOGRAMMETRIC PLOTTERS

Name	Contour C Factor	Spot C Factor
Multiplex	600-800	3,000
Balplex, ER55		
Kelsh 6 in. or 8¼ in.	850-1,000	4,250
Wild Autograph A5	1,000-1,200	5,000
Wild Autograph A6	900-1,100	4,500
Wild Autograph A7	1,000-1,200	
Wild Autograph A8	1,000-1,200	
Santoni Stereosimplex Model III	1,500-2,000 (7)	
Stereoplanigraph C7	1,200-1,250	6,000

Source of information: Manual of Photogrammetry (11) and various volumes of Photogrammetric Engineering (2, 7, 9).

height. The various plotters are assigned these relative factors based on the experience of the operator, ground control available, and field tests of prepared maps. The above factors are actually based on medium and small scale mapping projects with contour intervals of 10 and 20 ft. There is some question as to their direct application in large scale mapping as required by highway engineers. It is reported that they can be increased about 30 percent for ideal conditions and decreased at least 30 percent under unfavorable conditions where there is little photographic contrast in the ground or where the area is highly forested (9).

In the analysis of photogrammetric plotters, the volume and type of work conducted by a highway department would not justify the expenditure of large sums of money for individual first order universal type plotters. It appears more practical, with limited technicians and small equipment budgets, to have a small group of plotters all performing about the same operations. There are strong arguments against this statement. Of course, the best argument is that ground control for a photogrammetric survey is the expensive item, and to eliminate extensive ground control a first or second order instrument is needed to bridge control and to establish supplemental picture point control for topographic and planimetric mapping.

The ideal conditions are generally realized by the established photogrammetric engineering concerns. Under these conditions the photogrammetric system consists of a first order instrument to bridge and develop the base map with coordinate grid and topography and several second-order or "single model" instruments are used to plot planimetry and sometimes additional topographic details. This system is ideally suited for area mapping of a city, a reservoir or other regional mapping project, and for preliminary survey of a highway route in excess of perhaps 10 mi. It is recommended, for the types of surveys mentioned, that advantage be taken of these elaborate systems (as suggested by Section 121, Mapping, of Public Law 627—Title 1: Federal Aid Highway Act of 1956) to increase the productivity of the highway department.

The highway department can further increase its productivity by having a small but adequately equipped photogrammetric section to make preliminary surveys for design of the location and preparation of construction plans, measurement of profile and cross-sections, and survey of sites for preparation of plans for short highway sections. Using this premise it is appropriate to consider only two photogrammetric plotters of similar capabilities and of comparable price. These two plotters are the Kelsh stereoscopic plotter with either 6-in. Metrogon (wide-angle) lens or 8¼-in. normal-angle lens projectors and the Balplex plotter with ER 55 projectors using 6-in. Planigon or Metrogon photography. Each of these plotters are termed "single model" instruments as they do not lend themselves to extensive bridging applications directly by stereoscopic methods. The Kelsh stereoscopic plotter enlarges original negative scale 4 or 5 diameters, depending on focal length, and the Balplex plotter 3.4 diameters. The

Kelsh is equipped to handle 9½ by 9½-in. diapositives contact printed; the Balplex is equipped to handle 4- by 4-in. diapositives that are prepared in a special reduction printer. One reduction printer may serve several Balplex just as the special electronic printer mentioned previously will serve several Kelsh plotters. Of course, the special electronic printer is not absolutely necessary as a much more economical contact printer will suffice, although prints and diapositives will not be as uniform in quality unless made by a highly skilled darkroom technician.

In analysis of the needs in Indiana for use in conjunction with the K17C 6-in. Metrogon precision mapping camera it was decided that the 6-in. Kelsh stereoscopic plotter with a 5-diameter enlarging factor fulfilled the requirement. Three Kelsh plotters appear to serve the immediate needs. One plotter will serve the Road Location Department, another the Bridge Location Department and the third will be used by the Joint Highway Research Project to handle overflow and to investigate additional applications and limitations.

It is expected that the research applications will be developed by graduate civil engineering students, and the instrument will also be used to assist in training plotter operators for the central office. The plotter located at Purdue will also be used on the undergraduate level in transportation and surveying courses to keep the future highway engineers cognizant of modern mapping methods, applications, and limitations.

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Relationships in Contour Interval, Scales, and Instrument Usage*

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● FOR large-scale preliminary survey mapping it should be stressed that map specifications should result in an economical and efficient balance between map scale and contour interval and the photogrammetric instrument. The considerations which must be made in writing specifications to attain this balance are the focal length of the aerial camera and photogrammetric instrument, the optimum number of times the map manuscript scale (expressed as an enlargement ratio) may be larger than the scale of the aerial photographs, and the C-factor customarily employed for the instrument. Such considerations affect the flight height for the photography, and the flight height will be governed by either the instrument C-factor or enlargement ratio whenever the specified contour interval and map scale are not in balance.

Tables 1, 2, and 3 show the manner in which the flight height is governed by the requirements to attain either the specified map scale or the required contour interval, according to the characteristics of various photogrammetric plotting instruments commonly used in the United States. The 8¼-in. and 6-in. focal length Kelsh stereoscopic plotters with a 5:1 and 7:1 enlargement ratio, respectively, are new instruments presently available. They allow map compilation at scales larger than possible with the older Kelsh instruments of the same focal length.

The flight height listed in column 6 of Tables 1, 2, and 3 will assure compliance with the map scale specification, and the flight height listed in column 9 will assure compliance with the contour interval specification. If the specifications are in proper balance, as for the Kelsh 6-in. focal length and 5:1 enlargement ratio in Table 2, both map scale and contour interval specifications will be complied with at the same flight height. If the specifications are not in proper balance, the flight heights in columns 6 and 9 will be different, and the photographs must be taken at the lower of the two flight heights in order to assure compliance with both specifications.

In all cases, it is assumed that the map compilation scale will be no smaller (but may be larger) than the scale specified for the finished map—that is, no enlargement of map manuscript to produce the finished map is allowed.

The resultant minimum contour interval (column 7 under the requirements to fulfill map scale specifications in Tables 1, 2, and 3) is the minimum contour interval attainable by use of the customary C-factor when the photographs are taken from the flight height (column 6) which will assure compliance with the map scale specifications. If the resultant minimum contour interval is less than specified for the contours, a flight height must be used which is governed by the requirements to fulfill the map scale specifications. If the minimum interval attainable using photographs taken from this flight height would be greater than specified for the contours ([1] column 7, Tables 2 and 3), then the contour interval specifications govern and the photographs must be taken from the flight height (column 9) required to fulfill the contour interval specifications while using the customary C-factor.

The resultant manuscript scale (column 10 in Tables 1, 2, and 3), is the map compilation scale fixed by the instrument enlargement ratio (column 3, number of times map manuscript scale is larger than the photography scale), and the scale of photographs (column 8) taken from the flight height (column 9) required to fulfill the contour interval specifications when the customary C-factor is used. Thus, if this resultant scale is larger than the specified scale, the specified contour interval governs the flight height. If the resultant scale would be smaller than the specified scale ([2] column 10, Tables 1 and 2), then map scale governs, and the photographs must be taken from the flight height required to fulfill the map scale specifications. In all cases, the ac-

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TABLE 1

Map Specifications Scale 100 ft to 1 in
Contour Interval 5 ft

Photogrammetric Instrument	Instrument Characteristics			Requirements to Fulfill Map Scale Specifications			Requirements to Fulfill Contour Interval Specifications If Customary C-Factor Is Used		
(1)	Focal Length, in (2)	Enlargement Ratio (3)	C-Factor Customarily Employed (4)	Photograph Scale, ft to 1 in. (5)	Flight Height, ft (6)	Resultant Minimum Contour Interval, ft (7)	Photograph Scale, ft to 1 in. (8)	Flight Height, ft (9)	Resultant Manuscript Scale, ft to 1 in (10)
Multiplex aeroprojectors	6	2 4 1	600	240	1,440	2. 40	500	3,000	208[2]
Balplex stereoscopic plotter	6	3. 4 1	1,000	340	2,040	2. 55	833	5,000	245[2]
Kelsh stereoscopic plotter	8¼	4. 1	1,000	400	3,300	3 30	606	5,000	152[2]
Kelsh stereoscopic plotter	6	5. 1	1,200	500	3,000	2. 50	1,000	6,000	200[2]
Kelsh stereoscopic plotter	8¼	5. 1	1,000	500	4,125	4 12	606	5,000	121[2]
Kelsh stereoscopic plotter	6	7 1	1,200	700	4,200	3 50	1,000	6,000	143[2]
Stereocartograph, Model IV Autograph, Models A5 and A7	8¼	8 1	1,500	800	6,600	4. 40	909	7,500	114[2]
Stereocartograph, Model IV Autograph, Models A5 and A7 Stereoplanigraph, Model C8	6	8. 1	1,500	800	4,800	3. 20	1,250	7,500	156[2]

TABLE 2

Map Specifications Scale 200 ft to 1 in.
Contour Interval 5 ft

Photogrammetric Instrument	Instrument Characteristics			Requirements to Fulfill Map Scale Specifications			Requirements to Fulfill Contour Interval Specifications If Customary C-Factor Is Used		
(1)	Focal Length, in (2)	Enlargement Ratio (3)	C-Factor Customarily Employed (4)	Photograph Scale ft to 1 in. (5)	Flight Height, ft (6)	Resultant Minimum Contour Interval ft (7)	Photograph Scale, ft to 1 in (8)	Flight Height ft (9)	Resultant Manuscript Scale ft to 1 in. (10)
Multiplex aeroprojectors	6	2 4 1	600	480	2,880	4. 80	500	3,000	208[2]
Balplex stereoscopic plotter	6	3 4 1	1,000	680	4,080	4 08	833	5,000	245[2]
Kelsh stereoscopic plotter	8¼	4. 1	1,000	800	6,600	6. 60[1]	606	5,000	152
Kelsh stereoscopic plotter	6	5. 1	1,200	1,000	6,000	5 00	1,000	6,000	200
Kelsh stereoscopic plotter	8¼	5. 1	1,000	1,000	8,250	8 25[1]	606	5,000	121
Kelsh stereoscopic plotter	6	7 1	1,200	1,400	8,400	7. 00[1]	1,000	6,000	143
Stereocartograph, Model IV Autograph, Models A5 and A7	8¼	8 1	1,500	1,600	13,200	8 80[1]	909	7,500	114
Stereocartograph, Model IV Autograph, Models A5 and A7 Stereoplanigraph, Model C8	6	8. 1	1,500	1,600	9,600	6 40[1]	1,250	7,500	156

TABLE 3

Map Specifications: Scale 100 ft to 1 in.
Contour Interval 2 ft

Photogrammetric Instrument	Instrument Characteristics			Requirements to Fulfill Map Scale Specifications			Requirements to Fulfill Contour Interval Specifications If Customary C-Factor Is Used		
(1)	Focal Length, in. (2)	Enlargement Ratio (3)	C-Factor Customarily Employed (4)	Photograph Scale, ft to 1 in. (5)	Flight Height, ft (6)	Resultant Minimum Contour Interval ft (7)	Photograph Scale, ft to 1 in. (8)	Flight Height, ft (9)	Resultant Manuscript Scale, ft to 1 in. (10)
Multiplex aeroprojectors	6	2 4· 1	600	240	1,440	2 40[1]	200	1,200	83
Balplex stereoscopic plotter	6	3. 4. 1	1,000	340	2,040	2. 55[1]	333	2,000	98
Kelsh stereoscopic plotter	8¼	4 1	1,000	400	3,300	3. 30[1]	242	2,000	60
Kelsh stereoscopic plotter	6	5. 1	1,200	500	3,000	2 50[1]	400	2,400	80
Kelsh stereoscopic plotter	8¼	5. 1	1,000	500	4,125	4. 12[1]	242	2,000	48
Kelsh stereoscopic plotter	6	7 1	1,200	700	4,200	3 50[1]	400	2,400	57
Stereocartograph, Model IV Autograph, Models A5 and A7	8¼	8 1	1,500	800	6,600	4 40[1]	364	3,000	46
Stereocartograph, Model IV Autograph, Models A5 and A7 Stereoplanigraph, Model C8	6	8· 1	1,500	800	4,800	3. 20[1]	500	3,000	62

TABLE 4

CONTOUR INTERVALS AND MAP SCALES IN BALANCE FOR EFFICIENT USE OF PHOTOGRAMMETRIC INSTRUMENTS

Photogrammetric Instrument	Instrument Characteristics			Balance of Contour Interval and Map Scale			
(1)	Focal Length in (2)	Enlargement Ratio (3)	C-Factor Customarily Employed (4)	Map Scale for 1 ft Contour Interval, ft to 1 in. (5)	Map Scale for 2 ft Contour Interval, ft to 1 in (6)	Map Scale for 5 ft Contour Interval, ft to 1 in (7)	Map Scale for 10 ft Contour Interval, ft to 1 in. (8)
Multiplex aeroprojectors	6	2 4.1	600	40	80	200	400
Balplex stereoscopic plotter	6	3 4.1	1,000	50	100	250	500
Kelsh stereoscopic plotter	8¼	4.1	1,000	30	60	150	300
Kelsh stereoscopic plotter	6	5.1	1,200	40	80	200	400
Kelsh stereoscopic plotter	8¼	5 1	1,000	25	50	125	250
Kelsh stereoscopic plotter	6	7.1	1,200	25	50	125	250
Stereocartograph, Model IV Autograph, Models A5 and A7	8¼	8:1	1,500	20	40	100	200
Stereocartograph, Model IV Autograph, Models A5 and A7 Stereoplanigraph, Model C8	6	8.1	1,500	30	60	150	300

tual map compilation scale would be rounded off to the nearest usable scale in feet per inch. In doing this, projection distance tolerances of the instrument lenses would not be exceeded in the mapping operations.

Lack of proper balance between map scale and contour interval specifications will result in inefficient use of photogrammetric plotting instruments. Thus, in compliance with the specifications governing in Table 1, there is not full utilization of the instrument C-factor, because the resultant minimum contour interval attainable (column 7) is less than the specified contour interval when the photographs are taken from the flight height (column 6) governed by the requirements to fulfill the map scale specification.

In compliance with the contour interval specifications in Table 3 there is not full utilization of the instrument enlargement ratio (column 3) when the photographs are taken from the flight height (column 9) governed by the requirements to fulfill the contour interval specification using the customary C-factor.

Table 4 contains map scales in economically efficient balance for contour intervals of 1, 2, 5, and 10 ft and the various photogrammetric instruments. The map scales have been recorded in arithmetical values which will not cause the customary C-factor to be exceeded when the contours are delineated. It is realized that some of the map scales, such as 125 or 250 ft to the inch, are not in common use, and that in actual practice a scale of 100 or 200 ft to the inch would be used. Any variation from the balance given, however, reduces the efficiency of the plotting instrument. For any specific contour interval in Table 4, specification of a map scale larger than listed for that contour will cause the map scale to govern the flight height, and the C-factor actually used will be smaller than the C-factor customarily employed. Specification of a map scale smaller than listed for each contour interval will cause the interval to govern the flight height, and then a scale reduction (photographically, by pantograph, or some other suitable method) from the optimum scale afforded by the enlargement ratio of the photogrammetric instrument will be necessary.

Applications of Photogrammetry to the Location And Design of Freeways in California

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Aerial photographs are used in practically all of the stages of freeway planning and design in California. Among the uses mentioned for contact prints, enlargements, and mosaics are preliminary location studies, project reports, public meetings, study of design details, determination of drainage areas, materials investigations and right-of-way appraisal, negotiation and condemnation. Data are presented showing the extent to which aerial photographs have been used for route studies in a typical northern California highway district.

Where more specific information is required for route studies, the aerial photographs are supplemented by topographic maps. In areas where they are available, U. S. Geological Survey quadrangel maps will frequently suffice. In other cases reconnaissance-type mapping is obtained by contract. After the general location of the freeway is determined photogrammetric mapping, usually at a scale of 1 in. = 50 ft with 2-ft contours, is obtained for detailed design work. Accurate, adequately monumented control surveys for use in conjunction with the topographic mapping are an important feature of California practice. Specification requirements and other scales of mapping for design use are discussed.

The use of electronic computers for the calculation of earthwork quantities has largely superseded other methods. Terrain and roadbed notes similar to conventional survey notes are prepared by the designer for machine computation. Data for terrain notes are obtained from the large-scale photogrammetric maps. Changes in line or grade can be made by designating horizontal or vertical shifts of the roadbed notes. A few sample cross-sections for illustrative purposes are plotted as required usually at a small scale. Preliminary quantities from aerial contour maps have generally agreed with final quantities within less than 2½ percent. Substantial savings in cost and manpower through the use of photogrammetric mapping and electronic computers are reported.

● IN discussing photogrammetry as related to the location and design of freeways, it is convenient to classify the photogrammetric products used into three types: aerial photographs, reconnaissance mapping, and design mapping. The latter two are used in the stages of a highway project which their names indicate, while the first is used in practically every stage of planning, location, design, and acquisition of rights-of-way.

There are very few freeway projects in California where aerial photographs in the form of contact prints, enlargements, or mosaics do not play an important part. The requirements of a particular project frequently necessitate obtaining several different photographic flights at scales ranging from as small as 1 in. = 3,000 ft to as large as 1 in. = 200 ft. During the period from July 1, 1955 to June 30, 1956, the California Division of Highways contracted for over $80,000 worth of aerial photography in addition to that obtained in connection with topographic mapping.

Preliminary Stages

In the early stages of a project, contact prints are examined stereoscopically to select alternate routes for further study and to determine which of those routes is the best. The small scales (1 in. = 800 ft to 1 in. = 2,000 ft) are generally used in rural areas where there is little development or where a wide band of alternate routes must be considered, while larger scales (1 in. = 400 ft to 1 in. = 600 ft) are used in urban areas. If the project is in mountainous terrain, requiring an approximate profile for preliminary study, the contact prints are used with a stereoscope and parallax bar to determine relative elevations.

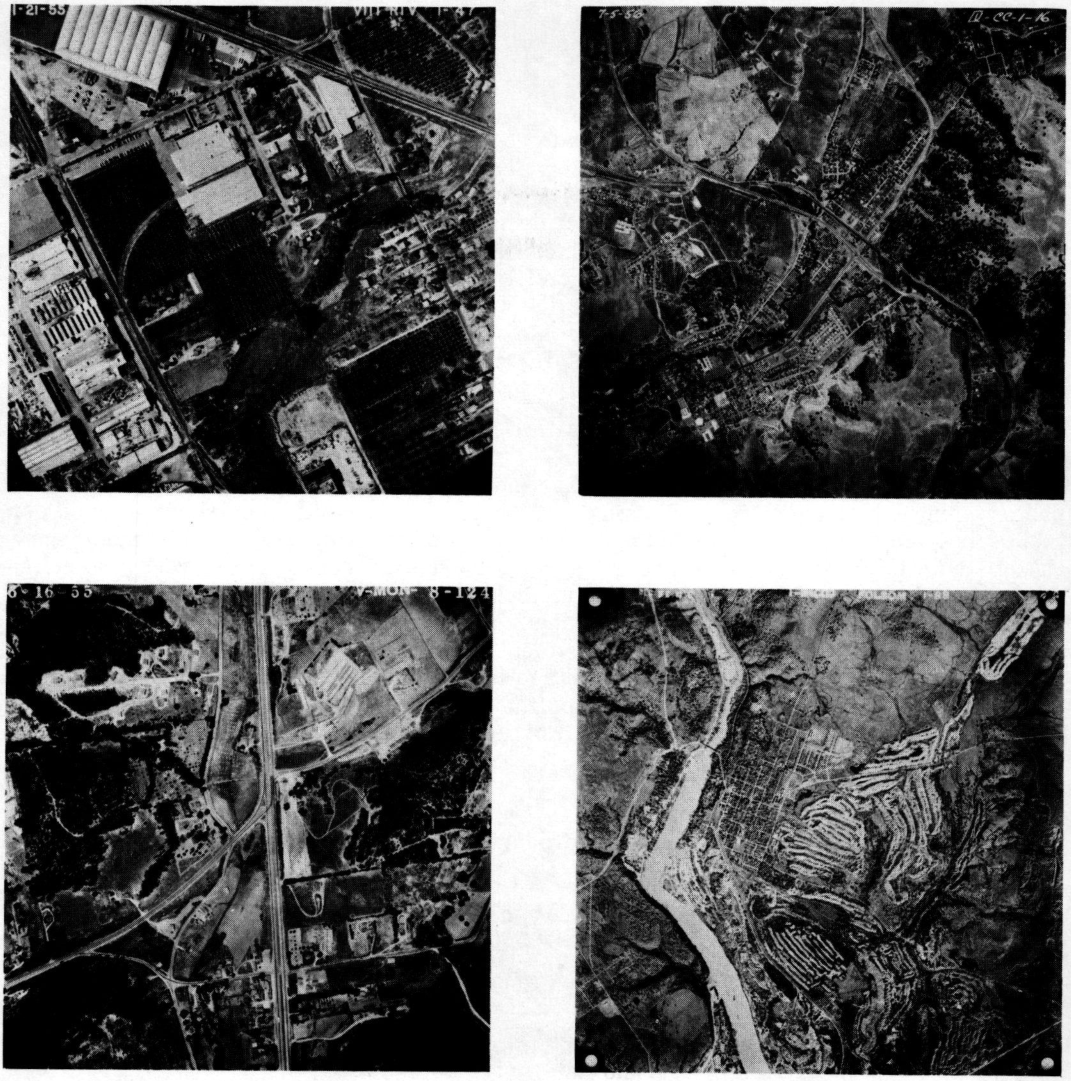

Figure 1. Contact prints at some of the scales being used for freeway planning and design. Scales of original photographs: upper left, 1 in. = 250 ft; lower left, 1 in. = 400 ft; upper right, 1 in. = 1000 ft; lower right, 1 in. = 2000 ft.

Small-scale contact prints or enlargements provide the best possible medium for the study of access conditions and tentative interchange locations, while larger-scale photographs are invaluable for making right-of-way estimates. Diazo prints of mosaics, showing the various alternate routes and locations of proposed interchanges, are used in practically all reports which summarize route studies on a particular project.

Public Meetings

A very important phase in the planning of the freeway program is the holding of public meetings and hearings on every project involving even minor relocation. Aerial photographic mosaics, showing the routes under consideration and proposed interchange locations, are considered an absolute necessity for such meetings. The mosaics are generally of the semi-controlled type with a rather low order of accuracy. Scales used range from 1 in. = 200 ft to 1 in. = 1,000 ft, depending on the size of the project and the extent to which the area is developed. The photographs are also useful for discussions with individuals concerning specific property and proposed freeway locations.

Design

In the design stage, study of large-scale contact prints or enlargements gives the squad leader and the designer an added knowledge of the project which could not be obtained in any other way. They also serve to reduce greatly the number of field trips which would otherwise be required. As it is impossible to show all of the detail available from the photographs on a topographic map, the designer frequently uses diazo prints made from positive enlargements on film to lay out and study tentative interchange designs and other details.

Contact prints, both large and small scale, are used for determining drainage areas, locating source of granular material, and for studying potential slide conditions and other foundation problems.

Right-of-Way

In the important phases of the appraisal and acquisition of rights-of-way, aerial photography is proving to be increasingly valuable. Large-scale enlargements and contact prints are used for appraisal and discussion with the property owner during negotiation, both in urban and rural areas. Where it becomes necessary to resort to condemnation, large-scale enlargements are used to show the court the details of the area to be taken and, in the case of large holdings, small-scale enlargements are used to show the relation of the proposed improvement to the entire property. Oblique aerial photographs have also been used to advantage in condemnation cases. Large-scale photography is frequently obtained on metropolitan freeway projects immediately before the start of right-of-way negotiation so it will be available for possible condemnation cases at a later date.

Location Studies

The second type of photogrammetric products, reconnaissance mapping, is used for

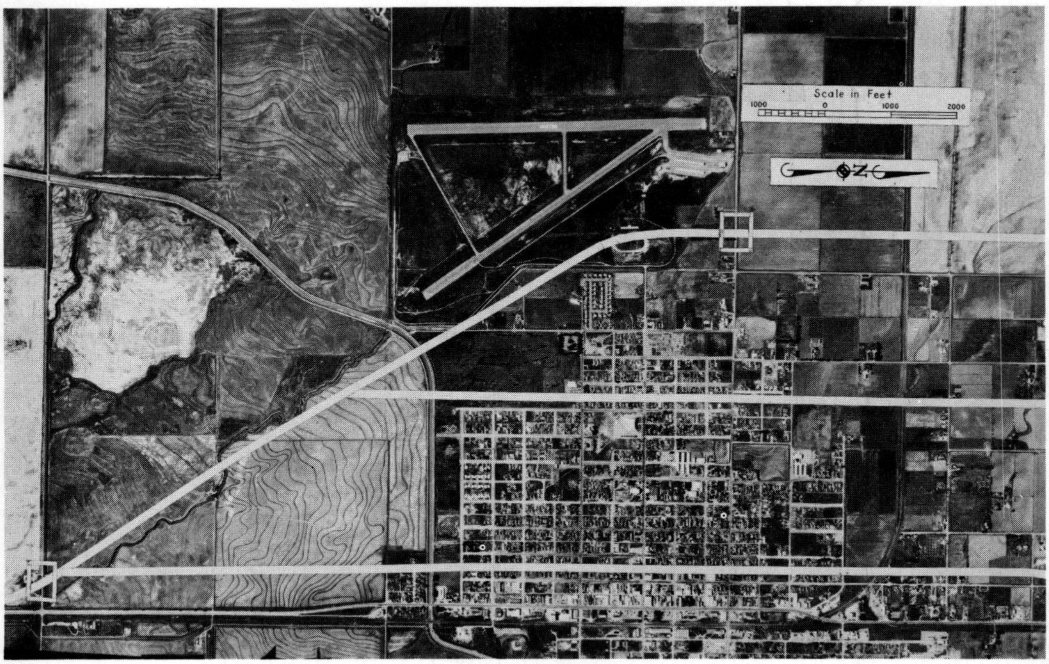

Figure 2. Several possible locations have been shown on this mosaic for a public presentation of route studies.

Figure 3. Photogrammetric mapping of this type is used for reconnaissance studies of several alternate routes in rugged terrain.

location studies where more than one possible route must be considered, where the terrain is such that excavation quantities are an important factor in the location, or where grade controls might govern. The important difference between aerial photographs and either reconnaissance or design mapping is that the latter is accurate in scale and is based on an actual field survey, with this survey being used to control the scale of the maps and the differences in elevation shown.

For reconnaissance work, the highway engineer planning to use photogrammetric mapping has a choice of several products. In areas where they are available, U. S. Geological Survey quadrangel sheets at a scale of 1 in. = 2,000 ft with contour intervals of 20 or 40 ft are one of the most effective tools of the location engineer. When used in conjunction with stereoscopic study of contact prints, the maps provide the answer to many location problems.

An excellent example of the effectiveness of aerial photography and Geological Survey quadrangle mapping in reconnaissance studies is shown by data concerning such studies in District II of the California Division of Highways, located in the extreme north-central and northeast portion of the state. In the period from August 1955 to August 1956, the District Planning Department studied the relocation of 183 miles of highway. Of this total, 123 miles were planned on either a full freeway or expressway basis. The studies involved consideration of a total of 567 miles of alternate routes of which 168 miles were in rugged terrain and included 273 bridge sites and 112 interchanges. The following tabulation shows the various methods used in the studies:

	Miles	Percent
Aerial photographs only	295	52
Photographs and U. S. G. S. quadrangle maps	125	22
Photographs and reconnaissance mapping (1 in. = 400 ft)	80	14
Other methods	67	12
Total	567	100

The fact that they were able to complete 52 percent of their studies with aerial photographs alone and an additional 22 percent with aerial photographs supplemented by Geological Survey maps is very impressive when it is considered that District II includes some of the most difficult, mountainous terrain in the state from the standpoint of freeway location.

Reconnaissance Mapping

Where conditions require a larger scale, or where U. S. Geological Survey mapping is not available, form line mapping from either existing or new photography is frequently obtained for reconnaissance work. A reasonably accurate map at 1 in. = 400 ft with 20-ft contours can be obtained from existing Commodity Stabilization Service photography at a scale of 1 in. = 1,667 ft, supplemented by a minor amount of ground control. In some cases existing road surveys or U. S. Geological Survey data will provide sufficient control. Such mapping is generally obtained on force account or plotter rental basis from mapping contractors and is usually confined to relatively small areas.

Where it is necessary to study several alternate routes covering a wide band of rugged terrain, the usual practice is to contract for reconnaissance mapping in the same manner as for design mapping. Scales used have ranged from 1 in. = 200 ft to 1 in. = 500 ft, with contour intervals of 5, 10, and 20 ft. Here again the larger scales are associated with intensive land use and the smaller scales are used in rural areas. Such a map at 1 in. = 400 ft with 20-ft contours will cover an area over 2 miles in width with a single strip of photography.

The use of reconnaissance mapping has practically eliminated the necessity for making preliminary field surveys of several alternate routes in order to determine the best location. Such mapping has been obtained for conditions ranging from metropolitan freeways in the larger cities to freeway relocations in the mountainous and heavily-timbered regions of northern California.

Design Mapping

After the route of the highway has been determined within rather close limits by one of the methods previously discussed, the next step is to obtain large-scale, small contour interval, photogrammetric mapping for detailed design of the freeway facility. The mapping is usually confined to a single strip of photography and is from 1,000 ft to 1,500 ft in width to allow for minor adjustments in the exact location. Additional width is frequently obtained at traffic interchanges. The scale found suitable for most conditions is

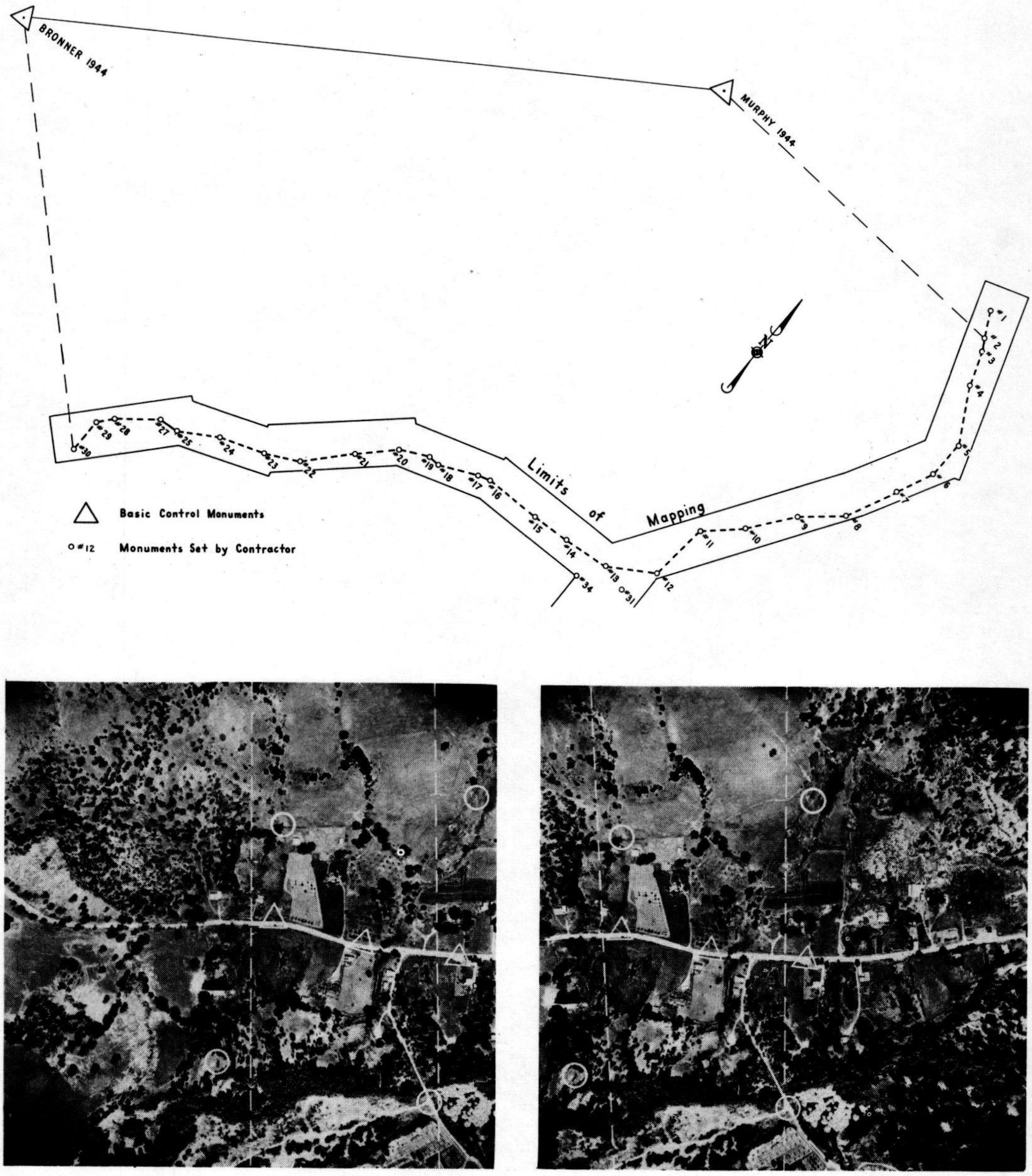

Figure 4. The primary ground control survey for an 8-mi design mapping project is shown in the upper diagram. The overlapping aerial photographs below illustrate the photo control points established for one of the stereoscopic models.

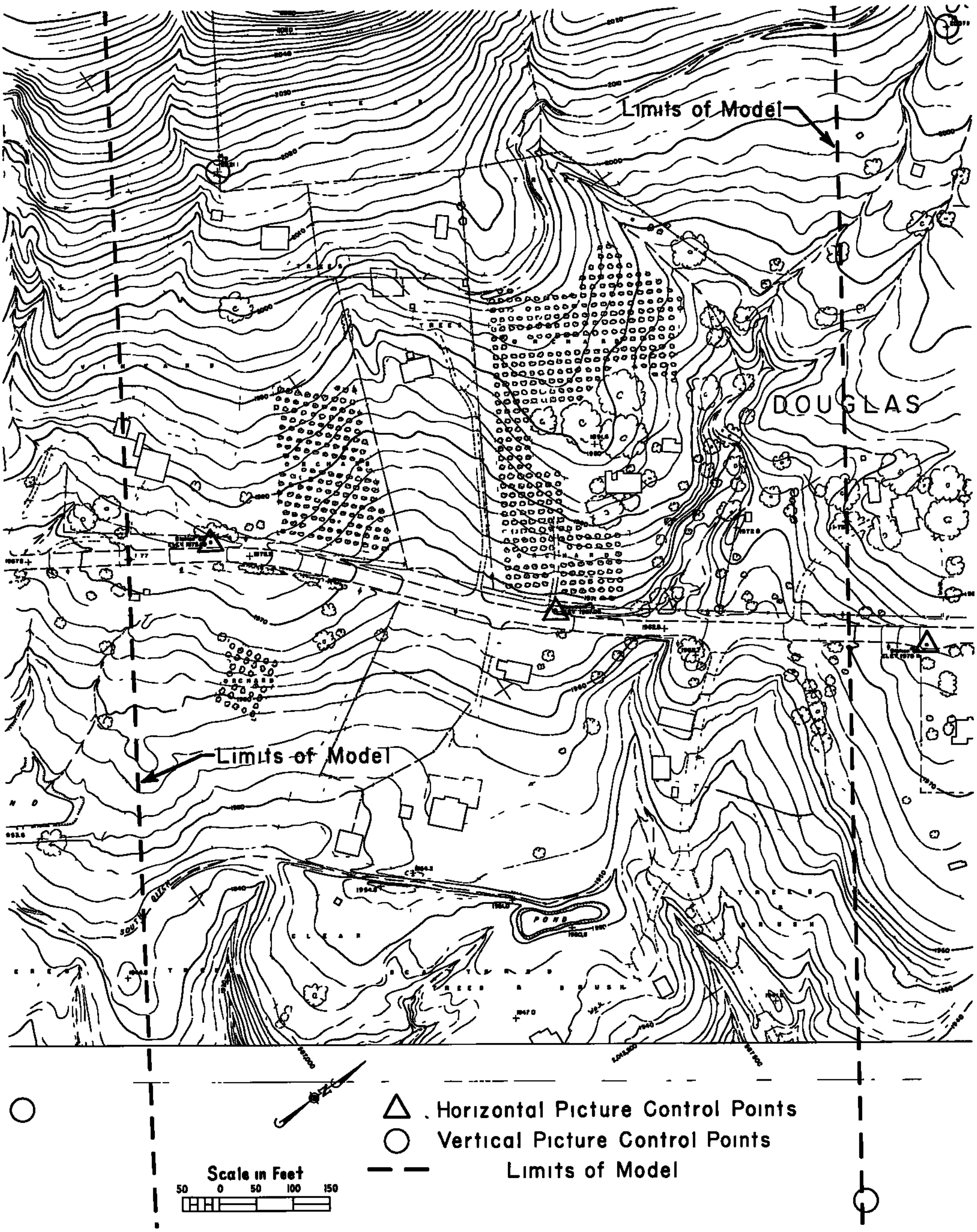

Figure 5. This portion of the final map at a scale of 1 in. = 50 ft with 2-ft contours was compiled from the photographs shown in Figure 4. Monument No. 8 shown on the control diagram in Figure 4 was used as the horizontal picture control point near the center of the model.

1 in. = 50 ft with a contour interval of 2 ft. Such mapping is used for the design of facilities ranging from metropolitan freeways to rural expressways in desert, mountainous, or agricultural terrain.

One of the most important features is the requirement for adequate control surveys, properly monumented at intervals ranging from 1,000 ft to one-half mile, as the basis for the topographic maps. Such surveys are generally made to second-order accuracy and are based on the California Coordinate System. They are carefully planned and include monumented control not essential for strictly mapping use. Complete survey notes, including data on adjustment of observed values, are furnished by the mapping contractor. The monuments may be key property corners or new points selected for later use by the Division of Highways. They will be used for any supplemental surveys that may be required, including property corner ties, and will be the basis for staking the projected final line in the field.

This practice results in maps from which it is possible to project the located line with computed ties to points of known position in the control net, complete the design, compute quantities, write deed descriptions for right-of-way, and advertise the construction contract with a minimum of additional field survey work. In some cases the located line is not run in the field until the right-of-way has been purchased and completely cleared. With key property corners and other permanent monuments, selected by the highway engineer, tied in by the survey and the entire survey based on the California Coordinate System, the located line as finally run in the field closes without difficulty.

Mapping Specifications

Other steps in the making of photogrammetric maps for design use include photography, picture point control, map compilation and, in some cases, field editing by the mapping contractor to determine the position of contours and planimetric features obscured by ground cover. To insure map accuracy satisfactory for detailed design work, it has been found advisable to specify a minimum of three horizontal and five vertical picture points for each model to aid in properly orienting the photographs in the stereo-plotting equipment. The specifications also limit the ratio between photography and final map scale for various stereo-plotting instruments.

While maps at 1 in. = 50 ft with 2-ft contours are satisfactory for most projects, there are some conditions where other types of mapping are best suited for design purposes. In comparatively level terrain for example, even 1-ft contours are not entirely satisfactory for accurately depicting the ground surface. In such cases, maps are obtained at 1 in. = 50 ft with a grid of spot elevations at 100-ft intervals in lieu of contours in areas where 2-ft contours would be more than 100 ft apart. The specifications require that the spot elevations by expressed to the nearest 0.1 ft, and that 70 percent be within 0.5 ft of their true elevation, and all be within 1.0 ft. While closer results than this can undoubtedly be obtained under ideal conditions, the specifications are realistic in recognizing the difficulties of extreme accuracy in photogrammetric measurements due to irregularities in the ground surface and the effects of grass and other ground cover.

On projects where the terrain is quite rugged or where the ground surface is extremely rough or obscured by brush and timber to the extent that 2-ft contour mapping by photogrammetric methods would be impracticable, design mapping at a scale of 1 in. = 100 ft with 5-ft contours is frequently used. The contours are supplemented with spot elevations accurate to 1 ft in areas so level that 5-ft contours would not depict the topography accurately.

Use of Maps in Design

In the calculation of earthwork quantities from photogrammetric maps, the use of electronic computers has almost completely supplanted both the contour grading or horizontal slice method and the conventional cross-section and planimeter method. The method used involves the submission of terrain and roadbed notes to the tabulating section for computation. The terrain notes, in the conventional form of field cross-section

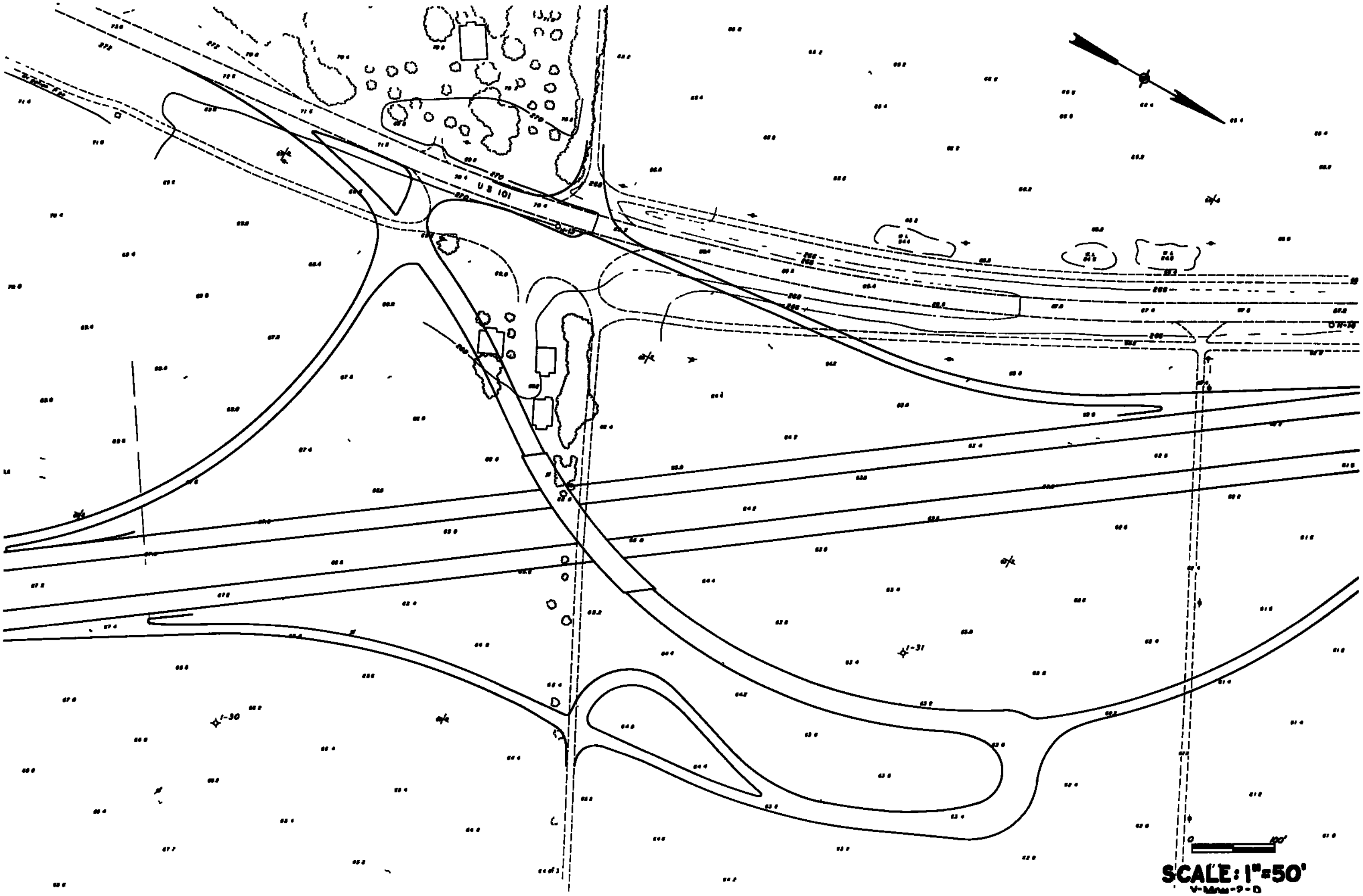

Figure 6. A grid of spot elevations at 100-ft intervals is used in lieu of contours for design mapping in comparatively level terrain.

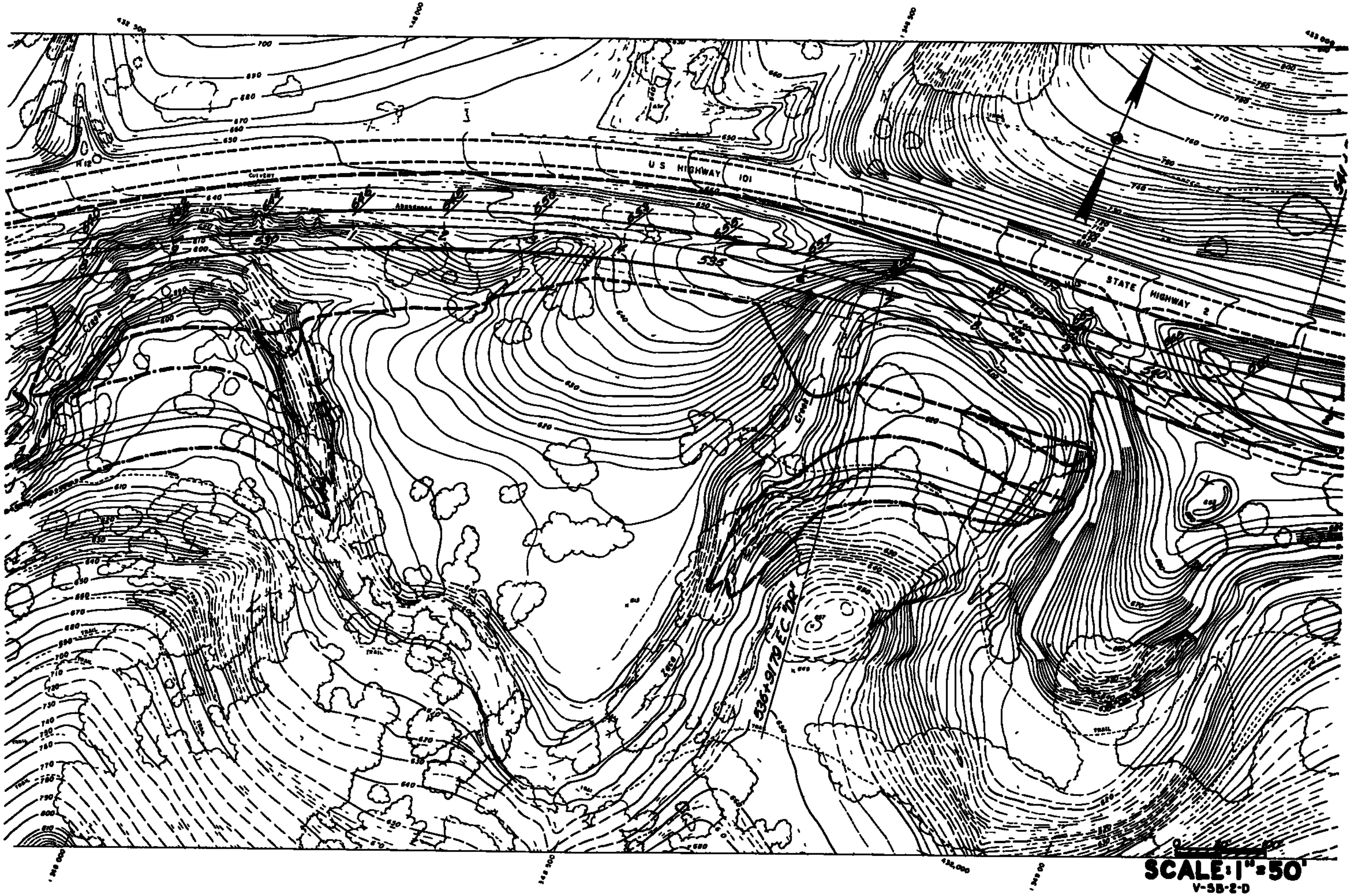

Figure 7. Outer limits of cut and fill slopes obtained by machine computation have been drawn on the contour map preparatory to laying out the right of way lines and designing the drainage.

notes, are taken from the contour maps. Roadbed notes, prepared in similar form, show the various breaks in the templet, which may include ditches, benches, etc., and rates of cut and fill slopes. Data furnished the designer by machine computation include cut and fill quantities, mass diagram ordinates, and distances out to catch points of cut and fill slopes.

The basic problem in design is to establish the line and grade to fit previously determined controls and design standards in the most economical manner. Preliminary computations for earthwork quantities involved in this projection work can be made by any one of various short-cut methods. At the stage of projection selected by the designer as the most efficient to start using machine computation, roadbed and terrain notes are developed for submission. After the results of the machine calculation are received and studied for balance and other factors, adjustments of line and grade are made by the designer if necessary. New roadbed notes or instructions to use the original notes with designated horizontal or vertical shifts are then submitted and combined with the previously submitted terrain notes for machine computation. By this method any number of variations of line and grade can be investigated in a fraction of the time formerly required.

With line and grade established, either in final form or within rather narrow limits, the designer plots cut and fill catch points furnished by machine computation on the contour map and lays out the right-of-way lines. Up to this point the center line has generally been in graphic form only on a print or transparency of the contour map which is being used as the design hard copy. The designer is then ready to establish the line mathematically by scaling the coordinates of various points on the projected line which may be used as controls. These data are set up on traverse sheets for machine computation of the actual traverses. The center line will subsequently by staked in the field by computing ties from monuments, whose position has been established by the mapping contractor, to convenient points on the calculated center line. As the contractor's basic surveys which included these monuments have been made to second-order accuracy, recalculation or adjustment of the center line traverse is seldom if ever required during the field staking.

At this point the designer is ready to plan and design the drainage for the project, using the contour map in lieu of the usual hard copy and cross-sections. As he is not restricted to cross-sections taken at right angles to center line, he generally plots a section on the skew proposed for the culvert at each location where cross drainage is required. These sections will be used for the calculation of structure excavation and back fill and ditch and channel excavation quantities. They can either be included in the contract plans or given to the resident engineer for his use in field staking and construction.

It is also desirable to plot sample cross-sections throughout the project at intervals varying from 200 to 1,000 ft depending on the terrain. These generally include one section in each cut and fill and any others which are necessary to show unusual conditions such as sliver cuts and fills, benches, special ditches, channel changes, etc. They are of use to the designer in studying the project as well as to field engineers in staking and construction. As the construction contractors will also be interested in such information for bidding purposes, the sample cross-sections are included in the contract plans. Since they are used for pictorial purposes only, the scale can be as small as 1 in. = 20 f or more horizontally, and to whatever vertical scale will best fit the individual project. The use of small-scale illustrative cross-sections has effected a material reduction in the volume of contract plans.

Results Obtained

There is no longer any doubt that photogrammetric maps such as these are sufficiently accurate for the computation of preliminary earthwork quantities. Present practice is to cross-section again immediately prior to construction for determination of final pay quantities. On several projects a comparison of preliminary quantities from photogrammetric maps and final quantities from field cross-sections shows a difference of less than 1 percent. Very few projects have been reported where the difference was greater than 2½ percent.

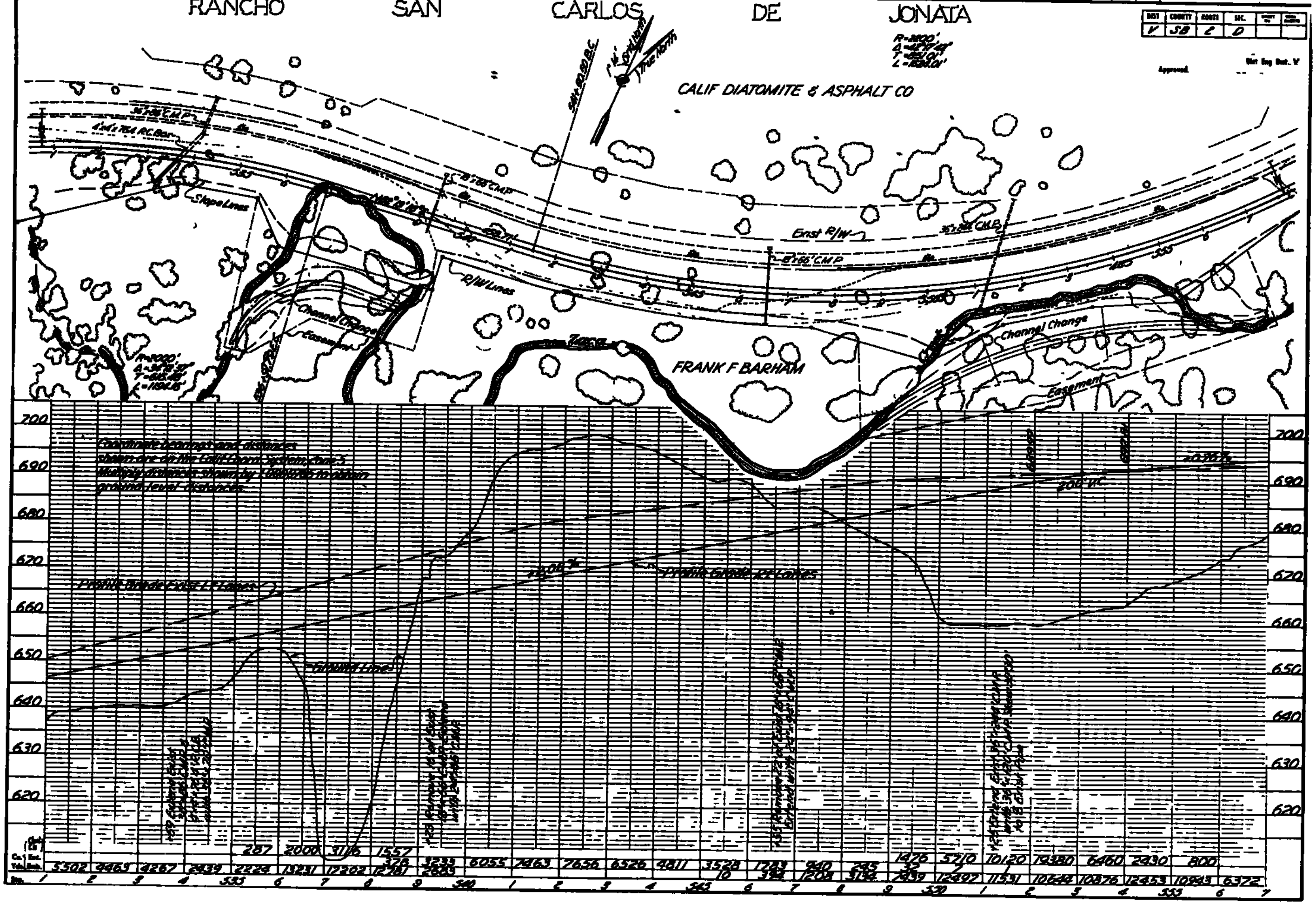

Figure 8. A sheet of completed contract plans has been developed from the photogrammetric mapping illustrated by Figure 7. Earthwork quantities obtained by machine computation are shown at the bottom of the sheet.

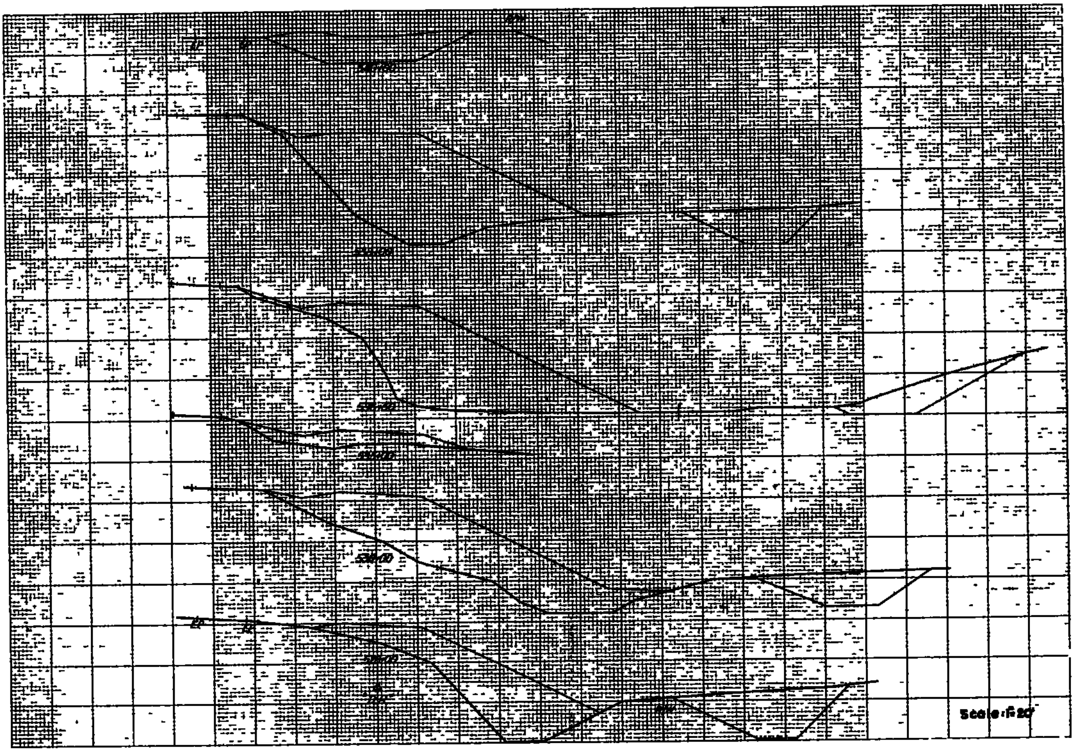

Figure 9. Small-scale pictorial cross-sections are useful to the designer, the construction engineer, and the contractor.

The actual savings effected by the use of design mapping are much easier to measure than those obtained from the use of aerial photos or reconnaissance mapping. Data reported by several districts indicate a saving of 40 percent is cost and 70 to 80 percent in manpower as compared to conventional field survey methods. A further saving of between 30 and 50 percent is achieved in design when photogrammetric mapping and electronic computers are used.

The use of large-scale photogrammetric mapping has been rapidly increasing during the past five years and is now generally accepted as standard practice for the design of freeways in California. At the present time the Division of Highways has 33 contracts for design mapping under way. These contracts provide for mapping a total of 376 miles at a cost of $560,000. Construction costs of the highway projects covered by this mapping are estimated at over 190 million dollars.

Planning Aerial Photography and Film Processing for Mapping Work

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All successful accomplishments are attained through thoughtful planning by competent personnel. It may be highway site location, design, construction, or maintenance. As the aerial photograph has aided the highway engineer in these accomplishments and grows in importance today and tomorrow, it stands to reason that here, too, thorough planning is required to successfully attain a photograph for its required purpose.

To secure a usable photographic negative, it must be exposed in a selected camera in the proper relationship to the terrain and its accompanying negatives, and be developed by proven procedures using chemical formulas that will satisfactorily convert the emulsion into permanent images of recognition.

To acquaint the uninitiated and further inform the more experienced of some of the problems confronting the engineer who plans aerial photography and processes films for mapping work, the paper discusses the photographic mission, including reconnaissance, flight design, camera and airplane selection, flight crew, films, filters, and exposures; and film processing, including personnel, equipment, facilities, procedures, developers, washes, fixers and drying.

● ALL professional endeavors require thorough and adequate planning to provide a creditable service. Therefore, this paper is intended to inform the highway engineer of the problems encountered in photogrammetry and to acquaint him with the procedures a photogrammetric engineer must concern himself with in planning for aerial photography and film processing for mapping work. It is designed to remove some of the clouds of mystery or misconception and afford more background for determining how products of photogrammetry may serve as an aid to the solution of highway engineering problems.

The aerial photographer has to be placed at a prescribed site in space. He must be there at a time which affords acceptable atmospheric conditions for aerial photography and be supplied with cameras and associated equipment operating satisfactorily. These primary factors are to insure that with the click of the shutter the camera will ideally record all the required detail on the film. This is a task requiring effective plans which are not merely dreamed up or hastily thrown together. To assure that the film will be developed properly in the photographic laboratory, planning must establish an operating procedure that is flexible enough to afford intelligent departure therefrom and that can be reestablished as experience is gained.

The engineer who plans a photographic mission will plan an entire mapping project, not stopping, as may be indicated here, with the development of the photographic negative. This person must understand the intended use of the picture and coordinate all equipment, operations, and use of personnel all along the work processes to obtain full benefit of his experience and ingenuity.

There are primarily three ways in which the photogrammetric engineer will be introduced to and know of a client's need for his services, as follows:

1. He may enter a proposal of work having designed a new application of photogrammetry.
2. He may establish contact with a client and negotiate for his services.
3. He may receive an invitation to bid from a customer who distinctly knows his own requirements.

Any of these approaches is a means to the same end—that of engineering a service which will be of aid in the construction of highways as programmed by the states and designed by the highway engineer. Reputable photogrammetric firms can obviate the necessity for highway departments to devote a portion of their scarce supply of talented engineering personnel to the performance of strictly photogrammetric functions. This is not to suggest that application of photogrammetry be limited only to those products provided by aerial photography and mapping firms. It is felt, however, that contracting to companies whose livelihood depends on the successful day-to-day application of photogrammetry allows a better utilization of staff engineering manpower and brings to the client the benefit of current improvements in photogrammetric methods. If the contracting firm has the facility to fulfill an engineering objective which involves the use of photogrammetry, it is to mutual advantage if the highway engineers concern themselves with making the objectives clear and leave the methods and means by which it is accomplished to the judgement and discretion of the experienced photogrammetric engineer.

To best fulfill his client's needs the engineer is continually conscious not only of the specifications which the end product must meet but also of the useful by-products which can be and are being obtained in the process. To do this intelligently, he must be thoroughly familiar with the type of information which is of value to the highway engineer and be cognizant of how he may help by providing additional services. For instance, today aerial photography is used to obtain useful information in addition to the photogrammetric compilation of planimetric and topographic maps. Aerial photographs, under the stereoscopes of specialists, yield information concerning topography, drainages, soil types, surface geology, vegetation, and land use data. The value and economical advantages of extracting these types of data from aerial photography are becoming increasingly evident to the highway engineer. With a thorough knowledge of the requirements of these users, the engineer can, where applicable, intelligently recommend a slight modification of flight planning to improve their function without in the least impairing the usefulness of the photography for mapping purposes.

With the end products firmly fixed in mind, the engineer will proceed through a cycle of accomplishments. There are no specified steps of procedure, but for efficient work which will help assure the timely delivery of the desired aerial negative, planning for the photographic mission must include consideration of area reconnaissance, camera and aircraft selection, evaluation of flight crew, and flight design.

The investigation involved in making a reconnaissance of the area is to be so tailored that the findings will divulge all the physical factors of the project area which affect the performance of the photographic mission. It is to establish the nature of the terrain and what man has placed on it, solar angles that will prevail, prediction of prevailing weather conditions, location of existing control lines and possible routes for additional survey work, and the imposed flight restrictions.

Selection of the ideal camera for a particular project is a complex problem, as so aptly put by Deeg (1), as follows:

> There are many types of aerial cameras. In fact, there are so many types that a full treatment of them would require more space than that allocated to this entire manual. To some individuals, this is well understood To others, a superficial examination of the existing literature on the subject leaves them in a highly perplexed state of mind. The question heard most often from tyros is simply· "What camera should I use?" From individuals well versed in the subject, the reply is likely to be a suggestion that they first study. basic mathematics of photogrammetry. .
>
> Unless an individual is well financed, he should not attempt to select an aerial camera for a particular purpose until he has a thorough understanding of photogrammetric fundamentals. It must be remembered that aerial cameras, film, qualified personnel, and flying time are costly expenditures

In selecting a camera, his thoughts would be to have available the proper camera that would most accurately portray the terrain which is to be photographed so that the terrain and features of details can be identified or interpreted and, if required, transferred to a map medium at a desired scale. This would require a camera possessing optical qualities which would resolve the necessary detail and place it on the film with geometrical qualities so that the relationship between the images can be measured and their positions established as they existed at the time of exposure. After he determines the proper camera, an assessment of the airplane characteristics must be made to afford the desired camera platform. The plane must be structurally designed to properly accommodate the camera and related equipment, have adequate crew facilities, have aerodynamic qualities consistent with the speed, range and altitude required of the mission, and, foremost, itself be operational and in good maintenance.

The engineer has an array of planes from which to make his selection, each possessing certain flight characteristics and structural design which narrow the applications for photographic work. The author's company alone has 35 aircraft ranging in size and complexity from the Piper Cub to the B17 Yet, hardly a week passes that there is not some earnest thought given to the desirability of having another which possesses certain additional flight or structural characteristics.

Therefore, the engineer must have intimate knowledge of the characteristics of each of these pieces of equipment in order to select the best combination for the job.

The experienced engineer instinctively knows that the best equipped aerial surveying airplane is no better than the men he assigns to use it, for it is impossible to separate the airplane from the skills and proficiency of the crew in predicting the success of a photographic mission. Unlike the planned and systematized operations of a ground survey crew in which mistakes can, as a general rule, be immediately discovered and corrective action taken while the work is in progress, in aerial surveying mistakes, defects, and poor execution only become apparent upon completion of the flight and development of the film. Therefore, the engineer assigns a photographer and pilot who function reliably as a team.

Knowing what he has to work with, the engineer who is involved in the preparation of maps or reports from data which were arrived at from the intelligent use of aerial photographs can proceed with a realistic program for accomplishment and make his final plans. His experience comes into play now, for here he must assess the liberties he must take in departing from an established procedure to have efficient project work suited to obtain a photograph most accurately portraying the terrain and, if need be, possessing characteristics which will afford geometrical reconstruction into an end product.

With all these considerations that must go into the flight design of a photographic mission, it is next to impossible to compile information to which one can readily refer and say: "This tells me how to design my flight." Experience is, really, the only teacher—with academic courses and study of the fine literature available being a prerequisite. Foremost of the good literature available is the "Manual of Photogrammetry," published by the American Society of Photogrammetry.

Flight planning is a design, for it conveys to the operating personnel the results of planning. The details it contains, if properly applied, furnish aerial photography as the product. Here, specifications dictate how exhaustively and/or elaborately they must be presented. In any case, the essentials are the same—to obtain a usable photographic negative.

The design entails the presentation of detailed instructions for the plane-camera crew regarding the location of the exposure stations, the flight strip, and the boundaries of the project area to be covered. This will, of necessity, include information regarding the camera to be used, the flight height, and the time at which the mission is to be accomplished, and any other pertinent data relating to the project which would give aid to the photographic crew.

These data may be presented on numerous media, the most desirable being the best available map of the area most suited for plotting the flight design information and of such character that it will afford the necessary navigational aids for contact flying by the photographic pilot.

Having established the criteria, the engineer steps out of the active role upon presenting his findings for the detailing necessary in the preparation of the flight map.

Processing the Film

After a photographic mission has been completed, attention is directed toward processing of the film.

The purpose of film processing is to convert the latent image, obtained by film exposure, into a permanent silver image. This is accomplished by successively developing and then fixing the photographic material.

Development is the process of converting the exposed silver halides into metallic silver by immersion of the film emulsion in a suitable reducing agent. Since the fixing operation has little effect on the characteristics of the finished product, this part of the process is not discussed at length. The primary purpose of the fixing bath after development is to dissolve out the unexposed silver halide particles, which with exposure to light darken and degrade the negative. In the process of development it is possible to control, to some extent, the grain structure of the silver image and to establish the relative densities of the silver deposit in the various items in the photographic scene.

Grain size in the developed image is important because it limits the size of the smallest items that can be portrayed by the photograph. It is, therefore, of primary concern to obtain as small grain size as possible while developing to a suitable contrast. Extremely fine grain development of emulsions suitable for aerial photography is, unfortunately, associated with development to a low contrast, which, as shown later, imposes serious limitations on its application to aerial photography. It is, therefore, necessary to select the development process that allows the best combination of small grain size and necessary negative contrast.

Before undertaking a discussion of the control of negative contrast in development, it is necessary first to discuss the significance of contrast and to define certain pertinent terms. A developed emulsion conveys information to the observer by virtue of the differences in density of the silver deposit that has resulted from differences in intensity of light reflectance from the various objects within the scene.

Without going into great detail concerning the theory of photographic tone reproduction, it may be said in general that the difference in density of the silver deposit of two items within a scene is related to the difference in light intensity reflected from the two objects by a factor known as the "gamma" of the negative. When the gamma is low, the differences in density of the silver deposits are also low and the photograph has a very flat appearance. Much detail in the photograph is lost due to the fact that the differences in density produced by adjacent objects is not sufficiently large to be discernible to the human eye. On the other hand, when the gamma is too high the photograph tends to be overly contrasty, presenting an abnormal appearance to the eye, and detail is lost in the highlights of the photograph.

To obtain the correct gamma on a terrestrial photograph, particularly of nearby objects, is a relatively simple matter compared to aerial photography. The complicating factor in aerial photography is aerial "haze" caused by light reflection from the numerous particles suspended in the atmosphere. Even on an apparently clear day, there is some atmospheric haze present. Aerial photography for commercial purposes is flown only under the best atmospheric conditions; but in some areas the best is still considerably hazy because of the presence of industry and other contributors to aerial haze. The effect of haze is to add a uniform increment of light to all objects within the scene, thereby reducing the effective differences in light intensity between objects.

To a certain extent this effect can be compensated for by developing the emulsion to a higher gamma to heighten the density differences between objects. Because the gamma increases with time of development when the proper developer is used, it is necessary to determine the development time required to obtain the desired contrast. Because no two rolls of film have been exposed under exactly the same conditions, there is no substitute for a large backlog of experience, both recorded and personal.

It may be interesting to consider the step-by-step procedure of processing a typical exposed roll of aerial film as it is done under operating conditions. The film is sent to the photographic laboratory by the flight crew as soon as it has been exposed. The photo lab begins processing immediately, because the flight crew can not be released from its assignment until the photography is known to be satisfactory. When the film is received by the laboratory, a search is made of all records concerning the procedure used on photography of the same area. These records show the developer used, length of development, an assessment of the resulting quality, and include pertinent exposure information (such as the date and time of exposure, weather conditions, flight altitude, camera number, and even the name of the photographer). These records are compared to the mission report for the film to be developed and, when applicable, serve as a valuable guide to the procedure to be followed. The film is then placed on one of two spools of a Fairchild-Smith tank apparatus. This equipment allows for the winding of the film from one spool to the other and back again while both spools are submerged in liquid. The film is first placed in water and manually wound onto the second spool. The purpos of the preliminary water bath is to insure that the developer which follows will flow evenly on the film. Now the apparatus is submerged in a suitable developing bath, either Kodak formula DK-50, D-19, or D-76, and the film is continually wound from one spool to the other by electric power. A constant temperature of 68 F is maintained for all liquids used during development. Several minutes before the end of the anticipated development time, the film is examined under a dark green safelight by a laboratory technician, who then determines how much longer the film shall be developed to obtain the desired contrast. When development is completed, the film is immersed in stop bath or water during a complete cycle of winding, and then placed in a fixing bath for continuous winding for 10 to 20 minutes. Drying is carried out by passing the film around the outside of a large drum, the back of the film being held against a series of rollers by air pressure through many small slits. The instrument is so designed as to insure that no stretching of the film base occurs.

The success of a photographic mission and the value of any derived products is directly dependent on competent planning at all stages.

For the successful execution of the complex job of planning aerial surveys, experience is the best teacher.

The use of aerial photography in highly precise stereoscopic mapping instruments is beyond the scope of this paper. Nevertheless, it should be apparent that photography is the basis on which subsequent maps are to be made. Therefore, proper planning and execution of the photographic mission is of the utmost importance.

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The Engineer's Approach to Electronic Computing Methods

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● THE glamorous and exciting descriptions of giant electronic "brains" so common in today's press have attracted the attention of all highway engineers. In highway research design, construction, and administration, computation by hand has long been a bottleneck preventing rapid fulfillment of ever expanding construction requirements. Each engineer, therefore, wants to learn what electronic computers can do to increase his output and remove the bottleneck. The purpose of this paper is to provide guideposts for the engineer who wishes to evaluate electronic methods with reference to his specific problems.

DEFINITION

An electronic computer is a very fast calculating machine with the ability to memorize numbers and instructions. To solve a problem on an electronic computer, the engineer must reduce his method of solution to a very detailed list of instructions. The instructions, when memorized by the computer, will be executed at lightning speed to arrive at an answer. Desk calculators, which have no memory, have their arithmetic speed geared to the speed of the operator and are not classified as computers. It is important to note that the computer does not replace the calculator. The computer, the calculator, and manual arithmetic supplement each other to provide more answers in less time to the great variety of problems facing highway engineers. An electronic computer is not an electronic "brain." A brain is capable of making calculations and memorizing information; but, in addition, a brain can analyze data, draw inferences, make decisions, exercise judgment, and exhibit emotion. These things an electronic computer cannot do. But in its simplemindedness, an electronic computer is more useful than a brain since it is too unimaginative to make mistakes.

Basic Components

1. Input. Means of entering instructions and data for each problem into the compute Information must be written in some electronic or mechanical code that the machine can read. Typical input media are punched cards, keyboards, punched paper tape, and magnetic tape. In general, a special transcription of data is required to prepare the input records (for example, survey notes must be copied from the field book to the punched card in order to feed them into the IBM Type 650 Magnetic Drum Computer when running the standard earthwork volume computation). This may represent additional work not required in a hand calculation. On the other hand, the transcription may eliminate work. Such a case occurs when punched cards are prepared automatically from readings obtained by a Kelsh plotter (in a device built for Ohio) and no field books are needed

2. Arithmetic and Logical Unit. Electronic circuits that can add, subtract, multiply, divide, and compare numbers. The circuitry of most computers contains built-in checking features that prevent the wrong answer from occurring without detection.

3. Control. Electronic circuits that interpret instructions and execute them by directing the operation of the other components.

4. Memory. High-speed storage for instructions and data. Each item stored in the memory has an address that enables the control unit to locate it directly and rapidly. The larger the memory, the more complicated the problem that can be solved at high speed. When the set of instructions exceeds the capacity of the memory, the computer has to refer to the slow input for the additional instructions. Typical memory units store data on the surface of magnetic cylinders that rotate at high speed past reading devices or in tiny magnetic cores, in vacuum tubes, or electromagnetic relays.

5. Output. Means of producing usable results. Output generally takes the same forms as input. An additional important form of output is the printed page. Printers

can be controlled to prepare reports, tables, lists, vouchers, and even graphs. By taking advantage of output flexibility, many manual operations can be eliminated.

It is important to note that there is no component in the computing system that thinks. The engineer still does all the thinking—the computer only does the arithmetic. In fact, by relieving him of hand calculations, a computer allows the engineer to spend the majority of his time on creative and supervisory projects.

Available Computer Systems

1. Analog. The computer does not accept digits; instead it measures quantities. Gears or electronic circuits within the computer can be arranged to look like a physical problem and as the measurements are fed in one end, results come out of the other end of the machine. Since the circuits will differentiate and integrate, an analog computer is often an excellent tool for solving differential equations. It is usually inexpensive (less than $50,000) but limited in speed, accuracy, and versatility. Analog computers are most often found in research organizations where numerical solutions to problems are hard to formulate but where approximate answers are acceptable as a guide to further experiments. They are also useful in devices such as aggregate mixing scales where the computed results are subordinate to the act of measurement. Numerous electronics and instrument manufacturers produce a wide variety of analog computers.

2. Digital. The computer accepts actual digits and alphabetic characters and performs arithmetic in the manner of a desk calculator. All data must be converted to digits before it can be entered into the computer. Because all mathematical and logical problems (with the exception of some unsolvable problems and some problems for which no solution has been proven) can be solved by the rules of arithmetic, a digital computer is completely versatile. It is limited only by its speed and capacity. As a result, digital computers are preferred to analog except when analog-to-digital conversion is prohibitively expensive or when mobility and field conditions are critical. Digital computers, since they deal with numbers, are generally produced by the manufacturers of business machines Digital computers can be subclassified as:

a. Slow speed—speed per operation measured in the tens or hundreds of milliseconds (0.001 sec = 1 ms). Slow computers are usually desk size and have typewriters for input and output. They depend on the operator for many directions and store only a small set of instructions. They cost under $50,000 and are very easy to operate; therefore, they are useful in laboratories and engineering sections for short non-routine computations.

b. Intermediate speed—speed per operation is less than 10 ms but more than 1 ms. Costing from $50,000 to $400,000 depending on versatility, capacity, etc., the intermediate-speed computers offer the most advantages to large engineering organizations. One such machine could handle all the earthwork computations for a large state plus bridge computations, accounting, etc., in a single shift of operation The computer requires a staff of programmers and operators to keep it busy, but it is easy to use on both scientific and accounting calculations. Modular in design a small computer installation can be gradually expanded to meet changing requirements.

c. High speed—speed per operation less than 1 ms. Simple operations are completed in a matter of microseconds (0.000001 sec = 1 μs). High-speed computers are the real giants. In cost they range from about $1,500,000 up. Most such computers, although general purpose, are designed to do some jobs better than others. Thus, a high-speed, scientific computer will be faster at arithmetic than a high-speed data processing machine but not so good at reading and writing. No high-speed computers have yet been placed into operation solely for highway computations. Although this would not be impossible, it is unlikely that any single highway engineering organization could generate enough work to keep a high-speed machine busy year round. However, certain jobs that exceed that capacity of smaller machines can be solved, by a giant computer rented only for the time required.

ECONOMIC JUSTIFICATION OF USE

The only justification for the use of electronic computation methods is economy.

This economy need not refer to a money saving; any economy of manpower, materials, or time is reflected in a lower unit cost of construction. It is necessary for the engineer to determine whether electronic methods will lower his unit costs and, if so, what type of computer will yield the greatest reduction. He can learn the value of electronic methods only by studying his requirements and existing procedures. Then, with the assistance of computer experts, manufacturers' representatives, and short training courses he can compare the relative cost of various systems.

To evaluate the use of computers in his organization, the engineer should answer the following questions:

1. Am I missing deadlines?
2. Are my engineers and engineering aides at their desk calculators more than a few minutes a day?
3. Am I accepting inferior designs because there is no time for analyzing alternates?
4. Am I losing the statistical value of performance data because I have no one available to process it?
5. Do I spend too much time on accounting and administrative paperwork?
6. Am I unable to take on more construction obligations because my office staff is overloaded?

If the answer to any of the above questions is "yes," an electronic computer may be worthwhile. The organization should appoint a computer committee to investigate the problems in detail and solicit expert advice on how to correct the problems through mechanization. Preferably the committee should contain members from each division of the organization—engineering, research, and administration—to provide a complete picture of requirements

The committee will find certain specific processes which can be automated but, which by themselves, do not justify the expense. Several processes, however, can often be performed by a single computer, the cost of which is less than the accumulated savings from all the processes. Such is the case with a large group of engineering problems:

1. Survey: a. traverse closure, b. triangulation net adjustment, and c. coordinate conversion.
2. Highway plan and profile design: a earthwork volume, b land value, and c. grade and curve layout.
3. Bridge design: a. stress analysis, b. beam and bent design, and c. span length.
4. Traffic analysis: a. origin and destination and b. demand forecast
5. Drainage design: a runoff and b. drainage structures.
6. Traffic engineering: a. intersections and b. urban traffic movement control.
7. Drafting: a. cross-section, b. plan and profile, and c. mass diagram.

Each of these represents a great deal of manual effort. A single intermediate speed computer could handle the majority of them for a large engineering outfit.

Despite the ability to solve more than one problem on a single computer, the committee will see that some jobs do not easily fall into the same pattern as the rest. For instance, the data for all the above jobs can be punched into cards for direct entry into a digital computer; but the amount of computing per punched card varies from practically none for drafting of various charts, to a vast amount for traffic analysis Obviously, all of the best features of a computer could not be used all of the time for such different jobs.

The committee should separate these problems into three categories.

1. The mechanical jobs requiring little computing, such as drafting, should be considered for analog plotting machines and standard electronic accounting machines. The plotting machines interpret holes in punched cards (or other input media) as coordinates of the point to be plotted. The result can take the form of a graph, a contour map, or a scatter diagram. Standard card operated accounting machines, normally used for preparing tabulated lists, can also be programmed to draw a chart Since their output is very rough, they are preferred only if they are already installed for accounting purposes. After all other jobs have been accommodated, a digital computer could perform such jobs in its spare time.

2. The very bulky computing jobs such as traffic analysis should be considered for high speed digital computers. The detailed programming and operation of the computer

can be performed by the service bureau from which computer time is purchased.

3. All other jobs, which represent the bulk of daily computations should be considered for an intermediate (or slow) speed digital computer installed in the organization.

After breaking down the categories, the committee must compare the cost of existing procedures to the cost of computer methods. In the case of existing methods, the factors involved are cost of personnel (man-hours), cost of equipment (hourly rate), and cost of limited data handling capacity (lost contracts, missed deadline penalties).

For the computer, the same factors are considered although different personnel grades and equipment are used. An additional factor—cost of conversion to new methods—can be estimated. If the total computer costs, including intangibles, are less than present costs, the computer should be installed. If the computer costs more but does a great deal of desired work beyond present capacity, the computer is still justified. Otherwise, a computer will merely increase costs, and the committee should investigate sharing a machine with another group, or purchasing computer services from a commercial services bureau.

The above list of engineering applications was presented as an example of the types of job facing the computer committee. They are also concerned with the mechanization of research and administrative problems. Research wanders all over the lot as far as computation is concerned. Many projects are concerned with devices; here, analog computers, small enough to fit into a field test or experiment, are useful. Other projects are based on mathematical theory and statistical analysis. The latter can be handled by a digital computer, the speed of which depends on the scope of the problem. It is convenient for a small research group to plan on using their organization's intermediate speed computer except for the occasional problem that may call for a high speed service bureau machine. There should be no reluctance on the part of the scientists to put even small computing jobs on a digital computer. The more arithmetic he farms out, the more time the researcher leaves for thought.

For the administrator, there is no need to explain that electronic computers can do his payroll, cost accounting, budget preparation, fiscal accounting, personnel accounting, supply and inventory control, equipment and maintenance reporting, sales analysis, profit and loss statement, and bid evaluation. In every case, machine accounting is a proven advantage over manual accounting. The speedup available in an electronic computer is that much more desirable. Less obvious to the non-professionals in an engineering organization is the tremendous saving possible by letting the computer do operations programming. The assignment of vehicles and earthmoving equipment can be correlated with various material stockpile locations to arrive at minimum haul distances and a reduced number of trips. The computer can assign equipment daily as a direct assistant to the dispatcher. The procedure used is called "linear programming" and can be applied to the optimization of any definable system of linear inequalities. In addition, statistical analysis of operational data can be readily processed by the computer to yield correlation coefficients and variance in a fraction of the time formerly taken by the statistician.

COMPUTER PERSONNEL

Rough estimates of benefits from electronic methods will lead the computer committee to recommend detailed studies of a selected computer. The computer committee should select a small staff to study computer programming in order to work out exact cost figures on the most important problems. The staff should consist of two or three of the best men in the organization at an operational level. They must devote full time to their computer work to turn out the desired results. Since these same men would logically organize and run the computer installation, their assignment to the computer committee must be a permanent relocation and calls for a new job description. The prestige and pay associated with this job must be attractive enough to hold a good man. The cost of any computer is so high that it would be foolish to economize on supervisors at the expense of an efficient installation.

A training course of from 1 to 6 weeks is adequate preparation for the staff members. The courses given by manufacturers teach the students programming and data handling techniques. After training, and with the help of manufacturers' personnel, the staff will prepare programs that take advantage of machine features not obvious to the computer committee. For instance, in IBM's earthwork volume computation, the mass diagram is a by-product of the computation. The simplicity of such a combination of results was not clear until much of the program had been written. The staff must be familiar with all aspects of the organization's operations so that they can reduce the work necessary to provide data for computation. For example, in any problems involving survey data, no processing should be required before computation other than the punching of cards directly from the field notes. Or, as in Ohio, certain stages of survey can be eliminated when equivalent terrain data can be obtained from aerial photos. In design of structures, ground rules calling for 4 repetitions of a moment distribution or comparisons of 6 alternate designs for pricing can be replaced by more desirable computer methods. Iterative methods can be carried out until no further improvement is obtained by successive trials. Price comparisons can be made in detail for all feasible alternate designs regardless of their number. Perhaps speed is more important than quantity of computations. The staff can set up a schedule for routine computations so that results can be returned to the field the day after data are received at the computer site.

When the major problems have been laid out for the computer, it is time to build up the permanent computer staff. From 4 to 15 full time programmers and machine operators will be required some 12 to 18 months before the computer is to be delivered. Before the date of installation, they must receive training and then proceed to program new jobs, revise earlier programs, test programs, and teach the organization how the computer will serve it. The most efficient computer installation is a relatively large closed shop where all programming is done by professional programmers only. Such an arrangement is not always possible. As an alternate, selected people outside the installation learn to program part time in order to augment a small permanent staff.

The closed shop is not to be construed as preventing outside engineers from originating problems. They should be encouraged to bring problems in for solution, but they should not be asked to spend a couple of weeks of valuable engineering time writing a program that could probably be written better by a programmer.

All people using the computer will have to reorient themselves with respect to mathematics and logic. Unfortunately, the effort to reduce computation time has, over the years, substituted simple form solutions for algebraic or geometric problems. Engineers who can calculate double meridian distance areas flawlessly would be hard put to find the area of a combination cut and fill section by trigonometry. Lack of practice prevents the engineer from remembering how a given method was derived—what equations apply. Since an equation is generally more efficient than any procedure substituted for it, the computer should be programmed to solve equations. This means that engineers as a group will have to relearn the fundamentals of their trade. Fortunately, such a reversion, not only is an aid to computations, but it is also a stimulant to the development of new and improved engineering methods.

INSTALLATION

The planning and preparation for a computer installation takes a considerable amount of time. Depending on the variety of jobs to be assigned to the computer, from 6 to 24 months should be allowed for detailed planning after the computer has been ordered and before it is installed. As stated earlier, there are only two general classes of jobs to be done on the computer—daily routine data processing jobs, such as earthwork calculations, and recurring jobs, such as bridge design, have the characteristic that the computer program used in their solution is written once and used endlessly; one-shot jobs, such as traffic analysis, which occur with random frequency but are too big for hand calculation, may require a different program for each occurrence. But neither class can be done without a completely tested program. All programs for recurrent jobs and foreseeable occasional jobs must be finished prior to machine installation so that useful work can be done the day the computer is turned over to the organization. For large engineering organizations, routine data processing is the bread and butter paying for the computer. Experience of one manufacturer which has installed some 500 intermediate-speed computers primarily for data processing, indicates that the most successful installations were those allowing from 15 to 24 months for preparatory planning.

The location of the computer must be recommended by the computer committee. In engineering organizations where a single intermediate-speed computer can handle all computations, the machine should be centrally located at the organization headquarters. Data from the field can be funneled to the center (via mail, messenger, radio, teletype, transceiver, etc.), processed, and returned immediately. If the communication lag offsets the advantages of centralization as it might in international operations, smaller computers would be appropriate at each sub-headquarters. A more common reason for decentralizing occurs in a completely decentralized organization. When sub-headquarters do all their own work and merely send reports to the super-headquarters, a computer would be assigned to each group that has a work load justifying electronic methods. In this case, it is often important to have a similar or, at least, compatible machine at super-headquarters to process the field reports and to present data for management decisions.

NEED FOR COMPUTERS

Computers are needed to solve engineering computations presently done by professional personnel or not done at all. They provide additional benefits in accuracy, speed and ease of operation, as well as research and development possibilities. Results become available in minutes rather than weeks and they represent a more complete analysis of the data than was ever possible with manual methods. So far the most urgent projects have come under attack from the computer planners. Survey and earthwork problems have been solved in programs which are available from manufacturers' libraries and computer user groups. Bridge design is rapidly being adapted for electronic methods. So are the other problems listed earlier.

For example, an organization which is faced with extensive culvert construction may wish to take advantage of the benefits of a computer. The engineer would examine his problem and see that the size and gage of each culvert can be based on such field data as rainfall intensity, drainage area, etc. But the solution of Manning's formula which involves fractional exponents is not easy. By collecting all the field data for a culvert in a punched card, the engineer can write a computer program to solve Manning's formula for a single culvert. Then, by repetition all the culverts can be designed using the same program. As he writes his program, the engineer will see that it is practical to place a table of pipe sizes, gages, and standard culvert areas in the memory of the computer. As the quantity of runoff to be handled by each culvert is calculated, it can be used to find the exact area of culvert required. This area, when compared to the table of standards, will determine the particular type of culvert to use. The time to run through the entire process would take only a few seconds on an intermediate speed computer (after the data have been prepared). Therefore, this job would easily fit on a machine originally procured to do other types of calculations.

The drainage example illustrates how many distasteful or difficult manual computations can be converted to electronic methods. Another important area is the initiation of jobs not now done. Today, it is assumed that aggregate should be hauled from the nearest yard or borrow pit to the destination When there are many aggregate sources with different capacities, the assumption does not always result in the least cost of hauling But no one has time to compute what source should supply each destination on a large contract. There is a method, called the "transportation problem," for mathematically minimizing the cost of hauling. All that is required is a list of aggregate available from each source along with requirements at each destination and the distance between each source and each destination. The data all arranged into a set of simultaneous equations which are solved by a repetitive process. At each stage of the process there are sufficient clues to indicate how to make the next try better than the last. At the end, a simple clue shows that no further reduction in hauling cost is possible. The results tell exactly how many yards to ship from each source to each destination to fill the requirements at the lowest cost.

Such a transportation computation is very time consuming when more than a few sources are considered. Even on a computer, a day's hauling assignments might take half an hour to solve. But there is this advantage—using a program available today in program libraries, the best hauling assignments for each day's operations can be made as soon as all the requirements are submitted. By processing phone reports from the aggregate sources against radio, phone, or written requisitions from the road gangs, daily programming of haul trucks can become an efficient, economical procedure.

The transportation problem and its more general parent "linear programming" optimize more than just aggregate hauling costs. They will compute maximum profit or minimum cost for any operation which can be adequately described. It would be desirable to optimize, the dispatching of earth moving equipment for an entire organization as a unit. But those who have tried know that the task is impossible without the aid of electronic computers. On the other hand, an electronic computer can speed through the repetitive arithmetic at a rate inconceivable by other means. So the organization which uses a computer to take the burden of daily engineering calculation from the engineers' shoulders automatically has a tool capable of improving management efficiency by programming all organizational operations.

CONCLUSION

The immensity of the new Federal highway programs has highlighted the need for increasing engineering productivity. New earthmoving equipment will increase speed of building. New prefab and surface laying techniques will also contribute to the "doing" end of highway construction. New instruments, better surveying methods, new techniques of reproduction will speed up the "collecting" phase of design. But none of these changes affect the "thinking" phase. The only way to improve "thinking" output is to put more brain cells to work. That doesn't mean waiting until a new generation graduates from college. It means trying for 100 percent use of the trained, experienced brains now available. Electronic computers will do this in two ways: (1) the computers will do the back work now occupying a major portion of each engineer's time; (2) the computer will amplify the output of each engineer by giving him improved analyses of the facts on which he bases his decisions.

For these reasons, each manager must investigate electronic computing methods as they pertain to him, and he must bear in mind that he is studying equipment which is so powerful that it must be operated by his best men lest it become a hindrance instead of a help. He must realize too that the computer will not think for him but will merely provide him with better information, sooner, and in more quantity than he ever had before. Properly used, the computer will be a tool contributing to his more effective leadership.

Coordination of Plotting Instruments and Computers in Cross-Sectioning and Calculation of Quantities

E. S. PRESTON, Engineer of Location and Design
Ohio Department of Highways

● THE shortage of trained engineers needed to meet the increasing demand for highway construction plans has prompted the search for ways and means of increasing engineering productivity. Necessity has accelerated the development of new techniques employing new tools in highway engineering. As these new methods, are developed and proved it is not only possible to increase production beyond original expectations, but errors will be substantially reduced and the quality of finished plans will generally be improved.

In the past ten years aerial photogrammetry has been slowly gaining acceptance and is now approaching universal recognition as an essential tool for highway engineers. More recently, high speed computers have been considered as a useful tool. Each of these tools is now proven to be of great value to highway engineers. However, when aerial photogrammetry is coupled with electronic data processing equipment, each is a very practical supplement to the other and results in automation of standarized routine operations.

Because of its simplicity and comparitively low cost, the Kelsh plotter has been adopted for photogrammetric work in Ohio. When proper procedure is followed, a very satisfactory degree of accuracy is achieved quite economically. Original cross-sections are taken directly from the plotter as "spot" readings and not interpolated from a contour map. Cross-sections obtained by direct readings from the plotter, similar to those taken in the field, are faster and are far more accurate than when taken from a contour map.

The plotting table of a standard Kelsh plotter provides instrumentation which makes possible accurate and easy reading of elevations. Horizontal distances, however, are determined by scaling between marks made on the manuscript with the pencil stylus. Obviously, this method of determining horizontal distances is much slower, less accurate and has more possibility of errors than the simple operation of reading elevations from an indicator which is calibrated to 0.1 ft.

To overcome this disadvantage a device has been developed to be used in connection with the Kelsh plotter that will measure horizontal distances with equal ease and with the same degree of accuracy as in reading elevations. This attachment measures the distances from the centerline for cross-sections to the nearest 0.1 ft. By installing an electronic counter onto both the vertical and horizontal measuring devices the cross-section data is recorded automatically. The electronic counter impulse, when fed into a digitizer, is transformed into a usable signal for a printing key punch machine. Thus, the operator sets the plotting head and adjusts the dot of light on the apparent surface of the ground at the point where he wishes to take a cross-section reading. Then by pressing a treadle switch with his foot, the elevation and distance from centerline are automatically punched into a card and printed across the top of the card simultaneously. By printing simultaneously, a visual record of the observations as well as the punched card is obtained. The keyboard on the key punch is used by the plotter operator to key in the project code number and identifying station number.

The original cross-section (terrain data) is thus automatically punched onto cards by the Kelsh plotter operator. The terrain cards, along with other cards containing basic information for the proposed design section, are then fed into an electronic computer for development of coordinates of the proposed design section. The first step of calculation deals with roadbed information between the outer limits of the outside shoulders. The proposed section between these points falls into three primary conditions; i.e., normal crowned section, superelevated right, and superelevated left. By entering the coordinates for the three conditions into the memory unit of the computer and assigning each a code number, the appropriate section can be applied to each station. For developing the design template beyond the shoulder the computer is scheduled to select the proper backslope and embankment slope ratios, based upon the height of fill, the depth of cut, and other predetermined conditions. For sections that are not identical to the coded sections already introduced (such as widening or narrowing of median on 4-lane divided pavements, transitions from 4-lane divided to 2-lane undivided, spill-through slopes at bridge abutments, acceleration lanes and deceleration lanes, and interchange ramps) coordinates are entered for each individual section. However, once the coordinates for such conditions are worked out, each set is indexed and used repetitively in like conditions. Thus, the computer develops the basic design data into a complete set of coordinates for the design template at each station, disregarding special ditches, special benching, unusual cut slope, etc.

At this point it was necessary to develop another piece of new equipment for the system of automation. This consists of an assembly of equipment that will take the cards originally punched with the terrain sections and the design data cards which were produced by the computer, and automatically plot the sections graphically, showing the design template superimposed on the terrain cross-section, the station number, proposed profile grade elevation and the elevation of the original ground at the centerline. These basic sections, as automatically plotted, will then be studied by the designer, along with large topographic maps that are available, and will provide the information needed to refine the design and lay out special ditches, benching, backslope modification, etc., that are essential to good design.

After the designer has made his analysis and established the special conditions that should be incorporated in each section, the revised data is added to the design cards. The original terrain cards, along with the completed design data, will then be put back through the original process to provide a graphic plotting of each cross-section of the final proposed design. The designer can then examine each section as a check on the adequacy of the proposed design and also eliminate any obvious errors. Occasional sections can also be selected to be included in the construction plans. In order that the proposed work will be clearly indicated to the contractor, the occasional sections will be photographically reproduced on transparent plan size sheets and will be incorporated into finished plans.

The next step of the computation is the actual calculation of end areas, volumes of cut and fill, information for slope stakes, area to be seeded, and the ordinates for a mass diagram. The coordinate cards that were used to plot the cross-sections are used as the input information for the quantity computations. The quantities as calculated are automatically tabulated and printed in table form and photographically reproduced for direct inclusion in the construction plans.

A mechanical plotter that will plot the points on the mass diagram is a proposed addition. The mass diagram will also be photographically reproduced and included in the construction plans. The mechanical plotter can also be used to plot a straight-line diagram of the construction work limits from the design cards. The plotted work limits will be used for the immediate determination of rights-of-way taking lines. This early determination of taking lines for rights-of-way will expedite the negotiation and acquisition of right-of-way.

Another application of data processing equipment that is now in the development stage is the tabulating and summarizing of the various construction quantities of detailed plans. In present practice, the various quantities are shown on the individual line or detail sheets. The quantities of all items are then gathered into a sub-summary according to sheet number and specification item number. The totals of the sub-summaries are then used to prepare the estimated quantities for each of the various items of the general summary which is used for bidding purposes. By punching cards for each sheet with the quantity of each coded item number, one can mechanically summarize, tabulate and print the sheet summary, sub-summary and the general summary in the proper form for direct reproduction into the plans.

There are several other phases of plan development where the electronic computer will be extremely useful, such as traverse closures, hydraulic analyses, and especially in bridge design. Ohio practice, however, has been concentrated on roadway design and earthwork problems which are considered to be the most fruitful area in which to increase engineering productivity immediately Photogrammetry, electronic computers and other modern devices of automation are considered essential tools that must be employed to meet the challenge now confronting highway engineers.

General Discussion

WILLIAM R. ALLEN, Maryland State Roads Commission, Baltimore: It would be desirable to have more specific information as to the best way to learn how to prepare the information for a computer.

JOEL D. ARON, International Business Machines Corp., Washington, D.C.: There are several textbooks that may be found useful as sources of information on computer usage. One extremely interesting book is W. J. Eckert's "Faster and Faster," published by IBM (590 Madison Ave., New York 22, N.Y.) which has been out for about two years. Another is Bowden's "Faster Than Thought." Both of these describe in considerable detail what a computer is and what it does, but they do not get specifically into highway engineering. The reason for this is primarily that highway engineering is only now starting to use computers. Because none of the men who are developing this area has yet written a book about it, there are no references. A more practical method of learning the details might be to do what is done in the aerial photography field: go to a consultant or an expert.

There are several consultants who deal with computer use; one is Computer Usage Company, in New York, another is Canning, Sisson and Company, on the West Coast. But better, perhaps, than these would be the manufacturer's special representatives. Most computer manufacturers now maintain at least one special representative in highway work to call on state highway engineering groups and discuss the use of computers with them, as specifically related to their own problems. This is probably the best reference, because at present most books on the subject deal with, say, aeronautical engineering; but they do not tell the reader how to go about setting up data for highway engineers.

In general, the method of preparing data will be merely to copy the information presently available into machine language, which means to punch it into cards or paper tape, or to get it onto magnetic tape in some cases. This is strictly a mechanical process, which would be explained by the supplier of the equipment. Much more important, in every case, is the development of the logic behind the problem. For assistance in developing the logic there are numerous courses in how to program a computer; that is, how to write the instructions for the computer. These courses, offered by the manufacturers and by an increasing number of universities, are short courses. The university courses are frequently in the summer and from two to four weeks long. The manufacturers' courses are scattered through the year and of about the same duration. Such courses constitute the best way to find out exactly how to solve a particular problem on a particular computer.

S. E. MARTIN, Royal Canadian Air Force, Ottawa: In the California work in photogrammetry, has the contractor been paid on the basis of photogrammetric quantities?

L. L. FUNK, California Division of Highways, Sacramento: Present practice is to re-cross-section immediately prior to construction, at the time of slopestaking. In several districts—in several of the active contracts— those cross-section notes are simply checked against the maps, and minor adjustments are made in the preliminary quantities, based on the errors.

S. E. MARTIN, Royal Canadian Air Force, Ottawa: Have any comparative checks been made on the actual instrument work versus the photogrammetry?

L. L. FUNK, California Division of Highways, Sacramento: Yes, checks are made of practically all of the mapping contracts by running profiles on them. In general, they comply with the accuracy specifications, which are within 90 percent within a half-contour interval; in the case of 2-foot contours, that would be 90 percent within 1 ft. As to comparative quantities, there are probably ten or twelve projects on which percentage comparisons have been made between preliminary quantities by photogrammetry and final quantities by ground survey methods. On six projects those differences were less than 3 percent; in several cases they were less than 1 percent; in other cases they have run as high as 5 or 6 percent. It should be noted, however, that this is a poor way of expressing it, because in a 100-ft cut a ½-ft difference between the photogrammetric ground surface and the field survey ground surface means little, percentagewise, whereas in a 2-ft cut it would mean much more. In any event, the percentage is far less in error than the estimate of shrinkage factor would be. Furthermore, there is some ground for question in a lot of cases, particularly in rugged terrain, as to whether the photogrammetric or the field survey quantities are right—the field cross-sections could be in error too.

E. S. PRESTON, Ohio Department of Highways, Columbus: In Ohio, three projects have been measured—the original and final—by aerial photogrammetry; but a contour method is not used in calculation of earthwork. Instead, a spot elevation is used, the final payment being made on preliminary and final cross-sections obtained by photogrammetry. The procedure, it is hoped, will be developed as a standard practice will include cross-sections by photogrammetry on the heavy earthwork projects. That is where such methods will pay their greatest dividends. It is not expected that the entire state will be covered, because that much equipment is not available.

WILLIAM T. PRYOR, Bureau of Public Roads, Washington, D. C.: Aside from its use in determining the best location for a highway, one of the greatest benefits of photogrammetry lies in making measurements to determine quantities for the payment of contractors.

The Bureau of Public Roads has a project relevant to this on trial now, in a heavily timbered area on which the preliminary survey was made on the ground. After the initial design had been made, the project was staked for clearing. After the clearing is completed this year, the project will be photographed. Then, using the ground control, tied to the preliminary survey mapping, it will be mapped by photogrammetric methods. This procedure should give good ground data for accurate measurement of the ground's surface. When the construction is completed the route will be photographed again. The ground control used for mapping after clearing will suffice for mapping the constructed highway by photogrammetric methods to determine moved graded quantities. The extra (second) photography will be very inexpensive and the ground control needed for after-construction mapping will be practically nil, because the initial ground control can be used after the construction.

It is felt, therefore, that synchronization of these methods can be easily accomplished. Where there is no ground cover, of course, a preliminary survey on the ground will not be necessary; the first set of photographs can be used to make that survey, to design the location, and to prepare construction plans. Pennsylvania has done one project in this manner and found it to be very satisfactory.

FRED B. BALES, Virginia Department of Highways, Richmond: In the selection of a camera, where is the line drawn between the 16- and the 8¼-in. focal lengths?

J. H. WICKHAM, JR., Aero Service Corporation, Alexandria, Va.: The choice is predicated on one thing—what will the camera be used for? Some of the papers of this session have pointed out that if the photography is to be used for reconnaissance, the longer focal length camera is desirable. If large-scale maps are to be compiled, the camera should possess all of the geometric qualities needed to assure that the resulting film can be reconstructed into the map, as well as afford factors of economy and accuracy. For this, a shorter focal length camera is desirable. The cameras referred to by Miles are cameras of American make and have been and will continue to be extensively used with great success in obtaining reconnaissance and large-scale photography; but some foreign cameras, such as those by the Zeiss and Wild, have desirable lens and shutter features that must be evaluated with the job requirements when selecting the make of camera.

It is difficult to say exactly what camera to select, as no one will efficiently suit each requirement. Also, the camera has to be selected for the equipment that the photogrammetric operation is geared to, so that geometrics of the camera and the plotting equipment will be alike, or can be compensated for.

R. D. MILES, Purdue University, W. Lafayette, Indiana: In the highway field or in a highway department it is not really economical to set up a large photogrammetric organization. A large organization would require having expensive cameras, running anywhere from government surplus cameras at $3,000 up to the new cameras that cost as much as $20,000 each. The type of photogrammetric equipment required to be used with them can run into first- and second-order instruments, which are very expensive. The highway department primarily should contract for the larger projects with the companies that have distortion free cameras and the first-order types of plotting instruments. On the smaller projects, such as site plan preparation and small location problems, maps can be obtained within the highway department by using the government surplus cameras and the Kelsh plotter, or some plotter like that of single model type.

WILLIAM T. PRYOR, Bureau of Public Roads, Washington, D.C.: Consideration should be given to the type of photography and the ground cover to be met before a decision is made as to what focal length camera to use. A camera of long focal length is quite effective for mapping areas that are very rugged, especially areas where the timber is tall and not so dense as to prevent seeing intermittent portions of the ground from the air. But short focal length aerial cameras give "perspective lay-over," an effect which causes the trees to hide the ground, even though they may be somewhat dispersed. Thus, regardless of the proficiency of the lens or the length of the air base, sometimes the ground will be hidden whenever the short focal lengths are used. Consequently, longer focal lengths (from 8¼ to 12 in.) have advantages under such circumstances. But as long as the ground is not covered densely with tall trees the shorter focal lengths, which increase the air base, are advantageous the 6-in. being the most commonly used in this country.

L. LYNCH, Wayne County Road Commission, Detroit, Michigan: What are the problems of training personnel in the use of the method?

L. L. FUNK, California Division of Highways, Sacramento: In California, electronic equipment has been used for road inventories and various statistical material for something like 18 years, and a tabulating section has been built up and gradually increased. This section has a number of statistical employees, mathematicians, and so on. It should be noted, however, that engineers are not used for programs, but to advise and work with the people who are carrying on the program. Very little engineering time is devoted to the unit, an attempt being made to get mathematics graduates wherever possible for that type of work.

JOEL D. ARON, International Business Machines Corp., Washington, D.C.: Most highway engineering departments cannot afford to put an engineer in the programming staff because of the shortage of engineers. Nevertheless, it is desirable to have an engineer programmer. To train either an engineer or a mathematician to use a computer, he normally would be sent to a school where the manufacturer teaches the programming of that particular computer, and then he would be sat down and given problems to solve for a period of several months—six months is a good figure—with the help of applied science assistance from the manufacturer. IBM, for instance, has in each of its offices an Applied Science Representative who will go into the users office. He has thorough knowledge of the computer, will advise on what to do at any certain point with the computer. But the user will still have to understand the problem thoroughly enough to get through from beginning to end. The figure of six months is a good guide to the extent of training one should have, in any event, before he starts to use a computer in his own office.

L. L. FUNK, California Division of Highways, Sacramento: There are so many programs being written for all types of equipment that the writing of new ones, particularly by smaller organizations, should be approached with some caution, because of the many programs already available.

WILLIAM T. PRYOR, Bureau of Public Roads, Washington, D.C.: Mr. Radzikowski, of the Bureau of Public Roads, who has headed the work of the Bureau in developing the use of digital computers in conjunction with photogrammetry, is intending to work out and effect a plan whereby he will have a record, if not the actual program itself, of the kind and location of all programs developed for highway engineering purposes. He in-tends to request cooperation in establishing a procedure for obtaining and distributing information on all electronic computer programs prepared for highway engineering purposes. The record would be useful in avoiding duplication of effort and perhaps pointing the way to adaptations that could be made to fulfill new needs or to programs that someone else has already worked out. Either of these would probably involve less effort than would the preparation of an entirely new program for the digital computer.

T. F. MORF, Illinois Division of Highways, Springfield: An engineer with the knowledge of what kind of computer to use is very valuable to an installation. All are trying to accomplish the same end; and the end has to be understood as an engineer would understand it, in order to decide new approaches to it. There are two functions involved. The first is to translate the problem into the type of thinking that a computer does. The second, having done that, is to translate that method into machine language. Establishing a compatibility between the engineer's thinking and the machine's thinking is a job for an engineer trained in computer usage. Also, translating the engineer's ideas into things the machine itself can handle is the coder's or program writer's job.

JOEL D. ARON, International Business Machines Corp., Washington, D.C.: The program library that Mr. Radzikowski has in mind is extremely important. It will explain a problem in engineering terms, but it will not necessarily translate it for a specific computer. The major advantage of this is that any program developed and worked out into great detail can be further coded for any manufacturer's machine. There need be no worry as to whether an IBM program can be adapted to the use of a Bendix machine; it is possible under such circumstances.

L W. BROWN, Mississippi State Highway Department, Jackson: Is it true that some of the foreign makes of cameras are distortion free?

R. D. MILES, Purdue University, W. Lafayette, Indiana: Distortion is caused by the lens system, and in this country quite a few lens systems are of the Metrogon or wide-angle type. Then there are the Planigon, Pleogon, Avigon, and a couple of other types. These generally have correction plates designed into the lens system so that they are as distortion free as an optical system can be made.

L W. BROWN, Mississippi State Highway Department, Jackson: If so, why couldn't the necessary requirement be written into the specifications for the contract? For example, with the Kelsh plotter each time a different company flies the pictures, there must be a special fixture or cam the particular camera used.

R. D. MILES, Purdue University, W. Lafayette, Indiana: It is entirely possible to specify the characteristics of the distortion system involved, such as cams or correction plates, and to specify a maximum and minimum range for them. It also would be wise to require a test report to see that the camera to be used on the project fulfills the needs.

J. H. WICKHAM, JR., Aero Service Corporation, Alexandria, Va.: It is much better to specify the end product. That is, it is known what map specifications will be needed to accomplish the work, therefore, one should concern himself only with these specifications. To get into the details of specifying distortion-free lenses or other special equipment needlessly complicates the matter and enlarges the highway engineer's problems. It is true that the distortion-free lenses have a lot of advantages, but certain complications may not require the use of a camera with lenses having distortion-free characteristics. Their use should not be arbitrarily required; the requirements of the job should dictate their use to the photogrammetric engineer.

H. A. HENRY, Texas Highway Department, Austin: What type of paper is preferred? Should it be in a roll, or in sheets? Which is the most practical?

L. L. FUNK, California Division of Highways, Sacramento: It all depends on the requirements of accuracy. Seven California districts have specified maps on good quality tracing cloth, which is satisfactory; others are requesting K and E Stabilene, a mylar-base film which has a high degree of stability. Some request map sheets up to 10 ft long; others like sheets 36 in. by 72 in. The sheet size, of course, is a matter of individual preference, experience, and filing problems. The material is a matter of requirements as to accuracy and a stability of the material to hold scale over a long period of years.

E. S. PRESTON, Ohio Department of Highways, Columbus: The choice of material and size depends largely on the use intended to be made of the particular topographic map. If a map is intended to be used as a site plan for structures, the entire site plan probably would be on one sheet. However, the topographic map may not be accurate enough to be used as a basis for design. On the other hand, if the topographic map is to be used in a reconnaissance survey it should be in a roll and on linen.

L. E. GREGG, Kentucky Department of Highways, Frankfort: What would be suitable map materials for mapping by photogrammetric methods?

WILLIAM T. PRYOR, Bureau of Public Roads, Washington, D. C.: The first important decision to be made about map materials concerns the map compilation manuscript itself—the base material on which the map is to be made. One good scale-stable material has a Mylar (polyester) base and is scribecoated so that the map can be compiled on it with a pencil. A needle can then be used to scribe through the coating to make a manuscript, which can be used to make reproductions in the same manner that a photographic negative is used.

Prints of the original can be made on any material adequate for an engineer's use. First, however, a plane coordinate grid must be placed and scribed on the manuscript, its values having been accurately adjusted for scale and elevation so as to apply at the average elevation of the survey project. In other words, the state plane coordinates are lifted up to the level of the area where the highway survey is made. There are two corrections necessary to make state plane coordinates apply along the preliminary survey of a highway route not at sea level. One is called scale correction, which is obtainable from the U. S. Coast and Geodetic Survey; the other is the correction for elevation above sea level. Elevation correction factors for aerial surveys and photogrammetric highway mapping have been prepared by the Photogrammetry for Highways Committee of the American Society of Photogrammetry and the American Congress on Surveying and Mapping, and were published by the U. S. Government Printing Office in 1956. Dividing the elevation correction factor by the scale correction factor gives a combined correction factor that will lift the basic horizontal control up to the level of the survey, give accurate coordinates for control survey station markers, and cause all distances measured on the maps to agree by scale with horizontal distances measured on the ground. It really would not matter then what the map reproduction material is, because if it shrinks a little or expands a little all map details which were previously positioned accurately on the scale-stable manuscript will retain their relative positions. Therefore, adjustments can be made mathematically for map detail in relation to the coordinates. This can be done to allow for scale changes on map reproductions when the highway alignment is being computed or any other position determinations are being made on the map. Accuracy then is commensurate with the compilation—and that can be accurately done at map scale to within about 0. 01 in. for the plane coordinate grid lines, about 0. 025 in. for most contours and points or lines in the planimetry, and about 0. 05 in. or less for not over 10 percent of the map detail.

N. J. SOLLENBERGER, Princeton University, Princeton, N. J.: What is the IBM policy with respect to training personnel in the use of computers?

JOEL D. ARON, International Business Machines Corp., Washington, D. C.: Various training course are offered at no cost to the customer who has the machine on order or installed. In the case of the Federal Government, the meaning of that phrase is extended to include training for all members of the Federal Government, because some part of the Federal Government does have machines installed. It is reasonable to assume that the same would be the case for a state government; if a machine is installed in the state government, but not in the Highway Department, the highway engineers would normally be trained at no cost. A commercial customer can only be trained if he has a machine on order or installed. The training is not sold. This means that a person normally cannot enroll unless his organization (in the broad sense of that word) has a computer on order. The training courses vary in length from one to four weeks and cover two different major subjects. One subject is, more or less, on "hardware"—what the machine consists of and how the pieces are put together. The other type of course is programming, or how to make the machine work.

Most of the company's branch offices—these courses, incidentally, are offered in local regions—are now conducting courses for engineers where the examples are mathematical in nature, in addition to their standard courses which are designed for commercial accounting customers. Therefore, highway engineers normally would be most interested in specific courses for engineers in programming on machines of intermediate speed, which in the IBM case is a 650. The longer courses are for larger machines, for which there has not yet been established any justification in most highway departments. Intermediate speed machines, however, are in quite high demand among highway engineers.

L. W. BROWN, Mississippi State Highway Department, Jackson: What is meant by the ratio between the denominator of the map scale, expressed as a representative fraction, and the contour interval of the map, expressed in meters or feet?

WILLIAM T. PRYOR, Bureau of Public Roads, Washington, D. C.: In my paper I couldn't deal with the principle in detail, but could only introduce it. For efficiency in mapping by photogrammetric methods for highway engineering purposes, highway engineers would do well to maintain a relationship between the map scale and the contour interval which can be expressed numerically. There are two ways to express scale. One is by a representative fraction, such as 1 ft in 5,000 ft, which means that 1 ft on the map represents 5,000 ft horizontally on the ground. The second way is in feet to the inch, or a number of feet on the ground represented by 1 in. on the map.

The paper suggests that the denominator of the scale of the map as a representative fraction should be 1,600 times the contour interval if the contour interval is expressed in meters, and 480 times the contour interval if the contour interval is in feet. As a representative fraction, consider the denominator 4,800 of a scale of 1: 4,800—which in the feet-to-one-inch system represents a scale of 400 ft to 1 in. If the contour interval is 10 ft, the map scale should be 1: 4,800, or 1: 480 x 10; if the contour interval is 1 ft, the scale of the map should be 1: 480, or 1: 480 x 1.

Now consider the same problems while expressing scale in feet to one inch. The representative fraction scale of 1: 480 equals a scale of 40 ft to the inch. In the paper, it is mentioned that if the map scale were expressed in feet to one inch and the contour interval in feet, the ratio between map scale and contour interval should be 40 to 1. Thus, a map scale of 40 ft to 1 in. and a contour interval of 1 ft are in balance. Also, a scale of 200 ft to 1 in. and a contour interval of 5 ft are in balance for efficiency in photogrammetric mapping.

These principles also mean that if, for example, a contour interval of 2 ft is requested on a map to be compiled at a scale of 200 ft to 1 in. the contour interval would govern the aerial photography scale for the mapping. Conversely, if a contour interval of 10 feet is asked for on a map scale of 200 ft to 1 in., the scale of the mapping would govern the scale of the aerial photography. Such are examples of the relationship between map scale and contour interval, which, although somewhat empirical, if properly applied will enable one to employ photogrammetric methods with economic efficiency.

WILLIAM H. MEYER, Jack Ammann Inc., Manhasset, N. Y.: What contour interval is the 3 percent variation between preliminary and final quantities based on?

L. L. FUNK, California Division of Highways, Sacramento: In five projects in which the variation was less than 2 percent, the range was from 0.11 percent up to 1.9 percent. The four highest were on 2-ft contour intervals, the 0.11 percent was on a 5-ft contour interval project which was supplemented with field profiles through level areas where the 5-ft contours would not show up. In all of those, it might be pointed out, it was a case of balancing back and forth, as certain cuts would vary by 10 to 15 percent; the errors, however, compensated.

WILSON T. BALLARD, The Wilson T. Ballard Company, Baltimore, Md.: Is there any information available regarding design costs by full automation methods compared to conventional methods?

L. L. FUNK, California Division of Highways, Sacramento: That information is not available. However, information regarding photogrammetry only, before California started using the electronic computer for earthwork, is available. It is estimated that by the use of large-scale photogrammetric maps for design around 40 percent has been saved in costs and about 70 to 80 percent in manpower in the survey stage. When that is carried on into the design stage, about 30 percent additional can be saved in design costs; this is, without automation, and based on the contour grading or horizontal slice method. In design, it is estimated that at least 50 percent would be saved when full automation is combined with photogrammetry.

E. S. PRESTON, Ohio Department of Highways, Columbus: There is not only a substantial difference in cost, but also a substantial saving in personnel, which is of great importance to all highway departments under the stepped-up program.

WILLIAM T. PRYOR, Bureau of Public Roads, Washington, D. C.: Suppose it cost as much to make the designs by rental of computers as it does by present methods? The benefits derived from the computer work, even if the costs were the same as by doing the work in the usual manner, would warrant its use in conjunction with photogrammetry. This is so for two reasons—the saving of time and manpower, important savings these days; and, more important, the better engineering achieved by the making of better locations and designs.

On all projects where comparisons have been possible, the chance came unexpectedly. It was not pre-planned, because the organization for which the writer works is conservative and usually does not do its work two or more different ways to find out which way is the best. By chance, however, situations have been found where someone had done part of the work one way, and where we (by completion assignment) were called upon later to do the whole in order to attain continuity. Thus, the work done previously on the ground was later duplicated by aerial photogrammetric methods—and usually for other purposes. In every such case encountered the estimated savings in construction costs have been phenomenal. In addition, the quality of alignment, gradients, and cross-sections has been better on the route determined by aerial survey.

One 15-mi project in Central America can be mentioned where the savings were almost unbelievable. A decision had to be made whether or not to abandon a $30,000 ground survey, because a different location determined by aerial survey was being recommended. This situation happened to occur because the route location problems included the determination of feasible route alternatives between terminal points 100 air-miles apart. The ground survey had been made by other engineers over the southern 15 mi one year previously. It was not feasible to connect with the ground-surveyed location and use it as part of the aerial-surveyed route. Therefore, a different route location for the southern end—an alternative to the ground-surveyed section—had to be recommended. After the aerial survey had been completed and the two were compared by going over the routes on the ground with profiles in hand, savings between the ground-surveyed and the aerial-surveyed highway were $300,000 for grading and $4,000 for bridges! Incidentally, there were eight rivers that had to be crossed.

On a second route location project in Alaska, the aerial survey route was only 40 mi long as compared to a 53-mi ground survey route—a shortening of 13 mi. It was shown that it was possible to abandon 14 mi which had already been built at the beginning of the 53-mi route and still save money. Not only that, there were grades no steeper than 5 percent and curves no sharper than 5 deg as compared to grades as steep as 7 to 10 percent, and curves as sharp as 10 to 40 deg on the longer route. The big benefit then, regardless of survey costs, is in the end result obtained by full use of photogrammetry and aerial survey methods. The secondary benefits are the combined savings in time and manpower.

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The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.