Introduction to Photogrammetry and 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-

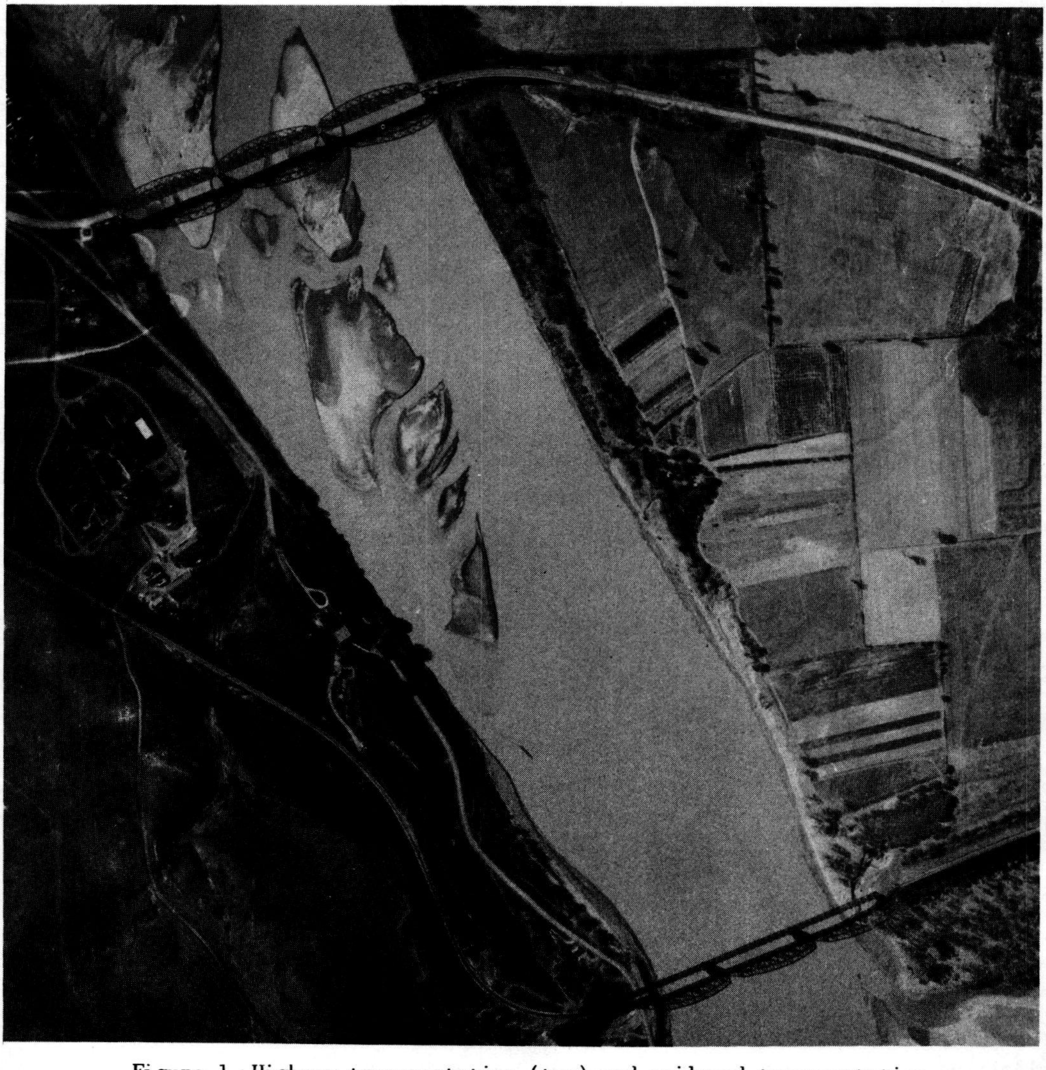


Figure 1. Highway transportation (top) and railroad transportation (bottom): other land use includes farming on right, river in center, and industrial plant on left.

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.

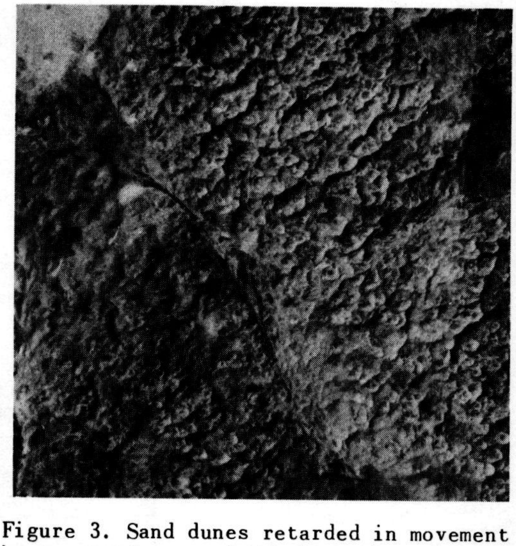


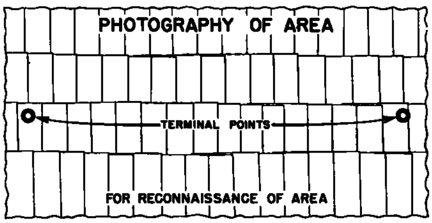
Figure 3. Sand dunes retarded in movement by vegetation; such wind erosion characteristics are easily determined by examination of aerial photographs.

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.

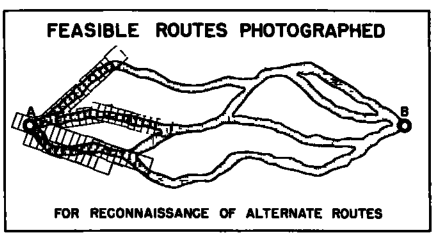
Highway location and design are the use of essential qualitative information and quan-



FIRST STAGE

RECONNAISSANCE SURVEY OF THE ENTIRE AREA BETWEEN TERMINAL POINTS

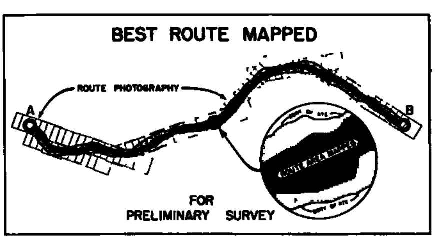
1 STEREOSCOPIC EXAMINATION OF SMALL SCALE AERIAL PHOTOGRAPHS OF THE AREA, SUPPLEMENTED BY AVAILABLE MAPS
2 DETERMINATION OF CONTROLS OF TOPOGRAPHY AND LAND USE
3 LOCATION OF FEASIBLE ROUTES ON THE PHOTOGRAPHS AND MAPS



SECOND STAGE

RECONNAISSANCE SURVEY OF FEASIBLE ROUTES·

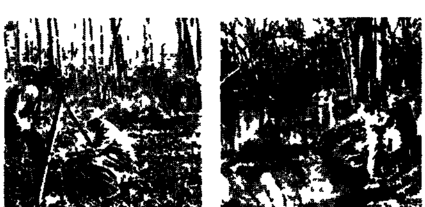
1 STEREOSCOPIC EXAMINATION OF LARGE SCALE AERIAL PHOTOGRAPHS OF EACH ROUTE
2 DETERMINATION OF THE DETAILED CONTROLS OF TOPOGRAPHY AND LAND USE
3 PREPARATION OF ROUTE MAPS BY PHOTOGRAMMETRIC METHODS WHEN NECESSARY
4 LOCATION AND COMPARISON OF FEASIBLE ROUTES ON PHOTOGRAPHS AND MAPS
5 SELECTION OF THE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

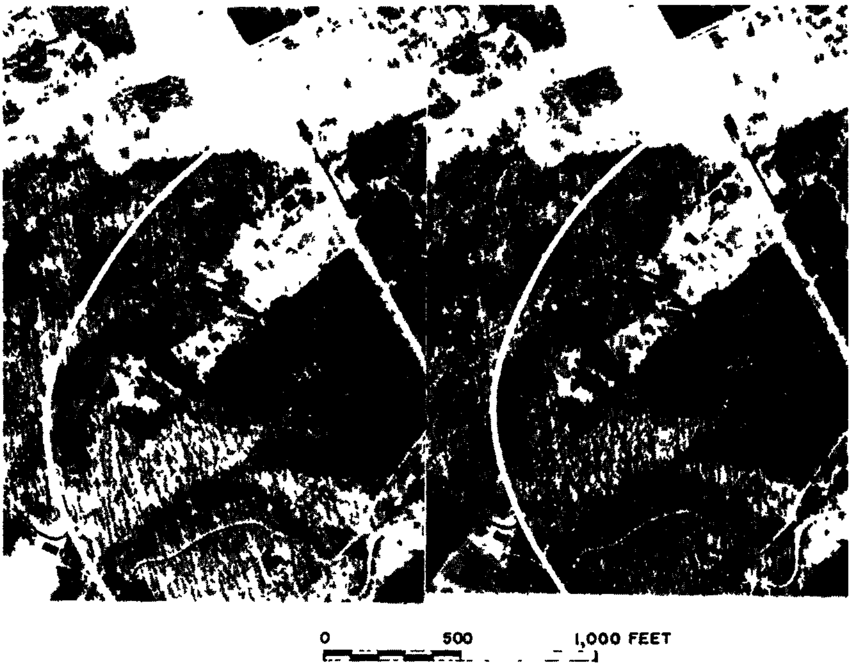


Figure 5. Stereogram of portion of highway route located in Stage 1 and selected in Stage 2 for preliminary survey in Stage 3. To examine a stereogram stereoscopically either of two methods may be employed—a lens-type stereoscope or the unaided eyes. To examine a stereogram with the unaided eyes, look 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

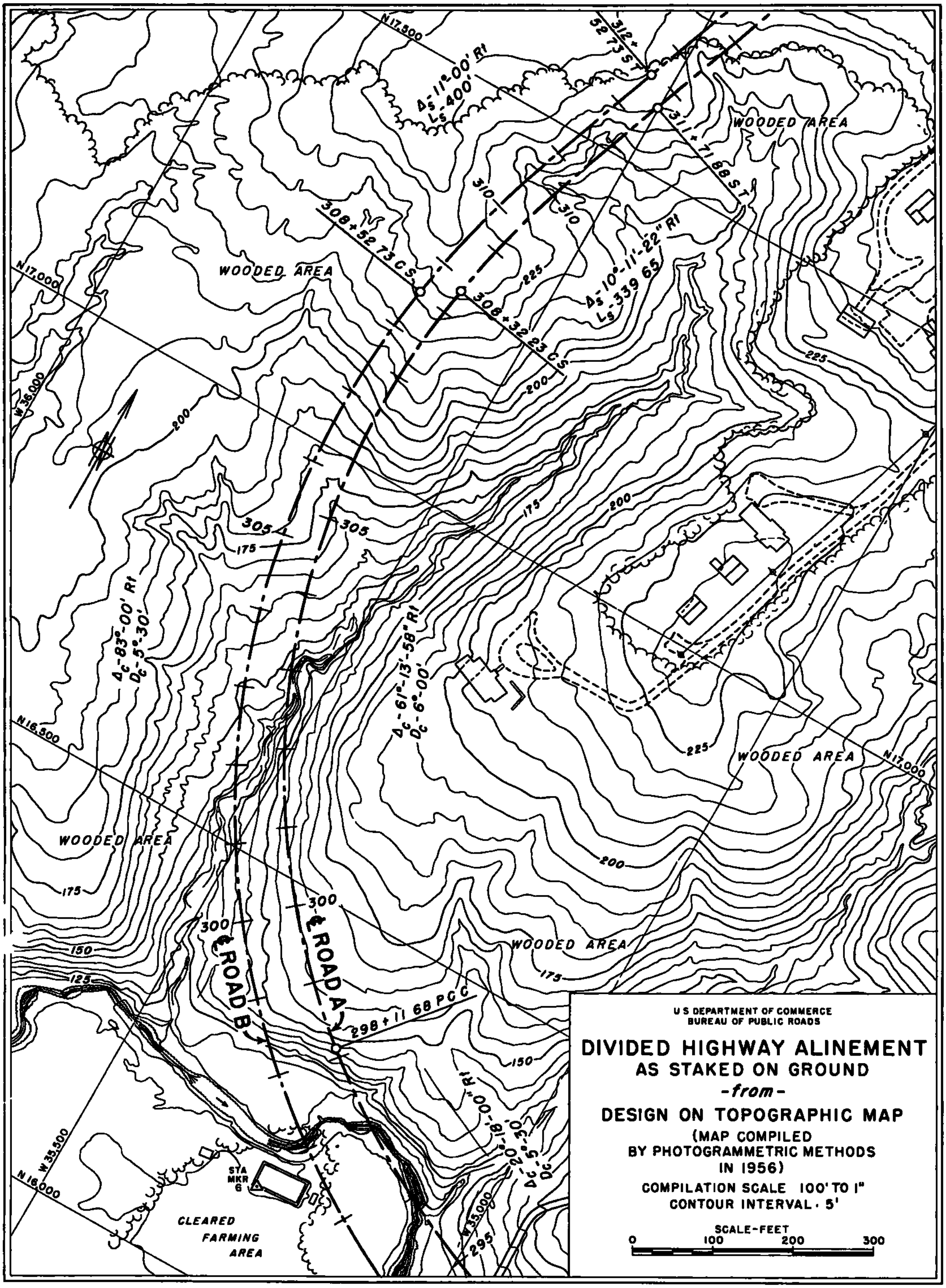
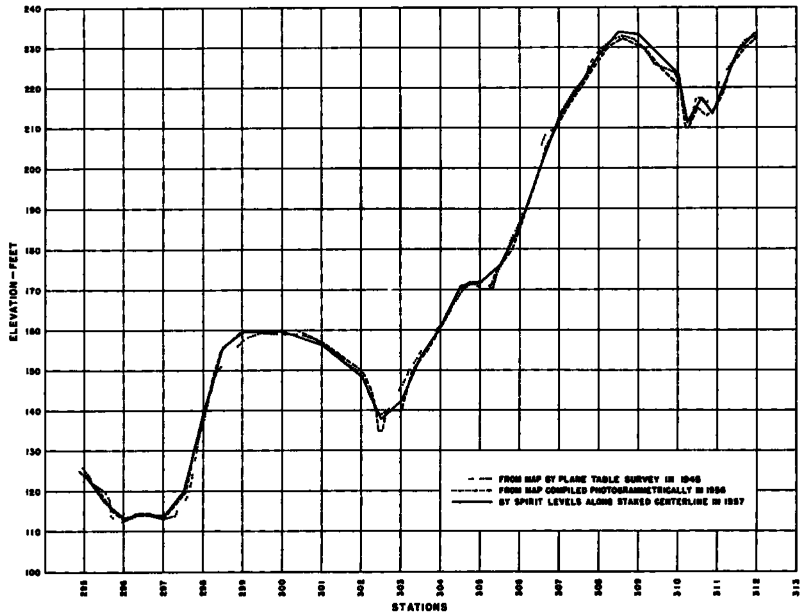
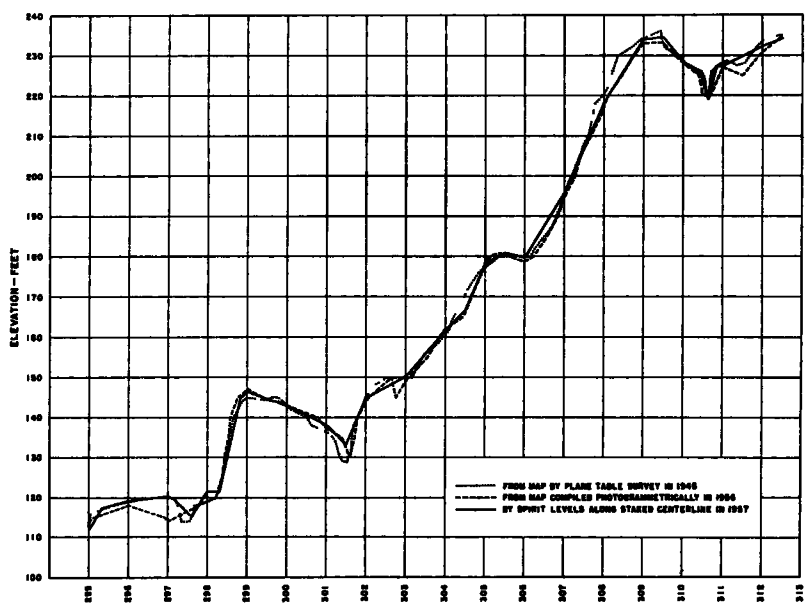


Figure 6. Section of topographic map compiled at 100-ft to 1 in. scale for preliminary survey, Stage 3 by use of photographs shown in stereogram (Figure 5). The designed location of roads A and B of a divided highway and station marker 6 are shown.



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-

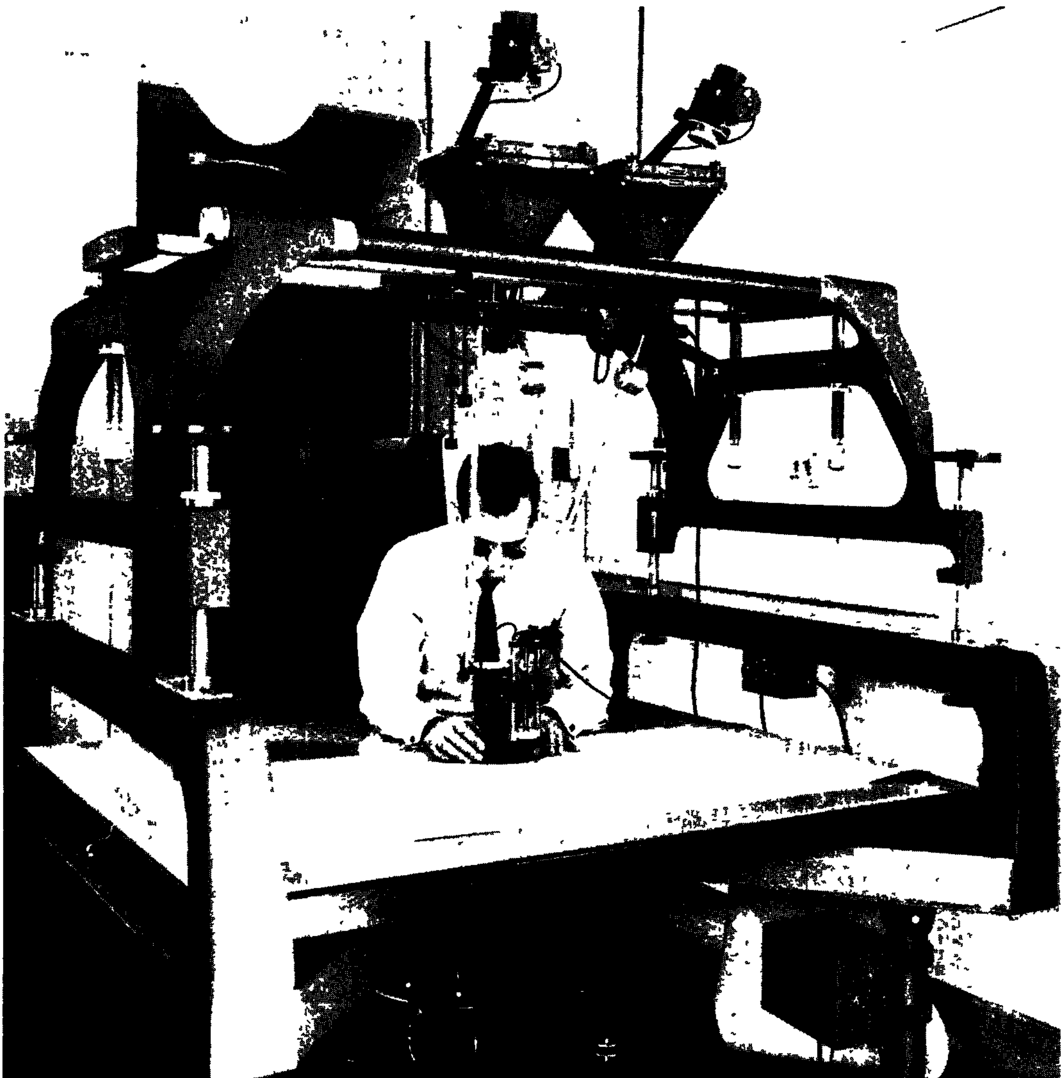


Figure 9. A Kelsh stereoscopic plotter, one of the types of precise photogrammetric instruments used for large-scale topographic and planimetric mapping by photogrammetric methods in the preliminary survey stage. Map in Figure 6 was compiled with this instrument.

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

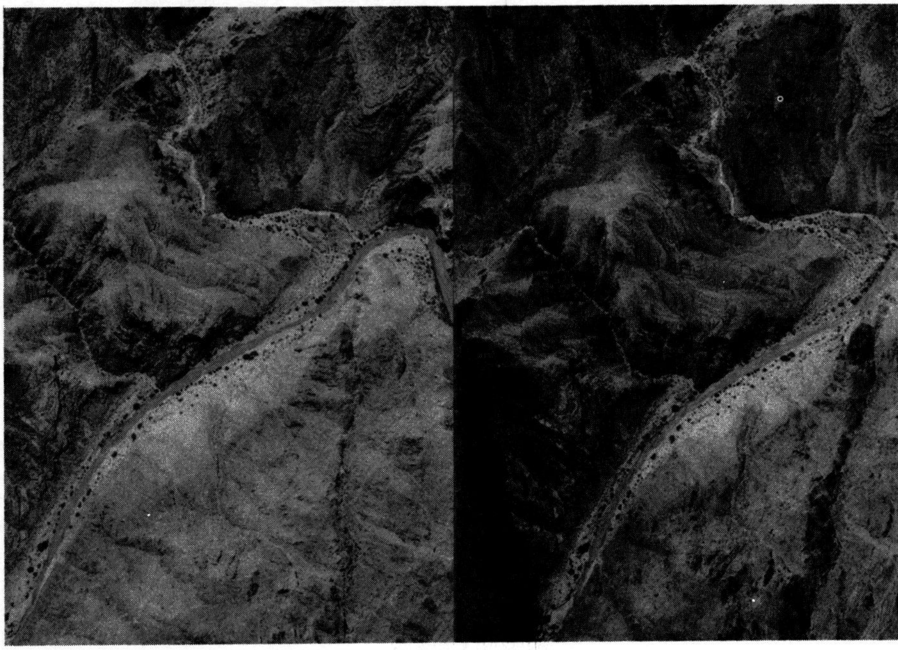


Figure 10. Vertical photography stereogram of rugged region eroded by river.

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.