Precision Photogrammetry and Highway Engineering

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•THERE is great need on the part of highway engineers to obtain as much information as possible regarding the nature and extent of the terrain along the route of a proposed highway location. In past years this information was collected from the field in the form of rough sketches, field survey notes, traverses, field-measured cross sections, and similar data, and transported to the office for evaluation and use in design. The methods used for these on-the-ground topographic surveys were accurate and the information obtained was necessary to the designer. However, it became more and more obvious that the methods were incomplete and that the time consumed in these topographic surveys was requiring a larger and larger percentage of the overall time allotted for the completion of the highway. Therefore, the engineer had to decide whether to continue his usual method of operation under a system that offered him something less than complete information from the field or to find a new and more acceptable means which could be used as a basis for his design. Photogrammetry has supplied part of the answer to this need and is now used successfully throughout the world as an economical and rapid method of obtaining topographic information in a minimum of time.

Photogrammetry in the beginning consisted mostly of very rough and inaccurate measurements taken from the aerial photograph itself. Although the precision involved in this type of data gathering was not that required for highway design, it was at least a method of transferring information regarding the character of the terrain from the field to the office in a very rapid manner. As the science of photogrammetry became more sophisticated, and newer and more accurate instruments were available which could translate the information on the aerial photographs to maps with a consistent and accurate scale, both horizontally and vertically, a new tool came into existence which enables the engineer to spend more time in design work and less in gathering data.

This paper concerns itself with the method employed by the Texas Highway Department Division of Automation in the photogrammetric compilation of topographic and planimetric maps and measurement of cross sections, preparation of photographic mosaics, and obtainment of other engineering data. It also outlines the uses of photogrammetrically obtained data in the different phases concerned with locating and designing a highway.

GROUND CONTROL

At the beginning of the operation when the survey is in the planning stage, if time and weather permit, a high-altitude photographic flight is made of the area. Contact prints or uncontrolled photographic mosaics made from this photography are furnished to the field crews to enable them to plan the control surveying work as closely as possible before arriving at the site in the field. In many instances, the general survey can be laid out on the photographs before the field crew begins its work. It is obvious, however, that this can never be done completely and a decision must be made in the field concerning the individual placement of each survey point.

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Since the photogrammetrically compiled maps must have complete and accurate ties to the terrain, it is of course necessary to conduct a field survey as the first step in the photogrammetric compilation of any map. The type of ground survey involved is not unique and has been used for many years and called by a variety of names, such as location survey, meander traverse, and basic control survey. As used by the Texas Highway Department, it can best be described as a survey of at least second-order accuracy, meandered through the general area of which the map is to be compiled. The survey is either closed upon itself or tied at each end to Federal Government triangulation stations or closed by celestial observations. Of necessity, this survey must be done as rapidly and as accurately as possible since its expense will exceed that of any other step involved in the photogrammetric mapping procedures. In addition, if the survey were not a rapid and efficient operation, then photogrammetry could offer no advantages over the regular ground location survey for a highway except completeness of detail. Therefore, automation in this phase is at least as important as automation of any other phase of photogrammetric methods. In the Texas Highway Department, Electrotapes are employed for all distance measuring and one-second theodolites (at times 2/10-second theodolites) are employed for measuring angles.

When need has been established for a new highway location, this Electrotape-theodolite traverse surveying usually begins on a USC&GS or a USGS triangulation monument and traverses the area to the end of the project, tying into a similar monument. The survey is conducted much as if it were a simple tie from one triangulation station to another with semipermanent points being established along the traverse at intervals of from ½ to 1 mile. Naturally it is necessary that the survey be confined to a particular corridor which the photogrammetrically compiled maps will cover so the control points will appear on the aerial photographs. Because of the very few restrictions imposed on this survey it is a rapid, therefore economical, procedure and the main concern of the crew in conducting the survey is to establish and survey control points which are intervisible, recoverable, and remain within the general area of the maps. If necessary, survey towers are used to avoid cutting lines of sight through wooded areas. Automation of this phase has progressed in many cases to the point where helicopters are used to transport the crew from point to point, and this is fully justifiable for extended surveys in rough country because of the economics involved.

To make this survey as efficient and economical as possible, the crews are equipped with 5-passenger pickups having specially constructed enclosures for the transportation of the surveying equipment. All crews are equipped with at least three portable two-way radios ("walkie-talkies"), two sets of binoculars, and two sets of more powerful two-way radios installed in the trucks for communication with the photographic aircraft, with the resident engineer, and with the walkie-talkies. Simple tape recorders have been utilized in the past to enable the instrument operators to describe the terrain, weather, instrument stations, and so forth, as quickly as possible without the necessity of manually writing this information on the data sheets. However, we discovered this type of information is rarely necessary and abandoned this means of communication completely, as it did not seem to add to the efficiency of the overall survey project.

Instruments have been tested which record the numerical information produced by the Electrotape and the theodolites directly upon magnetic tape. These units were used in the field with the hope that the ordinary data sheet could be abandoned and the process completely automated from beginning to end. However, the instruments now available on the market which are small enough and portable enough for efficient field use do not provide for checking of the information which has been entered and therefore it has been our experience that more transposition errors occurred which could not be definitely located than in the utilization of the written data sheet. Consequently, the data sheet remains in effect and has been simplified and reduced as much as possible so as not to delay the control surveying work in any manner.

We have chosen the 5-passenger pickup truck for obvious reasons. Its only competition as far as efficiency is concerned would be either the regular pickup or the station wagon. The station wagon is an excellent means of transporting personnel or equipment; however, as a transporter of both personnel and equipment, it is extremely inefficient and cumbersome. In addition, it is strictly a

road car, and operations off the paved highway are severely curtailed. The normal 2-passenger pickup has the same advantage as the station wagon, inasmuch as it will transport both personnel and equipment. It is at a greater disadvantage, of course, in transporting personnel since a majority of the crew must ride in the pickup bed, which is not only unsafe on the open highway, but also extremely uncomfortable. Therefore, the 5-passenger pickup is a compromise which, in our opinion, combines the better qualities of each since it will carry 5 crew members comfortably and all the equipment necessary to maintain this crew in the field. With the installation of a steel cover on the bed of the 5-passenger pickup, a higher degree of security for the $15,000 to $20,000 worth of specialized equipment which is transported in it is obtained, particularly when compared with the station wagon. This is an important feature to consider, inasmuch as these trucks are in the field for at least a week at a time and if station wagons were used it might not be uncommon to find that the loss of equipment would be somewhat higher due to the extensive glass area in the station wagon and the rather easy entrance that can be gained into such a vehicle.

Texas is unique among the States in that its shape and area present a considerable problem in transporting the crew from one survey project to another. It was the original intention, and remains so, that the photographic aircraft be able to transport the survey crew from project to project as much as possible; however, since the Texas Highway Department began to use photogrammetry in its highway design work, it has been impossible to release the aircraft from its primary duty of securing aerial photographs and to assign it to serve as a transportation vehicle. It might be possible that the aircraft would be available to transport the crew to a project but would be unavailable for the return trip to the home office. Therefore, this step has not been satisfactorily resolved as of this time. In addition, the variance in weather conditions throughout the State presents a problem in that the departure station may be clear and suitable for aircraft flight but the landing station might be experiencing conditions which would make arrival impossible. Therefore, even though transportation is slower, it has become necessary to use the modified 5-passenger pickups for crew placement throughout the State. This slower travel can consume as much as one entire working day; however, with the advantages of the equipment and techniques which have been developed for this crew, the small percentage of the overall time can be absorbed without raising the cost of the survey by an appreciable amount.

With the utilization of these instruments and procedures, it has been possible to arrange the personnel involved in the field survey in a very efficient manner. Though this procedure must be altered for each individual project, broad outlines can be mentioned which form the framework of a normal survey project. One crew consisting of three or four men begins at the first triangulation station and selects the points to be surveyed by driving the concrete reinforcing steel rods at intervals throughout the project. Naturally, the work of this crew requires that at least one member be completely familiar with the operation and have the ability and judgment that is necessary in choosing the path for the crews that follow. The Electrotape crew follows and makes the measurements between the points that have been previously set. This crew consists of a minimum of two men but usually has an additional one or two men for transportation and carrying equipment. The theodolite crew then measures the horizontal and vertical angles from one point to another. These three basic crews can be manipulated in a variety of ways. For instance, the Electrotape crew and the monument-setting crew can be combined. This is sometimes more efficient in reducing the number of personnel required to complete a project, so long as the Electrotape is not unduly delayed because of this combination. It is also obvious that the theodolite crew could precede the Electrotape crew without a loss of time or efficiency. Therefore, some phases are completely interchangeable unless other factors intervene. If the theodolite crew precedes the Electrotape crew, then the monument crew can be combined with the theodolite crew to effect a savings in the number of personnel involved.

Another item favorable to this setup, particularly in Texas, is the fact that the entire ground control survey need not be completed in one continuous operation. In fact, it has been common in such operations to send the monumenting and Electrotape crew to one project for the initial phase of the survey and to send the theodolite crew to a

different part of the State on a completely different project to finish up a survey already begun. Since this combination of crews is an Austin-based operation in the Texas Highway Department, it is essential that flexibility be maintained, particularly when the vast amount of territory that must be covered throughout the State is considered. Therefore, it is possible to have two or three surveys in different stages of completion at one time and also to have all surveys being processed to completion without delay.

Monumentation of this field control is usually done by using iron pins, usually one-inch diameter concrete reinforcing rods driven into the ground approximately 3 feet, where soil conditions will permit. Although this type of monument cannot properly be considered permanent, it seems to offer adequate service and requires much less time to install than the more familiar concrete shaft and brass cap arrangement.

When the survey has been completed, the data sheets from both the theodolite and Electrotape measurements are returned to the office where the information is automatically recorded on magnetic tape as computations on the field data sheet are being checked. This small magnetic tape is processed through a translator to produce the standard magnetic tape and then fed directly into the 1604 computer along with a traverse program to obtain the order of closure of the traverse, the State plane coordinates of each control point set and surveyed in the field, the adjusted surface coordinates of each point, the true horizontal distance between the points adjusted throughout the traverse, and the true angle at each PI station between traverse courses adjusted for closure error. The computer program used in this process is written in such a manner as to reject traverse survey data which does not meet at least second-order accuracy (1:10,000). It is interesting to note here that such a rejection by the computer is extremely rare and accuracies have been obtained of one part in 95,000 with no increase in effort beyond what has been described.

Concerning progress obtained using the procedures described, it is difficult to give an average rate per day of miles surveyed or control points set because of the extremely varying nature of the terrain and ground cover found in Texas. In areas where ground cover and trees are not a limiting factor and the terrain is easily accessible, progress has been recorded of up to 20 miles of traverse surveyed in one day. This of course requires that the vehicles be driven from point to point without excessive meandering, and that beginning and closing monuments be readily available.

TARGETING

Immediately upon completion of the ground control surveying and the verification of its closure accuracy by the computer, the survey project is targeted for the photographic flight. The Texas Highway Department has experimented with a great variety of materials and substances which could be used as photographic targets. These experiments began with a simple lime cross, progressed through a painted automobile tire, strips of aluminum foil, white plastic material and colored plastic material, centerline striping paint, regular gauze cloth, cotton muslin, strips of lumber painted white, and large aluminum or cardboard pie plates and similar materials.

For economy and ease of installation, a lime cross on the ground has no equal. However, it has many disadvantages in other regards. The main disadvantage which might be cited is that a rain shower, after completion of the targeting and prior to the photographic flight, can obliterate all targets placed along the project. In addition, in areas where cattle or other livestock are common, the targets can be scattered and identification can become extremely difficult.

The target must, of necessity, be formed by hand and therefore does not give a very clear and accurately defined image on the photography as do other materials. Pie plates and round shapes of other materials of this nature offer the danger, in certain areas, of misinterpretation of the targeted points and are not recommended. Painted strips of board are expensive and difficult to handle and transport and therefore should be used only when the supply is readily available and may be used again and again. Aluminum foil is not acceptable because of the highlights and configuration it imposes upon the photographic film. In some instances it may appear black and in some instances

totally white, and in other instances any shade in between. Therefore, identification of this type of material is extremely difficult. Targets made of cloth or muslin or other woven material are very acceptable as far as registry is concerned. However, for new location work they appear to be very appetizing to local livestock and will not remain in place for any period of time. In addition they must be staked to the ground at several points to prevent the wind from destroying the configuration or completely removing the targets. In short, all types of targeting material have their shortcomings and one particular type cannot be used on all different survey projects. One project will require use of a certain material and another project something else for targeting purposes.

In the Texas Highway Department, we have narrowed the choice down to about two materials. One is the simple lime cross. Although it does have disadvantages, it still remains the simplest target to construct in the field. It is used only in those instances where targeting is completed immediately prior to the photographic flight and there is no indication that weather conditions will delay the flight for any considerable period of time. In the other instance, it has been found in large-scale mapping that white cardboard cut into strips and placed in the form of an X or a cross have served the intended purpose very well.

It is contended that almost any target can be made to work if the interval of time between the targeting and the photographic flight is kept to an absolute minimum. No great difficulty has been experienced in identifying the target on the photographs because of its configuration or the material used, or at least not nearly so much difficulty as has been experienced in targets being moved or destroyed prior to the flight. The size of the individual legs of each target are of course dependent upon the scale of the photography and therefore the flight height of the aircraft. Targets with legs 4 feet in length are adequate for photographic scales of 200 feet to one inch.

On locations along existing highways, targeting is much less of a problem. Painted targets on an existing highway can be made to remain for long periods of time—at least two or three months. In fact, this is one of the shortcomings of painted targets on highways. This type generally exists for several months after the project has been completed and is a source of extensive curiosity to the neighboring landowners or passersby. If this sort of target is used, it is recommended that a paint be employed which can be removed without much difficulty or which would wear off the pavement within a reasonable length of time.

As to the color of the target employed, white has been found to be excellent where the background is contrasting though not of an opposite color in contrast. By that it is meant that white against green or grey stands out very well and no difficulty has been experienced in regaining this point both horizontally and vertically on the stereoscopic models. However, the white target on concrete and at times even on weathered asphalt pavements appears to have a height of from 1 to 1½ feet when viewed and measured on the stereoscopic models. If the purpose of the target is strictly horizontal control this does not become a problem; however, if the target must be used as a point of vertical control, then the purpose has been defeated and the target is practically useless in accomplishing large-scale mapping by photogrammetric methods. William T. Pryor of the Bureau of Public Roads has done extensive work in the investigation of colored targeting material and it is suggested that his publications be consulted for further information concerning this subject.

In addition to the targeting of the basic control points, it is desirable to target as many as possible of the existing property corners, intersections, and so forth, with other survey lines and facilities which cross the control survey traverse. This procedure allows for the measurement of the plane coordinates of each of these points with the photogrammetric instrument and provides a tie which could become invaluable during the progress of the surveying, mapping, and engineering for the project.

AERIAL PHOTOGRAPHS

To obtain aerial photographs for photogrammetric surveying and mapping projects, the Texas Highway Department uses a Cessna 206 Skywagon aircraft equipped with a

Wild RC-8 6-inch focal length aerial camera. The Cessna 206 was originally a 6-passenger aircraft but has been modified so that it now has the pilot and co-pilot's seat and a seat for the photographer behind the camera. This leaves ample room for the storage of extra magazines and film and also provides space for to-and-fro movement by the cameraman. This type of aircraft was chosen primarily because of its ability to reach the farthest part of the State in a reasonable time and to carry sufficient fuel to enable it to remain in the air for approximately 6 hours at cruising speed, and because of its ability to fly at the rather slow speeds which are necessary in obtaining aerial photography for large-scale mapping.

The operation of the flight crew must be correlated very closely with the operation of the field survey crew. Information concerning the estimated completion date of the survey is transmitted to the Austin office for relay to the photography crew to insure that the aircraft will be available as soon after this completion as possible. Of course, weather is a contributing factor in the smooth operation of this phase.

A flight map is constructed from the photography which was obtained for the original ground survey to enable the pilot to plan the flight lines, to determine the number of photographs necessary and the amount of film required on the project, and to ascertain all other needed items. If photography was not taken for the original survey, the flight map generally consists of a United States Geological Survey topographic map or a Texas Highway Department planning and survey county map.

In the interest of economy, an effort is made to have several survey projects scattered throughout the State ready for photography flight. In this manner, the aircraft spends much less time on the ground due to poor weather conditions at any one project, since in the event one portion of the State is overcast, it may be possible to fly to and photograph a project at the opposite end of the State and utilize the aircraft to its fullest extent. In addition, an effort is always made, when a project is to be photographed, to notify the Highway Department District Offices in areas along and immediately surrounding the flight route so they may have the advantage of securing aerial photographs for purposes other than mapping at considerably less expense than would be involved in a separate aerial photography trip for each purpose.

After exposure, the film is returned to the Austin office for processing in the Reproduction Section of the Automation Division. This section can process a 200-foot roll of aerial film in approximately 2 hours and return it to the Photogrammetry Section for inspection. The aerial film negatives are studied for location of targets on markers of survey control and determination of scale and then returned to the Reproduction Section for production of blueprint positives from the roll of negatives. This continuous roll of blueprint positives is cut into individual photographs, overlapped, and stapled together to form one continuous strip. This index is inspected for excessive x-tilt and y-tilt, for excessive crab in the flight line, and to insure that the desired area had been photographed. If at the completion of this phase the flight has proven to be a successful one, contact prints are made from the roll of aerial photography negatives. The ground survey stations are identified on one set of these contact prints and this information is forwarded to either the layout section or the optical train photogrammetric instrument bridging section for further handling. Another set of contact prints is forwarded to the District Office concerned with the survey project for study and evaluation by engineers in that office. A third set of contact prints is formed into a photographic index for future reference and the recall of individual photographs.

If a photographic mosaic is to be made of the area, work is now begun in cutting and assembling the individual photographs to form a composite of the entire area of survey. An uncontrolled photographic mosaic is a valuable aid in determining a preliminary location for the highway route to avoid undesirable grades, curves, and man-made obstacles. Preparation of a controlled photographic mosaic requires at least as much field work as the photogrammetric compilation of maps and does not provide sufficient accuracy over that of an uncontrolled mosaic to justify its greater expense. A good controlled mosaic would cost nearly as much as a completed planimetric map and does not offer the same accuracy.

It has been contended that a good designer with a set of aerial photographs providing stereoscopic coverage of an area and an uncontrolled photographic mosaic of the same

area can select the most feasible location for a highway route in a very short period of time and with very little difficulty. This condition does not hold true, however, if the designer intends to obtain angles and distances from the mosaic or the photographs. The camera eye sees the ground and features thereon in perspective, as if they were on a perfectly level plane. All differences in elevation are reduced to this plane along lines which radiate from the center of the camera lens. This perspective positioning of images is impossible to remove in contact printing of aerial photographs and its effect can only be reduced by projection printing techniques. When this deficiency is combined with x-tilt and y-tilt, which may occur in any photograph, the difficulties presented constitute an absolute barrier to the obtainment of accurate measurements by use of photographs without employing complicated mathematical computations.

An example of image displacements on an aerial photograph can be imagined by observing a picture taken with a 180-degree fisheye lens. The image displacement present in this type of photograph is identical to the displacement present in any aerial photograph, except in a greater degree. The science of making measurements directly from aerial photographs is an art in itself and usually requires complicated electronic computer programming and use of very precise measuring instruments.

The Texas Highway Department has recently begun to experiment with aerial color photography with fairly good results. Two types of film have been used in this experimentation. One type produces a color positive transparency and the other produces a color negative. Both have their definite places in the practice of photogrammetry. It is believed, however, that the type of film which produces a color negative has the greater promise for overall use. The color negative film is much simpler to process and it is possible to produce from the negative either a color print or a black and white print as needs may dictate. The development of this color negative film is similar to development of ordinary black and white film with the exception of closer temperature control and the number of development solutions which have to be used in the process. Color photography promises to provide extremely valuable information to the geologist, the soils engineer, the forestry engineer, the hydraulics engineer, the right-of-way engineer, and others.

EXTENSION OF CONTROL BY PHOTOGRAMMETRIC METHODS

In the compilation of large-scale maps by photogrammetric methods, such as those compiled at a scale of 40 feet to one inch, it is necessary to have a control point approximately every 300 feet along the flight strip of photographs in order that the projection-type stereoscopic plotters can be used to compile the map. There are two methods of obtaining these necessary control points. One is by ordinary field surveys and the other is by the extension of field survey control points by using photogrammetric instruments.

The methods employed in establishing the basic survey lines described previously in this paper were based on the assumption that the control would be extended using the optical train Stereoplanigraph Model C8. As has been mentioned before, the ground surveying portion of a photogrammetric surveying project must be kept to an absolute minimum if the full value of photogrammetry is to be realized. Therefore, in setting and surveying on the ground control points which are from one-half to one mile apart in the control phase it is possible to measure the position of intermediate supplemental control points, using a Stereoplanigraph or similar instrument, spaced at intervals of 300 feet along the survey path. These intermediate supplemental control points do not exist on the ground. They are, of course, selected images on the photographs of ground objects, man-made features, and photographic patterns. It is possible to measure the coordinates of these points and to use them throughout the photogrammetric process as though they had been set directly on the ground by a survey crew.

As utilized by the Texas Highway Department, the Stereoplanigraph Model C8 will measure a traverse from one-half to one mile in length or further if necessary, beginning with one field-surveyed control point and ending on another field-surveyed control point, and will furnish coordinates for any number of intermediate supplemental control points that may be desirable. The digital record of Stereoplanigraph measurements

comprises the data used in a computer program to compute the X, Y, and Z coordinates of all measured points in the coordinate system used in photogrammetric compilation of the maps.

The horizontal extension of control is more than adequate for the compilation of planimetric maps at a scale as large as 40 or 20 feet to one inch, but for topographic mapping at such scales, vertical extension of control is not possible within reasonable accuracy requirements. A procedural system is now being developed in conjunction with the University of Texas Research Department which will allow both horizontal and vertical extension of control to be done on a purely mathematical basis using photogrammetrically made measurements in a computer. It is anticipated that this system, when perfected, will by no means replace the Stereoplanigraph. It will, however, supplement its abilities to a great degree. When the scale of a map to be compiled is as small as 200 feet per inch or smaller, vertical control can be bridged in the same manner as the horizontal control. When the process of establishing supplemental control points is complete, the information obtained is forwarded to the layout section.

LAYOUT

Information concerning location of the basic control points measured by the field survey crew and the supplemental control points measured by use of the Stereoplanigraph is forwarded to the layout unit to be placed on the original manuscript. This process includes utilization of an Aristo Coordinatograph with the capability of establishing and reestablishing any particular point within an accuracy of 1/1000 inch. The operator sets up and draws the coordinate grid system, identifies each grid line, and plots the control points in their proper position in relation to the grid system on the manuscript. The coordinatograph is equipped with either drawing heads or scribing heads, either of which may be utilized in this process. It is in this phase that the breakpoints of individual sheets are determined and the limits of the project are established on the manuscript.

In addition to the layout capabilities, this unit is charged with the responsibility of relating points on a previously compiled map to some coordinate system. This involves calibrating the coordinatograph to integrate its vernier system into the grid system of the existing map sheet and measuring the position of each property corner, building corner, highway intersection, or similar point in terms of plane coordinates for that particular grid system.

Plans are now being formulated to automate this instrument with the installation of magnetic tape drive. When this is complete, information obtained from the field survey crew and from the Stereoplanigraph will be processed through the computer for the production of a programmed magnetic tape which will in turn operate the coordinatograph automatically in the drawing of grid lines, setting up of coordinate systems, and plotting the position of control points. When the control data have been transferred to the manuscript, both the manuscript and the digital information are forwarded to the stereoscopic plotting unit.

STEREOSCOPIC PLOTTING AND CROSS SECTION MEASURING

The Texas Highway Department now uses nine double projection stereoscopic plotters, two of which are equipped with Auto-trol measuring and digital recording devices. Because of the work load, the plotters are operated from 6:00 a.m. to 11:00 p.m. each working day. Upon receipt of the basic control information contained on the map manuscript sheet, the stereoscopic plotter operator orients his instrument and begins to measure and delineate the actual map features. The planimetric portion of the map is completed first, then all necessary contours are measured and delineated, and spot elevations are measured and recorded. The manuscript on which this information is placed consists of a sheet of mylar plastic covered with a coating of orange-colored emulsion. The emulsion has a matte finish which will accept ink or pencil lines. The photogrammetric instrument operator traces out the information provided by the photographic images in the stereoscopic model and with a pencil delineates desired details on the manuscript, and does finishing work with a straightedge and ballpoint pen.

In the event cross section dimensions are desired on a particular project, the manuscript is properly oriented on the working surface of the stereoscopic plotter equipped with the electronic measuring and recording device. This device enables the operator, through manipulation of attachments to the tracing table of the stereoscopic plotter, to measure and have recorded automatically on IBM key-punch cards the centerline station, distance from the centerline at which the elevation is measured, either right or left, and elevation of each individual point. This phase is completely automated. The input information consists of the map manuscript directly from the layout unit, and the output information consists of computer cards which contain all necessary information for automatic plotting of cross sections or for making earthwork computations. At a map scale of 40 feet per inch, the average accuracy of a group of points on a cross section is held to plus or minus 0.25 foot. In tests conducted as a comparison between this method of measuring cross sections and the regular field method of measuring cross sections, the difference in vomume resulting from the two methods (insofar as earthwork computations are concerned) is less than 2 percent.

SCRIBING AND REPRODUCTION

When a map has been compiled using a stereoscopic plotter, it is sent to the scribing unit where the pencil lines imposed by the instrument operator are scribed. Scribing is a process whereby the emulsion coating on the plastic is scraped off by use of edged tools, each of which has a specific line width. This process turns a manuscript into a negative and prepares it for the reproduction processes which follow. The planimetric portion of the map is scribed first and a positive reproducible copy is obtained for use in preparing right-of-way sheets and for other utilizations which do not require elevation indicators. After this is complete, a scriber returns to the manuscript and scribes all contours and spot elevations which have been indicated by the stereoscopic plotter operator. Thereafter, another positive reproducible copy is made of the manuscript which is in effect a master topographic map containing all planimetric features and all elevation indicators.

The positive reproducible copies, which have been printed on translucent cronaflex material, are then sent to the Reproduction Section for a variety of processes. If the original map manuscript was compiled at a scale of 40 feet to one inch, then photographic reductions are made to produce map copies at scales of 50 or 100 feet per inch, as the design engineer may require. In addition, the scale-reduced maps are printed in a plan and profile arrangement which is complete with a profile grid on the lower half of each sheet. Such sheets are used in submission of completed construction plans. The planimetric sheets are reduced to standard plan sheet size and used by the design engineer to construct the right-of-way plans for the highway construction project.

PHOTOGRAMMETRIC COMPILATIONS AND MEASUREMENTS AND THEIR USES

The uses made by design engineers of the photogrammetrically obtained data can best be described by the step-by-step procedure of the typical work involved in designing a highway. After the need for a highway has been established, the first step is selection of a route for its location. The designers request that either a photographic mosaic or a small-scale topographic map be made of the area of survey. If it appears that several alternatives are feasible and economics will dictate selection of the best route for the location, then preparation and use of the small-scale topographic maps enable the engineers to determine the best choice. The map offers the advantages of determining and comparing various grades and alignments, and computing the approximate cost of the highway based on each alternative. If the area of survey is such that only one obvious route is feasible, then use of a photographic mosaic is the better choice. The mosaic is much cheaper to obtain than a topographic map and allows the design engineer to determine highway location control points along a route which either must be met or missed, depending on the nature of the points involved. It is obvious that the highway location can be selected in the design office, using the topographic map

or the photographic mosaic and stereoscopic examination of the aerial photographs, without doing extensive field reconnaissance work.

Once the route location has been determined, the engineer is ready to begin design of the highway on the route and preparation of detailed construction plans. To facilitate this phase, topographic maps are compiled at a convenient scale for the design. The scale is usually 40 feet to one inch to gain the advantage of a one-foot contour interval on the topographic maps. The designer selects the position for PI points along the route for establishing the highway location, and identifies these points directly on the maps. From the coordinate grid lines on the maps, the plane coordinates of these PI points are measured and recorded.

These plane coordinates, together with the curve data for alignment, are furnished to the Division of Automation. Through use of the computer and automatic plotter, the exact alignment, which has yet to be staked on the ground, is plotted precisely on the maps and stationed according to whatever system the engineer desires. Once the centerline data have been secured, ground surface cross sections are measured from the topographic maps through use of the Auto-trol and its electronic read-out and recording system. The design engineer can now determine the design template of the roadway for each station, and the profile gradients for the highway from the topographic maps. This design template is furnished to the Automation Division, combined with the ground-line cross sections measured in the office, and processed through the computer. Earthwork quantities are furnished to the design engineer from this information.

The engineer may then continue with his work in establishing the necessary right-of-way limits to enclose the highway in its three dimensions. This work is usually done on the planimetric maps. If all property corners have been targeted so they can be seen on the stereoscopic models and can be plotted on the maps, it is a simple matter to determine the amount of private property that must be purchased. Property ownership boundaries and ownership data are drafted directly onto the maps, and right-of-way limits are delineated to indicate the area of taking in each individual case. If the design engineer wishes, he may furnish the Division of Automation with the plane coordinates of the corners of each parcel and he will be furnished in turn the area involved, the length and bearing of each property line, and any other information he may desire. It should be noted at this point that the designer has not as yet found it necessary to go into the field to any extensive degree in designing the highway. With information at hand, deed descriptions may be written and right-of-way deeds prepared for ultimate purchase of the essential property. Drainage areas for design of bridges and culverts can be delineated on and measured from the original small-scale topographic maps, or in some instances, from the aerial photographs.

The photographic mosaics or the topographic and planimetric maps can be used at any of the public hearings concerning the highway location and design to furnish the landowners and other interested parties all the information necessary for them to understand the intent of the Highway Department. If condemnation proceedings are necessary, large-scale aerial photography discloses exactly all improvements which have been made on a piece of property and the extent to which these improvements may be damaged or enhanced by the highway.

Although this, of course, does not constitute all the work that must be done to locate and design a highway and to prepare its detailed construction plans, it does indicate that a highway project can be surveyed photogrammetrically with a great deal of efficiency, and that the resultant engineering can be as comprehensive, detailed, and accurate as necessary.