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Photogrammetry and Aerial Surveys

Developments and Applications—1961

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Contents

Aerial Photography and Photogrammetry In Georgia

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● BEFORE 1940 county maps, U.S. Geological Survey quadrangle sheets, and other maps of Georgia were few, of scattered areas, and inadequate for any type of highway planning or location.

In order to do any amount of planning or location, it was necessary for the field parties to make a survey and prepare a map of the area between control points before any initial work could be started.

In 1940 the State contracted for 1,200 mi of aerial photographs of some of the main primary routes for reconnaissance work, and again from 1946 to 1950 other contracts were let for photography as required.

Realizing the value of aerial photography and knowing that the demand for this service would increase, an aerial photography department was organized. Aerial cameras and photographic processing equipment were purchased and a plane was chartered. In 1950 a single-engine Cessna plane was purchased; in 1952 a full-time pilot was employed.

Since the department was orgainzed, the demand for aerial photography had increased to such an extent that in 1955 a new building was built specifically designed for processing aerial photographs. In 1957 a twin-motored Aero Commander airplane was purchased, and in 1958 a building was completed for the purpose of stereo-plotting, computing, and tracing. Figure 1 shows the organization chart of the photogrammetry section, and Figure 2 shows the physical layout of the buildings and parking facilities.

PHOTOGRAPHY

Building

Figure 3 shows the floor plan of aerial photography building.

Airplane

The plane used for aerial photography is a 1957 Aero Commander, 560-A especially modified for a Wild RC-8 camera. In this modification, the aperture for vertical photography is in the floor of the plane directly behind the co-pilot's seat. The baggage compartment door is modified to open inward, and it can be removed for oblique photography.

Cameras

The majority of all vertical photography is taken with a Wild RC-8 camera with 6-in. F5.6 Avignon lens, which was delivered in March 1958. Other types of cameras used for varied kinds of photography are as follows:

Fairchild K-17B camera with 6-in. lens, calibrated for mapping;
Fairchild K-3-B camera with 8¼-in. lens;
Fairchild K-17 camera with 12-in. lens;
Keystone F-8 camera with 15-in. lens;
Cine Kodak Special II 16-mm movie camera with F1.4 lens;
Bell and Howell model 200 16-mm movie camera with 1.9 lens;
Pacemaker Speed Graphic 4 x 5 press camera;

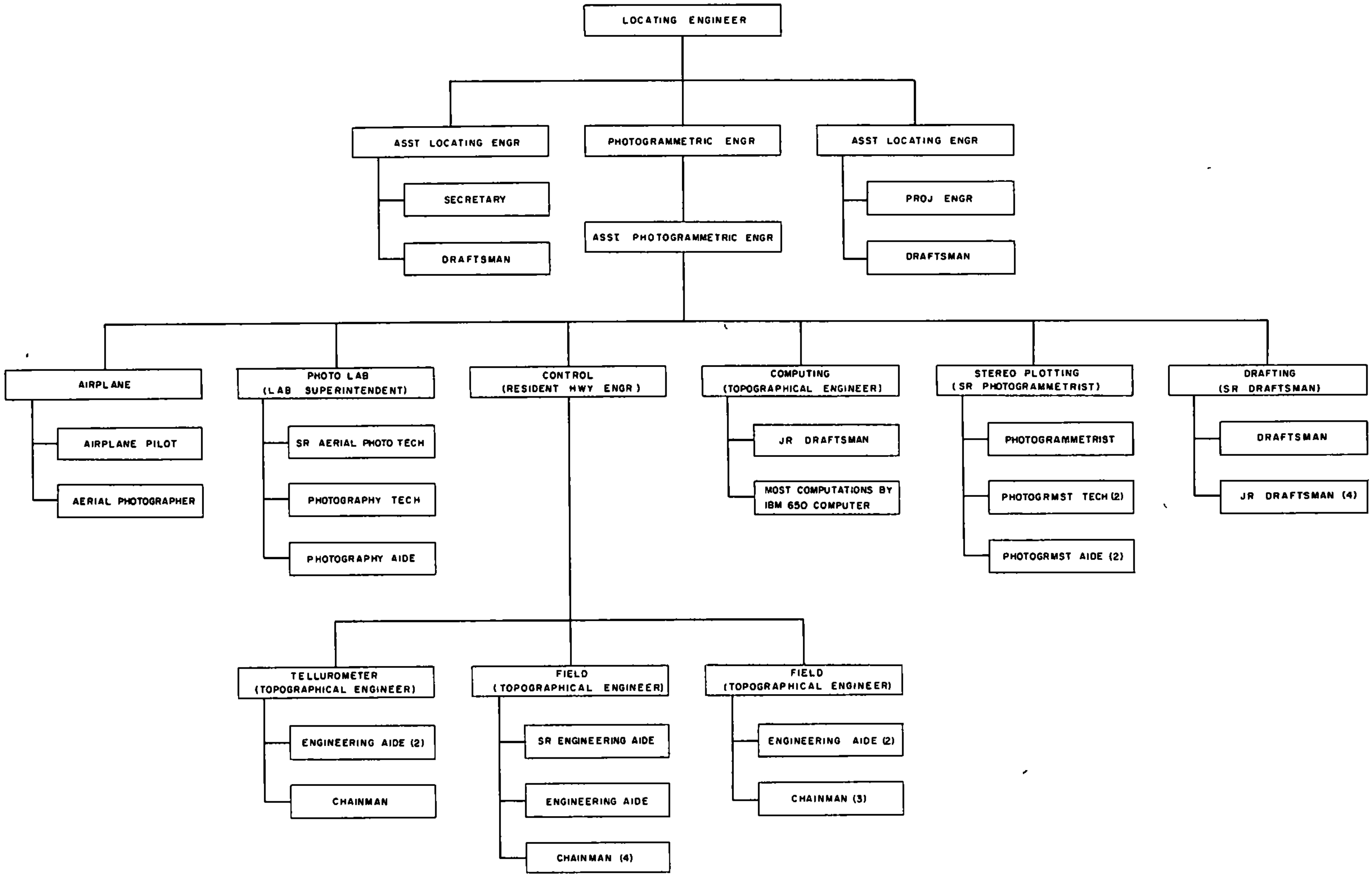

Figure 1. Organization chart.

Leica IIIF 35-mm camera with F1.5 lens;
Calumet 8 x 10 copy camera with 14-in. lens and copy stand;
TDC Instructor No. 500, 35-mm slide projector;
Filmsound, Bell and Howell No. 202, 16-mm movie projector with 12-in. speaker; and
Custom-built copy camera with overhead tracks, 70- x 50-in. copy frame, 27- x 27-in. negative holder, Artar F11, 24-in. lens, arc lamps, and Luxometer electronic timer.

All these instruments are equipped with the necessary accessories for production work: that is, magazines, filters, tripods, light meters, view finders, etc.

The photographic processing equipment in use is as follows:

2 custom-built oak film viewing tables, 110 x 36 x 24 in. with glass tops and fluorescent lamps;
1 Smith automatic film stabilized air dryer;
1 Pako Drycab model 2 small sheet film dryer;
1 A-7 aerial film dryer with heating element;
1 set of custom-built stainless steel sinks, 3 compartments 53½ x 48 in., one compartment 48 x 24 in.;
1 custom-built stainless steel sink 130 x 27 x 38½ in.;
1 Omega DII printer with 135-mm Wollensak enlarging lens;
1 Morse 11- x 14-in. contact printer;
1 Morse 10- x 10-in. contact printer;
1 Logetronic contact printer model CP 10-S;
2 Oscar Fisher 20- x 24-in. automatic rocker trays;
1 60-in. circular stainless steel washer;
1 Pako Pakolux revolving print washer;
1 Pako economy model 48-paper dryer;
1 custom-built air dry rack with 16 racks 48 x 71 in.;
1 Morse electrical unit for developing aerial film;
1 Auld electrical unit for developing aerial film;
1 Pako 50-gal chemical mixer; and
3 tower-mounted stainless steel 25-gal storage tanks with plastic pipes and gravity flow to all developing trays.

Numbering System

The beginning of each flight is shown on the first picture and the ending on the last flight picture. The North and South flights are numbered from West to East and the East and West flights are numbered from North to South. The individual pictures are numbered consecutively from South to North and West to East throughout the job, regardless of the direction flown. The identification shown on the left edge of each picture, in the forward direction, is the date of photography, scale per inch, county code number, State route number, or other special designation as C.R. (county road), F.D. (flood damage), S.M. (Stone Mountain), and flight number and picture number.

Filing System

All photography is numbered according to the county code number and flight numbers. A master record of photography is kept on a county map. On this record are kept the flight numbers, scale per inch, and date of photography.

A card record of all photography is kept by counties. On this card are shown the same identification that appears on each picture, a description of the coverage, and the number of the film roll.

Each roll of exposed and numbered film is numbered consecutively as completed and is filed in a custom-made file rack. A record showing the request and disposition of any photography or mapping is kept on a work card. This card follows the processing through the plant and is then filed as a permanent record.

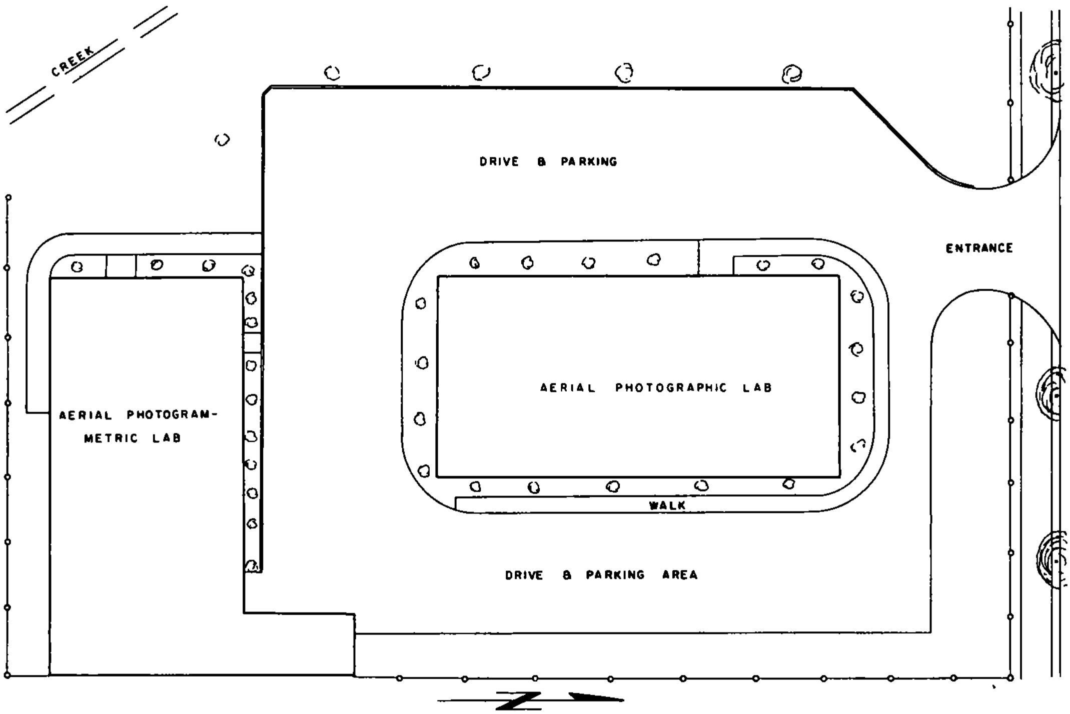

Figure 2. Physical plant, Division of Surveys & Aerial Mapping (scale: 1 in. = 20 ft).

MAPPING

In 1958 a photogrammetric section was established. For the purpose of photogrammetric mapping, layouts, computations, and tracing, a specially designed building was constructed. Figure 4 shows the floor plan of this building.

Controls

All controls are by ground methods. At the present time, no bridging is done. The equipment for ground controls is as follows:

2 Wild T-2 theodolites;
3 Zeiss self-leveling levels;
1 Wild precise level;
1 Tellurometer, master (microwave measuring instrument);
2 Tellurometers, remote (microwave measuring instruments);
1 Friden square root calculator, Model SRW;
1 Monroe calculator model No. 8N213;
1 K and E 30-sec transit;
1 K and E Wye level; and
1 K and E plane table and alidade.

With these items, the necessary accessories for running precise surveys—calibrated chains, thermometers, barometers, psychrometers, line rods, tripods, optical plummets, etc.—are furnished. There is a 650 IBM computer available for making coordinate computations.

Photographic, vertical, and horizontal points are selected on photographs by stereoscopic study in the office and furnished to the field parties.

Concrete posts 5 x 5 x 36 in. with a 3-in. brass identification in the top are used as permanent markers. These are set along and near the proposed survey centerline at intervals of not less than 1 mi.

On large jobs, the field notes are sent to the General Office to be computed by the IBM 650 computer.

Stereoplotting

All plotting is done by Kelsh stereoplotters, 5x magnification, with 6-in. lens cones. All maps are compiled to the Georgia coordinate system on "Moldrite," a 0.01-in. thick stabilized vinylite with a polished matte surface.

All compilation sheets are filed by consecutive numbers in a custom-made rack. A card record and a reduced photographic index map are kept of each job. A progress chart of each job is kept showing the step-by-step progress.

Tracing

All drafting is done in ink on tracing linen, over-all size, 30 x 42 in., inside border, 26½ x 38½ in. This size was selected for ease in filing. Each linen is thoroughly edited for errors and omissions before it is considered completed.

APPLICATION TO LOCATION AND DESIGN

Reconnaissance

Reconnaissance is considered the most important phase of location and design of the proposed improvement of any highway, and the one most frequently neglected.

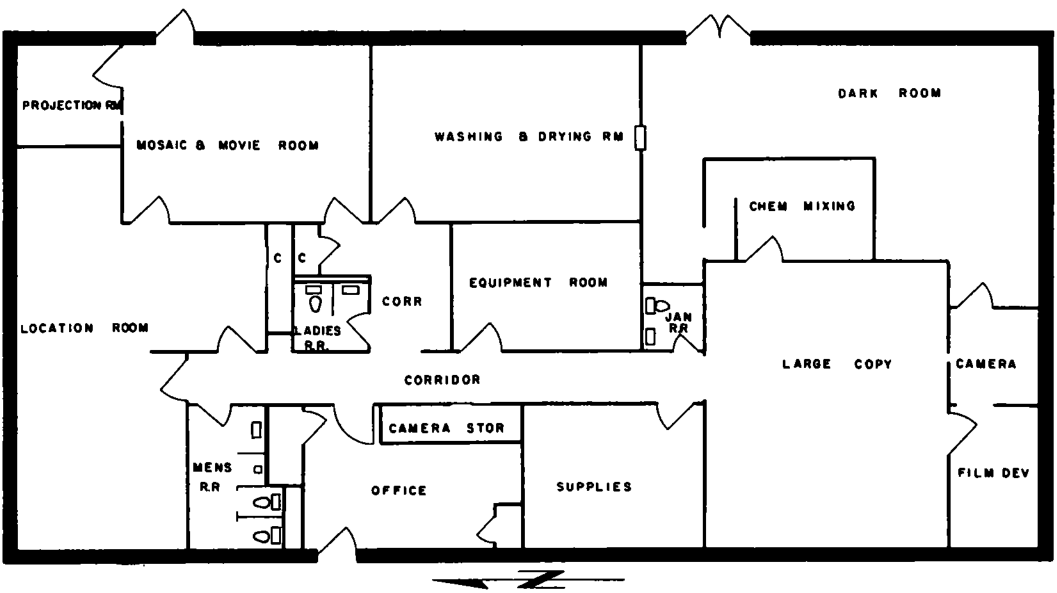

Figure 3. Aerial Photographic Laboratory (scale: 1/8 in. = 1 ft).

The flight lines of the area to be covered are between control points and are furnished to the pilot for photographing. The photography for reconnaissance purpose is usually to a scale of 1 in. = 800 ft in rural areas, and 1 in. = 400 ft and 1 in. = 200 ft in urban areas. This scale was selected for the reason of the direct proportion to enlarging to a scale of 1 in. = 200 ft, 1 in. = 100 ft and 1 in. = 50 ft for more detailed studies.

The prints are stripped up by counties covering the area between control points, and lined up side by side on drafting tables. The area of photography usually covers a width of one-fourth to one-third the length between control points. A visual study is

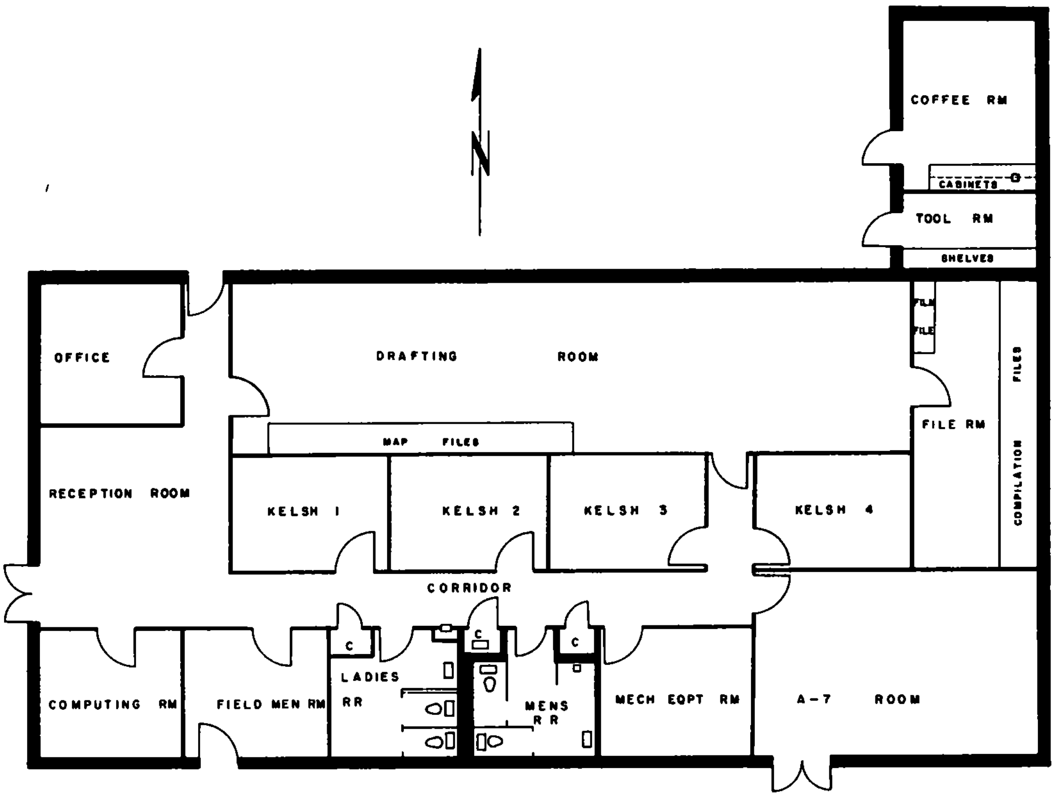

Figure 4. Aerial Photogrammetric Laboratory (scale: 1/8 in. = 1 ft).

made of the entire area photographed. The lines found most desirable are studied by pairs of pictures under a stereoscope to select the lines or combination of lines thought most practical.

All preliminary work is coordinated with the Materials and Tests Department, Roadway Design Department, the Division of Highway Planning, and the Bureau of Public Roads to determine the factors involved in the selection of the final route. The most important factors are (a) service to traffic, populations, and industrial areas; and (b) directness; (c) type of terrain; (d) interchange of main highways; and (e) stream and railroad crossings.

All practical locations are then field-checked with the aid of the photographs. Further stereoscopic study is made and the least desirable routes eliminated. Studies are then made of the route selected, both in the field and by stereoscope. At this point a field inspection is made with a representative of the Bureau of Public Roads. Any necessary revisions are then made.

A reduced index map, usually 1 in. = 1,600 ft with the recommended line in ink, is sent to the Bureau of Public Roads for review with a letter requesting approval of general location.

Photogrammetric Mapping

After tentative approval of the general route by the Bureau of Public Roads, the area to be mapped is narrowed to the width thought necessary for contour mapping. A thorough reconnaissance study is helpful in determining the width of the area to be mapped.

Photography is taken as nearly as possible along the centerline of the proposed location at a scale appropriate for the finished map scale and at a contour interval needed for highway location and design. The scale of this photography is usually 1 in. = 1,000 ft, 1 in. = 500 ft, and 1 in. = 250 ft. The respective altitudes of these flights are 6,000, 3,000, and 1,500 ft above the mean ground elevation. In urban areas, most of the mapping is done to a finished scale of 1 in. = 50 ft with 1-ft contour interval. In less congested areas, mapping is done to a finished scale of 1 in. = 100 ft with 2-ft contour interval. In rough terrain, for location and preliminary design, mapping is done to a finished scale of 1 in. = 200 ft with 5-ft contour interval. There is very little mapping done for reconnaissance work except in very mountainous country.

After delivery of the photography, picture points are determined, field control is accomplished on the ground, and computation is made of vertical and horizontal values. The horizontal order of accuracy is never less than 1 in 15,000 and on one project of 15 mi it was 1 in 52,000.

Coordinate grid lines are drawn, and the manuscript map is made by means of a Kelsh plotter on 0.01-in. thick "Moldrite." The finished map is then traced in ink on linen sheets and edited for errors.

When the prints of the contour maps are made, they are laid out continuously on large drawing tables, and weighed down by shot weights for the purpose of selecting the final location.

The final location is made by establishing the intermediate control points and marking on the map other important points of the location. A spline line 12 ft long is placed along the maps, and it is held by spline weights as near the desired location as visual inspection can determine. After the spline is shifted and adjusted to fit the terrain and culture, a line is drawn the length of the spline for a trial location.

A profile is drawn of the line and studied for any shifts that can be made to better the vertical alignment. After many trial lines have been tried and profiles plotted, the final location is selected. This is refined by plotting in the tangents and curves.

In preliminary work preceding the selection of the final location, all trial lines and corresponding profiles are numbered alphabetically. Profiles are plotted by direct vertical projection methods along the tangents and scaled around the curves. This method avoids stationing and equalities.

Field Procedure

The prints of the proposed location are furnished to the field parties for staking out the centerline. Each tangent is established on the ground and blocked out to intersection throughout the entire project. Each intersection point is tied to the State plane coordinate system. The line is staked out on the ground and profile levels are taken along the line. Permanent markers are set at the intersection points, and iron pins set at points on tangents. Concrete posts with bronze markers are set for permanent bench marks and geodetic positions.

Extra copies of prints are furnished to the field parties for right-of-way information, such as property corners and property ownership. The information is plotted on the prints in the field. Photographs are also furnished as an aid in locating property lines.

Large drainage areas are plotted on county maps and checked in the field for correctness; small drainage areas are plotted from contour maps. The stationing of location structures is determined on the contour sheets and checked in the field.

Design

Topographic sheets showing alignment, coordinate points of intersections, delta angles, degree of curvature, bearing of lines, bench marks, other permanent markers, and stationing of drainage structures are furnished the design department together with all field notes, drainage maps, and property line maps.

Trial grade lines are laid and preliminary design is started. All cross-section data are scaled off the contour sheets and adjusted to the elevation of the field level notes. Grade elevations are computed and construction plan quantities are computed by the electronic computer. When the preliminary construction plans are completed, the Bureau of Public Roads is requested to make a joint P.S. and E. inspection.

After this inspection, the plans are revised as necessary, and prepared in detail for letting the project to contract.

Additional Services

Although the Photographic and Photogrammetric Section of the Georgia Highway Department was established primarily as an aid in highway location, we are constantly receiving requests for work from other State agencies such as the State Department of Commerce, Stone Mountain Memorial Association, Department of State Parks, State Forrestry Commission, Mineral Leasing Commission, State Ports Authority, Georgia Institute of Technology, Department of Public Safety, Atlanta Airport, Atlanta Federal Penitentiary, State Toll Bridge Authority, State Toll Road Authority, and the State Bridge Authority of Georgia.

Photographs are furnished various agencies as a valuable aid in highway planning studies, urban studies, property locations, road inventories, right-of-way procurement, condemnation cases, highway accidents, parking facility studies (in use and planned), bridge location studies (streams and railroads), stream, highway, and railroad crossing studies, traffic studies, drainage areas and location of drainage structures, revision and correction of county maps, city planning, progress reports, highway exhibits, and county fair exhibits.

Movies and slides are furnished for publicity purposes and highway conferences.

SOME UNUSUAL USES OF PHOTOGRAMMETRY IN GEORGIA

Highway

Rectified photographs produced on continuous tone film are being used as a base for right-of-way maps. They save considerable time in field surveys and drafting. The film is printed reversed. Emulsion is on one side and drafting on the other. Centerline, property lines, and owner's names are added. Blue line prints are run. They are especially valuable in condemnation cases before juries not familiar with the property involved.

The same basic practice, photograph on continuous tone film base is being used as base for design and construction drawings on resurfacing and widening projects.

State Department of Commerce—Industrial Development Branch

Vertical B and W and color oblique photographs are being used to aid in securing new industry, promote better interest rates on city and State government bond issues, and make studies of value of airrights of railroad yards for City of Atlanta.

State Department of Commerce—Aviation Branch

Vertical and oblique photographs and topographic maps are being used for determining location of new airports and also for construction progress records of Atlanta Airport.

Stone Mountain Memorial Commission

The most unusual request ever made of the mapping division was for contour maps of the partially completed vertical Stone Mountain Memorial. After unsuccessful attempts with two standard types of airplanes and one helicopter, photographs suitable for plotting topographic maps were finally obtained with the use of an 86-ft hydraulically operated ladder mounted on a mobile unit. The aerial photographer ascended the ladder with an aerial camera, and the ladder was raised over the ground targets previously placed on a base line approximately 300 ft from the carving. The aerial photographs obtained in this unorthodox manner had the proper overlap for stereoplotting, and contour maps with 0.25 contour interval were plotted and furnished the Stone Mountain Memorial Commission.

State Surveyor General—Mineral Leasing Commission

The Secretary of the State of Georgia, who is also the State's Surveyor General, is making a study to determine possible lease areas and mean low tide, and to establish definitely the 3-mi limit to Georgia's eastern coastline.

The aerial mapping division is now making, when weather and time permits, complete aerial coverage of the 2,400 sq mi of coastline required by the Secretary to complete the study.

The photographs are being taken with a Wild RC-8 camera to a scale of 1 in. = 2,000 ft. The finished prints are rectified to existing Geological Survey sheets, then laid as a controlled mosaic.

Proposed Improvements

It is proposed to purchase in the near future a first-order stereoplotter for bridging controls and making maps for cities and counties from high altitude photography.

It is also planned to purchase steel towers to be used in connection with an electronic device for measuring distance by means of microwaves. The towers will increase the efficiency of the units and materially reduce the time required by field parties to measure great distances for basic horizontal control work. Future plans also include the purchase of a modern rectifying copy camera.

Drainage Studies from Aerial Surveys

IRWIN STERNBERG, Arizona State Highway Department, Tucson

Aerial vertical photographs examined stereoscopically provide a useful three-dimensional medium whereby drainage areas can be successfully determined with sufficient accuracy for the design of culverts for highway drainage.

Use of large-scale photographs for determining the placement of these culverts and other facilities connected with the collection and dispersion of surface water during runoff period is also discussed.

Methods, corrections to be applied, and techniques that have been successfully employed, all of which are within the capabilities of the average field engineer with limited photogrammetric training and equipment, are described. Examples are given to show the degree of accuracy that can be expected.

●THIS PAPER proposes (a) to prescribe a method whereby stereoscopic pairs of aerial photographs can be used by field engineers with limited photogrammetric training for determining drainage areas accurate enough and in sufficient detail to be used in estimating culvert sizes, and (b) to consider the use of such photographs for the actual positioning of culverts and related drainage features with an accuracy sufficient to be used as a guide in design.

The investigation was confined to the southern part of the State of Arizona, but with minor changes the same methods should be applicable in other areas. No claims are made for originality in developing the techniques. No doubt they have been used before, but a presentation of the procedures developed and a summary of the results obtained may be of interest to many who are involved in the location of modern highways and in other undertakings involving the location and design of drainage structures.

Drainage areas are usually determined by utilizing existing maps or by traversing each watershed. Both methods have their shortcomings. Maps can be unreliable or so lacking in detail as to preclude accurate determination of larger areas or any determination at all of smaller areas. Traversing by stadia, plane table or transit and tape is both time and labor consuming especially in regions of rough terrain or where ground cover interferes.

In the arid southwest, the extent and character of drainage areas become very important in determining culvert sizes. During the rainy seasons storms are frequent and, though of short duration, are violent in nature. This characteristic plus the impervious nature of the soil and the sparse vegetation contribute to the rapid runoffs encountered in this section of the country. Normally dry washes suddenly become raging torrents, and in the flat desert regions washes frequently overflow the surrounding country. It is necessary therefore to provide adequate drainage across highways both to safeguard the highway against excessive erosion and to protect the surrounding land.

In the past much of this runoff was taken care of by constructing dips across the highways. Where properly constructed and protected, these were both economical and satisfactory. However, with the rapid increase in traffic and the increased importance of the highway in the economy of the country, their practicality decreased and the enforced delays to the motorist during flash floods were not only irksome but economically expensive. And of course on divided highways of the Interstate System and other heavily traveled limited-access facilities such a treatment would be not only archaic but unworkable.

Arizona has found the Talbot equation for determining culvert sizes quite satisfactory. Here the character and slope of the terrain as well as the general shape of the watershed area are important. Its extent, and whether the runoff is confined or covers an extensive area, must also be considered. Experience, of course, counts much in selection of runoff coefficient for use in the equation and the size and placement of a culvert.

Drainage areas to be used in the application of this equation were, and in many cases, still are determined by measurement in the field or from existing maps. In the comparatively unsettled West suitable maps are scarce, not too accurate, and often lacking in sufficient detail to be reliable or useful. The recent 7½-min USC & GS quadrangle topographic maps are very helpful for this purpose and are quite accurate. Unfortunately they are not now plentiful and in many cases the contour interval is too large to ensure a true determination of the drainage area boundaries.

Figure 1 illustrates how errors could inadvertently occur in outlining an area where the contour interval is too great. The figure is a section taken from a recent 7½-min quadrangle map with a contour interval of 40 ft. The solid black line shows the boundary of a drainage area as would be determined from the contour information given. The dashed black line shows the boundary of the area resulting from a stadia traverse run by regular field methods. A low ridge cuts transversely across the area with its crest along the dashed line. It so happens that the elevation along the top of the ridge is about 2,340 ft, while the elevation of the trough behind it to the east is around 2,330 ft. The contours on the map therefore give no indication that such a ridge exists. The effect of this ridge on the drainage area is clearly evident in the figure.

DETERMINING DRAINAGE AREAS

Aerial photography naturally suggests itself as a possible solution and the problem then resolves into the various possibilities open to the use of this medium. It is desirable to limit its use to such forms as are practical for field survey personnel with a minimum of photogrammetric training and to such equipment as can be available to such men.

Where an area has been photographed for reconnaissance survey purposes, the aerial photographs thus secured can be used, particularly where the drainage area is of considerable extent. Photographic mosiacs can also be used but the three-dimensional effect attained from stereoscopic examination of pairs of aerial photographs is very desirable in tracing the boundaries of watershed areas. The contours of topographic contour maps compiled photogrammetrically are extremely desirable but they are generally of such limited extent as to impair their usefulness except for the smaller areas within their limits. For larger areas, manuscript maps compiled from existing photography at the scale of 1 in. =1 mi to be used in preparation of the general county highway maps are very useful when available, as in Arizona. Here again drainage detail is not sufficient for determining boundaries of the smaller areas. In many cases and especially for drainage area studies it therefore becomes desirable to photograph the region under consideration. Such photography is cheap and its cost can be saved many times over in time and labor. A scale of 2,000 ft per in. for normal size areas is generally satisfactory though a smaller scale can be used for areas of greater extent.

The following discussion is based primarily on the use of aerial photographs, as the use of other media, such as maps, requires no special comments. In addition it is limited to smaller areas that can be plotted on one or two strips of photography. Larger areas can perhaps best be determined by other methods, such as on existing quadrangle maps or on drainage maps especially prepared in the photogrammetric laboratory.

First, the scale of the photography is determined and centerline of the highway is plotted on the photographs. On photography made before location of the survey centerline, this plotting will have to be done by photographic identification. On photography taken without control being premarked on the ground by photographic targets, scale can be determined with sufficient accuracy from existing features such as section lines, property lines, existing roads, or other features the length of which is known or can be determined. On photography where photographic targets appear as placed on control

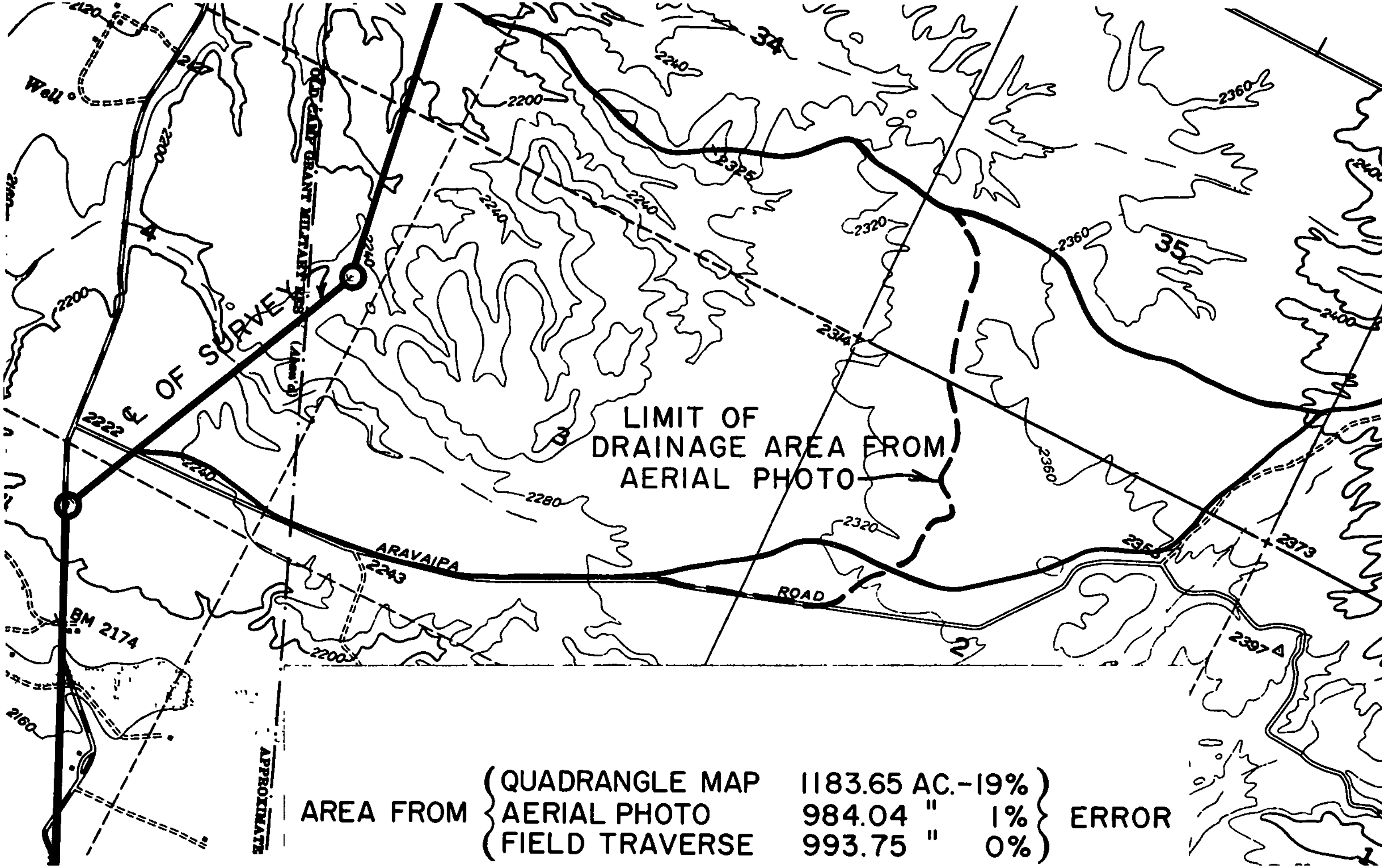

Figure 1. Section of quadrangle map showing drainage area.

points, the scale can be easily determined, and as placing of photographic targets before photography is becoming more and more prevalent this will frequently be the case.

Drainage area boundaries should be plotted stereoscopically using a pocket or mirror stereoscope and a red pencil. It is necessary to trace the boundary on only one of the overlapping areas and preferably on the one on which the entire area occurs. On larger areas that extend over adjacent flight strips, care should be taken in transferring the watershed boundaries from the edge of one photograph to another. This should be done preferably by radial plot to minimize errors. Where there is moderate relief or where the drainage areas are not of great extent, such areas can be planimetered directly on the photographs and converted to acres or square miles according to the average scale as determined. For larger areas and places where differences of elevation are not too great, a scale based on an average elevation of the drainage area to be considered can be used and the area converted on this basis.

Where there is a difference in elevation of 200 ft or more within the limits of the drainage area, however, adjustments should be made for relief displacement. If this is not done excessive error can easily occur. In such cases it is more feasible and convenient to transfer the drainage areas and other pertinent features from the photographs onto tracing paper. Elevations required around the perimeter of each area for making the adjustments can be determined from the photographs with sufficient accuracy by means of parallax measurements using either a parallax bar or engineer's scale. Necessary measurements can then be made and the adjusted areas drawn and planimetered on the tracing. If USGS or USC & GS topographic maps of sufficient detail and accuracy of the area are available, these elevations can be taken directly from the contours on the maps with a considerable saving in time. Other means of obtaining the elevations would be acceptable as elevations to the nearest 50 ft will be accurate enough.

Relief displacement can then be easily determined to a selected datum by radial plot and the drainage area thus adjusted for relief displacement can be plotted and planimetered as usual, computing its extent to a scale as computed by the elevation of the datum plane selected. It appears to be more convenient, though not necessary, to select this datum plane so that it will pass through one of the lower elevations along the centerline of the survey as plotted on each photographic print.

Corrections for tilt are not necessary where the vertical photographs do not contain more tilt than allowed by the usual specifications. Moreover, corrections for tilt require some ground survey data, are quite complicated to make, and are generally beyond the understanding of field engineers to compute. Any errors in drainage area due to tilt in vertical photographs should not exceed the limits of accuracy required. Investigations have shown that error in area over 3 percent because of tilt would be unlikely.

Drainage areas in flat desert or similar regions are more difficult to determine than in places where topography is rolling or rugged. This is due partly to the relief and partly to shifting channels sometimes altering an individual area considerably during storm periods. Also the enormous amount of sediment carried down these shallow channels during a cloudburst will frequently fill a shallow wash and cause the stream to cut another channel and perhaps to cross over to an adjacent area. Close examination of aerial photographs will discover these occurrences or their possibilities much better than determination in the field. Abandoned channels will be evident and in many cases future behavior of the stream flow can be predicted.

OTHER DRAINAGE DATA OBTAINABLE FROM AERIAL PHOTOGRAPHS

In addition to quantitative data pertaining to drainage area size determinable from aerial photographs, other vital quantitative data and qualitative information may be obtained.' All of these data are not obtainable from topographic maps and are difficult and expensive to ascertain by investigation methods on the ground.

Aerial vertical photography viewed stereoscopically is particularly adaptable to the determination of type and extent of ground cover and the extent of ponding and water-retarding features of each drainage area. These features are vital factors regarding surficial drainage and essential components of a judicial analysis of a specific drainage problem. They cannot be obtained from topographic maps or easily obtained in the field.

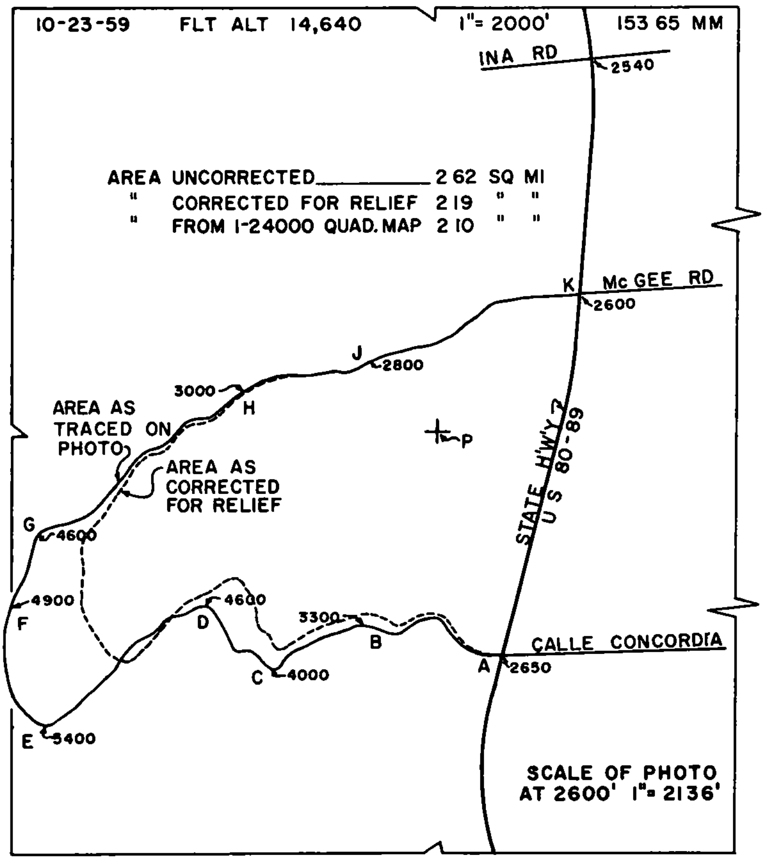

Figure 2. Effect of relief.

Ground cover, depending on type and intensity, reduces the runoff volume and retards the runoff velocity. When viewed stereoscopically, aerial photographs enable the engineer to determine precisely not only the amount of cover but also its character and type. This knowledge is important in identifying underlying types of soil and judging internal drainage characteristics of soils. All of these are essential for accurate determination of structure-opening sizes and shape.

Ponding or retarding of water above drainage structure openings is another significant factor to consider in the structure design. Some drainage channels, whether wide or narrow, are deep with steep, fast draining characteristics. These require structures of considerable headroom. Other areas are extensively wide and flat in character and may be broken by a large lake. Such areas tend to collect large amounts of surficial runoff and act as dispersal areas preceding the site in the drainage channel where the drainage structure must be placed. When this happens, the drainage structure opening may be reduced somewhat from the size indicated by the factor obtained from the drainage area only. When aerial photographs are used, these drainage features are easily and accurately determined and result in a better and more economically drained highway.

EXAMPLES OF DRAINAGE AREA DETERMINATION

Figure 2 shows the amount of drainage boundary displacement that can occur due to extreme relief. At this point the existing highway is adjacent to the Santa Catalina Mountains and the difference in elevation between the low and high points of the area to be measured amounts to 2,750 ft over a distance of about 0.8 mi. Slopes are very rugged and determination of the area by ordinary field methods would be extremely difficult. The photographs were taken from a flight height of approximately 12,000 ft with a 6-in. focal length lens. Scale was estimated from known distances along the highway.

This photograph was chosen because of the extreme conditions encountered and because a recent 7½-min USC & GS quadrangle map was available that could be used for comparison. At the time the photograph was taken there was no intention of using it

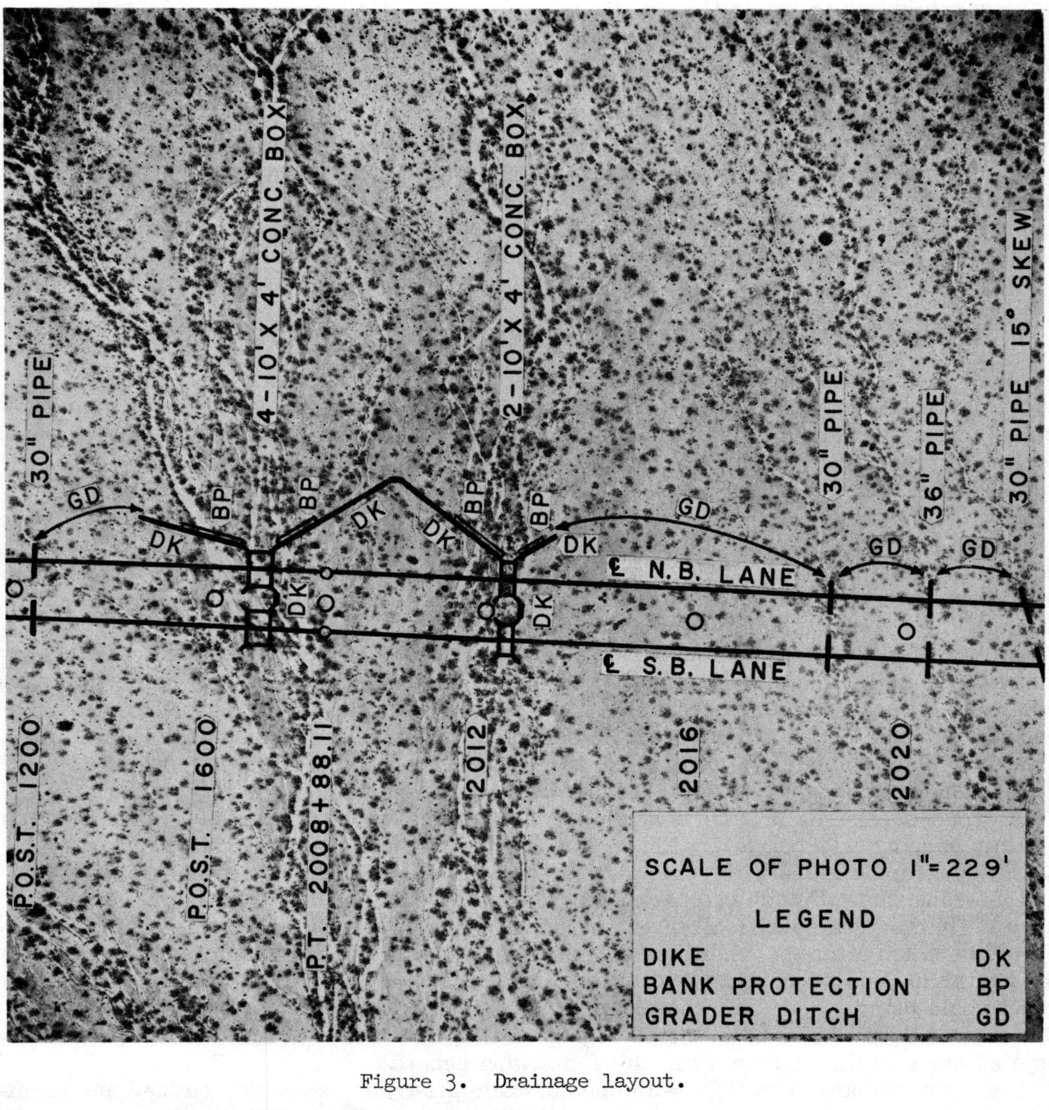

Figure 3. Drainage layout.

for other than pictorial purposes. It should be noted that the drainage area as sketched was not completely covered by the photograph and it was necessary to estimate the upper limits of the boundary. The boundary was determined stereoscopically from this and an adjacent photograph.

In spite of the limitations, there was only a difference of 0.09 sq mi between the area computed from the quadrangle map and from the photograph after correction for relief displacement as shown. This is an error of only 4.3 percent, assuming the area computed from the quadrangle map is correct. Without relief displacement correction, the error would be in the neighborhood of 25 percent. This is of course an extreme condition. Much better accuracy could be expected in the majority of cases.

On one recent project 6.4 mi long, 50 separate drainage areas were considered with an aggregate area of 11,567 acres. Although relief was moderate, the country was difficult to traverse and it would have taken three men at least two weeks to measure the areas out by transit and stadia. The areas were plotted on existing photographs with a scale of 2,000 ft per in. on which targets marking control point positions appeared and were plotted and computed by one man in about two days with greater detail than would have resulted from regular field methods.

Relief differential was moderate and it was not necessary to correct for displacement of watershed boundaries due to this factor. In three cases, the larger drainage areas encountered extended beyond the limits of the photographs and it was necessary to determine these on existing topographic maps. This could have been avoided if the original photographic coverage had been extended to cover the entire area. Comparisons made with existing 7½-min quadrangle maps in this area showed a difference of under 0.5 percent. A stadia survey made of one area of 984 acres (Fig. 1) took two men one full day to complete and showed a difference of under 1 percent between the field survey and the area as taken from the photograph. Savings here in both time and labor are apparent.

POSITIONING OF CULVERTS AND RELATED DRAINAGE FEATURES

After the drainage areas have been determined, it becomes necessary to select the proper size structure and to locate it on the ground in the most desirable and economical position. Generally this is done by examining each drainage channel along the centerline of the survey, measuring or estimating the stationing, estimating the angle of skew, and making sufficient notes so that the structure can be designed and incorporated in the plans.

There is nothing wrong with this method. It has worked for years, but it is time consuming and frequently difficult to determine the exact position where it would be most desirable to construct the culvert, especially when vegetation along the stream is thick or the channel is complexly divided or braided.

Culverts can be positioned accurately on aerial photographs of suitable scale and in many cases better than by examination on the ground. Photographs of a large scale are desirable. Those at 250 ft per in. have proved quite satisfactory. This scale is large enough to supply detail and coverage is sufficient to follow the course of a stream far enough to place the culvert in its most efficient position and determine the need for dykes, channel changes, or other items to assure the control of the stream flow.

If cross-sectioning is to be done photogrammetrically, vertical photographs secured for this purpose will be ideal. These can also be used for the preparation of large-scale topographic maps with contours at a sufficiently small interval for bridge sites and interchanges. If such photography is not to be secured, it will probably be necessary to fly the area specifically for the drainage study. In any event, the photographs should be taken after the centerline has been run, the area photographically targeted so the centerline can be accurately positioned and stationed on the photographs, and their exact scale determined. Narrow Chart-Pak striping is ideal for delineating the centerline so that it will be seen on the photographs. Besides being clean to handle, it can be applied more rapidly than a wax, china-marking pencil.

Culverts can now be spotted with considerable accuracy, skew determined and necessary dykes, channel changes, and other details spotted. Bridge sites can be studied and tentative bridge positions determined. Later, large scale topographic maps can be made of the bridge sites from this same photography in preparation for the bridge design.

In many cases, areas subject to flooding can be spotted on the photographs and an engineer practiced in photographic interpretation can spot other potentially dangerous areas where trouble might be encountered during peak runoff periods.

It is not to be inferred that all field work can be eliminated by use of these methods. It will be desirable to examine many culvert sites on the ground before the construction plans are completed. These field trips can be planned at more convenient times and will progress much more rapidly than would ordinarily be the case. In some cases where ground cover is extremely thick the method might not be practical or might require more detailed field checking.

After all drainage studies have been made, it would be desirable to ink the placements permanently on a set of the photographic prints. The photographs will not only be valuable to design engineers while preparing the construction plans but they will be valuable to construction engineering crews when the highway is being built. Figure 3 shows one print prepared in this manner. In the interest of clarity on the halftone reproduction, tabs were used on the print for stationing and other information. Red ink or tempera normally used would make this refinement unnecessary.

In this instance, cost and time are not as critical as in drainage area determinations. Drainage studies are generally made by the location engineer during survey progress while the crew is otherwise engaged. There is a saving in cost and time, however, and better, more efficient, and more workable drainage systems will result from this method.

CONCLUSIONS

It appears that aerial photographs can be used to considerable advantage in determining drainage areas and deciding on the placement of culverts. Results based on comparisons with other methods indicate that indicate that with ordinary care accuracy can be assured. Use of aerial photographs for these purposes should be anticipated far enough in advance so that the photography will be available when required. Necessary extension of aerial photography flights for other purposes should also be considered so that adequate photographic coverage can be obtained.

Photogrammetric Map Checking

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Checking of photogrammetric mapping by field methods can be costly and time consuming. Unless such checking is thorough there is no assurance that portions not actually covered by field checks will comply with specifications. Recognizing these disadvantages, the California Division of Highways has developed a system of photogrammetric analysis preliminary to field checking.

Photogrammetric analysis consists of reviewing the compilation data in the form of map manuscripts, contact prints with control information identified thereon, diapositives, and field survey notes, as submitted by the mapping contractor. The results of the analysis are used as a basis for recommending field checks.

This paper discusses the development of the checking system, and its performance in routine practice. Photogrammetric analysis is an integral part of over-all checking procedures, and the results of numerous field checks are included. Also included is a discussion of the direct and indirect benefits toward improvement of mapping specifications.

● TOPOGRAPHIC MAPS make it possible for the highway engineer to study, analyze, plan, and design without extensive trips to the field. Viewed in this way, we recognize that the map brings the field into the office, thereby providing the engineer with a basis for increasing his productivity. This presumes that the map is reliable and that the engineer-user has confidence in it.

Many highway engineers have had difficulty accepting topographic maps as being sufficiently accurate for their needs. This has been especially true with their slow acceptance of topographic maps made by photogrammetric methods. In many instances the lack of confidence in the photogrammetric map originated with misunderstanding about how it was made. On the other hand, critical analysis was needed to establish accuracy standards sufficient for the requirements for highway planning and design.

The California Division of Highways has been using photogrammetric mapping for highway design since 1950. From the very start, photogrammetric products were obtained from private sources by competitive bidding procedures. With the advent of the Federal Highway Act of 1956, increased demand for planning and design data required extensive photogrammetric output by private firms. During the past four years about 1,850 mi of design-type mapping have been accomplished, with 578 mi obtained in the peak fiscal year of 1956-57. The current demand is for approximately 300 mi per year.

The subject of this paper should be placed in proper perspective by reviewing the procedure by which this organization obtains its mapping. It is the opinion of the author that the Division of Highway's system of checking photogrammetric maps is especially applicable when contracting for a large volume of work.

The procedure for obtaining photogrammetric mapping by the Division of Highways is composed of several well-defined steps:

1. Prequalification of bidders. All prospective bidders must be experienced in performing similar work, list clients for whom past work was satisfactorily completed, and submit complete information concerning technical organization, equipment and plant facilities, and financial resources. They must also have a registered civil engineer or licensed land surveyor in their employ who is responsible for all technical performance under the terms of the contract.

2. General specifications. The over-all policies, both legal and technical, under which the Division of Highways operates, are incorporated in a set of specifications entitled, "Photogrammetry, General Specifications." These specifications serve as a basic guide to contract performance, and are effectively up-dated by the special provisions for particular contracts.

3. The mapping project. An area where up-to-date map data is needed is reviewed for the type of map required and the extent of desired coverage. In addition the proposed project is analyzed for methods and procedures aimed at producing the map data within specified accuracy tolerances.

4. Special provisions. The special provisions modify and amplify the general specifications. Included as part of these provisions are plan sheets showing location of project, mapping limits, ground cover conditions, existing horizontal and vertical control, and specified flight lines. The results of all the planning are incorporated in the text and on the plan sheets.

5. Bidding and award. A bid list is drawn up, composed of those qualified bidders who have demonstrated that they can handle the type of job in question, especially considering capacity of the firm in relation to the size of the job. Sealed proposals are received, and award is ordinarily made on the basis of the lowest bid.

6. Production. Upon award of the contract all production as specified in the special provisions is the direct responsibility of the contractor. Any variations from the special provisions are mutually agreed on by the contractor and the State and covered by contract change order.

7. Checking. The checking of all materials and data required under the contract commences on delivery or shortly thereafter. Checking is the main subject of this paper, and will therefore be discussed in greater detail.

8. Acceptance. For practical purposes the acceptance of a map merely means that the contract is completed and the contractor is authorized to receive final payment for his efforts under the terms of the contract. It sometimes happens that acceptance is complicated by circumstances that had developed during production phases. It is especially important that a thorough review be made at this time to ascertain the reasons for the difficulties, whether they were extenuating and beyond the control of either the State or the contractor, or whether the difficulties could have been prevented by either party. In other words, this is the last opportunity to review and analyze for the purpose of improving future contract procedures and specifications.

These eight steps comprise a complete system for obtaining photogrammetric mapping, and negligence in the performance of any one of them may contribute to an unsatisfactory product.

The Division of Highways has developed a system of map checking that is particularly satisfactory as a part of the over-all method of map procurement. This system is divided into two steps: (a) photogrammetric review or analysis, and (b) field checks dependent largely on the results of photogrammetric analysis.

A corollary to the map checking program is the influence it has had on the acceptability of the maps by the engineer-user. The application of this program has prevented poor jobs from reaching their destinations, so to speak, and over a period of time confidence in the photogrammetric methods has been attained.

SPECIFICATIONS AND PROCEDURES

Accuracy specifications for large-scale mapping are an outgrowth of National Map Accuracy Standards. The so-called Standards are not entirely satisfactory, but they do serve as a foundation for incorporating the requirements for highway design maps. Investigations have demonstrated that mapping specifications, wherein earthwork quantities are to be considered, must recognize the fundamental importance of statistical accuracy (1, 2, 3).

Current California accuracy specifications (4) for a typical project with mapping at 1 in. = 50 ft with 2-ft contours and/or spot elevations can be summarized as follows:

In areas not obscured by brush or field crops:

1. 90 percent of the contours shall be within 1.0 ft.
2. 90 percent of the spot elevations shall be within 0.5 ft.
3. The arithmetic mean shall not exceed:
   ± 0.40 ft for 20 points tested,
   ± 0.30 ft for 40 points tested,
   ± 0.20 ft for 60 or more points tested.

These limiting tolerances for the arithmetic mean are based on a standard deviation of 0.6 ft and 99 percent probability. Exact values computed on this statistical basis have been rounded out to the next higher 0.1 ft. In establishing such tolerances two factors should be recognized:

1. The desirability of testing small segments of the mapping to minimize varying systematic errors. This is necessary if anticipated balances of earthwork quantities between individual cuts and fills are to be maintained.
2. The effects of irregular ground surface and even minor amounts of ground cover on photogrammetric readings at the map scales now being used.

About 98 percent of California contracts are with firms that use the Kelsh-type plotter as the basic photogrammetric instrument. Methods and procedures, as required in the special provisions of the contract, are directed toward this type of instrumentation together with the associated phases of photography and supplemental control.

Before 1956, a minimum of detailed specifications was included in the special provisions of each contract. With the start of photogrammetric analysis, it was immediately apparent that greater emphasis had to be given to the principles of photogrammetric engineering if satisfactory mapping was to be obtained. The current detailed specifications provide a fairly complete outline of procedures that the mapping contractor must observe, and constitute a sound (though conservative, in some respects) approach to the making of large-scale maps by photogrammetry. Although certain items are considered standard, each project is individually planned before the writing of the specifications.

The major technical considerations follow in logical order:

Aerial Photography

The proper planning of aerial photography centers around the photogrammetric instrument to be used. Hence, for the Kelsh-type plotter careful flight planning is essential because of projection limitations. Special attention is given to the range of relief to be accommodated on any one flight line in relation to mapping width. Reasonable tolerances in flight altitude and position are allowed in planning so that complete stereo-coverage within the limitations of the projection equipment is assured. Adequate aerial photography is absolutely necessary, for this is the initial phase upon which all subsequent phases depend.

Aerial photography must be taken with precision cameras that have satisfactory calibration certificates. Usually 6-in. focal length cameras are required, although on occasion 8¼-in. focal lengths have been permitted and even encouraged in areas of moderately heavy vegetative growth.

Until very recently experience with cronar-base aerial film has been lacking. However, from our limited experience to date we are encouraged by the prospects this modern film promises to offer. Some of the mystifying vagaries in relative orientation have disappeared, and model definition seems to be improved. Consideration is being given to the mandatory use of the film on future projects.

Diapositives are required to be made on glass that at least 0.130-in. thick, and with the emulsion surface down. The metrical data pertaining to diapositives has been reported previously (5).

Supplemental Control

The basic concept of supplemental photo-control for large scale, small contour interval mapping is that each neat model area must be fully controlled and that its absolute orientation should not depend on the orientation of adjoining models. In other words, the bridging of control is not permitted.

The arrangement and placement of wing points for vertical control in model corners is the responsibility of the contractor. However, in order to convey the single-model concept, wording similar to the following is included in the special provisions: "Establish and use for supplemental vertical control points, placed advantageously near the four corners of each model used in compilation within a radius of 5 in. from the center of the two photographs forming the neat model. No point should be located more than 3.5 in. from the X-axis of either photograph. The four points should be located to form a rectangular pattern for the corner control of any neat model."

In addition to the four-corner vertical control points, a fifth vertical control point is required near the center of the neat model. This specification is frequently modified if a specified or existing horizontal control line runs along the middle of the mapping strip and ground elevations are available at the monuments.

The pre-marking of all or a portion of the vertical control before photography is sometimes specified, especially in flat terrain devoid of definitely photo-identifiable features. This is applicable to farm lands, deserts, and grassy terrain. The common practice is to locate pre-marks on the ground along the margins of the mapping strip at uniform intervals of 200 to 300 ft. Elevations need be established on only those points that fall near model corners, but may be established on all the points if the contractor so elects.

In line with the single-model concept, at least two well-spaced horizontal control points should be located in each model. For many years, three horizontal points have been required, the extra point serving as a check.

Primary horizontal control is usually done by State forces, with monuments set at intervals of 1,000 to 2,000 ft through the center of the mapping strip. The current trend is to require supplemental horizontal control to be traversed between the primary monuments. In order to take advantage of the necessary taping, the supplemental points are located at tape-lengths of 200 to 300 ft.

Pre-marking of horizontal control has become standard practice. Further, with elevations established on the pre-marks, vertical control throughout the center of the mapping strip is readily available. This procedure is fairly routine and especially adaptable to flat terrain conditions.

Compilation

Before the availability of mylar polyester films, considerable difficulty was encountered with manuscript materials. The mylar films, of which several commercial varieties are obtainable, have virtually eliminated "paper stretch" as a source of error in photogrammetric compilation. The use of this type of material is a specification requirement.

The results of prior planning and production (photography and control) directly affect compilation. If the planning has been satisfactory, and production of photography and control progress accordingly, compilation difficulties are greatly minimized. The most important remaining source of error is the amount of vegetative growth existing at the time of photography. In areas of heavy cover, specifications provide for relaxed accuracy tolerances, as previously noted, and must be indicated by dashing the contours. Field completion surveys are necessary under very heavy growth conditions.

Spot elevations are required to supplement contours in locations where interpolation of elevations would be troublesome. Typical features are tops, saddles, depressions, benches, and places where the ground is so flat that contour spacing exceeds 2 in. at map scale.

Ordinarily all planimetric detail visible in the model must be shown. There are certain exceptions, such as very small buildings. However, important planimetric features not visible in the models are sometimes required, indicating the necessity of field completion surveys.

Delivery Schedules

Delivery schedules specify that all materials pertinent to compilation be included in required shipments of completed maps. From the date the compilation materials are received, the State has 90 days in which to complete the checking of the maps.

The foregoing outline of specifications may be modified according to individual job requirements, but in the main constitute the essential considerations for the making of large-scale photogrammetric maps to the specified accuracy tolerances. In addition, careful planning of the basic production operations affords a better understanding of the map checking problem.

MAP CHECKING PROGRAM

The fundamental rule serving to govern map checking procedures is that the method used to check the map should be capable of a higher order of accuracy than the method used to make the map. An academic interpretation of this rule often leads to confusion and may not produce the desired results. With the variations in survey procedures now available, any number of acceptable alternatives are at the disposal of the engineer, depending upon scale and contour interval of the map, accuracy specifications, ground cover conditions, and nature of the terrain.

As an example, the use of stadia may or may not be applicable for the checking of photogrammetric maps. Stadia is considered suitable for checking small-scale, large contour interval mapping, such as 1 in. = 200 ft with 10-ft contours. Errors inherent in the method are not critical at that scale and contour interval. However, the application of stadia to the checking of the usual design scale map at 1 in. = 50 ft with 2-ft contours is more restricted, and must be used with considerable judgment. On the other hand, the use of transit traverse for checking of large-scale maps of rugged, timbered terrain may not be justified, especially considering reduced accuracy tolerances in such situations.

For large-scale mapping, field checks require relatively high survey technique in order to discriminate photogrammetric errors. As reported in the article, "Terrain Data for Earthwork Quantities" (2), the taking of cross-section data by routine field procedure proved to be less accurate than by photogrammetric procedure. In this test a precise field survey was made for the purpose of comparison, permitting the segregation of errors in both the routine field survey and the various photogrammetric surveys. It is interesting to note, however, that had the precise survey not been made, the differences between the photogrammetric survey and the routine field survey would have been undoubtedly attributed to errors in the photogrammetric work. The common assumption that field survey is naturally superior to photogrammetric survey is not necessarily valid and frequently leads to erroneous conclusions.

The cost of field survey can be prohibitive, especially if a thorough check of the mapping is desired. The practice of running one field profile on each map sheet without regard to the number of stereomodels comprising the sheet is hardly a thorough check. If the stereomodel is to be considered an independent compilation unit, theoretically it should be checked accordingly. A map sheet may comprise one model or several models. It is not suggested, however, that such field checking is warranted, unless detailed method and accuracy specifications are unknown.

The Division of Highways recognized the map checking problem associated with the volume of mapping required for the planning and design studies. In 1956, a Kelsh plotter was purchased for the sole purpose of checking contract work. It became necessary, therefore, to require the mapping contractors to deliver their compilation materials, consisting essentially of manuscripts, control-photographs showing identifications and values, and diapositives, along with completed map sheets. These materials are necessary for the resetting of stereomodels in order to investigate the probable areas of weakness. Accordingly, field survey parties are advised to check these areas for compliance with accuracy specifications.

Although confidence was expressed in this initial endeavor, the procedure was in reality on trial. For one thing, one hesitates to call it "checking" because the findings had to be substantiated by field survey. Also, frequently there was doubt because the data furnished by various contractors was sometimes so indefinite that findings were unavoidably inconclusive. It was apparent that method specifications had to be improved in order to assure reasonably that accuracy tolerances could be attained. Consequently, the over-all approach has developed more logically as a photogrammetric analysis because the entire photogrammetric procedure for large-scale mapping is investigated. Two positive outcomes are now recognized:

1. The improvement of specifications to assure with greater certainty the possibility of meeting required accuracy tolerances for design-type maps.
2. The reduction of checking costs by isolating the probable weak areas of the mapping, which permits the more expensive field checking to be concentrated in the recommended areas.

During the 23½-month period from January 1959 through the middle of December 1960, 2,349 models were investigated, using 3 Kelsh-type plotters. This is equivalent to about 400 mi of design mapping, or approximately 2/3 of the total mileage acquired during this period, involving 20 contractors and 69 contracts. Approximately 26 percent, or 600 models, were recommended for further field checking. This amounts to a reduction of 74 percent in field checking on the basis of checks in every model. It is emphasized at this point that many models recommended for field checking were of borderline accuracy and very few were actually rejected. Detailed records were kept on the results of 62 of the 69 contracts. A more detailed breakdown of results follows, showing a distribution according to findings on the 62 contracts.

Table 1 shows the record for individual contracts by stereomodels. In this type of work it is generally impossible to differentiate precisely between the models that are substandard and those that are borderline. Thus, those recommended for field checks are subdivided according to the extent of check the photogrammetrist believes necessary.

An explanation of row headings will demonstrate the significance of the recommendations for field checks. Between those models determined satisfactory (or "OK") and those requiring field checking, lies an indefinite zone that comprises models that are "probably OK." Within this latter category further subdivision is made to separate control from compilation problems. Control problems are of two types, vertical and horizontal, but occasionally both types occur. Compilation problems, on the other hand, may stem from several different sources:

1. Omissions, either planimetric or topographic (such as buildings or poles), or top contours, depression contours, significant spot elevations, and other map-worthy features required in the specifications.
2. Generalized topography, especially in rugged terrain, resulting from hasty compilation.
3. Systematic differences in elevation between the contract map and the reset model, indicating the possibility of systematic errors.
4. Ground cover, especially those small areas not so indicated on the contract map, that probably do not conform to standard accuracy requirements.
5. Weak areas, usually isolated and small, wherein vertical disagreements between the contract map and the reset model are apparent.
6. Minor differences between the contract map and the reset model comprising several of the previously mentioned sources.
7. Erratic compilation wherein nothing too definite can be isolated and the causes are unknown, other than simply careless workmanship.

Miscellaneous comments are usually confined to those models that are poorly illuminated, and therefore difficult to read, and to models that indicate vague photographic problems suggested by residual parallax.

Models classified in this indefinite zone of "probably OK" are noteworthy to the extent that the problems associated with them are not considered significant enough to cause rejection if subjected to field checking. In other words, they undoubtedly conform to the 90 percent concept expressed in the accuracy requirements. If, in the judgment of the photogrammetrist, any or a combination of the various classifications are significant to warrant field investigation of particular models, then the type of field check is suggested that should reveal whether the model meets specifications.

A spot check, meaning a scattering of field elevations in the model area to determine the trend of errors, is suggested when vertical control problems or general brush conditions are serious enough to make standard accuracy problematical. This is a sort of borderline condition, difficult to pinpoint definitely.

A limited field check is usually confined to specific areas that are either large enough to cause the model to fail to meet the 90 percent concept or significant enough regardless of size to give rise to problems in the design phase. An an illustration, errors in particular vertical control points may not have been resolved during compilation to the satisfaction of the State's photogrammetrist, perhaps making a definite portion of the model suspect for vertical accuracy. However, if the errors had been resolved to his satisfaction, the model would have been classified as probably OK, noting the difficulties with vertical control.

Should brush-covered draws or other drainage features indicate serious vertical errors, a limited field check of the specific area would be suggested. Such areas are typical of the problems that later arise during design and cause doubt as to the reliability of the entire mapping. Because of this, it is fairly common practice to require before compilation field profiles of particular drainage features to control the plotting of contours on the manuscript.

A complete model check is recommended for those models that are so erratic that compliance with accuracy standards is extremely doubtful. It sometimes happens in these situations that the contractor had at the time of compilation information that enabled him to meet specifications, whereas without this information the State's photogrammetrist was obliged to recommend complete field checking.

Table 2 is a summary of the photogrammetric analysis record of individual contracts listed in Table 1. In this form, it is a record of individual contractors.

TABLE 1

PHOTOGRAMMETRIC ANALYSIS RECORD STEREOMODELS, INDIVIDUAL CONTRACT

CONTRACTOR	A		B								C			D	E	F
CONTRACT NUMBER	1	2	1	2	3	4	5	6	7	8	1	2	3	1	1	1
OK - (No Comments)	16	13	30	36	13	9	16	7	6	15	7	11	9	3	8	5
PROBABLY OK																
Control																
vertical		2	1	3	1	8	3								1	4
horizontal						2										
both																
Compilation																
omissions	3		1			2			1	1	2					
generalized																
systematic	3		1	2			1			2		1			1	
ground cover	1								1				1		1	
weak areas	8	1	3	1				2				2			2	2
minor diff	1	4		2			1		1							
erratic			1	2		3			1	1	2		1			
Miscellaneous	2	2	1													
FOR FIELD CHECKING																
spot check					2	6				1					3	
limited check	3		4	4	5	2	2			1			1	1	3	
complete check	2		5	6	3									1	1	1
TOTAL STEREOMODELS	39	22	47	56	24	32	23	9	10	21	11	14	12	5	20	12

CONTRACTOR	G					H						
CONTRACT NUMBER	1	2	3	4	5	2	3	4	5	6	7	8
OK - (No Comments)	20	22	25	10	12	4	14	8	4	9	12	7
PROBABLY OK												
Control												
vertical		1				1	1	2		3	2	
horizontal												
both												
Compilation												
omissions			4					3		7		
generalized			13			1					1	
systematic							1	1	1			
ground cover	1							5		1		
weak areas			1		1	2	2		1	2		
minor diff					2							
erratic	2							5	1	7	2	
Miscellaneous			2	1			1	6		1		
FOR FIELD CHECKING												
spot check				3					4	4		3
limited check	1	4		3	3	2	1	1	3		3	3
complete check	5				1	1	1	12	6	4	1	
TOTAL STEREOMODELS	29	27	45	17	19	11	21	43	20	38	21	13

CONTRACTOR	I		J		K			L					
CONTRACT NUMBER	1	2	1	2	1	2	3	1	2	3	4	5	6
OK - (No Comments)	27	6	14	39	14	41	6	25	26	12	2	20	8
PROBABLY OK													
Control													
vertical	1		1		1	2		1	1				
horizontal													3
both													
Compilation													
omissions	1					1			1				1
generalized			1				1			1			
systematic	1	1	2	1		1			2	15		1	
ground cover								1		1		1	
weak areas	1	1		1	2	8	2	4	3	1		1	3
minor diff			1			1		1	2				
erratic										4		1	3
Miscellaneous	1		2		1				1			3	
FOR FIELD CHECKING													
spot check	2		1					1	2	1		3	1
limited check	1	18		6		2	1	3	5	7		5	6
complete check		2	2			4	1			13		1	2
TOTAL STEREOMODELS	35	28	24	47	18	60	11	36	43	55	2	36	27

CONTRACTOR	M		N											O	P	Q			R	S
CONTRACT NUMBER	1	2	1	2	3	4	5	6	7	8	9	10	11	1	1	1	2	3	1	1
OK - (No Comments)	5	25	28	24	10	12	27	10	29	6	18	20	4		10	3	17	8	49	4
PROBABLY OK																				
Control																				
vertical		1	2	9		8			1	2					1		2	1	2	
horizontal					1		2										5		1	2
both										1							4			
Compilation																				
omissions		3		1		1											1	1		
generalized			1			1		1		1		2				1			2	
systematic		1	1	3			1		5			1	1						1	
ground cover	3	2	9	9		3			1							2	2	1	1	3
weak areas		1	4	6		4	4	1	2	1		1	1		2		1		2	1
minor diff		2		3		2	3	1	4			1					1			
erratic				1	2	2	1	1	1											2
Miscellaneous									6								1		2	
FOR FIELD CHECKING																				
spot check			1	3	1	1	2	2	8	2			1					1	1	3
limited check		2	6	7	2	7	2	2	19	1		6	1			2	1	2	7	
complete check			6	3	2	1	8	2	7	1		4	1	4		1	1	1	4	5
TOTAL STEREOMODELS	8	37	58	69	18	42	50	20	83	15	18	35	9	4	13	9	36	15	72	20

TABLE 2

PHOTOGRAMMETRIC ANALYSIS RECORD: SUMMARY OF STEREOMODELS, INDIVIDUAL CONTRACTORS

CONTRACTOR	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
OK - (No comments)	29	132	27	3	8	5	89	73	33	53	61	93	30	188		10	28	49	4
PROBABLY OK																			
Control																			
vertical	2	16			1	4	1	10	1	1	3	2	1	22		1	3	2	
horizontal		2										3		3			5	1	2
both														1			4		
Compilation																			
omissions	3	5	2				4	10	1		1	2	3	2			2		
generalized							13	2		1	1	1		6			1	2	
systematic	3	6	1		1			3	2	3	1	18	1	12				1	
ground cover	1	1	1		1		1	6				3	5	22			5	1	3
weak areas	9	6	2		2	2	2	10	2	1	12	12	1	24		2	1	2	1
minor diff.	5	4					2			1	1	3	2	14			1		
erratic		8	3				2	15				8		8					2
Miscellaneous	4	1					3	8	1	2	1	4		6			1	2	
FOR FIELD CHECKING																			
spot check		9			3		3	12	2	1		8		21			1	1	3
limited check	3	18	1	1	3		11	16	19	6	3	26	2	53			5	7	
complete check	2	14		1	1	1	6	27	2	2	5	16		35	4		3	4	5
TOTAL STEREOMODELS	61	222	37	5	20	12	137	192	63	71	89	199	45	417	4	13	60	72	20
Number of Jobs	2	8	3	1	1	1	5	8	2	2	3	6	2	11	1	1	3	1	1

TABLE 3

PHOTOGRAMMETRIC ANALYSIS RECORD:
PERCENT OF STEREOMODELS, INDIVIDUAL CONTRACTORS

CONTRACTOR	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
OK - (No comments)	48	59	73	60	40	42	65	38	52	75	69	47	67	45		77	47	68	20
PROBABLY OK																			
Control	3	8			5	33	1	5	2	1	3	2	2	6		8	20	4	10
Compilation	34	14	24		20	17	17	24	8	8	18	24	27	21		15	17	8	30
Miscellaneous	7	1					2	4	2	3	1	2		2			1	3	
FOR FIELD CHECKING	8	18	3	40	35	8	15	29	36	13	9	25	4	26	100		15	17	40
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Number of Jobs	2	8	3	1	1	1	5	8	2	2	3	6	2	11	1	1	3	1	1

Table 3 is derived from Table 2, the values being expressed in percent. Thus, as a record summarizing the performance of individual contractors, Table 3 provides a quick reference. However, the tabulated data should not be interpreted too rigorously in all cases.

For instance, the record for contractor D is not realistic because only five models were reset on the one project investigated. In this particular case, the photogrammetric work was compiled with a universal instrument. The five models were reset in a similar instrument belonging to another agency. Time did not permit a more thorough analysis, therefore the record is not indicative of the contractor's potential performance.

For contractor I, Table 3 shows 36 percent of the models recommended for further field checking. This was caused largely by the fact that contract I-2, Table 1, shows 20 models out of 28 suggested for further field checking. This contract required standard accuracy mapping throughout, specifying field completion surveys in the areas of heavy ground cover. During photogrammetric analysis it was not certain how much field completion was actually accomplished, and the recommendation for field checks merely indicated that the areas in question could not have been compiled photogrammetrically to the required accuracy. The field completion surveys had been made as required and no models were rejected as a result.

Of the 62 mapping contracts investigated, 2 (O-1 and S-1) were found to be very poor because of failure to follow specifications. Both of these contracts were willingly corrected by the respective contractors.

Table 4 summarizes the photogrammetric analysis record for the 62 projects. It is noted here that only 128 models, or 7.4 percent, of the 1,739 that had been reset were recommended for complete field checking, compared with 174, or 10.0 percent, for limited field checking. Without the advance information furnished by photogrammetric analysis, extensive and unproductive field effort would be unavoidably expended.

Field checking data based on the information provided by photogrammetric analysis show a definite correlation of results. Whenever enough field data are available, it is the practice of some District offices to make a statistical analysis as illustrated by Figure 1. The derivation of the cumulative frequency curve is explained in the article, "Photogrammetric Map Accuracy" (1).

TABLE 4

PHOTOGRAMMETRIC ANALYSIS RECORD:
SUMMARY, 62 PROJECTS, 19 CONTRACTORS

	Summary by Category Models	(%)	Summary by Item Models	(%)
OK - (No comments)	915	52.6	915	52.6
Probably OK:				
Control:	91	5.2		
vertical			70	4.0
horizontal			16	.9
both			5	.3
Compilation:	334	19.2		
omissions			35	2.0
generalized			27	1.6
systematic			52	3.0
ground cover			50	2.9
weak areas			91	5.2
minor diff.			33	1.9
erratic			46	2.6
Miscellaneous	33	1.9	33	1.9
For field checking:	336	21.1		
spot check			64	3.7
limited check			174	10.0
complete check			128	7.4
Total	1,739	100.0	1,739	100.0

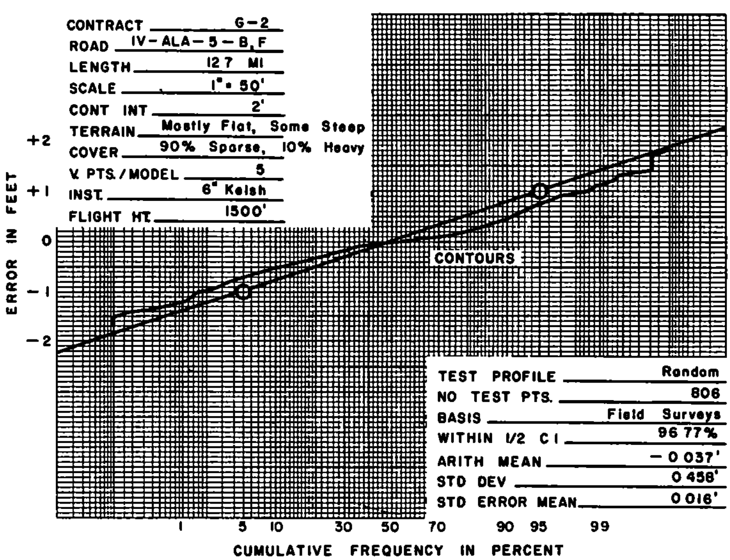

Figure 1.

G P Katibah

For contract G-2, 27 models had been reset (Table 1), or about 36 percent of the total number of models covering the project. This was considered to be sufficient to anticipate a satisfactory job. Subsequent field checks based on random profiles demonstrated that excellent mapping was performed. Figure 1 very adequately summarizes the results. Because of heavy brush in certain draws, 4 models had been recommended for limited field checking.

CONCLUSIONS

The photogrammetric map checking system used by the California Division of Highways was developed to investigate the accuracy of large-scale design mapping obtained under contract. The volume demand for this type of mapping was caused by the accelerated highway program stimulated by the Federal Highway Act of 1956.

Two direct benefits of the program have been demonstrated:

1. Reduction in field checking time and effort.
2. Continuous analysis and consequent improvements of mapping specifications.

Adequate mapping specifications are absolutely necessary to guarantee satisfactory results. Of 62 contracts investigated, 2 were found to be substandard. In both cases, the contractors had failed to follow specifications.

The over-all records of the map checking program prove that whenever good specifications are diligently followed standard accuracy mapping will be assured.

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Photogrammetric Measurements of Cross-Sections For Pay Quantities

R. K. SHEIK, Engineer of Photogrammetry, Ohio Department of Highways

This paper presents the experience of the Ohio Department of Highways in the use of aerial photography and photogrammetric methods for computing earthwork quantities on final cross-sections.

Progressive steps from the development stage to the present universal use of these methods are outlined. The experience of the Department covers four years of application with satisfactory results.

Comparison between photogrammetric methods of computing final cross-sections and actual ground surveys indicates that photogrammetry is generally more accurate, much more economical in both time and money, and safer in all respects.

● THE TIME-CONSUMING METHODS of measuring cross-sections of major highway projects has always presented a perplexing problem. Ohio is meeting this problem today by photogrammetric measurements to determine earthwork quantities. Final payments to contractors are now based on information obtained in this manner.

The Ohio Department of Highways, a pioneer in aerial surveys, began measuring cross-sections for pay quantities by photogrammetry in 1956. It is believed this was the first attempt made on a highway project to secure such measurements by this method.

The test was made that year on a 1.8-mi highway project. The site was selected in an area having exceptionally rough terrain so that it would offer a multitude of problems. The results proved satisfactory in every respect. The were accurate and efficient, conserved engineering manpower, and above all, offered considerable savings in time.

The full import of this operation was not realized until the advent of electronic computers and digitizing readout devices for stereo plotters in the highway field. Its necessity became acutely apparent as projects neared completion in Ohio's huge highway program. From January to October in 1960, cross-sections were measured by photogrammetric methods on 230 mi of major highways, mostly on the four-lane interstate system for determination of pay quantities.

Aerial photogrammetry has proven to be of exceptional value in several respects. It is considerably more economical than ground surveys in saving the Highway Department both time and money. Final payments to contractors have been expedited as a direct result of this process. The safety risk in field personnel formerly involved in making surveys on the ground has been greatly reduced. Finally, aerial photogrammetry has demonstrated a greater accuracy, in general, than ground survey.

EVOLUTION OF METHODS

In the beginning, the photogrammetric instrument operator recorded elevation reading on the manuscript alongside the plotted horizontal position of each measured point on each cross-section. An aide later scaled the distance to each point and prepared notes similar to those taken in the field except that elevations were used instead of rod readings. The completed cross-sections were then delivered to the project engineer in the form of notes. When prototype electronic readout became available, the cross-section measurements were punched directly onto IBM cards (Figure 1).

With original ground and constructed highway cross-section data on cards, it was then possible to compute the earthwork and at the same time plot the cross-sections on an electronic line plotter, which had now been introduced. It was thought that a plotting of the constructed highway cross-sections on tracing paper could be superimposed over the corresponding cross-sections of the original plans in order to determine any deviations. Its main use was to indicate graphically the fit of the sections and to point up errors.

During this stage of development the project engineer received a tab list of the original sections, a tab list of the constructed highway sections, a data line plotted on tracing paper of those sections, and tabulated earthwork quantities from which he determined pay quantities.

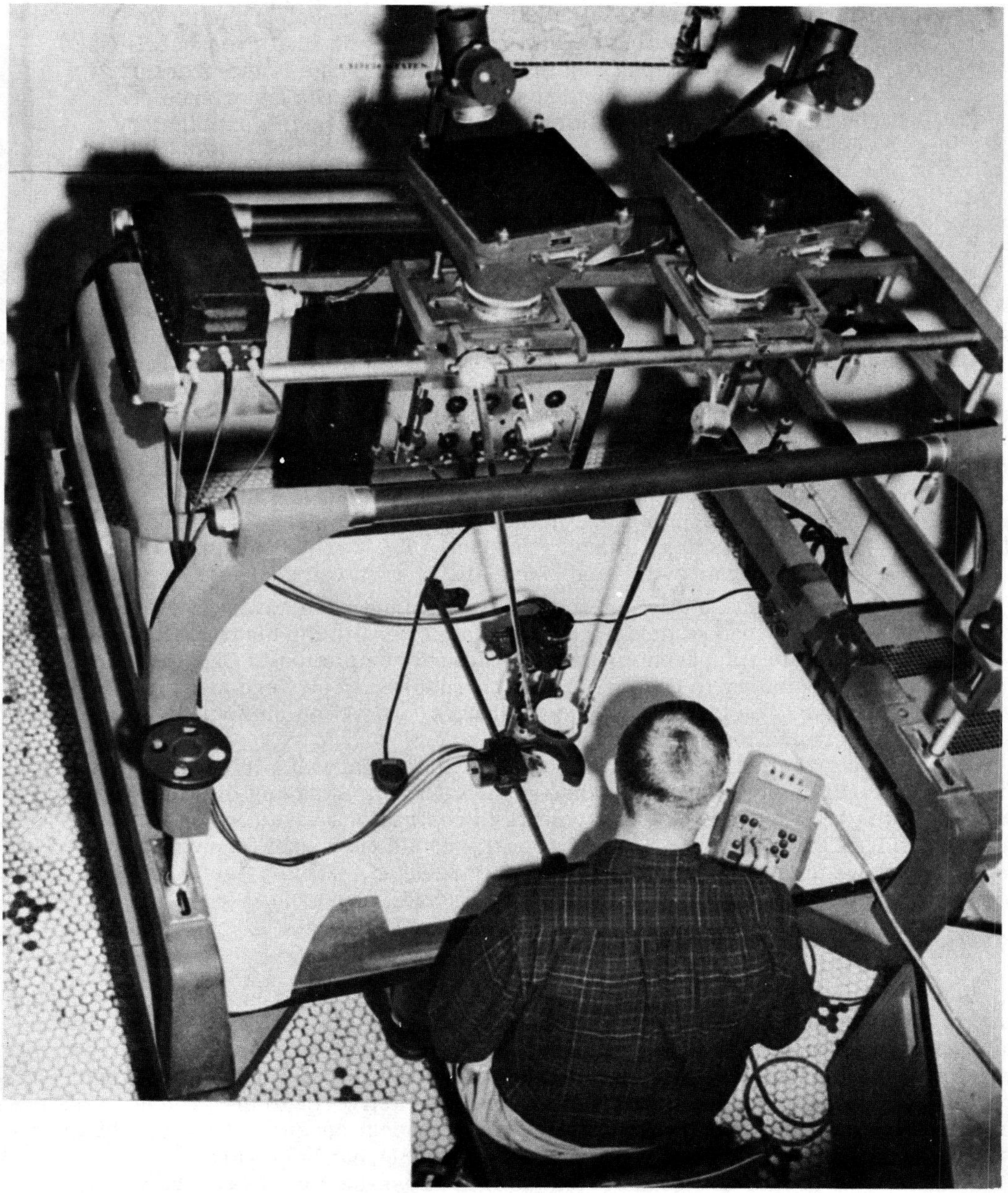

Figure 1. Prototype readout in operational position.

This procedure was adequate because of the time lag. It was impossible to obtain electronically plotted sections in the time needed. A very real urgency existed in processing earthwork quantities for final payment and so it became expedient to plot the sections by hand. This was accomplished, at the time, by using an extra man in the plotting booth whose job was to plot each reading onto a black and white copy of the plan cross-section. He also guided the stereoplotter operator by taking only those cross-sections necessary to shape the draft and at the same time calling his attention to necessary readings that might have been passed. By this method, closures were made at the ends of each cross-section with very little forcing.

It was found that the best closure adjustment could be made at the stereoplotter by making use of all the data accumulated. In some cases the original notes may have been incorrectly reduced or incorrectly plotted. In other cases, the "feel" for accuracy in the original sections gave an indication of the best way to make a closure. It was also possible to take sufficient readings at the ends of each cross-section to extrapolate the original ground. It was rarely necessary to refer to preconstruction photography.

With this procedure there was also developed the terrain edit program for checking cards as punched for computation. Most errors were caught before punching and the balance was corrected on the validity check before compilation.

These methods provided an improved service to the project engineer. Cross-sections were now plotted on a black and white print suitable for field check, adjustment of quantities, or use as an exhibit of the constructed highway cross-sections. The computations for end areas and accumulated volume were now reliable because every point on both the original and constructed highway cross-sections had been checked for validity.

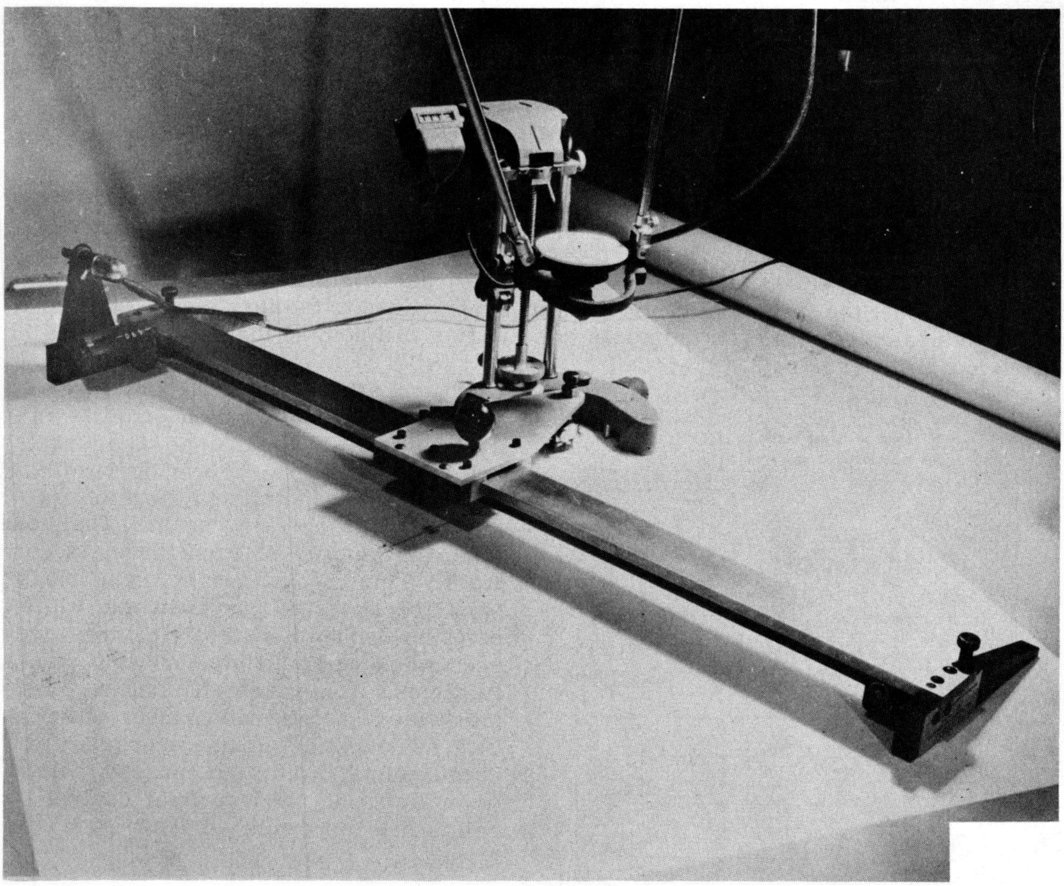

Figure 2. Prototype bar with mechanical readout.

Only two readout machines were available at this time, so it became necessary to develop parallel manual methods to obtain cross-section information on the completed highway. At present, the procedure consists of calling off readings from a cross-section scale to engineer aides who keep notes and plot the cross-sections. The cross-section scale is numbered both ways from zero and consists of a photographic reproduction on mylar or cronaflex. The notes must be hand-punched if computation is desired. This method is especially useful on ramps and side roads.

A horizontal bar with a mechanical read-out, developed by Photronix, Inc., is an important feature of the procedure. Figure 2 shows that the bar has two dials, one for reading the distance right of the centerline and one for left of the center. Covers on the dials automatically open and close according to the direction in which the tracing table is moved making it impossible to read the wrong dial. By this method, the operator calls out his cross-section measurement readings to the aide, who in turn records them in the form of field notes. These readings are later key punched and verified.

PREPARATION OF PROJECT FOR MEASURING CONSTRUCTION CROSS-SECTIONS

Preparation of projects begin in the office with scheduling, preflight planning, marking the job for flight, and punching and verifying IBM cards.

When machine computation of earthwork is called for, it is necessary to obtain the original cross-section field notes. If preconstruction sections were taken or change orders processed, these two must be obtained. The sections are punched on cards and verified.

Preflight preparations are important. Each project is visited and carefully analyzed and, with the assistance of the project engineer, a report is made of the findings. The report covers information on side roads, ramps, channel changes, borrow pits, and any changes made from the original plans. Changes in ditches and slopes are noted and waste areas and batch plant sites located. Each project is reviewed station-by-station and the job marked for photographic identification.

PREFLIGHT SIGNALS

Accuracy is greatly increased and succeeding operations greatly simplified if the project is properly marked with photographic targets on the ground before the aerial photography flight is made. This is imperative for horizontal control and helpful for vertical. Existing points that control alignment should be marked by targets. It is advisable to offset the targets of centerlines or survey lines to the inside edge of divided pavements, as station targets painted in this location will hold up for several months in usable condition (Figure 3).

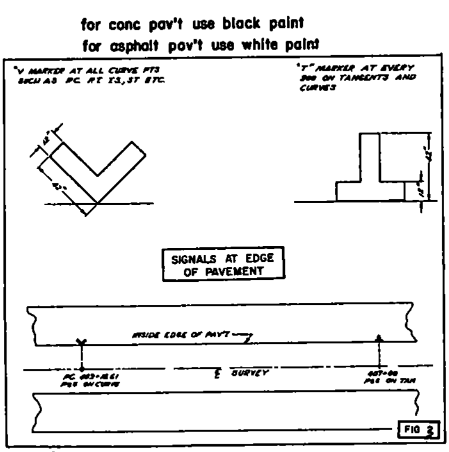

Figure 3. Divided highway station markers on pavement for photo identification.

Practically all signaling with targets on completed construction projects is done with fast-drying paint. The targets are made bold in order to be readily visible in the photography for assignment and for checking scale. The most important quality of each target is contrast. This is obtained by using black paint for concrete pavement and white paint on asphalt. Natural features are used whenever possible for wing points. At times, it is more efficient to premark these points with panels of unbleached muslin. Target markers for curve points, points on tangent, points of intersection, and vertical control points are distinguished from each other by shape.

FLIGHT PLAN

After an inspection of the job has revealed the full extent of the project, the flight plan is formulated by reference to the highway plan.

In general the aerial photography flight plan should cover these points:

1. Breaking the project into tangents,
2. Assigning flight altitudes for each tangent, and
3. Planning flights of intersecting roads along their centerline to insure adequate photographic coverage.

The most important features of an aerial photography flight include excellent light, good overlap, absence of crab due to high wind velocity, and careful control for good results.

The pilot and photographer are guided in their coverage of the project by bold, adequately target-marked control.

PROCESSING, INSPECTION, AND PHOTOGRAPHY SELECTION

Negatives are usually processed and inspection prints made available within 24 hours after flight. If acceptable, the photographs best covering the project are selected for preparation of photographic transparencies on glass plates.

The plates are exposed in an automatic dodging logetronic printer, holding desired density.

CONTROL

It is essential that ground control be taken and measured on the ground accurately. However, it is desirable to reduce the amount of control, but not at the expense of accuracy.

In Ohio, the control is generally selected in the office by identifying the targets on all pre-marked points and identifying and describing natural features to be used for vertical control.

When a highway project is to be designed by use of survey data obtained by photogrammetric methods, the ground control points should be measured and identified in such a manner that they can be used later for measurement of cross-sections once construction is completed. Design photographs are obtained during the winter or spring and cross-sectioning photographs are taken during the growing season. Thus, many ground control points do not appear the same in the two sets of photographs and are sometimes neither identifiable nor usable for the second flight. The most usable ground control points are natural features that will not be obscured by growth. For the highway design map manuscript, the stereoplotter operator can locate additional control pass points for use later in cross-section measuring. This procedure will help reduce control costs. The original control is appraised and, if found suitable, is transferred to the cross-section manuscript.

Edge-of-pavement elevations are used for control wherever possible. Where differences from construction plans are found, further check-in becomes necessary.

One week is usually alotted for controlling the average construction project in the field to prepare for measurement of cross-sections to determine construction quantities.

PREPARATION OF PLOTTING MANUSCRIPT

A plotting manuscript covering the highway construction project is used, if available. If not, a manuscript is prepared. Tangents can be made of templets. However, interchange layout is sometimes a real problem. The job is greatly facilitated if there is a sheet in the plans entitled "Geometric Layout" (Figure 4). This sheet contains the coordinates of all curve data and control survey points and the nomenclature of all ramps.

After the project is laid out geometrically, it is necessary to describe accurately to the photogrammetric instrument operators the extent of the work to be done. This is greatly facilitated if there is a sheet in the plans entitled "Cross-Section Layout"

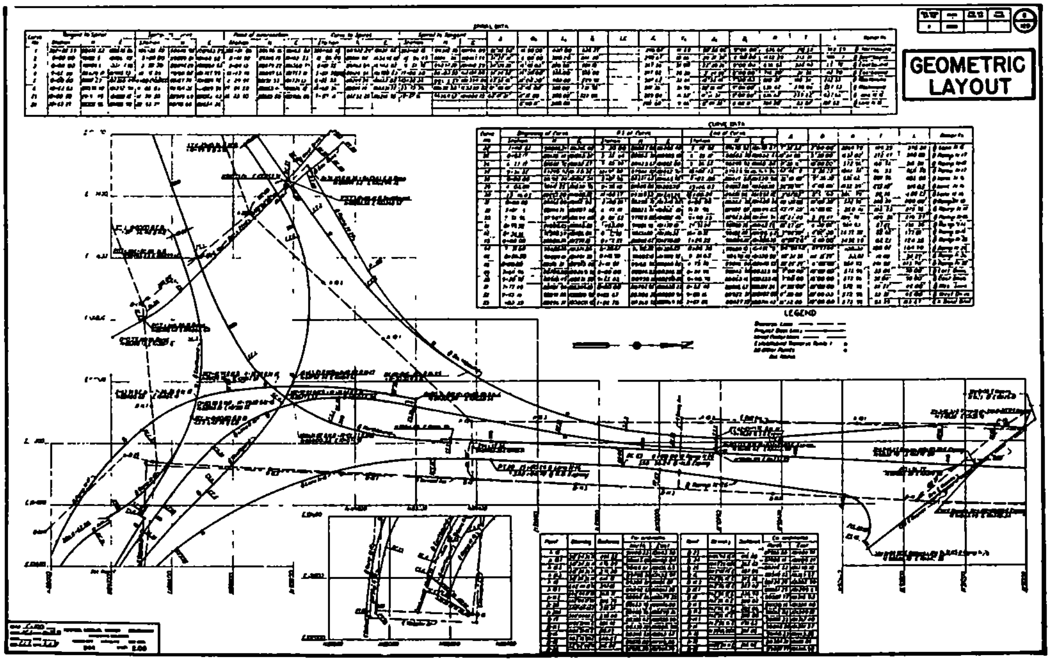

Figure 4. Geometric layout.

showing how the earthwork estimate was obtained at interchanges, intersecting roads, and structures (Figure 5). Usually this information must be assembled by a detailed

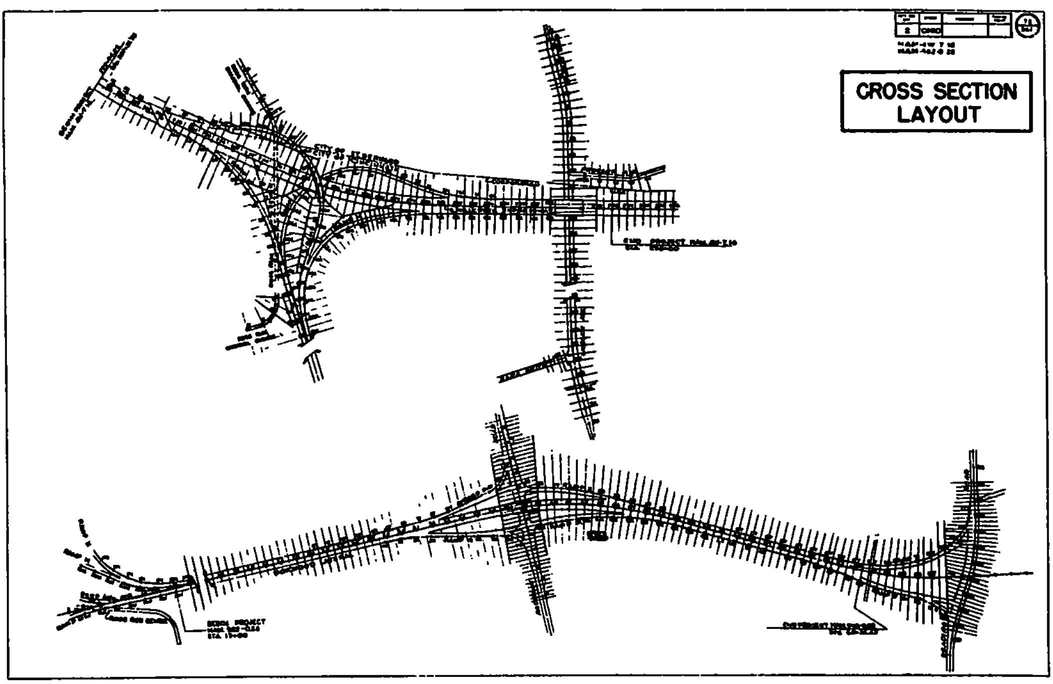

Figure 5. Cross-section layout.

inspection of the plans. Each section to be plotted must be indicated and numbered on the manuscript and its match point plotted if it intersects other cross-sections. Finally, edge-of-pavement elevations and the marked control are indicated.

PLOTTING

After clearing, each stereoscopic model is scaled by fitting the marked control to its plotted position on the manuscript. It can then be leveled to wing and previous pass points and, finally, to the edge-of-pavement and constructed-grade elevations. Since the area of interest is between the right-of-way lines, it is essential that this area of each stereoscopic model be parallel clear and level and that the height index be representative of the area and not an average of the entire model. In cases of difficulty, re-indexing should be carried out as often as necessary.

With the stereoscopic model satisfactorily set up, the readout equipment is made ready and an aide records the cross-section measurements on the plan. Measurement readings are taken at standardized locations on the section and wherever the aide requests (Figure 6). Closure is made at the end of each cross-section and an additional point read. If closure is not obtained, the cross-section is continued to the right-of-way line. Reference is made to the inspection report and a decision made. This depends on whether it is a waste or borrow job, whether the cross-section measurement is high or low with respect to previous data, whether unscalped terrain has been reached, and what the method of payment for the construction project is. It is the job of the plotter operator and his aide to establish each construction cross-section on paper and to record the coordinates of the points necessary to define the sections. This type of work demands a positive, bold display of the readout information that can be quickly read. This was not anticipated and neither digital data readout machine in use adequately meets this demand.

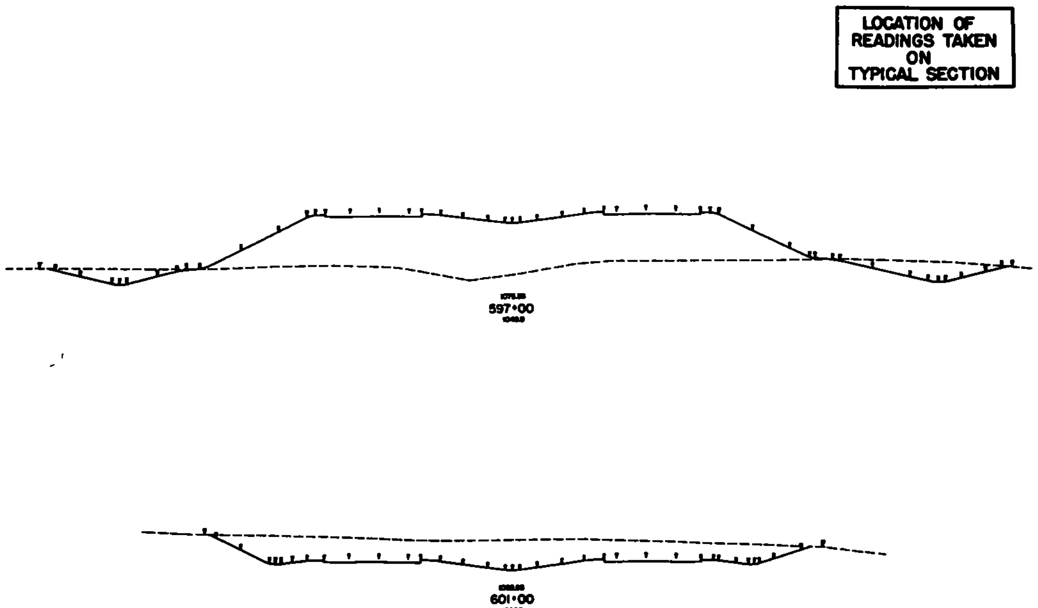

Figure 6. Location of readings taken on typical section.

Because only two readout machines are available, it is necessary at times to use one of a variety of horizontal scales or a horizontal bar already developed and to add a recorder to the team for keeping notes of the cross-section measurements. These teams can read and record cross-section points at the rate of about 500 points per hour, or about the speed of a key-punch operator. Records for the past year indicate that it has been necessary to punch manually and verify only 20 percent of the cross-section data measured on construction projects.

COMPUTATION

Machine computations are made to give the differences between cross-sections of the original terrain and cross-sections of the constructed highway. These computations are also used as a check of the planimetered plan quantities and as a basis for making small planimetered adjustments in case extra work or deductions were allowed by the project engineer. Structure areas are cropped out and, in general, side roads and ramps are not machine computed.

One of the most valuable features of the machine computation program is the terrain edit program which developed out of a need to check original ground and constructed highway cross-section data for validity before determining earthwork quantities moved during construction. With this program all points on each cross-section are checked and more than one error can be detected at any station. Six possible types of errors are identified and located if they occur, as well as improbable values for verification or correction.

VOLUME AND ACCURACY OF CONSTRUCTED HIGHWAY CROSS-SECTIONS

By far the greatest volume of photogrammetric cross-sections of constructed highways has been accomplished in the past year since the aerial survey and electronic computer sections were requested to help furnish terrain data on interstate projects awarded in 1957 and 1958. In that period, 52 construction projects with a total contract value of $150, 276, 000 and a total work length of 231 mi were photographed, controlled, plotted, and, on 45 projects, computed.

Production of these cross-sections takes approximately one-half the capacity of the State's plotting section, which is geared to making the cross-section measurements each week for about one highway construction project, at an average construction cost of $3, 000, 000. Elapsed time between the preparation of the project for aerial photography and the delivery of plotted black and white prints of the cross-sections is approximately one month.

Summary sheets for all projects are not yet available. However, the first 10 construction projects with earthwork exceeding 1, 000, 000 cu yds per project had an arithmetic mean of .19 percent difference between the proposed earthwork quantity and actual quantity removed.

TABLE 1

ANALYSIS PHOTOGRAMMETRICALLY MEASURED CROSS-SECTIONS ON FIRST 10 PROJECTS EXCEEDING 1, 000, 000 CU YD OF EXCAVATION[a]

% Diff.	x	x^2
+4.87	+4.68	21.90
1.41	1.22	1.48
1.04	.85	.72
0.40	.21	.04
0.31	.12	.01
-0.06	- .25	.06
-0.38	- .57	.32
-1.68	-1.87	3.50
-1.69	-1.88	3.53
-2.30	-2.49	6.20
		37.76

[a]Arithmetic Mean of Differences = +.192%.
x = deviation from mean
Standard Deviation from the mean: $\sigma = \sqrt{\frac{\Sigma (x^2)}{n-1}} = 2.045$
(Square root of the sum of deviations squared divided by the total number of items minus one.)

In order to analyze the data in Table 1 it is necessary to ascertain the extent to which the differences vary from chance. A difference, to be significant at the .05 level of confidence, would have to be at least ± 4.01 percent (2.045 x 1.96). Only the difference in the first project listed could be considered as occurring no more frequently than 5 times out of 100. A difference, to be significant at the .01 level of confidence, would have to be at least ± 5.28 percent (2.045 x 2.58). None of the observed differences, then, is significant at this confidence level. It may be stated that in 9 of the 10 projects considered, differences were not significant between proposed earthwork quantities and earthwork removed. That is, such differences could very easily have occurred as a result of chance. When a reasonably significant difference occurs, such as in the case of the first project listed, an explanation other than chance behavior may be sought. Such an explanation, among other things, might consider the variability of one contractor from another, the lack of precision of work on the part of a particular contractor, and difficulty in necessary estimations relative to the nature of the terrain involved in the project.

Again, Table 1 shows that in no case did the removed earthwork quantity equal the amount proposed to be removed. This becomes more apparent when 22 projects of 100,000 cu yd and up are examined. The average difference in this group is + 2.38 percent. Twice as many projects had excess excavation as were overestimated.

That this is by no means unique to projects processed by photogrammetry is illustrated by 16 projects not processed by photogrammetric measurement of cross-sections. Eliminating projects of less than 100,000 cu yd and 3 projects of -24.07 percent, +34.34 percent, and -44.90 percent, the arithmetic mean difference of 11 projects was +1.11 percent. Only one project within this group was within ± 1 percent of its estimated quantity.

Some years ago a study was made of 10 construction projects with excavation of over 100,000 cu yd. Each project was estimated from photogrammetrically measured cross-sections of the original ground and processed by ground survey methods. The arithmetic mean was +3.71 percent with only one project less than estimated.

It can safely be said that photogrammetric measurement of earthwork on construction projects is fully competent for revealing reasonable compliance with the specifications and when combined with electronic computer calculations gives satisfactory results and permits reasonable scheduling of operations.

COSTS

Final engineering charges are available for some projects for which construction cross-section data were obtained by photogrammetry.

Average Length of Project: 5.260 mi (22 projects)
Average Contract Cost: $652,000 per mi (52 projects)
Photogrammetry Cost:
Field: $177.00 per mi (Approximate average)
Office: $246.58 per mi
Total: $423.58 (22 projects)
Electronic Computation: $63.74 per mi (45 projects)

SEEDING

Seeding areas are determined by use of photogrammetry and the electronic computer during the processing of construction cross-sections. This service has been enthusiastically received by the project engineers.

CONCLUSIONS

Photogrammetrically measured cross-sections of constructed highways are more accurate than cross-sections of the original ground that were measured by photogrammetry because advantage is taken of more and better control data not previous available.

Photogrammetrically measured cross-sections of the original ground are generally agreed to be better than the same cross-sections measured by conventional surveys on the ground over difficult terrain. Therefore, photogrammetrically measured cross-sections of newly constructed highways are entirely adequate.

Information is provided in proper form for computation both by analog and digital methods.

Alterations to original plans caused by change orders are not always incorporated into the plans for reference. Therefore, data computed from photogrammetrics provide a progressive record of construction.

Central processing of construction pay quantities measured by photogrammetric methods has emphasized the necessity for further standardizing plan presentation. This is especially true for more efficient computations of pay.

Savings in time, economy, safety, and accuracy are the most notable features of photogrammetric methods.

Discussion

G. P. KATIBAH, Supervising Photogrammetrist, California Division of Highways—Terrain data necessary for the calculation of earthwork quantities must be sufficient in density to be an adequate statistical sample. It makes little difference whether the acquisition of the data is by field methods or by photogrammetric methods provided the result has "statistical" accuracy.

The belief that field methods for this objective are naturally better than photogrammetric methods is frequently misleading. Because the size of the sample requires that a great many points be measured, such as points on cross-section lines, it is not economically justifiable to attempt high-order accuracy for each point. Investigative evidence indicates that photogrammetric measurements fulfill the fundamental requirement of "statistical" accuracy, and in some types of terrain are probably superior to measurements made by the routine type of field survey. This has been reported by L. L. Funk (1, 2).

The Ohio Department of Highways has introduced the concept of electronic recording of photogrammetric measurements directly on punched cards. The imaginations of many individuals in the business of highway engineering have been stimulated, and now many highway organizations are engaged in similar endeavors. There are, however, some differences in approach, the major difference being concerned with the basis for calculation of quantities used for payment.

Many State highway departments pay for the quantities as staked on the ground before any excavation of earthwork. Thus, the computed quantities are based on the original terrain data combined with the design template for roadbed and slopes.

The Ohio method requires that pay quantities be based on the amount of earth removed as determined by "as built" roadbed and slopes. Photogrammetry is used for original terrain and also for "as built" terrain.

The significant photogrammetric data with regard to accuracy is the original terrain before construction. After that step is taken, the basis for pay quantities is a matter of organizational policy; i. e., a cross-section template composed of original terrain and "proposed" terrain (adjusted for changes in plans during construction), or original terrain and "as built" terrain.

One would expect that the number of elevations recorded along "as built" cross-section would be the same whether measured by field methods or measured by photogrammetric methods. The breaks in finished slopes should be just as apparent in the stereomodel as on the ground.

On the other hand, the number of elevations recorded along an original terrain cross-section before construction seems to be greater when measured photogrammetrically than when measured in the field. Thus, the size of the statistical sample is increased when photogrammetry is used. Experience shows that break points are more readily defined in the stereomodel than on the ground. The operator is, therefore, able to define more completely the ground profile along the cross-section line. It is also significant that the operator can more exactly follow the cross-section line because he is not obliged to offset for trees or other objects, and he does not drift downhill (a real problem with rodmen). Photogrammetric measurements, especially when electronically recorded, are not subject to the gross errors found in routine field cross-section surveys.

The one factor that still plagues photogrammetry, and promises to continue to do so, is the existence of vegetative cover. When the cover makes it impossible to realize sufficient elevation accuracy of photogrammetric work, field surveys should be employed.

REFERENCES

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2. Funk, L. L., "Adjustment of Photogrammetric Surveys." HRB Bull 228, 21-27 (1959).

Drainage Studies From Aerial Surveys

F.C. RILEY, Park Aerial Surveys, Inc., Louisville, Kentucky

This paper discusses the need for control surveys in highway work, the Federal authority to extend the existing first- and second-order control networks, the burden placed on the U.S. Coast and Geodetic Survey, and items of cooperation between Federal and State agencies to supplement and expedite the work. In this need the States turn to experienced private engineering firms.

Also discussed are the use of State plane coordinates as a basis for control, electronic measuring devices, and precise surveying equipment and methods. Benefits to highway departments of adequate horizontal and vertical control on a national scale are outlined, as are National Defense benefits.

● A FEDERAL Highway Act enacted in 1956 became an important impetus to the future security and economic well-being of the United States. Today, some of the fruits of this most ambitious of peace-time engineering undertakings are beginning to show. The face of the Nation is being changed. Arterial highways are gradually creeping from city to city and state to state, over mountains, rivers, deserts, and fertile valleys, pumping new life-blood into the heart of America. The benefits of the program are many and varied. To an engineer it represents a challenge to his initiative and ability. The contractor sees the job taking shape with new and better construction equipment. Truckers see shorter, faster, more economical routes. Land developers envisage mushrooming of cities at interchanges. It is evident then that these new highways will be the center of much activity and development. So it is no accident that Section 119 amends the Federal Aid Law definition of the term "construction" to include "the establishment of temporary and permanent geodetic markers in accordance with specifications of the Coast and Geodetic Survey in the Department of Commerce."

The U.S. Coast and Geodetic Survey is the recognized authority on control surveys and is charged with establishing the basic first- and second-order horizontal and vertical control on which all other surveys in the country depend. Due to its efforts, data on the 1927 North American datum are available for use by engineers and surveyors on some 150,000 triangulation stations throughout the United States. These and other data are available in two forms: (a) geographic positions with latitudes, longitudes, and true azimuths; and (b) State plane coordinates with X and Y rectangular coordinates (eastings and northings) in feet and grid azimuths.

Of course, when the vast reaches of this country are envisioned, one can see that theirs is no small assignment. In an effort to establish a rapidly expanding control network in the shortest possible time it was necessary to follow the less formidable routes and to triangulate over large areas from mountain top to mountain top. The USC & GS has long been aware of the sparseness and relative inaccessibility of triangulation stations. Realizing this, it has for many years been supplementing the primary network by the establishment of additional stations near towns, airports, and colleges and along existing highways and railroads. Still, there remain areas that have not been touched. Several means of filling in the gaps have been proposed. It seems that the USC & GS is quite flexible in its thinking and is willing to cooperate in any possible manner that will result in the filling-in of these areas. In a talk presented at the 17th Annual Meeting of the American Congress on Surveying and Mapping, Captain I. E. Rittenburg, Assistant Director for Administration, USC & GS, had this to say:

ERRATUM

HRB Bulletin 312, p. 40: Title of paper should read "Geodetic Control for the Interstate Highways."

We are working closely with the Bureau of Public Roads in the formulation of policy and procedures in initiating and implementing control-survey projects in cooperation with the various States. It is important that the necessary accuracies be maintained and proper connections to the Federal Network be made if these surveys are to perform their designated functions.

Under the policies and procedures established jointly by the Bureau of Public Roads and the Coast and Geodetic Survey the initiative must be taken by the States. The Bureau of Public Roads is ready to approve those projects which meet the established criteria. The Coast and Geodetic Survey is likewise willing to assist any State which desires to establish permanently marked geodetic control along its interstate highway routes. The assistance we offer is most flexible and will be tailored to the wishes of any State. We are prepared to cooperate fully with any State and to work out the best method of operations within the policy and budgetary limitations of that State.

It appears that geodetic control might be extended by utilizing any of several possible programs. For example, in Tennessee and in other states some geodetic control extension is being accomplished by USC & GS field parties. In Mississippi, control is being extended by State highway personnel under the direction of the USC & GS; however, due to the limited manpower of the USC & GS, and geodetic surveying being a highly specialized field, other states have resorted to negotiation with private engineering firms for prosecution of the work. The Kentucky Department of Highways feels that there is merit in the latter method. Therefore, it engaged Park Aerial Surveys, Inc., Louisville, Ky., to begin control extension about a year ago. Priority for work was established, and since that time approximately 120 mi of second-order traverse have been established with errors of closure ranging from about 1:19,000 to 1:275,000. In addition to the 120 mi of traverse, approximately 165 mi of second-order levels were run. Permanent bench marks were established at intervals of approximately 1 mi. Traverse stations were set at intervals of approximately 3 to 5 mi. Each station consisted of a surface mark and underground mark, two reference marks, and an azimuth mark. Bronze disks with appropriate markings were used and were set in concrete posts in accordance with USC & GS specifications. The traverse was accomplished by second-order methods as described in USC & GS publication. The instruments used for the traverse work consisted of a Wild T-2 theodolite, a Tellurometer for measuring distances electronically, a set of traverse lights consisting of seal-beam units set on tripods for stability, and also a pair of Standardized Lovar chains used to measure distances of less than ½ mi. All angles were turned through 12 positions of the circle, direct and reverse. Any single observation that differs more than 5 sec from the mean is rejected and rerun. The leveling was also run using USC & GS second-order methods. The equipment consisted of a Wild N-III precise level, a pair of calibrated geodetic leveling rods, an umbrella to shade the instrument at all times, and a pair of steel turning pins for use by the rodmen. Out of 54 level lines and spur lines that were run, 37 met first-order criteria, 15 met second-order criteria, only 2 were rejected because they exceed the second-order limit and they were satisfactorily rerun. However, even though 37 lines appeared to be first order, second-order methods were used and considered of that accuracy unless notified otherwise by the USC & GS. All field notes were recorded in regular USC & GS field books, and all computations were made in the Louisville office on standard USC & GS computation forms. Traverse computations were based on the Kentucky State plane coordinate system and were in a nature of preliminary or field computations. These computations were then sent to the USC & GS office in Washington, where they were checked and final adjustments were made.

All control lines originated and terminated on USC & GS triangulations stations or bench marks, which were of second-order accuracy or better. This is necessary to insure that the resulting work is of the required accuracy. Furthermore, when second-order accuracy is required, second-order methods and precise instruments must be used.

The use of State plane coordinate systems offers the better approach to the extension of control. More engineers and surveyors are familiar with plane surveying than with geodetic surveying. Most engineers and surveyors have had little or no training in the making of geodetic computations. On the other hand, the system of plane coordinates presents the opportunity to translate the old familiar metes and bounds surveys into positions having definite X and Y values when ties are made to known positions. From here, it is a relatively simple matter to convert those plane coordinate positions to geographic positions or to the Universal Transverse Mercator System of coordinates. The mathematics is not too difficult and the critical part of the operation rests with the performance of the field work. It must be done by second-order methods, and definitely has to be tied to control monuments of second-order or better accuracy.

Some engineers may question the need for this work, but it is generally conceded that the intricacies of modern highway design require accuracies in surveys that were unwarranted in the early years of highway building. One has only to compare a modern complicated interchange to a simple grade crossing of a few years ago. What better means is there to "nail down" an interchange or a bridge location than by a tight system of coordinated positions? Also, this density of control stations will provide an easy and economical means for starting and terminating all Interstate Highway centerline surveys. After the line has been hubbed it can be computed, thus eliminating equations in the line. Property ties may also be made to the computed centerline, resulting in X and Y coordinates of property corners. This method of describing property is permitted in several States. Errors in design computations or layout become apparent at once because of the many cross-checks that are afforded. Also, over-all planning and design have not yet reached the place where they can be performed instantaneously. Thus it is necessary to work on a few segments at a time. Coordinated positions assure that the pieces will fit together perfectly.

Although this paper deals with geodetic controls for the interstate system, it is felt that eventually such controls will be extended and used in connection with the design of all future primary and secondary highways and also railroads throughout the country.

Digitizing Stereoplotter Output for Preliminary Design and Construction

The Auto-trol Scaler, an analog-digital converter developed for the Federal Highway Projects Office, Region 9, Denver, Colorado, is one answer to the problem of cross-sectioning with the Kelsh stereoplotter. Actual development of this instrument was begun in October 1959 and completed in March 1960. The impetus for this definite step forward was the need for a modern and applicable instrument designed to extract accurate, basic terrain data necessary for highway design by photogrammetric methods.

This instrument compiles the information in a conventional manner acceptable to the highway engineer and at the same time prepares the information in a form acceptable for electronic processing.

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● TO ASSIST the engineer in extracting basic information for highway design by photogrammetric methods, a number of electronic readout devices have been developed. These devices, like many electronic computer programs, have been designed by electronic engineers without the benefit of highway design experience. In order to take advantage of these new methods, it has been necessary for the highway engineer to change his design procedure. This situation has led to considerable controversy over accuracy of measurements and adequacy of design.

The Federal Highway Projects Office in Region 9 of the Bureau of Public Roads has taken a different approach to the use of these new tools. Electronics should work for the user in the design procedure elected for use. With this in mind, the office has developed instruments, revised computer programs, and written new ones to produce a complete highway design in an acceptable format.

About 95 percent of its highway location and design is accomplished through the effective use of photogrammetric and electronic methods. The basic terrain information extracted by commercial electronic readout devices was not completely satisfactory. The terrain data were not entirely acceptable because the many errors in mispunched cards caused expensive computer stops. To correct this situation, it was decided to have an electronic scaler constructed, tailored to the needs of the highway engineer.

AUTO-TROL SCALER

The Auto-trol Scaler, an analog-digital converter developed for the Federal Highway Projects Office and described in Appendix A, is an answer to the problem of cross-sectioning with the Kelsh stereoplotter. The actual development of this instrument was begun in October 1959 and completed in March 1960. As previously stated, the impetus for this definite step forward was the need for a modern and applicable instrument designed to extract accurately by photogrammetric methods basic terrain data necessary for highway design. This instrument compiles the information in a conventional manner acceptable to the highway engineer and at the same time prepares the information in a form acceptable for electronic processing.

The scaler, which converts horizontal and elevation measurements into digital data, can be adapted for use with practically any stereoplotter equipment. In cross-sectioning, when the photogrammetric instrument operator is satisfied that he has placed the measuring dot at a break in the ground slope on the stereomodel, he then presses the record button at which time the distance and elevation are recorded on the output device. The internal programming hardware makes it unnecessary for the operator to trouble himself with such things as end-of-card hesitation and typewriter control. In the case of cards, the identification, station number, H.I. elevation, card code, and card number are all automatically punched on the cards under the direction of console programing. There is an automatic interlock on the readout so that readings can be taken on the run. When the readout button (record) is pressed, the console automatically places the horizontal and vertical readings in memory and begins the readout cycle. This means that there is no waiting period necessary. The operator is free to move on to the next measurement point.

The horizontal and vertical scaling device may be attached to the tracing table of the stereoplotter in approximately 5 min. Cross-section measurements for any normal distance each side of the designed centerline or any station interval may be speedily made for any map scale. The cross-sectioning rate of the scaler is about two times faster than that of some similar instruments because of ease of operation. An average stereoinstrument operator can measure about 30 to 35 cross-sections an hour. Considering an average time of one hour to orient each stereomodel, one instrument operator can normally be expected to complete 1 to 1½ mi of cross-sections during an 8-hour period scaling on a 100-ft-to1-in. scale map manuscript and measuring the cross-sections at a 50-ft interval on the highway centerline for a distance of 200 ft each side of that centerline.

The results from this instrument have been reasonably satisfying. Considerable "down time" was originally experienced due to malfunctions of various components. Numerous changes in counters and circuits have been made since the scaler was first put into operation. It now appears that most of the "bugs" have been eliminated. Its ease of operation, versatility, and handy recording methods, which eliminate a great deal of the lost motion prevalent on other scalers, lead to high productivity and lower highway survey and design expenditures.

The Federal Highway Projects Office has developed and assembled a "package" electronic computer program that extends the use of the output from the new electronic scaler and readout device, originally used only for preliminary design, through the construction engineering phase. To be specific, photogrammetry and electronics have been put to work for the highway engineer to its best advantage.

Because the office performs all the basic control for topographic mapping by photogrammetric methods, regardless of whether the mapping is done by the office or contracted to commercial firms, a traverse program for immediate checking of the field control survey work is extremely valuable. This provides a quick method of checking such field work before the control survey crew leaves the project. This program along with many others, some original and some borrowed, are at the disposal of the automatic data processing section for step-by-step electronic control from preliminary reconnaissance through completion of highway construction.

The program for computing basic control for highway location and all mapping done by photogrammetric methods is original with Region 9 and has been used since January 1960. The program computes the control traverse and tabulates the plane coordinates of the horizontal control and elevations of vertical control to be used in the mapping by stereophotogrammetric methods. This program has several options:

1. Given azimuth and distance, output is sine and cosine functions, latitude and departure, and the plane coordinates of all traverse stations.

2. Given azimuth, distance, or subtended subtense bar angle and vertical angle to foresights or backsights, output is the same plus elevations of all stations by trigonometric level computation.

3. Given subtended subtense bar angle and vertical angle to elevation control points of the aerial photographs, output is distance from control station to each vertical control point and its elevation.

After the topographic mapping has been completed in manuscript form by photogrammetric methods, the proposed highway alignment is plotted on the manuscript by means of the plane coordinates calculated by conventional methods. The azimuth program mentioned previously, or the State of California traverse program were the directions are expressed in bearings, checks the plane coordinates computed by conventional methods. Such a procedure saves manual checking, which is both tedious and time consuming.

PROFILE GRADE AND EARTHWORK PROGRAM

As to the design of earthwork quantities program, the automatic data processing section utilizes the Colorado Department of Highway's profile grade and earthwork program. Several changes made in Region 9 have better adapted this program to the Region's work. Two short supplemental programs written in this Region have reduced appreciably electronic computer time in revising the original profile or alignment.

Design criteria for each project are listed on a permanent form and include the following:

1. Design speed,
2. Type section expressed in punched-card form,
3. Slope selections used by electronic computer for cuts and fills,
4. Superelevations used,
5. Swell or shrink factors,
6. Widening used on curves, and
7. Widening for guardrails and guide posts.

The results of preliminary earthwork computations are in the form of three tabulations:

1. Grade elevation for each station,
2. Earthwork quantities and end areas for each station, and
3. Slope staking details.

From this preliminary computation, all slopes that are 2:1 or steeper on fills are selected to be widened for guardrail or guide posts. A grade revision is usually necessary in order to bring excavation and embankment quantities into desirable balance. Generally, the design is completed with the third computer run, provided an optimum in earthwork balances has been reached.

Modifications of the Colorado Department of Highway's profile grade program can now handle the prorating of the superelevation on compound curves. Guardrail and guide post widening can be prorated independently on the right or left side of the roadway. A program revision has been made to edit the profile input. This revision should save many time-consuming computer stops and reruns of the profile computations.

Revisions of the Colorado Department of Highway's program by Region 9 include the following:

1. Output of grade elevations on staking details corrected for superelevation on all curves.
2. Rotation of a typical section template from low shoulder point on all curves, whereas previously rotation was made from shoulder plus widening point.

A supplemental program to earthwork computations is used when only a portion of the original quantities is recalculated due to grade change or slope revisions. Formerly, because the earthwork quantity punched cards carried the mass ordinate, the entire design had to be rerun through the complete program to reflect the corrections in the mass diagram ordinate from a recomputed partial section. This was costly in machine time and necessary before this supplemental program was written. Now, the last quantity card in the project, beyond which there are no further end area changes, is used as the first data card for initial input into a program that runs at a punch-speed rate and reads in the remaining quantity cards. This operation adjusts the mass diagram ordinates to the corrected figure and punches out new quantity cards with corrected mass ordinates.

Since many computer stops were experienced because of faulty terrain cards punched through Benson-Lehner's Terrain Data Translator and the Auto-trol Scaler, a terrain note-editing program has been instituted. Cards are run through the IBM 650 at the speed of 250 cards per min, and among the items checked for are the following:

1. Blank columns and double-punched columns,
2. Centerline vertical difference between stations exceeding a 25-ft limit,
3. Cross-section vertical distance between ground slope breaks exceeding 50 ft difference in elevation, and
4. Station numbers.

At the same time that the editing is done, the IBM 650 reads centerline elevations and interpolates the 25-ft interval between stations and punches out a card that is used to tabulate the actual ground elevation at centerline. This profile can be plotted on the IBM 407 Accounting Machine in the same manner as the mass diagram ordinates are plotted and is to a horizontal scale of 100-ft-to-1-in. and vertical scale of 20-ft-to-1-in.

Work is under way to program for reduction of construction project cut and fill notes for use with the present earthwork program. At present when the cross-sections obtained by photogrammetric methods do not match actual ground, the project engineer, during slope-staking, records the actual ground cross-section by cut and fill notation with respect to the highway cross-section. These notes are reduced to elevations before submitting to the computer; and, with the cut and fill program addition, this note reduction can be done by the electronic computer. Catch slope points will be introduced into all original terrain notes for construction engineering computations later.

COMPUTATION OF RIGHT-OF-WAY

A new and original right-of-way program is in use for electronic computation of plane coordinates to locate parcels of full ownership. These are plotted onto the map manuscripts compiled by photogrammetric methods. This phase is considered to be the first third of a group of complete right-of-way programs. To date, this program accepts a series of twenty ownerships with a maximum of 6 ground ties and not exceeding 3 ties per ownership. By designating the principal tie, the program will output 6 different computations or one with each principal tie. Input can be either bearing or azimuth, and distances can be in any units; e.g., feet, chairs, or rods generally found on older plats. The program outputs errors of closure from plat descriptions and lists errors to given ties. The program will handle a traverse of 99 courses from a section corner to the centerline of the proposed highway or to a tied corner or a parcel, using options of either bearings or azimuths. The program will output the plane coordinates of all intermediate points or only point of origin and tie. The corners of each ownership are located by plane coordinates.

The California traverse program is still used in computing parcel areas, and a Colorado Department of Highway arc segment area program is used to compute the area of parcels lying withing highway curves.

A metes and bounds traverse program has recently been completed. This program takes tangent bearing and distance, curve information (including transitions), width of right-of-way on the right and left, and computes bearing and distance of each course to be used for input of California traverse program.

CONSTRUCTION ENGINEERING

Because of the detail required to present properly the subject of construction engineering and its computer application, only a summary of its current status will be considered. This phase of computer application presents an almost unlimited field. The Federal Highway Projects Office has not presented this work officially to the field project engineers but is developing construction control methods on two current projects.

The project engineer uses electronic tabulation of the staking details developed in the project design for an accurate guide in slope-staking. About 10 percent of the slope selections require field changes and approximately 15 to 20 percent of the electronically scaled cross-sections from the Kelsh stereoplotter model do not match the actual ground cross-sections. After slope-staking the project, the field engineer submits new terrain cross-sections to replace the following:

1. Areas of daylighting,
2. Catch basin locations,
3. Areas where different slopes are fixed,
4. Widened shoulders or ditch cross-sections, and
5. Areas that do not match catch points within the desired accuracy.

Setting up the files and terrain cards for construction engineering is a rather time-consuming task. Once this has been done, however, there is an exact digital duplication of the project as staked on the ground. From this point on, or after the first construction program computer run, as the project progresses, a field engineer can have his project recomputed for earth work quantities with only a telephone call or letter indicating grade changes, slope changes, or shrink or swell factor revisions. After the first construction run on one of our test projects with actual slopes fixed, catch basins inserted, shoulders widened on transitions, daylights added, etc., the computed quantities were 3,000 cu yd over the design quantities of 220,000 cu yd, or within 1.5 percent. Later, when a single grade change was made, the new computation showed a savings of 12,000 cu yd. Furthermore, this project was recomputed and completely rebalanced twice within 7 days.

The program to recompute a corrected mass diagram ordinate is also used to good advantage for construction engineering earthwork revisions. Another supplemental program is used for recomputing earthwork quantities when the only change is the shrink factor. This program reads the previous output cards, removes the quantity previously added or subtracted for shrink or swell respectively, and recomputes new volumes using the new shrink factor. The program also punches new output cards with the corrected mass diagram ordinate and volumes. This supplemental program will recompute an average project for a revised shrink or swell factor in about 15 min of computer time.

Not mentioned earlier, but used in design, is the Colorado Department of Highway's plotting of the mass diagram ordinates. This enables the design engineer and the project engineer to visualize earthwork quantities. The mass diagram ordinates can be plotted after each quantity run in 5 min. This allows for an over-all solution to correcting a quantity balance; i.e., a single grade change over a small section can serve to bring the entire project into a balance.

We have an addition to the staking detail tabulation whereby the actual ground elevation as well as corrected grade elevation will be calculated.

DESIGN CONTROL

The Federal Highway Projects Office in Region 9 has instituted a progress of design program whereby the data processing section tabulates weekly the progress of each design phase—from setting photographic targets along photography flight strips, mapping, projecting, surveying materials and drainage, computing grades and quantities, staking centerline, drafting plans and writing special provisions, to finally assembling plans for contract. This program is not computed on the IBM 650 electronic computer but is accomplished entirely by peripheral equipment; e.g., sorters, collators, interpreters, and the IBM 407 accounting machine. The weekly tabulation is on the desks of the federal highway projects engineer, the supervisory design engineer, and the supervisory contracting engineer each Tuesday morning, showing current status of all projects in the process of location or design. This program could have a far-reaching effect and has been set up with an eye for future implementation with actual expenditures for accurate and up-to-date determination of design costs. This system could be used by State highway departments to ascertain detailed design cost records. The report shows man-hours of design time actually expended in each phase of the work, and these phases are broken down into 30 separate operations.

DATA PROCESSING ACCOUNTING

Federal projects data processing has been set up under a separate account. Beginning in August 1960, this account was disbursed by machine accounting. The tabulations will show work distribution of section personnel, computer and peripheral equipment rental, and prorated charges; e.g., programing, debugging, and board wiring. The tabulations will indicate account balance after charges are made for the month, the rate at which account is expended, and a projected rate to show future expenses, if the current average monthly rate is maintained.

FUTURE REVISIONS

The Federal Highway Projects Office has produced construction staking details tabulated on printed forms that serve as the project engineer's field notebooks when bound. These books have a self-duplicating paper that does not require carbons and will provide the automatic data processing section with any field changes from the original design. A contemplated revision to the present earthwork program for use on a 4,000-word IBM 650 will automatically reduce cut and fill notes to elevations and will allow these figures, when punched into cards, to be used interchangeably with terrain notes using elevations.

Most changes that have been made in the earthwork program must be handled on a 4, 000-word IBM 650, which is commercially available. The reason for this is that there is no available space for instruction storage in the earthwork program, when using an IBM 650 computer with a 2, 000-word drum.

It is expected that, within the next two years with the use of magnetic tape electronic computers, it will be possible to combine the grade program and the earthwork program into a single linear type of program. This will enable the engineer to give grade parameters; e.g., maximum, minimum, and fixed grades, and the distances within earthwork balances that are to be optimized. With this type of operation, the electronic computer can put data from punched cards onto tape and compute the quantities to the point where earthwork balance is desired. If it has not been attained at this point, the answer tape would be erased, the data tape would be reversed, and the machine would automatically adjust grades within the program parameters. This will give optimum earthwork quantities with the use of grade alignment only. Later program changes could incorporate horizontal alignment changes for further optimization and develop along the lines of curvilinear (spline line) alignment rather than solely by means of tangents, circular curves, and transitions. Furthermore, additional computer applications will include evaluation of materials with respect to estimated costs and estimations, such as low-price, intermediate, and costly excavation, and land values in addition to alignment features.

ECONOMICS

In the Federal Highway Projects Office of Region 9, it is estimated there is a possible \$500, 000 savings yearly for each \$10, 000, 000 in the construction budget through the effective use of photogrammetry and electronic processing for design and construction. Formerly, survey, design, and materials investigated cost an average of about \$5, 000 per mi, but with electronic processing and photogrammetry the cost has been reduced substantially. Half of this saving is attributed to photogrammetry and the other half to electronic processing. Currently, engineering costs on construction projects are considered too high. With rapid recomputation of earthwork quantities and savings in staking time, about 10 percent of these costs can be saved. With magnetic tape and linear programing and with machine-optimized earthwork quantities, there is a further possible savings of 2.5 percent, due to a more efficient earthwork design. More savings are possible through the application of drainage, right-of-way, and structure programs. Furthermore, if organizations would purchase electronic computers outright rather than rent, the cost of these facilities would be less than half of current rental prices.

CONCLUSION

The Federal Highway Projects Office in Region 9 believes that photogrammetry and electronic processing will eventually make possible a savings of 5 percent on an average construction budget. This means that with full electronic data processing in operation, Federal projects could have one additional project annually, in addition to a more efficient operation in design, construction, and administration.

Appendix A

AUTO-TROL SCALER: DETAILED INFORMATION

The Auto-trol Scaler, is a precise electronic instrument with many technical applications possible. The present unit, which is designed as an aid in gathering basic information for calculating end areas and volumes of earthen structures, is accurate to 1 part in 2,000 over its entire scale. The Auto-trol Scaler is an analog-digital converter. It takes analog data from maps, aerial photographs, aerial photogrammetric plotters, graphs, etc., and converts them to standard digital form. It then tabulates these data on a typewriter and at the same time punches them on a card or paper tape in any format desired.

The following application is for the highway engineering field. Reference is made from time to time to the alphabetic characters in Figures 1, 2, 3, and 4 denoting various parts on the scaler and aerial photogrammetric plotter.

Step 1. As shown in Figures 1 and 2, the scaling bar (F) of the horizontal unit (M) is connected to the tracing table (P) by slipping the neck of the scaling bar over the pencil lead holder of the tracing table (this fit is machined to 1/10,000 in.). The vertical end coder (R) is attached to the vertical counter of the tracing table by means of a small chuck and two thumb screws. The record actuation device (Q) is clipped to the tracing table, left or right side, or can be left free of the tracing table and conveniently placed elsewhere.

Step 2. The horizontal unit (M) is now oriented on a line previously drawn at right angles to centerline (or base line). This orientation is accomplished by setting the pointer (E) of its scaling unit (M) and the pointer (D) of the tracing table (P) on the line. It will be noted that the tracing table is completely free to swing on an arc limited only by the arms (S) of the photogrammetric plotter itself. This allows the instrument operator to scale easily a centerline drawn in any position on the manuscripts.

Step 3. The station of the centerline (the y coordinate of an x, y, z coordinate system) is set on the 8 rotary dials (J) of the console (Figure 3).

Step 4. The elevation of the counter on the tracing table (P) is set in the console with the 6 elevation set buttons (T). This is done only when the elevation counter of the tracing table is indexed, usually once per set-up of the stereoplotting instrument.

Step 5. The set button (record button) (B) is pressed either on the console (Figure 3) or on the record actuation device (Q). This causes the typewriter to tabulate and the punch unit to punch the station, the H.I. (if any), the computer code, and the card number if cards are used. It records all information required for each station that is preparatory to the actual cross-sectioning.

Step 6. The tracing table pointer (D) is moved to rest on centerline. At this time the zero "x" button (C) is pressed. This sets the console horizontal counter (the x coordinate) (I) to zero, thus indexing the horizontal counter to centerline.

Step 7. The first break in ground slope is found by moving the table out left or right of centerline any desired distance and visually picking the change in slope of the ground

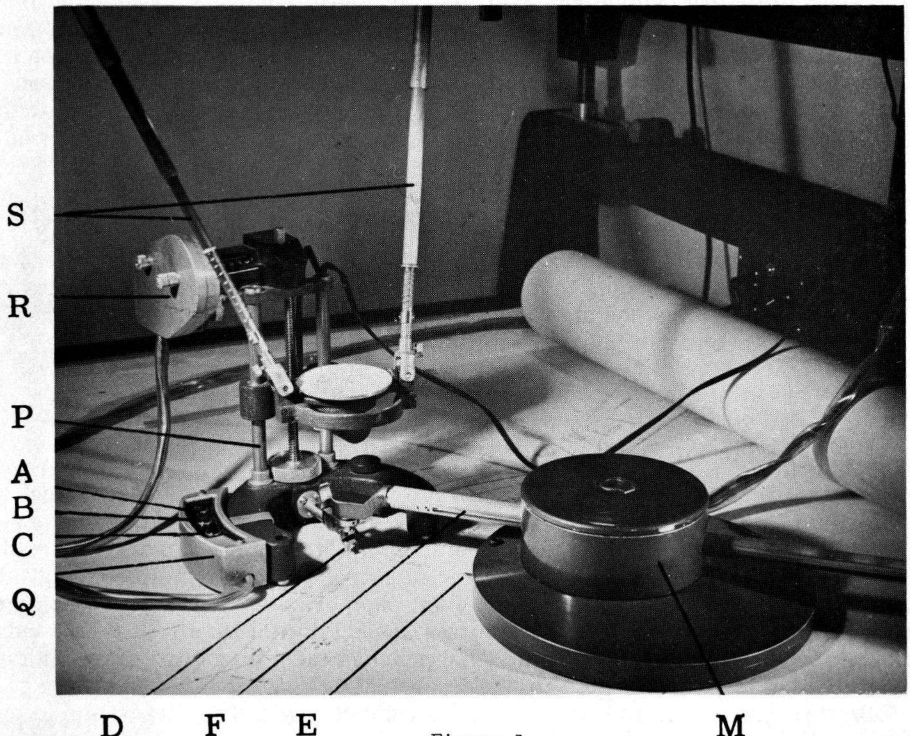


Figure 1.

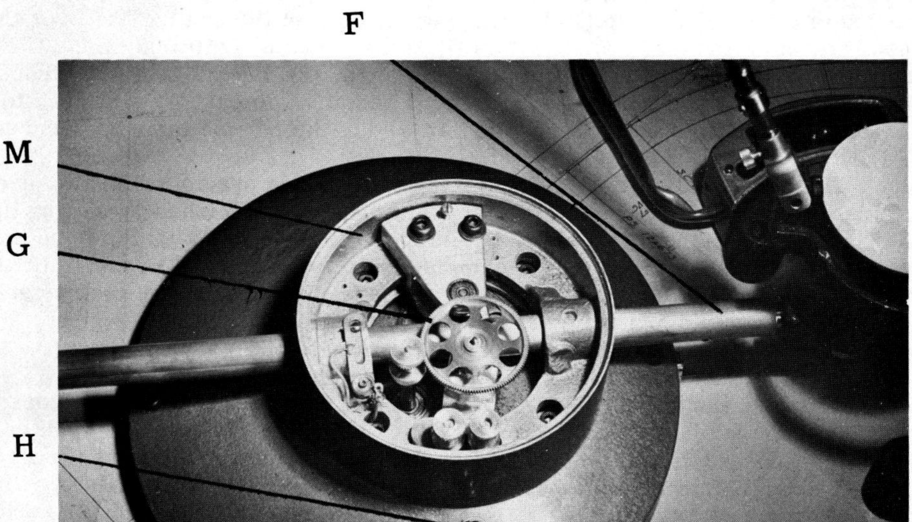


Figure 2.

line. The tracing table is kept on a straight line path at right angle to centerline by the horizontal unit (M). When the break in slope is found, the record button (B) is pressed. This causes the distance displayed on the horizontal counter (I) and the elevation on the elevation counter (T) to be recorded on the output devices previously mentioned. The alphabetic character "L" for left or "R" for right can be recorded on the tabulation. The positive horizontal direction is controlled by the switch (H) on the horizontal unit (M). When the switch is set on left, the counter will add going from right to left; and when set on right, it will add from left to right. The operator does not need to wait for the apparatus to finish its record cycle before moving the tracing table in search of the next break. The console puts the last reading in memory and keeps it there until it finishes recording the reading through the output units. This is true even when, in the case of punch cards, the card unit is going through the process of feeding another card. The record button (B) can be pressed during this cycle.

Step 8. The operator continues recording breaks in ground slope as they are found. When the operator reaches the centerline, he presses the zero "x" button (C) and the record button (B) simultaneously. This insures an exact zero recording for centerline and not a 000.1 recording. This is due to the fact that the operator will have difficulty in coming back to the exact point from which he started as the scaler is dividing each inch into 1,000 parts.

Step 9. He follows the procedure of recording the measurements at breaks in ground slope as he finds them until the last break of the cross-section at this particular station is reached. At this time the final record button (A) is pressed. This causes the console to reset and prepare itself for the next station. It causes such things as the card punch to skip to a new card, the card counter (L) automatically to reset to one, and the typewriter to return carriage and space down one line. The operator now continues making the cross-section measurements at stereomodel scale by repeating Steps 2, 3, 5, 6, 7, 8, and 9. This is done on the stereoplotter until all cross-sections on one stereomodel have been measured.

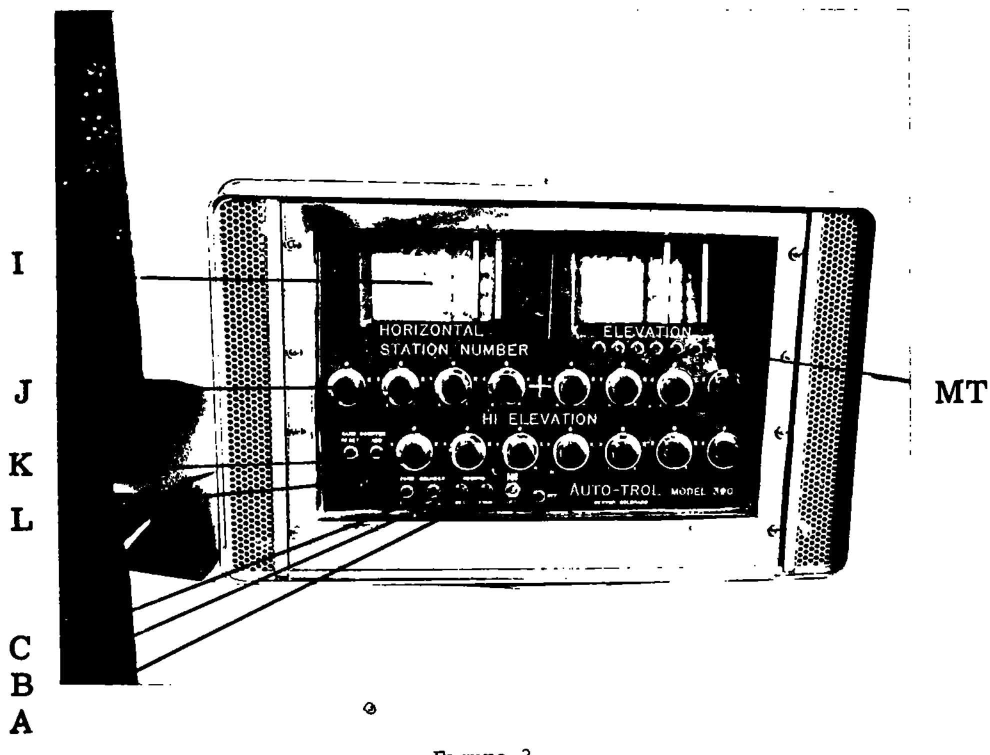


Figure 3.

The seven Height of Instrument (H. I.) dials (K) of the console are used in the following way. If it is desired to have the separate measurements of all breaks in ground slope on each cross-section in reference to a given elevation (H. I.), the elevation is set on the H. I. dials (K). The elevation counter (T) is set at zero. Now all elevations recorded will be plus or minus, up or down from the given reference (H. I.) elevation.

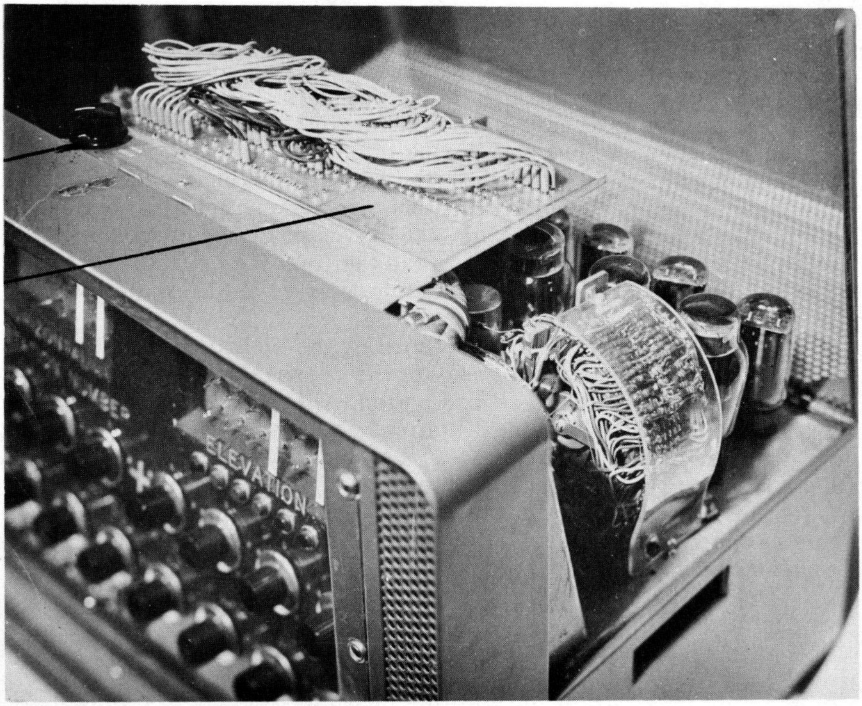


Figure 4.

Pictured in Figure 4 (O) is the console control board (patch board). This board is used to program the console and its supporting output devices. It is through this board that complete versatility is obtained in variable formats, counter control, the emitting of fill in digits, and so forth. This is very necessary as this allows the cross-section scaler to output its information in any desired form, thus making it possible to suit the needs of any customer who wishes to use his own computer program.

The intensity of the panel lights may be varied by the dimmer control (N) in Figure 4.

Appendix B

EXAMPLES OF FORMS USED

Forms used in electronic processing of the photogrammetric data are shown on the following pages.

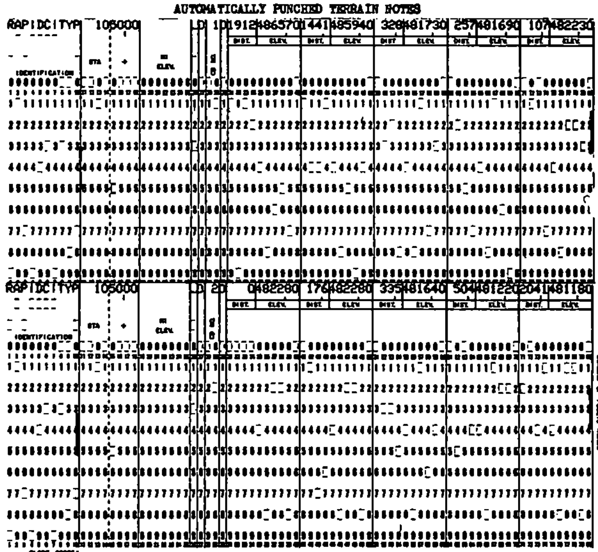
TRAVERSE COMPUTATIONS

PROBLEM 1 GIVEN: Azimuth, Angle on Bar, $\frac{\text{Bar Length}}{2}$
" 2 " : Azimuth, Distance

TRIG LEVELS 1 - No Trig Level Computation
" 2 - Traverse with Trig Levels
" 3 - Wing Point Computation

JOB	P (PROBLEM)	T (TRIG LEVELS)	TN (TRAVERSE NO.)	G (GROUP)	CRSE	DIST	AZIMUTH	COS	SIN	NS DIST	EW DIST	NS COORD	EW COORD
TESTPROBLM	1	1	1	1								10000.000	10000.000
	1	1	1	1	1	100.000	210 00 00.0	0.866025406	0.499999991	86.602	49.999	10086.602	10049.999
	1	1	1	1	2	100.000	300 00 00.0	0.499999994	0.866025401	49.999-	86.602	10036.603	10136.601
	1	1	1	1	3	100.000	000 00 05.8	1.000000000		100.000-	0.000	9936.603	10136.601
	1	1	1	1	4	100.000	359 59 54.2	1.000000000		100.000-	0.000	9836.603	10136.601
	1	1	1	1	5	100.000	089 59 54.2		1.000000000	0.000	100.000-	9836.603	10036.601
	1	1	1	1	6	100.000	090 00 05.8		1.000000000	0.000	100.000-	9836.603	9936.601
	1	1	1	1	7	100.000	179 59 54.2	1.000000000		100.000	0.000	9936.603	9936.601
	1	1	1	1	8	100.000	180 00 05.8	1.000000000		100.000	0.000	10036.603	9936.601
	1	1	1	1	9	100.000	269 59 54.2		1.000000000	0.000	100.000	10036.603	10036.601
	1	1	1	1	10	100.000	270 00 05.8		1.000000000	0.000	100.000	10036.603	10136.601
	1	1	1	1	11	100.000	000 00 58.0	1.000000000	0.000281190	100.000-	0.028-	9936.603	10136.573
	1	1	1	1	12	100.000	359 59 02.0	1.000000000	0.000281197	100.000-	0.028	9836.603	10136.601
	1	1	1	1	13	100.000	089 59 02.0	0.000281197	1.000000000	0.028-	100.000-	9836.575	10036.601
	1	1	1	1	14	100.000	090 00 58.0	0.000281183	1.000000000	0.028	100.000-	9836.603	9936.601
	1	1	1	1	15	100.000	179 59 02.0	1.000000000	0.000281192	100.000	0.028-	9936.603	9936.573
	1	1	1	1	16	100.000	180 00 58.0	1.000000000	0.000281186	100.000	0.028	10036.603	9936.601

AUTOMATICALLY PUNCHED TERRAIN NOTES



TERRAIN DATA

JOB	STATION	NO.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.
RAPIDCITYP	10-50.00	1	191.2	4865.70	144.1	4859.40	32.8	4817.30	25.7	4816.90	10.7	4822.30
RAPIDCITYP	10-50.00	2	00.0	4822.80	17.6	4822.80	33.5	4816.40	50.4	4812.20	204.1	4811.80
RAPIDCITYP	11-00.00	1	189.9	4857.10	136.6	4848.40	63.2	4830.50	39.3	4819.60	13.0	4821.70
RAPIDCITYP	11-00.00	2	00.0	4821.70	22.2	4821.60	40.9	4811.60	232.8	4811.30		
RAPIDCITYP	11-50.00	1	192.2	4850.50	114.7	4830.90	55.7	4819.90	12.7	4821.30	00.0	4822.20
RAPIDCITYP	11-50.00	2	19.9	4821.20	39.7	4812.80	219.2	4812.80				
RAPIDCITYP	12-00.00	1	212.2	4846.90	182.1	4839.30	78.4	4819.60	30.5	4814.90	09.1	4821.00
RAPIDCITYP	12-00.00	2	00.0	4822.00	21.9	4821.40	45.6	4811.80	229.1	4811.80		
RAPIDCITYP	12-50.00	1	240.8	4836.60	136.0	4819.20	114.4	4819.20	51.1	4811.50	37.1	4812.60
RAPIDCITYP	12-50.00	2	06.4	4821.50	00.0	4822.60	20.7	4822.00	54.0	4806.20	67.7	4806.20
RAPIDCITYP	12-50.00	3	100.3	4813.40	114.4	4813.40	122.4	4812.50	185.1	4812.50		
RAPIDCITYP	13-00.00	1	231.8	4828.30	181.6	4819.20	157.9	4819.20	54.4	4809.70	44.3	4809.70
RAPIDCITYP	13-00.00	2	10.0	4821.90	00.0	4821.90	20.4	4821.90	54.6	4805.60	142.6	4803.70
RAPIDCITYP	13-00.00	3	176.3	4805.80	201.8	4812.10						
RAPIDCITYP	13-50.00	1	192.8	4817.70	46.5	4807.80	41.3	4808.50	05.9	4821.10	00.0	4821.90
RAPIDCITYP	13-50.00	2	20.6	4821.30	53.1	4803.10	138.4	4803.10	189.7	4798.60		
RAPIDCITYP	14-00.00	1	198.3	4811.60	95.2	4805.30	48.6	4804.20	10.1	4820.70	00.0	4820.70
RAPIDCITYP	14-00.00	2	20.5	4820.50	59.1	4801.30	100.1	4804.30	186.9	4849.80		
RAPIDCITYP	14-50.00	1	196.0	4807.00	110.0	4803.20	49.1	4803.20	07.2	4822.10	00.0	4822.10
RAPIDCITYP	14-50.00	2	20.0	4820.90	58.4	4803.00	88.8	4804.00	168.8	4843.10	198.0	4857.40
RAPIDCITYP	15-00.00	1	183.6	4803.10	52.5	4801.60	05.7	4822.10	00.0	4822.10	20.1	4821.20
RAPIDCITYP	15-00.00	2	52.6	4807.10	63.9	4805.80	191.4	4858.30				
RAPIDCITYP	15-50.00	1	270.8	4798.30	172.9	4798.30	156.4	4801.00	90.7	4801.00	52.4	4799.00
RAPIDCITYP	15-50.00	2	05.6	4821.60	00.0	4822.10	23.3	4820.80	44.2	4817.60	82.5	4869.30

EARTHWORK EDITING PROGRAM. . . DESCRIPTION OF ERROR CODES. .

KEY PUNCH ERRORS. INVALID PUNCHING HAS BEEN SENSED IF COLUMN 80 CONTAINS A 2 OR 3.

THE FOLLOWING CODE INDICATES THE CARD WAS NOT PROCESSED BEYOND THE ERROR. IF THIS SHOULD BE A VALID CARD, SEVERAL OTHER ERROR INDICATIONS WILL BE PRODUCED--FOR EXAMPLE, THE CARD NUMBER WILL BE WRONG.

IDENT PCH   STATION NUMBER, 11 18, OR CARD NUMBER AND HEIGHT OF INSTRUMENT, 27 29 AND 20 25, WERE MISKEYPUNCHED.

THE FOLLOWING CODES INDICATE THE ENTIRE CARD WAS READ. A VALIDITY CHECK OF THE STATION WAS MADE ONLY IF IT WAS LATER RESTARTED BY A NEW CARD 1.

DATA1 PCH   COLUMNS 31 40 MISKEYPUNCHED.
DATA2 PCH   COLUMNS 41 50 MISKEYPUNCHED.
DATA3 PCH   COLUMNS 51 60 MISKEYPUNCHED.
DATA4 PCH   COLUMNS 61 70 MISKEYPUNCHED.
DATA5 PCH   COLUMNS 71 80 MISKEYPUNCHED.
28 32 PCH   COLUMNS 28 32 MISKEYPUNCHED.

THE VALIDITY ERRORS NOT INVOLVING KEYPUNCHING CONTAIN A 1 IN COLUMN 80.

ONE OF THESE ERRORS BYPASSES OTHER VALIDITY CHECKS.

WD1 MISSN   WORD 1 OF DATA ON CARD 1 WAS ZERO. IT IS ASSUMED THIS CARD WAS LEFT IN BY MISTAKE, AND IT IS NOT PROCESSED FURTHER.

CERTAIN ERRORS BYPASS THE CREATION OF A CENTERLINE ELEVATION PLOT.

STAT ORDER	STATIONS ARE NOT IN ASCENDING SEQUENCE. CENTERLINE PLOT WILL BE RESUMED ONLY WHEN STATIONS IN ASCENDING SEQUENCE FROM THE LAST PLOTTED POINT ARE AGAIN ENCOUNTERED.
NO CLINE	NO CENTERLINE, THEREFORE NOT USED IN PLOTTING.
STAT FAR	STATIONS ARE TOO FAR APART. TENATIVELY THIS DISTANCE HAS BEEN SET AT 500 FEET.
H I WRONG	IF DIGIT 7 OF CONSOLE IS 9 HI IS NOT EQUAL TO ZERO. THE PROGRAM SETS IT TO ZERO AND PROCEEDS WITH A NORMAL CENTERLINE CALCULATION. IF DIGIT 7 OF CONSOLE IS 8 HI IS EQUAL TO ZERO. SINCE THIS IS AN ERROR, THIS POINT WILL BE SKIPPED IN THE CENTERLINE CALCULATIONS.

MOST COMMON ERRORS DO NOT AFFECT THE CREATION OF A CENTERLINE PLOT. SOME OF THESE MAY CREATE OTHER FALSE ERRORS.

CARD ORDER	CARD NUMBER DOES NOT START WITH 1 AND INCREASE 1 EACH CARD FOR THIS STATION.
STAT REPTD	STATION RESTARTS WITH CARD 1 AFTER AN ERRONEOUS OR CORRECT START.
PTLY BLANK	A CARD IS BLANK OR ZERO IN A DATA WORD, YET ANOTHER CARD OR MORE DATA FOLLOWS. THIS CAN EASILY GENERATE A NUMBER OF FALSE ERROR CARDS.
CD1 MISSN	THE FIRST CARD OF A STATION IS NOT THE 1 CARD.
NO PT LEFT	NO POINTS TO LEFT OF CENTERLINE.
NO PT RIGT	NO POINTS TO RIGHT OF CENTERLINE. NO CENTERLINE WILL CREATE THIS ERROR ALSO.
TWO CLINE	TWO OBSERVATIONS AT CENTERLINE.

HORIZ SAME	TWO ADJACENT OBSERVATIONS ARE THE SAME DISTANCE FROM CENTERLINE.
HORIZ INVR	TWO ADJACENT OBSERVATIONS SHOW AN INVERSION IN DISTANCE FROM CENTERLINE. NORMALLY NO CENTERLINE WILL PRODUCE THIS ERROR ALSO.
NOT L CARD	CARD DOES NOT HAVE L IN COLUMN 26.
NAME DIFF	THE NAME IN COLUMNS ONE TO TEN DIFFERS FROM THAT ON THE FIRST CARD OF THE JOB.

TWO CHECKS OF REASONABLENESS ARE MADE.

CRSVT NG	TWO ADJACENT OBSERVATIONS ON A CROSS SECTION DIFFER BY MORE THAN A MAXIMUM. AT PRESENT THIS MAXIMUM IS 50 FEET. THIS RESULTS IN A FEW FALSE WARNINGS IN AN AREA OF CLIFFS, BUT THESE SEEM WORTHWHILE.
CLVRT NG	TWO ADJACENT CENTERLINE READINGS DIFFER BY MORE THAN A MAXIMUM. AT PRESENT THIS MAXIMUM IS 25 FEET.

TERRAIN DATA

JOB	STATION	NO.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.
DINOSAURNM	13-50.00	2	10.0	5970.00	00.0	5967.40	10.0	5965.00	25.0	5960.00	42.0	5955.00
DINOSAURNM	13-50.00	3	70.0	5950.00	*	0	*	0	*	0	*	0

CRSVT NG ERROR

JOB	STATION	NO.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.
→ DINOSAURNM	14-5			0		0		0		0		0
DINOSAURNM	14-00.00	1	90.0	6030.00	68.0	6010.00	55.0	6000.00	43.0	5990.00	28.0	5980.00
DINOSAURNM	14-00.00	2	15.0	5975.00	00.0	5970.00	25.0	5965.00	40.0	5960.00	62.0	5955.00
DINOSAURNM	14-00.00	3	120.0	5950.00	*	0	*	0	*	0	*	0
DINOSAURNM	14-50.00	1	80.0	6025.00	62.0	5915.00	42.0	6000.00	34.0	5995.00	22.0	5985.00
DINOSAURNM	14-50.00	2	12.0	5980.00	00.0	5975.60	10.0	5970.00	35.0	5965.00	60.0	5960.00
DINOSAURNM	14-50.00	3	80.0	5955.00	*	0	*	0	*	0	*	0

→ DATA3 PCH ERROR Cols 51-60 Invalidly Punched

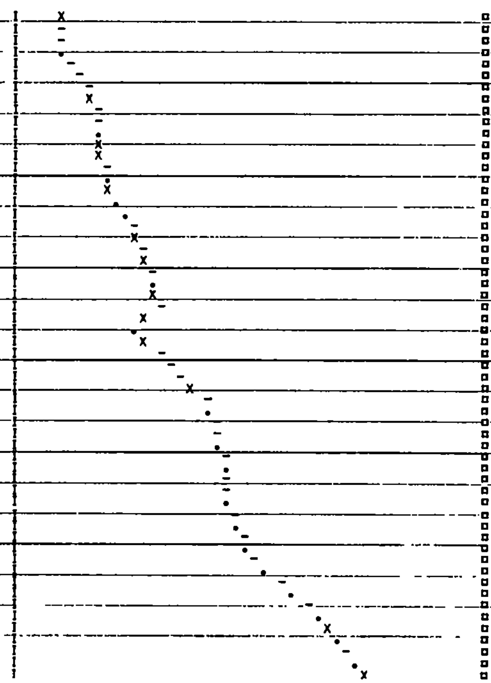
JOB	STATION	NO.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.
DINOSAURNM	15-00.00	1	70.0	6025.00	62.0	6020.00	500.0		*	0	*	0
DINOSAURNM	15-00.00	1	70.0	6025.00	62.0	6020.00	50.0	6015.00	35.0	6005.00	30.0	6000.00
DINOSAURNM	15-00.00	2	18.0	5990.00	08.0	5985.00	00.0	5982.40	35.0	5970.00	50.0	5965.00
DINOSAURNM	15-00.00	3	80.0	5960.00	*	0	*	0	*	0	*	0
DINOSAURNM	15-50.00	1	70.0	6035.00	54.0	6025.00	50.0	6020.00	40.0	6015.00	28.0	6005.00
DINOSAURNM	15-50.00	2	12.0	6000.00	00.0	5992.00	10.0	5985.00	38.0	5975.00	53.0	5970.00
DINOSAURNM	15-50.00	3	70.0	5965.00	*	0	*	0	*	0	*	0
DINOSAURNM	16-00.00	1	70.0	6035.00	50.0	6025.00	35.0	6020.00	05.0	6000.00	00.0	5997.00
DINOSAURNM	16-00.00	2	06.0	5995.00	12.0	5990.00	35.0	5985.00	60.0	5975.00	74.0	5970.00
DINOSAURNM	16-50.00	1	76.0	6040.00	58.0	6035.00	40.0	6025.00	30.0	6020.00	18.0	6010.00
DINOSAURNM	16-50.00	2	00.0	6005.00	08.0	6000.00	20.0	5995.00	30.0	5990.00	55.0	5985.00
DINOSAURNM	16-50.00	3	70.0	5980.00	*	0	*	0	*	0	*	0

STAT REPTD ERROR # 28-32 PCH ERROR

JOB	STATION	NO.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.	DIST.	ELEV.
→ DINOSAURNM	17-00.00	7		0		0		0		0		0
DINOSAURNM	17-00.00	1	70.0	6035.00	58.0	6030.00	50.0	6027.00	44.0	6025.00	28.0	6020.00
DINOSAURNM	17-00.00	2	20.0	6015.00	10.0	6010.00	00.0	6005.00	12.0	6000.00	18.0	5995.00
DINOSAURNM	17-00.00	3	23.0	5990.00	30.0	5985.00	38.0	5980.00	80.0	5975.00	*	0

GROUND PROFILE PLOTTED FROM TERRAIN NOTES — SCALES - HORIZONTAL 1" to 200' VERTICAL 1" to 20'

625.00	590954
650.00	590858
675.00	590847
1600.00	590894
1625.00	591043
1650.00	591222
1675.00	591401
2600.00	591580
2625.00	591620
2650.00	591660
2675.00	591700
3600.00	591740
3625.00	591793
3650.00	591845
3675.00	591898
4600.00	591950
4625.00	592110
4650.00	592270
4675.00	592430
5600.00	592590
5625.00	592668
5650.00	592745
5675.00	592823
6600.00	592900
6625.00	592960
6650.00	593020
6675.00	592760
7600.00	592500
7625.00	592770
7650.00	593040
7675.00	593250
8600.00	593460
8625.00	593730
8650.00	594000
8675.00	594110
9600.00	594220
9625.00	594250
9650.00	594280
9675.00	594400
10600.00	594520
10625.00	594460
10650.00	594400
10675.00	594510
11600.00	594620
11625.00	594710
11650.00	594800
11675.00	594920
12600.00	595040
12625.00	595320
12650.00	595600
12675.00	595925
13600.00	596260
13625.00	596495
13650.00	596740
13675.00	596870
14600.00	597000
14625.00	597280
14650.00	597560

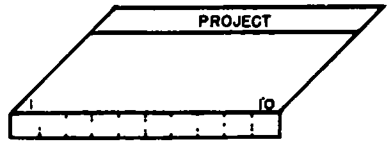


FORM PDP 104
AUG 1960

	PUNCHED
	VERIFIED

DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

GRADE DATA



CARD CODES

0 Compute-Gen Mode
1 P I Station
2 Horiz Equation
3 Odd Station
4 Vert Equation
5 Chg Interval
6 Tfr to Terr Mode
7 Tfr to Gen Mode
8 Compute-Terr Mode
9 Reset
J Begin Max Super
K End Max Super
L Center Line Shift
M Widening

FROM ____________________

ADDRESS ____________________

DATE ____________ SHEET ____ OF ____

	11 – 18	19 – 25	26	29 – 32	33 – 40	41 – 45
	NUMERIC CODES					
	P I STATION OR STATION BACK	STATION ELEVATION	CODE	LENGTH OF V C OR V DIFF	STATION AHEAD OR INTERVAL	DESCRIPTION OR TEMPLATE
	ALPHABETIC CODES					
	P I STATION OR STATION BACK	WIDENING NORMAL SLOPE OR SHIFTING	CODE	LENGTH OF TRANSITION	MAXIMUM SUPER ELEVATION	
1	+					
2	+					
3	+					
4	+					
5	+					
6	+					
7	+					
8	+					
9	+					
10	+					
11	+					
12	+					
13	+					
14	+					
15	+					
16	+					
17	+					
18	+					
19	+					
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25	+					
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27	+					
28	+					
29	+					
30	+					

FORM PDP 103
AUG 1960

PUNCHED
VERIFIED

INITIAL RUN
CORRECTED RUN

DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

EARTHWORK DATA SHEET

PROJECT

SHEET NO. ___ OF ___ SHEETS

CARD CODES

- U RESET
- R END OF JOB
- S FACTOR & GRADE COR SINGLE LANE
- A EQUATION
- B ZERO AREA
- W ADDED QUANTITIES
- F FIX SLOPES
- J TOTAL SHIFT
- Q QUIT TEMPLATE
- C BRIDGE
- T NOTE MAJOR AND MINOR TEMPLATES
- K TEMPLATE
- E CUT SLOPE SELECTION
- G DITCH SLOPE SELECTION
- H COMPLEX 1 (CUT)
- I COMPLEX 2 (FILL)
- Y FILL SLOPE SELECTION

LINE	TEMPLATE / SLOPE / ETC.	LT SLOPE / RT SLOPE	CODE	TEMP	C.C. / S / C / FACTOR	LAST STATION / Δ Y 1 / SLOPE 1 / LAST STATION	D 1 / Δ X 1 / Δ Y 1 / C / Δ Y 2 / SLOPE 2	D 2 / Δ X 2 / Δ Y 2 / C / Δ Y 3 / SLOPE 3	D 3 / Δ X 3 / Δ Y 3 / C / Δ Y 4 / SLOPE 4 / LT FIXED	D 4 / Δ X 4 / Δ Y 4 / D 5 / Δ X 5 / Δ Y 5 / D / Δ Y 5 / SLOPE 5 / RT FIXED
1										
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GPO 840177

GRADE TABULATION

BUREAU OF PUBLIC ROADS

FORM PDP 107

PROJECT	STATION	DESCRIPTION		GRADE* ELEVATION	GRADE — %	TANGENT ELEVATION	SHIFT	SUPER	WIDENING	
									LEFT	RIGHT
RAPIDCITYP	13.00	WIDE	A	4858.93	1.0690-					
RAPIDCITYP	20.00	PC	X	4858.86	1.0690-				3.00	3.00
RAPIDCITYP	50.00		A	4858.36		4858.53			3.00	3.00
RAPIDCITYP	1 00.00	PI	A	4856.81		4858.00			3.00	3.00
RAPIDCITYP	1 50.00		A	4854.33		4854.50			3.00	3.00
RAPIDCITYP	1 80.00	PT	X	4852.40		4852.40			3.00	3.00
RAPIDCITYP	2 00.00		A	4851.00	7.0000-				3.00	3.00
RAPIDCITYP	2 50.00		A	4847.50	7.0000-				3.00	3.00
RAPIDCITYP	3 00.00	PC	A	4844.00	7.0000-				3.00	3.00
RAPIDCITYP	3 50.00		A	4840.64		4840.50			3.00	3.00
RAPIDCITYP	4 00.00		A	4837.55		4837.00			3.00	3.00
RAPIDCITYP	4 50.00		A	4834.74		4833.50			3.00	3.00
RAPIDCITYP	5 00.00		A	4832.20		4830.00			3.00	3.00
RAPIDCITYP	5 50.00		A	4829.94		4826.50			3.00	3.00
RAPIDCITYP	6 00.00	PI	A	4827.95		4823.00			3.00	3.00
RAPIDCITYP	6 50.00	WIDE	A	4826.24		4822.80			3.00	3.00
RAPIDCITYP	7 00.00		A	4824.80		4822.60			1.50	1.50
RAPIDCITYP	7 50.00		A	4823.64		4822.40				
RAPIDCITYP	8 00.00		A	4822.75		4822.20				
RAPIDCITYP	8 50.00		A	4822.14		4822.00				
RAPIDCITYP	9 00.00	PT	A	4821.80		4821.80				
RAPIDCITYP	9 50.00		A	4821.60	0.4000-					
FAPIDCITYP	10 00.00		A	4821.40	0.4000-					
RAPIDCITYP	10 50.00		A	4821.20	0.4000-					
RAPIDCITYP	11 00.00		A	4821.00	0.4000-					
RAPIDCITYP	11 50.00		A	4820.80	0.4000-					
RAPIDCITYP	12 00.00	WIDE	A	4820.60	0.4000-					
RAPIDCITYP	12 50.00		A	4820.40	0.4000-				1.50	0.00
RAPIDCITYP	12 67.30	TS	X	4820.33	0.4000-				2.02	0.00
RAPIDCITYP	13 00.00		A	4820.20	0.4000-			SR.010.000	3.00	0.00
RAPIDCITYP	13 50.00		A	4820.00	0.4000-			SR.025.000	3.00	0.00
RAPIDCITYP	14 00.00		A	4819.80	0.4000-			SR.040.000	3.00	0.00
RAPIDCITYP	14 50.00		A	4819.60	0.4000-			SR.055.000	3.00	0.00
RAPIDCITYP	14 67.30	SC	X	4819.53	0.4000-			SR.060.000	3.00	0.00
RAPIDCITYP	15 00.00	PC	A	4819.40	0.4000-			SR.060.000	3.00	0.00
RAPIDCITYP	15 50.00		A	4819.15		4819.20		SR.060.000	3.00	0.00
RAPIDCITYP	16 00.00	WIDE	A	4818.80		4819.00		SR.060.000	3.00	0.00
RAPIDCITYP	16 50.00		A	4818.35		4818.80		SR.060.000	1.50	0.00
RAPIDCITYP	17 00.00		A	4817.80		4818.60		SR.060.000		
RAPIDCITYP	17 50.00		A	4817.15		4818.40		SR.060.000		

* ALL GRADES ARE NOT CORRECTED FOR SUPER ELEVATION

EARTHWORK QUANTITIES - BUREAU OF PUBLIC ROADS

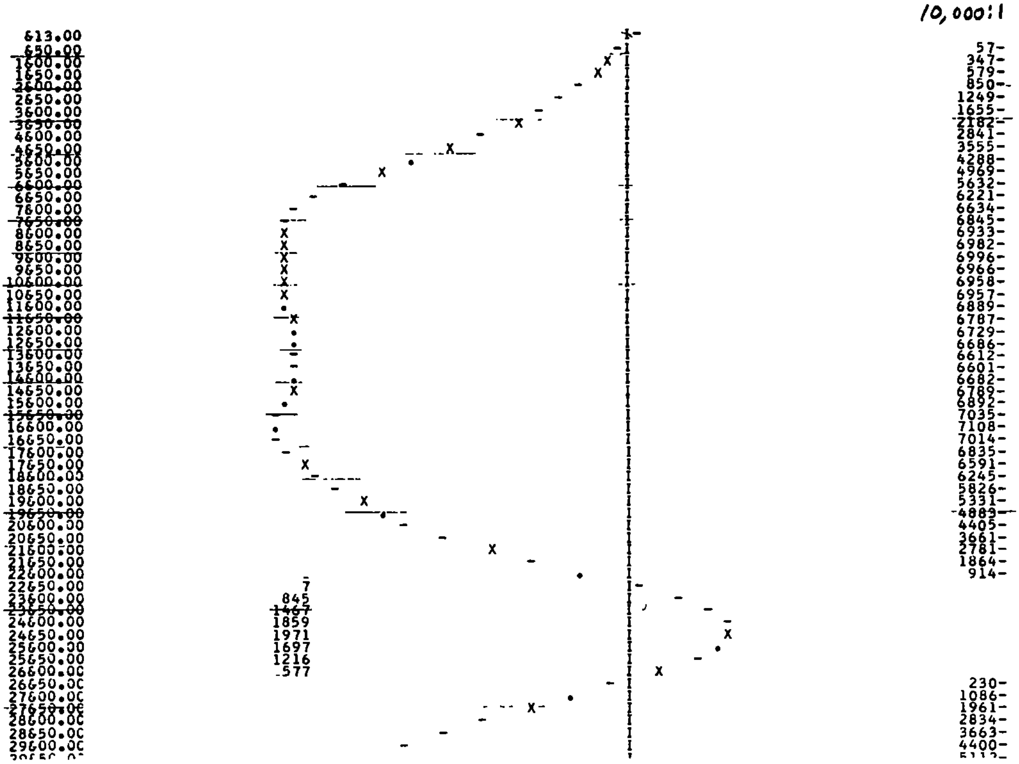
FORM PDP 106

PROJECT	STATION	FACTOR	EXTRAPOLATION LEFT	EXTRAPOLATION RIGHT	MASS ORDINATE	ADDED QUANTITIES (MASS TEMP) EXCAVATION	ADDED QUANTITIES EMBANKMENT	COMPUTED QUANTITIES (MINOR TEMP) EXCAVATION AREA S.F	EXCAVATION VOLUME C.Y	EMBANKMENT AREA S.F	EMBANKMENT VOLUME C.Y
RAPIDCITYP	0-13.00	0.008	000	000				62			
RAPIDCITYP	0-50.00	1.108	000	000	57-				42	131	99
RAPIDCITYP	1-00.00	1.108	000	000	347-				42*	154	290
RAPIDCITYP	1-50.00	1.108	000	040	579-			118	109	181	341
RAPIDCITYP	2-00.00	1.108	000	000	850-				109	192	380
RAPIDCITYP	2-50.00	1.108	000	000	1249-				218*	200	399
RAPIDCITYP	3-00.00	1.108	000	000	1655-					198	406
RAPIDCITYP	3-50.00	1.108	040	000	2182-					320	527
RAPIDCITYP	4-00.00	1.108	040	000	2841-					327	659
RAPIDCITYP	4-50.00	1.108	040	000	3555-					374	714
RAPIDCITYP	5-00.00	1.108	000	000	4288-					345	733
RAPIDCITYP	5-50.00	1.108	000	000	4969-					323	681
RAPIDCITYP	6-00.00	1.108	000	000	5632-					329	663
RAPIDCITYP	6-50.00	1.108	040	000	6221-					249	589
RAPIDCITYP	7-00.00	1.108	000	000	6634-					156	413
RAPIDCITYP	7-50.00	1.108	000	000	6845-			2	2	54	213
RAPIDCITYP	8-00.00	1.108	000	000	6933-			7	9	41	97
RAPIDCITYP	8-50.00	1.108	120	000	6982-			34	38	44	87
RAPIDCITYP	9-00.00	1.108	040	000	6996-			22	51	19	65
RAPIDCITYP	9-50.00	1.108	040	000	6966-			48	65	16	35
RAPIDCITYP	10-00.00	1.108	000	000	6958-			27	70	45	62
RAPIDCITYP	10-50.00	1.108	000	000	6957-			57	78	31	77
RAPIDCITYP	11-00.00	1.108	000	000	6889-			51	100		32
RAPIDCITYP	11-50.00	1.108	000	000	6787-			58	102		7562*
RAPIDCITYP	12-00.00	1.108	000	000	6729-			46	97	38	39
RAPIDCITYP	12-50.00	1.108	000	000	6686-			67	105	23	62
RAPIDCITYP	13-00.00	1.108	000	000	6612-			69	126	28	52
RAPIDCITYP	13-50.00	1.108	000	000	6601-			51	111	70	100
RAPIDCITYP	14-00.00	1.108	000	000	6682-			25	70	78	151
RAPIDCITYP	14-50.00	1.108	000	000	6789-			57	76	101	183
RAPIDCITYP	15-00.00	1.108	000	000	6892-			68	116	114	219
RAPIDCITYP	15-50.00	1.108	000	000	7035-			95	151	174	294
RAPIDCITYP	16-00.00	1.108	000	000	7108-			64	148	43	221
RAPIDCITYP	16-50.00	1.108	000	000	7014-			96	148	10	54
RAPIDCITYP	17-00.00	1.108	000	000	6835-			115	196	7	17
RAPIDCITYP	17-50.00	1.108	000	000	6591-			156	251		7
RAPIDCITYP	18-00.00	1.108	000	000	6245-			217	346		1399*
RAPIDCITYP	18-50.00	1.108	000	000	5826-			235	419		
RAPIDCITYP	19-00.00	1.108	000	000	5331-			300	495		
RAPIDCITYP	19-50.00	1.108	000	040	4883-			184	448		

MASS ORDINATE PLOT

Rapid City

10,000:1 9-29



FORM PDP 109

BUREAU OF PUBLIC ROADS

STAKING DETAIL

* TO SHOULDER POINT OR BOTTOM OF DITCH
Δ MINUS INDICATES FILL SLOPE
NO SIGN INDICATES CUT SLOPE

Rev. 9-29-66
Revised 10/26/66

PROJECT	STATION	TEMPLATE	LEFT SLOPE STAKE				ADJUSTED GRADE	RIGHT SLOPE STAKE			
			SLOPE Δ	ELEVATION	DISTANCE	CUT OR FILL *		CUT OR FILL *	DISTANCE	ELEVATION	SLOPE Δ
RAPIDCITYP	13.00	A	3.00	4857.9	29.4 L	C 0.80	4858.93	C 3.50	37.5 R	4860.5	3.00
RAPIDCITYP	50.00	A	2.00-	4847.7	41.6 L	F 10.30	4858.36	F 4.80	30.6 R	4853.2	2.00-
RAPIDCITYP	1 00.00	A	2.00-	4845.5	42.8 L	F 10.90	4856.81	F 11.30	43.6 R	4845.1	2.00-
RAPIDCITYP	1 50.00	A	1.50-	4835.6	48.5 L	F 18.30	4854.33	C 11.90	47.9 R	4864.3	1.50
RAPIDCITYP	2 00.00	A	1.50-	4831.3	50.0 L	F 19.30	4851.00	F 10.50	36.8 R	4840.1	1.50-
RAPIDCITYP	2 50.00	A	1.50-	4826.3	52.1 L	F 20.70	4847.50	F 10.50	36.8 R	4836.6	1.50-
RAPIDCITYP	3 00.00	A	1.50-	4832.5	37.7 L	F 11.10	4844.00	F 13.50	41.3 R	4830.1	1.50-
RAPIDCITYP	3 50.00	A	1.50-	4825.6	43.1 L	F 14.70	4840.64	F 11.10	37.7 R	4829.1	1.50-
RAPIDCITYP	4 00.00	A	2.00-	4826.1	43.2 L	F 11.10	4837.55	F 12.40	39.6 R	4824.7	1.50-
RAPIDCITYP	4 50.00	A	2.00-	4825.3	39.2 L	F 9.10	4834.74	F 10.80	42.6 R	4823.5	2.00-
RAPIDCITYP	5 00.00	A	2.00-	4823.4	37.8 L	F 8.40	4832.20	F 9.40	39.8 R	4822.4	2.00-
RAPIDCITYP	5 50.00	A	2.00-	4822.5	35.0 L	F 7.00	4829.94	F 8.70	38.4 R	4820.9	2.00-
RAPIDCITYP	6 00.00	A	2.00-	4819.7	36.6 L	F 7.80	4827.95	F 7.30	35.6 R	4820.2	2.00-
RAPIDCITYP	6 50.00	A	2.00-	4818.6	35.6 L	F 7.30	4826.24	F 7.30	35.6 R	4818.5	2.00-
RAPIDCITYP	7 00.00	A	4.00-	4820.0	37.1 L	F 4.40	4824.80	F 3.50	33.5 R	4820.9	4.00-
RAPIDCITYP	7 50.00	A	4.00-	4819.5	33.2 L	F 3.80	4823.64	F 4.40	35.6 R	4818.9	4.00-
RAPIDCITYP	8 00.00	A	6.00-	4819.6	34.8 L	F 2.80	4822.75	F 0.20	18.8 R	4822.2	4.00-
RAPIDCITYP	8 50.00	A	4.00-	4816.1	40.8 L	F 5.70	4822.14	C 0.00	27.0 R	4820.3	3.00
RAPIDCITYP	9 00.00	A	6.00-	4819.3	31.2 L	F 2.20	4821.80	C 0.10	27.3 R	4820.0	3.00
RAPIDCITYP	9 50.00	A	6.00-	4818.9	31.8 L	F 2.30	4821.60	F 1.30	25.8 R	4819.9	6.00-
RAPIDCITYP	10 00.00	A	6.00-	4818.7	32.4 L	F 2.40	4821.40	C 1.00	30.0 R	4820.5	3.00
RAPIDCITYP	10 50.00	A	6.00-	4818.0	34.8 L	F 2.80	4821.20	F 1.30	25.8 R	4819.6	6.00-
RAPIDCITYP	11 00.00	A	3.00	4820.3	30.6 L	C 1.20	4821.00	F 1.50	27.0 R	4819.2	6.00-
RAPIDCITYP	11 50.00	A	3.00	4820.7	32.1 L	C 1.70	4820.80	F 1.00	24.0 R	4819.4	6.00-
RAPIDCITYP	12 00.00	A	4.00-	4815.5	36.8 L	F 4.70	4820.60	C 0.30	27.9 R	4819.0	3.00
RAPIDCITYP	12 50.00	A	2.00-	4814.5	30.5 L	F 5.50	4820.40	C 0.20	27.6 R	4818.7	3.00
RAPIDCITYP	13 00.00	A	2.00-	4812.0	37.8 L	F 8.40	4820.20	C 0.20	27.6 R	4818.5	3.00
RAPIDCITYP	13 50.00	A	1.50-	4810.1	36.8 L	F 10.50	4820.09	F 1.30	25.8 R	4818.3	6.00-
RAPIDCITYP	14 00.00	A	1.50-	4807.1	41.9 L	F 13.90	4820.16	F 1.20	25.2 R	4818.3	6.00-
RAPIDCITYP	14 50.00	A	1.50-	4804.3	46.7 L	F 17.10	4820.23	F 1.50	27.0 R	4817.8	6.00-
RAPIDCITYP	15 00.00	A	1.50-	4803.9	47.3 L	F 17.50	4820.12	F 1.90	29.4 R	4817.1	6.00-
RAPIDCITYP	15 50.00	A	1.50-	4799.1	54.2 L	F 22.10	4819.87	C 2.00	36.0 R	4818.8	3.00
RAPIDCITYP	16 00.00	A	1.50-	4810.5	36.5 L	F 10.30	4819.52	C 1.90	35.7 R	4818.3	3.00
RAPIDCITYP	16 50.00	A	3.00	4820.0	32.1 L	C 1.20	4819.07	C 2.30	34.6 R	4818.2	2.00
RAPIDCITYP	17 00.00	A	3.00	4819.6	31.5 L	C 1.50	4818.52	C 4.00	42.0 R	4819.4	3.00
RAPIDCITYP	17 50.00	A	3.00	4818.2	29.1 L	C 0.70	4817.87	C 19.90	49.9 R	4834.7	1.00
RAPIDCITYP	18 00.00	A	3.00	4819.0	33.9 L	C 2.30	4817.12	C 3.10	33.1 R	4817.1	1.00
RAPIDCITYP	18 50.00	A	2.00	4820.1	35.6 L	C 4.30	4816.27	C 7.40	37.4 R	4820.6	1.00
RAPIDCITYP	19 00.00	A	1.50	4822.9	39.0 L	C 8.00	4815.32	C 7.70	41.6 R	4820.0	1.50
RAPIDCITYP	19 50.00	A	6.00-	4814.6	22.8 L	F 0.80	4814.27	C 7.00	44.0 R	4818.2	2.00

SLOPE STAKE BOOK MADE ON IBM 407 FROM EARTHWORK OUTPUT CARDS

PAGE 47 — BUREAU OF PUBLIC ROADS — FORM PDP 105 — COMPUTER STAKING DETAIL OR EARTHWORK COMPUTATIONS

STATION	ACTUAL PROFILE	GRADE AND PROFILE	TEMPLATE	AREA EXC SLOPE	AREA EMB ELEV OF STAKE	VOLUME EXC DIST FROM CL	VOLUME EMB CUT OR FILL
				2094 SF	SF		
WARREN PEAK 129+75.00		76.4 GN 5450.38GR	060 SL 060 16.0 13.0	1.00 C 1.00 C 1957 SF	5477.8 5479.0 SF	51.9 LT 48.4 RT 1875 CY	C 29.9 C 29.4 CY
+							
130+00.00		75.2 GN 5450.80GR	055 SL 055 15.8 13.0	1.00 C 1.00 C 1771 SF	5474.5 5479.4 SF	47.8 LT 48.3 RT 1726 CY	C 26.0 C 29.3 CY
+							
130+50.00		71.0 GN 5451.46GR	040 SL 040 15.0 13.0	1.00 C 1.00 C 1232 SF	5468.2 5474.3 SF	39.6 LT 42.6 RT 2780 CY	C 18.6 C 23.6 CY
+				PAGE BOOK JOB	TOTAL TOTAL TOTAL	6381 CY 40151 CY 40151 CY	CY 28484 CY 28484 CY

GPO 841800

COORDINATES OF RIGHT-OF-WAY OWNERSHIPS FROM ORIGINAL PLAT DESCRIPTIONS

OWNERSHIP CO ORDINATES

JOB	PARCEL	CRNER	NS CO ORD	EW CO ORD
HOLMANTAOS	HES 317	1	53,890.72	75,302.70
HOLMANTAOS	HES 317	2	53,721.40	75,251.53
HOLMANTAOS	HES 317	3	53,642.24	75,218.44
HOLMANTAOS	HES 317	4	53,541.72	75,175.36
HOLMANTAOS	HES 317	5	53,641.44	74,935.20
HOLMANTAOS	HES 317	6	53,765.13	74,423.93
HOLMANTAOS	HES 317	7	54,068.73	73,842.37
HOLMANTAOS	HES 317	8	54,177.70	73,936.32
HOLMANTAOS	HES 317	9	53,955.91	75,053.01

ERRORS

HOLMANTAOS	HES 317	1.36	0.31	53,640.88	75,218.75

FORM C D H 220 REV FEB. 1960

Dayton - Kane ROW Parcel No 2

COLORADO DEPARTMENT OF HIGHWAYS

TRAVERSE COMPUTATIONS

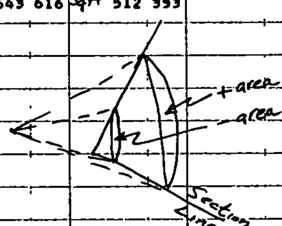
1 ALL SIDES AND BEARINGS KNOWN
2 TWO SIDES UNKNOWN
3 ONE SIDE & ONE BEARING UNKNOWN
4 TYPE 1 WITH AREA

PROBLEM TYPE:
5 TYPE 2 WITH AREA
6 ONE SIDE & ITS BEARING
7 TYPE 3 WITH AREA
8 TYPE 4 WITH AREA
9 TYPE 6 WITH AREA
0 TWO BEARINGS UNKNOWN

Problem Type	Group	Batch or Course	Trav No. / Area in Square Feet or Distance	Bearing					Cosine	Sine	Latitude or Area in Acres (Error of Closure)	Departure or Sine of Delta (Error of Closure)	Coordinates North (Progressive Totals)	Coordinates East (Progressive Totals)
4	E	1	2										100000 000	100000 000
		1	133 990	S	89	10	00	E	0 014543896	0 999894230	S 1 949	E 133 976	99998 051	100133 976
		2	450 420	S	43	14	30	W	0 728470613	0 685077041	S 328 118	W 308 572	99669 933	99825 404
		3	132 260	N	00	24	00	E	0 999975626	0 006981255	N 132 257	E 923	99802 190	99826 327
		4	263 250	N	41	17	00	E	0 751456085	0 659783102	N 197 821	E 173 688	100000 011	100000 015
		99									011	015		
		Area	33.674	Sq Ft							Area 773	Acres		
			33 674								773			
										Plus Arc Area	467			
										Parcel	Area 1.240	Acres		

Problem Type	Group	Batch or Course	Trav No / Area in Square Feet or Distance	Bearing					Cosine	Sine	Latitude or Area in Acres (Error of Closure)	Departure or Sine of Delta (Error of Closure)	Coordinates North (Progressive Totals)	Coordinates East (Progressive Totals)
2		4	263,248	S	41	16	60	W	CHORD	CALC	Acres = 0.282	- 12292 192	SqFt 306 258	
2		2	450 416	S	43	14	30	W	CHORD	CALC	Acres = 0.749	+ 32643 616	SqFt 512 333	
										Net	Area 0.467	+		

RIGHT OF WAY PARCEL COMPUTATION



DESIGN PROGRESS CONTROL FORM

001	JOB	CEDAREDGE-MESA 13 E C							10 3 60

OPERATION MATERIALS SURVEY LINE

ROBERT BOHMAN	7-29-60	ORIG							95%
ROBERT BOHMAN	8-12-60	ORIG							95%
ROBERT BOHMAN	9-02-60	ORIG							95%
			*						

OPERATION CROSS SECTION LINE

DAVID WAGNER	7-22-60	ORIG	8	790 00	962 50			HAND	80%
DAVID WAGNER	7-23-60	ORIG	8	790 00	962 50			HAND	70%
DAVID WAGNER	7-24-60	ORIG	8	790 00	962 50			HAND	90%
RICHARD BRAUNLICH	8-11-60	REV-01	8	790 00	960 00	845 00	945 00	HAND	40%
RICHARD BRAUNLICH	8-12-60	REV-01	8	790 00	960 00	845 00	945 00	HAND	85%
RICHARD BRAUNLICH	8-15-60	REV-01	4	790 00	962 50	845 00	945 00	HAND	100%
			44*						

OPERATION CALCULATE GRADE

RICHARD BRAUNLICH	8-09-60	REV-01	4	790 00	960 00	845 00	945 00	HAND	30%
RICHARD BRAUNLICH	8-10-60	REV-01	8	790 00	960 00	845 00	945 00	HAND	100%
			12*						

OPERATION MINOR DRAINAGE

CHARLES POWELL	8-23-60	REV-01	8	790 00	962 50	790 00	962 50	HAND	50%
CHARLES POWELL	8-24-60	REV-01	8	790 00	962 50	790 00	962 50	HAND	100%
			16*						

OPERATION DRAFT PLANS

JOHN HARPER	7-26-60	ORIG	1	790 00	962 50	790 00	962 50	HAND	98%
JAMES ERICKSON	7-26-60	REV-06	2	790 00	962 50	790 00	962 50	HAND	100%
JUNIOR CUBBAGE	8-26-60	REV-07	4	790 00	962 50	790 00	962 50	HAND	100%
JUNIOR CUBBAGE	8-30-60	REV-07	4	790 00	962 50	790 00	962 50	HAND	
			11*						

II. Ohio Department of Highways

E. S. PRESTON, Director, Ohio Department of Highways

●OHIO'S PLANS for digitizing stereoplotter output were outlined to the Conference on Improved Engineering Methods and Procedures sponsored by the Illinois Highway Department and the AASHO at Chicago, March 6, 1956.

In reporting at that meeting on the role of photogrammetry in highway location and design, the advantages of taking cross-sections directly from a stereoplotter rather than from a contour map were pointed out. It was stated that automatic recording would eliminate human errors in transcribing notes and would provide an output that would be immediately available for use in electronic computers performing highway design computations.

Afterwards, the development of such a system was discussed with individuals within the Ohio Department of Highways. On August 15, 1956, the Department began work on a system that would accurately follow the movements of a Kelsh plotter tracing table, give an indication of the horizontal and vertical distances measured by the Kelsh plotter, and automatically record on punched cards these distances whenever a record button was pushed.

THE KELSH PLOTTER

Components

The system developed by the Ohio Department of Highways is an analog-to-digital converter. The development consisted of modifying and interconnecting various standard devices and designing the necessary circuitry to enable them to operate as a unit. The basic components of the system are the following:

1. The Kelsh plotter modification (Figure 1).

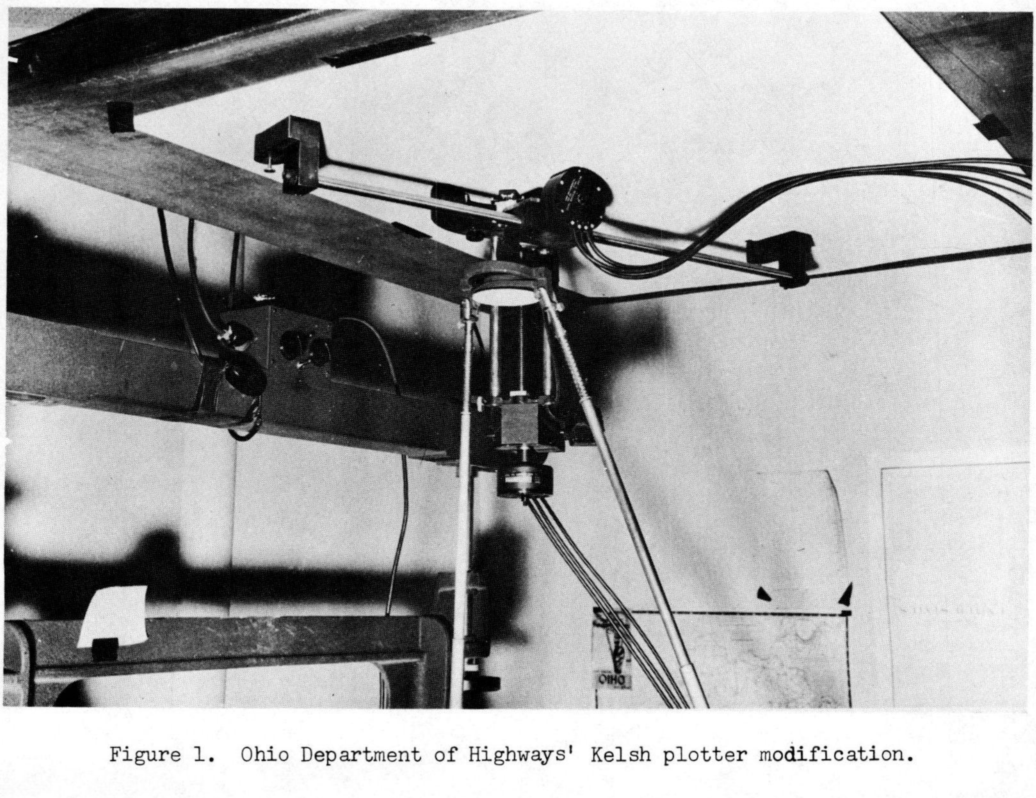


Figure 1. Ohio Department of Highways' Kelsh plotter modification.

2. Analog-to-digital conversion circuits purchased from the Telecomputing Corporation and consisting of (a) horizontal and vertical quantizers, (b) demodulator unit, and (c) input units (Figure 2),
3. Electronic Counters purchased from Beckman Instruments, Inc.,
4. Readout circuits, and
5. IBM 526 printing summary punch.

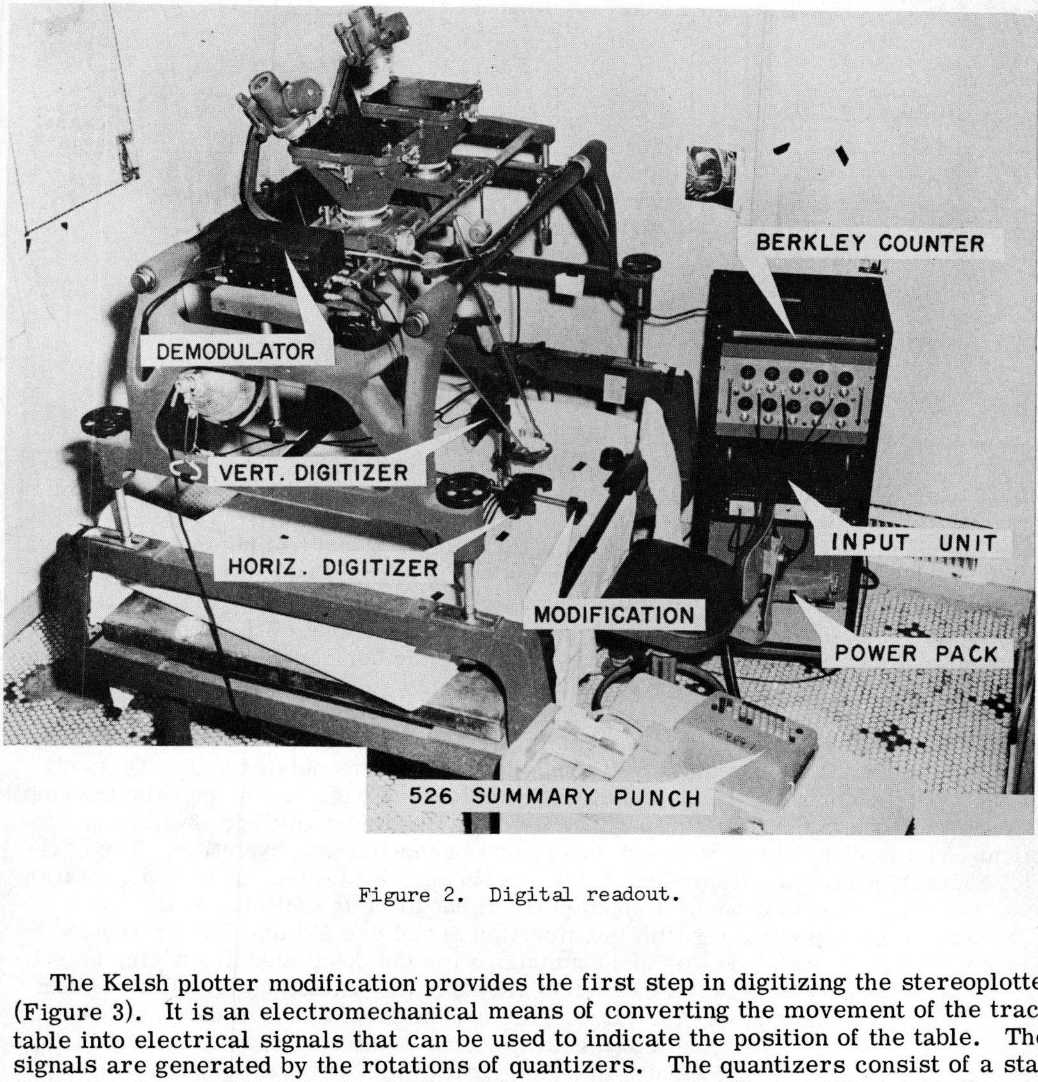


Figure 2. Digital readout.

The Kelsh plotter modification provides the first step in digitizing the stereoplotter (Figure 3). It is an electromechanical means of converting the movement of the tracing table into electrical signals that can be used to indicate the position of the table. These signals are generated by the rotations of quantizers. The quantizers consist of a stationary and a rotating disc on which patterns are etched. These patterns are of such a nature that when a signal is applied to one of the discs and the other rotated 500 pulse counts per revolution of the rotating disc are generated. In addition, an equal number of direction pulses, either leading or lagging the count pulses, are also produced in order to determine the direction of rotation. In this way, each revolution of the quantizer is broken into 500 count pulses plus a direction signal. To monitor the position of the tracing table it is only necessary that a quantizer be so connected to the table that the quantizer rotates for any movement of the table along a desired axis. The count pulses and direction signal can then be used to indicate the deviation of the table from any reference point. If the count and direction signals are appropriately combined

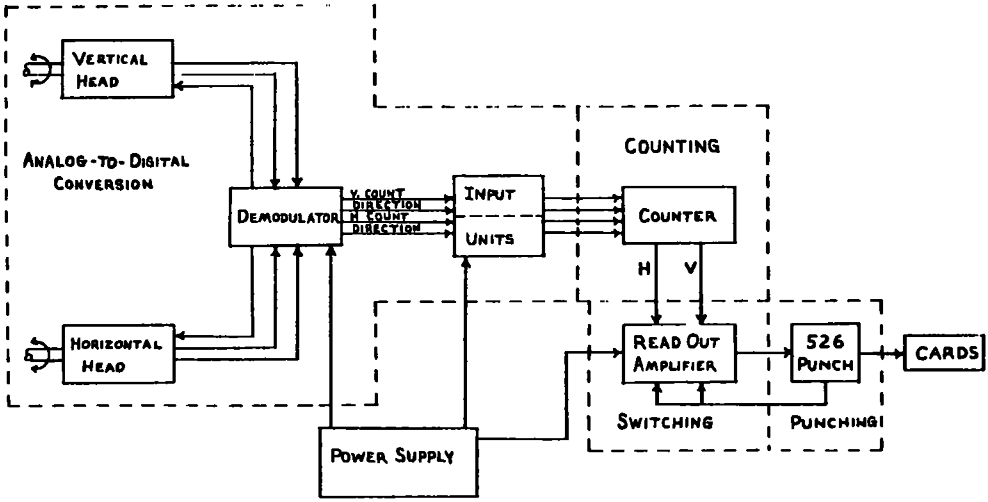


Figure 3. Kelsh plotter recorder system.

with a quantity equal to the coordinate of the reference point along the quantized axis, the movements of the tracing table along the axis will be followed by the accumulated total. At any instant the accumulated total will then be the coordinate of the position of the tracing table at that instant.

The Kelsh plotter modification quantizes the motion of the tracing table along both vertical and horizontal axis. Vertical quantization is accomplished by gearing a quantizer directly to the vertical mechanism of the table in such a manner that the vertical quantizer makes one revolution for each 2 in. of vertical travel of the tracing table. Horizontal quantization is accomplished by attaching the horizontal scale attachment to the tracing table. This attachment restricts the horizontal motion of the tracing table to a straight line and causes the horizontal quantizer to rotate 1 revolution for each 4 in. of horizontal travel of the tracing table.

The input signal for the quantizers is supplied by the demodulator unit. This unit also receives the quantizer count and direction output signals. These signals are amplified and then fed into the input units where they are further amplified. In addition, the vertical count is doubled to produce 1,000 counts per quantizer revolution. The horizontal count is quadrupled to produce 2,000 counts per revolution. This multiplication is necessary in order to produce 1 count pulse at each 0.1-ft scale interval.

The multiplied signals along with the direction signal are fed into the electronic counter unit. This unit serves as an accumulator for the count signals, adding or subtracting counts depending on the direction of travel of the tracing table. The counter unit can be preset to any reference value. The accumulated totals in the counters, therefore, can indicate the actual coordinate position of the tracing table at any instant. The horizontal counter is provided with a left-right switch to reverse the direction of counting when the centerline is crossed so that true distances from the centerline will be accumulated. The contents of the counters are visually displayed at all times.

The output of the counter unit is connected through the readout circuits to the key punch machine. The readout circuits consist of a relay switching matrix and 10 control tubes. The relay matrix is driven as a slave unit by the key punch machine. As the machine prepares to punch a column it causes the relay matrix to connect the appropriate counter tube to the control tubes. The control tubes, representing the digits 0 to 9, then cause the key punch unit to punch the digit displayed in the counter for that position. This is repeated at each column until the contents of the counter unit have been punched into cards. Record cycles are initiated by depressing the record button.

Operation

The development of the system just described was completed in December 1956. Detailed instructions were drawn up and it was put in operation shortly thereafter. The system is controlled by the plotter operator who moves the Kelsh plotter tracing table in the normal manner to the points on the cross-sections at which he desires to take readings (Figure 4).

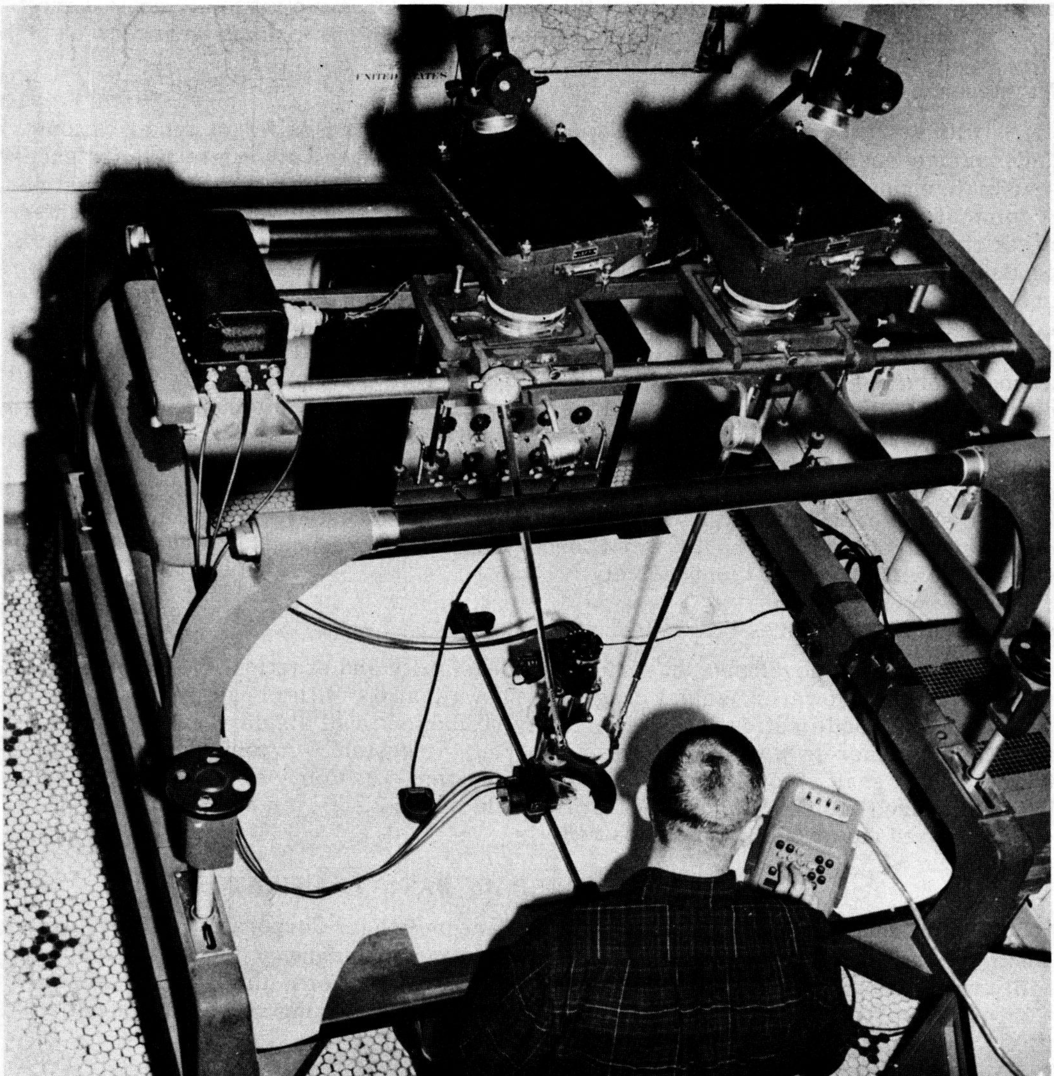


Figure 4. Phototype readout in operational position.

The system is initially set up by aligning the index markers at each end of the modification on the line representing the cross-section. The horizontal counter dial switches (decade switches) are set to indicate zeros, the tracing table is centered over the centerline of the highway and the horizontal reset button is pressed to bring all horizontal counter dials to zero. The centerline elevation is then entered into the vertical counters with their corresponding decade switches and the vertical reset button is pressed. From this point on, for the remainder of the data relating to this cross-section, the counters automatically follow the tracing table's movements. The horizontal and vertical positions of the tracing table at 0.1 ft intervals are visually displayed by the counters at all times and can be recorded by depressing the record button. At each new cross-section the station number must be entered manually into the first card of that cross-section, and the horizontal counters indexed at the centerline. Once the vertical counts have been set they need not be readjusted unless the aerial photographs are changed.

Maintenance

As with any prototype equipment, this system required a number of modifications. Line voltage fluctuations, heat, dirt, and vibration caused the system to require excessive maintenance. On July 1, 1957, the system was subjected to several modifications. A commercial voltage regulator was added to stabilize the input voltage. The counter reset circuit was modified to produce more positive reset operation. Previously the readout circuit would allow recording of data for as long as the record button was depressed, allowing the same point to be recorded over and over again. An interlock relay was added so that one and only one record cycle is initiated per record button depression. The readout circuit also has been modified so that multiple punching in a single column has been eliminated. The original relays frequently failed to make positive contact, thereby not allowing the information in the counter unit to be transferred to the key punch machine. Replacement by modern high-speed, plug-in-wire contact relays has corrected this difficulty. It has been found that the counter unit itself is excessively sensitive to electronic tube variations and aging, causing the counter tubes to skip several digits and at times to rotate continuously from digit to digit without external count signal input. Component changes have reduced these occurrences and eventually will eliminate them entirely.

Other Desirable Features

The system, as developed, has shown the feasibility and practicality of digitizing stereoplotters. However, actual usage has shown that its utility could be increased by several minor modifications. A more easily readable visual display, such as in-line, illuminated numerals would facilitate monitoring the system. A variable scale, rather than the fixed scale, would greatly expand the system's usefulness. The system could be made more flexible if the output format could be variable. An easier method of entering fixed data would also be desired.

THE BENSON-LEHNER TERRAIN DATA TRANSLATOR

A similar system has been developed by the Benson-Lehner Corporation of Los Angeles. Realizing the extensive use of photogrammetry in modern highway design and the feasibility of adopting techniques of digital readout to stereoplotters, the Benson-Lehner Corporation produced the first production machine for digitizing stereoplotter output. Their system is called a "terrain data translator."

Components

The Benson-Lehner terrain data translator is composed of the following units (Figure 5):

1. An electronics unit containing the analog-to-digital conversion circuits, the horizontal position digital display, readout circuits, and format control patchboard,
2. Elevation digital display unit,

3. A horizontal scale, and
4. A control unit.

The functioning of this system is very similar to that of the system developed by the Ohio Department of Highways. Horizontal and vertical axes are digitized by quantizers. Count of the horizontal position of the tracing table is kept in the electronics unit, which also contains a patch board for controlling the output format. Fixed data can be entered into the output by means of the control unit.

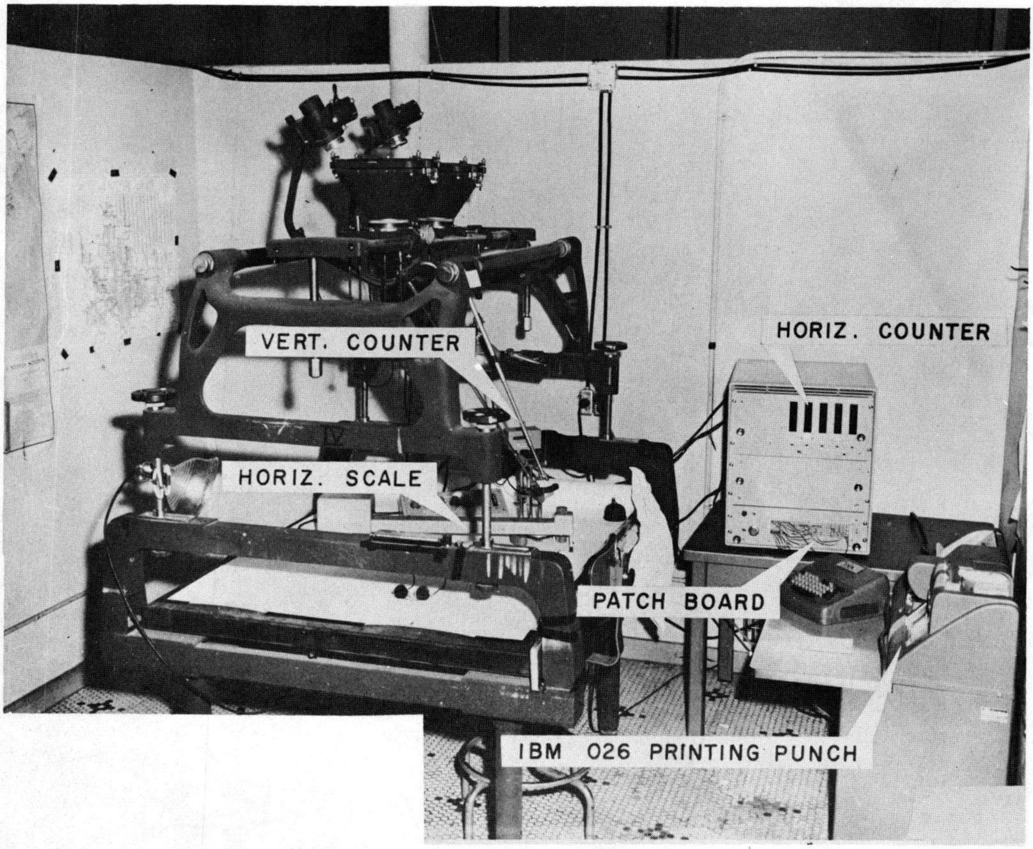


Figure 5. Benson-Lehner terrain data translator.

Because this system is a later development than that by the department, it has several additional desirable features. The position of the illuminated numbers is more advantageous for the operator. Plotting at various scales can be accomplished by changing gears. Output form and format can be varied. Fixed data can easily be entered by the control unit. Actually, both the department system and the Benson-Lehner system could be improved by providing larger, and more easily visible and readable numerals.

In general, the operating procedure for the Benson-Lehner system is very similar to that of the department system (Figure 6).

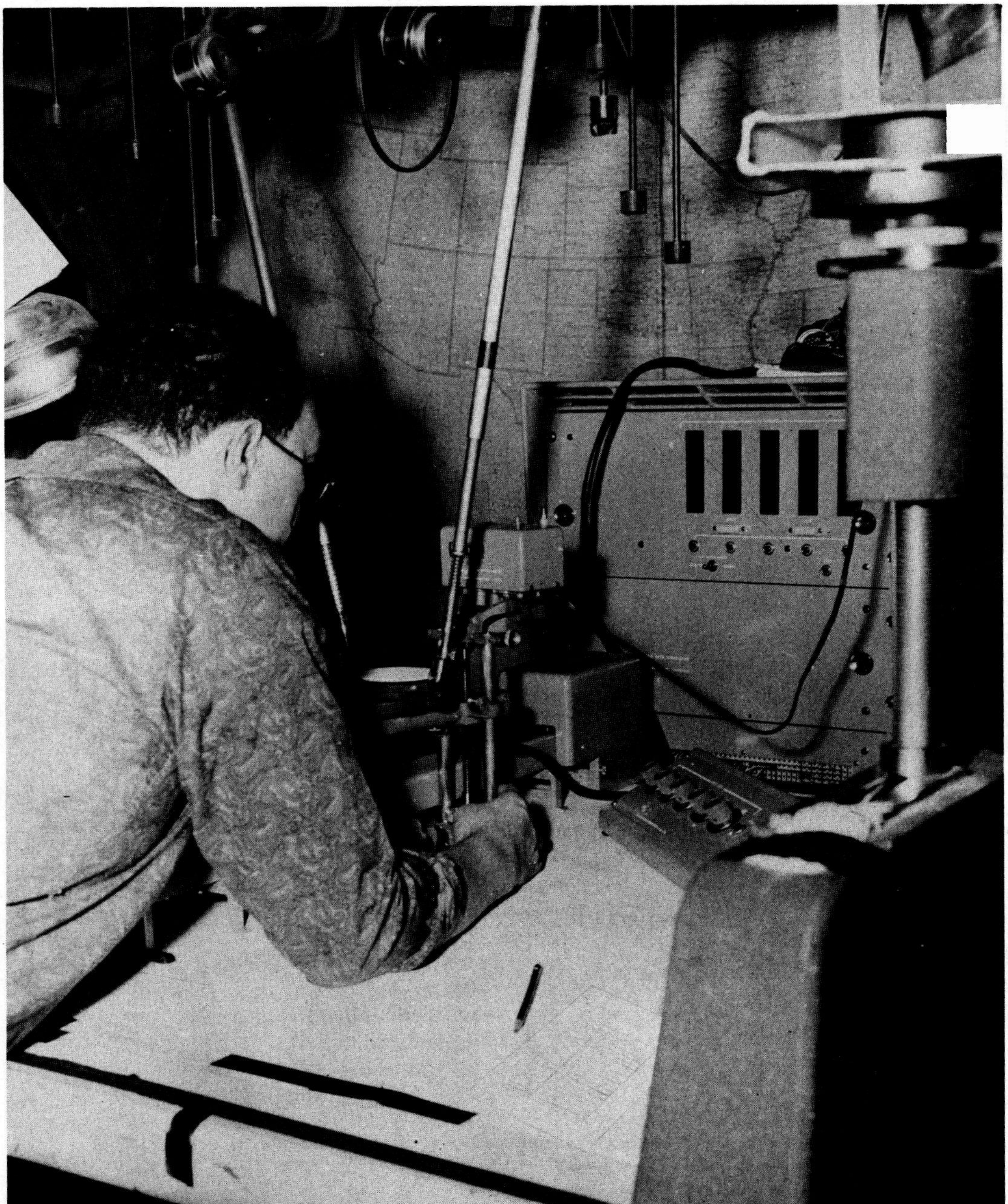


Figure 6. Benson-Lehner terrain data translator in operation.

Maintenance

The Benson-Lehner terrain data translator has been used in production work for only one year, but during this time it was operated on a two- and three-shift basis. Excluding a warranty period during which a number of service calls were required, this system has demonstrated a high reliability, which is a most important attribute of any electronic device. During a 9-month period in which the machine was operated 1,450 hours, only a routine monthly maintenance check was required.

Use of Automatic Readout for Preliminary Location Studies

Some experience has been obtained in the use of the department readout in obtaining terrain data for use in digital terrain model (DTM) programs. Comparative data are available from an evaluation study of the DTM system presented to the Committee on Electronics of the American Association of State Highway Officials in 1958.

This project involved five models in rough terrain, with two DTM base lines. An abundance of points was read in order to establish criteria for frequency of readings and sections needed. Fourteen thousand points were read at a rate of 200 points per hour for a total of 70 hours stereoplotter time. A 5-ft contour map of the area was then prepared in 50 hours stereoplotter time. The same data were then scaled from the map by two men at the approximate rate of 300 points per hour or 150 points per man-hour. The data were then keypunched at the rate of 500 points per hour and finally verified at 500 points per hour.

Data were stripped from this map with the department readout device the rate of 400 points per hour and with the Benson-Lehner at 500 points per hour.

The data indicate that the most efficient method of procuring DTM data is by production of a suitable map and subsequent stripping by automatic readout. The contour map with its multiplicity of uses is made available at less than 2 extra hours per model. The Benson-Lehner machine appears to be more versatile for this work in terms of selection of scales and flexibility of input. A special increment input control might further speed map stripping.

It is advisable to use a terrain edit program following readout with either machine. This is a computer program for identifying errors and checking the validity of punched data. It is emphasized that a distortion-free copy or the mylar plotting manuscript itself be used to avoid adjustment of data to meet grid positions.

Use of Automatic Readout in the Preparation of Detail Plans

Both readout machines were specifically designed for obtaining cross-section data for the preparation of design plans and to do an adequate job. On timed runs, practically identical results (500 points per hour) were obtained with each machine.

Except for periods when modifications were being made, the Ohio Department of Highways' instrument has been in constant service for four years.

Use of Readout for Obtaining Data for Final Pay Quantities

The Benson-Lehner readout has proved to be better fitted to Ohio's method of reading final sections primarily because of its display. Display of both horizontal and vertical readings on the department instrument is similar to the dial display of a gas meter. The horizontal reading on the Benson-Lehner TDT is somewhat similar but the display is easier to read. The vertical display of the TDT is much superior because it consists of an electric counter on the tracing table within the operator's range of reading vision. Because his eyes are covered with dichromatic filters the quickest recognition of readings outside his near vision range is not permitted.

On test runs the Benson-Lehner TDT records at the rate of 400 points per hour, the department instrument at 300.

THE PHOTRONIX SYSTEM

A third system for digitizing stereoplotter output is that developed in 1957 by Photronix, Inc., of Columbus, Ohio. This system, although not used by the Department, deserves mention in this paper in view of its relevance to the area under consideration.

The Photronix system compares favorably with the department system and includes the following modifications:

1. The Photronix system was built to provide a positive zero registration at centerline without requiring the use of a reset button.
2. The horizontal encoder is driven by a steel band rather than a steel wire.
3. All coding is done directly by means of coded discs that are contained within the Gianni readout heads for both horizontal and vertical measurements. Because the encoder for vertical measurement is larger, it is mounted on a trailer behind the tracing table and is geared directly to the vertical screw of the table.
4. The recording device is a flexo-writer with attached paper tape punch rather than key card punch.
5. Station numbers are entered by means of decade switches rather than by keyboard. Other constant data are programmed into the machine.

There are several distinct advantages to some of the modifications contained in the Photronix system. For example, the advantages of a coded disc readout over a digitizer are that: (a) the unit can be moved more quickly, (b) the risk of dropping bits is eliminated, (c) the operation of the unit is simpler because there are no electronic components, and (d) it is virtually maintenance free.

Another desirable aspect of the Photronix system is the use of a flexo-writer and attached paper tape punch rather than a card punch as the recording device.

This results in considerable space saving in addition to providing an immediate tabulated listing of all readings made by the operator.

CONCLUSIONS

Through the processing of vast amounts of terrain data over a period of four years, it has been demonstrated that digitizing equipment in its present stage of development is accurate, dependable, and practical for many applications in photogrammetry.

Data should be coded as soon as possible in order to take complete advantage of machine processing.

The advent of automated stereoplotters will greatly extend the source of digital terrain information.

Finally, there is a need for simpler, inexpensive coding devices, such as electric counters, that can be used with existing punching equipment for specialized work, such as stripping data from maps and recording comparator measurements, survey data, and readout from stereoplotters.

Discussion

G. P. KATIBAH, Supervising Photogrammetrist, California Division of Highways—The California Division of Highways has purchased an Auto-trol digital scaler, Model 3900, for the purpose of recording photogrammetrically made measurements directly on IBM cards. This instrument was reported by D. E. Winsor at the annual meeting on January 12, 1961. At present the scaler is being used on a State highway improvement project for the conversion of an existing two-lane facility to full freeway standards. Throughout the length of this 9-mi improvement, cross-sections will be measured photogrammetrically for a distance of 200 ft each side of a calculated centerline. The cross-sectioning interval is 50 ft, plus cross-sections at the additional breaks along the centerline.

The terrain is open, rolling, grass lands for the most part. The western portion of the project abruptly changes into cut-up tailings, the remains of past hydraulic and dredge gold-mining operations. This portion is a small percentage of the total project, but is covered with scrub oak growth and is therefore expected to present a photogrammetric problem. For a very short distance, the eastern portion of the project is covered with chaparral growth, which will also present a problem. In general, the area is considered ideal for a "first try" with the new cross-section measuring and digital recording equipment.

Throughout the 9-mi length, a planimetric map will be made on mylar material for the total 400-ft width. Complete topographic maps will be compiled at 6 interchange locations.

The photography has been taken with a 6-in. Zeiss 15/23 camera at a scale of 250 ft to 1 in. Stereomodel scale in the Kelsh stereoplotter is 50 ft to in. A horizontal control baseline was established throughout the entire length of the project, with points targeted every 400 ft on the approximate flight lines. The elevation of each targeted point was measured by surveys on the ground. With the exceptions of the short sections at the very western and eastern ends of the project, wing points were also targeted. Wing points in the very western and eastern ends were images of natural objects selected and identified by a photogrammetrist.

This is California's first experience in attempting an integrated project with the Auto-trol digital scaler. Some initial difficulties with the equipment have been encountered that are being corrected by the manufacturer. The instrument is capable of extremely rapid operation. It is anticipated that, with further experience, a large volume output should be fairly routine.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

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.