*Special Measurements by Photogrammetric Methods**

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ABSTRACT: *The planning, location, and design of modern highways is the cooperative effort of many engineer specialists and groups of experts progressively adding their bit until finally a project is ready for construction. Of course there is no substitute for training and experience, but to each highway engineer specialist involved, photogrammetry offers a means of adding to the basic data needed for making sound decisions.*

This discussion of the uses of photogrammetry is limited to applications within the Ohio Highway Department's Division of Design and Construction, of which the Aerial Engineering Section is a unit.

INTRODUCTION

THE design and construction of a highway can be divided into 5 easily recognized phases:

1. Initial studies, which are reconnaissance surveys.
2. Preliminary Surveys and Design of a Location on the Route.
3. Location Surveys and Final Design.
4. Construction.
5. "As-built" Surveys.

In each phase, data from aerial photographs can be utilized so as to permit more complete and economical engineering.

To indicate the interplay of data from aerial photographs with survey and design, consider present typical steps in the development of plans for relocation of a major highway.

INITIAL STUDIES

During the period of making the initial studies, the planners—highway locators—are concerned with highway systems and terminal points as dictated by the origin and destination of traffic. Their interests are primarily with area and they must necessarily be given small-scale maps and stereo prints. More detail would be confusing. For Ohio small-scale means 1/10,000 to 1/24,000 stereo prints and maps. The new topographic maps made and published in quadrangle sheets by the Geological Survey, using photogrammetric methods, are ideal.

Available photography is sometimes used. However, since there may be many changes in land use within the area, new photography can be obtained at any season of the year because foliage does not detract heavily from its use at this stage.

These maps and aerial photographs are brought photographically to a common scale, usually 800 ft. to one inch. Although surprisingly accurate estimates can be made using small-scale stereo-prints, the fact remains that the primary interest is the determination of general routes for additional study and comparison. Other agencies of the department are requested to furnish such as road inventory sheets, sufficiency ratings, maintenance records, accident reports, traffic studies, and traffic volume and cost estimating data.

From this information a reconnaissance survey report is made. In this report several alternate routes are presented on the photographs, along with profiles and grades based upon elevations from existing topographic maps, stereo inspection of the photographs, and data from old plans. Data on the existing routes in the area are presented in diagram form. Decisions as to

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the design speed, roadway cross-section, and maximum grades, and curves are made. The several alternate routes are compared for over-all economy including capital investment, maintenance and benefits to the road user. A proposed route location is then selected. This is broken down into workable projects and each project is assigned a priority.

When complete, the report is turned over to the various highway officials for their consideration, and approval. They use it to coordinate the proposed work with other projects over the state and include it in their future planning. It is necessary that long range planning and programming take into account the season for obtaining fully satisfactory mapping photography.

Preliminary Surveys

In rough terrain good location work requires a map having a contour interval of about five feet. This can be attained by photogrammetric methods at 200 ft. to one inch with sufficient accuracy. A single strip map at this scale contains generous lateral coverage for projecting and comparing alternate locations along the route.

To give the map horizontal accuracy for refinement of location, a traverse is usually run through the area of the proposed route. This is tied to existing government control where available, otherwise the azimuth is checked by astronomical observations at approximately 5 mile intervals.

In very rough country the traverse is commonly a short base triangulation-net, with stations at approximately 2,000 foot intervals, from summit to summit.

Horizontal and vertical-controls are established simultaneously. Vertical angles are read to wing-points on the photographs and the corresponding horizontal distances are later scaled from the map manuscript for elevation determination.

It is desirable that new stations and existing control be signalized with cheap muslin for positive identification. This is done as soon as hubs are driven so that the flight can be made at the first opportunity. Actual survey is sometimes delayed several weeks.

Aerial photographs are taken at a scale of 800 ft. to one inch, with a precise $8\frac{1}{4}''$ Cartographic Camera. This general purpose camera is well suited to provide the range of mapping scales needed in Ohio, and simultaneously to provide the required image size at contact print scales. Since more than 90 per cent of all present mapping consists of strips and single models, ample width of coverage and a convenient working size model are the important criteria. The same mileage of horizontal control is called for under any mapping system, if it is assumed that a ground-traverse is needed along the route. The mileage of leveling needed for excessively large models may actually be more.

After processing and indexing, stereo prints and a strip mosaic at a scale of 800 ft. to one inch are made. As control for the mapping at a scale of 200 ft. to one inch becomes available it is plotted by coordinates on large rolls of stable plastic or top quality drawing paper. Whenever it is economically feasible the state system of plane coordinates is used. The models are then plotted directly onto this base. The location engineers are given the opportunity of viewing the stereo models during the map plotting period. After plotting, the map is photographed and a precise paper-intermediate is made by dry-process reproduction so as to avoid inking.

Depending upon the use of the map, it is possible to dispense with much of the ground-control. Stereo models may be bridged graphically or analytically between widely spaced known ground survey data to provide both horizontal and vertical-control for all intermediate stereo models. Also by relaxing the specifications for the finished map it is possible to expedite plotting.

Since we have proved to ourselves that the highway location projected on maps can be accurately placed on the ground by reference to points of detail without tying to coordinated control, we have lately questioned the economy of running a traverse before finally selecting the location.

The essential elements of control are provided if only the relative positions of points, such as the lengths or the orientation or the slopes of lines are known, together with an occasional elevation for indexing. This floating-line method of control allows mapping to proceed concurrently with control extension. Maps made by this method, by bridging or by control obtained from stereo models of higher altitude photography have been used for preliminary survey and design with apparent success.

Preliminary Design

Once the design standards have been established the engineer of preliminary location lays out several probable alignments for the highway on the map. Each alignment is stationed and a profile is made by plotting the elevation of each contour where it is crossed by the projected alignment. A grade line is laid on the profile and the proposed typical cross section for the highway is put on the ground-line cross sections.

After adjustment horizontally and vertically the alignment of each location is examined with regard to drainage, intersections, right-of-way, total cost, and road user benefits. The best alternate alignment locations are selected for cost comparison. These alignments are then replotted on a second print of the map. The traffic lanes are shown and sketches of important intersections are made along with their profiles and grades. The location and approximate size of culverts are determined. The extent of any channel work is also shown. Preliminary design work on large structures may also be done in conjunction with the Bridge Bureau.

For making cost comparisons, grading contours of the highway-to-be, based on the recommended grade, are super-imposed on the map. Amounts of cut and fill are determined by planimetering areas of horizontal sections defined by each grading contour and the original ground contour, and multiplying by the contour interval. This method gives a graphic picture of the finished highway from which work limits, lengths of structures, extent of seeding, as well as right-of-way and grading, are determined.

After the proposed location alignment and its various details have been plotted on the map, photographic exhibits are prepared to help in considering the proposed project.

Location Survey

Since a staked centerline is necessary in the early stages of project location and later for construction, it is necessary to transfer accurately the selected location alignment to the ground. This can be done:

1. By scaling coordinates of alignment points on the location from the map and tying these points to points on the previously signalized base line, or
2. By scaling reference measurements on the map manuscript which will serve as control for determining the position and direction of each of the various tangents.

It is now the usual procedure for a survey party from the Photogrammetry Section to use this second method to stake points on the tangents. This is done by setting up an instrument on points commanding a view of as much of the entire tangent as possible, and by using radio communication and balloons or flares to set additional stakes on line. In this way no changes in the intended alignment are introduced by poor instrument work, and the best possible fit to the designed location is obtained. It is therefore important for the engineer to indicate on the map the physical control features used by him in designing the highway alignment.

Field crews then project the tangents to intersection, measure the deflection angles and stake the whole alignment with its curves on the ground.

A field check of the skeleton location staking is made during the early stages of centerline running. Then the alignment location is approved for completion of the staking. The centerline is signalized at 300 foot intervals together with PI's and curve points; bench marks are set and profile levels are run. The signalized stations on the actual centerline provide excellent vertical and horizontal-control for the low-level photography; while it is used for the location survey mapping also it is an exact guide to the photographic crew.

After notification that signals have been set aerial photographs are taken at a scale of 200 ft. to one inch. Prints for control identification and diapositives covering the entire project are made. The centerline is replotted on map manuscript rolls at a scale of 50 ft. to one inch for planimetric mapping and is traced on narrow rolls of linen for cross-sectioning. Profile elevations are labeled on this roll from ground surveys to provide a local index if needed for measuring cross sections photogrammetrically. Site-plans for the project with contours on a two-foot interval are plotted first, then the planimetry is plotted and X-sections are measured and recorded. All cross sections are extended well past any possible Right-of-Way line. Elevations that would be taken if the cross sections were measured in the field are read with the plotter. The attempt is to present the data to the designer in a manner similar to notes taken in the field.

Contours are delineated to the extent necessary for each drain that would be a factor in design, as are interchanges and other areas where detailed data are required for design purposes.

Alignment sheets on linen are traced from the plotting manuscript. Before tracing, site plans are precisely ratioed to a scale of 20 ft. to one inch.

Design Computations

It is probable that changes will take place in design that will challenge those that have occurred in construction. As engineers make full use of the potentials of modern electronic computers, automation will ease the enormous labor of detailed design and will bring refinements now impractical of realization.

By developing auxiliary equipment and a comprehensive card program, steps have been taken to wed the potentials of photogrammetry and electronic computing.

We have just put into use on the first job, auxiliary equipment for recording stereoscopic plotter data directly to cards. It consists of a device to restrain the floating mark to a given X-section line and to provide a distance output, plus electronic units for operating a visual counter and a printing punch.

By indexing first on the C_L station and setting the floating mark in turn on each break in the X-section, readings are punched into cards by depressing a switch. At the same time readings are printed at the top of the card to provide easy identification. All readings are measured and punched to one-tenth foot.

A computer section is being set up centered around an IBM model 650 computer. For the past several months work has progressed on programming the complete design problem.

The computer programs that have been worked are:

1. Profile grade computation with vertical curves.
2. Edge of pavement elevations computation for superelevating roadway.
3. Section templet design
4. Earthwork computation and related quantities.

The programs that we contemplate developing in the near future are:

1. Data assembled from profile-grade and super-elevation programs to provide data for design program.
2. Ditch design.
3. Culvert design.
4. Bridge design.
5. Aerial triangulation.
6. Survey computations.

Miscellaneous Applications

Controlled-scale photography has proven to be very useful in flat or level country and particularly so for widening and resurfacing projects. The procedure for this type of project is as follows:

The centerline is run and signalized.

The project is photographed at a scale of 200 ft. to one inch.

The signals are then identified on contact prints, and the curves are plotted at a scale of 50 ft. to one inch from the control furnished. The film is then enlarged to the same scale and rectified to fit the control. Each final printed enlargement is made on water resistant paper to provide dimensional stability. The planimetry is traced from the enlargements onto cloth for preparation of alignment sheets of the construction plan.

Where there is no change in line or grade the earthwork is paid for by station-to-station grading rather than by cubic yards. Right of Way is acquired by taking a strip of sufficient width to accommodate the proposed work rather than by metes-and-bounds description.

The Right-of-Way Section has found aerial photography to be very helpful.

Negotiators experience less resistance from property owners when they are shown a photographic enlargement of their property with the proposed location, right-of-way line, and work limits indicated on it.

Photographs are used in appropriation cases. The jury is able to see just how the property looked before construction was started.

From time to time we are requested to map certain areas for damage claims. A large-scale map is now being made to determine the quantity of gravel in an esker appropriated for highway right-of-way.

For public hearings, mosaics showing the proposed location and oblique photographs with the artist's conception of the proposed project, are very useful. Oblique photography is often used to show conditions before and after. They are also used to show projects under construction. Some projects are photographed periodically to show progressive developments.

The Bureau of Traffic uses aerial photographs in its traffic studies of roadway facilities and the movement of traffic on the facilities. The principal use has been to obtain an over-all view of the traffic movements and the physical conditions which affect those movements in the area surrounding a point where traffic is experiencing difficulty. Also, photographs have been used to obtain specific information that could have been obtained otherwise only from time-consuming field surveys.

Limited and controlled access projects are photographed to compare the access of one date to that of a later one.

The Research Engineer makes use of aerial photographs to study experimental pavements. Pavement failures, cracks and pumping are readily observed from 40 ft. to one inch scale photography and are helpful in comparing sections.

Construction

The contractor has a very limited time to prepare his bid. He therefore welcomes any materials that will aid him in the job investigation and increase the accuracy of his estimate.

Large-scale maps, vertical photography, mosaics and pictorial views are made available to him and have the effect of bringing the job to his office.

Some contractors now employ soil engineers who have been trained in the photographic interpretation of stereo-pairs for determining probable locations of classified embankment and subbase materials. In conjunction with the location map the contractor can locate sites to obtain borrow at convenient locations, obtain approval for its use, and estimate quantities. This is important in Ohio since the taking of borrow within 500 ft. of the right-of-way, without approval of the Director, is not permitted.

Final Sections

As soon as the contractor has completed fine grading and seeding, final sections can be requested. At this time the centerline is again signalized together with other permanent marks unaffected by construction. It is always important to consult with the project engineer before attempting signalization. The flight can be made at any season since the line is cleared, but must be made on the first photographic day and must be designed so as to secure illumination on the slopes of deep cuts and high fills.

The original plotting manuscript is used to scale the models and a duplicate of the original cross section overlay is prepared. On this is indicated the edge-of-pavement or other control elevations, and the work limits as indicated by the design sheets. The plotter operators plot to at least this line and as much farther as indications of earth movements dictate. The sections are immediately measured and plotted on to black-and-white copies of the design cross-section sheets to check tie-in edges of sections. All sections are measured to attain an accurate record of construction "as built" whether needed for payment or not. The extent of seeding, pavement removal, borrow and other pay items are plotted on the manuscript and turned over to the construction engineer for determination of pay quantities.

The original control can be used if it lies outside the area of construction provided re-orientation can be established. This means that at least 2 points of permanent detail or position must be identifiable. This will not be much of a problem if the center line of the design flight was marked on the ground before the photographic flight, as is our practice.

General Notes on Large Scale Mapping

Large-scale map plotting, as for design and final cross sections, is attended with special problems not encounted in ordinary mapping. All operations are conducted near the optical and physical limits of the equipment. Limiting conditions of flight-height, shutter-speed, camera-aperture and cycling time, space rods, plotting table extensions and optical projection are encountered. In addition plottings are usually scheduled in terrain so difficult that ground methods are impractical. The construction C_L will often be set on steep hillsides overlooking extensive water areas, or will be located in deep V-shaped valleys where correct clearing of parallax will be ambiguous due to the model area lying on or approaching the "critical surface." In such areas correct parallax solution is difficult without reference to the elevations of control points in the corners and centers of the stereo-models. However, elevations in corners may fall in water or on densely wooded hillsides. In the latter case cloth signals provide missing wing-point detail. In all other cases natural details for wing-point control are preferred because of their permanence.

A useful method of improving stere-model set-up is the use of the typical model deformations caused by residual errors of relative orientation. This is especially true of large-scale stereo-models where cross-tilt is indeterminate due to location of parallax-clearing points near the critical surface of the model. In such cases the stereo-model can sometimes be intelligently brought into correct shape usually with no detriment to the correspondence of images, perhaps indicating incomplete original clearing of *Y*-parallax.

With $8\frac{1}{4}$ inch focal length photography, critical surfaces are encountered in the stereo-models when the elevations of wing orientation points of a typical valley situation are 15–20% of the flying height greater than the valley elevations. If elevation differences are 250 ft. then it is seen that critical surfaces may be encountered at the usual flying height for mapping at 50 ft. to one inch scale.

It would appear that numerical relative orientation might be helpful in setting up these stereo-models. So a trial of one numerical method was made. A precise dial indicator was installed on one of the plotters for reading *By* differences of parallax. Procedure followed methods outlined by Tewinkel. It was concluded that the results obtained were not better than by improving correspondence of images by the usual procedure. The method was time-consuming and uneconomical.

Numerical orientation does however provide a method of logically distributing non-removable parallaxes, but care must be taken to use valid formulas if large variations of ground elevation are to be encountered.

Conclusion

From time to time in history science has provided mankind with excitement and new vision. These are not necessarily occasions of basic discoveries but of disclosures which touch the imagination. The world became new with the telescope, the microscope and with X-rays. Today it seems we are in such a phase of history, with not one but a series of novel disclosures.

Some of us were eager practitioners of photogrammetry at the founding of this Society. Now less than twenty-five years later, we have ceased to feel completely at home; everything has become so new. When formerly someone would suggest analytical space resection, we would quote Von Gruber, "the calculation of resection in space either by the direct or the differential method is merely waste of time and is of minor practical importance." Today perhaps Von Gruber would object to being so quoted. We now do not have to waste our time with the calculations. The problem has been reduced to a study in vectors and is nicely programmed for our computers. It only remains for us to supply reasonable data. In the past we have avoided difficult problems as we would avoid predicting which way the cat would jump. But given a reasonable acquaintenance with facts we discover that there are laws of cat jumping.

With increasing frequency we will be called on to try new methods of doing our old jobs. We must come to appreciate the excitement of our times, and, in fairness to ourselves, give the new a fair trial.

MR. PRYOR:

Mr. Herd brings to mind a paraphrase that I might make from the Good Book. I believe it goes something like this: "You receive no witness until after a trial of your faith." Apparently, Mr. Herd has had his faith tried strongly. Now he is a witness of many of the things that can be done. Also he is looking forward to other trials of faith so that he will have further witness of things that can be done to pass on to you.