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

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

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

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

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

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

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

The original cross-section (terrain data) is thus automatically punched onto cards by the Kelsh plotter operator. The terrain cards, along with other cards containing basic information for the proposed design section, are then fed into an electronic computer for development of coordinates of the proposed design section. The first step of calculation deals with roadbed information between the outer limits of the outside shoulders. The proposed section between these points falls into three primary conditions; i.e., normal crowned section, superelevated right, and superelevated left. By entering the coordinates for the three conditions into the memory unit of the computer and assigning each a code number, the appropriate section can be applied to each station. For develop-

ing the design template beyond the shoulder the computer is scheduled to select the proper backslope and embankment slope ratios, based upon the height of fill, the depth of cut, and other predetermined conditions. For sections that are not identical to the coded sections already introduced (such as widening or narrowing of median on 4-lane divided pavements, transitions from 4-lane divided to 2-lane undivided, spill-through slopes at bridge abutments, acceleration lanes and deceleration lanes, and interchange ramps) coordinates are entered for each individual section. However, once the coordinates for such conditions are worked out, each set is indexed and used repetitively in like conditions. Thus, the computer develops the basic design data into a complete set of coordinates for the design template at each station, disregarding special ditches, special benching, unusual cut slope, etc.

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

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

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

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

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

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

General Discussion

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

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

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

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

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

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

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

L. L. FUNK, California Division of Highways, Sacramento: Yes, checks are made of practically all of the mapping contracts by running profiles on them. In general, they comply with the accuracy specifications, which are within 90 percent within a half-contour interval; in the case of 2-foot contours, that would be 90 percent within 1 ft. As to comparative quantities, there are probably ten or twelve projects on which percentage comparisons have been made between preliminary quantities by photogrammetry and final quantities by ground survey methods. On six projects those differences were less than 3 percent; in several cases they were less than 1 percent; in other cases they have run as high as 5 or 6 percent. It should be noted, however, that this is a poor way of

expressing it, because in a 100-ft cut a ½-ft difference between the photogrammetric ground surface and the field survey ground surface means little, percentagewise, whereas in a 2-ft cut it would mean much more. In any event, the percentage is far less in error than the estimate of shrinkage factor would be. Furthermore, there is some ground for question in a lot of cases, particularly in rugged terrain, as to whether the photogrammetric or the field survey quantities are right—the field cross-sections could be in error too.

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

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

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

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

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

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

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

R. D. MILES, Purdue University, W. Lafayette, Indiana: In the highway field or in a highway department it is not really economical to set up a large photogrammetric

organization. A large organization would require having expensive cameras, running anywhere from government surplus cameras at $3,000 up to the new cameras that cost as much as $20,000 each. The type of photogrammetric equipment required to be used with them can run into first- and second-order instruments, which are very expensive. The highway department primarily should contract for the larger projects with the companies that have distortion free cameras and the first-order types of plotting instruments. On the smaller projects, such as site plan preparation and small location problems, maps can be obtained within the highway department by using the government surplus cameras and the Kelsh plotter, or some plotter like that of single model type.

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

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

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

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

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

WILLIAM T. PRYOR, Bureau of Public Roads, Washington, D.C.: Mr. Radzikowski, of the Bureau of Public Roads, who has headed the work of the Bureau in developing the use of digital computers in conjunction with photogrammetry, is intending to work out and effect a plan whereby he will have a record, if not the actual program itself, of the kind and location of all programs developed for highway engineering purposes. He in-

tends to request cooperation in establishing a procedure for obtaining and distributing information on all electronic computer programs prepared for highway engineering purposes. The record would be useful in avoiding duplication of effort and perhaps pointing the way to adaptations that could be made to fulfill new needs or to programs that someone else has already worked out. Either of these would probably involve less effort than would the preparation of an entirely new program for the digital computer.

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

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

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

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

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

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

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

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

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

quirements as to accuracy and a stability of the material to hold scale over a long period of years.

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

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

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

Prints of the original can be made on any material adequate for an engineer's use. First, however, a plane coordinate grid must be placed and scribed on the manuscript, its values having been accurately adjusted for scale and elevation so as to apply at the average elevation of the survey project. In other words, the state plane coordinates are lifted up to the level of the area where the highway survey is made. There are two corrections necessary to make state plane coordinates apply along the preliminary survey of a highway route not at sea level. One is called scale correction, which is obtainable from the U. S. Coast and Geodetic Survey; the other is the correction for elevation above sea level. Elevation correction factors for aerial surveys and photogrammetric highway mapping have been prepared by the Photogrammetry for Highways Committee of the American Society of Photogrammetry and the American Congress on Surveying and Mapping, and were published by the U. S. Government Printing Office in 1956. Dividing the elevation correction factor by the scale correction factor gives a combined correction factor that will lift the basic horizontal control up to the level of the survey, give accurate coordinates for control survey station markers, and cause all distances measured on the maps to agree by scale with horizontal distances measured on the ground. It really would not matter then what the map reproduction material is, because if it shrinks a little or expands a little all map details which were previously positioned accurately on the scale-stable manuscript will retain their relative positions. Therefore, adjustments can be made mathematically for map detail in relation to the coordinates. This can be done to allow for scale changes on map reproductions when the highway alignment is being computed or any other position determinations are being made on the map. Accuracy then is commensurate with the compilation—and that can be accurately done at map scale to within about 0.01 in. for the plane coordinate grid lines, about 0.025 in. for most contours and points or lines in the planimetry, and about 0.05 in. or less for not over 10 percent of the map detail.

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

JOEL D. ARON, International Business Machines Corp., Washington, D. C.: Various training course are offered at no cost to the customer who has the machine on order or installed. In the case of the Federal Government, the meaning of that phrase is extended to include training for all members of the Federal Government, because some part of the Federal Government does have machines installed. It is reasonable to assume that the same would be the case for a state government; if a machine is installed in the state government, but not in the Highway Department, the highway engineers would normally be trained at no cost. A commercial customer can only be trained if he has a machine on order or installed. The training is not sold. This means that a person normally cannot enroll unless his organization (in the broad sense of that word) has

a computer on order. The training courses vary in length from one to four weeks and cover two different major subjects. One subject is, more or less, on "hardware"—what the machine consists of and how the pieces are put together. The other type of course is programming, or how to make the machine work.

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

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

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

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

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

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

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

L. L. FUNK, California Division of Highways, Sacramento: In five projects in which the variation was less than 2 percent, the range was from 0. 11 percent up to 1. 9 percent. The four highest were on 2-ft contour intervals, the 0. 11 percent was on a 5-ft contour interval project which was supplemented with field profiles through level areas where the 5-ft contours would not show up. In all of those, it might be pointed out, it was a case of balancing back and forth, as certain cuts would vary by 10 to 15 percent; the errors, however, compensated.

WILSON T. BALLARD, The Wilson T. Ballard Company, Baltimore, Md.: Is there

any information available regarding design costs by full automation methods compared to conventional methods?

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

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

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

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

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

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