*Electronic Computation of Photogrammetric Data**

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BEING last man on a panel, and especially following the capable group who have preceded me, there does not seem to be too much left to say on the details of electronic computers. You may be interested, however, in hearing of some results of the use of electronic computation and photogrammetric data.

Most of you are aware that highway engineers over the past ten years have become accustomed to photogrammetric maps 1″ = 200′, 5′ contours for studies and preliminary estimates. During this period as the great thruways, expressways and freeways have become known and popular, there has come also the gradual recognition that these designs require consideration of a broad band of topography, rather than the more customary line and profile concept. Indeed, today we find that the desired standards for interstate highways call for roadways completely separated in line and grade and with malls of 100-, 200- and 1,000-foot widths. Obviously, for effective design some medium must be used which will give the designer a picture of the whole band of interest, so that he can see the relation between the two main roadways, the frontage roads, the intersecting roads and streets, streams, railroads and utilities, land use and occupancy; in short so complete that he can see all possible solutions in his search for the best alignment. But a picture is not enough, it must have reliable accuracy both horizontally and vertically. The answer is a topo map, with an average width of about 1,200 feet, widening at intersections and interchanges, and comprising about 125 acres per lineal mile of highway. In these days of tight schedules and shortages of engineering personnel, precise photogrammetric maps have been adopted instead of field surveys. Their speed, detail and uniform accuracy have been proven for their intended purpose. Once an organization has invested in a 2-foot contour photo map, the photos may be made to yield elevations to a still higher degree of accuracy than the contours. This is because a stereo operator is able to read elevations of single spots to an accuracy of 1/5,200 of the flight altitude, whereas to follow the meanders of a contour line, he can be certain to only about 1/1,000 of the flight altitude. In fact, the so-called first-order instruments are rated at 1/12,000 of the flight altitude. If, then, we are plotting 2-foot contours we will have photographed from an altitude of 2,000 feet and have a potential vertical accuracy of 0.4 of a foot to the 0.2 of a foot.

Why not substitute photogrammetric readings for field cross-sections? This thought has occupied a good bit of our time for the past year, and we now feel we have some answers which may prove of interest. Our tests have been centered on using the Wild A-5. This is a first-order instrument. Let us assume that we have a map, and that the designers have laid out the roadway centerline and drawn the lines to be cross-sectioned. Let us return this map to the A-5 drafting table, put the aerial photos back in their proper orientation in the A-5, so that when the operator puts his reference mark in the optical system over a point, the pencil on the plotting table moves over the same point on the map, as it is linked to the floating dot by a train of gears. The assistant on the drawing board guides the pencil over the beginning of a cross-section line, the operator adjusts the floating dot to just touch the ground, reads and calls off the elevation, and the assistant writes it opposite the point marked by the pencil. Co-

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operatively they move the pencil to the next break in grade, repeat the process, and continue to the end of the section. For a 600-foot section an average plotting time is about 20 minutes. You can readily see that no bush cutting is involved, that the floating dot can move up or down changes in grade effortlessly that might require several instrument set-ups to traverse; and, as you might expect, the stereo operator takes many more "shots" than his friend the rodman.

Now having used this alignment of airplanes, cameras, lens, prisms, and gears to eliminate tedious field cross sectioning, it would hardly be consistent to take these cross-sections, plot them by hand, planimeter the areas, and then compute the earthwork volumes. As my predecessors have explained, electronic computing machines can be suitably instructed to compute the area of any given cross section. We believe, however, that their use should not be limited to mere arithmetical answers to a completely stated problem, but that they should actually be trained to take over some of the design of the cross-section. In cooperation with Illinois Highway department and Bendix Corporation, we have worked out a plan for what we are going to call a general program for interstate highways. This program will allow us with a G-15 to leave to the judgment of the computer, within instructed limits, such matters as side slopes in cuts or fills, ditch depths, and location of slope stakes. It will print all this out plus the earthwork volumes. But there is no need to stop there, and this to me is the real economy of the computer. If the earthwork between control points is not balanced on the first try, the designer does not have to go back through the tedious process of shifting the line or grade and recomputing by hand the new volume. He has merely to instruct the computer to move it in or out, up or down, start it up, eliminate the type out of everything except the final volumes, and in a very few seconds he has his new answer. Those of you who have had to design within time limits know what this should mean in terms of searching for and finding the most economical answer.

Now it is logical to ask that if the A-5 or similar instrument can replace field cross-sections for design why can we not also eliminate field cross-sections for pay quantities? This is no matter to be taken lightly, as the earthwork involved in this forthcoming highway program will amount to between 10–25 per cent of the construction value. Those of you in charge of designing these highways and disbursing these funds have a great responsibility to insure that they are disbursed for work actually done. On the other hand, the contractors when they undertake a job have a right to be certain that the engineer's estimate is close, and that pay quantities are correct. I think everyone recognizes at the start that there is no absolutely accurate method of computing earthwork quantities. Over the years we have come to use the so-called average end area method as a compromise accepted by both parties. We believe that for ready acceptance the next step should continue with the familiar average end area method, and hence if we take cross-sections by the stereo plotting machines and compute them similarly to field cross-sections, we are merely changing rodmen without upsetting the familiar computing process.

But if we are going to base these quantities upon measurements made from aerial photographs it is essential that both parties be equally certain of the quality of results to be expected. Now a photogrammetric map is based not upon, as many still believe, an airplane flying straight and level taking a series of photographs which are later reduced by some magical means to contour lines, but rather upon a series of photographs taken from an airplane which may be undulating in flight. These photographs are corrected by a network of precise horizontal and vertical survey points, marked on each photograph which serve to orient the photos in the stereo plotting machines. By means of deliberate procedures based upon the geometry of the camera lens and the plotting instruments, correlated with the ground control, the photos are oriented in the instruments so as to permit the operator, viewing stereoscopically, to plot a map correct in plan and elevation. Now this is a mathematical and physical process, and the results to be expected will be in accordance with the quality of the equipment and basic data used, the height of the aerial camera above ground, and the skill and judgment of the photogrammetrist.

For the owner and contractor to have mutual confidence in the accuracy of the map and aerial photographs from which the cross-sections and earthwork quantities are to be derived, the most authoritative standards recommend that the aerial camera be no higher above ground than 1,000 times the contour interval, and that the enlargement from aerial photo to final map be in the neighborhood of 5 times or less. This ratio should yield a map in which 85 per cent of the contours will be correct to within one-half the contour interval, and none, provided the ground is visible, will be in error by more than the contour interval. In every highway project a baseline is required at some stage of design or construction. We recommend that it be laid in the field during the photo mapping stage so that it will serve to strengthen the map. This costs no more and spreads the baseline's utility over the entire life of the project. The baseline should closely follow the proposed general alignment for maximum utility. For very little extra expense a profile can be taken along the baseline, and will further strengthen the accuracy of the map. Each pair of photos should have four vertical control points set near the corners of the model. Although it is possible to produce photogrammetric maps without this much control by resorting to what is known as bridging, the results in all cases will be inferior to those to be expected when actual field control is placed upon each aerial photograph.

Cross-sections taken by spot elevations in a first order stereo plotting instrument should yield results correct to within, let's say, 0.3 of a foot in elevation, if the photos were taken from 2,000 feet. While admittedly this is not as correct as a single ground-survey reading, the greater number of points taken, the better selection of cross-sections based upon contours of the whole ground, and the uniformity of results over the whole cross-section, in our opinion, make the method promising for use in computing pay quantities. If you will accept this method for computing preliminary quantities there is, of course, no reason why you should not also accept the same method for final sections. It can readily be done by rephotographing the completed project, establishing a little more ground control, and taking the cross-sections in the stereo instrument. Here again, both the owner and the contractor gain. The former gets an as-built plan of the project, while the latter gets the final estimate finished expeditiously, with subsequent payment in full, of his accounts.

Now you are probably saying that this all may sound very well, but what about some actual results. We have run some tests on a short section of highway on Long Island. This is a major project, the Long Island Expressway, and the width of the right-of-way and so forth will be comparable to much of the Interstate System. The test section is only 4,000 feet long, and in relatively minor relief. Our tests include ground cross-sections, cross-sections interpolated from the 2-foot contour map, cross-sections by A-5 spot elevations, and cross-sections by Kelsh-plotter spot elevations. We computed the quantities both by Bendix G-15 and planimeter. The cross-sections were plotted in distinctive colors on profile paper for comparison.

If you should look at them you would see very close agreement among the colored lines which are the photogrammetric sections. The black lines, the field cross-sections, in general fall right in with the other three. But you would also see instances where the black line leaves the others by two or more feet. We looked into some of the discrepancies by recross-sectioning, and found them to be field survey errors, and the correct elevations were found to fall within the photogrammetric values. This survey party was neither the best nor the worst in the business, but just a good average party that you would put on cross-sectioning. I dare say that without the photogrammetric comparison such errors would have gone undetected.

Comparative quantities in this sort of light grading were by field measurements, 134,800 cubic yards and by A-5 spot elevations, 138,900 cubic yards, a difference of 3 per cent. It is possible to say which is closest to the absolute value.

In summary, I think we can say that by using photogrammetry under tight specifications as to camera and stereo plotting instrument quality, based upon really adequate ground control, and used without stretching the permissible flying height of the camera, that reasonable earthwork quantities can be computed. The savings in engineering time and manpower should be substantial.