tions from such accuracy have not occurred in any consistent pattern or location.

NOTES

1. The last two wars have been intercontinental as contrasted to the continental nature of previous modern warfare. In the First World War the one amphibious action attempted was a failure. In the Second World War every action in which the full strength of the participating American Army was engaged began as a beach head activity (North Africa excepted). It may well be that the decisive battles of future wars may occur at beach heads. The cartographer need not consider the shore line in the light of its adaptability for military or other specific purposes. His primary interest and obligation is the accuracy of his presentation.

2. Foreign charts usually refer to "mean sea level" as the origin of their vertical control. The objection to the practice is that the mean tidal level is no physical feature identifiable, as such, on any shore. Knowing the tidal range, it can be delineated stereoscopically provided the foreshore area is covered by half or less of the depth of tidal range. Such a line follows no observable detail. Even where such a "mean sea level" notation appears on foreign maps, the actual shore line delineation appears to follow the mean high water line.

3. Vegetation, man made, tundra, glaciated, etc.; all shore lines follow the characteristics of rock or clastic material.

*The Use of Photogrammetry In Highway Work**

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THE California Division of Highways has utilized photogrammetry (aerial surveys) to a limited extent for the past 25 years. However, our first serious effort began three years ago.

Photogrammetry, especially in large-scale mapping, has been developed rapidly since World War II, bringing substantial savings in cost, time, and manpower. In general, it has a distinct advantage over ground surveys by providing wider coverage and enabling the engineer to see possibilities which otherwise might be overlooked.

Our expanded highway program developed mapping problems faster than the available supply of engineers could handle them by conventional ground survey methods. In conformance with the policy of the Division of Highways in contracting work whenever practicable, and because the transfer of engineers from ground to aerial surveys would not solve our manpower shortage, we contract almost all our photogrammetric work to private industry. We have practically no equipment of our own, and our organization is the minimum required for administration and for checking completed work.

Photogrammetry may mean a lot of things to different people. By definition the word means "the science of obtaining reliable measurements by photography." It can be used to measure the amount of crown rust in grain fields, the size and velocity of stars, or the diameter of microbes. As used in this paper, however, the definition is limited to aerial land surveys and may be considered as an improvement thereon.

Such aerial surveys fall in two general classes: (1) aerial photographic pictures,

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including enlargements, and mosaics; and (2) contour and planimetric maps made from aerial photographs.

The distinction between these two classes of work is important. Aerial photographs are limited in usage, and when used as a map cannot be depended on for accuracies better than 2 per cent under favorable conditions. Under unfavorable conditions inaccuracies may be considerable.

A contour map can be made by conventional methods or from aerial pictures. In general the aerial contour maps show the detail of ground forms more accurately than do plane table methods. Drainage channels, ridges, pipe lines, ditches and cultural details are more easily plotted from the photograph than from the ground itself. The accuracies of aerial contour maps are comparable to those taken by other methods and are within practical working limits.

AERIAL PHOTOGRAPHS

Too often the map users' concept of photogrammetry is limited to aerial pictures only, and these are expected to be accurate without exception. The inherent parallax and differences in elevation of the terrain make for inaccuracies in a picture map, unless extreme measures in costly techniques are applied. Tilt in the camera and weather conditions are the other two main sources of unsatisfactory work. The Los Angeles area, for instance, is difficult to photograph, sometimes for months, because of visibility. When the visibility is improved, high winds are encountered at flight elevations.

Our principal uses of pictures and mosaics are those of the uncontrolled variety which may be produced at only a fraction of the cost of accurate or controlled work. When we want accuracy, the use of contour and planimetric maps is a wise choice.

We are large users of aerial pictures for engineering purposes. Such uses vary somewhat in the several districts, but in general aerial photographs are used on all projects involving changes in alignment or rights of way. Practically all personnel involved in a project prior to construction make use of the pictures for planning and study of the general features for location, drainage, design, materials, and rights of way. Photographs have become a must in dealing with public bodies for route adoption and similar work. Even though our expenditure for aerial photographic work is less than 10 per cent of our total expenditure for photogrammetry, the use demand is greater for photography than for all other work and is probably the portion we could least do without.

Aerial photos are not expensive; the cost starts at about ½ cent per acre and may go as high as $1.00 per acre. Highway projects usually take the form of a strip along a proposed route; not much acreage is involved, and consequently acre prices do not really mean much. Most of our projects cost from $200 to $1,000. Once the pictures are obtained they can be enlarged, reduced, copied and duplicated in many forms at nominal cost. In rural areas they can be used for years, but cities and suburbs are changing so fast that pictures often become obsolete in a few months.

CONTOUR MAPS

Our contour maps fall into two main categories, namely reconnaissance maps and design maps. For reconnaissance maps the contour intervals are usually 10 feet and 20 feet and a strip from one to three miles wide is covered. The maps are used for various route studies and for pin-pointing the located line. Occasionally the final location line is made directly from reconnaissance maps. Ground control is not required and bridging of controls is permitted.

Design maps have two feet and five feet contours and scales of from 50 to 100 feet per inch. One important factor of our design maps is that we obtain ground controls, both vertical and horizontal at intervals of at least ½ mile and often at intervals of 1,000 feet. This control is of second-order accuracy and is additional to controls required by the photogrammetrists for making the map. Such controls increase the efficiency of the map by at least 100 per cent. The controls are used for calculating the located line so that it will fit the ground and will coincide with the topography on which the road was designed. It enables the highway engineer to make a complete set of plans and to let the work to contract prior to staking in the field. The ground control is also used as a basis for right-of-way calculations and serves as check points on numerous occasions during the course of construction.

Such ground control monuments will last indefinitely and may become a permanent record for future work.

Cost data for contour mapping for highway strips during the past 18 months are given in Table 1 as follows:

TABLE 1. COST OF CONTOUR MAPPING FOR HIGHWAY STRIPS

	Cost per mile		Cost per acre	
	Max. Min.	Avg.	Max. Min.	Avg.
2′ contour	$1,640	$847	$15.09	$6.26
at 1″=50′	312		3.28	
5′ contour	878	683	8.47	4.34
at 1″=100′	431		1.88	
10′ contour	771		1.69	1.18
at 1″=200′	198	522	.62	
20′ contour	472		.93	
at 1″=400′	256	359	.23	.54

The per acre costs do not necessarily match up with the per mile costs as width of strip and other factors vary considerably. These figures are handy for estimating programs but are not practical for estimating specific projects.

We often obtain a 20 foot contour map covering an area of from one to three miles wide. After the location is pinpointed, we obtain a 2 foot contour map for a width of 1,000 feet or less.

A good practical map which we have used successfully on projects involving both rough and gentle terrain is to specify the project as a 2 foot contour map, but when the contours fall closer than 10 per inch, all but the heavy contours (every 5th contour) are omitted. This results in 2 foot contours on gentle slopes and 10 foot contours on steep slopes, and still maintains the accuracy of a 2 foot contour map.

We have one going contract which provides for spot elevations obtained photogrammetrically on a 50 foot grid in lieu of contours; this should be an improvement in flat terrain. We also hope to have a set of grading cross-sections plotted directly with a stereo instrument.

Our map accuracy is specified as 1/30 inch for plotting—somewhat below national standards—with 90 per cent of the contours to be within $\frac{1}{2}$ contour interval, except in brush areas, where a full contour interval is allowed. This 90 per cent specification appears to have grown up with the business and probably came up from the small-scale type of mapping. Five foot contours at a scale of 1,000 feet per inch result in about 5 inches per mile, whereas, on large-scale mapping of 100 feet per inch, 1 mile = 52 inches approximately. It is easily seen that the contours must be most accurately plotted. For a long time we despaired of obtaining adherence to the 90 per cent specification, because we were adhering to standard practices of using "*C*" factors. In general on large-scale mapping, the scale of the map becomes the controlling factor rather than the contour interval or *C* factor. We have therefore dropped the use of *C* factors completely and now specify by scale.—Since making this change we have had no trouble in obtaining adherence to the 90 per cent specification. We have also found that numerous contractors, if left to their own devices, will crowd the working limits of their equipment. You who have made ground surveys like to brag about the time you crossed the Sierras using only a hand level and at the end of the line, blinded with the sun in your eyes, you checked out flat and stumbled over the corner stake. Photogrammetrists are human too.

It may be of interest to know that we have discontinued the use of plane-table maps as we have found the plane-table method to be much less accurate than that of photogrammetry. Plane-table maps do not show ground forms as well; several drainage channels are often eliminated entirely; and on flat areas drainage is not properly tied together and often is going in the wrong direction.

The cost of aerial mapping has dropped approximately 50 per cent in the last 18 months. As a service to the Division of Highways we estimate a savings of about 75 per cent in cost over conventional ground methods and a savings of 80 per cent in man power. The man power savings is based on the fact that we do not do all the work; if we could eliminate administration of the contracts and checking the maps, the savings would be 100 per cent. Other advantages are:

(1) The coverage obtained is far greater in width than that obtainable by ground

methods, with the result that location advantages are not apt to be overlooked.

(2) The maps furnish a wealth of data and material from the inception of a project through completion, with a minimum of effort on our part.

(3) Expediting the completion of plans permits acquisition of rights-of-way during the early stages of a new location, and further development within the proposed right-of-way is restricted, a procedure which often saves us large sums in the cost of rights-of-way. Early acquisition also allows us to relieve distress cases; that is, once a new highway route has been adopted the State becomes the logical purchaser of property within the right-of-way area, and a property owner with a home under construction is not desirous of completing the structure, or a home owner who is transferred to another location wants to dispose of his property so that he can buy elsewhere. The availability of adequate maps enables the State to obtain the property quickly.

One of the important values to engineers as users of photogrammetry, is that no specialized training is required. An engineer who can develop projections and quantity estimates from conventional ground surveys can do equally well if not better from aerial survey maps. How the map was made or the data obtained is of no importance as long as the engineer has confidence in the map.

GRADING QUANTITIES

The final result in the accuracy of contour maps is made known as a result of checking of pay quantities for earthwork, after construction. There is usually a lag of from two to five years between the production of the map and the completion of construction; consequently we have only a small number of projects that have been completed through the entire cycle. A few worthy of mention are as follows:

One large project with 5-foot contours was found suitable for projection only, and was unsatisfactory for earthwork calculations which averaged about 25 per cent error. This reduced the value of the maps to us by at least 50 per cent.

On the better side of the picture, a grading project containing 760,000 cubic yards, estimated from a 5-foot contour map, checked out with an over-all error of .11 per cent. The error however was compensating; had the error all gone in one direction, the total error would have been 3.8 per cent. One large cut containing 175,000 yards showed an error of 2.5 per cent. Another project containing 1,200,000 yards checked out with an error of 1.71 per cent on grading quantities.

On another project in rough country of heavy grading, it was necessary to obtain field cross-sections on about 5 per cent of the area.

Our over-all experience indicates that the poor jobs have been very bad and the good jobs have been very good, with little mediocrity in between. The greatest errors in grading quantities occur on light work, and the minimum errors occur on heavy work. Errors within 5 per cent are considered tolerable and compare with errors in judgment of shrinkage factors used in balancing preliminary grading quantities.

In our early days of using photogrammetry, we obtained some good maps merely by relying on the integrity and ability of the firms. We also obtained some very poor work by the same process. We then began soliciting bids from the industry at large and had difficulty obtaining bids, primarily because qualified bidders were already loaded with work; consequently time limits had to be made excessively long. The few bids received were price quotations and could hardly be considered as competitive bidding.

In the spring of 1953, we solicited bids nationwide for a $100,000 project and received only two bids; one from Los Angeles for $95,000; the other bid was from the east at $191,000. Two weeks later no bids were received for a $10,000 project. Since that time several concerns have gone into photogrammetry on the Pacific Coast and particularly in California. This was brought about by the advent of low cost stereo-plotting instruments. In general we have received some excellent work from these small firms with very satisfactory time limits. Our practice during the last three years has been to solicit bids from a large group of photogrammetrists.