Getting from Map to Ground

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Transferring the designed centerline of a highway location from photogrammetrically compiled topographic maps to the ground can be accurately and efficiently accomplished when a system of plane coordinates is used for control of the mapping and for preparation of a mathematical description of the centerline. Accurate surveys on the ground, and/or accurate photogrammetric triangulation, through man made or natural objects or features which appear as small and easily identifiable images on the mapping photography, provide the horizontal control and checks on vertical control for compilation of the topographic maps. The ground position and plane coordinates of each of the surveyed images, and the computed plane coordinates of points of changes in curvature on the designed centerline, are the basic data from which distances and bearings are computed for measurement on the ground. Such data are the essentials for beginning centerline staking and serve as intermediate ties for checking position during the process of transfer of the centerline from maps to ground when the designed location is staked in readiness for construction of the highway.

This paper describes the techniques involved in the foregoing procedures and gives illustrations of their applications in specific cases.

●SUCCESS, or lack of it, in getting from maps to the ground is the yardstick by whicl the quality of maps, especially those compiled by photogrammetric methods, and thei accuracy are judged. The manner in which the maps are used and the way in which transfer of position from maps to the ground is accomplished are seldom, and in som cases never, considered to be the cause of engineers' difficulties.

This paper gives some facts regarding common difficulties which are encountered in getting from map to ground, and methods of eliminating these difficulties. Unless these difficulties are removed, their multiplicity arising from improper use of maps will continue.

The procedures and techniques were developed through the employment of variations in and adaptations from work accomplished on numerous highway surveys. The may be new to many users of photogrammetry and aerial surveys for highways. It is hoped that they will give stimulus for further research and development to devise new and improve old methods and procedures of using photogrammetry and aerial surveys.

OLD METHODS

In the past, essential topographic data for highway location and design were obtained by surveys on the ground and plotted in map form at a scale of 40, 50, or 100

= 1 in. These maps were generally accompanied with a profile of the P-line (pre-
minary traverse) which constituted the base line of the survey. Using such data (often
mited in detail, scope, and accuracy) the location engineer established the centerline
f the proposed highway. Because the topographic data were usually restricted to a
elatively narrow band centered approximately by the P-line, the position-projected
enterline for the highway could not be very far from it. Large displacements from
e P-line could be made only when the field survey crew anticipated the probable de-
rability of a substantial line shift and secured more than the usual band-width of field-
urveyed data, or returned to the field to obtain such data.

While making a field reconnaissance, the location for the P-line was flagged on the
round. Then stakes were set at each 100-ft station, at the intermediate major breaks
ground slope, and at the instrument points where angles in this traverse were mea-
ured with a transit. A profile of the traverse was measured by spirit levels, and
ross-sections were measured for a distance of approximately 100 ft from and as nearly
ormal to it as could be readily determined by the cross-sectioning party. After the
round profile of the P-line had been plotted, a tentative grade line (including vertical
urves) was established for subsequent use in designing the highway. Following all
esirable adjustments in tentative locations for the centerline of the highway—as pro-
cted on the map—so that the entire highway was fitted to the topography horizontally,
ertically, and cross-sectionally, the location centerline (called the L-line) was staked
the ground.

Because the L-line had been designed in relation to the P-line, which existed on
e ground, and because some segments of the L-line and P-line were coincident, and
here not coincident their points of intersection and points of maximum separation were
nown, staking of the L-line in its designed position was never considered to be a par-
cularly difficult problem. Without the P-line to "hold on to," however, the same
ngineers, who successfully staked many miles of L-line from P-line data, seemingly
ecame frustrated and "lost" in transferring to and staking on the ground an L-line de-
gned and delineated on photogrammetrically compiled topographic maps. They miss-
the "holding, guiding hand" of the P-line. Actually though, with a fair understanding
procedures used to compile maps by photogrammetric methods, it is easy to rec-
nize, in essence, that a P-line-like base line does exist, both on the ground and on
e maps, and that the designed L-line may be mathematically tied to and staked from
is "base line" to accurately position it on the ground.

METHODS WHEN AERIAL SURVEYS ARE USED

With the advent of using aerial surveys and photogrammetry in the engineering of
ghways, a significant change in location and design procedures evolved. Through
e use of stereoscopic pairs of aerial photographs, the location engineer accomplishes
major portion of his reconnaissance surveys and route determinations in the office.
s theater of operations need no longer be confined to what he can see on the ground
he trudges from one visibility vantage point to another, but includes all of the broad
ea for which he has aerial photographic coverage. A number of route alternatives
ay be determined and compared, and the best one selected for preliminary survey.
longer is such reconnaissance a one-man operation. Now the talents of specialists
ay be quickly used and the accomplishments of each one of them easily presented for
view and correlation with the work of all others concerned.

In using aerial survey methods, the route is located on the small-scale photographs
they are examined stereoscopically while making the reconnaissance survey. Then
e route is photographed and topographically mapped by photogrammetric methods.
is mapping is accomplished as a preliminary survey in ample detail and at large
ough scale (100 ft = 1 in. or larger) as necessary to design on the topographic maps
use of a spline line and/or appropriate curve templates the best location for the
ghway on the ground. Thus, by use of the aerial photographs and maps, the L-line
cation is fully established so that the highway fits the topography and land use, both
ysically and aesthetically. Consequently the location engineer may move directly
om the photographs and maps to the ground without the intermediate step of P-line

staking. Only after mutual agreement on the design of the highway need the location survey staking of the L-line on the ground, in readiness for construction, be undertaken.

Survey Control

Horizontal and vertical control based on accurate surveys made on the ground and an accurate system of plane coordinates mathematically related to that control are of utmost importance in compiling maps photogrammetrically. Without accurate ground control to insure proper orientation of each stereoscopic model in the photogrammetr instruments, it is impossible to secure maps which meet the necessary accuracy requirements for location and design of highways. For plotting the surveyed control points and establishing the points of change in curvature on the designed centerline, use of the system of plane coordinates assures positioning precision and eliminates cumulative errors in using the maps and in doing all subsequent centerline and other staking. Having the system of plane coordinates based on a statewide network of basic horizontal control that is part of the national network, as established by the U. S Coast and Geodetic Survey, is highly advantageous.

Both horizontal and vertical control points that will be used to control the mapping by photogrammetric methods are called supplemental control, and must be within the route band of topography to be photographed and mapped. Before the mapping photography is taken, a suitable photographic target must have been placed on the ground centered over each point to be used for supplemental horizontal control or such points must be natural objects or features appearing as small and easily identifiable images on the mapping photography which can be easily and accurately tied to basic control points in the project ground control surveys. Each basic control point is preserved in its position as a permanent station marker, which is usually a metal pin or concrete monument centered by a metal tablet appropriately marked to identify it.

The spacing in feet of points at which photographic targets are placed for constitutir the principal supplemental horizontal control along the lengthwise direction of the rou zone of photography should be not more than approximately two times the mapping pho raphy scale expressed in feet to one inch. They should also be alternately on one si and then the other of the approximate center of the route, laterally separated in feet not less or more, respectively, than one or five times the photography scale in feet t one inch. Occasional additional targeted points to serve as basic project control poir should be on or near the center of the route at a ½- or 1-mi interval, centered by a permanent station marker. All other targeted points should be centered by a semipermanent station marker, which may be a tack in a wooden stake driven into the ground to where its top is flush with the ground surface.

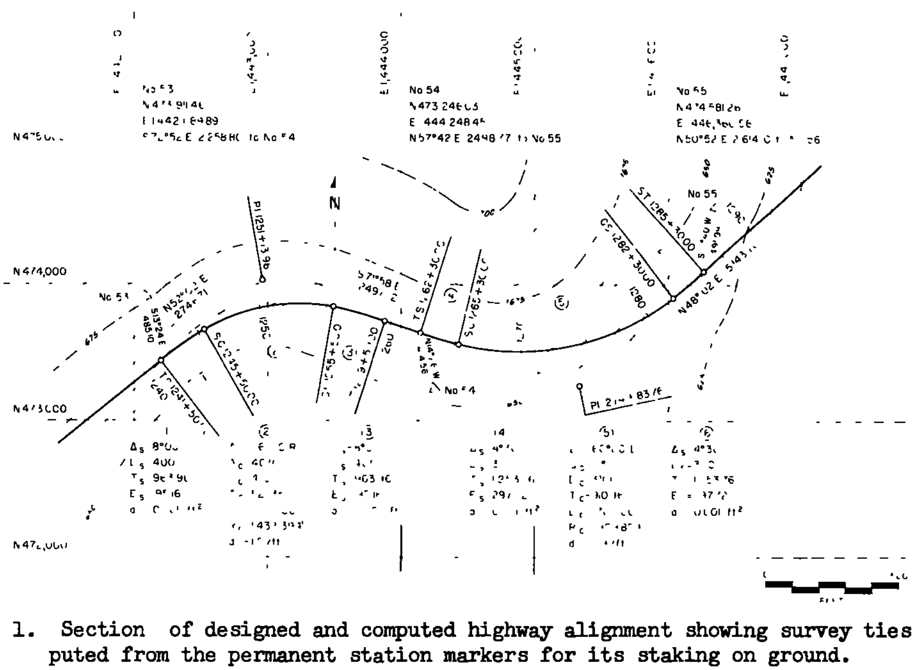
Bench mark levels measured through the horizontal control points may provide a necessary portion of the vertical control near the center of each stereoscopic model. In addition to vertical control thus obtained, the elevation of pass points—photographi image points easily identified on smooth, preferably level, ground near the corners c each stereoscopic model—are also required.

Use of the Surveyed Control

With the plane coordinate grid system constructed on each map manuscript and each ground survey control point plotted thereon in its exact coordinate position, the stereoscopic model from which each segment of the maps is to be compiled is oriente to the control. If pre-set targets are not available and survey station markers do no appear as photographic images on the mapping photography, it is necessary to tie, on the ground, the objects or features which appear as small and easily identifiable images on the photography to the basic, permanent, station markers set and surveye in the project control surveys. These images—for which coordinates have been computed from the control surveys data—are the control points plotted on the map manuscripts to control the mapping. In addition, the position of each permanent station marker is plotted accurately and symbolized on the applicable map, and its plane coordinates are also noted thereon for subsequent use.

With a plane coordinate grid system existing on the maps, the position of each con-
ol point accurately designated thereby, and each point on the designed centerline
athematically computed thereto, cumulative error is eliminated. Also, scaling
oility is improved. This is achieved by interpolation between the plane coordinate
rid lines, and, when done, the effects of changes in map scale are eliminated. The
athematically ascertained position of each surveyed control point is known. An er-
oneously scaled position of the highway alignment, as an L-line, is not used. General-
, the spacing interval of plane coordinate grid lines is 5 in. By converting this
oacing to its ground distance equivalent, the effects of any change in map scale are
oplied immediately to points in the designed alignment, and to any other points, as
esired, during engineering use of the maps. Consequently, the desiged and computed
osition of the L-line is exact.

The coordinate positions determined for horizontal control points on the ground,
hich appear as photographic images on the mapping photography, constitute a base
ne—a traverse similar to that used in P-line surveys on the ground. This base line
xists on the ground and on the maps. The designed alignment is easily tied to the
ontrol points on this "traverse" for transfer to the ground. The distance and bearing
om a control point to the nearest point on the centerline are computed by use of their
ane coordinates. Then each centerline point is staked on the ground—points of change
curvature and other points on the centerline, as the nearest P.O.T. and P.O.C. on
ests and other essential visibility points (Figs. 1 and 2). This procedure is applied
uccessively for all centerline points to be staked, which separately lie in reasonable
roximity to a control point, particularly one of the basic control points. In this way,
ch basic centerline point for instrument occupancy is staked in its proper position
an accuracy possibility as good as the ground survey control on which the plane
oordinates, mapping, alignment design and computations, and centerline staking are
sed. From such centerline instrument points, each 100-ft station and the essential in-
rmediate plus points are line in and measured in their proper position. It is not necessary
actually stake and occupy each P.I. of the highway tangents. Moreover, this method
using computed data for numerous centerline points and staking them from nearby
roject survey control points, rather than only from preceding points on the L-line,
iminates the possibilities of cumulative error in taped distances or measured angles.



gure 1. Section of designed and computed highway alignment showing survey ties computed from the permanent station markers for its staking on ground.

STATION	DIST.	BEARING	COSINE	SINE	COURSE		COORDINATES	
					NORTH	EAST	NORTH	EAST
No. 53							473,911.46	1,442,089.89
	485.10	S 13°24'E	97277588	23174790	-471.89	+112.42		
1241+50 00 T.S.							473,439 57	1,442,202 31
	963 96	N 52°02'E	61520293	78836880	+593 03	+759 96		
1251+13 96 PI							474,032.60	1,442,962 27
	963.96	S 71°58'E	30957024	95087658	-298 41	+916.61		
1259+50.00 S.T.							473,734.19	1,443,878.88
	280.00	S 71°58'E	30957024	95087658	- 86 68	+266.24		
1262+30.00 T.S.							473,647.51	1,444,145 12
	414 56	S 14°26'E	96843832	24925334	-401 48	+103 33		
No. 54							473,246.03	1,444,248 45
	414 56	N 14°26'W	.96843832	.24925334	+401 48	-103.33		
1262+30 00 TS							473,647.51	1,444,145.12
	1,253.76	S 71°58'E	30957024	.95087658	-388.13	+1,192.17		
1274+83 76 PI							473,259.38	1,445,337.29
	1,253.76	N 48°02'E	66869815	74353398	+838.39	+932.21		
1285+30.00 S.T.							474,097.77	1,446,269.50
	491 99	N 10°40'E	98272065	.18509492	+483.49	+91 06		
No. 55							474,581.26	1,446,360 56
	2,614.10	N 50°52'E	63112719	.77567936	+1,649 83	+2,027.70		
No. 56							476,231.09	1,448,388.26

Figure 2. Computation of plane coordinates.

Subsequently, accuracy in transfer of the designed and computed highway alignmer from the maps to its proper position on the ground depends on the initial accuracy of the project ground control surveys, the proximity and accessibility of the targeted station markers of the control surveys to the intended ground position of the L-line, the accuracy with which the L-line, during design, was projected on the maps, and the working accuracy of the field survey party in staking it on the ground. Thus, the positioning and staking of the L-line on the ground are governed by, and related in ac curacy to, the basic control established for and used to control the mapping. Accord ingly, all field work is readily accomplished in a methodical, efficient, and effective manner. Should errors in closure occur, their position, cause, and magnitude are easily determined. Therefore, they can be corrected with certainty. By such use of a system of plane coordinates, accuracy requirements are met in each step of the wo The L-line is actually staked on the ground where position-designed on the maps.

Use of Planimetric Features as Position Control

Attempts have been made by some engineers to transfer a designed L-line from th maps to the ground by relating the position of the line to planimetric features which were plotted on the maps photogrammetrically. Most specifications indicate that 90 percent of all planimetric features, which were well defined on the aerial photograph iall be plotted so that their position on the finished maps will be accurate to within : least 1/40 in. of their true coordinate position, and that none of the features tested iall be misplaced on the finished maps by more than 1/20 in. from their true coordinate ısition. It is evident from these specifications that the probability is remote indeed at a planimetric feature will be plotted precisely in its correct coordinate position. oreover, when the L-line is transferred from the maps to the ground by relating it such features, even if they were precisely in their true coordinate position, there is e possibility that the offset measurement from the feature to the nearest line point ay be in error as much as 2 ft when the map scale is 100 ft = 1 in. This is because ɔility to measure with greater accuracy on a map at this scale is limited.

Worse still is the fact that any misplacement of features used as origin for offset easurement are likely to be additive to the inaccuracy in measurements made on the aps. At the scale of 100 ft = 1 in., the on-the-ground magnitude of errors resulting om the allowed misplacement of 1/40 in. on the map represents 2½ ft and 1/20 in. repre-ɛnts 5 ft. Such displacements enter directly into the displacement of any designed line at is staked on the ground by use of offsets measured from planimetric features equal- displaced (Fig. 3). The solid line in Figure 3 is the centerline in its designed and ɔmputed position. The distances of 80, 104, 84, and 58 ft, respectively, were mea-ɪred on the map to the designed line from planimetric features. The respective dis-ɪnces were then measured on the ground from the objects, for which the true ground sition of each of the features is as shown by their dotted representations, to establish sitioning points for staking the map-projected alignment on the ground. Inasmuch as e map position of the features used were in error, the distances therefrom placed e alignment, as shown in the dashed position, where it is displaced horizontally from signed position, and the central angle at the intersection of the tangents and length the semitangents are larger than computed.

Thus, wherever the position of an L-line point is established on the ground from an ject symbolized as a planimetric feature, which contains error in position on the ıp, it is evident that, regardless of the accuracy with which a mathematical descrip-ɔn of the designed L-line has been computed, it will be impossible by this method to ɪke it on the ground in its designed position. By relating numerous points on the

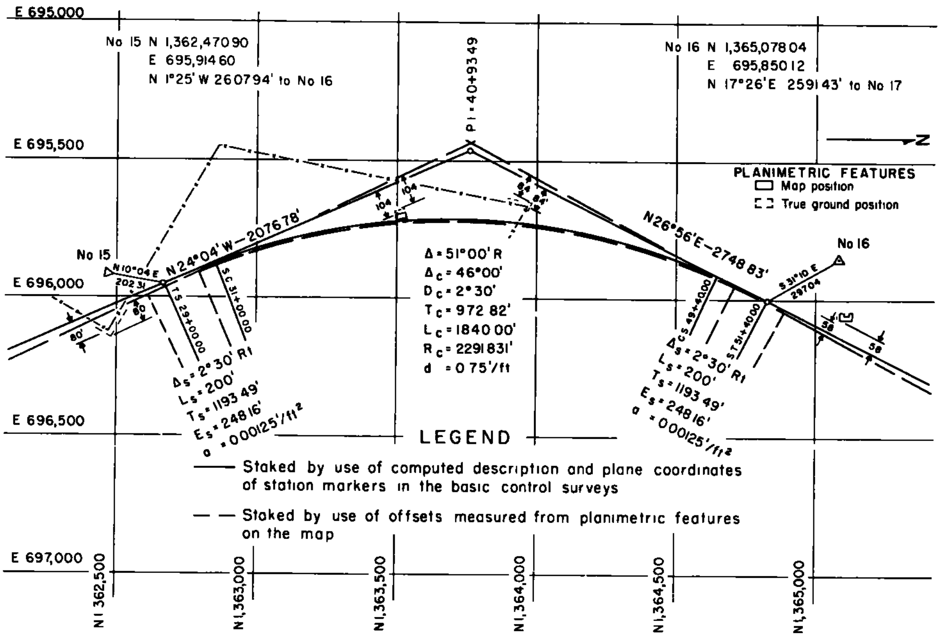


Figure 3. Comparison of staked positions of designed centerline.

designed L-line to nearby planimetric features, it will be possible to achieve only an average positioning related statistically to the average error in position of features used as points of position origin, but the pre-computed curve data, bearings, and distances could not be used. Consequently, the actual positioning of the L-line on the ground would be in variance with the topographic data used, as compiled on the maps.

On the other hand, with the designed L-line tied to control points of known plane coordinates and ground positions, the pre-computed curve data, bearings, and distances are used without alteration, and any error in field survey work while staking the line is quickly determined and corrected by checking into succeeding control point At the same time, frustrations and delays in survey party work, and engineering deficiencies which would otherwise occur, are prevented by eliminating cumulative erro Distances on the ground from an L-line staked in that manner to objects represented by planimetric features on the maps will seldom be the same as distances determined from the map. Differences between such separately determined distances represent the actual error in plotting these features on the maps. If the maps fulfill their accuracy requirements, however, 90 percent of such differences will not exceed the ground distance represented by 1/40 in. at map scale, and the remaining 10 percent no more than the distance represented by 1/20 in.

Use of Maps Without Plane Coordinates

Attempts to project alignment designed on a map not containing plane coordinates have proven hazardous. Generally, in such attempts a protractor or tangent offset method is used to determine the angles and an engineer's scale to measure the tangen distances. On any map at a scale of 100 ft = 1 in., accuracy in measuring and plottin to the equivalent of 1 ft on the ground is difficult to achieve. And it is virutally impossible to determine an angle to an accuracy better than several minutes of arc by such methods, and bearings cannot be established for checking by polaris or solar observation. In addition, it is apparent that regardless of the accuracy achieved in the initial plotting, large cumulative errors will result from changes in map scale, due to shrinkage or expansion of the material on which the maps are compiled, the finished maps drafted, and, finally, map copies produced for engineering use.

Without plane coordinate grid lines having been placed on the map manuscripts and accurately transferred to the finished maps at an interval equivalent to a predetermined ground distance, it is impossible, from map data only, to become aware specifically of, and to determine the direction and magnitude of errors resulting fron any changes in the map scale caused by the shrinkage and/or expansion of the material on which map details exist. Moreover, it is unlikely that any errors may be isolated, or even discovered, until an attempt is made to stake the L-line on the ground. Then frustrations and blaming of the maps begin. Seldom is the real cause—imprope use of the maps—identified.

CONCLUSION

The procedures and techniques advocated in this paper for transferring a designed L-line from a photogrammetrically compiled map to the ground have been used succe fully for many years on thousands of miles of highway location. Nevertheless, achie results, as for any similar survey, are dependent on the accuracy with which the designed alignment is projected and its plane coordinate positions are computed on the maps, and the accuracy of the field survey party in staking the L-line on the ground. In no way are inaccuracies in basic control eliminated, but they are easily localized and corrected where they occurred because the effects of cumulative error have been eliminated.