

Adjustment of State Plane Coordinates

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The system of plane coordinates established on sea level datum by the U.S. Coast and Geodetic Survey for each state is an excellent, unified method for coordinating and preserving all types of surveys, whether plotted to small or large scale. Most of the distances, however, from coordinates on maps controlled by and compiled on such a system, will not agree with distances on the ground unless scale corrections are applied. This effect becomes especially consequential wherever the maps are compiled at large scale.

To circumvent the need for correction of each map distance, as it is used for engineering, cadastral, or other purposes, it is easy to compute project coordinates by use of a combined scale and elevation adjustment factor applied to the system of state plane coordinates. When this is done before the mapping is accomplished, there is no need for scale correction because differences in coordinates and distances on the maps will agree with horizontal distances measured on the ground. Whenever state plane coordinates at sea level datum are required, they can be computed from the project coordinates by reverse use of the adjustment factor.

The principles of state plane coordinates and methods of their adjustment for large-scale engineering surveys are discussed.

● **THE SURFACE** of the earth is spheroidal in shape, which makes its representation in orthographic form on a plane extremely difficult. This is especially noticeable in large-scale mapping of extensive areas for engineering purposes. Although small segmental areas of the earth's surface do not curve perceptibly, the effects of curvature within them and their real or projected elevation above or below sea level must all be resolved to achieve a high degree of accuracy. The effects of curvature and elevation on the accuracy of projections of the earth's surface can be reconciled in several ways, or by some combination of ways.

In survey mapping at large scales for highways, the earth's surface is usually partitioned into small areas or short segmental strips whenever routes must be mapped in the preliminary survey stage for location and design purposes. Then certain types of adjustments are applied in making projections of the earth's surface onto a plane. The purpose of this paper is to discuss methods applicable to making such adjustments. Procedures are proposed for doing this in the beginning of surveying and mapping operations so that distances measured on the ground will agree, without adjustment, with distances determined from plane coordinates on the maps.

Within the national network of basic control surveys, it is unlikely that the precisely measured distance on the ground between any two stations would be exactly the same as the distance computed between the geodetic positions (latitude and longitude) or the plane coordinates (X and Y) of the stations. Such a difference in distance would not be an error. It is a difference which is exactly predictable because it is the result of elevation differences and distortions in map projections and the necessity for recording geodetic data of the control surveys on a common, national basis. Anyone who has been responsible for or involved in the planning or performance of surveys that are referenced to or are part of the national network is probably familiar with basic principles causing these differences, but a simplified presentation of them may refresh the memory.

For simplicity, large segments of the earth, as a country or a state, may be considered to have the surface shape of a sphere, although the earth is really a spheroid. The position of each survey station in the national network of control surveys are geodetic coordinates on the sphere and the distances between the stations are distances along terrestrial arcs. For any given subtending angle, this distance would be proportional to the length of the radius of the arc. Thus, if a standard radius were not used, the distance between stations would be affected by their elevation. For example, the radius would be approximately one mile greater at Denver, Colorado, than at Miami, Florida. To consider the extreme in the United States, the radius would be almost three miles greater at Mt. Whitney than at Death Valley. Consequently, to provide a common standard, distances between stations in the national network must be recorded along an arc at some arbitrary but convenient elevation. The natural and most convenient elevation is the mean sea level spheroid, and the geodetic data of the national network of the control surveys are based on this surface which is one of the elements of the 1927 North American datum.

Geodetic surveying is a specialized field and to be of practical use in plane surveying for engineering purposes the geodetic position of stations on selected segments of the spheroid of the earth must be presented in a system of rectangular coordinates on a plane. Since any segment of the curved surface of the spheroid cannot be transformed to a plane without distortion some compromise had to be made. The solution accepted was to develop a system of rectangular coordinates on a plane related to a sphere by limiting the area of the curved surface to be represented on the plane so that the projectional distortions would be kept within acceptable limits. The designs made to accomplish this resulted in a system of state plane coordinates, by zones as necessary to limit distortions, on either a Lambert conformal (conic) or a transverse Mercator (cylindrical) map projection system, mathematically related to the curved surface of the earth (Figs. 1 and 2, respectively).

The first of the systems of state plane coordinates was established in 1933 by the Coast and Geodetic Survey in the United States Department of Commerce. This was done to fulfill the request made that year by a state highway engineer. Soon after, a system of plane coordinates was established for each state, positioned by the basic first- and second-order control survey network which extends from border to border and coast to coast of the United States. In these systems of coordinates, third-order control surveys have also been coordinated. In each of the systems of state plane coordinates, the Coast and Geodetic Survey has made available the X and Y coordinates of each control-survey monument and marker for which it has determined an adjusted geodetic position. By now, many of the states have adopted the applicable system of plane coordinates by legislative act.

Highway engineers will benefit in many ways by making fullest possible use of the system of state plane coordinates applicable where they must make surveys for highway location and design, for procurement of highway rights-of-way, and for highway

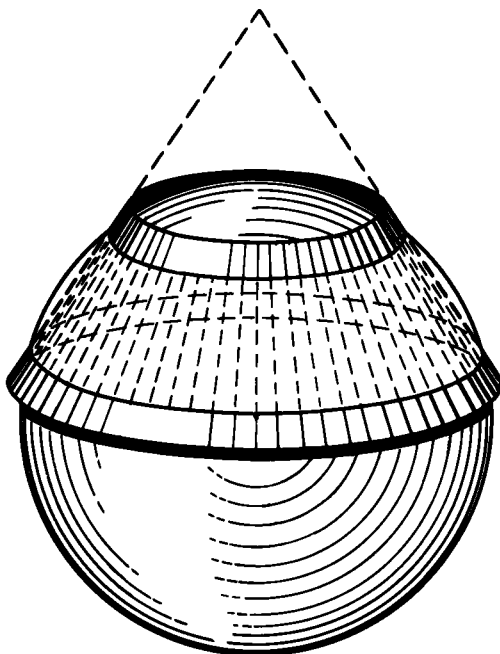


Figure 1. Lambert conformal projection (secant cone).

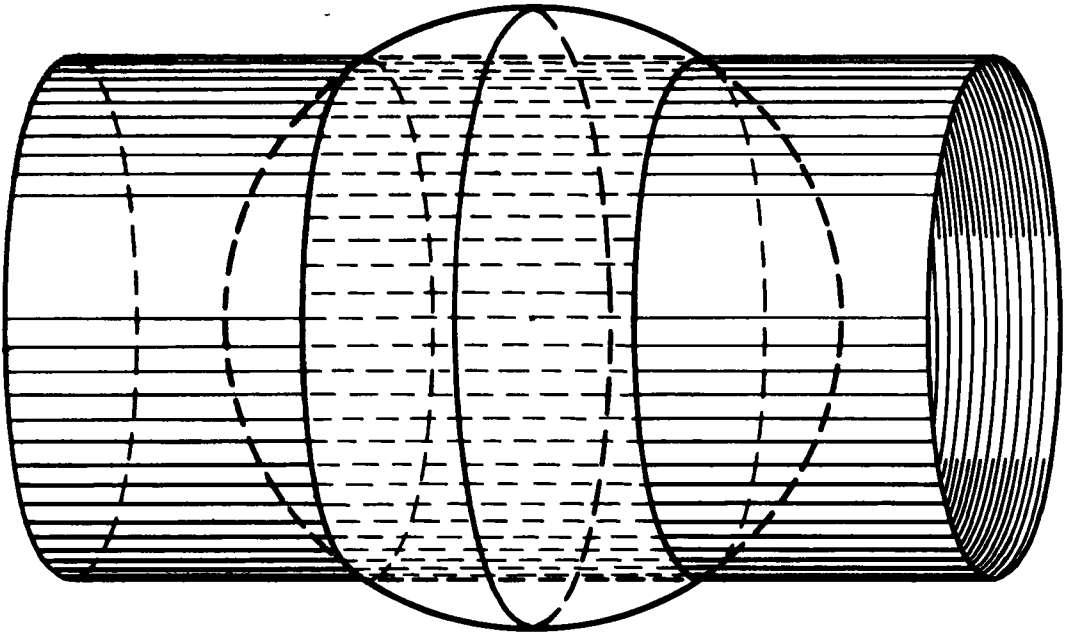


Figure 2. Transverse Mercator projection (secant cylinder).

construction. Furthermore, continuity in, and the preservation of all surveys made for highway engineering and cadastral purposes cannot be properly and fully attained until each survey is tied to and becomes an integral part of the state plane coordinate system established for the area of the state in which the survey is made. When this is done, highway surveys will attain continuity and uniformity, and the order of accuracy adequate for the detail and precision essential in both preliminary and location surveys for highways.

Since the plane coordinates of each state system were developed directly from the geodetic positions of station markers in the national network of horizontal control, the distance measured on the ground and the distance computed from plane coordinates of these stations will differ. The difference is caused by the combined effect of reduction to mean sea level of all stations physically above or below that datum and to the distortions occurring by projection of a curved surface onto a plane. These principles are portrayed in the accompanying illustrations for both the Lambert conformal and transverse Mercator projections. Actually, these projections (Figs. 1 and 2) are not perspective and cannot be displayed exactly graphically. Each projection is strictly a mathematical development, but the illustrations do indicate approximately what takes place.

In Figures 1 and 3 the sphere represents the sea level surface of the earth on which geodetic data are recorded and for the Lambert projection the cone represents the surface onto which points are projected from the curved surface. Whenever such a cone is cut along an element and a segment of the part intersecting the sphere is rolled out flat, it becomes the Lambert conformal projection. The cone cuts through the sphere on minor (small) circles of diameter T-U and V-W (Fig. 3) which is a cross-section (diagrammatically drawn, although not representative in scale) of the cone and sphere. Where the cone and sphere are coincident along T-U and V-W, two parallels of latitude are formed, known as standard parallels. These two parallels are the only lines along which geodetic and plane coordinate grid distances are equal. Thus, along these standard parallels, the scale factor between geodetic arc distances and distances on the Lambert conformal projection is one. Inside these parallels, the scale factor is less than one and grid distances on the plane of the projection are less than geodetic

distances on the arc; outside, the scale factor is greater than one and plane coordinate grid distances are greater than geodetic arc distances. A selected segment of the cone cut along its elements and rolled out flat to form the completed Lambert conformal projection, with a plane coordinate system superimposed thereon, would have the appearance illustrated in Figure 5. Scale factors of the plane coordinate grid on this projection are constant along each parallel of latitude, are variable along any line other than a parallel of latitude, and their greatest variation occurs along true North-South lines. At any one point, however, the scale is the same in all directions.

In Figure 3, the difference in distances is illustrated between points A and B, height A_1-A above the sphere, which are survey stations in the national network of basic ground control surveys. The distance that would actually be measured on the ground at the elevation of the survey project is arc A-B. The geodetic distance computed from the latitude and longitude of the stations is along the smaller arc A_1-B_1 at mean sea level. The grid distance computed from the state plane coordinates is the straight line distance A_2-B_2 on the projection surface.

The magnitude of the differences in distance, between A-B and A_1-B_1 , between A_1-B_1 and A_2-B_2 , and especially between A-B and A_2-B_2 may be so large as to seriously affect the apparent accuracy of a ground survey. For example, two U.S. Coast and Geodetic Survey triangulation stations in California, Sol and Eddy Gulch, may be substituted for A and B, and the appropriate values would be:

Plane coordinate grid distance	18,076.6 ft
Geodetic distance on arc of sphere	18,078.2 ft
Measured distance on ground at an elevation of 5,500 ft	18,082.8 ft

If the coordinate grid and measured distances were accepted at face value, a closure of 1:2,920 would be indicated. Such a closure is far below third order accuracy of 1:5,000 and does not greatly exceed fourth order accuracy of 1:2,500. Actually, however, when scale factors and elevation corrections are applied, it would be found that these distances are all correct at the datum and on the projection for which they were computed. Consequently a proper understanding and use of them is what is required.

The projection of points on the earth's spherical surface to a transverse Mercator projection is illustrated in Figure 4, in which there is shown diagrammatically the cross-section of an east-west cylinder intersecting the sphere on minor circles T-U and V-W. Points on the sphere representing the sea level surface of the earth, on which geodetic data are recorded, are projected to the surface of the cylinder. After a segment of the cylinder is cut along its elements and rolled out flat in a plane containing a line such as T-V (Fig. 4) it becomes the transverse Mercator (cylindrical) projection (Fig. 6) to which all distances were projected and on which a plane coordinate grid is superimposed. Scale factors of the plane coordinate grid on this projection are constant along the central meridian and all lines parallel to it, are variable along any other line, and their greatest variation occurs along lines perpendicular to the central meridian.

Only along the minor (small) circles T-U and V-W equidistant from the central

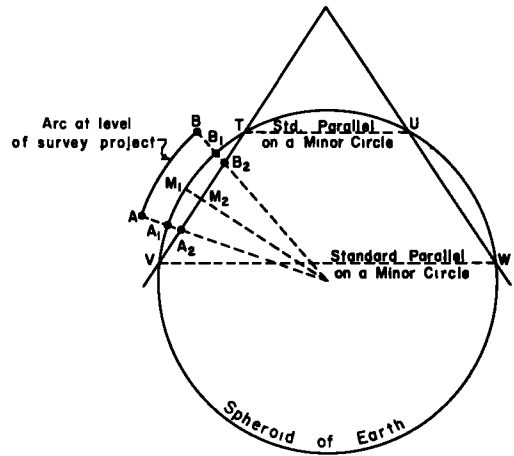


Figure 3. Lambert conformal projection; cross-section of intersection of cone and sphere.

meridian are the geodetic and grid distances equal and the scale factor is one. Between these two minor circles, grid distances on the projection plane are less than geodetic distances on the arc and the scale factor is less than one. Outside the two minor circles the grid distance is greater than the arc distance and the scale factor is greater than one. Again it should be noted that the scale is the same for all directions at a given point.

The difference in distances between points A and B at elevation of survey and points A_1 and B_1 on the sphere, and between points A and B and points A_2 and B_2 on the grid projection plane, are obvious in the illustration.

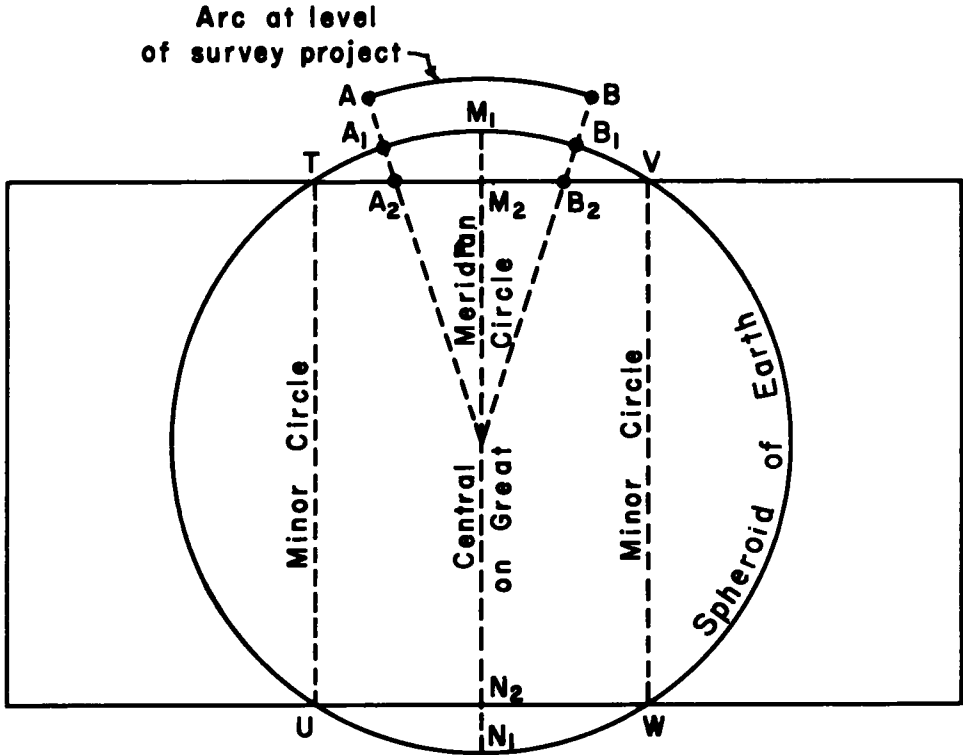


Figure 4. Transverse Mercator projection; cross-section of intersection of cylinder and sphere.

The Coast and Geodetic Survey has compiled and made available by segments scale factor tables for each of the established state plane coordinate systems. As previously demonstrated, these factors range from one, where the cone is coincident with parallels of latitude on the Lambert conformal projection and where the cylinder is coincident with parallel lines equidistant from the central meridian on the transverse Mercator projection, to less than one between such lines, and to greater than one outside of them. Moreover, these variations are caused by the fact that the rolled-out cone or cylinder forming the plane on which each plane coordinate system is projected coincides with the spheroid of the earth at only two parallels of latitude for the Lambert system and at only two north-south projection lines parallel to and equidistant from the central meridian for the transverse Mercator system. Other portions of the plane are either above or below the spheroidal surface. For the portions below the spheroid the distances measured horizontally on the ground are longer than distances projected onto the plane by either method. For those above the spheroid the effect is the opposite, and ground-measured distances are shorter than distances projected onto the plane.

TABLE 1

Distance the plane of projection is above or below the earth's spheroid (ft)	Number of times horizontal distance on the plane is larger or smaller than distance measured on spheroid. (These values are scale-correction factors expressed as a ratio of distance on ground)	Difference in distance on plane and spheroid expressed as an approximate fraction of any total distance
+2,400	1.000115	1:8,700
+2,200	1.000105	1:9,500
+2,000	1.000096	1:10,400
+1,800	1.000086	1:11,600
+1,600	1.000077	1:13,000
+1,400	1.000067	1:14,900
+1,200	1.000057	1:17,500
+1,000	1.000048	1:20,800
+ 800	1.000038	1:26,300
+ 600	1.000029	1:34,500
+ 400	1.000019	1:52,600
+ 200	1.000010	1:100,000
0	1.000000	--
- 200	0.999990	1:100,000
- 400	0.999981	1:52,600
- 600	0.999971	1:34,500
- 800	0.999962	1:26,300
-1,000	0.999952	1:20,800
-1,200	0.999943	1:17,500
-1,400	0.999933	1:14,900
-1,600	0.999923	1:13,000
-1,800	0.999914	1:11,600
-2,000	0.999904	1:10,400
-2,200	0.999895	1:9,500
-2,400	0.999885	1:8,700

Note: In practice these scale factors are taken from the state plane coordinate tables. They are listed for every minute of latitude in the Lambert projection, and for every 5,000 ft of x-distance from the central meridian in the transverse Mercator projection.

Table 1 contains in numerical form the effects, at 200-ft increments, of the plane of projection of state plane coordinate systems being above or below the earth's spheroid. A careful study of Table 1 will reveal why the various systems of state plane coordinates were established by zones so as to prevent differences between distances measured on the spheroid and distances determined from coordinates of the maps compiled at datum of the plane coordinate system from producing errors greater than approximately one part in 10,000. To achieve this, the zones of each state plane coordinate system were designed so that the height of the central parallel of latitude of each Lambert conformal system, and the central north-south meridian of each transverse Mercator system does not greatly exceed 2,000 ft above the plane on which the coordinate system is projected. Likewise, extensions of the plane beyond its intersection with the spheroid is limited to an altitude of about 2,000 ft above sea level. Actually, however, the scale factors were developed mathematically, not from consideration of the elevation of the plane above or below the spheroid.

From the foregoing, it is evident there are two causes of differences between dis-

tances measured horizontally on the ground and distances determined from coordinates on maps compiled on a state plane coordinate system. These are the variable distance that the plane of representation is below or above the spheroid of the earth, and the elevation that the survey project is above it or below it for the few places where the ground is lower than mean sea level. To cope with these conditions, the usual method of handling the associated problems is to reduce basic ground control survey data from values at elevation of survey to obtain the applicable coordinate data, geodetic or plane, as desired. Thus, arc distances measured horizontally by increments on the ground are combined with an elevation correction factor to determine an arc for this distance on the sea level spheroid; then a grid scale correction factor is applied to the spheroidal arc distance to determine the plane coordinate grid distance.

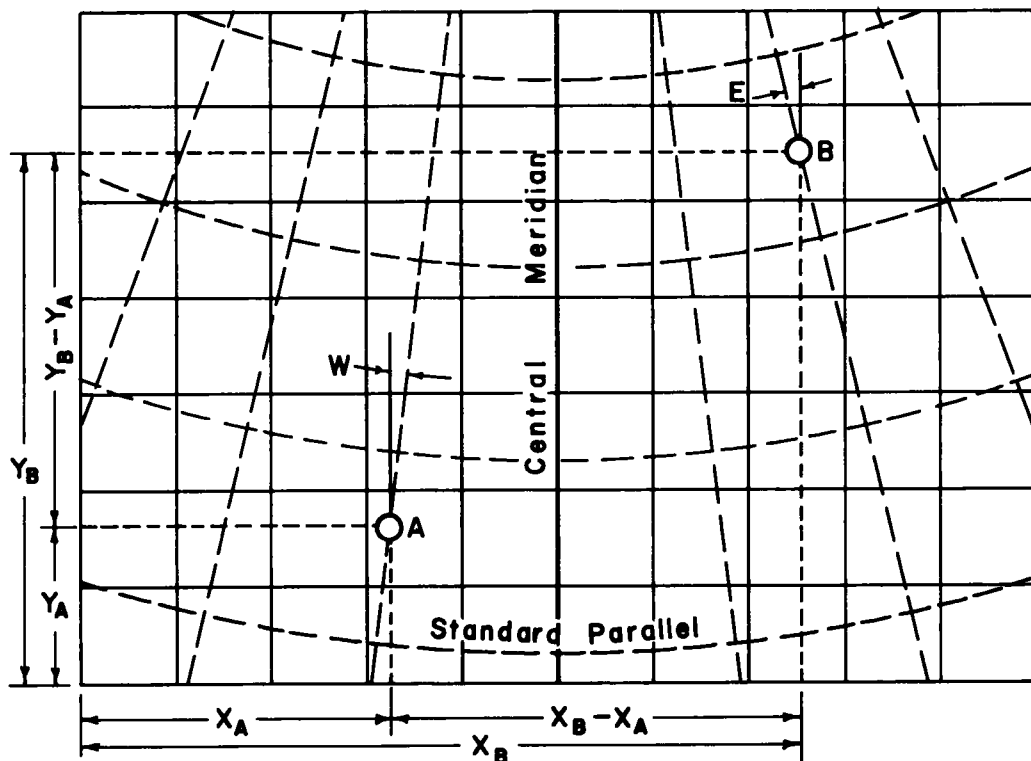


Figure 5. Plane coordinate grid on Lambert conformal projection (W and E are declinations of grid from true north at points A and B).

When the scale of a map is based upon plane coordinate grid control determined in such a manner, the ground and features on it are not delineated at constant scale, but at the variable scale occurring when projected onto a plane below or above the sea level spheroid illustrated. This does not create serious problems for users of small-scale maps, as 2,000 ft to one inch or smaller, because accuracy to the nearest foot or fraction of a foot is usually of no consequence in the reconnaissance surveys for which such maps are used. In compiling and using large-scale maps at a scale of 200 ft to one inch or larger for engineering design and cadastral purposes, however, the difference between map distances and ground distances caused by such variations in scale must be considered and appropriately resolved.

Practice has been to reduce all horizontally measured ground survey distances to the datum of the state plane coordinate system. Thus, where there is much elevation, distances measured on the ground must be adjustment-corrected in going from ground to map or from map to the ground. For example, if the alignment of a highway location at an elevation of several thousand feet is designed on maps compiled on datum of

a state plane coordinate system, the designed curves, their radius and degree, tangent distances, distances along property and right-of-way lines—in fact every distance computed from the map for engineering or cadastral purposes—would have to be adjusted before the highway is staked on the ground in order to attain ground survey closures and assure proper positioning as designed.

Procedures are proposed for applying an essential adjustment to state plane coordinates so that map compilation datum is established at the average elevation of the survey rather than at the datum of the state system. This should be done in the beginning. Then distances measured on the ground will agree without need for correction-adjustment with distances determined from coordinates on the map. In this way, both convenience and savings in work are achieved by eliminating the need for adjustment of

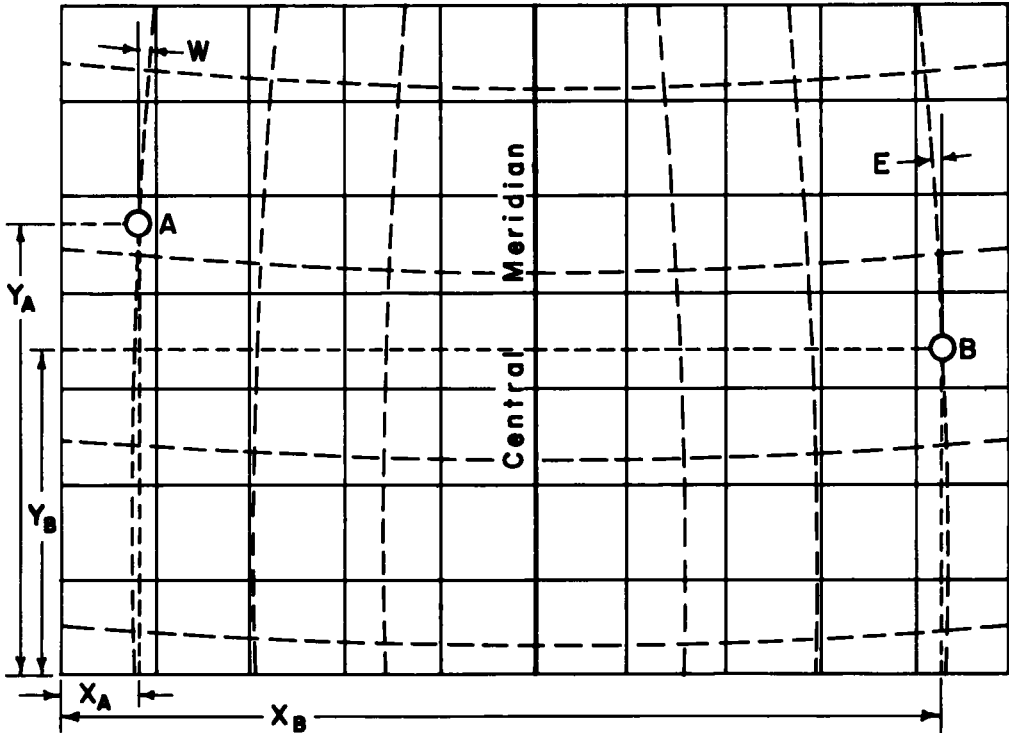


Figure 6. Plane coordinate grid on transverse Mercator projection.

each map distance to agree with its ground distance—the distance that was or will be measured depending upon its use sequence in highway engineering.

This method, contrary to some concepts, does not discard the state plane coordinate system. State plane coordinates of any point or feature on a map compiled in this survey system is readily determinable merely by the simple process of dividing coordinates of the point or feature in the system by the adjustment factor recorded on each map sheet.

Before considering procedures for doing this, analyze the numerical effects of distances measured in surveys made at an elevation above the sea level spheroid of the earth being reduced to the datum of a plane coordinate system. As illustrated in Figures 3 and 4, distance A-B of the survey is longer than its projection on the sphere. In Table 2, at 1,000-ft increments of elevation, the effect of elevation on horizontal distances, as compared to the unit distance 1.000000 along an arc of the earth at sea level datum is given.

Such differences cannot be ignored without serious consequences, especially when

TABLE 2

Elevation of survey above mean sea level (ft)	Number of times horizontal distance on ground at elevation listed is larger than horizontal distance at sea level datum (a multiplication factor)	Difference in distance expressed as an approximate fraction of any measured total distance.
0	1.000000	--
1,000	1.000048	1: 20,800
2,000	1.000096	1: 10,400
3,000	1.000143	1: 7,000
4,000	1.000191	1: 5,200
5,000	1.000239	1: 4,200
6,000	1.000287	1: 3,500
7,000	1.000335	1: 3,000
8,000	1.000383	1: 2,600
9,000	1.000430	1: 2,300
10,000	1.000478	1: 2,100
11,000	1.000526	1: 1,900
12,000	1.000574	1: 1,700
13,000	1.000622	1: 1,600
14,000	1.000670	1: 1,500
15,000	1.000717	1: 1,400

their effects are additive to the effects of projecting map details onto any plane coordinate system established by either the Lambert or the transverse Mercator method, as given in Table 1. With this fact in mind, the next task is to devise a method which eliminates the need for any adjustment of distances other than the X and Y plane coordinates of the basic ground control survey stations. This must, of course, be done so that distances measured or to be measured on the ground have, without adjustment, the desired proportion to distances determined from the plane coordinates of planimetric and topographic features on the maps, and to the dimensions of designed highway alignment, structures, rights-of-way and so forth. There are three steps to achieving this, after the average elevation of the project survey has been ascertained.

First, select from Table 2 the multiplication factor applicable at the average elevation of survey project. This elevation should be a median not exceeding approximately 1,000 ft above the lowest and 1,000 ft below the highest point within the engineering survey area where large scale mapping (200 ft to one inch or larger) is required. Should much larger differences in elevation exist between the extreme high and low, consideration should be given to dividing the survey project into segments so as to prevent large discrepancies from occurring.

Second, select the appropriate scale-correction factor from the applicable state plane coordinate projection tables. In the tables prepared and made available for each state by the Coast and Geodetic Survey, this factor is expressed as a ratio of distance.

The scale-correction factor to use depends upon the latitude of the point or points to be adjusted in any Lambert designed system of plane coordinates, or upon the distance east or west of the central meridian of the point or points in any transverse Mercator designed system of plane coordinates. Actually, all scale-correction factors are similar in character to the numerical values in column two of Table 1, but which one to use for a particular survey point or geodetic station marker in the national network of control surveys must be obtained from the appropriate plane coordinate projection tables. The scale-correction factor which is median for surveys of small areas or short routes, or of selected segments of large areas or long routes extending across a major part or all of a state plane coordinate zone, will usually suffice.

Third, the combined-adjustment factor, which corrects for both elevation and scale

variation, is computed by dividing the multiplication factor applicable from Table 2 by the scale-correction factor.

Once an applicable combined adjustment factor has been so determined, then the X and Y plane coordinates are computed, which would be applicable at the elevation of the survey project for each geodetic station marker to be used as basic control for the project. This is done by multiplying the state plane coordinates of each marker by the combined adjustment factor which is applicable.

Two geodetic station markers in Zone I of the Lambert conformal plane coordinate system in northern California may be considered, namely Sawtooth and Thompson Peak. Their geodetic coordinates are N 40° 58' 20.94" and W 123° 00' 04.22" and N 40° 56' 36.62" and W 122° 52' 18.17", respectively. Using their geodetic coordinates, other data pertinent to the markers were computed, such as their state plane coordinates in Zone I, the distance of 37,280.7 ft between them on the state plane coordinate grid, the geodetic distance of 37,284.5 ft on a great circle arc at sea level, and the arc distance of 37,293.4 ft on the ground at the survey project elevation of 5,000 ft.

The X and Y plane coordinates of Sawtooth and Thompson Peak station markers are 1,723,554.9 and 598,703.6 and 1,759,194.9 and 587,765.4, respectively. These station markers are about midway between the standard parallels of Zone I.

Although Sawtooth is actually at an elevation of 8915 and Thompson Peak at an elevation of 8383 ft, a combined scale- and elevation-adjustment factor must be ascertained which will apply at the average 5,000-ft elevation of the area of survey. This is because the survey area is in the canyon between the mountain tops on which the station markers are situated. For their average latitude of 40° 57.5', the scale factor in projection table of Zone I is 0.999897. Multiplication of distances on the spheroid by this factor gives distances on the state plane coordinate system, which is about 2150 ft below sea level in this area. Another way to visualize the significance of this correction is that each 100 ft on the spheroid is represented by 99.990 ft on maps compiled on state plane coordinate datum in this area. From Table 2 the multiplication factor applicable at the average elevation of 5,000 ft is 1.000239. Likewise, each 100 ft on the spheroid becomes 100.024 ft at the 5,000-ft elevation of the survey. The combined adjustment factor is 1.000342, which is 1.000239 divided by 0.999897. Thus, each 100 ft at datum of the state plane coordinate projection would measure 100.034 ft on the ground. In highway surveying and all construction stake-out work, such a difference would result in discrepancies of closure and in errors of positioning. Unfortunately these discrepancies and errors may cause engineers who are not familiar with the fact that the differences causing them are mathematically computable and adjustable to feel that the initial survey on state plane coordinate datum is full of errors.

The way in which to avoid the occurrence of such differences and to make distances determined from plane coordinates on the large-scale maps agree with distances measured on the ground at the level of the survey without affecting azimuth is to adjust the state plane coordinates of the geodetic station markers. Then use them in their adjusted position to control all surveying and mapping. In this example the new X and Y coordinates for Sawtooth are 1,724,144.4 and 598,908.3, and for Thompson Peak 1,759,796.5 and 587,966.4, which are merely the initial state plane coordinates multiplied by the combined adjustment factor of 1.000342. When desired in the future, X and Y coordinates of any points (the initial control, highway alignment points, property corners and right-of-way markers, and so forth) could be reduced for use at datum of the state plane coordinate system, as desired, by merely dividing their survey X and Y coordinates, respectively, by the same combined adjustment factor.

Plane coordinates for all surveys and mapping for highway engineering purposes can be easily utilized in the same manner. Thus, the systems of state plane coordinates are retained and used advantageously. In so doing, the need for resolving differences in distances is eliminated. Each designed alignment with its circular curves, transition spirals, and joining tangents can be staked on the ground without the nuisances of "apparent" errors in position, lengths, degrees of curvature, and the like.

In conclusion, it is urged that each and every highway engineer, organization, and department adopt and fully use these suggested methods. Then, and only then, will it be possible easily to attain accuracy, continuity, and permanency in surveys, and through these highly desirable benefits accrue savings in both time and money.

Discussion

L. G. SIMMONS, Coast and Geodetic Survey — It is evident from the paper on the Adjustment of State Plane Coordinates that the author has a good working knowledge of the nature of the projections forming the bases of the State Plane Coordinate Systems.

These systems were devised as a result of a request from a highway engineer about 25 years ago in order to take a practical advantage of the geodetic network throughout his state. Surveyors and engineers not engaged in geodetic work are unfamiliar with the type of computation required. The conversion of latitudes and longitudes of the triangulation stations to x and y rectangular coordinates puts the control network in a much more usable form.

Objections have frequently been raised by engineers throughout the country in regard to these state systems because of the fact that the actual ground lengths differ in some instances quite materially from the grid lengths, as determined by plane coordinates. There are two possible approaches in answer to this objection. One is to reduce each measured length for the scale of the grid and for its elevation above sea level and compute the coordinates which will be referred directly to the grid. Then, if any particular ground distance is needed to a high degree of accuracy for some special purpose, this can be determined by a reverse application of the sea level and grid scale factors. The other method proposed by Mr. Pryor is merely to change all the grid coordinates in a relatively small area by applying a combined elevation and scale factor and then proceed with the survey employing actual ground lengths in the computation.

For highway work, the second method appears to be quite practical. It minimizes the amount of computing necessary and results in a set of coordinates from which actual ground lengths can be determined immediately. Moreover, should it be desirable to obtain true grid coordinates after the detailed highway programs have been performed, these may be computed merely by applying the combined sea level and scale factors in reverse.

A note of caution should be injected here to avoid confusion in determining whether a set of coordinates applies strictly to the state grid or to a particular area within the grid at a certain elevation. Any list of coordinates, therefore, should carry a definite statement which will leave no doubt in the user's mind as to their nature.

WILLIAM T. PRYOR, Closure — Mr. Simmons discusses two vitally important points. The first is the fact that the distance between any two points, as determined from state plane coordinates, may not agree with the distance measured on the ground between the points with sufficient accuracy to satisfy engineering requirements, unless an adjustment is made. The purpose of the paper was to propose a method of making this adjustment in the state plane coordinates before mapping is undertaken. In this way the need for adjusting each measured distance on the ground, or each distance determined from coordinates on each map is precluded. Distances determined from maps compiled on an adjusted system of plane coordinates will agree within practicable limits of accuracy, without need for adjustment, with distances measured on the ground. Thus, a major obstacle to the adoption by highway engineers of the state plane coordinate systems is eliminated. Each engineer who makes use of the suggested method of adjusting state plane coordinates is not discarding the state plane coordinate system. He is actually using it in the most practicable way.

The second point, a note of caution by Mr. Simmons, is a good one. In order to avoid any confusion, each map sheet should contain a statement of the fact that the mapping coordinates were obtained by adjustment of the state plane coordinate system. In this way, the map user will be made immediately aware that the plane coordinates used apply only to the particular mapping project. Each map sheet should also contain the combined adjustment factor used to compensate distances for scale of the state

plane coordinate system and the average elevation (datum) of the mapping project. Then whenever it is desired to convert the coordinates of any points or map features or engineering data to the datum of the state plane coordinate system the combined adjustment factor to use is readily available. The conversion can be accomplished by merely dividing their plane coordinates on the map by this factor.