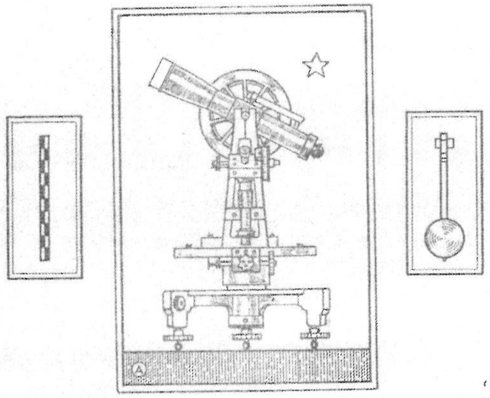
GEODETIC LETTER



STATE PLANE COORDINATES

No. 1
Vol. 4

JANUARY
1937

ISSUED BY

DIVISION · OF · GEODESY
UNITED · STATES · COAST · AND · GEODETIC · SURVEY ·
WASHINGTON D.C.

R. S. PATTON · Director

M-115

STATE-WIDE SYSTEMS OF PLANE COORDINATES[1]

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The U.S. Coast and Geodetic Survey has established a nation-wide network of arcs of triangulation that at the present time has a total length of some 65,000 miles. These arcs are fairly evenly distributed throughout the country and they thus form the basis for the control of further surveys that may be made locally or regionally wherever the data are readily accessible. Experienced engineers and surveyors realize the fundamental importance of rigid checks on any observational data. In an independent survey certain checks can be afforded by the methods of observation but an external check by means of work that has already been established and shown to be correct by various checks in the net to which it belongs, is of the greatest importance in all such subsidiary surveys.

Much remains yet to be done in the establishment of these fundamental Federal surveys. In spite of the fact that, during the past few years, there has been a rapid expansion of the horizontal control net of the nation, very much more remains to be done. There are large areas that are not now supplied with the fundamental data. The rapidity with which the national net may be completed will depend almost entirely upon the demands made on the Federal Government by engineers, planners and others who may require the horizontal control survey data in the execution of their work.

In addition to the data established by the Coast and Geodetic Survey, there are many surveys that have been made by other bureaus of the Government, such as the Geological Survey, the Army Engineers, etc. Whenever these surveys are properly tied in with the fundamental net of the Coast and Geodetic Survey showing an error of closure acceptable for first-, second- or third-order surveys, they in turn may become control data for subsequent work. In sum total, therefore, there exist many thousands of stations that are accurately located and correlated to each other scattered fairly evenly over the country.

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1 Paper read before the Surveying and Mapping Division of the American Society of Civil Engineers, Pittsburgh, Pa., October 14, 1935. Abstract of paper appears in the January number of CIVIL ENGINEERING

In view of this fact, it is of supreme importance to arouse the interest of engineers and surveyors throughout the country in the great advantages to be gained by basing local and regional surveys on this fundamental control. Since this control net is so extensive and reaches from one end of the country to the other, it is necessary to take into account the curvature of the earth in the computations. The final data are consequently expressed in terms of latitude and longitude and in azimuths and lengths. These geodetic computations are rather involved and it generally requires some study before they can be made with ease and certainty by even well trained engineers and surveyors. The actual computations are not so difficult but if one wishes to delve into the theory upon which they are based, the mathematics involved is often beyond the grasp of those who may wish to understand fully the significance of the computations.

The Coast and Geodetic Survey has tried for fifty years more or less to encourage the use of control surveys in the form of geodetic positions among the engineering profession. While in certain instances we met with success, on the whole the batting average was very low. Although I am sure that many were needlessly frightened off by an exaggerated view of the difficulties to be encountered, yet the fact still remains that they were frightened off and as a result failed to take advantage of the control surveys. A wise general, when he does not meet with full success in one method of attack, will change his tactics and seek to attain his objective in some other way.

During 1932 and 1933, the Coast and Geodetic Survey cooperated with the State of North Carolina in the completion of the first-order horizontal control in that State. Early in 1933, Mr. George F. Syme, of the State Highway and Public Works Commission, requested us to consider the possibility of setting up a system or systems of plane coordinates for the State, At the request of Dr. William Bowie, Chief of the Division of Geodesy, I undertook a study of the possibilities for the State. While working on the project, I had several conferences with Colonel C. H. Birdseye of the U.S. Geological Survey, who was much interested in the subject of plane coordinates for use in State-wide survey operations. As a result of my study and of the various conferences, the system for North Carolina was devised. Not long after the computation of the tables occurred the tragic death of Mr. Syme and the direction of the work in the State passed into the hands of Mr. O. B. Bestor, who has been carrying on survey operations in the State with the coordinates of the triangulation stations on the State system used as control of his local surveys. Several thousand miles of traverse have been run and computed on the plane with no greater complications than those involved in latitudes and departures.

This was, therefore, the start of the computation of tables for State-wide systems of plane coordinates, a computation which was undertaken at the request of a practical engineer and surveyor. What I wish to convey is the fact that the incentive for the initiation of such schemes came from engineers outside of the Government departments and not as a result of a brain storm of some theoretical mathematician and geodesist.

As a basis of the North Carolina system the Lambert conformal conic projection with two standard parallels was chosen. A conformal projection was employed because the angles are better preserved in this class of projections than in any other class. By holding the scale exact along two standard parallels it is possible to keep the departure from true scale within a prescribed maximum for a much wider strip of country. The tables for the reduction of geodetic positions to plane coordinates were confined to the elements necessary for such reductions. No table of meridian and parallel intersections was computed. It was planned that the Coast and Geodetic Survey should compute the plane coordinates of all of the stations in the control net and have these available as well as the geodetic positions. The engineer or surveyor would then have nothing more to do than to make use of the computed coordinates in his work.

The Lambert projection is suitable for a State with greatest extent in an east-and-west direction since it can be carried almost indefinitely in that direction. If the departure from true scale is to be kept within one part in 10,000 the extent in a north-and-south direction must be kept to the limit of 158 miles.

After the system for North Carolina had been established, we began a study to see what could be done for a State with greatest extent in a north-and-south direction. New Jersey was chosen as the State to be studied in this respect. Again we wished to make use of a conformal projection for the same reason as before. After a careful consideration of the matter we finally decided to apply a modified form of the transverse Mercator projection. To apply this projection with complete rigidity it would be necessary first to map the ellipsoid on the conformal sphere and then to map this sphere on the plane. However, we wished to hold the scale constant along the central meridian of the region to be mapped. This could not be done unless slight departures from full rigidity should be introduced. Accordingly we found that for the limited region to be mapped a satisfactory solution could be found by adapting our formulas for geodetic positions to the calculation of the elements required for the computations of the coordinates.

I shall not attempt at this time to explain the process but I think you can get a picture of the whole by thinking of the ordinary Mercator projection with which, I take it, you are all more or less familiar. Let us suppose that we have a zone of 79 miles on each side of the equator mapped on an ordinary Mercator projection. Then if we reduce the scale along the equator by one part in 10,000 we shall have a map that has the scale too small along the equator and too large by the same amount along the top and bottom of the map.

As a consequence there will be two parallels equidistant from the equator along which the scale will be exact. Now if we use our imagination further and think of the great circle from which the surface is mapped as being a meridian instead of the equator, we shall have a true picture of what is done. Unfortunately for our purpose, the earth is not a true sphere and the meridian is an ellipse and not a circle. However, with slight sacrifice of conformality we can neglect the ellipticity and thus attain our purpose for the small area that is to be included in any one system.

We thus found that this system gave a satisfactory solution for the State of New Jersey and accordingly tables were prepared for that State and satisfactory formulas were devised for the reduction of geodetic positions to coordinates.

We had thus developed two systems of conformal projections that are admirably suited as bases for plane coordinates: the Lambert projection for regions of greatest extent in an east-and-west direction and the transverse Mercator projection for those regions with greatest extent in a north-and-south direction.

Soon after we had reached this point in our investigations the Civil Works Administration program was launched. The need of such plane-coordinate systems for all of the States was apparent and accordingly the computations were expedited and systems for the forty-eight States were completed early in 1934.

As before stated, it is the plan of the Coast and Geodetic Survey to reduce all of the stations from geodetic positions to plane coordinates on these systems. After these computations have been made the resulting coordinates will be made available for distribution either in the State triangulation and traverse publications or in the form of lithographic reproductions. Up to the present time three State publications have been issued which contain both the geographic positions and the plane coordinates of the stations. These publications are those for the States of Tennessee, California and Minnesota. Several other States have all of the computations ready for publication but at present our program is held up due to lack of funds for publication.

In all of the arcs of triangulation that have been orbserved since about 1927, there is established at each main station an azimuth mark distant a good fraction of a mile from the station and such that it is visible from the ground at the station. In the main scheme of the arcs, it is generally necessary to use observing towers as the main scheme stations are seldom intervisible from the ground. In view of this fact the establishment of the azimuth marks is a great aid to the use of the control for local or regional surveys. The azimuth of this mark from the station is determined and in the plane-coordinate computations this geodetic azimuth is in turn reduced to a plane or grid azimuth for use in local plane surveys. These grid azimuths are given in the lists of plane coordinates so that the surveyor will have all of the data necessary for the control of his work.

After the coordinates of the control stations have been computed, it scarcely makes any difference on which of the two projections the computations were based. The method of using the coordinates is essentially the same on both of the systems and the computation of surveys by plane coordinates is about the same on either system. The method of traverse computation by means of latitudes and departures is familiar to all who have studied plane surveying and is in general use among surveyors and engineers in some form or other.

In almost all of the systems, the aim was to keep the variations of scale within one part in 10,000. This limit was slightly exceeded in the North Carolina system because the engineers in that State preferred to let the departure exceed this limit rather than have the State divided into two zones. In the computation of third-order traverses it is probably not necessary to take into account these variations of scale. In the most accurate work, however, it is advisable to correct the measured lengths for this variation of scale before computing a given traverse.

Since in both systems of coordinates the reductions to coordinates are made from geodetic positions, the sea-level lengths are involved in the starting data. There are, therefore, two separate reductions that should be applied to measured lengths before they are employed in the computation of a traverse, if the most accurate results are required. That is, the lengths should first be reduced to sea level and then a correction should be applied for the variation of scale on the grid. These grid variations are listed for every minute of latitude on the Lambert grids and for every 5,000-foot distance from the central meridian on the transverse Mercator grids. It is thus a very easy matter to determine this grid correction for any given line and in most cases it is sufficiently accurate to determine a mean correction for any given traverse. For a traverse that is properly tied in with the control, there will be a starting station and an ending station for which the coordinates will be given. By consideration of these coordinates it is very easy to determine from the coordinate tables just what mean grid factor may be required for the measured lengths of the traverse in consideration.

A number of the States have already made very extensive use of the coordinates in their local work. The use of the grid was started at once in North Carolina and it is still in active use for all local surveys under the direction of Mr. O. B. Bestor. In New Jersey the system has been used extensively in the computation of local traverses and under the able direction of Professor Philip Kissam of Princeton University, a law has been passed that legalizes the definition of property boundaries in terms of the coordinates of the angle points of the property. This is a significant advance both in the interest of the coordinate systems and in the interest of cadastral surveying in the State, and it forms an important advance in the method of the definition of property boundaries.

The coordinates in Tennessee are in wide use by the various divisions of the Tennessee Valley Authority. Traverses are being computed directly on the grid and the corners of all Government purchases of property are being tied in with the State system of control. This method fixes for all time the exact location of these points. If at any future time the marks at any of them should be destroyed, they could be restored by means of their coordinates. Monuments, even of the most permanent type, may be destroyed in time but the coordinate relations still persist and the actual situation of the monument can be relocated and remonumented in all cases of loss by destruction of the mark.

Extensive use is being made of the coordinates in North Carolina, South Carolina, Georgia, Florida, Alabama, Tennessee, Louisiana, New Jersey, Connecticut, Massachusetts, Iowa and many other States. An accurate map of Denver and vicinity is being made by the U.S. Geological Survey under an appropriation of the Works Progress Administration and the work is being based on the Colorado grid.

The matter of city surveys brings up the question regarding sea level and ground level, or rather, whether grid scale should be used, or a scale on a mean ground-level plane. It seems to me that the importance of having the work tied in with the control net far outweighs the need for exact ground level distances. A circular letter was sent to a number of representative engineers and surveyors to get a general recommendation on this very point. Most of the replies that we received looked at the matter in the same way as we had considered it. Actual lengths and areas can easily be determined from a map made on the State grid even though the coordinates may give slightly different results. Denver is probably at a higher elevation than any other large city in the country and, if its engineers find the use of the State grid satisfactory for their work, it should be equally so for any other such city in the country.

It is our opinion that all local surveys that consist merely of traverse can be computed on these State-wide plane coordinate grids with much less effort than would be required by any other method. If, however, a local survey is carried on by means of triangulation, then it is probably simpler and more economical to compute the work geodetically. Triangulation can be computed and adjusted on the grid but the calculations required are equal if not greater than would be required by the geodetic method. Of course, if any engineers or surveyors wish to compute all of their work geodetically, we would not desire to discourage them, if they will base their work on the Federal control surveys. We think, however, that they would be overlooking a great advantage if they did not use the grid for their traverse computations.

The members of the Corps of Engineers, U.S. Army, are becoming much interested in the State grids and they are actually using them in some sections. There is no doubt that they would use them much more extensively if stations of the control surveys were more accessible in regions in which they are carrying on their work. It is hoped that arcs of triangulation may be observed along the principal rivers of the country in the not distant future. These arcs would then serve as bases for the more detailed surveys of the Army Engineers.

At the instigation of Professor Philip Kissam, the Federal Board of Surveys and Maps appointed a subcommittee on control to study the advisability of the Board taking action of approval of the use of the State-wide plane-coordinate systems. After an exhaustive study of the matter, the subcommittee presented a report to the full committee on control recommending the approval of the use of the State grids whenever feasible both by Federal bureaus and by private engineers and surveyors. Final action was taken by the Board at its meeting on September 8, 1936. This should give an added impetus to a wider use of this tool which we feel to be very important to the engineering profession and which will tend to increase the accuracy of local surveys and as a result, put them in shape to be of further service to other surveys in the same vicinity.

The Coast and Geodetic Survey has issued three special publications on the subject of these coordinate systems and their use and these publications can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C., for a nominal sum. These are Special Publications Nos. 193, 194 and 195. The first is a general treatise applying to both of the systems but the other two apply each to only one system; 194 to the Lambert grid and 195 to the transverse Mercator grid. For any further information about these plane-coordinate systems and their use or about the subject of projections in general, application should be made to the Director of the Coast and Geodetic Survey, Washington, D.C. We are always glad to furnish any information we can on this important phase of geodesy which is destined to become even more important in the time to come.

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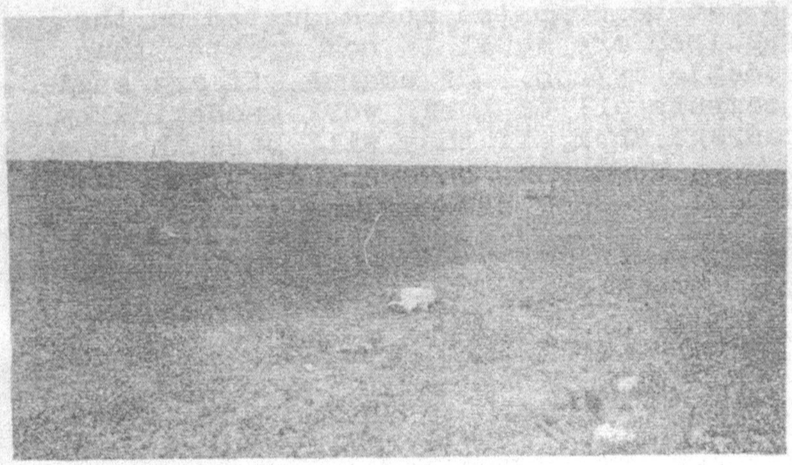

The north boundary of Texas was originally marked with fifteen monuments. This illustration shows one of the seven which were identified seventy years later.

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