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Specifying Site Feature Locations in Terms of State Plane Coordinates

Dave Goss, CDG

Geographical information regarding the location of points on the surface of surveyed land areas usually can be found in one of three interrelated forms: latitude and longitude; range and township, section and subdivisions of section; state plane coordinates (in feet or meters). Latitude and longitude can be found from astronomical measurements, and are in some sense absolute. State plane coordinates are in fact projections of a curved reference grid onto some base level plane, and hence require specification of the projection scheme as well as the latitude and longitude of some tie points. Examples of projections are Universal Transverse Mercator, Lambert Conformal, and various polyconic projections that set up the grid. For example, in the transverse Mercator projection, the spheroid representing the Earth is mapped onto a cylinder (which then gives the base level plane when unrolled). This is done in section so that there are two meridian (longitude) lines along which the scale of the grid matches the scale on the spheroid. The Lambert conformal projection is onto a cone in similar fashion, such that the scales of the projection and spheroid match along two standard parallel (latitude) lines. The English and metric grids on which a given map is based are frequently based on different projections. The conversion factors are given in tables and formulae published by the National Geodetic Survey. Thus, for a given state, one or more grid systems define state plane coordinates for any surface point, so that a location with known latitude and longitude has known state plane coordinates in say, feet. The topics of map projections and state plane coordinates are treated in detail in Chapter 14 of Davis et al. (1981).

The ISP Footprint (J. Sanford, SSC-N-524, 6/88) has the coordinates of various SSC facilities and features defined by rectangular coordinates (X,Y) with the center of the main ring located at (100000,100000) (ft). The corresponding coordinates of such features with the origin taken at the center of the main ring are (x,y), where

$$x = X - 100000 \text{ ft}$$
$$y = Y - 100000 \text{ ft}.$$

If the state plane coorinates for the center of the ring are at $x = c(1)$ and $y = c(2)$, any location in the region can be found as a linear transformation of the ring coordinates.

That is, any location of a ring feature can be expressed in terms of the basic oriented ring coordinates $r(1) = x$ and $r(2) = y$ (themselves related to X and Y by translations) by a rotation R plus a translation. In terms of eastward and northward locations of a given point, $e = a(1)$ and $n = a(2)$, the relation between the (e,n) and the (x,y) coordinates is given by

$$a(j) = T(j,k)\, r(k) + c(j) \quad \text{(summation convention).}$$

The two dimensional rotation matrix T is given in terms of an angle u as

$$T = \begin{pmatrix} \cos u & \sin u \\ -\sin u & \cos u \end{pmatrix} = \begin{pmatrix} T(1,1) & T(1,2) \\ T(2,1) & T(2,2) \end{pmatrix}.$$

The angle u is the negative of the clockwise azimuthal angle that specifies the obliquity (skewness) of the long axis of the main ring (E3/E8); that is, it is the angle between the e and x axes or the n and y axes, with the sense of rotation from the first axis to the second. Alternatively, it is the angle that specifies the orientation of the main ring long axis taken counterclockwise from North, with the direction of the long axis from E8 to E3 in the "up" ring position (with Area I and the Near Cluster to the left and the far cluster to the right).

Real estate boundaries are often described (at least in part) by range, township, and section information. A standard rectangular method of subdivision is used in 32 states: all except the original thirteen states, Hawaii, Kentucky, Tennessee, Texas, and West Virginia. The grid is based on a reference point (the initial point) at which a standard parallel (latitude) line called the base line intersects with a standard meridian (longitude) line called the principal meridian. Secondary lines are established at intervals of 24 mi east or west of the principal meridian and at intervals 24 mi north or south of the base line; the secondary parallels (correction lines) are continuous lines along some latitude, and the secondary meridians (guide meridians) are broken at the parallels so that each is along a particular longitude. This system of standard lines is referenced to the initial point: there are first, second, third, etc. parallels North or South (of the Base Line) and first, second, etc. guide meridians East or West (of the Principal Meridian). A sketch in Davis et al. (1981) p 811 illustrates the layout of standard lines. Meridional lines (range lines) at equal intervals of 6 miles within each 24 mile sided quadrangle and latitudinal lines with similar spacing (township lines) form a quadrilateral termed a township. The location of a township is then found with respect to the initial point by designating the range and township number. For example, the designation T4S, R6W means the township in the fourth row of townships south of the base line and the sixth row west of the principal meridian. Township and range lines are illustrated in a sketch on p 812 of Davis et al.

Townships are divided into 36 parcels known as sections by constructing lines parallel to the east boundary of the township and by joining section corners established at intervals of one mile with straight lines running east/west.The sections are numbered from east to west on the north section row, west to east in the next row south, and so on (plow fashion). All the sections will be one mile square, except the sections 6,7,18,19,30 and 31 on the west edge of the township where the convergence of the longitudinal range lines with latitude makes the north section lines in these sections shorter than the south. The subdivision of a township into sections is illustrated on p 812 of Davis et al.

Parcels of land may be specified to the nearest 40 acres by successive quartering of sections. Example: the NW 1/4 of the SE 1/4 of Section 32, T7S, R3E. The details of surveying a region down to subdivision of areas smaller than sections is covered in detail in Chapter 19 of Davis, et al. For purposes of illustration of land boundary determination, I quote Example 19.3 directly from p 793 of that work: "A tract of land lying in Jackson County, State of Alabama, in the South Half (S 1/2) of the Northwest Quarter (NW 1/4) of Section Three (3), Township Six (6) South, Range Five (5) East of the Huntsville principal meridian, and more particularly described as follows: Beginning at a fence corner at the southwest corner of the Northwest Quarter (NW 1/4) of Section Three (3) (coordinates X416,239;Y1,470,588), said corner being six degrees twenty-four minutes West (N6^24'W) twenty-six hundred feet from the southwest corner of Section Three (3) (X416,529;Y1,468,004), and a corner to the land of T.E. Morgan; thence with Morgan's line the west line of Section Three (3), and a fence line, North five degrees thirty-three minutes West (N5^33'W) thirteen hundred and four (1304) feet to a fence corner (X416,113;Y1,471,886), a corner of the lands of T.E. Morgan, and the G.T. Cabiness estate...thence with Week's line, the south line of the Northwest Quarter (NW 1/4) of Section Three (3), and a fence line, North eighty-nine degrees eleven minutes West (N89^11'W) two thousand five hundred and fifty (2550) feet to a point on the ground shown by S.L. Cobler, a corner of the lands of H.O. Weeks and T.E. Morgan; thence with Morgan's line, the south line of the Northwest Quarter (NW 1/4) of Section Three (3), and the fence line North eighty-nine degrees eleven minutes West (N89^11'W), one hundred twenty-five (125) feet to the point of beginning. The above described land contains seventy-nine and six-tenths (79.6) acres more or less, subject to the rights of a county road which affects approximately five-tenths (0.5) acres, and is known as Tract No. GR 275, as shown on Map No. 8-4159-45, prepared by the Engineers of the Tennessee Valley Authority. The coordinates referred to in the above description are for the Alabama Mercator (East) Coordinate System as established by the U. S. Coast and Geodetic Survey, 1934. The Central Meridian for this coordinate system is Longitude eight-five degrees (85^) fifty minutes (50') no seconds (00")." A sketch map of the land boundaries is given on p 794 in Davis et al., who also describe land location by subdivisions in Examples 19.5 and 19.6.

The township system works fairly well in the places where it operates. However, owing to longitudinal convergence and errors of surveying in times past, the section lines are frequently not straight nor equal to a mile in length nor oriented along local North or East. Legal specifications of property are limited by the finite accuracy of surveying. For siting purposes, it does little good to specify the boundaries of a land parcel and its relation to proposed SSC features with much more accuracy than the survey method can determine. The site proponents have specified the location of various SSC features by overlaying a map of the footprint on the USGS topographic (1:24000 scale) 7.5 minute by 7.5 minute quadrangle maps of the site. Provided this overlay of the footprint is accurately positioned with respect to the location of fixed points or lines (e.g. monuments, roads, buildings,..) on the map, the parcels of land to be deeded to DOE for the SSC can be determined to within an accuracy of a few feet. This is usually somewhat better than the absolute boundaries of real property are known in terms of state plane coordinates. At any rate, it is possible to fix the location of particular parcels of property via the comparison of the legal description versus the particular plane coordinate locations of the boundaries.

This comparison can be carried out to any desired degree of accuracy if the geographic and parcel maps are both digitized and the analysis is assisted by computer.

Information about the main ring center location and the bearing of the long axis (obliquity) in terms of latitude, longitude and heading enables the ring center to be found in terms of state plane coordinates and the parameters of the coordinate transformation found for a particular center by either geometric comparison on a quadrangle map, or by calculation using the appropriate projection formulae. The former method is adequate for the specification of facility locations to the precision of real property locations. Table 1 shows the parameters useful in making the transformations, as determined from replicas of overlays of the footprint on 1:24000 USGS topographic maps.

A BASIC program (Program COORD) was written to perform the linear transformations from the local footprint coordinate system of the footprint to the state plane coordinate system. As an example, the inner land boundary of intermediate access area E3 at the center of the upper arc was chosen as a sample point, and its location in state plane coordinates calculated for each of the seven BQL sites. The results are listed in Table 2.

The National Geodetic Survey (NGS), National Ocean Service, Charting and Geodetic Services, a branch of the National Oceanic and Atmospheric Administration, administered by the U. S. Department of Commerce recently announced a revision of the projections, state plane coordinates, and geographic positions called the North American Datum of 1983 (NAD 1983). It bases the National Geodetic Horizontal Network on a geocentric (center of mass of the earth) reference system, and corrects distortions in the Network. This supersedes the North American Datum of 1927 (NAD 1927) system, which is based on the Clark ellipsoid of 1866 as the standard reference figure. In addition to furnishing a new set of Universal Transverse Mercator state plane coordinates (in meters) and corrected values of the latitude and longitude of the various stations, the local geoid height value, the deflection of the vertical at the station, point position accuracy referenced to the Earth's center of mass and standard errors in the above quantities are also available as information in the new system. A number of PC compatible computer programs are available for potential users to determine positions.

Three of these have been ordered by CDG to aid in refining site location information. The program GPPCGP converts NAD 27 state plane coordinates to NAD geographic positions (latitudes and longitudes), and conversely. It also includes the defining constants for all the NAD 27 plane coordinate zones. The program LEFTI transforms geographic positions from one datum to another. The program SPCS83 converts NAD 83 state plane coordinates to geographic positions and conversely. It also includes the defining constants (all the projection information) for all NAD 83 plane coordinate zones. It should be borne in mind that Federal and State agencies will be switching over to the NAD 83 system during the time of construction of the SSC, so that it is important to be able to go back and forth between NAD 83 and NAD 27. For example, all the USGS maps referring to site information (especially the ones submitted with the site proposals) are based on NAD 27.

Charting and Geodetic Services of the NGS also distributes Global Positioning System (GPS) Orbital Data. An ASCII mini 9-track 1600 bpi unlabeled magnetic tape with the ephemeris information (orbital positions and velocities) in 5-minute epochs spanning 7 days is available as a standard product. Each such tape currently costs $98, and is available for a 6 month subscription for $2057. Using GPS data and some software, it is possible to determine the position at which a receiver received the satellite signal with a precision of the order of a centimeter. Another NGS service that will be useful for the site survey work is the establishment of a calibrated base line using electronic distance measuring instruments. This is a standard operation on projects that require three dimensional locations of features to high precision. Commercial surveying firms often avail themselves of this service. The NGS also sponsors workshops on the following topics, among others: GPS satellite surveying, coordinate transformations, survey instrumentation and coordinate conversion, and vertical control.

It is therefore possible to specify the absolute locations of points on a site extremely accurately. In particular, from a knowledge of the state plane coordinates of the center of the main ring and the obliquity of the long axis, it is possible to determine the state plane coordinates of any point on the SSC footprint to the same degree of precision as the input data.

Table 1. Site Coordinates

STATE	LOCATION OF CENTER OF FOOTPRINT				OBLIQUITY
	Deg., min., sec.		State Plane Coords.		Deg., min., sec.
	Latitude	Longitude	North(ft)	East(ft)	Ref. Axes
AZ	32^58'14"	112^23'53"	717,181	352,350	S4^18'04"E
CO	39^57'31"	103^37'16"	233,300	2,526,700	N8^50'30"E
IL	41^49'46"	88^22'58"	1,880,400	486,450	S2^00'43"E
MI	42^27'18"	84^21'09"	348,075	1,994,850	S18^00'25"W
NC	36^19'09"	78^48'22"	935,165	2,057,162	N88^02'19"W
TN	35^42'13"	86^33'23"	477,890	1,834,765	N49^05'55"W
TX	32^21'44"	96^48'37"	253,600	2,212,900	N12^58'28"W

X = 1000,000 ft, Y = 148,181 ft

STATE	EAST (FT)	NORTH (FT)
AZ	355,963	669,136
CO	2,534,106	280,908
IL	488,141	1,832,249
MI	1,979,172	302,516
NC	2,009,009	936,814
TN	1,871,182	446,343
TX	2,202,083	300,551

REFERENCES

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U. S. Department of Energy, Office of Energy Research, SSC Site Task Force, (April, 1987) Invitation for Site Proposals for the Superconducting Super Collider (SSC) = ISP

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100 REM PROGRAM COORD: CALCULATES STATE PLANE COORDINATES OF POINTS
101 REM ON FOOTPRINT OF OBLIQUITY = -u GIVEN SPC OF RING CENTER
105 INPUT "X=", X
110 INPUT "Y=", Y
120 PRINT "ENTER OBLIQUITY (CCW) DEGREES, MINUTES, SECONDS"
130 INPUT D,M,S
140 INPUT "CENTER EAST, FEET", C(1)
150 INPUT "CENTER NORTH, FEET", C(2)
160 (U=D+M/60+S/3600)*.017453293#
170 T(1,1)=COS(U)
180 T(2,2)=T(1,1)
190 T(1,2)=-SIN(U)
200 T(2,1)=-T(1,2)
210 R(1)=X-100000
220 R(2)=Y-100000
230 FOR I=1 TO 2
240 FOR J=1 TO 2
260 A(I)=T(I,J)*R(J)+C(I)
270 NEXT J
280 NEXT I
285 PRINT "e=", A(1)
290 PRINT "n=", A(2)
300 END
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