1.3 Coordinate Calculation

1.3.1 Coordinate calculation processing in 1999

Regarding the survey results in 1999, the results of the coordinates (latitude, longitude, ellipsoidal height) of GRS80 coordinate system have been first gained. Next, the results of the other five types of coordinate have been gained by calculation processing of coordinate conversion in the order of 2) -> 3) -> 4) -> 5) -> 6) on the basis of these coordinate results.

1) Calculation of the latitude, longitude and ellipsoidal height of GRS80 coordinate system
The latitude, longitude and ellipsoidal height of GRS80 coordinate system of all points in the network are obtained through a three dimensional network adjustment in which the total station observations (range, horizontal angle and vertical angle), leveling observations are used as fixed point of height components, and the coordinates and orientaion at the station datum determined by GPS survey are used as the known.

2) Coordinate conversion from GRS80 coordinate system to ITRF94 coordinate system
The latitude, longitude and ellipsoidal height of GRS80 coordinate system have been converted to X,Y and Z of ITRF94 coordinate system according to the following formula:

$$X = (N+h) \cos(phi) \cos(lambda)$$
$$Y = (N+h) \cos(phi) \sin(lambda)$$
$$Z = \{N (1-e^2) +h\} \sin(lambda)$$

Where, phi:latitude, lambda: longitude, h : ellipsoidal height, N : radius of east-west curvature, e : first eccentricity.

3) Conversion from ITRF94 coordinate system to local coordinate system (without geoid correction)
X,Y and Z of ITRF94 coordinate system have been converted respectively to X_{local}, Y_{local} and Z_{local} of local coordinate system according to the following formula:

$$X_{local} = X-X_0$$
$$Y_{local} = Y-Y_0$$
$$Z_{local} = Z-Z_0$$

Where, X_0, Y_0, and Z_0 are the coordinate values of the ITRF94 coordinate system of the station datum at each observation station.

4) Conversion from local coordinate system (without geoid correction) to horizontal coordinate system (without geoid correction)
X_{local}, Y_{local} and Z_{local} of local coordinate system have been converted to N, E and U of horizontal coordinate system according to the following formula:

$$\begin{bmatrix} N \\ E \\ U \end{bmatrix} = \begin{bmatrix} -\sin(phi)\cos(lambda) & -\sin(phi)\sin(lambda) & \cos(phi) \\ -\sin(lambda) & \cos(lambda) & 0 \\ \cos(phi)\cos(lambda) & \cos(phi)\sin(lambda) & \sin(phi) \end{bmatrix} \begin{bmatrix} X_{local} \\ Y_{local} \\ Z_{local} \end{bmatrix}$$

Where, phi : latitude, lambda : longitude.

5) Conversion from horizontal coordinate system (without geoid correction) to horizontal coordinate system (with geoid correction)
Geoid correction of horizontal coordinates has been executed according to the following formula by using the angle of inclination of the primary inclination constituent of geoid inclination (constituent xi for north-south direction and constituent eta for east-west direction). (Refer to 1.4 for the details regarding the primary inclination constituent of geoid.)

$$\begin{bmatrix} N_{geoid\_correction} \\ E_{geoid\_correction} \\ U_{geoid\_correction} \end{bmatrix} = \begin{bmatrix} \cos(xi) & 0 & -\sin(eta) \\ \sin(eta)\sin(xi) & \cos(eta) & \sin(eta)\cos(xi) \\ \cos(eta)\cos(xi) & -\sin(eta) & \cos(eta)\cos(xi) \end{bmatrix} \begin{bmatrix} N \\ E \\ U \end{bmatrix}$$

6) Conversion from horizontal coordinate system (with geoid correction) to local coordinate system (with geoid correction)
Horizontal coordinate system (with geoid correction) has been converted to local coordinate system (with geoid correction) by rotating the geoid correction ($N_{geoid\ correction}$, $E_{geoid\ correction}$ and $U_{geoid\ correction}$) of horizontal coordinate system to reverse direction according to the formula described in 4. The deviation that has been found with this rotation is only limited to the vertical deviation of the coordinate axis and had almost no effect at all to the conversion since the angle difference was very small.

$$\begin{bmatrix} X_{local\_geoid\_correction} \\ E_{local\_geoid\_correction} \\ U_{local\_geoid\_correction} \end{bmatrix}$$

$$= \begin{bmatrix} -\sin(phi)\cos(lambda) & -\sin(lambda) & \cos(phi)\cos(lambda) \\ -\sin(phi)\sin(lambda) & \cos(lambda) & \cos(phi)\sin(lambda) \\ \cos(phi) & 0 & \sin(phi) \end{bmatrix} \begin{bmatrix} N_{geoid\_correction} \\ E_{geoid\_correction} \\ U_{geoid\_correction} \end{bmatrix}$$

Where, phi : latitude, lambda : longitude.

1.3.2 Coordinate calculation processing in 1996 - 1998

1) The same procedure for coordinate calculation processing in gaining the survey results in 1999 is applied to data obtained once every year between 1996 - 1998.

2) However, as for the coordinates (latitude, longitude and ellipsoidal height) and the azimuth angle (station datum -> azimuth reference point) of the station datum (as shown in Table 6) which were necessary in the three-dimensional network adjustment for determining the latitude, longitude and ellipsoidal height of GRS80 coordinate system, the values gained in 1999 have been used.

Table 6 Station datum and Azimuth reference point

	Koganei station	Kashima station	Miura station	Tateyama station
Station datum	S3	S3	S3	L2
Azimuth reference point	S1	S1	L2	L1