Concept of the New Japanese Geodetic System

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Abstract

The new geodetic reference system for horizontal and vertical positioning adopted in 2002 in Japan will be described. The geodetic reference system, or "Japanese Geodetic Datum 2000", includes the geocentric geodetic system as the standard for measuring latitudes and longitudes, and the orthometric height system. The transition of the geodetic reference system was realized by an amendment of the Survey Act, which defines the standard for land surveying in Japan.

1. Introduction - Geodetic Reference System -

A geodetic reference system is defined as a total of the datums for representing a position on the earth and the reference frames for realizing the datums. Latitude, longitude and height are common concepts for representing a position on the earth. Many people may think that these concepts are defined by natural law and consequently are uniquely defined. In fact, references for these are artificially defined by each nation and had varied in each nation until the middle of the 20th century, as is well known in the geodesy community. The reason why the references varied by nation is that these had been established and defined by the results of astronomical observations in each nation or area and surveying and mapping were carried out based on their own references.

In the late 20th century, "classic" geodetic reference systems were replaced by space geodetic technologies such as VLBI (Very Long Baseline Interferometry), LLR (Lunar Laser Ranging), SLR (Satellite Laser Ranging), and GPS (Global Positioning System). The geocenter and the rotation axis of the earth and other parameters, which are necessary for obtaining globally common geometric position by latitude and longitude, could be observed with high accuracy by these new technologies. On the other hand, the vertical reference systems of each nation, which depend on potential of gravity, are not yet globally common at the moment.

In this report, the "Tokyo Datum" represents the old geodetic reference system, which had been used until March 31, 2002 and "Japanese Geodetic Datum 2000"represents the new geodetic reference system, which has been used since April 1, 2002. "Geodetic Coordinates 2000" represents both a set of latitudes and longitudes of national reference points as the realization of the Japanese Geodetic Datum 2000 in the horizontal, and a set of heights of national benchmarks of the results in the vertical adjusted in 2000.

2. Horizontal Positioning

2.1 References for Determining Latitude and Longitude

In Japan, references for determining latitude and longitude are legally defined in the Survey Act and the Hydrographical Operation Act (ref. "3. Survey Act and Geodetic Reference System"). Defining references for longitude and latitude is important for precise positioning, because they are defined not by natural law nor uniquely but artificially.

It is easily understood that the reference for determining longitude is artificially defined, because longitude cannot be determined without defining the primary meridian. The reference for determining latitude is also artificially determined, which might be strangely received by lay people who think that the reference for latitude is the rotation axis of the earth. The rotation axis of the earth is not exactly identical with the axis of the reference ellipsoid of the earth because of polar motion, and therefore it is necessary to define artificially the axis of the earth ellipsoid to determine latitude.

2.2 Local Geodetic Reference System

A local geodetic reference system is defined as a system for determining longitude and latitude, based on an origin point whose longitude, latitude and azimuth are determined by astronomical observation, and an ellipsoid adopted by each nation. Disagreement among local geodetic reference systems may sometimes extend to several hundred meters, because vertical deflection affects the results of astronomical observations carried out at the origin points.

Until the enforcement of the amended Survey Act on April 1, 2002, the local geodetic reference system had been used in Japan, based on the origin point at the former Tokyo Astronomical Observatory, Azabudai in Tokyo, whose longitude, latitude and azimuth were determined by astronomical observation carried out in the 19th century, and based on the Bessel Ellipsoid adopted by the Meiji Government.

2.3 Global Geodetic Reference System

A global geodetic reference system is defined as a geocentric geodetic system for determining a geometric position, which has its origin at the mass center of the earth, its Z-axis along the assumed rotation axis of the earth, its X-axis along the prime meridian direction and a right-hand Cartesian coordinate system, which is a globally common standard for positioning.

Generally, latitude and longitude are used to express a position in a global geodetic reference system, because of the intuitively difficult apprehension of geocentric Cartesian coordinates. Geocentric Cartesian coordinates can be transformed to latitude and longitude by assuming a reference ellipsoid.

Strictly speaking, there are several kinds of realizations of global geodetic reference system. Differences among these realizations are caused by slight differences of realized mass centers of the earth, adopted reference ellipsoids and plate motions.

In the amended Survey Act, the realization of the global geodetic reference system is based on ITRF, International Terrestrial Reference Frame, which is one of the major realizations.

2.3.1 ITRF

ITRF is a realization of ITRS, International Terrestrial Reference System, which is a definition of geocentric system adopted and maintained by IERS, International Earth Rotation and Reference Systems Service. IERS was established in 1987 on the basis of the resolutions by IUGG and IAG. The GRS80 ellipsoid is recommended by IERS to transform Cartesian coordinates to latitude and longitude.

The ITRF is a set of points observed by VLBI, LLR, GPS, SLR, and DORIS with their 3-dimensional Cartesian coordinates and velocities, which realizes an ideal reference system, the International Terrestrial Reference System. The ITRF has been updated almost every year. Each ITRF is identified by the digits of the year as ITRFyy (yy=89,90,91,92,93,94,96,97,2000). ITRF94 (Boucher et al. 1996) was adopted for establishing the Japanese Geodetic Reference 2000 because it was the latest version we could use during the establishment of JGD2000 started.

2.3.2 WGS84

WGS84 is the geocentric geodetic system adopted by GPS, Global Positioning System. WGS84 includes definitions of a reference ellipsoid and a geoid model as well as a definition and realization of geocentric geodetic system. WGS84 was developed and is maintained by the United States Department of Defense. WGS84 has become more consistent with ITRF after several revisions. Its present version is WGS84 (G1150), which introduced velocity fields for the first time as WGS (Merrigan et al., 2002). The present WGS84 is coincident with ITRF within 1-centimeter accuracy. The WGS84 reference ellipsoid is slightly different from GRS80 ellipsoid by about 0.3 millimeters of its minor-axis radius.

2.3.3 Densification of the Geocentric Geodetic System

The number of stations directly realized by the geocentric geodetic system is not enough for practical use, as there are several hundred realized stations in ITRF and about twenty stations in WGS84 over the world. Therefore, it is necessary to raise the density of local stations based on the given stations realized by geocentric geodetic system in each nation or area, which is called “densification”. Examples of densification projects are “NAD83” or “North American Datum of 1983” in North America, “SIRGAS” or “Sistema de Referencia Geocentro para America del Sur” in South America, “ETRF” or

"European Terrestrial Reference Frame" in Europe, "APRGP" or "Asia and the Pacific Region Geodetic Project." The Japanese Geodetic System 2000 can also be thought of as one densification project.

NAD83 covers not only the North American Area such as Canada, the USA and Mexico but also the other areas such as Hawaii, the Caribbean islands and Greenland. These nations and areas have adopted the geocentric system as their national geodetic system.

In Asia and the Pacific Area, several nations and areas such as Japan, Korea, Taiwan, Indonesia, Australia, and New Zealand have adopted the geocentric system.

2.4 Determination of Latitude and Longitude in Japan

In this section, the way latitude and longitude were determined in Japan will be introduced. Firstly, the astronomical determination of latitude and longitude carried out from the late 19th century to the early 20th century, and secondly the latest determination carried out by space technologies at the end of the 20th century will be described.

2.4.1 Realization of Tokyo Datum

Precise astronomical determination of longitude in Japan started in the Meiji Era at the end of the 19th century. In 1874, observation parties from the USA and other countries came to Japan to observe the transit of Venus on the sun. The USA party had planned to determine the difference of the longitudes between Nagasaki and Vladivostok, which were already connected by a submarine cable laid in 1871. The USA party carried out the additional determination of the difference between the longitude of Nagasaki and Tokyo at the request of the Navy Hydrographic Department. While the determination of the longitude carried out in Yokohama by England was based on the chronometer transportation method, the determination of the longitude by the USA party was based on the telegraph longitude method, which uses wire telegraph signals for time synchronization. The telegraph longitude method highly improved the accuracy of longitude determination. The Geographic Department of the Interior Ministry also carried out the determination of the longitude difference between Nagasaki and Tokyo from 1879 to 1880.

In 1881, the determination of the longitude difference between Madras and Nagasaki was carried out by the USA. As longitude determination in Madras had already been carried out by England, the longitude in Nagasaki was determined. The longitude difference between Nagasaki and Tokyo was determined by the determination of the longitude difference between Nagasaki and Yokohama carried out by the USA and the determination of the longitude difference between Yokohama and Tokyo carried out by the Geographic Department of the Interior Ministry. The average of this result, the result by the USA in 1874 and the result by the Geographic Department from 1879 to 1880, was adopted as the longitude at the Tokyo Naval Observatory, later the Tokyo Astronomical Observatory. The Hydrographic Bureau of the Navy and the Survey Bureau of the Staff Headquarters of the Army, which took over the work of the Geographical Department of the Interior Ministry in 1884, adopted this longitude as the unified standard. The Land Survey Department, which was established as an organization under the Chief of the General Staff of the army, settled *Nihon Keiido Genten* (the origin point for the horizontal datum of Japan) at the Tokyo Naval Observatory in 1892 based on this value.

The Hydrographic Department of the Navy newly carried out the determinations of the longitude differences between Guam and Tokyo in 1915, and between Vladivostok, under the circumstance that the longitude difference determinations were carried out globally. Based on this result, the determination, the content of which is that the value of the longitude at the origin point should be added by 10.405 seconds of arc, was made in the form of an Education Ministry Announcement in 1918. The Land Survey Department also adopted the revised longitude at the origin point as the longitude standard for surveying. This longitude was used as the standard for surveys until the amendment of the Survey Act was enforced in 2002.

Concerning the latitude of the origin point, the value determined by the astronomical observation at the Tokyo Naval Observatory in 1876 was adopted as the standard until the Survey Act Amendment.

The latitudes and longitudes of the triangulation points in Japan were calculated by land triangulation surveys and baseline surveys to determine the latitude and longitude difference relative to the origin point, excluding the control points of the isolated islands. The latitudes and longitudes of the first order triangulat survey ion points were calculated based on results of surveys carried out from 1882 to 1913. The network adjustment calculation was done by dividing the whole country into 15 block areas. The latitudes and longitudes of the second order and third order triangulation points were sequentially calculated based on the survey carried out from 1883 to 1920 and the latitudes and longitudes of the first order triangulation points. After that, these latitudes and longitudes were basically used unless they were updated by the re-surveys following some major earthquakes such as the 1923 Kanto Earthquake in Tokyo. Actually, the azimuth at the origin point was also revised after the Kanto Earthquake. From 1951, the establishment of forth order triangulation points began to promote cadastral surveys.

This set of latitudes and longitudes of the triangulation points and the origin point is called the “Tokyo Datum”. It was gradually found that there were some problems in the Tokyo Datum, which are not only the shifts of the latitudes and longitudes caused by neglecting the vertical deflection and the geoid height at the origin point, but also the distortions caused by the errors of survey and calculation and the accumulated crustal movements by earthquakes and plate motions.

2.4.2 Geodetic Coordinates 2000: Realization of Geocentric Geodetic System

In 1989, GSI formed an internal committee or “Sectional Committee on Geodetic System and Control Points”, which compiled a report in March 1993, based on consideration of what a geodetic system and control points in Japan should be. After that, under the condition of unexpectedly rapid development of the facilities of GSI, such as construction of about 900 GPS-based control stations at the time of March 1997, and expectation of fast-paced generalization of the GIS or Geographic Information System, GSI formed the second “Sectional Committee on Geodetic System and Control Points in March 1997. In its report, compiled in 1998 March, the new policy, which includes the adoption of a geocentric geodetic system, the Japanese Geodetic Datum 2000, and the establishment of realization of geodetic results or the Geodetic Coordinates 2000, was decided. To realize the adopted policies, the amendment of the Survey Act was necessary.

The outlines of the reports are as follows.

1) Report of Sectional Committee on Geodetic System and Control Points

- Object

  Provision of a standard for positioning at any time, at any location and at necessary accuracy

- Necessity

  Catching up with user’s severer requirements on accuracy and extended needs for various services for providing information of positions in an information society

- New Geodetic System and Control Points

  Their requirements are

  (a) Easy-to-use for positioning

  (b) Positioning with the necessary accuracy

  (c) More increased options for positioning

  Policies to be realized in the next decade are

  (a) Reconstruction of the present control points and establishment of about fifty GPS-based control stations

  (b) Maintenance of precise three-dimensional coordinates by periodic repetitions of integrated geodetic surveys

  (c) Establishment of a new datum at an early stage and online provision system of geodetic coordinates under both the Tokyo Datum and geocentric geodetic system

2) Peport of 2nd Sectional Committee on Geodetic System and Control Points

- Problems of the geodetic system at the time

  Misfits between the geocentric geodetic system and the geodetic system adopted at the time, such as difference of ellipsoidal parameters, while an adoption of geocentric geodetic system was internationally recommended by the International Civil Aviation Organization, the International Hydrographic Organization and the United Nations Regional

Cartographic Conference for Asia and the Pacific and the like.

Needs for accuracy of the geodetic datum, which has been rapidly increasing under the circumstances of rapid progress on survey technology.

Difficulty in maintaining a big number of control points.

- Circumstances of the reconstructing geodetic system

  Development of GPS-based control stations at high density as its skeleton

- Requirements on geodetic system and control points
  - (a) Scientific rationality: Adoption of a precise reference ellipsoid and reference system based on modern geodesy, astronomy and geophysics
  - (b) Internationalism: Adoption of a geocentric geodetic system recommended by the international organizations
  - (c) Accuracy: Precise coordinates all over Japan determined by space geodetic technology such as VLBI and GPS
  - (d) Maintenance: Easy maintenance of reference frame with GPS-based control stations and minimum control points
  - (e) Availability: More varied and effective services for users such as online data provision, containing GPS data of GPS-based control stations
- Specifications for new geodetic system and control points
  - (a) Denomination: Japanese Geodetic Datum 2000 or JGD2000
  - (b) Reference Ellipsoid: GRS80 Ellipsoid
  - (c) Reference Frame: ITRF94 fixed at the epoch of 1 January 1997 0:00 UT
  - (d) Densification of Reference Frame

  The procedure for the densification is as follows.

  1) VLBI station: Coordinates reduced at the epoch of 1 January 1997 0:00 UT at Kashima VLBI observation station in ITRF94
  2) GPS-based control stations: Network adjustment all over Japan under the condition of fixing the coordinates of the several VLBI stations reduced at the epoch of 1 January 1997 0:00 UT
  3) First-order triangulation stations and a part of second-order triangulation stations whose total number is about 2500: Network adjustment all over Japan with data of observation by EDM and GPS since 1974 under the condition of fixing the coordinates of the GPS-based control stations
  4) Other resurveyed second-order triangulation stations and third-order triangulation stations: Network adjustment all over Japan with data of observation by EDM since 1974 under the condition of fixing the coordinates of the above triangulation stations
  5) Un-resurveyed second-order triangulation stations and third-order triangulation stations: Network adjustment with data of the latest available observation, almost all of which were carried out several tens of years ago, at each point under the condition fixing the coordinates of the above triangulation stations
  6) Fourth-order triangulation stations: Transformation with parameters determined by the differences between the old and new coordinates of the first, second and third-order triangulation stations

3. Vertical Positioning

Vertical position is expressed by height. Height is not a geometric quantity but a quantity based on gravity potential, differing from latitude and longitude. It is natural for human sense because it is natural to people that water flows to a lower position, the physical meaning of which is that a body is moved to a lower potential position by gravity.

3.1 Tokyo Bay Mean Sea Level

Survey Act Article 11 describes that position should be principally represented by geographical latitude and longitude, and height above the mean sea level. The “mean sea level” of the article is defined in the Cabinet Order of the Survey Act, which describes that the numeric value of *Nihon Suijun Genten* (the origin point for the vertical datum of Japan) is 24.4140 meters above the mean sea level at the Tokyo Tokyo Bay. The numeric value at the origin point, which is located at Nagata-cho 1-1, Chiyoda-ku, Tokyo, was at first determined to be 24.0000 meters by tidal observation from 1873 to 1879 at Reigan-jima in Tokyo Bay and a tie survey between the origin point and the tidal observation station. The numeric value was revised to the present value due to the crustal movement accompanying the Kanto Earthquake in 1923, based on the recovery survey.

3.2 Definition of Geoid

A geoid is defined as an equipotential surface of gravity that is coincident with mean sea level, which is used as the theoretical standard of height, as it is an ideal mean sea level, which is not affected by tide, ocean currents or waves, differing from the real mean sea level.

3.3 Vertical Reference System in Japan

In the Japanese vertical reference system in 2000, the orthometric height system is adopted, which displaced the normal orthometric height system used in the former vertical system, the Japanese vertical reference system, in 1969. Approximately, orthometric height is defined as the length along a plumb line between a point and the standard equipotential surface. While a general method for determining an orthometric height is a leveling survey, a sum of measured values at each measuring point with a leveling survey without any gravitational correction is not coincident with the orthometric height, because of the effect whereby equipotential surfaces are not exactly parallel.

Correction considering gravity potential is necessary to determine an orthometric height from measured values. While measured gravity values are used for correction of an orthometric height, normal gravity values, which are calculated by a function of latitude derived from a normal gravity model, are used for correction of a normal orthometric height.

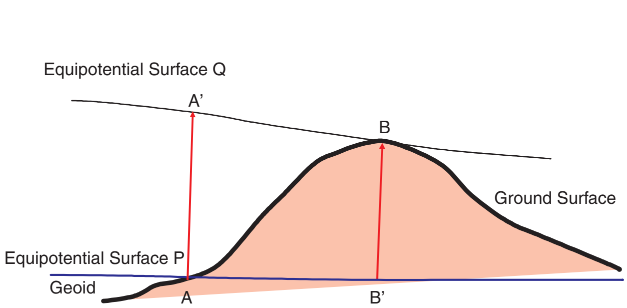

Fig. 1-1 The results of leveling surveys, paths of which differ such as along AA' and A'B, and along AB' and BB', are not correspondent

3.4 Ellipsoidal Height and Geoidal Height

Ellipsoidal height, which is defined as the length between a point and the surface of the reference ellipsoid along the normal line on the ellipsoid, is a geometric quantity, while orthometric height or normal orthometric height is a quantity based on gravity potential. Ellipsoidal height is a quantity concerning vertical direction firstly determined by using space geodetic techniques such as GPS, which can directly determine a three-dimensional geometric position. GSI has been providing a geoid model since 1998 for transforming an ellipsoidal height to an orthometric height consistent with the vertical system prescribed in the Survey Act with the background of the rapid popularization of GPS. "Geoid 2000 in Japan" is the latest version of a geoid model that is available for fundamental and public surveys.

4. Survey Act and Geodetic Reference System

The Survey Act defines the standard for land surveying in Japan, which includes the geodetic system. Based on an amendment of the Survey Act effective from 1st April 2002, Japanese Geodetic Datum 2000 was adopted, succeeding the Tokyo Datum. In this section, the Survey Act before and after the amendment will be called the Old Act and the New Act respectively.

4.1 Scope of Survey Act

4.1.1 Scope of Article 11 "Survey Standard"

The Survey Act regulates land surveys, which includes fundamental surveys, public surveys and surveys other than fundamental surveys and public surveys. The standard for land surveys is defined in accordance with the provisions of Article 11 of the Survey Act. Article 11 is the regulation that fundamental surveys and public surveys should be based on. As land surveys other than fundamental and public surveys depend on fundamental surveys and public surveys, almost all land surveys are substantially based on the standard defined in Article 11.

Article 11 is understood to be the regulation on not the results of surveys but the actions of surveys as it prescribes that surveys must be carried out under this regulation. Therefore after the amendment of the Survey Act, the results of surveys, which were carried out under the Old Act and are based on the old standard, are not illegal in themselves, while new surveys should be carried out based on the new standard and the old results which new surveys are based on should be transformed according to the new standard.

4.1.2 Relationship of Survey Act and Hydrographical Operation Act with other Acts

Generally amendments of acts are enforced by enforcements of other acts, which amend the objective acts. The Survey Act was amended with the Hydrographical Operation Act, which defines the provisions of the standard for hydrographical surveys as well as the Survey Act, by the enforcement of an "Act which amends partially the Survey Act and the Hydrographical Operation Act". An "act which amends partially the Survey Act and the Hydrographical Act" contains not only the amendments of the survey standards of both acts but also the amendments of the other three acts in which the numeric values of latitude and longitude are described. The numeric values of latitude and longitude in these acts were revised from those based on the Tokyo Datum to those based on the Japanese Geodetic Datum 2000. As there is no other act that defines the standard of latitude and longitude, excluding the Survey Act and the Hydrographic Operation Act, both acts are thought to be a kind of basic act concerning latitude and longitude, which affects other acts which contain numeric values of latitude and longitude.

4.2 Representation of Position

Article 11 Term 1 of the Survey Act, which prescribes representation of position, describes that position should be principally represented by geographical latitude and longitude, and height above the mean sea level, while position can be represented by each of 1) rectangular coordinates and height above the mean sea level, 2) polar coordinates and height above the mean sea level, and 3) geocentric Cartesian coordinates, according to circumstances. The provision of geocentric coordinates, which is useful for surveys based on space geodetic technology such as GPS and VLBI, was newly added by the amendment.

4.3 Distance and Area

Article 11 Term 1 also describes that distance and area should be represented as values projected on the ellipsoid defined in Article 11 Term 3, while it was described in the Old Act that distance and area should be represented as values projected on a horizontal plane. Though the prescriptions in the Old Act and the New Act differ literally, the prescribed requirements are same. It became a more strict expression in the New Act because the prescription on ellipsoid was added explicitly by the amendment.

4.4 Origin Point

4.4.1 Origin Point for Definition of Geodetic System

The Commentary of the Survey Act (Kawaguchi, 1963) describes on origin point as follows.

Representing a position of a point is performed by both defining a position of a given point and locating a geometrical relative position between the given point and the position-unknown point. A position of a point on the earth is represented by geographical latitude and longitude. Datum or numerical values of latitude, longitude and azimuth at *Nihon Keiido Genten* (the origin point for the horizontal datum of Japan) were determined by the astronomical observation of latitude, longitude and azimuth whose target is the Kanozan first-order triangulation point at the origin point, which is located at Azabudai, Minato-ku, Tokyo. A position of a triangulation point over Japan is determined by locating relatively a geometrical position between the point and the other triangulation points or the origin point. Latitude and longitude based on such a procedure are called "geodetic latitude and longitude" in the field of geodesy, while the term "geographical latitude and longitude," which indicates the same content, is used in the Survey Act.

While it is prescribed in the Survey Act that height should be represented by height above the mean sea level, it is also prescribed that a determination of height should be based on the *Nihon Suijun Genten* (the origin point for the vertical datum of Japan), because it is practically impossible to measure directly a height at any point from mean sea level, which lacks uniformity of measurement. Datum or numerical value of height at the origin point was determined with the mean sea level as zero meters, which was determined by long-term and continuous measurement at Tokyo Bay. Therefore determination of all heights of triangulation points and benchmarks are based on the datum at the origin point for the vertical.

Though the Commentary explains the content of the Old Act, its description concerning the origin point is still applicable to the New Act, excluding the description concerning the astronomical determination of the datum at the origin point.

Briefly,

1) It is necessary for precise positioning to locate a relative position from a point whose position is already given.
2) It is necessary for representing positions of points uniformly and consistently over a nation to determine only one starting point whose position is given.
3) The starting points are the origin points for the horizontal datum and the vertical datum.

This explanation concerning the origin point is common to the Old Act and the New Act. According to the classic theory of geodesy, the origin point has another meaning, that it defines a geodetic system, the role of which is to define the relationship between the substantial earth and a reference ellipsoid based on the origin point itself and the plumb line at the origin point. That is

1) Six parameters, or three parameters for translation and three parameters for rotation, are necessary to define the relation between the substantial earth and a reference ellipsoid.
2) The values of latitude, longitude and azimuth at the origin point for the horizontal datum and the value of height at the origin point for the vertical datum determine four parameters.
3) Besides them, the coincidence of the plum line and the ellipsoid normal at the origin point for the horizontal determines two parameters, which comes from adopting astronomical latitude and longitude values as datum at the origin point.

In the New Act, the origin points have no role in defining the relation between the substantial earth and a reference ellipsoid, which is prescribed in Article 11 Term 3 as a description of a geocentric geodetic system. The origin point in the New Act realizes symbolically the concept of a geocentric geodetic system and has the role of a starting point of latitude and longitude in Japan.

4.4.2 Location of Origin Point

The Cabinet Order of Survey Act prescribes the location of the origin points. The location of the origin point for the horizontal datum are described respectively in the New Cabinet Order and the Old Cabinet Order, "The intersection point of the cross carved on the metal mark of *Nihon Keiido Genten*, Azabudai 2-18-1, Minato-ku, Tokyo" and "The center point of the meridian circle of the former Tokyo Astronomical Observatory, Azabudai 2-18-1, Minato-ku, Tokyo", which indicate different places.

In the Meiji Era the origin point for the horizontal datum was settled at the point at which latitude and longitude was first determined in Japan when there was the Naval Observatory, which later changed to the Tokyo Astronomical Observatory, and at which the Land Survey Department started its triangulation surveys. The position of the meridian circle of the former Tokyo Astronomical Observatory was displaced by about one meter because of the crustal movement caused by the Kanto Earthquake in 1923. When recovery surveys over the earthquake area were carried out under the condition of fixing the outer first-order triangulation points like Tukuba-san as immobile points, and the latitudes and longitudes of the triangulation points in the earthquake area were re-determined, the latitude and longitude at the origin point were unchanged and only the azimuth whose target was the Kanozan first-order triangulation point was revised.

"The intersection point of the cross carved on the metal mark of *Nihon Keiido Genten*" was settled at the point at which the meridian circle of the former Tokyo Astronomical Observatory had been settled and displaced by the Kanto Earthquake. The datum or the latitude, longitude and azimuth at the origin point described in the New Cabinet Order were determined by surveying based on the Japanese Geodetic Datum 2000. In chronological order, the datum at the origin point was determined after the latitudes and longitudes of the other points had been determined by GPS and VLBI surveys, while the latitude and longitude at the origin point are the legal starting values of latitudes and longitudes over Japan.

4.4.3 Numerical values at the Origin Point

As latitudes and longitudes or heights represented in fundamental and public surveys are based on the numeric values at the origin points, if a crustal movement caused by an earthquake moves locally the origin points, the revision of the numerical values at the origin points will be considered from the point of view of social influence.

When the Kanto Earthquake occurred in 1923 in the Kanto Area, in which the origin points are settled, the numerical value of the origin point for the vertical and the azimuth at the origin point for the horizontal were revised. There is some possibility that it will be necessary to revise the numerical values at the origin points because of a local crustal movement in future, as several earthquakes have occurred in the past, such as the Keian Earthquake in 1649, the Genroku Earthquake in 1703, the Edo Earthquake in 1855 and the like, which could have moved the origin points, in this area.

Besides earthquakes, the land over Japan is gradually becoming distorted at the rate of several centimeters per year because of plate motion. But, as long as consistency in the results of the surveys is maintained, it is not rational to revise the numeric values at the origin point frequently, for example every year, which causes the revision of latitudes and longitudes in the results of fundamental and public surveys. The revision of the numeric values at the origin point will be considered when the accumulated distance of the origin point caused by plate motion reaches several meters after about 40 or 50 years, under the social conditions at the time such as accuracy and popularization of location-based services.

4.5 Definition of Geocentric Geodetic System

In Article 11, Term 3, the concept of the geocentric geodetic system is prescribed as the survey standard for determining latitude and longitude assuming the earth to be an ellipsoid meeting the following requirements.

1) Its semi-major axis and flattening are the numerical values defined in the Cabinet Order based on the international decision concerning the determination on the geographical latitude and longitude.
2) Its center coincides with the center of mass of the earth.
3) Its minor axis coincides with the rotation axis of the earth.

This definition does not explicitly describe the prime meridian direction, which is implicitly defined in the word of geographical longitude. The international decision concerning determination of the geographical latitude and longitude in the Survey Act means the geocentric geodetic system using ITRF and the GRS80 ellipsoid, which IUGG, the International Union of Geodesy, and Geophysics, and IAG, the International Association of Geodesy, resolved to adopt for precise positioning.

Acknowledgements

The authors would like to express their sincere appreciation to Mr. Kozo Kamada and Dr. Yuki Kuroishi for their suggestions and comments.

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