INTERNATIONAL UNION OF
GEODESY AND GEOPHYSICS

Japan

Report of the Geodetic Works in Japan
for the Period from Jan. 1967 to Dec. 1970

PREPARED FOR THE XV GENERAL ASSEMBLY
MOSCOW, U.S.S.R.
JULY 30TH—AUGUST 14TH, 1971

COMPILED BY
SECTION OF GEODESY,
NATIONAL COMMITTEE FOR
GEODESY AND GEOPHYSICS OF JAPAN
Triangulation, Traverse and Trilateration

The geodetic triangulation, traverse and trilateration in Japan have been conducted by the Geographical Survey Institute. The fundamental framework of the triangulation was established until 1913 and consists of 330 principal first order stations.

The revision survey of the network was started in 1947 and was completed in 1967. In this survey, 26 sides in the network were measured directly with geodimeter and 74 Laplace stations were established, while the old survey included only 13 base lines and had no Laplace control.

Since then, the next turn of the revision survey has been in progress as shown in Fig. 1. The revision survey aims to maintain the network as well as to detect the crustal deformations which is considered to be the basic material for a study on prediction of earthquakes. In the present survey, angle observations are made with Wild precision theodolites using direction method and laser geodimeter is used for distance measurements. About two thirds of the whole first order stations are planned to be Laplace stations and are occupied with GSI astrolabe for astronomical observations.

As to the second and third order triangulations, resurveys are carried out only for areas where they are required owing to remarkable crustal deformations or other causes. Recently these resurveys have been planned and accomplished by method of the traverse survey with the geodimeter or other electronic distance measuring instruments.

Minor control points have been established by the fourth order triangulations or second order traverse surveys mainly in areas where large scale mapping or cadastral survey is planned. The geodimeter traverse survey is more economical and has been taken frequently.

The number of established and revised stations for this period is summarized in the following table.

<table>
<thead>
<tr>
<th></th>
<th>Revised 1st order triangulation station</th>
<th>2nd and 3rd order triangulation station</th>
<th>Base line observed with geodimeter</th>
<th>Laplace station</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947–66</td>
<td>309</td>
<td>110</td>
<td>23</td>
<td>70</td>
</tr>
<tr>
<td>67</td>
<td>21</td>
<td>29</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>68</td>
<td>16</td>
<td>38</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>69</td>
<td>22</td>
<td>39</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>70</td>
<td>22</td>
<td>30</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>390</strong></td>
<td><strong>246</strong></td>
<td><strong>33</strong></td>
<td><strong>104</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>4th order triangulation station (including precise geodimeter traverse station)</th>
<th>2nd order traverse station</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947–66</td>
<td>23,323</td>
<td>8,348</td>
<td>31,671</td>
</tr>
<tr>
<td>67</td>
<td>2,014</td>
<td>579</td>
<td>2,593</td>
</tr>
<tr>
<td>68</td>
<td>1,927</td>
<td>580</td>
<td>2,507</td>
</tr>
<tr>
<td>69</td>
<td>1,974</td>
<td>544</td>
<td>2,518</td>
</tr>
<tr>
<td>70</td>
<td>1,668</td>
<td>630</td>
<td>2,359</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30,906</strong></td>
<td><strong>10,681</strong></td>
<td><strong>41,648</strong></td>
</tr>
</tbody>
</table>
In 1968, a new comparison base line was established with invar wires near the base line constructed in 1965. These two base lines were connected by angle observations to form a base line network, the Musashino comparison base line net, which will serve for studying problems on the distance measurement.

Prior to 1966, 4 quadrilateral base line nets were established in some parts of the country to study the detailed crustal movements for the area and 7 new nets have been added until 1970. The mean side length of the nets is about 10 kilometers or less. Observations are made with the geodimeter and are planned to be repeated every few years.

The precise trilateration observations were commenced in 1970 in the South Kanto District, which was designated as an intensified observation area by the Coordinating Committee for Earthquake Prediction, to pursue the crustal deformations in that area. The trilateration forms a loop of chains covering Boso, Miura and Izu Peninsulas and Oshima Island and is planned to be observed every other year. The length of trilateration net is about 30 kilometers and is measured with the laser geodimeter. Angle observations are made only at some stations to improve an accuracy. The effect of meteorological elements along a light path on the accuracy in distance measurements was studied by using kytoon observations.

According to a demand in satellite geodesy, two legs of arc observations were planned to serve as the long base line. One is from Kanozan Geodetic Observatory to Sapporo station and was completed in 1970, and the other is from the Kanozan to Kanoya station. Both are about 800 km in length. The traverse survey method is taken using the laser geodimeter. At most of the intermediate stations, astronomical observations have been made.

For the purpose of studying crustal deformations in specially interested areas, distance measurements with the geodimeter have been repeated by several organizations such as the Earthquake Research Institute of University of Tokyo, Nagoya University and Kyoto University.

Bibliography


LEVELLING AND MOVEMENTS OF THE CRUST

Levelling

Since 1947, all routes of the first order levelling net have periodically been revised by the Geographical Survey Institute. During the period from 1962 to 1968, the fourth revision survey was completed except the Hokkaido District. The fifth revision started in 1969 from the southern part of Japan and now in progress towards north.

Besides the above-mentioned country-wide survey, local revision surveys of the first order levelling have been carried out in some districts. The first is a survey in an area disturbed by a large earthquake to detect the crustal deformations as well as to revise the results of disturbed bench marks. For example, precise levellings were repeated several times in the Matsushiro area where an earthquake swarm occurred. Observed total length amounted to 800 km in this area. Next is that for an area which was designated as the observation intensified area, the South Kanto District, by the Coordinating Committee for Earthquake Prediction or that for areas of special observations. These surveys aim to follow up crustal deformations in those areas which are considered to be the most valuable material for a study of earthquake prediction. The last is that for main levelling routes in the ground subsidence area such as Tokyo-Yokohama, Osaka-Kobe, Nagoya, Kita-Kyushu and Niigata.

The second order levelling is carried out in some parts of the country to establish supplementary levelling network, to detect crustal deformations and to detect ground subsidence.

Revised or established lengths of levelling are summarized in the following table.

<table>
<thead>
<tr>
<th></th>
<th>1st order levelling</th>
<th>2nd order levelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947-66</td>
<td>32,731 km</td>
<td>14,596 km</td>
</tr>
<tr>
<td>67</td>
<td>4,455</td>
<td>1,584</td>
</tr>
<tr>
<td>68</td>
<td>3,337</td>
<td>1,703</td>
</tr>
<tr>
<td>69</td>
<td>3,428</td>
<td>1,390</td>
</tr>
<tr>
<td>70</td>
<td>3,000</td>
<td>1,203</td>
</tr>
</tbody>
</table>

Tidal Observations

Tidal stations are maintained by the Geographical Survey Institute, the Hydrographic Department, the Japan Meteorological Agency and other organizations. New stations were established at Katsuura and Mikuni in 1967, Oga in 1969, Akune and Hagi in 1970, all belonging to the Geographical Survey Institute. Records obtained at 77 stations belonging to the above-mentioned three organizations and some other governmental organizations are collected and published by the Coastal Movements Data Center, G.S.I., in order to be data of studying vertical movements of the crust and changes in sea level.

Underground Crustal Movement Observation Stations

Continuous observations of crustal movements are carried out with various kinds of tiltmeters, extensometers and other instruments at many stations distributed over the land of Japan and conducted by the Earthquake Research Institute of University of Tokyo, the Disaster Prevention Research
Institute of Kyoto University, geophysical institutes of Tokyo, Kyoto, Nagoya and Tohoku universities, and the International Latitude Observatory of Mizusawa. These observations aim to study the relation between crustal movements and seismic activities, and many interesting results on the prediction of earthquakes have been discovered.

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Geodetic Astronomy

The astronomical survey on the land of Japan is carried out by the Geographical Survey Institute. The routine observations of time and latitude are made at the Tokyo Astronomical Observatory and the International Latitude Observatory of Mizusawa.

During the period from 1967 to 1970, 34 Laplace stations were established in the first order triangulation network as shown in Fig. 3. GSI astrolabes after Tsubokawa, 66 mm in aperture and 800 mm in focal length, equipped with electric transit detectors, and Wild—T3 theodolites were used for astronomical longitude, latitude and azimuth observations. The longitude and latitude observations on islands in the Pacific Ocean were carried out by the Hydrographic Department, Maritime Safety Agency. The Tsubokawa astrolabe mentioned above, Carl Zeiss Ni2 astrolabe and Kern DKM3A theodolite were used for these observations.

Time and Latitude Services

At the International Latitude Observatory of Mizusawa, time and latitude observations with PZT and Danjon astrolabe have been made as well as latitude observations with the visual and floating zenith telescopes. The observing programme of the ILS for the visual zenith telescope was changed at 1967.0. The data processing unit for the micrometer reading and the electromagnetic level of the visual zenith telescope were developed.

At the Tokyo Astronomical Observatory, time and latitude observations with the PZT have been made continuously. At the end of 1967, the atomic frequency standard of Cesium 133 was installed.

New PZT's are under construction at both observatories.

Satellite Geodesy

Researches on satellite geodesy have been carried out jointly by the Tokyo Astronomical Observatory, the Geographical Survey Institute and the Hydrographic Department. The following stations participate in the cooperative simultaneous observations for satellite triangulation.

<table>
<thead>
<tr>
<th>Organization</th>
<th>Station</th>
<th>Camera</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. A. O.</td>
<td>Dodaira</td>
<td>Baker-Nunn, 50 cm/50 cm</td>
<td>Yes</td>
</tr>
<tr>
<td>&quot;</td>
<td>Taniyama</td>
<td>Astrograph, 11 cm/50 cm</td>
<td>No</td>
</tr>
<tr>
<td>G. S. I.</td>
<td>Kanozan</td>
<td>Astrograph, 10 cm/113 cm</td>
<td>Yes</td>
</tr>
<tr>
<td>&quot;</td>
<td>Sapporo</td>
<td>&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>&quot;</td>
<td>Kanoya</td>
<td>&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>&quot;</td>
<td>(temporary)</td>
<td>&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>H. D.</td>
<td>Sirahama</td>
<td>Astrograph, 13 cm/60 cm</td>
<td>No</td>
</tr>
<tr>
<td>&quot;</td>
<td>Simosato</td>
<td>&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>&quot;</td>
<td>(temporary)</td>
<td>&quot;</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Since 1968, the Tokyo Astronomical Observatory has made experimental observations of the laser satellite tracking system at the Dodaira station, and now preparations for the experiment of
lunar laser with the use of 74-inch reflector of the Okayama Astrophysical Observatory are being pre-
pared.

The Geographical Survey Institute has conducted a series of simultaneous observation to
determine the position of Oki Island, Shimane Prefecture, from 1967 through 1969. The long base
line between Kanozan and Sapporo was established to serve as a base line as was described in the first
section of this report.

The Hydrographic Department sent observing teams to Titi Sima (Bonin Islands) in December
1968, August 1969 and February 1971, and simultaneous observations of Echo II and later PAGEOS
were conducted. From the first observations, the absolute plumb line deviations of Titi Sima basing
on the SAO C7 standard earth were preliminarily found as follows:

<table>
<thead>
<tr>
<th>Meridional vertical</th>
<th>Prime vertical</th>
<th>N (Geoidal height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-12''1 ± 0''8</td>
<td>-10''0 ± 0''5</td>
<td>+45 m ± 8 m</td>
</tr>
</tbody>
</table>

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**GRAVIMETRY**

**Absolute Measurement of Gravity**

In 1967, the National Research Laboratory of Metrology completed the absolute measurement of gravity at Kakioka station by the method of freely falling of a graduated scale. Its result gives 1.55 milligals lower value than the hitherto adopted one, which was based on the Japanese fundamental gravity value at Tokyo old pendulum station, 979.8010 gals in Potsdam system.

A new absolute gravity measurement is now being planned by the Earthquake Research Institute of University of Tokyo. The up and down method is adopted using a cat's eye, reflector with lens, as the falling body and an optical interferometer with laser light for distance measurement.

**International Connection**

Since 1965, the Geographical Survey Institute has carried out international gravity connections by means of the GSI pendulum apparatus to establish the Western Pacific Calibration Line. During the period from 1967 to 1970, four new stations, Sydney, Canberra, Hong Kong and Brisbane, were occupied as shown in the following table. This series of pendulum observations will be completed by occupying Christchurch in 1971.

<table>
<thead>
<tr>
<th>Station</th>
<th>Gravity difference from Tokyo in mgals</th>
<th>Gravity value based on Tokyo in gals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney</td>
<td>— 92.7±1.1</td>
<td>979.6843</td>
</tr>
<tr>
<td>Canberra</td>
<td>— 160.9±0.8</td>
<td>979.6161</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>—1,010.8±0.3</td>
<td>978.7662</td>
</tr>
<tr>
<td>Brisbane</td>
<td>— 607.6±0.3</td>
<td>979.1694</td>
</tr>
<tr>
<td>Tokyo, GSI</td>
<td>(Reference station)</td>
<td>979.7770</td>
</tr>
</tbody>
</table>

Using these results together with those of preceding international work, it was determined as an interim result that the hitherto adopted fundamental gravity value at Tokyo, 979.8010 gals, is 0.7 milligals low than the most probable value.

**Domestic Survey**

The GSI pendulum apparatus and LaCoste & Romberg gravity meters are used for observations at the fundamental gravity stations, and those at the first and second order gravity stations respectively. Six fundamental gravity stations will serve as the local base station. The first order gravity stations amount to 90 in number and are located at main cities distributed over the land of the country. About 10,000 bench marks along lines of the first and second order levelling were established as the second order gravity stations until 1960. Since then, revision survey and establishment of new stations including some triangulation stations have been in progress. During the period from 1967 to 1970, four fundamental stations, 70 first order gravity stations and about 4,000 second order gravity stations were established newly or reoccupied.

Detailed gravity surveys with several LaCoste & Romberg gravity meters were conducted in 1969 and 1970 jointly by three organizations in the Miura, Boso, Tokai and Kii Districts to detect the
secular change in gravity values as well as to fix the scale factor of the used meters. Participated organizations are the Earthquake Research Institute of University of Tokyo, the Geophysical Institute of Kyoto University and the Geographical Survey Institute.

Besides them, several organizations conducted detailed gravity surveys in earthquake active areas such as Matsushiro and Ebino, in volcanic zones and on ocean islands.

Gravity Measurement at Sea

Sea gravity surveys were made with two kinds of surface ship gravity meters constructed by the Ocean Research Institute of University of Tokyo and the Geographical Survey Institute as shown in the following table.

<table>
<thead>
<tr>
<th>Date of obs.</th>
<th>Name of ship</th>
<th>Instrument</th>
<th>Organization</th>
<th>Surveyed area</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 1968</td>
<td>Meiyo</td>
<td>T.S.S.G.</td>
<td>H.D.***</td>
<td>Japan Trench</td>
</tr>
<tr>
<td>Nov. 1968～Mar. 1969</td>
<td>Hakuho-maru</td>
<td>G.S.I.</td>
<td>G.S.I.</td>
<td>South Pacific</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G.S.I.</td>
<td>G.S.I.</td>
<td>Japan Sea</td>
</tr>
</tbody>
</table>

* T.S.S.G.: Tokyo surface ship gravimeter  
** O.R.I. : Ocean Research Institute  
*** H.D. : Hydrographic Department

Others

A gravity survey along the traverse route from the Japanese antarctic base, Syowa station to the south pole was carried out by the Japan Antarctic Research Expedition team during the period from September 1968 to February 1969.

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EARTH TIDES

General Activity

At the Kyoto University, continuous observations of earth tides with an Askania Gs–11 gravimeter have been made in the Geophysical Institute and those with various kinds of tiltmeters, extensometers and other instruments have also been made in both Kamitakara Crustal Movement Observatory and Osakayama Crustal Deformation Observatory during the period from 1967 to 1970.

The International Latitude Observatory of Mizusawa has been made continuous observations of earth tides with three kinds of pendulums including Verbaandert-Melchior type in Akagane Observation Station and with an Askania Gs–12 gravimeter in the Observatory since 1967.

Data obtained during the period concerned are successively analyzing to detect not only for earth tides but also for related phenomena. On the other hand, an improvement of observational instruments is now in progress, in order to increase a measuring accuracy, by the respective institution.

Observation of earth tides on volcanic island was made for three months by means of other two Askania gravimeters under the cooperation of the Meteorological Research Institute of Japan Meteorological Agency and the Earthquake Research Institute of University of Tokyo. Continuous observations of the crustal movement are being made by the Geophysical Institute of Kyoto University, the Disaster Prevention Research Institute of Kyoto University, the Earthquake Research Institute of University of Tokyo, Faculty of Science of Tohoku University and Inuyama Crustal Movement Observatory of Nagoya University. Data obtained are also available for a study of earth tides.

Further, some trials to detect the earth tidal effects from astronomically observational data were tried by the International Latitude Observatory of Mizusawa and the Tokyo Astronomical Observatory.

Observations of Earth Tides with Gravimeters

Since the International Geophysical Year, gravimetric tidal observations have been made at many stations in the world. But the obtained values of tidal factor of gravity and phase lag show fairly large fluctuations with time even at the same station, and they are too large to be attributed only to observational errors. In order to investigate the cause of such fluctuations, simultaneous observations of earth tides with 4 Askania gravimeters and 2 LaCoste & Romberg gravimeters were made from August 30 to November 17, 1968 at the International Latitude Observatory of Mizusawa under the cooperation of the Geophysical Institute of Kyoto University, the International Latitude Observatory of Mizusawa, the Earthquake Research Institute, the Geographical Survey Institute and the Meteorological Research Institute. The results obtained were as follows: (1) There appears to be the discrepancy among the gravimeter types. (2) Large fluctuations of the tidal factor recognized by Askania Gs–11 gravimeters amount to about ±35%, and it may be considered that they are mainly due to non-linearity of recording system. (3) It is to be noted that trustworthy results cannot to be expected so far as continuous observations of earth tides are made by a single gravimeter.

Tidal observations were carried out by means of a LaCoste & Romberg gravimeter during the period of 7 days from June 18 to June 25, 1968 in Showa station, Antarctica.

Observational results obtained in Kyoto (December 1967—March 1968) and those in Mi-
zusawa (November 1967—February 1968) showed a similar variation in both tidal factor and phase lag, and it was considered to be a part of seasonal variation in comparison with the observation made formerly in Kyoto. Taking the seasonal variation into consideration, it was then found that the obtained values of tidal factor gave greater values than those obtained at about 10 years ago in both stations of Kyoto and Mizusawa, showing a possibility for existence of variation with longer period more than 10 years or of secular change in tidal factor of gravity.

**Observations of Earth Tides with Tiltmeters and Extensometers**

Tidal observations of the ground tilt have been made with various kinds of tiltmeters in Osakayama Crustal Deformation Observatory, Kamitakara Crustal Movement Observatory, Nokogiriyama Observation Station, Akagane Observation Station and other stations. A vertical and several horizontal components of tidal strains have been observed in Osakayama Crustal Deformation Observatory, Kamitakara Crustal Movement Observatory and other stations. Data obtained were harmoniously analyzed and the following results were obtained: (1) A large discrepancy is recognized with directions in values obtained by tiltmetric observations. (2) Cubical dilatation and areal strain have little effects of oceanic tides. (3) Direction of larger axis of the strain ellipse is perpendicular to that of Japan islands.

An electromagnetic tiltmeter, rotationmeter and extensometers of new type were newly devised and they have been used in tidal observations. A possibility to detect the torsional type of deformation in earth tides by means of observations of tidal strain and of latitude variation has been studied.

**Diurnal Nutation and Theoretical Investigations**

It was clearly found that there is a close relation between Kimura's annual z-term and semi-annual solar nutation term based on the hypothesis of a fluid core of the earth. The annual z-term observed by astronomical observations was in excellent agreement with theoretical results and also with observational results of earth tides.

An effect of compressibility of a fluid core on rotational motion of the deformable earth was discussed in detail. It was found that the compressible fluid core has increase mobility as compared with Molodensky's model and gives a small correction factor to the rigid earth for 19 yearly nutational component.

A bibliography of the papers published during the period concerned is annexed to the followings.

**Bibliography**


Ozawa, I.; Rotational strainmeter and the observation of the shear strain of the earth tide with this instrument, Bull. Inf. Marées Terr., 52, 2398, 1968.


Ozawa, I.; New types of highly sensitive strainmeters—H-70 type extensometer and R-70 type rotationmeter—, ibid., 10, 137, 1970.


FIRST ORDER TRIANGULATION NET
1 : 6,500,000

LEGEND

- Triangulation net revised prior to 1966
- Triangulation net revised during 1967–1970
- Sides measured with Geodimeter prior to 1966
- Sides measured with Geodimeter during 1967–1970
- Quadrilateral base line net prior to 1966
PROGRESS OF REVISION SURVEY OF PRECISE LEVELLING

LEGEND
Lines of Precise Levelling Revised prior to 1966
Lines of Precise Levelling Revised during 1967-1970
Cross Sea Levelling
Tidal Station
Geographical Survey Institute
Japan Meteorological Agency
Other Organization

Fig. 2
DISTRIBUTION OF GEODETIC ASTRONOMICAL STATIONS

1 : 6,500,000

LEGEND
Laplace Points observed prior to 1966
Latitude and Longitude Station observed prior to 1966
Laplace Points observed during 1967–1970
Latitude and Longitude Station observed during 1967–1970
Satellite Observation Station
Fig. 4

ACTIVITIES OF GRAVITY WORKS
1 : 6,500,000

LEGEND
Fundamental Gravity Station
First Order Station observed during 1967–1970
Area covered prior 1966
Area covered during 1967–1970

HOKKAIDŌ

JAPAN SEA

HONSHU

KYUSHU

PACIFIC OCEAN