COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1963/125

VISIT TO JAPAN
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SUMMARY

The writer visited Japan for four weeks to participate in acceptance tests and to receive training in the use of gravity pendulum apparatus which had been manufactured in Japan for the Bureau. The equipment was designed by the Geographical Survey Institute (GSI) Tokyo, and built by Sokkisha Ltd, Tokyo. Training was provided by members of the GSI and a series of measurements were made at the GSI Tokyo, and the Fujiya Hotel, Hakone.

Between periods spent in using the pendulum apparatus, visits were made to other geophysical institutions and two observatories where some interesting developments in gravity work and in other geophysical fields were examined.

1. INTRODUCTION

The most economical means of carrying out most gravity surveys is by means of gravity meters. However, these are generally unsuitable for gravity measurements where long distances, long travelling time, or large gravity intervals are involved. Gravity pendulum apparatus is the only equipment suitable for accurate measurements under these conditions. It is most important that gravity measurements on each land mass and over large areas of the world be referred to a common reference level; this is one of the principal aims of the International Association of Geodesy of which Australia is a member.

Generally a reference network using pendulum apparatus has first to be established within each land mass (as has been done in Australia) to which gravity-meter surveys can then be tied to ensure that an overall accuracy in gravity values is maintained. In addition, the calibration factor of a gravity meter changes with time and the instrument has to be checked periodically on a calibration range. The only completely satisfactory way of establishing a calibration range is by using gravity pendulum apparatus of suitable accuracy.

There is a limited number of designs of pendulum apparatus available that have the accuracy required by the International Association of Geodesy. The Geographical Survey Institute (GSI) equipment is one of the approved types. The prototype of the present equipment was inspected in Melbourne in 1959 during the course of measuring the gravity interval between Tokyo and Melbourne (Inoue and Seto, 1961).

The Bureau decided to purchase a set of this equipment and the order was placed with Sokkisha Ltd, Tokyo, Japan, manufacturers of the equipment, in January 1961. Because of difficulties associated with the casting of the quartz pendulums the equipment was not ready for delivery tests until August 1962.

The writer visited Japan to take part in these tests and to receive training in the use of the apparatus. He departed from Sydney on 13th September 1962 arriving in Tokyo that night. On the return trip he departed from Tokyo on 13th October and arrived in Sydney on 14th October 1962.

Three periods,each of six days, were spent in setting up and operating the equipment. Two of these periods were spent making sets of observations in the basement of the GSI Building, Tokyo. This site is used by the GSI as the base station for its gravity network throughout Japan; it has been connected by pendulum and gravity-meter ties to Kyoto, a first-order world gravity station. Accepting a gravity value of 979,721.5 mgal for Kyoto, the value adopted for the GSI site is 979,777.0 mgal (Inoue and Seto, 1961). Between the two sets of readings at Tokyo a set of observations was made at an international gravity station at the Fujiya Hotel, Hakone. This site had also been connected to the GSI station by gravity-meter ties on several occasions (see also Williams, Goodspeed, & Flavelle, 1961).

The equipment was transported between Tokyo and Hakone and return using a taxi truck. It was interesting to note that the GSI made almost exclusive use of the railway system for transport of their field equipment throughout Japan. This meant a considerable amount of extra packing and sometimes resulted in damage to the equipment because of rough handling in transit.

Visits were also made to observatories at Kakioka and Canozan, to the Earthquake Research Institute and the Geophysical Institute of the Tokyo University, to the Geophysical Institute of Kyoto University, and to Sokkisha Ltd, the makers of the pendulum equipment. At these establishments the author had discussions with workers in various fields of geophysics. Parkinson (1962) described several of these geophysical institutions in more detail.

2. THE GSI PENDULUM APPARATUS

The construction and operation of the GSI pendulum apparatus is described by Inoue (1961) and these details will not be repeated here. However the present set of equipment incorporates some modifications of the equipment described by Inoue although the principle and operation are the same. The principal modifications are:

(a) the recording side of the apparatus has been further improved and the total time for a set of observations for one 'swing' of the pendulums has been reduced to approximately 18 minutes,

(b) the positioning and starter device for the pendulum has been slightly modified,

(c) the temperature range of the main pendulum case has been modified to meet our particular requirements. The present range is 10°C to 45°C in five-degree steps,

(d) some improvement in the general layout of the electronics has also been made and most parts of the equipment are now easily accessible for testing and repairing. Vacuum tubes are still used in the circuitry,

(e) the thermal jacket of the pendulum chamber has been modified to operate on 240-V supply. The remainder of the electronics operates from a 100-V input which is obtained by means of a transformer supplied,

(f) the precaution of earthing all the units of the equipment has been carried out in Melbourne.

Each of the six main units on the recording side are in steel boxes which have inspection flaps at the top and the bottom; in addition to this, each unit can slide out from its case after a few screws have been removed. The provision of several inspection points on the Divider Unit panel and a CRO also facilitates the location of any faults that may develop in the equipment.

To make a set of observations the equipment is set up in the manner described by Inoue (op.cit.). The heaters for the pendulum main case and the crystal oven are switched on the day before the measurements are to begin. It was found that it was of distinct advantage to employ two persons during the course of the measurements; one person operates and reads the equipment while the other person books the data and commences reduction of the results.

The practice was adopted of making a comparison between the rate of the crystal clock and a time standard during the morning and night of each day of observation. Generally JJY on a frequency of 10 Mc/s was used for this purpose. It was noted that only on rare occasions could signals from WWV or WWVH be clearly received. Signals from both the crystal clock and JJY were recorded on the spark record and the time difference between the two events was scaled off and plotted during the period of the measurements at a particular station. The 'rate' of the crystal clock can also be obtained by observing the 'beat' effect, between the radio carrier-wave and a harmonic of the crystal oscillator, on an 'S' meter on the radio cabinet or on an oscilloscope built into the equipment. A departure of up to 5×10^{-8} sec from the (assumed) constant time-frequency can be tolerated in the measurements. For differences greater than this figure an adjustment to the crystal output has to be made.

The record sheet obtained for a single 'swing' consists of four separate recordings each of 12 to 15-sec duration and 6 min apart. Timing for the commencement of the separate recordings is by means of the clock (crystal driven) mounted on the recorder unit.

The drum is kept rotating during the full set of recordings (i.e. for 18+ min) so that the spark recordings due to the passage of the pendulum across the light path (which occurs approximately each $\frac{1}{4}$ sec) will line up across the record sheet. Measurements in time are made of successive pendulum recordings from an arbitrarily-chosen time line on the record sheet. Two values of the period of each pendulum are calculated using the time interval of 12 min (which can be accurately calculated)between alternate recordings on the record sheet.

The temperature of the room, the swinging chamber, and the crystal oven, the vibration of the centre pendulum, and the pressure showing on the Geissler tube are noted before and after each record. The amplitude of the outside pendulums are noted each 6 min near the time of commencement of each recording. These amplitude readings are used to apply a correction to the pendulum periods as measured.

Relative values of gravity, g, at two stations A and B are calculated using a least-square adjustment of the various corrected values for the period of each pendulum and the relation:

$$g_B = g_A(T_A/T_B)^2$$

For convenience the pendulums are labelled 1, 2, and 3. The adopted configuration of the pendulums when looking at the front of the chamber is 3-1-2 from left to right.(the corresponding configuration of the record from left to right across the drum is 3-1, time line, 2-1). In the first set of measurements at Tokyo there was reason to believe that Pendulum 2 was slightly unstable. In the repeat set of measurements there, this tendency was more pronounced. However, for the intermediate set of readings at Hakone, Pendulum 2 did not show this tendency. Therefore, it may be necessary to interchange Pendulums 2 and 1 to improve the quality of the results.

This tendency of the period of a pendulum to 'drift' has been noted in the two sets of equipment which the GSI use although the frequency of 'tares' seems to decrease with time, suggesting that it is connected with the aging of the quartz pendulums.

The pendulums are the most delicate components of the apparatus. They must be handled carefully and guarded against mechanical shock at all times; it is also necessary to guard them against thermal shock e.g. the pendulum main case should not be opened for about a day after the heaters have been switched off. In this regard there seems to be some merit in the design of, for instance, the Gulf pendulum apparatus in which the pendulums are not removed from the swinging chamber during transit. However, it is considered a greater advantage for the operator to be able to carry the pendulums separately and thus reduce the possibility of their sustaining physical damage.

As yet, the GSI has not worried greatly about the effect on the period of the pendulums of the collection of any electrostatic charge on the pendulums. This topic has been discussed by Rose (1962). It seems to the writer that because the metal knife edge and the steel plate are involved in the raising and lowering mechanism, any charge collecting near the knife edge will be quickly dissipated. There may be some local high concentrations of charge on the pendulums themselves but because of the pressure inside the chamber (roughly 0.1 mm of mercury) it is felt that the period of the pendulum would not be noticeably affected. However, GSI intends to use a small radium source in one of their swinging chambers to study this effect.

There are some small flaws in the present set of pendulums but members of Sokkisha Ltd and GSI asserted that it is practically impossible to cast and age such a piece of quartz without some small cracks developing in it. One of the rejected pendulums originally cast for the set of Bureau equipment was inspected and this pendulum showed severe cracking with aging.

3. MEASUREMENT OF GRAVITY DIFFERENCE BETWEEN TOKYO AND HAKONE

These measurements were made, partly to test the equipment under field conditions (although these conditions were almost ideal) and also to give the writer experience in setting up and operating the equipment.

The method of evaluating the results is as outlined by Inoue and Seto (1961). It was not necessary to apply any correction for the slight variation in clock rate during the measurements. The periods of the pendulums were reduced to their values at 31.03°C using a temperature coefficient of 2.25×10^{-7} sec/°C (this figure was determined experimentally).

The results are summarised as follows:

Date (1962)	Station	No. of observ-ations	Mean temp. (°C)	Pendulum No.3 Period (sec)	Pendulum No.3 Stand. dev. x10^{-8} (sec)	Pendulum No.3 Mean error x10^{-8} (sec)	Pendulum No.2 Period (sec)	Pendulum No.2 Stand. dev. x10^{-8} (sec)	Pendulum No.2 Mean error x10^{-8} (sec)
13th to 17th September	Tokyo	14	31.03	1.00556410	29	8	1.00555858	55	15
27th to 28th September	Hakone	22	30.29	1.00559113	54	12	1.00558552	38	8
5th to 8th October	Tokyo	14	31.06	1.00556353	45	12	1.00555778	52	14

These when reduced to 31.03°C give the following periods :

	Pendulum No. 3	Pendulum No. 2
Tokyo 1	1.00556410	1.00555858
Hakone	1.00559130	1.00558569
Tokyo 2	1.00556352	1.00555777

From these mean values of the pendulum periods at each station the gravity difference between GSI, Tokyo, and the Fujiya Hotel, Hakone, is calculated by least-square method to be :

$$g(\text{Hakone}) - g(\text{Tokyo}) = 53.49 \pm 0.59 \text{ mgal}$$

Accepting $g(\text{Tokyo,GSI}) = 979{,}777.0$ mgal

This gives

$$g(\text{Hakone}) = 979{,}723.5 \pm 0.6 \text{ mgal}$$

Thirteen connexions between Tokyo (GSI) and Hakone using gravity meters indicate a gravity difference of :

$$53.85 \pm 0.04 \text{ mgal}$$

The pendulum and gravity-meter results are therefore in fairly good agreement.

4. VISITS TO GEOPHYSICAL ESTABLISHMENTS

Geographical Survey Institute, Tokyo

Most of the training in the use of the pendulum equipment was given here by Messrs Fuzii and Suzuki, members of the Institute. The equipment was set up in the basement of the building and occupied a site that is used as the base station for extensive gravity surveys throughout Japan by the GSI.

Two other (older) sets of similar-type pendulum apparatus were set up in the Institute during my stay. Measurements with them are made at regular intervals and one set is used to occupy various control stations in Japan at regular intervals. The GSI, in conjunction with other institutions and universities, has established a tightly-controlled network of gravity stations throughout the islands of Japan.

While I was at the Institute the first test results of the three-fibre shipborne gravity meter were being analysed for a traverse across Tokyo Bay, but there seemed to be some trouble with the timing device in the equipment. However, the people engaged on the project seemed to be happy with the performance of the gravity meter itself as the measurements were made on a day when the sea was quite rough.

The Institute took delivery of a La Coste gravity meter (No. 29) during my stay, and I was able to offer some information concerning its testing and operation on the basis of experience obtained with the Bureau's La Coste instrument. The Institute plans to use this meter for international ties, as well as for regional work in Japan, commencing with a tie between Singapore and Bangkok early in 1963. The participation of the Institute, using GSI pendulum equipment and the La Coste gravity meter, towards the establishment of the West Pacific calibration line was also discussed with Dr Okuda, Director of the Institute.

Several other activities carried on by the Institute were inspected. These included the geodetic length standards laboratory, the workshops where a proton-precession magnetometer for airborne work was being developed and the seaborne gravity meter was being repaired, the photogrammetry and map-compilation sections, and the plate-making and printing section where maps for a variety of purposes are produced, mostly in multi-colour, at various scales from 1:5000 to 1:2,500,000.

Sokkisha Limited

I visited workshops and inspected the range of surveying and other equipment produced by this firm.

I also saw some repairs being made on the GSI-designed three-fibre gravity meter which was built by Sokkisha Ltd.

Earthquake Research Institute

Here I met Dr Rikitake who was working on several geomagnetic studies including the analysis of magnetograms in connexion with volcanic activity on Oshima Island and a study of the abnormally large changes in Z that occur in central Japan.

I also had a very interesting discussion with Mr Jitsukawa, Chief of the Technical Services of the Earthquake Research Institute (ERI), who has made extensive regional gravity surveys throughout Japan, including the investigation of the variation in level of the land surface due to causes such as volcanic activity and pumping of underground water.

The seismic vault containing several low-magnification seismographs was inspected.

Geophysical Institute of Tokyo University

Here I met Professor Tsuboi and we discussed geophysical activity, particularly gravity work in Japan and Australia. The discussion led to an inspection of the single-fibre vibration-type shipborne gravity meter which was under test in the Institute's laboratory. This gravity meter is described by Tsuboi, Tomoda, and Kanamori (1961). In it a weight is suspended from a thin metallic strip placed in the narrow gap between two poles of a permanent magnet. Under the tension due to the weight, the string makes rapid vibrations. The vibration is maintained by the coupling of the field within the weak intermittent electric current that is made to flow in the string through a feed-back circuit. Any change in the value of gravity causes a corresponding change in the tension of the string and hence in its period of vibration. The vibration of the string is approximately 1800 c/s and the number of vibrations in a small fixed time-interval (measured by means of a crystal clock) is recorded on perforated tape.

In practice 1000 such continuous perforation records are obtained in 10 min and this forms one set of observations from which the gravity value, g, is to be reduced using this relation :

$$T_i = K / \sqrt{g + a_i}$$

Where i has integral values from 1 to 1000,
a_i is the momentary vertical acceleration of the ship for readings during the ith interval

It is assumed that g is constant over the interval of 10 min. The true value of g obtained from T, the period with which the string would vibrate in the absence of the ships vertical motion, is obtained by taking successive overlapping averages of the 1000 values of

$g + a_i = K^2/T_i$. This gives a value of :

$$g^* = (i/550) \left[\sum_{i=225}^{i=775} g_i \right]$$

It has been found that it is necessary to apply a further correction to this relation to get the true value of g, given by :

$$g = g^* \left[1 - c\ (a/g)^2 \right]$$

where the value of c, a constant, is determined experimentally.

The overall accuracy obtained in sea trials in Tokyo Bay was estimated to be 3 to 5 mgal. I believe some results obtained during trials on Lake Hakone were better than this even though the levelling and stabilising devices used there were not so elaborate. In laboratory tests the accuracy of the gravity meter is as high as 0.3 mgal.

Kakioka Observatory

One day was spent inspecting the various projects being carried out and in discussion with Dr Hirayama who was deputising for Dr Yoshimatsu. In addition to inspecting the various activities listed by Parkinson (1962) I also inspected the Observatory workshop. Several types of instruments generally connected with geomagnetism are designed and constructed for the various research projects being undertaken.

Kanozan Observatory

This is a geodetic and geomagnetic observatory situated about 30 miles south of Tokyo. I spent one day inspecting the activities there under the guidance of Mr Omagai, Director of the Observatory. It is a GSI fundamental observation station for astronomical work, gravimetry, and geomagnetic surveys.

There is a first-order trigonometrical station here and frequent measurements of the Tokyo - Kanozan baseline are made.

The astronomical equipment and the magnetic huts were also inspected. Continuous latitude observations are made to investigate local movements of the Earth. The observatory also puts out a considerable amount of star observation data. An activity not reported on by Parkinson (op.cit.) is the erection of a new dome to house an 8-in. telescope (built by Sokkisha Ltd). This work should be completed early in 1963. I gather that one of the functions of this group will be the observation of Earth satellites.

In regard to geomagnetism, there seems to be some disturbance due to the D.C. from the Tokaido electric railway line which is about 15 miles distant. One of the particular problems being studied by research workers is the effects upon the magnetic results of the high conductivity of the salt water in Tokyo Bay.

Geophysical Institute of Kyoto University

Here I discussed various aspects of geophysics with Professor Ischinohe and Dr Nakagawa. The talks were mainly connected with the recording of Earth tides. Dr Nakagawa has done a lot of work in this field, mainly using an Askania instrument. He showed me an excellent record of the 1961 Chilean earthquake from which a value of 53.4 min for the free period of oscillation of the Earth was calculated. For calculating the tidal effect, the mean curve on the record is used, but for the study of free oscillations of the Earth, the actual observations at2-min intervals are scaled. Another type of Earth-tide recorder, an 'extension meter', which consists of 30 to 40 metres of pre-strained invar wire stretched horizontally between two supports (walls), has been used by the Institute in a disused tunnel near Osaka.

At its centre, the wire carries a weight to which a mirror is attached. The movement of a spot of light reflected back from this mirror is recorded photographically; the spot will move with the contractions and expansions of the Earth. It is claimed that this apparatus is sensitive to one microgal. However, neither this set nor the Askania Earth-tide recording equipment were in operation during my stay.

Other activities carried on by the Institute in Kyoto include atmospheric studies (including static atmospheric potential gradient and conductivity measurements), hydrographic studies of the coastal water about Japan (including measurements of the compressibility and the specific gravity of sea water), and some geomagnetic work. A first-order world gravity station is located in the basement of the Institute building. The Institute also has a set of GSI pendulum equipment.

Abuyama Seismological Observatory

This observatory is attached to the Geophysical Institute of Kyoto University and is situated some 25 miles from Kyoto. Dr Matsushima showed me the array of seismographs (of several magnifications) installed in the observatory.

I also saw a demonstration model of the 'extension meter', and a variation of this in which a long vertical wire, to which a weight and mirror were attached, was hung down the centre of a tall tower. The set-up was designed to detect the bending of the tower at times of earth movements, but I gathered that this equipment was never used for any serious study of this sort.

Attached to the observatory is a laboratory for studying the deformation of rocks at high temperatures and pressures. Rocks (mainly granite, diorite, and basalt) from all parts of Japan are studied here by several research workers. Air pumps and oil pumps produce an initial pressure of 1000 bars which, by means of a pressure intensifier, can be raised to 10,000 bars. Another piece of equipment in use was capable of subjecting a sample to a pressure of 30,000 bars and a temperature of 1000°C. This equipment was being used to study the phase diagrams of silicate rocks at high temperatures and pressures. The samples being tested were cylindrical pieces approximately 6 mm in diameter and 10 mm in length. Another experiment in progress was the measurement of the ultra-sonic wave velocity of rocks under high temperature and pressure by using energy from an ultra-sonic crystal.

Institute of Geology and Mineralogy, Kyoto University

This institute does a little gravity work in central Japan and has a torsion balance for special problems. It also has a set of Vening Meinesz three-pendulum equipment.

I talked with Professor Hatuda. One of his main interests is the age determination of granites, particularly at the Tertiary-Mesozoic boundary, using the lead-decay method of dating. Some palaeomagnetic study is also carried out in this institute.

5. ACKNOWLEDGEMENTS

I wish to gratefully acknowledge the kindness and assistance shown to me by members of the various organisations I visited during my stay in Japan. In particular I wish to thank Dr Okuda, Director of GSI, for his kindness in arranging for my period of training at the Institute, and Dr Tsubokawa who arranged my itinerary during my stay. My special thanks go to Mr Fuzii and Mr Suzuki, who conducted me through most of the training period, and Mr Ohashi of Sokkisha Ltd who provided much of the transport to enable me to visit many places of interest during my stay.

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