MEASUREMENT OF GRAVITY AT SEA

by

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(Translated from the Italian)

Gravity, that mysterious force which is at the base of the formation of the Universe acts, as everyone knows, on each body on the surface of the Earth, being directed towards the centre of the Earth.

Being directed towards the centre and maintaining itself constantly in the same place, it defines the vertical of that place, represented by the direction of the plumb line. The fact that it maintains itself constant in a given place enables us to erect, in places where no earthquakes are to be feared, bold structures such as the Mole Antonelliana, American sky-scrapers and the Eiffel Tower. Alas for such constructions, however, if at any time the direction should change.

This force, exerting itself on a given body, depends on the mass of this body and on a quantity which, as the schools teach us, is always indicated by g and is commonly known as the intensity of gravity, although it should be called the "acceleration". This quantity on our globe has, with trifling variations, in all parts accessible to man from the highest ridges to the greatest depths, a value very close to 9.80 metres — which means that the falling velocity of a body left free in space increases by about 9.80 metres per second.

If one moves away from the centre of the Earth, for example if one rises above the mean level of the sea to which all measures of gravity are referred for terms of comparison, the intensity decreases. Thus at the poles which, owing to the Earth's ellipticity are nearer the centre than places located on the equator, g is greater than at the equator. The intensity of gravity varies therefore with the latitude.

When an observation has been carried out at a certain altitude it is necessary, in order to reduce it to sea level, not only to apply the correction for variation in altitude proper above the ground (the so-called *Faye's* correction), but also to take into consideration the mass of earth between the observation spot and the mean sea level (*Bouguer's* correction).

For observations in a submarine, about which we intend to speak here, this *Bouguer* correction changes sign and it is necessary to make it twice : a first time because at the moment of observation a certain mass of water is lacking below the vessel ; a second time because this same mass of water, above the submarine, exerts on the latter an attraction equal, but of contrary sign, to its normal action on a body lying at mean sea level.

Further, mountains, submarine depressions and in general all irregularities of the Earth's crust exert an influence on the intensity of gravity. For instance, a mountain towering above the observation spot diminishes g; this mass attracts upwards, i.e. in a direction opposed to the centripetal force of gravity.

With regard to a submarine depression, a lessening of the force of gravity is also experienced, as a depression is equivalent to a portion of the earth's crust of density 1 as compared to nearly 3 which is the density of the solid crust. This depression has the same effect as a mountain of equal volume and of density $3 - 1 = 2$, roughly, or of a mountain of density 3 but of an altitude equal to the depth of the depression multiplied by the ratio 2/3, roughly speaking.

Our scientists are obliged to take into account a great many corrections. For us Italians, for instance, it is necessary to take into due consideration the influence of the Alps, far off though they be, although such influence decreases rapidly with the distance. It is necessary also to make allowance for the Asiatic high plateaus and for depressions of the Pacific.

In order to facilitate the evaluation of the corrections, 15 annular zones around the observation spot, taken as centre, are considered, and subsequently 18 zones, until the antipodes are reached. The zones increase in breadth as their distance from the centre becomes greater : thus the first zone about the centre is 2 metres in breadth — that at the antipodes more than 3000 kilometres in breadth ; to each zone correspond one or several corrections. Tables facilitate the computation.

It should be recalled — because of its interest — that scientists are not in agreement with respect to the true value of these corrections.

AIRY has put forward an hypothesis according to which the earth's crust simply floats on molten lava at a depth of about 100 kilometres.

PRATT on the contrary holds — and his opinion seems to be well founded — that to a visible mountain there corresponds an invisible mountain five times greater in volume, buried in lava, in the same manner that to the emerged part of a ship there corresponds a greater submerged portion.

According to the latter hypothesis the influence of the mountains would be greater than with the former.

In order to overcome such difficulties, nothing remains to science but to multiply the observations ; above all observations at sea are useful and these — prior to the invention of VENING MEINESZ's apparatus described hereafter — have been conspicuous by their absence. Thus, lately the trend has been to give greater weight to AIRY's simpler hypothesis after passing through a period of faith in the superiority of PRATT's.

In spite of all these well-studied influences, the measurements exhibit certain anomalies. So it is in all that Nature offers us. It should be remembered that these anomalies are due to irregularities in the sea bottom still unknown to us or to ancient irregularities of ocean bottom itself now covered with sediment. It has been recalled elsewhere, in speaking of echo sounding, that the ocean floor continues to be found much more uneven than was formerly believed to be the case.

Here we find an aid to geology which gravimetric measurements are capable of rendering.

Before examining how the acceleration of gravity is determined at sea, let us cast a rapid glance at the method followed for its determination on land.

Mechanics offer us a very simple and very remarkable relation which comprises the time a pendulum takes to perform an oscillation, the length of the pendulum and the acceleration g. The longer the pendulum the longer the duration of the oscillation and, *vice versa*, the greater g the shorter the duration of the oscillation.

Applying this classical relationship, by measuring the time of oscillation and the length of pendulum, the local value of g is obtained.

The relation is indeed very simple ; but, as already noted, the limits between which the intensity of gravity on Earth varies being very narrow, g will have to be measured with extreme accuracy to enable us to appreciate its minute variation from place to place.

To give an idea of this accuracy, let it be stated that it has sometimes been necessary to measure to the millionth part of g or milligal (g is about 9.80 metres or 980 gal). For obtaining such results it is also necessary to attain, for example, an accuracy of one-thousandth of a millimetre in the determination of the length of a simple pendulum one metre long and an accuracy double that in the evaluation of the time duration, i.e. one-twentieth of a second for a period of oscillation of one day. At the moment scientific and mechanical progress permits the attainment of accuracies of this degree.

At first measurements were made with simple pendulums, or their equivalent, i.e. a thin thread with a bob attached to its extremity oscillating in space. Then composite pendulums were constructed, very robust and suspended on knife-edges resting on hard supports ; these gradually became real precision instruments. They are compared at a base station, Potsdam as a rule, where sufficiently accurate measurements of the absolute intensity of gravity have been carried out. Data obtained from measurements made elsewhere are reduced to those carried out at the base station, thus yielding relative values of a fairly high degree of accuracy.

This is termed making *transportations of gravity*, employing the same expression as in the *transportations of chronometers* for the measurement of longitudes.

Lately science has been enriched by the HOLWECK-LEJAY pendulum composed of an oscillating elastic system, which enables the transportations of gravity to be made in a much simpler way than in the past.

While formerly it was necessary to know the rate of the clock used for determining the period of oscillation with extreme accuracy, to-day, with the HOLWECK-LEJAY instrument of essential differential design and with which only the intensity of gravity from the base station is measured, it suffices to know the time with much less accuracy. In this way, while formerly sidereal pendulums of high perfection were employed, to-day one may content onself with a simple pocket chronometer.

Also the transportation of this instrument may be effected without great precaution, whereas with the preceding apparatus special care had to be taken ; hence the measurements may be carried out anywhere provided a robust stable base is available. Formerly, on the contrary, one had to search for meanders and caverns.

It may therefore be stated that this kind of measurement which, up till a few years ago, required much care and a specialised personnel, is now within the reach of any person of ordinary intelligence.

The aim of these gravimetric measurements is more of a scientific than a practical order, although it is said that in Russia and in Mexico gravity measurements are made on a large scale in the search for oilfields.

Finally we come to the determination of the intensity of gravity at sea.

This determination has been made possible, only within recent years, by the introduction of a pratical instrument due to the Dutch professor VENING-MEINESZ.

This instrument is preferably used on submarines at a depth of a few tens of metres, i.e. at a depth susceptible of insuring a state of quiescence. It can, of course, also be used on board surface craft but only with a smooth sea.

Broadly speaking, it is composed of two pendulums mounted on the same support, oscillating in phase opposition. The small impulses due to the sea or to the vibrations of the ship act in the inverse sense on the two pendulums and cancel out, so that the mean value of the oscillation comes out to the exact figure. A third pendulum, motionless at the beginning, is suspended from the support of the two main pendulums and starts oscillating if the phase opposition of these is not perfect — as is usually the case in practice. The amplitude of oscillation of the third pendulum, as compared to the amplitude of oscillation of the two main pendulums, provides the possibility of effecting small corrections.

In opposition to pendulums used on land, these pendulums oscillate in the free atmosphere and are therefore subjected, according to the law of Archimedes, to an upward push which diminishes their weight in a manner which depends on the density of the air : hence a source of error and therefore to be corrected (allowance must be made for barometric pressure, humidity and density of the air). The air likewise acts as a damper. In order to render them independant of the magnetic field of the submarine, the pendulums are made of bronze, a material with large thermal coefficient of expansion (allowance must be made for temperature). The metal *invar,* having a coefficient of expansion equal to zero, is not immune to magnetic influences.

The support of the pendulums is not fixed, in an absolute sense, and, for this reason, due account must be taken of the successive inclinations of the plane of oscillation.

If the ship is under way, allowance must be made for her speed and course. In fact, if the ship is heading eastward, the centrifugal acceleration with respect to the axis of the Earth increases, and g decreases.

Finally, as stated from the beginning, allowance must be made for the immersion of the submarine in order to apply the *Faye* and *Bouguer* corrections.

For these so-called topographical corrections, it is necessary to know the submarine relief of the zone in which the work is being carried out, that is to say, continuous sounding must be effected ; the submarine therefore, if operations are carried out in a zone where the relief of the bottom is not well known, will have to be provided with an apparatus for acoustic sounding.

The character of the oscillations of the pendulums is followed photographically ; for this reason no special ability is required for these measurements. A measurement of g at sea requires only one hour of immersion.

Gravity measurements have been carried out by Professor VENING-MEINESZ on behalf of our *Istituto Idrografico* in the submarine *Vettor Pisani* in the Mediterranean, i.e. in one of the most interesting seas on earth from the seismological point of view ; two voyages were made by this submarine, and two on behalf of France with the *Fresnel* and *L'Espoir* in the western Mediterranean. It is hoped to be able to derive from these gravity measurement cruises some information on the subsidence in the Mediterranean and the landslip of the Maritime Alps.

Among others, Professor VENING-MEINESZ has performed a long gravimetric cruise in the Dutch submarine *K XVIII* carrying out measurements at many places on the Equator, and determined that no appreciable variations of gravity exist, and that all the points on the Equator are equidistant from the centre of the earth, a fact which could have been foreseen for many other reasons.

Gravimetric cruises with promising results were executed as early as 1928 by American submarines, with the collaboration of Professor VENING-MEINESZ, and a comprehensive literature already exists on measurements of gravity at sea.

NOTE OF THE I. H. B.

The Italian expeditions in the Mediterranean to which reference is made in the preceding article have been described in "HYDROGRAPHIC REVIEW", Vol. IX, N° 1, of May 1932, page 148 and Vol. XI, N° 2 of November 1934, page 185. (See also Hydrographic Review, Vol. VIII, N° 2, November 1931, page 250).

The American gravimetric expeditions have been described in an article by Captain L. R. Leahy, published in Vol. XIV, N° 2 of the November 1937, Review, page 69 and in Vol. XII, N° 1, May 1935, of the same Review, page 134.

Below we shall include a report on the gravimetric expeditions of the French submarines *Fresnel* and *Espoir* extracted from the *Report of the French National Committee on Geodesy and Geophysics for the years* 1933-1936 (with sketch).

The pendulum apparatus of professor Vening Meinesz has been described in the Hydrographic Review, Vol. XII, N° 1, page 134. The elastic pendulum of Holwek-Lyjau has been described in the Hydrographic Review, Vol. VIII, N° 2, page 250.