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E. LESTER JONES, Director

GEODETIC OPERATIONS IN THE UNITED STATES JANUARY 1, 1924, TO DECEMBER 31, 1926

[Report to the Section of Geodesy of the International Geodetic and Geophysical Union, International Research Council]

BY

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GEODETIC OPERATIONS IN THE UNITED STATES, JANUARY 1, 1924, TO DECEMBER 31, 1926

By WILLIAM BOWIE, *Chief, Division of Geodesy, United States Coast and Geodetic Survey*

GENERAL STATEMENT

The geodetic work of the United States is carried on principally by the United States Coast and Geodetic Survey, although the United States Geological Survey also does some geodetic work in connection with its topographic work. There has been a noticeable increase in the interest shown in first-order and second-order triangulation and leveling by a number of cities of this country which has resulted in the organization of several groups of engineers outside of the Government for the purpose of carrying on such classes of work.

As is well known, the operations of the United States Coast and Geodetic Survey in the geodetic field consist of first-order triangulation, astronomic observations for latitude, longitude, and azimuth, first-order traverse, first-order leveling, and gravity observations, in the interior of the United States, and the establishment of arcs of triangulation, usually of a third order, along the coasts of the United States and Alaska, and in the Philippine, Hawaiian, and Virgin Islands, and in Porto Rico.

The details regarding the various classes of field work and the results accomplished since the report made to the conference at Madrid in 1924 are given in the latter part of this report.

READJUSTMENT OF TRIANGULATION, WESTERN UNITED STATES

The most important accomplishment in the geodetic field during the past three years has been the readjustment of that part of the first-order triangulation net of the United States which extends from the ninety-eighth meridian to the Pacific coast. The total length of the arcs of triangulation included in this adjustment is approximately 13,000 miles.

The necessity for making a readjustment of the triangulation net was made apparent when attempts were made to fit any new work into the previously adjusted arcs. When the North American datum was adopted in 1901 and the triangulation of the country was adjusted to it, no Laplace azimuths were used to control the directions of the arcs composing the net. About 1909 it was decided that Laplace azimuths should be used in the adjustment of arcs of triangulation, and hence they were introduced into all of the new arcs, but it was evident that a Laplace azimuth could not be used at the beginning or end of an arc when it started from or ended on old triangulation. The result was that the central portion of a new arc would have its azimuth held to the true value by the Laplace azimuth, but the ends of the new arc would have the azimuths rather badly distorted in order to hold the azimuths of the lines to which the new work was joined.

Although the arcs of triangulation in the western part of the country were quite far apart, the closing errors of circuits were not very large. The ratio of the closing error to the perimeter of each circuit was within reasonable limits, but, as the larger circuits were divided by new arcs and the circuits became smaller and smaller, the closing errors became quite large as compared with the distance around the circuits.

It will be recalled that a short paper by Doctor Adams, of the United States Coast and Geodetic Survey, on the method adopted for the readjustment of the triangulation net was presented at the Madrid meeting of the section of geodesy of the International Geodetic and

Geophysical Union. The plan outlined there was fully developed and put into practice during the summer of 1925. In order that the adjustment of the net to the westward of the ninety-eighth meridian might be carried out in the shortest possible time, the efforts of the geodetic division were concentrated on it. Field work was also done to complete the net and to reduce it to small circuits only. The several arcs which were executed during the past three years are shown in Figure 1.

One of the most difficult pieces of triangulation that the Coast and Geodetic Survey has had to execute was that along the forty-ninth parallel to the westward of Oroville, Wash. The difficulties consisted of smoke from forest fires and the lack of roads and trails in the Cascade Mountains, across which the arc extends. A triangulation party was sent into that region in 1925, but it was badly handicapped during the summer by the smoke from forest fires, and then in the early fall, when the rains began in the valleys and the fires became less frequent, the mountain peaks became covered by snow and the party was forced to abandon its operations for that season.

At the beginning of 1926 it was realized that serious delay to the adjustment of the triangulation net would be occasioned if the arc along the forty-ninth parallel were not completed in that year. In order to complete this arc, if possible, an observing party was organized with four separate observing units. The party went to the field late in June after the snow had melted from the mountain peaks sufficiently for the members of the party to operate. At the beginning of the season the four highest peaks were occupied by the four observing parties. Each observing party showed signal lights to each of the other observers, and, at the stations beyond the quadrilateral occupied by the observers, light keepers were posted to show signal lights to the observers.

The atmospheric conditions remained very unfavorable for observations during nearly the entire summer. There were only occasional days when the lights could be seen from station to station. However, by persistent effort and by the utilization of every moment when the smoke settled and the lines were clear, the observations were completed.

The last arc to be added to the western net extends from the Pacific coast eastward to the one hundred and fifteenth meridian, approximately along the thirty-fifth parallel of latitude. That arc was not finished until December, 1926.

Prior to the completion of field work much had been accompilshed in the adjustment of the net. The most probable lengths and azimuths of lines at the junction points had been derived, and each completed section of the net between junction points had been adjusted by the time the arc along the thirty-fifth parallel had been executed. An adjustment of that arc was then made, and all was ready for the solution of the equations from which the most probable geographic positions of junction points were obtained. The details in regard to this adjustment are given in a short paper by Doctor Adams, which is included in this report.

The length of the line joining the stations Donna and Rio, at the southern end of the ninety-eighth meridian arc of triangulation, was held fixed in the western readjustment. That was the line from which the triangulation was extended southward along the ninety-eighth meridian through Mexico by the Direccion del Estudios Geograficos y Climatologicos. The geographic positions on the new datum for the stations Donna and Rio and the azimuth of the line joining those two points have been furnished to Pedro C. Sanchez, director of the organization referred to, who is in charge of the triangulation of Mexico.

For the next few years the funds available for carrying on geodetic work in the United States will be largely devoted to the extension of arcs of triangulation in the eastern half of this country, in order that the area may be cut up into comparatively small circuits as was done in the West. When this has been accomplished a readjustment of the eastern half of the triangulation net of the country will be made in a manner similar to that which has been followed in the adjustment of the western half. The positions, azimuths, and lengths at the junction points along the ninety-eighth meridian will be held fixed at the values derived from

the western adjustment. It is probable that the adjustment in the eastern half of the country may be undertaken within the next three or four years.

Before the readjustment of some of the arcs in the western part of the country could be made it was necessary to increase the number of Laplace stations. This work was accomplished by observing parties during the seasons of 1924, 1925, and 1926. In some cases astronomic longitudes were determined for triangulation stations at which the astronomic azimuths had been observed during the execution of the triangulation. At other stations both the astronomic longitudes and azimuths were determined. For these Laplace azimuths the time signals sent from the United States Naval Observatory in Washington, through the radio stations at Annapolis, Md., and Bellevue, D. C., were used to determine the difference of time between the local station and the Naval Observatory. The receiving apparatus for radio signals, designed and constructed some years ago under the direction of Dr. E. A. Eckhardt, of the Bureau of Standards, has been used with some modifications in the longitude work carried on during the past few years.

After very careful consideration of the various spheroids which might be used in the readjustment of the triangulation net of the country it was decided to hold to the Clarke spheroid of 1866 as expressed in meters, since all of the surveys, maps, and charts of this country and of Alaska have been based on that spheroid. Careful tests were made which showed that the Clarke spheroid of 1866 would not introduce any material errors in the geographic positions of the triangulation net of North America. Of course, if no satisfactory spheroid had been previously adopted for the surveying, mapping, and charting of this country, undoubtedly the Hayford spheroid would have been used. It is planned, however, to have the geographic positions of the junction points of the net computed also on the Hayford spheroid. When that has been done it will be a very simple operation to determine the Hayford position of each of those triangulation stations for which astronomic data in the form of latitudes, longitudes, and azimuths are available. The results will be made readily available for anyone who may wish to use the triangulation of this country in the redetermination of the shape and size of the earth or in a study of the density of materials of the outer portion of the earth.

GEODETIC OPERATIONS

The Coast and Geodetic Survey has executed some triangulation along the coast of our continental area and that of Alaska and the Philippine Islands during the past three years. The triangulation of the Philippine Islands has been largely completed and adjusted. Details in regard to the work along the coast of the United States and Alaska will be found on pages 8 to 10 of this report.

The United States Geological Survey, as already mentioned, has executed some geodetic-control surveys of the third order, largely in the continental area of the United States. (See p. 11.)

The Bureau of Standards has continued to standardize the invar tapes used in the measurement of bases for the triangulation and in measuring traverse, which is used instead of triangulation along routes that are comparatively flat and heavily wooded. Certain tests have been made of invar metal by Dr. L. V. Judson, of the Bureau of Standards, and he has also investigated the effect of weights placed at different points on the base tapes. There will be found on pages 15 to 23 of this report an article by Doctor Judson, which includes a discussion of the methods employed by the United States Bureau of Standards for standardizing base tapes and a study of the effect of concentrated loads on the length of measuring tapes.

The Bureau of Standards has secured a dividing engine for graduating circles and also a testing machine for circles. Although these pieces of apparatus have been in the office of the Bureau of Standards for nearly a year, they have not yet been put into operation. However, it is hoped that they will be ready for use in the very near future, and then the circles of some of the older theodolites of the Coast and Geodetic Survey will be tested and, if found in error, regraduated.

Some work has been done in the re-marking and redescribing of the triangulation stations of the old arcs. It is believed that, at rather frequent intervals, the triangulation stations of a country should be visited to see whether the marks are in a satisfactory condition and whether the descriptions, as published, enable one to find the station easily.

The United States Coast and Geodetic Survey cooperated with geodetic and astronomic organizations of a number of other countries in the determination of differences of longitudes extending around the world. The stations occupied by the observers of the United States Coast and Geodetic Survey were Honolulu and Manila. It would have been rather expensive for the Coast and Geodetic Survey to purchase modern astronomic clocks and install them in vaults or structures where the temperature could be kept constant at each of these stations. Instead of clocks, therefore, the gravity pendulum was used as an accurate timepiece with which to determine the interval between the mean epoch of the local time observations and the receipt of the radio signals from the different sending stations. The details of the method were worked out by E. J. Brown, an engineer of the United States Coast and Geodetic Survey, in consultation with the officials of the Washington office. A preliminary test proved conclusively that the method was satisfactory, and it was put into operation at both Honolulu and Manila. The results obtained at those stations indicate that a very high degree of accuracy was obtained by the use of the pendulum as a timepiece.

In 1897 an adjustment was made of the longitude net of the United States. The differences of longitude used in the adjustment were those for which there had been an exchange of observers in order that the effect of their personal equations might be eliminated or at least minimized. All of the work involved in the adjustment was accomplished prior to the use of the impersonal or transit micrometer. Two of the stations in the net were Washington, D. C., and Seattle, Wash. In the autumn of 1925 the observer engaged on longitude work in connection with the establishment of Laplace stations reoccupied the station at Seattle and redetermined its astronomic longitude by means of radio time signals sent from the Naval Observatory at Washington, D. C. It is rather interesting to note that the astronomic longitude of the Seattle station, as thus determined by the radio signals, differs only 0.03 second of time from the value obtained in the net adjustment referred to above. This close agreement shows that both the radio and the wire methods for determining longitudes give high degrees of accuracy. It shows also that there has been little or no relative shifting of geographic positions of the two stations.

Very little gravity work has been done during the past three years, although there is a great deal of interest shown in gravity determinations by geologists, geophysicists, and others. It is hoped that, within the near future, an apparatus may be devised by some one which will make it possible to determine a value of gravity with a high degree of accuracy in a very short time and at reasonable cost. When this desired improvement is accomplished undoubtedly great activity will take place in the gravimetric surveys of many parts of the world. Gravity results are of value in determining the shape of the spheroid and the geoid and also in throwing light on the isostatic condition of the earth's crust. It seems probable that buried geological structure can be disclosed, at least in its general outlines, by gravity determinations.

A complete account of the astronomic and gravity work done in the period covered by this report will be found on pages 6 to 8 and 11 to 13.

Only a moderate amount of first-order leveling has been done by the United States Coast and Geodetic Survey during the past three years, although the results of first-order leveling are needed very badly in carrying on the topographic work of the country. As is mentioned above, the funds available for geodetic field work were largely used in completing a skeleton for the triangulation net of the western half of the country in order that the readjustment might be made at an early date.

From time to time, some of the funds of the United States Geological Survey appropriated for topographic mapping are made available to the United States Coast and Geodetic

Survey for the extension of lines of first-order leveling which are needed immediately in the topographic work.

Some leveling has been done in California, under special authorization of the Congress of the United States, to furnish the means of disclosing whether vertical movements of the earth's surface are occurring between earthquakes and also to furnish the basis by means of which the amount of vertical movement during any earthquake may be determined.

The triangulation extending from central Nevada, on the thirty-ninth parallel, westward to the Pacific coast, thence along the coast to the vicinity of San Diego, Calif., thence eastward to the Colorado River, has been reobserved during the last five years in order to discover whether or not any changes in geographic position have occurred since the triangulation was first executed. No final report has been made on the changes of positions thus disclosed, because it was felt to be desirable to delay discussion of the results until the completion of the western readjustment. It is probable that, in the near future, a study can be made of the old and the new triangulation and that a report on the results may be issued. The Coast and Geodetic Survey has the valuable assistance of the committee on seismology of the Carnegie Institution of Washington in planning the geodetic field work for testing the stability of the ground.

Some work has been done in recent years in stamping elevations of bench marks on the metal tablets used as bench marks. This has only been done, however, where it seems reasonably certain that no readjustments of the lines involved will be necessary.

The officals of the Geodetic Survey of Canada and of the United States Coast and Geodetic Survey have had a number of conferences over the question of fitting the level nets of the two countries into a single net. There have been outstanding differences in elevations of certain bench marks along the boundary, as determined by the leveling of the two countries. Some of these differences have been rather puzzling and have led to a search for their causes. It is believed that an accord in the elevations of the bench marks common to the level nets of the two countries will only be reached through an adjustment involving both nets.

In my report to the Madrid meeting it was stated that the first-order leveling of the United States Coast and Geodetic Survey seemed to be developing the fact that the planes of mean sea level at adjacent tidal stations along a coast are not necessarily in the same level surface. In order to learn whether there are slopes in the mean sea level as determined by tidal observations, an adjustment of the level net of the United States was made without holding any tidal planes fixed. The results of that adjustment are given on pages 28 to 30 of this report in a short article by H. G. Avers, mathematician in this office. It is hoped that similar studies will be made for the level nets of other countries in order to throw more light on a very interesting problem. Each country is confronted with the problem as to whether it shall base all of its leveling on a single tidal determination of mean sea level or shall hold mean sea level at each of a number of tidal stations fixed in adjusting the level net. In the United States we have definitely adopted the plan of holding the tidal planes at many stations at zero elevation.

Observations have been made continuously for the study of the variation of latitude at Ukiah, Calif., since the Madrid meeting of the section of geodesy. The property involved in the Ukiah station is owned by the University of California, but the station is being operated by funds appropriated by the Congress of the United States to the United States Coast and Geodetic Survey. The observer, H. G. Wrocklage, is following carefully the program of observations submitted to him by Professor Kimura, chairman of the committee on variation of latitude of the section of geodesy and of the International Astronomical Union.

A method has been devised in the office of the United States Coast and Geodetic Survey, which makes it possible to determine the mean sea-level plane from a very short period of tidal observations, provided the station at which such a plane is desired is not too far distant from a tidal station at which observations have been extended over a few years. A statement in regard to the method in question has been prepared by G. T. Rude, Chief of the Division of Tides and Currents of this office, and it is given on pages 25 to 28 of this report.

Dr. Paul R. Heyl, physicist at the Bureau of Standards, Washington, D. C., has for several years been carrying on researches with a view to learning whether the tuning fork may be used as a precision instrument in determining short intervals of time. If he should be successful in finding a material of practically perfect elastic properties, from which a tuning fork can be made, then it would be possible to use the tuning fork as a timepiece in determining relative values of gravity by means of the usual invariable pendulum. A short paper by Doctor Heyl, telling of his work, appears on pages 23 and 24 of this report.

The Division of Geodesy of the United States Coast and Geodetic Survey has, for a number of years, prepared and published manuals each covering some branch of geodetic work. These manuals that now exist are the following:

1. Astronomic manual, entitled "Determination of time, latitude, longitude, and azimuth," special publication No. 14.
2. Formulæ and tables for the computation of geodetic positions, special publication No. 8.
3. Modern methods for measuring the intensity of gravity, special publication No. 69.
4. Reconnaissance and signal building, special publication No. 93.
5. General instructions for precise and secondary traverse, special publication No. 58.
6. Manual of first-order triangulation, special publication No. 120.
7. Instructions to light keepers on first-order triangulation, special publication No. 65.
8. Application of the theory of least squares to the adjustment of triangulation, special publication No. 28.
9. General instructions for the field work of the United States Coast and Geodetic Survey, special publication No. 26. (This contains general instructions for second-order and third-order triangulation and base measurements.)
10. Fourth general adjustment of the precise-level net in the United States, special publication No. 18. (This contains general instructions for first-order leveling.)

At the time of preparing this report manuals for first-order leveling, first-order traverse, and for second-order and third-order triangulation are being revised. It is expected that the new editions will be available the latter part of the year 1927.

It will be recalled that about five years ago the Board of Surveys and Maps of the Federal Government of the United States adopted the designations "precise," "primary," "secondary," and "tertiary" for the four classes of triangulation, base measurement, traverse, and leveling. These designations seemed to meet with very little favor after their adoption, and, as a consequence, in 1925 the board changed them to first, second, third, and fourth order respectively, the first order being the highest grade. The Coast and Geodetic Survey is now using these designations for the several classes of geodetic work.

GEODETIC ASTRONOMY

The methods employed and the accuracy attained in all recent astronomic determinations by the Coast and Geodetic Survey are practically the same as described in previous reports to the section of Geodesy. Chronographic registration of radio time signals, in connection with astronomic observations requiring precise time determinations, has been in use by the United States Coast and Geodetic Survey since 1922. The first radio recorders were designed by Dr. E. A. Eckhardt, of the United States Bureau of Standards, and they were successfully used in all parts of the United States and in Alaska for recording the United States Naval Observatory time signals transmitted by Annapolis on a wave length of 17,000 meters.

In 1925 the many records made in long-distance transmission by the use of short waves led to an investigation of their possibilities in connection with signal registration, and, in consequence, a short-wave recorder was built in the shops of the Coast and Geodetic Survey during the spring of 1926. The equipment was used throughout the world-longitude observations at Honolulu during October and November, 1926, and proved superior to the long-wave recorders. During December, 1926, the short-wave apparatus was used to determine time for gravity observations on the island of Hawaii. Daily records were obtained of the 71-meter time signals transmitted by the United States Navy station at Bellevue, D. C., at a distance of about 4,900 miles (7,900 kilometers).

AZIMUTHS

Azimuth observations have been made at a number of stations along all arcs of first-order triangulation or traverse executed in this country during the three years covered by this report. Many of these azimuth stations are Laplace stations at which the observations were made on two different nights and with a probable error seldom exceeding 0.3″. Altogether there were 65 azimuths determined in the United States between January 1, 1924, and January 1, 1927. Of this number 21 were Laplace azimuths.

LATITUDES

Astronomic latitude determinations at geodetic stations are used chiefly in figure-of-the-earth investigations. After a datum has once been established for a country these determinations do not have the direct and immediate value in connection with geodetic surveys that longitude determinations have. It has been found, however, that latitude observations can be made at stations where the astronomic longitude is being determined at a very small additional cost, especially where the instrument employed is the Bamberg broken-telescope transit, as this instrument can be adapted to both kinds of observations.

For the reasons just stated practically all latitude stations established by the United States Coast and Geodetic Survey during the period 1924–1926 are coincident with longitude stations. There are 19 of these latitude stations.

LONGITUDES

The completion of the first-order triangulation net over the western part of the United States, and the adjustment of the new arcs and the readjustment of the old arcs of this extensive net (see pp. 30 to 34), required the determination of a number of Laplace azimuths. These control azimuths were established along all the new arcs as a matter of course, but a few were also required along some of the old arcs in addition to those which had been established when the arcs were measured. The astronomic longitude determinations at these Laplace stations were all made by the radio method and are therefore referred to the center of the clock room at the Naval Observatory. In all, 31 longitude differences were observed during the three years.

WORLD-LONGITUDE OBSERVATIONS

In addition to the various observatories in the United States which made observations to connect their stations with the world-longitude net, there were four stations occupied by United States observers in this great international project. Two of these stations—Washington, D. C., and San Diego, Calif.—were occupied by observers from the Naval Observatory, and the other two, Honolulu and Manila, by observers from the United States Coast and Geodetic Survey.

At Honolulu satisfactory time determinations were obtained on 35 different nights, and radio signals from Bellevue, Honolulu, and Saigon were recorded. At Manila there was some delay in getting the radio instruments to operate properly, but from November 8 to the end of the month satisfactory time determinations were obtained on 16 different nights and the time signals from Honolulu and Saigon were recorded quite consistently, and on two different days those from Nauen were also recorded.

One of the interesting features of the work at the Honolulu and Manila stations was the use of the gravity pendulum in place of an accurate astronomical clock. The various radio signals received at Honolulu were spread out over an interval of more than 17 hours, the first one coming in at 3.20 and the last one at 20.40, Greenwich civil time. The time determinations each night were made near the middle of this interval. It was necessary, therefore, to carry the time very accurately for 8 or 10 hours if all the signals were to be connected to the local time determination. An ordinary chronometer could not be relied upon to give the required accuracy for such a long interval.

An interesting check on the accuracy of the pendulum method for carrying the time was obtained in a number of cases by referring the Honolulu signals at 20.40 to the time determinations on both the preceding and following nights, the two intervals being of about the same length. On three such tests the discrepancy was less than 0.01 second of time and on two others it was slightly greater than 0.02 second. As the intervals involved in these tests, during which the time was carried by the pendulum, were all about 12 hours in duration they give a very good indication of the accuracy of the method. Incidentally it should be noted that these tests also indicate that the time determinations involved are remarkably consistent.

HORIZONTAL AND VERTICAL CONTROL

FIRST-ORDER TRIANGULATION

Most of the first-order triangulation done during the years 1924, 1925, and 1926 is in the western part of the United States. It has been included in the readjustment of the triangulation west of the ninety-eighth meridian. Some first-order triangulation was also done in Alaska and in the United States east of the ninety-eighth meridian.

The arc of first-order triangulation along the boundary between the United States and Canada, which had been completed between the one hundred and ninth and one hundred and thirteenth meridians in 1922 and 1923, was extended to the Pacific coast in 1924, 1925, and 1926. In 1924 the party engaged on this work was in charge of A. H. Wagener; in 1925 there were three parties in the field, in charge of A. H. Wagener, G. L. Bean, and P. C. Doran, and in 1926 the western end of the arc was completed by a party in charge of P. C. Doran. The Geodetic Survey of Canada has extended this arc from the one hundred and ninth meridian to the ninety-eighth meridian, and the first-order triangulation along the forty-ninth parallel is now completed.

During the summers of 1924 and 1925 an arc of first-order triangulation and traverse was extended across the States of South Dakota, Wyoming, and Montana, from the ninety-eighth meridian arc in the vicinity of Salem, S. Dak., to the one hundred and eleventh meridian arc in the vicinity of Bozeman, Mont. This arc was connected with the one hundred and fourth meridian arc in the vicinity of the Black Hills. It consisted of traverse from Salem to Kimball, S. Dak., and of triangulation for the rest of the arc. Four bases were measured to control the lengths. Both seasons' work was in charge of Herman Odessey.

In the winter of 1924–25 an arc of triangulation was extended from Del Rio to San Antonio, Tex., connecting the ninety-eighth meridian arc with the Rio Grande arc. Herman Odessey was also in charge of this party.

A party in charge of W. H. Bainbridge made the observations in the summer of 1925 on an arc extending from Umatilla, Oreg., to Oroville, Wash. This arc made a connection between the Utah-Washington and the forty-ninth parallel arcs of first-order triangulation.

The arc of triangulation connecting the Texas-California arc in the vicinity of Needles, Calif., with the thirty-ninth parallel arc south of Salt Lake City, Utah, was completed in the summer of 1925 by a party in charge of William Mussetter. In the fall of 1926 Mr. Mussetter also made the observations on the arc connecting the above-mentioned arc in the vicinity of Las Vegas, Nev., with the California arc in the vicinity of San Luis Obispo, Calif.

The reoccupation of the old triangulation stations along the California arc in connection with the earthquake investigations was continued in 1924 and 1925. The gap which had been left between the northern and southern portions of the arc in 1923 was completed in 1924 by a party in charge of F. W. Hough. In 1925 a party in charge of William Mussetter extended the work north of San Francisco to Ukiah and Point Arena and also eastward in Nevada along the thirty-ninth parallel. This party also revised the triangulation along the Santa Barbara Channel and measured a first-order base in the vicinity of Santa Maria and connected it with the triangulation.

TRIANGULATION

U.S. Coast and Geodetic Survey

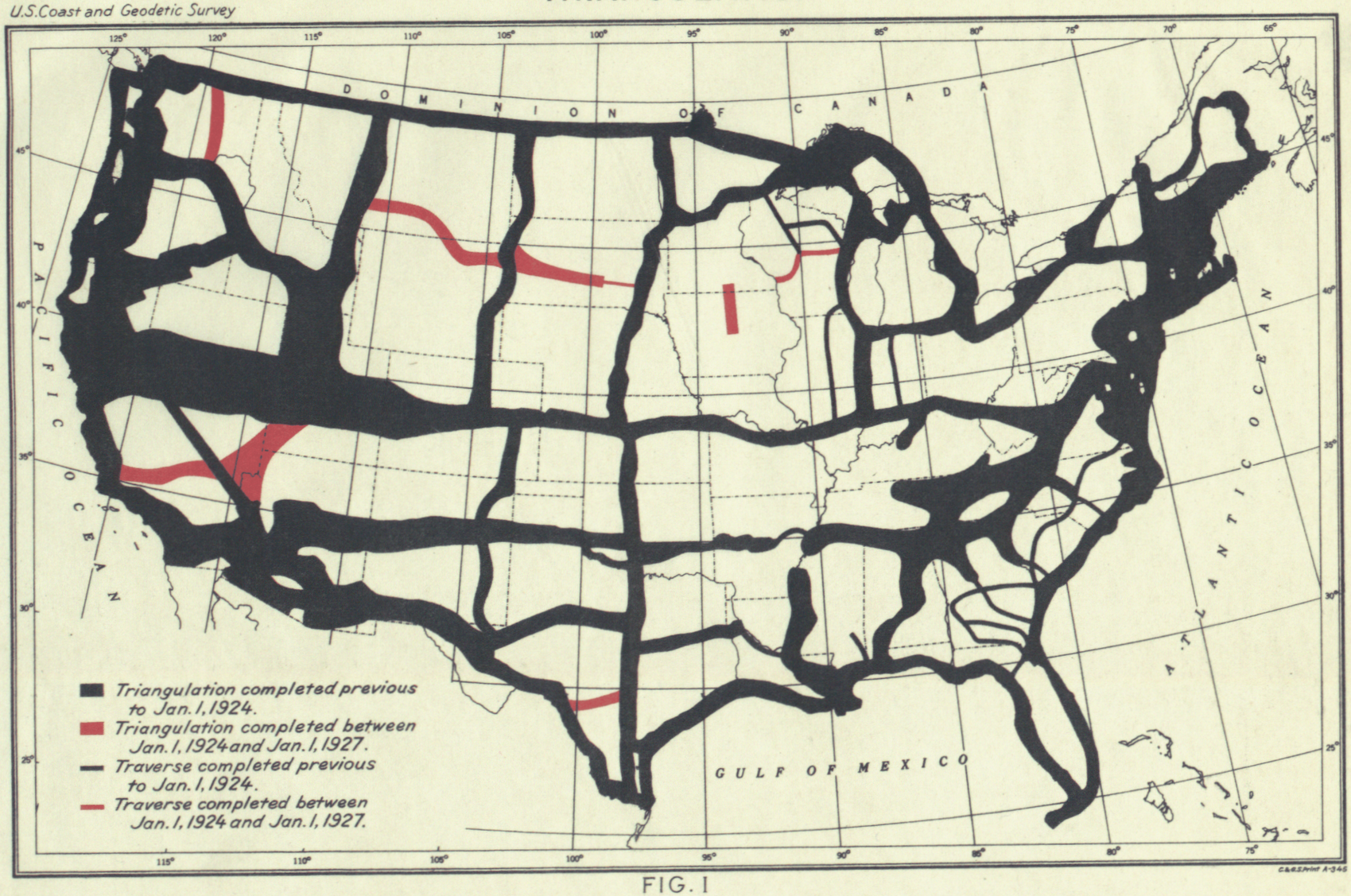

FIG. I

The triangulation along the international boundary from Basswood to Namakan Lakes, Minn., was completed in the summer of 1924. This work was also under the direction of Mr. Mussetter.

The triangulation to control the survey of the city of Rochester, N. Y., was executed in the summer of 1925 under the direction of E. O. Heaton. This work included the measurement of two base lines and about 80 miles of traverse. The city furnished men and materials and paid all expenses in connection with this work except the salaries of the Coast and Geodetic Survey officers. A similar survey of the city of Atlanta is at present being made, the observations for both triangulation and traverse having been started late in 1926. Mr. Heaton is also in charge of this survey.

Late in the summer of 1926 observations were started on the arc of first-order triangulation which will extend through the States of Iowa and Missouri along the ninety-fourth meridian. This arc was completed from a point just north of the Iowa-Minnesota State line to the forty-second parallel. H. W. Hemple was in charge of this party.

During the summers of 1924 and 1925 field work was completed on the arc of first-order triangulation in southeastern Alaska, extending from Dixon Entrance to Skagway. In 1924 two base lines were measured and connected with the triangulation, and the observations were completed across Dixon Entrance, connecting this arc with the triangulation of the Geodetic Survey of Canada. In 1925 the triangulation was extended from Lynn Canal to Skagway, and four base lines were measured and connected with it. Jack Senior was in charge of this work during both years.

Observations on the arc of first-order triangulation extending from the head of Cook Inlet to Fairbanks, Alaska, were continued in the summer of 1924, and the work was completed as far as Broad Pass, where a base line was also measured. This party was under the direction of W. M. Scaife. Progress on this arc has been slow, due to the difficulties of transportation. The reconnaissance has been completed from Broad Pass to Fairbanks and also from Fairbanks to Eagle by Sam O. White.

FIRST-ORDER AND SECOND-ORDER TRAVERSE

During the month of January, 1924, a party in charge of C. M. Durgin measured about 50 miles of first-order traverse over the ice of Rainy and Namakan Lakes, which form the boundary between the United States and Canada. At the end of the traverse a first-order base line nearly 5 miles long was also measured over the ice of Namakan Lake. In measuring the traverse and base line, portable tripods were used to support the tape ends. These tripods had legs about 3½ feet long, and each one had a decimeter scale fastened to the marking table. The position of each tape end was read on this scale instead of being marked on a metal strip. A ball-and-socket joint made it possible to place the scale on the same slope as the tape and also permitted a small amount of shifting of the table for alignment. The temperature during the measurements was from 20° to 40° F. below zero nearly every morning and on only a few days did it rise above freezing in the middle of the day. The traverse stations had been established on small islands and marked and the angles measured during the preceding summer.

During the summer of 1924 first-order traverse was run along the railroad between Salem and Kimball, S. Dak., by a party in charge of Herman Odessey. In 1926 G. L. Bean had charge of a party which measured first-order traverse along the railroad between Green Bay and La Crosse, Wis.

In connection with the survey of the city of Rochester, N. Y., about 80 miles of first-order and second-order traverse were run in 1925. Most of the measurements were made along the city streets. Portable tripods were used, and the tape ends were marked on copper strips fastened to the marking tables. E. O. Heaton was in charge of this work. (See above.)

In 1924 second-order traverse was run from Palm Beach to Lake Okeechobee, Fla., and from Myrtle Beach to Winyah Bay, S. C., by a party in charge of E. B. Roberts, and from Charleston to Beaufort, S. C., by a party in charge of L. P. Raynor.

FIRST-ORDER BASE LINES

During the calendar years 1924, 1925, and 1926, 11 first-order base lines were measured in the United States and 7 in Alaska. Seven of those measured in the United States were for the control of lengths in the first-order triangulation and the remaining four were measured in connection with the survey of the city of Rochester, N. Y. Three of these bases were measured over ice, the Namakan Lake base over the ice of Namakan Lake, on the international boundary between Minnesota and Ontario, Canada, and the Conesus and Lakeville bases on the ice of Conesus Lake, N. Y.

All the bases measured in Alaska were to control the lengths in the first-order triangulation extending from Dixon Entrance to Skagway, with the exception of the Broad Pass base, which is on the Cook Inlet to Fairbanks arc of triangulation. The measurement of these bases presented unusual difficulties. The country is very rough and heavily wooded, the trees extending down to the water's edge and the shores being steep and rocky. The cost of clearing base sites through the forests would have been very great, and it was necessary to measure the bases along the shore—many of which on this account were broken bases—and to make the measurements at low tide, the base sites being covered with water at high tide. The rocky shores made it impossible to drive stakes to support the tapes, and so the stakes were fastened to platforms heavily weighted with stones. Parts of the base sites were covered with water, even at low tide, and some of them extended across swift streams of icy water. Part of the measurements were made with the men immersed in water to their waists.

All the bases were measured with 50-meter invar tapes, which were standardized by comparison with the 5-meter iced bar by the United States Bureau of Standards before and after each field season.

The location of the first-order bases, with their lengths and probable errors, is shown in the following table:

First-order bases measured in the United States and Alaska, between January 1, 1924, and December 31, 1926

Name of base and State	Length in meters	Probable error		Name of base and State	Length in meters	Probable error	
		Millimeters	Proportional part of 1 in—			Millimeters	Proportional part of 1 in—
Namakan Lake, Minn	7,544.4286	±5.7	1,300,000	Osoyoos, Wash	8,857.3485	±5.4	1,600,000
Kimball, S. Dak	7,475.9459	±8.6	870,000	Santa Maria, Calif	20,043.0800	±6.0	3,300,000
Wall, S. Dak.[1]	13,012.3709	±7.6	1,700,000	Luck Point, Alaska[1]	5,983.5307	±5.5	1,100,000
Conesus, N. Y	1,255.0640	±2.0	630,000	Broad Pass, Alaska	6,045.3395	±2.9	2,100,000
Lakeville, N. Y	1,184.7776	±1.1	1,100,000	Metlakatla, Alaska[1]	3,220.8753	±2.2	1,500,000
Presho, S. Dak	23,379.6015	±17.6	1,300,000	Holkham Bay, Alaska[1]	2,204.5692	±4.3	530,000
Mount Read, N. Y.[1]	3,455.6096	±.6	5,800,000	Gastineau Channel, Alaska[1]	2,313.8942	±1.0	2,300,000
Winton, N. Y.[1]	3,478.1822	±1.2	2,900,000	Eagle River, Alaska	3,277.5452	±2.8	1,200,000
Ranchester, Wyo	9,056.5792	±5.3	1,700,000	Glacier Point, Alaska	3,726.5350	±7.7	480,000

[1] This is a broken base. The length given is the projected length of the base, but the probable error given is for the sum of the actual measured lengths.

FIRST-ORDER LEVELING

In southern California first-order levels were run in 1924 by F. W. Hough from Santa Ana to Barstow, from Burbank to San Fernando, and from Riverside to Ontario, a total of 175 miles. The line from Santa Ana to Barstow was a rerunning of a portion of the line from San Diego to Barstow, which was first leveled by E. H. Pagenhart in 1906.

During the season of 1924, 207 miles of first-order levels were run by J. C. Bose from Perth Amboy to Delair, N. J.; from Delair to Philadelphia, Pa., and Pleasantville, N. J.; and from

U.S.Coast and Geodetic Survey

FIRST-ORDER LEVELING

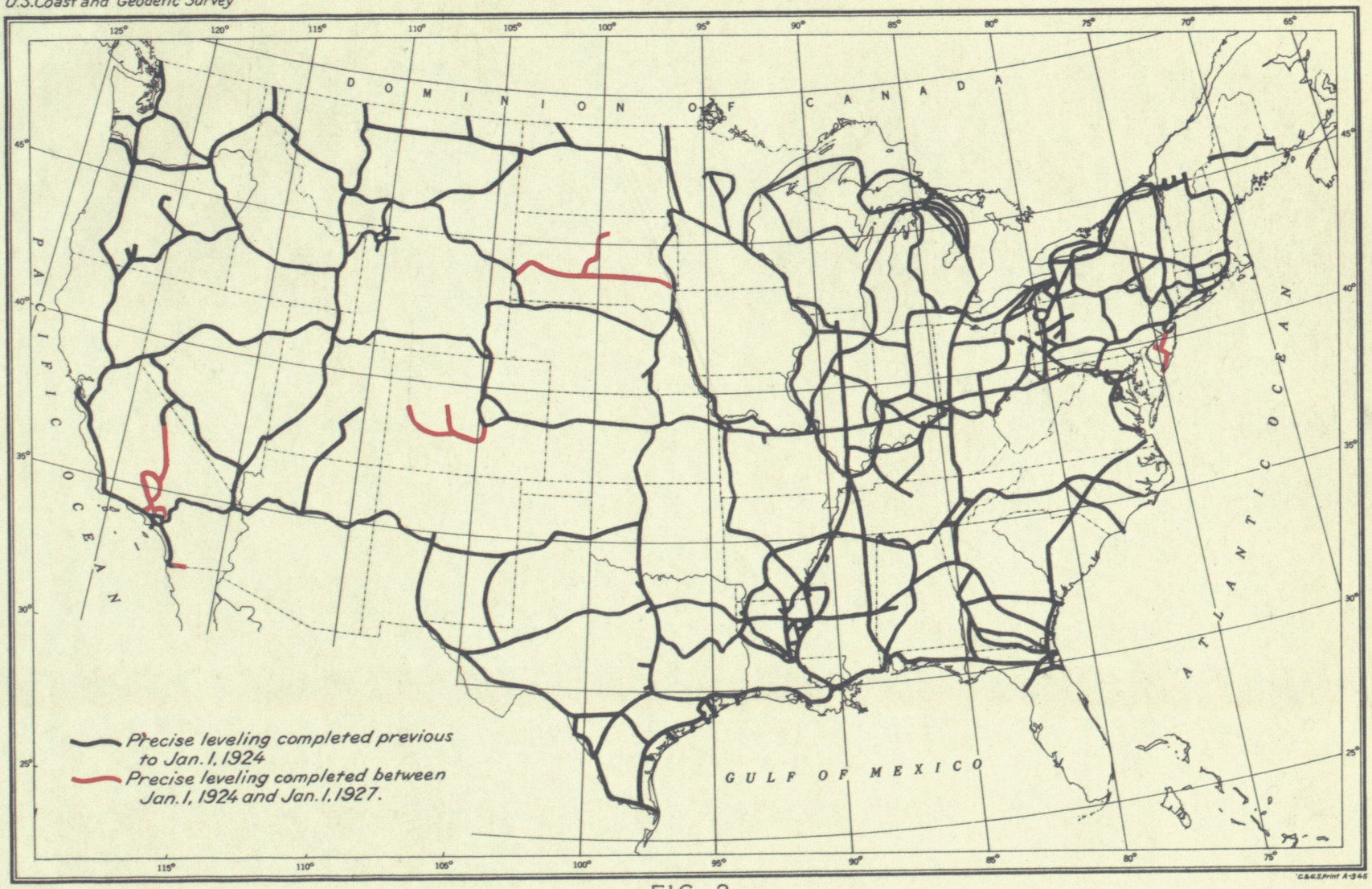

FIG. 2

Pleasantville to Atlantic City and Cape May, N. J. Connections were made with tidal stations at Atlantic City and at Cape May.

A total of about 3 miles of first-order levels was run in the vicinity of San Francisco, Calif., during March, 1925, for the purpose of connecting several tidal bench marks already in existence and also to add a number of new bench marks as protection against the total loss of certain well-determined tidal planes. The observing was done by G. E. Boothe.

First-order levels were extended from Colorado Springs to Pueblo and Salida and from Salida to Leadville and Grand Junction, Colo., by G. E. Boothe in the seasons of 1925 and 1926. These two seasons' work gave a total of 420 miles of leveling.

During the seasons of 1925 and 1926 C. M. Thomas, operating in South Dakota, extended first-order levels from Sioux Falls to Vivian and from Vivian to Loyalton, Rapid City, and Edgemont. The leveling in this project totaled 633 miles.

In California several lines of first-order levels were run during the seasons of 1925 and 1926. A line from Laws to Mojave and a line from Chatsworth via Wilmington to Pomona were run by L. G. Simmons between August, 1925, and January, 1926.

In 1926 J. M. Smook reran the section from Burbank to San Pedro, which had first been leveled in 1920, and extended first-order levels from San Fernando to Saugus, Bakersfield, Mojave, and Acton and back to Saugus. The total leveling in this group of lines is 633 miles.

At the close of the year 1926 first-order leveling was in progress from San Diego, Calif., toward Yuma, Ariz., 48 miles having been completed.

TRIANGULATION, TRAVERSE, AND LEVELING BY THE UNITED STATES GEOLOGICAL SURVEY

According to the latest definitions adopted by the Board of Surveys and Maps, the control work of the Geological Survey, which is entirely for use in topographic mapping, is classed as third order. It is of such accuracy, however, that no errors in position or elevation will be apparent on maps of any scale likely to be undertaken in the near future.

Since January 1, 1924, control work has been carried on in 30 States, and in Alaska and Hawaii, and 336 triangulation stations and 14,024 transit-traverse stations have been established. For vertical control, 18,700 miles of level lines have been run, along which metal bench marks have been placed at average intervals of 3 miles.

New books of instruction for Geological Survey control work were published in 1926. These are known as Parts B (triangulation), C (transit traverse), and D (leveling) of Bulletin 789. These contain 114 pages of text, besides numerous illustrations describing the latest methods adopted by the Geological Survey for carrying forward vertical and horizontal control.

The following figures indicate the growing importance of airplane photographs for topographic mapping. In 1924, 900 square miles of country were photographed for the Geological Survey for use in mapping; in 1925, 9,360 miles were covered; and in 1926 the plans called for 36,000 square miles of area in the United States proper, besides about 20,000 square miles in southeastern Alaska. Practically all of these photographs were made with multiple-lens cameras. The use of these photographs materially increases the accuracy of the maps and reduces their cost.

GRAVITY AND ISOSTASY

Nine gravity stations were established during the three years covered by this report and in the early part of 1927. Three of these are on the island of Hawaii and were established at the request of the Director of the United States Geological Survey. One of the three is on the summit of Mauna Loa, another at the volcano Kilauea, and the third in Hilo, a town on the coast. The values of gravity obtained are to be used in conjunction with data collected by the section of volcanology of the United States Geological Survey in studying certain problems of volcanology. In addition to the gravity stations mentioned above, a number of gravity determinations were made in 1926 in the southern and central part of the United States by

one of the large oil companies. The purpose of these determinations was to aid in the location of oil fields. The results have not been made public, but eventually they will undoubtedly be published, and, as the instruments and methods employed on this work are the same as those used by the United States Coast and Geodetic Survey, the data will form a very valuable addition to the gravimetric survey of the United States.

There have been several attempts during the past three years to develop a new type of gravity apparatus with which a determination could be made in less time than with the ordinary pendulum apparatus. None of these attempts have been entirely successful so far, although the torsion-spring apparatus developed by Dr. Fred E. Wright, of the Geophysical Laboratory of the Carnegie Institution, seems to have great possibilities.

ISOSTATIC REDUCTION OF SEA STATIONS

The Coast and Geodetic Survey has been cooperating with the president, Dr. J. J. A. Muller, of the Dutch Geodetic Commission, to the extent of making the isostatic reduction for gravity stations at sea at which the observations were made by Dr. F. A. Vening Meinesz. These stations are in the Mediterranean Sea and in the Indian, Atlantic, and Pacific Oceans. In all, there are nearly 100 sea stations for which the isostatic reduction has been made since the Madrid conference. As rapidly as the computations have been completed the detailed results have been forwarded to Doctor Muller. It is understood that Doctor Meinesz expects to make a detailed and extensive study of the relation of the isostatic anomalies to the configuration of the ocean bottoms upon his return to Holland from his recent voyage to Java. The final observed values for the stations determined in 1926, have not all been received from Doctor Meinesz at the time this report is being written, and no reductions have as yet been computed for the stations between Honolulu and Java and for those south of Java. The isostatic reductions of the stations between Holland and Java, determined in 1923 on the trip through the Mediterranean Sea and Indian Ocean, have been published by the Dutch geodetic committee.[1]

Over those parts of the Atlantic, Pacific, and Indian Oceans where the bottom is practically level for great distances around the station there is a tendency for the isostatic anomaly to be positive. A study of this problem by C. H. Swick, of the Coast and Geodetic Survey, and the author, indicates that this is a normal condition, due to the fact that the gravity formula used in computing the theoretical gravity at sea level at a station contains factors which were derived from data at gravity stations on land. As is well known, the geoid surface is above the spheroid surface under land areas and is below the spheroid over ocean areas. It is evident, therefore, that a station on the geoid surface under the continents would be farther away from the center of the earth than a station on an ocean in the same latitude. The land station would on this account have a smaller value of gravity than would the ocean station. Evidently there should be a correction to each observed value of gravity to reduce it to the spheroid surface. If this were done, it is believed that the average isostatic anomaly, with regard to sign, over ocean areas would be the same as, or only slightly different from, the corresponding average anomaly at land stations.

OTHER ISOSTATIC REDUCTIONS

It will be recalled that, in a resolution adopted at the Madrid meeting of the section of geodesy, the Director of the United States Coast and Geodetic Survey was requested to authorize the mathematicians of that organization to make the isostatic reduction of gravity stations for geodetic organizations of other countries. The resolution provided that the countries in question could make compensation to the mathematicians for the time spent by them in carrying on any such work. During the three years covered by this report, the mathematicians of the Coast and Geodetic Survey have made the isostatic reduction for 31 gravity stations in

[1] Isostatic reduction by the U. S. Coast and Geodetic Survey of the results of the pendulum observations at sea made in 1923 between Holland and Java. Delft. 1926.

Spain, in response to a request from the director of the Geographical and Cadastral Institute of Spain, and for 18 gravity stations in Holland, on request of the president of the Dutch Geodetic Commission. The results of the computations have been sent to the organizations mentioned above, and no doubt reports concerning this work will be presented in the national reports for Spain and for Holland.

By means of a small fund, furnished by the Philosophical Society of Washington, the isostatic reduction was made for five gravity stations located in the southern Pacific on the New Hebrides and Solomon Islands.[2]

The isostatic reduction was made at the office of the United States Coast and Geodetic Survey of one station in western Siberia and was estimated at eight others within an area that is comparatively level. It is believed that the local topography there has very little effect on the values of gravity, hence the isostatic reduction as made should throw some light on the isostatic condition of the earth's crust below the stations. It is rather noteworthy that the mean of the anomalies with regard to sign for eight of the stations in Siberia is only −0.005 dyne; the average anomaly without regard to sign for these stations is 0.007 dyne, and the maximum is −0.025 dyne. One of the stations involved in the Siberian group is located fairly close to a range of mountains; the anomaly for this station is −0.094 dyne.

A study was made of the isostatic reduction of 46 gravity stations in Norway, the details of which were contained in a paper by Dr. W. Heiskanen, of the Finnish Geodetic Institute, entitled "Isostatische Kompensation in Norwegen." Except for a very few anomalies at stations where the observed values of gravity are abnormally large, the isostatic anomalies indicate that isostasy prevails under Norway to as marked a degree as has been found in other parts of the world.

TIDE STATIONS NOW IN OPERATION OR WHERE THREE OR MORE YEARS OF OBSERVATIONS HAVE BEEN OBTAINED

[Stations now in operation marked by an asterisk (*)]

Eastport, Me., Jan. 9, 1860, to July 18, 1864.
Pulpit or North Harbor, Penobscot Bay, Me., Jan. 21, 1870, to Mar. 28, 1888.
*Portland, Me., Aug. 1, 1864, to Nov. 1, 1866; and Mar. 4, 1910, to present time.
*Portsmouth (Navy Yard), N. H., Aug. 24, 1926, to present time.
Boston (Navy Yard), Mass., Feb. 3, 1861, to Feb. 19, 1877; and
*Boston (Commonwealth Pier), Mass., May 3, 1921, to present time.
Cape Cod Canal, Cape Cod Bay Entrance, Mass., Jan. 1, 1912, to July 1, 1914 (2½ years).
Cape Cod Canal, Buzzards Bay Entrance, Mass., Jan. 1, 1912, to July 1, 1914 (2½ years).
Newport (Fort Adams), R. I., Mar. 31, 1892, to Feb. 7, 1895.
Providence, R. I., May 22, 1873, to Sept. 16, 1882; and Oct. 22, 1885, to June 2, 1890, and the year 1892.
Bridgeport, Conn., Jan. 13, 1911, to June 24, 1915.
*Fort Hamilton (The Narrows), N. Y., Dec. 30, 1892, to Nov. 30, 1920; and Nov. 26, 1926, to present time.
Brooklyn (Hamilton Avenue Ferry), N. Y., Jan. 1, 1856, to Dec. 31, 1875.
Governors Island, N. Y., Dec. 12, 1852, to May 1, 1879.
*New York (Barge Office), East River, N. Y., Nov. 22, 1926, to present time.
Belmont Island, East River, N. Y., June 24, 1920, to Dec. 31, 1922 (2.52 years).
Willets Point, East River, N. Y., July 1, 1891, to May 31, 1896.
Sandy Hook, N. Y., Oct. 21, 1875, to July 1, 1893; and Nov. 26, 1906, to Dec. 31, 1916.
Atlantic City (Million Dollar Pier), N. J., Aug. 15, 1911, to Jan. 16, 1921; and
*Atlantic City (Steel Pier), N. J., Nov. 30, 1922, to present time.
Breakwater Harbor (Government Lighthouse Pier), Del., Jan. 14, 1919, to May 12, 1923.
Reedy Island, Del., Feb. 22, 1897, to Mar. 31, 1903.
Philadelphia (Chestnut Street Pier), Pa., July 4, 1900, to Feb. 24, 1921; and
*Philadelphia (Pier 9 N., near Race Street), Pa., May 17, 1922, to present time.
Aberdeen Proving Grounds (off Black Point), Md., Feb. 3, 1919, to Sept. 21, 1922.
Fort Carroll (Patapsco River), Md., Oct. 1, 1897, to Jan. 1, 1901.
*Baltimore (Fort McHenry), Md., June 30, 1902, to present time.
Washington (Navy Yard), D. C., July 31, 1891, to Feb. 1, 1899.

[2] See William Bowie, Isostasy in Southern Pacific, Journal Washington Academy of Sciences, vol. 15, No. 20, Dec. 4, 1925.

Washington (Norfolk & Washington Steamboat Wharf), D. C., June 30, 1898, to Apr. 3, 1901 (2.76 years).
Colonial Beach, Potomac River, Va., June 27, 1906, to June 30, 1910.
Old Point Comfort (Hampton Roads), Va., Aug. 3, 1852, to July 10, 1878.
Wilmington (Cape Fear River), N. C., Jan. 24, 1908, to Feb 13, 1912.
Fort Sumter, Charleston Harbor, S. C., Mar. 22, 1882, to Jan. 15, 1909.
*Charleston (Customhouse), S. C., Jan. 26, 1856, to Aug. 2, 1861; and Sept. 30, 1921, to present time.
Tybee Island, Ga., Sept. 29, 1889, to June 8, 1892 (2.7 years).
Fort Clinch (Old Fernandina), Fla., Feb. 20, 1856, to Mar. 25, 1861.
Fernandina (De Soto Street Wharf), Fla., May 8, 1897, to June 27, 1924.
St. Augustine, Fla., Mar. 18, 1914, to Aug. 1, 1918.
Key West (Curry's Wharf), Fla., Jan. 18, 1913, to Jan. 1, 1927.
*Key West (Naval Submarine Base), Fla., Jan. 20, 1926, to present time.
Dry Tortugas (Fort Jefferson), Fla., Feb. 27, 1857, to May 1, 1861.
Cedar Keys, Fla., Mar. 12, 1914, to June 30, 1926.
*Pensacola (Baylen Street Wharf), Fla., Apr. 30, 1923, to present time.
Mobile Point (Fort Morgan), Ala., Jan. 13, 1846, to May 27, 1851.
Mobile (Battery Gladden), Ala., Jan. 2, 1903, to Sept. 6, 1906.
Biloxi, Miss., Jan 1, 1896, to Jan. 7, 1899.
Weeks Island, Vermillion Bay, La., Feb. 25, 1905, to Feb. 26, 1912.
Galveston (Fort Point), Tex., Nov. 28, 1903, to June 30, 1908.
*Galveston (Twentieth Street Wharf), Tex., Apr. 20, 1908, to present time.
San Diego (La Playa), Calif., Sept. 22, 1853, to Aug. 31, 1872.
San Diego (Quarantine Wharf), Calif., Jan. 20, 1906, to Dec. 31, 1925.
*San Diego (Municipal Pier No. 1), Calif., July 1, 1926, to present time.
*La Jolla (Scripps Institute Wharf), Calif., July 16, 1921, to present time.
*Los Angeles Harbor (San Pedro), Calif., Nov. 28, 1923, to present time.
Fort Point (Golden Gate), Calif., June 30, 1854, to Nov. 27, 1877.
*San Francisco (Presidio), Calif., July 15, 1897, to present time.
Sausalito (San Francisco Bay), Calif., Feb. 19, 1877, to Sept. 1, 1897.
Astoria (Ninth Street), Columbia River, Oreg., July 10, 1853, to Oct. 31, 1876.
*Astoria (Tongue Point), Columbia River, Oreg., Jan. 24, 1925, to present time.
Port Townsend (Admiralty Inlet), Wash., Aug. 1, 1873, to Mar. 31, 1877.
*Seattle (Madison Street), Wash., Dec. 10, 1898, to present time.
Anacortes (Guemes Channel), Wash., May 21, 1921, to June 14, 1924.
Bremerton Navy Yard (Port Orchard), Wash., Apr. 19, 1897, to Jan. 15, 1900 (2.74 years)
Olympia (Budds Inlet), Wash., May 1, 1916, to Oct. 21, 1924.
*Ketchikan (Tongass Narrows), Alaska, Oct. 12, 1918, to present time.
Craig (Bucareli Bay), Alaska, Apr. 30, 1914, to Oct. 23, 1920 (series broken, total observations about 3½ years).
Juneau (Gastineau Channel), Alaska, Nov. 1, 1911, to Nov. 30, 1915.
Skagway (Chilkoot Inlet), Alaska, Aug. 13, 1908, to Oct. 31, 1911.
*Seward (Resurrection Bay), Alaska, May 14, 1925, to present time.
*Valdez (Prince William Sound), Alaska, Sept 5, 1923, to present time.
Kodiak, Kodiak Island, Alaska, Aug. 1, 1880, to Apr. 30, 1891.

LIST OF GEODETIC PUBLICATIONS BY THE UNITED STATES COAST AND GEODETIC SURVEY ISSUED SINCE JANUARY 1, 1924

Earth movements in California. William Bowie. Special publication No. 106. 1924.

Wireless longitude. G. D. Cowie and E. A. Eckhardt. Special publication No. 109. 1924.

A gravimetric test of the "roots of mountains" theory. William Bowie. Serial No. 291. 1924.

Astronomic determinations by the United States Coast and Geodetic Survey and other organizations. Sarah Beall. Special publication No. 110. 1925.

Elliptic functions applied to conformal world maps. Oscar S. Adams. Special publication No. 112. 1925.

Triangulation in Maryland. Hugh C. Mitchell. Special publication No. 114. 1925.

Manual of first-order triangulation. C. V. Hodgson. Special publication No. 120. 1926.

First-order leveling in Oregon. H. G. Avers. Special publication No. 122. 1926.

Use of data of the United States Coast and Geodetic Survey in the surveys of farms and other properties. Serial No. 347. 1926.

Report on the readjustment of the first-order triangulation net of the western part of the United States. Oscar S. Adams. Serial No. 350. 1926.

Use of the gravity pendulum as a timepiece. William Bowie. Serial No. 356. 1926.

Isostatic condition of the United States as indicated by groups of gravity stations. William Bowie. Serial No. 366. 1926.

SPECIAL ARTICLES

GEODETIC STANDARDIZATION AT THE UNITED STATES BUREAU OF STANDARDS [3]

By Lewis V. Judson, *Associate Physicist, United States Bureau of Standards*

I. STANDARDIZATION OF INVAR BASE-LINE TAPES [3]

The standardization of the invar base-line tapes of the United States Coast and Geodetic Survey is carried out on the geodetic tape comparator of the United States Bureau of Standards. This comparator is designed especially for 50-meter tapes of high precision, although tapes having a length of an integral number of meters up to 25, also 30, 35, 40, or 45 meters can be compared. Should a demand arise, modifications could be made permitting 100-foot tapes properly graduated for geodetic work to be tested on this apparatus.

This comparator [4] is shown at the left and central portion of the view of the tape tunnel given in Figure 3. This apparatus is modeled after the field apparatus used on the Holton (Ind.) base in 1891 and described in Appendix No. 8 of the Report of the United States Coast and Geodetic Survey for 1892. Some of the equipment previously used in the field, notably the Woodward iced bar No. B_{17}, is in use in the comparator at the Bureau of Standards.

There are 11 concrete piers at equal intervals of 5 meters apart. Each of these piers has attached to its upper surface an adjustable mounting for a micrometer microscope. The two end microscopes are the most important ones, the cross hairs of the intermediate ones serving only as reference points in laying off the 50-meter interval by means of the 5-meter standard. In building up the 50-meter interval the cross hairs are set on the lines of the 5-meter bar and thus play a part analogous to that of pencil marks used by a carpenter in connection with his 2-foot rule in laying off a distance on a board.

The working standard in this geodetic-tape comparator is the Woodward bar. This bar, which is steel with very low carbon content, is mounted in a Y-shaped trough so that ice ground into small pieces can be packed around it. The bar in its trough is mounted on trucks and can be moved by successive steps under the microscopes lengthwise of the tunnel. The trucks have the necessary focusing and lateral adjustments.

In testing a 50-meter base-line tape a distance of 50 meters is first laid off by means of the 5-meter bar and the microscopes, and then the interval on the tape is compared with this distance. In order to compare tapes differing in length from 50 meters by more than 1 or 2 millimeters a movement of one or both of the end microscopes is necessary. To measure the movement of the end microscopes, either intentional or accidental, the positions of the microscopes are determined with relation to two fiducial points at the floor level by means of a special device known as the cut-off, which is described on page 17.

A correction, commonly termed the "grade" correction, must be applied, because the foci of the intermediate microscopes are not absolutely in the plane passing through the foci of the two end microscopes. To obtain this correction the relative tilt of the 5-meter bar, when it is in position for observation at the 10 successive positions, is read by means of a graduated sector reading by two opposite verniers to 10″. This sector, with a sensitive spirit level attached to the vernier arm, is mounted at one side of the trough near its middle point. The total grade correction is the length of the bar times the sum of the differences from unity of the cosines of the angles made by the bar with a line joining the end points of the base.

The 5-meter bar has been compared with the platinum-iridium standard meter No. 21 a number of times, beginning in 1892. Special facilities for this comparison are incorporated in the equipment of the present geodetic tape apparatus. For the limited number of bars of this type requiring test in this country a very simple arrangement gives adequate results. In Europe where 4-meter and 5-meter bars are more frequently used in geodesy, rather elab-

[3] Published by permission of the Director of the National Bureau of Standards of the U. S. Department of Commerce.

[4] For a more complete description of this apparatus and its use, one should consult Bureau of Standards circular No. 328, The Testing of Measuring Tapes at the Bureau of Standards, by Lewis V. Judson.

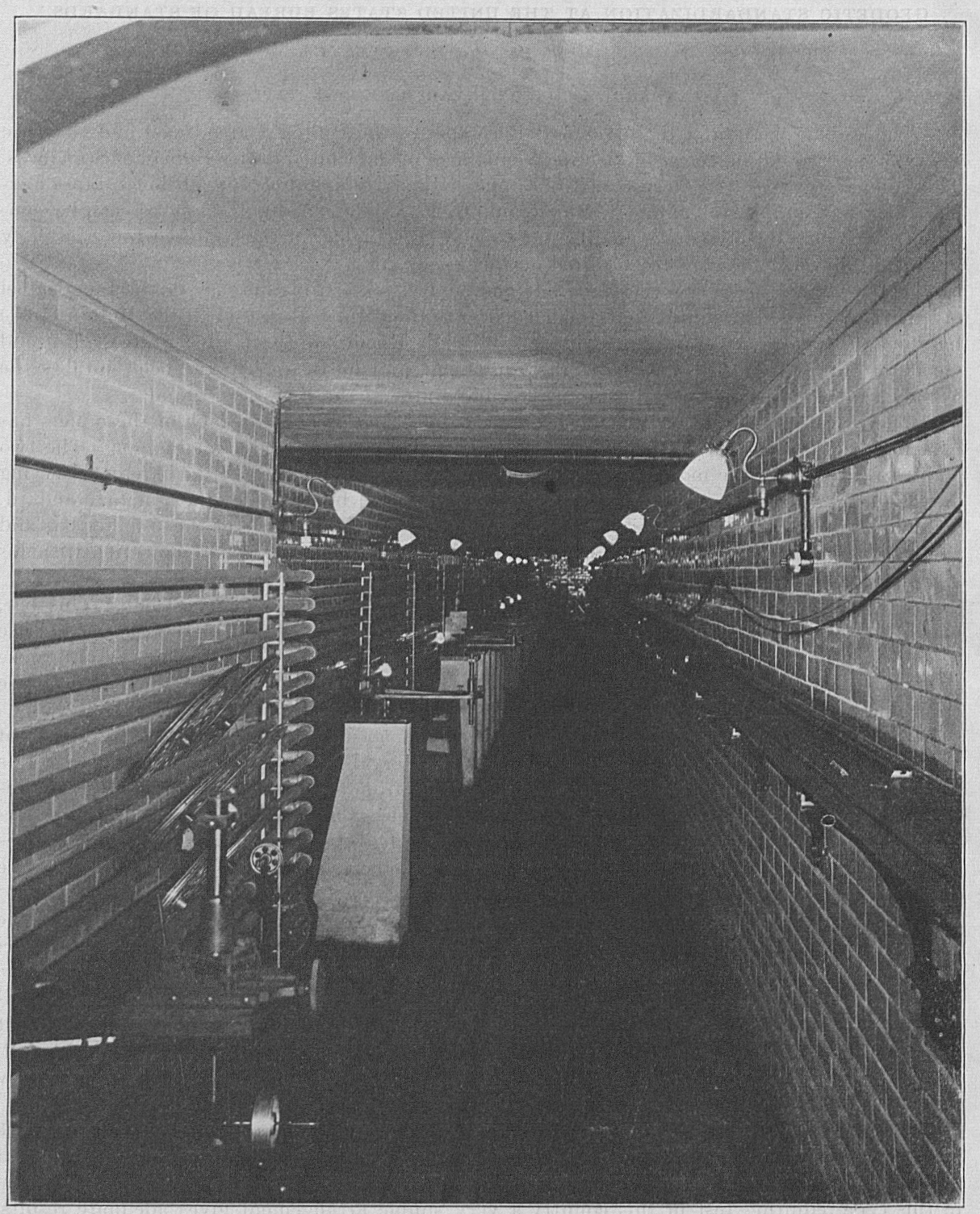

FIG. 3.—Tape standardization hall at the United States Bureau of Standards

orate instruments have been constructed. Between the fifth and sixth piers, counting from the north end of the bureau's tape tunnel, there are intermediate piers with an interval of 1 meter between them. With microscopes mounted on these piers, it is a relatively simple matter to build up a 5-meter interval by the use of a 1-meter bar packed in ice and mounted so as to be movable in a longitudinal direction and to have the requisite adjustments for focus and alignment. By substituting the 5-meter bar under the microscopes its total length can be compared with a distance equal to five times the length of the 1-meter bar. A repetition of this process fifteen or twenty times generally results in a comparison of adequate precision.

Secondary in importance, as far as the general principles of the measurements of geodetic tapes are concerned, the cut-offs are of primary importance in securing a high degree of precision. The cut-off appears to have originated with the German instrument makers, Repsold, and consists of a long cylindrical piece, at the lower end of which is a conical hole which is coaxial with the cylinder itself. A spirit level is mounted on the cylinder, and a scale divided to millimeters is attached to the top of the cylinder which is movable with respect to the body of the cylinder by a rack and pinion. This motion permits the scale to be brought into focus. One cut-off is mounted in a frame at each end of the 50-meter base. The lower end of each cut-off is set on a sphere specially mounted on a pier the top of which is at the level of the floor, and this apparatus will, therefore, project a point in the focal plane of a microscope down to a horizontal plane passing through the center of the sphere at about the floor level, or vice versa. Hence, if the distance from a point in the focal plane of one terminal microscope to a point in the focal plane of the other terminal microscope is known, then the distance between the centers of the two spheres may be accurately determined, since the axis of the cone will always pass through the center of the sphere.

The 50-meter base is laid off by successive 5-meter steps using the iced bar. The terminal points are projected down by means of the readings on the cut-off apparatus and the horizontal distance between the centers of the spheres calculated. The centers of these spheres are sometimes called the fiducial points, and the distance between them is generally designated as the length of the base. For a complete establishment of the base two determinations of its length are made the first thing in the morning, one with the bar being moved to the right, the other with it being moved to the left, and two similar determinations are made in the afternoon after the day's comparisons of tapes are completed. This is the standard procedure for each day of actual testing. The grade correction is calculated from readings on the sector attached to the trough of the 5-meter bar.

After the establishment of the base the lengths of the tapes are compared with this distance. The tapes are supported on ball-bearing wheels which are adjusted for height so as to lie in the straight line passing through the focusing points of the two end microscopes, which line is essentially in a horizontal plane. The tension is applied to the tape by a calibrated weight hanging vertically and fastened to the tape by a wire passing over a frictionless pulley.

The tape is adjusted so that the lines are properly located in the field of the microscopes. If necessary to move one or both of the microscopes, cut-off readings give a precise value for the amount of this motion.

Standard conditions for invar base-line tapes of the United States Coast and Geodetic Survey are: Tension, 15 kilograms; suspension at 0, 25, and 50-meter points, and also at 0, 12.5, 25, 37.5, and 50-meter points; thermometers, with cases, weighing 45 grams attached to tape at 1-meter and 49-meter points. These invar tapes are usually about 6.3 millimeters wide and 0.5 millimeter thick and weigh about 25.5 grams per meter.

The length of a geodetic base-line tape, when supported throughout, is found more accurately by computation than by comparison on the steel bench. In this calculation the effect of the weight of the thermometers upon the length of the tape must be taken into consideration.[5]

The temperature of the tape is found by means of the two thermometers attached to the tape and nine equally spaced thermometers hung in the air very near the tape.

[5] Judson, L. V., The Effect of Concentrated Loads on the Length of Measuring Tapes, B. of S. Sci. Paper No. 534. See p. 18 of this report.

Although steel tapes can be compared on this geodetic apparatus, such tapes are not usually suitable for precise geodetic work and should not be submitted to the Bureau of Standards for this test without previous correspondence with the bureau about them.

The United States Coast and Geodetic Survey, in requesting the test of base-line tapes, usually specifies that the probable error shall not exceed 1 part in 1,000,000 and that the absolute error shall not exceed 1 part in 300,000. It is believed that the absolute error of the determinations as certified at the present time to the Coast and Geodetic Survey does not exceed 1 part in 1,000,000. The consistency of the results is still greater, judging from data on hand. For instance, the length of a tape supported throughout, as computed from observations made with the tape suspended in two loops, usually does not differ by more than 20 microns from that computed from observations made on the tape suspended in four loops; very frequently the discrepancy is less than 10 microns.

Certain potential sources of error are worthy of consideration. The absolute length of the base may be in error because of an error in the length of the 5-meter bar, B_{17}. This bar, however, has been determined with an accuracy such that 10 microns in the 50 meters will amply cover this error. Errors in sighting on the lines of bar B_{17}, due to improper focus, or improper illumination, or other similar causes, are not only small but are not of the cumulative type. The total grade correction is less than 50 microns. Its precision is indicated by the smallness of the changes which have occurred in it in the past three years. All determinations during that period lie between -35 microns and -44 microns. As an indication of the smallness of the error caused by friction in the pulleys, it may be stated that no ordinary means suffice to detect the friction. The weights, too, have been carefully calibrated. An unevenness of the temperature distribution and an uncertainty as to radiation effects are recognized, but the low coefficient of expansion of invar makes these relatively unimportant.

In fact, so satisfactory has this apparatus proved that, if an opportunity presented itself to construct a new tape-testing laboratory and apparatus, the present apparatus would either be duplicated with minor changes or used again. The changes would be more noticeable in the laboratory itself. Twenty feet additional length, thermostatic control, adequate means for hanging up tapes when not actually being compared, and a suitable ventilating system; these are some improvements that might well be made.

II. EFFECT OF CONCENTRATED LOADS ON THE LENGTH OF MEASURING TAPES

The 50-meter comparator has been used for obtaining information of considerable interest to geodesists. An account of this work was published in Scientific Paper No. 534, of the United States Bureau of Standards, under the title "Effect of Concentrated Loads on the Length of Measuring Tapes." In the standardization of metal tapes the tapes are supported either throughout their length or at intervals along their length. Although elementary cases of tape measurements are treated in textbooks on geodetic surveying, there are important variations arising in modern geodetic surveying and in the standardization of the tapes for the geodesist which are not discussed in the texts. One of these is the case of vertical forces concentrated at points along the tape, and it is the purpose of this paper to state the formulas used in computing their effect and to give the results of experiments which have been carried out to determine the validity of the formulas. The special application is to thermometers attached to base-line tapes.

A mathematical equation covering this case was derived by W. D. Lambert, of the Coast and Geodetic Survey. The equation differs in certain particulars from other equations which have been given, and a discussion of the differences is given in the original paper, to which reference should be made by those interested in the details of this research. Mr. Lambert's equation in its most general form is as follows:

$$L_n^1 = L - \frac{L}{6}\left(\frac{\rho L}{2n\,W}\right)^2 - \frac{\rho}{2\,W^2}\sum_{k=1}^{k=N}\left\{\left[\left(\frac{L}{2n}\right)^2 - x_k^2\right]\left[w_k + \frac{n w_k^2}{\rho L}\right]\right\}$$

where

L_n^1 = length of tape supported in n loops with N concentrated loads,
n = number of loops in which tape is supported,
ρ = linear density of tape,
W = terminal tension,
L = length of tape supported throughout at tension W.

NOTE.—(In some cases L may be taken as the nominal length of the tape.)

x_k = distance of the kth load from the lowest point of the loop in which it is placed.

The term $-\frac{L}{6}\left(\frac{\rho L}{2n\,W}\right)^2$, in formula (4) given above is a well-known expression for obtaining the length of a tape supported throughout when its length supported at equidistant points is known. Recognized as entirely legitimate for the ordinary engineer, its validity for the modern geodesist has occasionally been questioned, probably because of difficulties in obtaining precise standardizations of a tape when supported throughout. The following data, a comparison of of the measured change in length obtained for tapes supported in three and in five loops and the calculated change using the formula, show that the reliability of the formula is amply sufficient for all geodetic purposes.

TABLE 2.—*Effect of changing the number of spans in a 50-meter tape*

Tape	Weight of tape	Length in four spans minus length in two spans		Difference
		Observed	Computed from formula	
	g/m	*μ*	*μ*	*μ*
A	21.8	2,070	2,060	+10
B	25.1	2,740	2,733	+7
C	25.5	2,826	2,822	+4
D	25.8	2,878	2,888	−10
E	25.8	2,905	2,888	+17
F	26.6	3,049	3,071	−22

An investigation is now in progress at the Bureau of Standards to determine the validity of the formula for steel tapes not having uniform linear density, such as are often used in ordinary surveying, especially the type of tape having large solder or babbit-metal patches attached to the tape for the graduations.

The quadratic term in the equation was shown in the experimental work to be an essential part of the equation for cases in which the loads are not near the points of support. It is, however, practically negligible for the condition where thermometers are placed 1 meter from the ends of a 50-meter tape in three or five catenaries. The following table, taken from the original paper, shows the agreement between observed data and values computed from the term

$$\frac{\rho}{2\,W^2}\sum_{k=1}^{k=N}\left[\left(\frac{L}{2n}\right)^2 - x_k^2\right]w_k$$

it being noted that an even closer agreement is obtained by including the quadratic term.

TABLE 3.—*Effect of thermometers upon length of tape*

[Two thermometers, weighing 28.6 grams each, hung 1 meter from each end of tape]

Tape	Linear density of tape	Change in length in microns					
		Tape in two loops			Tape in four loops		
		Observed	Computed	Observed minus computed	Observed	Computed	Observed minus computed
	g/m						
A	25.7	−74.8	−78.5	+3.7	−44.2	−37.6	−6.6
B	25.4	−89.7	−77.7	−12.2	−46.4	−37.2	−9.2
C	25.8	−75.1	−78.8	+3.7	−43.8	−37.7	−6.1
D	25.7	−80.4	−78.5	−1.9	−39.6	−37.6	−2.0
E	25.6	−79.7	−78.2	−1.5	−44.6	−37.4	−7.2
F	25.8	−84.6	−78.8	−5.8	−42.7	−37.7	−5.0
G	25.7	−77.7	−78.5	+.8	−40.6	−37.6	−3.0
H	25.5	−76.9	−77.8	+.9	−40.2	−37.3	−2.9
I	25.6	−76.4	−78.2	+1.8	−41.6	−37.4	−4.2
J	25.7	−75.1	−78.5	+3.4	−39.4	−37.6	−1.8
K	25.8	−75.6	−78.8	+3.2	−40.2	−37.7	−2.5
L	25.2	−81.9	−76.9	−5.0	−42.8	−36.9	−5.9
Mean				−.2			−4.7

The general equation given above, expressing the effect of sag and of concentrated loads upon the distance between the terminal marks on a tape, is found from this investigation to be rigidly applicable even for the most precise work. For ordinary cases arising in geodetic practice, such as the application to the case of thermometers placed near the terminal graduations, the quadratic term may be omitted and the formula thus materially simplified for routine numerical computations. Care must be taken, however, to see that the quadratic term actually is negligible in any given case.

III. INVESTIGATION OF THE PERMANENCE OF LENGTH OF INVAR TAPES

The Bureau of Standards has been much interested in the questions relating to the permanence of length of invar tapes. A report on the variations of lengths of these tapes has already been submitted to the secretary of the section of geodesy by the United States Coast and Geodetic Survey and a supplementary report by the United States Bureau of Standards.

It is hoped that, as a result of the compilation of the data from various nations, a way may be found to obtain invar tapes on which more reliance may be placed in the length for a greater period of time. Whether the greater instability of tapes purchased in the last decade is due to an attempt to secure either very low coefficients or some other physical property is not known.

IV. NEW EQUIPMENT FOR GRADUATION AND CALIBRATION OF CIRCLES

The Bureau of Standards has recently purchased a high-precision circular dividing engine and also an apparatus for calibrating the graduations of precision circles. One special field of work in which both of these devices will have particular use at first is that of geodetic instruments of the United States Coast and Geodetic Survey. The survey granted an allotment to aid in the purchase of the dividing engine.

Both of these instruments have been purchased from the Société Genevoise d'Instruments de Physique and represent what is believed to be the highest grade instruments yet developed for the work which they are designed to accomplish. A special constant-temperature room in the basement of one of the buildings of the Bureau of Standards is now being prepared for these two instruments and for two high-precision length comparators. Until this room is completed and the instruments tested under suitable conditions no definite or final report can be made regarding them. It does, however, seem proper to give a brief description of

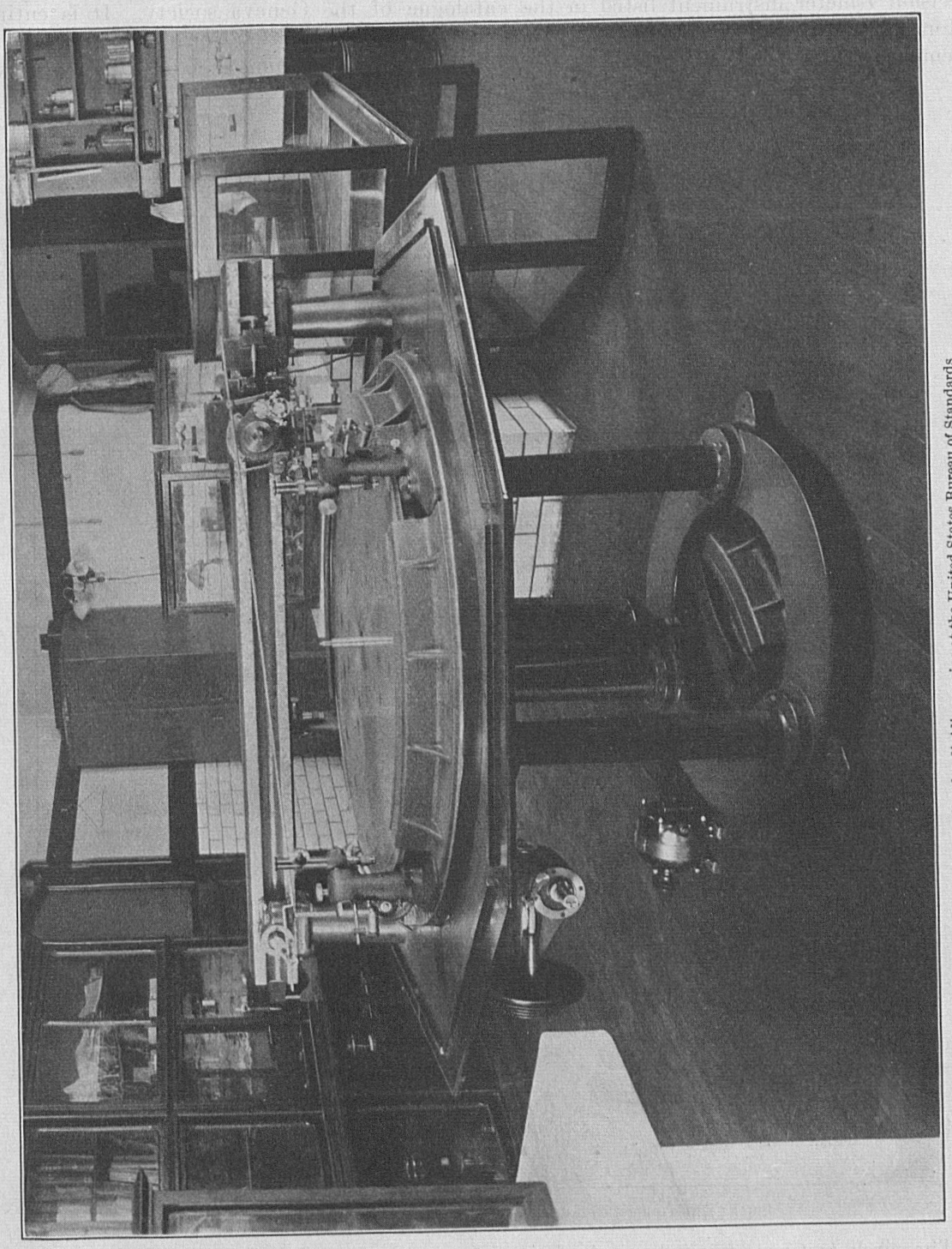

FIG. 4.—Circular dividing engine at the United States Bureau of Standards

the instruments at this time. It is expected that a further report will be submitted for presentation at the Prague meeting.

The circular dividing engine is shown in Figure 4 and is a modification of the highest precision 1-meter instrument listed in the catalogue of the Geneva society. It is entirely automatic in its operation, most of the residual errors in the mechanism being eliminated by a template which actuates the main screw. A precision of 0.5 second is claimed by the maker.

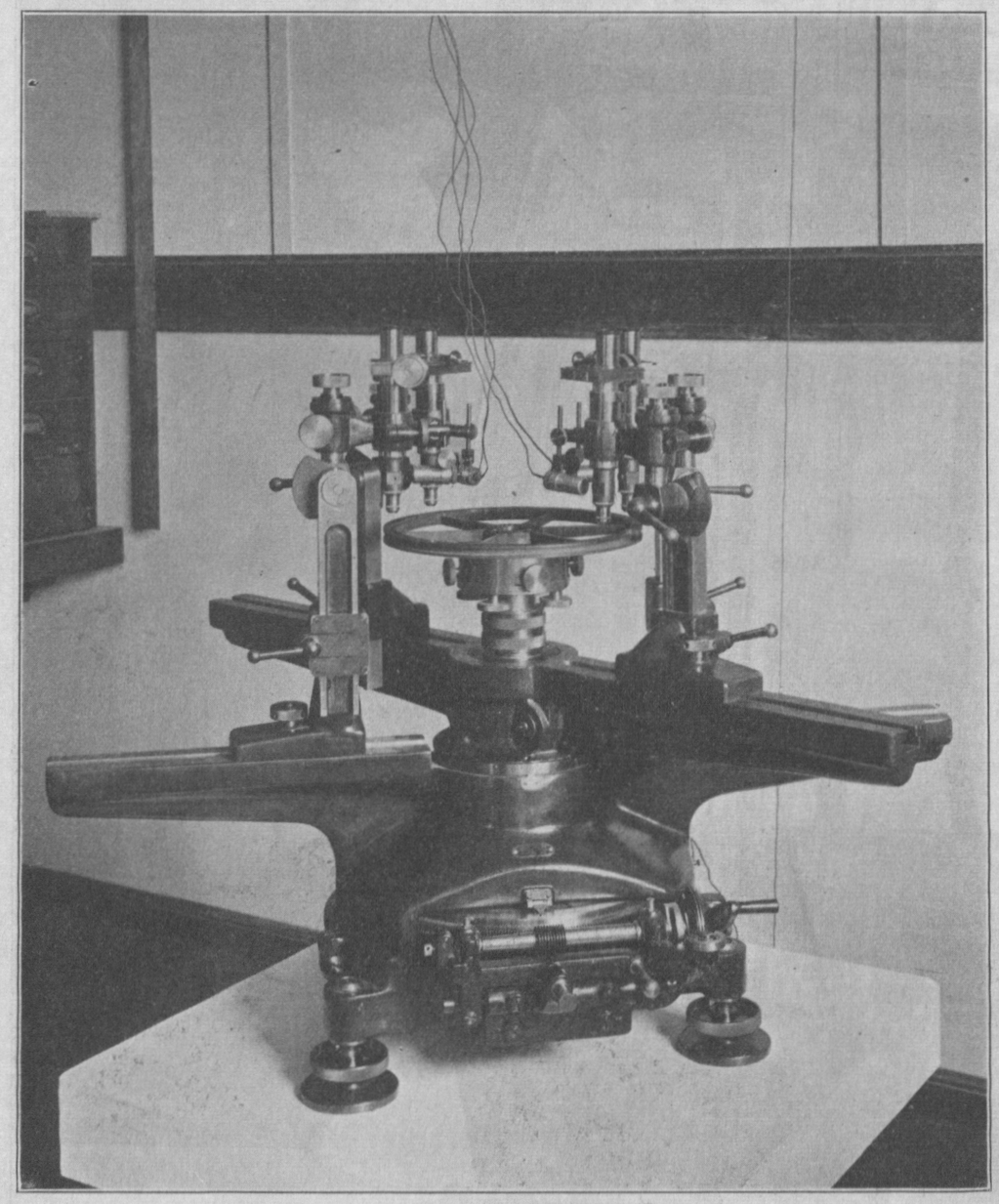

FIG. 5.—Circle-calibration instrument at the United States Bureau of Standards

The circle-testing device shown in Figure 5 consists of two pairs of microscopes which may be clamped in any desired relative position. The instrument is so designed that three types of calibrations may be made. In the first place, a single circle may be calibrated by intercomparing the various intervals on that one circle. In the second place two circles, placed

one above the other, the lower one being of slightly larger diameter than the upper one, may be intercompared by a double calibration. In the third place a circle may be calibrated by comparison, line by line, with a standardized circle of slightly larger diameter mounted below it.

As soon as it is possible to have these two instruments in regular use at this bureau it is expected that the beneficial results will aid the United States Coast and Geodetic Survey and others interested in precision angle measurements. Further developments of the testing and investigation of theodolites, transits, and other similar instruments will depend largely upon what can be accomplished in the program immediately ahead.

THE TUNING FORK AS A TIMEPIECE

By Paul R. Heyl, *Physicist, United States Bureau of Standards*

The possibility of using the tuning fork as a timepiece has been in the minds of scientific men for many years. Koenig's "Clock fork" will be remembered as one of the early attempts in this direction. The compactness of a tuning fork, its supposed uniformity of vibration, and the possibility of finely subdividing the second appear to have been the qualities which have recommended the tuning fork for this particular purpose.

The tuning fork has frequently been used successfully as a timing device where only short intervals of time are involved. For intervals so brief that a freely vibrating fork can cover them before its motion dies away, the problem is quite simple of solution; but when it is required to cover longer intervals of time the conditions have not yet been satisfactorily met.

To prolong the vibrations of a fork indefinitely some form of drive is necessary; and every form of drive suggested and tried up to the present time has its limitations. In one way or another slight variations are introduced into the period which can be neither foreseen nor controlled.

The old-fashioned magnetic drive involved a circuit-breaking device attached to a prong of the fork, usually a light needle dipping into mercury. Such a device will not run long without requiring cleaning and adjustment. Contact by means of a spring involves a variable force arising in the spring which may accelerate or retard the fork by a small amount.

The invention of the electron tube permitted the construction of a magnetic drive which required no contact breaker attached to the fork. Considerable improvement has been possible in the performance of driven tuning forks by means of such tubes, and for some purposes, where the highest accuracy in measurement of time is not of so much importance as a reasonably small division of the second, such a drive is all that can be desired. But precise measurements of the rate of a fork thus driven disclose residual variations in its period greater than can be tolerated in such work as gravity determinations. These variations may arise from several causes.

One cause of variation is that the effect of the drive upon the fork varies perceptibly with the position and adjustment of the driving magnet. The frequency is sometimes quite sensitive to small variations in this respect.

Perhaps the most serious source of difficulty is the fact that the period of a fork may be a function of the amplitude of its vibration; that is, the fork may not obey Hooke's law of proportionality of force and displacement when it is a question of accuracies of one part in a million. Temperature effects are comparatively easy to control, but control of amplitude is another matter. A slight and momentary fluctuation in the driving current may cause a change in amplitude and period of vibration sufficient to increase or decrease the period of time indicated by the fork by an amount intolerable for the purpose of exact measurements. Though a fork may maintain a surprisingly constant rate over long periods of time, due to the averaging out of such fluctuations in alternate directions, yet it must be remembered that it is for short intervals of time that the tuning fork is most desired as a timepiece. In gravity determinations, for instance, it is desirable to reduce the time involved in making a determination from hours to minutes and, if the tuning fork is constant over hours and variable over minutes, nothing is gained by its use.

With this difficulty in mind, the Bureau of Standards, in attacking the problem of the use of the tuning fork as a timepiece, has begun by investigating the accuracy with which forks of different materials obey Hooke's law. It was soon seen that the customary method of rating a fork against a calibrated break-circuit chronometer was not capable of carrying the accuracy of the rating far enough to give a sufficiently decisive answer to this question.

The most accurate standard of time is probably a freely swinging pendulum, as used by the Coast and Geodetic Survey for measuring the intensity of gravity. A method has been devised for rating a fork against such a standard of time, over periods as short as one cycle of a half-second pendulum. Certain difficulties in the behavior of this apparatus are now being dealt with. Like every extremely sensitive device, an attempt to use this apparatus has brought to light certain unsuspected disturbing effects in the vicinity, all of which have not yet been eliminated.

With this apparatus well in hand, it is intended to carry out studies of the effect of amplitude upon frequency with forks of a large number of materials, in the hope of finding some substance which will meet the very severe requirements of a tuning fork to be used as a timepiece over moderately short intervals of time.

THE UNITED STATES NAVAL OBSERVATORY TIME SERVICE

By Paul Sollenberger, *Associate Astronomer, United States Naval Observatory*

During the years of 1924, 1925, and 1926 the 6-inch transit circle and 3-inch Prin transit continued to be used for the determination of time at the United States Naval Observatory. For most of this period the results obtained with the two telescopes were given equal weight in the computation of time-signal errors, except on such dates as the Prin was not operated. During the months of October and November, 1926, when the world-longitude work was in progress, observations were made every clear night with the Prin, and the electric breaks, produced automatically by the motor-driven micrometer of that instrument, were recorded directly on the same chronograph as was used for the recording of time-signal transmissions. At other times different chronographs were used for the observations and the time signal. The beats of these chronographs were occasionally compared, and plans are now under way by which it is hoped to eliminate any possible difference between the two chronographs.

In computing the corrections and rates of the standard Riefler clocks all three of these clocks were taken into consideration. Empirical formulæ and graphs were used, so that the variations in clock rates were balanced against the errors of observation. The clock rates were sufficiently uniform to make it possible to improve the correction given by a single time sight by consideration of time sights on previous and following days. The empirical formulæ used take into account the number of clocks and the number of telescopes used and the length of time between time sights. During a part of this period the clocks gave unquestionable evidence of fairly uniform accelerations over periods of several weeks, which fact was taken into consideration in computing their corrections and rates.

The time signals were sent out ending at 3 and 17 hours, Greenwich civil time (10 p. m. and noon, seventy-fifth meridian time), regularly, via the naval radio station at Arlington on 113 kilocycles (2,650 meters) and on 690 kilocycles (435 meters), and via the naval radio station at Annapolis on 17.5 kilocycles (17,145 meters). Beginning in July, 1925, the naval radio station at San Diego transmitted the 17-hour signal on 30.6 kilocycles (9,810 meters), and also on 100 kilocycles (3,000 meters), which was changed to 102 kilocycles (2,940 meters) on April 15, 1926. The San Diego station was controlled by long-distance telegraph directly from the United States Naval Observatory. Owing to the length of this control line a large and somewhat variable lag was introduced, amounting to about one-half second.

Beginning in the latter part of 1926 the three-hour signals were also sent via the naval radio station at Bellevue on 4,015 kilocycles (74.7 meters). This wave length has proved very successful wherever the path of radio transmission has been mostly through darkness.

Even in Australia and the Far East the Bellevue signals have been plainly heard. Perhaps the greatest advantage of this frequency is that it may be received with comparatively simple apparatus, thus making accurate time signals available to many persons who were not formerly in a position to receive them. In addition to the transmissions already mentioned, the time signals were sent by the naval radio station at Key West on 205 kilocycles (1,460 meters) and on 102 kilocycles (2,940 meters), and by a number of private broadcasting stations on frequencies in the radiophone broadcast band. The Key West station was controlled by telegraphic means, while the private stations generally repeated Arlington automatically by reradiation. Experimental work was done in an attempt to control both San Diego and Key West by automatic reradiation, but the results were satisfactory only part of the time.

In addition to the regular time signals, the Naval Observatory has sent several special series of signals. Some of these were for the use of the United States Coast and Geodetic Survey in connection with surveying work in the western part of the United States, in Alaska, and in the Aleutian Islands, and for the use of the Canadian Government in similar work in Canada. During the world longitude work in October and November, 1926, special time signals were sent by the United States Naval Observatory and transmitted via Annapolis and Bellevue, and special signals were sent by the naval radio station at Pearl Harbor, Hawaii, under the direction of the United States Naval Observatory. During this work the observatory sent an expedition to San Diego, Calif., which made star observations and automatic records of time signals from all the transmitting stations which participated in the work, including Saigon, French Indo-China, Malabar, Java, and Bordeaux, France. The results of this work will be published at a later date.

The lag of the radio receiving apparatus has been measured from time to time and corrections applied to the time of the signals received. Improvements are now under way with a view to reducing this lag to a negligible amount. The break-circuit apparatus of the transmitting clocks has recently been improved so as to eliminate the errors of escapement, the time of the breaks being directly controlled by the pendulum.

Studies of international time-signal comparisons still show unexplained variations, although perhaps not quite so large as formerly. J. E. Willis, of the Naval Observatory, has studied the Washington-London variations and attempted to deduce a relation between them and the wind directions and intensities at the two places. His preliminary work, covering a period of three years, shows a surprising degree of correlation, but it remains to be seen whether or not further investigation will corroborate the theory.

MEAN SEA-LEVEL DETERMINATION FROM SHORT SERIES OF TIDE OBSERVATIONS

By G. T. Rude, *Chief, Division of Tides, United States Coast and Geodetic Survey*

At times it is necessary to have a mean sea-level determination for the initial point of a line of precise levels at a place at which the tide observations are not of sufficient length for a primary determination of mean sea level, or again it may be necessary to strengthen a level net by connecting at such a place as a "tie-in" point.

While a long series of tide observations is necessary for a very accurate determination of mean sea level at primary tide stations, a fairly accurate determination has been made by this bureau at a number of secondary stations in the last few years by comparison of simultaneous observations at the secondary stations with those at a suitably located primary station. A very close agreement, too, has been obtained in the results for the secondary stations from comparison with two near-by primary stations.

As is well known, sea level as determined by observations over various periods of time, varies in height, due to a number of causes, such as variations in barometric pressures, winds, etc. A mean sea-level determination for a month may vary as much as 1½ feet from a determination made from observations covering another month, and that made from one year's obser-

vations as much as one-fourth foot from that from another year. It has been found that these variations of sea level, however, are much the same at points near each other and subject to similar meteorological conditions. In fact, these variations may be somewhat similar along a considerable stretch of coast line.

This is brought out in Figure 6, on which are plotted sea levels as derived for each year at four primary tide stations along the Atlantic coast for the years 1912 to 1923, compared with a mean sea level determined at each of these stations over a long period of years, represented by the straight lines associated with the curves. The graph brings out the fact that sea level changes from year to year in much the same way all along the coast from Maine to Florida.

While sea level at the different stations does not vary by exactly the same amount from year to year, generally when for any one year it is high (or low) at any of the stations it is high (or low) at the other stations. In 1913 there was a low-level plane along the entire coast (fig. 6),

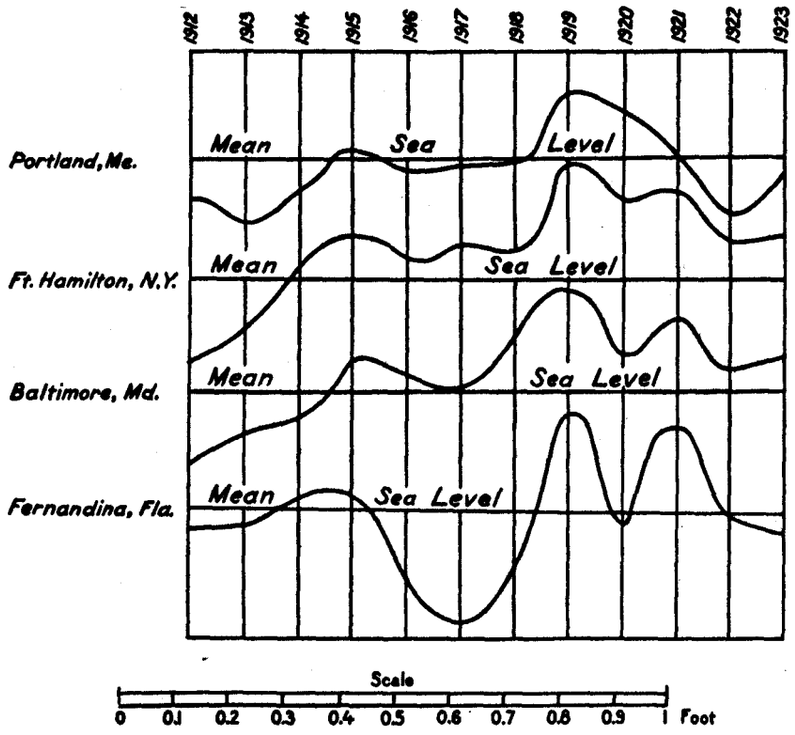

FIG. 6.—Variations of sea level at four Atlantic ports

1915 a high level, and a low for the years 1916–1918. In 1919 there was an unusually high level from Maine to Florida, decreasing in 1922. This similarity in variations in sea level also exists between stations along the Pacific coast.

Since a period of 19 years constitutes a full tidal cycle, it has generally been considered that the results derived from 19 years of observations constitute mean results. From a study of the variations in sea level, the existence has been found of a prominent variation in sea level with a period of about nine years,[6] and that for practical purposes nine years of observations may be taken to constitute a primary determination of mean sea level.

For tidal control along a coast, however, primary determinations of mean sea level need be made at only a few places. Advantage can be taken of the fact of the general similarity in variations of mean sea-level over a considerable stretch of coast line for satisfactory determinations of secondary mean sea levels by means of observations covering much shorter periods, if the re-

[6] Tidal Datum Planes, U. S. Coast and Geodetic Survey Special Publication 135, H. A. Marmer, 1927.

sults are corrected to a mean value by comparison with some suitably located primary tide station.

As an example, a primary determination of mean sea level at Atlantic City from nine years of observations is 6.58 feet on that tide staff. For purposes of illustration, let it be assumed that only one year's observations at Atlantic City are available and that the closest determination of mean sea level at that place from this one year is desired. The year 1913 may be taken, a year during which sea level was in a low-level phase all along the Atlantic coast, and a comparison made with the primary tide station at Portland, Me., for which 14 years' observations are available.

For the year 1913, sea level read 6.46 feet on the staff at Atlantic City, and at Portland sea level for that year was exactly 0.1 foot below the mean sea level from 14 years of observations. Increasing the 6.46 reading at Atlantic City for 1913 by 0.1, we get a corrected sea level at Atlantic City of 6.56, within two one-hundredths of a foot of the nine-year determination at that place. Again taking the year 1919, during which sea level along the coast was in a high phase, sea level at Atlantic City read 6.75 feet on the staff. At Portland, sea level for 1919 was 0.14 above the mean sea level from 14 years' observations. Applying this correction to the reading of 6.75 on the staff at Atlantic City, we get a corrected sea level at Atlantic City for that year of 6.61 feet, within three one-hundredths of a foot of the 6.58 feet from the nine-year determination at that place.

The actual use of a three-year determination of sea level at a station on the Pacific coast, corrected to two near-by long-period determinations of mean sea level, furnishes a good example having a check on the results.

For use in checking a line of precise levels, a sea-level determination was desired for Anacortes, Wash. A tide gauge was established and maintained for a three-year period at Anacortes and a mean sea-level determination of 19.73 feet on the tide staff obtained from these observations.

The Canadian Government, at the request of the Coast and Geodetic Survey, very kindly furnished the hourly tide readings for Victoria, British Columbia, for the same three-year period. These data from Victoria, with similar data from the tide station at Seattle, Wash., were used for correcting the three-year determination at Anacortes to the mean sea-level datum determined from long series at these two stations by comparison of the simultaneous observations.

Victoria is distant about 70 and Seattle about 35 nautical miles from Anacortes. The geographical position of Anacortes tide station is latitude 48° 31′, longitude 122° 36′; Seattle, latitude 47° 36½′, longitude 122° 20′; and Victoria, latitude 48° 27′, longitude 123° 23′.

Following are the results of correcting Anacortes datum by reference to the two ports by separate computations:

	Feet
Anacortes mean sea level on tide staff determined by averaging the hourly readings of the tide from three years of observations	19.73
Anacortes mean sea level on tide staff, corrected to a 17-year determination of mean sea level at Victoria, British Columbia, from comparison of three years of simultaneous observations	19.81
Anacortes mean sea level on tide staff, corrected to a 23-year determination of mean sea level at Seattle, Wash., from comparison of simultaneous observations	19.82

It was desired to make temporary use of the determination of a mean sea-level datum for Anacortes before the full three years of observations had been obtained, so the mean sea level as determined at Anacortes from 19 months of observations was corrected to the 22-year determination at Seattle, with the following results:

	Feet
Anacortes mean sea level on the tide staff, corrected to a 22-year determination of mean sea level at Seattle from comparison of 19 months of simultaneous observations	19.84

The value of the Anacortes sea level, corrected to a 17-year determination at Victoria, agrees within one one-hundredth of a foot with that corrected by comparison with the 23-year

determination of mean sea level at Seattle, while both these corrected determinations disagree with the uncorrected three-year determination by almost a tenth of a foot.

The possibilities are evident for the obtaining at a considerable number of secondary tide stations of mean sea-level determinations sufficiently accurate for all practical purposes by the use of short series of observations corrected by comparison with simultaneous observations at a suitably located primary tide station.

A STUDY OF THE VARIATION OF MEAN SEA LEVEL FROM A LEVEL SURFACE

By Henry G. Avers, *Chief Mathematician, Division of Geodesy, U. S. Coast and Geodetic Survey*

In each of the four general adjustments of the first-order level net of the United States it was assumed that the plane of mean sea level on the open coasts of the Atlantic Ocean, the Gulf of Mexico, and the Pacific Ocean is at the same elevation. Although evidence is increasing to show that the assumption may not be exactly true, it is believed that, under the circumstances, it was probably the best that could be made where the practical side of leveling is necessarily of great importance in the assignment of elevations to the bench marks.

At the time of the last adjustment of the level net in 1912 the tidal stations connected with the net were rather widely separated. Since then connections have been made with a number of additional tidal stations, and about 21,000 miles of leveling have been added to the net.

When the tidal stations on the Atlantic coast at Fort Hamilton, N. Y., and Portland, Me., were connected by a line of first-order leveling the results showed that the plane of mean sea level at Portland was 169.4 millimeters higher than the plane of mean sea level at Fort Hamilton. Similarly, on the Pacific coast, the leveling showed the plane of mean sea level at Vancouver, Canada, to be 102.8 millimeters higher than the same plane at Seattle, Wash.

These differences are about three times as large as those which could be attributed to the systematic or accidental errors in the leveling, and a study has been made to determine if, in general, there is a slope in the mean sea-level surface.

For the purpose of this study a special adjustment of the first-order level net has been made. In this adjustment certain level lines were omitted which had received very low weights in the previous general adjustments. These lines included all the leveling run by the United States Coast and Geodetic Survey previous to 1899 and some of the leveling run by the United States Geological Survey previous to 1905. The closing errors of the circuits of which these lines formed a part showed that they were weaker than the more modern lines of leveling. The total length of the leveling used in the adjustment is about 40,000 miles.

In the adjustment, the entire net was allowed to swing free on one mean sea-level connection, that at Galveston, Tex. There are 104 circuits in the net, and the adjustment was carried through by the method of conditions, each circuit closure requiring an equation. There were no conditions other than the closing errors of the circuits.

The adjusted elevation of the plane of mean sea level at each tidal station above the same plane at Galveston, Tex., is given in the first column of the accompanying table.

Starting at Galveston and proceeding eastward along the coast of the Gulf of Mexico the planes of mean sea level at Biloxi, Miss., Pensacola and Cedar Keys, Fla., are respectively, 0.07 meter, 0.02 meter, and 0.13 meter lower than the plane of mean sea level at Galveston.

Starting at St. Augustine, Fla., where mean sea level is 0.24 meter lower than at Galveston, and proceeding northward along the Atlantic coast the elevation of mean sea level at the following places is: Fernandina, Fla., −0.19 meter; Brunswick, Ga., −0.16 meter; Norfolk, Va., −0.16 meter; Cape May, N. J., −0.06 meter; Atlantic City, N. J., −0.05 meter; Fort Hamilton, N. Y., −0.05 meter; Boston, Mass., +0.01 meter; and Portland, Me., +0.07 meter.

Relative elevations of mean sea level determined by the adjustment

Station	Based on—									
	Galveston	Biloxi	Pensacola	Cedar Keys	St. Augustine	Fernandina	Brunswick	Norfolk	Cape May	Atlantic City
Gulf of Mexico										
Galveston, Tex	0.00	+0.07	+0.02	+0.13	+0.24	+0.19	+0.16	+0.16	+0.06	+0.05
Biloxi, Miss	−0.07	0.00	−0.05	+0.06	+0.17	+0.12	+0.09	+0.09	−0.01	−0.02
Pensacola, Fla	−0.02	+0.05	0.00	+0.11	+0.22	+0.17	+0.14	+0.14	+0.04	+0.03
Cedar Keys, Fla	−0.13	−0.06	−0.11	0.00	+0.11	+0.06	+0.03	+0.03	−0.07	−0.08
Atlantic coast										
St. Augustine, Fla	−0.24	−0.17	−0.22	−0.11	0.00	−0.05	−0.08	−0.08	−0.18	−0.19
Fernandina, Fla	−0.19	−0.12	−0.17	−0.06	+0.05	0.00	−0.03	−0.03	−0.13	−0.14
Brunswick, Ga	−0.16	−0.09	−0.14	−0.03	+0.08	+0.03	0.00	0.00	−0.10	−0.11
Norfolk, Va	−0.16	−0.09	−0.14	−0.03	+0.08	+0.03	0.00	0.00	−0.10	−0.11
Cape May, N. J	−0.06	+0.01	−0.04	+0.07	+0.18	+0.13	+0.10	+0.10	0.00	−0.01
Atlantic City, N. J	−0.05	+0.02	−0.03	+0.08	+0.19	+0.14	+0.11	+0.11	+0.01	0.00
Fort Hamilton, N. Y	−0.05	+0.02	−0.03	+0.08	+0.19	+0.14	+0.11	+0.11	+0.01	0.00
Boston, Mass	+0.01	+0.08	+0.03	+0.14	+0.25	+0.20	+0.17	+0.17	+0.07	+0.06
Portland, Me	+0.07	+0.14	+0.09	+0.20	+0.31	+0.26	+0.23	+0.23	+0.13	+0.12
Pacific coast										
San Diego, Calif	+0.40	+0.47	+0.42	+0.53	+0.64	+0.59	+0.56	+0.56	+0.46	+0.45
San Pedro, Calif	+0.32	+0.39	+0.34	+0.45	+0.56	+0.51	+0.48	+0.48	+0.38	+0.37
San Francisco, Calif	+0.44	+0.51	+0.46	+0.57	+0.68	+0.63	+0.60	+0.60	+0.50	+0.49
Fort Stevens, Oreg	+0.79	+0.86	+0.81	+0.92	+1.03	+0.98	+0.95	+0.95	+0.85	+0.84
Tongue Point, Oreg	+0.84	+0.91	+0.86	+0.97	+1.08	+1.03	+1.00	+1.00	+0.90	+0.89
Seattle, Wash	+0.66	+0.73	+0.68	+0.79	+0.90	+0.85	+0.82	+0.82	+0.72	+0.71
Anacortes, Wash	+0.64	+0.71	+0.66	+0.77	+0.88	+0.83	+0.80	+0.80	+0.70	+0.69

Station	Based on—									
	Fort Hamilton	Boston	Portland	San Diego	San Pedro	San Francisco	Fort Stevens	Tongue Point	Seattle	Anacortes
Gulf of Mexico										
Galveston, Tex	+0.05	−0.01	−0.07	−0.40	−0.32	−0.44	−0.79	−0.84	−0.66	−0.64
Biloxi, Miss	−0.02	−0.08	−0.14	−0.47	−0.39	−0.51	−0.86	−0.91	−0.73	−0.71
Pensacola, Fla	+0.03	−0.03	−0.09	−0.42	−0.34	−0.46	−0.81	−0.86	−0.68	−0.66
Cedar Keys, Fla	−0.08	−0.14	−0.20	−0.53	−0.45	−0.57	−0.92	−0.97	−0.79	−0.77
Atlantic coast										
St. Augustine, Fla	−0.19	−0.25	−0.31	−0.64	−0.56	−0.68	−1.03	−1.08	−0.90	−0.88
Fernandina, Fla	−0.14	−0.20	−0.26	−0.59	−0.51	−0.63	−0.98	−1.03	−0.85	−0.83
Brunswick, Ga	−0.11	−0.17	−0.23	−0.56	−0.48	−0.60	−0.95	−1.00	−0.82	−0.80
Norfolk, Va	−0.11	−0.17	−0.23	−0.56	−0.48	−0.60	−0.95	−1.00	−0.82	−0.80
Cape May, N. J	−0.01	−0.07	−0.13	−0.46	−0.38	−0.50	−0.85	−0.90	−0.72	−0.70
Atlantic City, N. J	0.00	−0.06	−0.12	−0.45	−0.37	−0.49	−0.84	−0.89	−0.71	−0.69
Fort Hamilton, N. Y	0.00	−0.06	−0.12	−0.45	−0.37	−0.49	−0.84	−0.89	−0.71	−0.69
Boston, Mass	+0.06	0.00	−0.06	−0.39	−0.31	−0.43	−0.78	−0.83	−0.65	−0.63
Portland, Me	+0.12	+0.06	0.00	−0.33	−0.25	−0.37	−0.72	−0.77	−0.59	−0.57
Pacific coast										
San Diego, Calif	+0.45	+0.39	+0.33	0.00	+0.08	−0.04	−0.39	−0.44	−0.26	−0.24
San Pedro, Calif	+0.37	+0.31	+0.25	−0.08	0.00	−0.12	−0.47	−0.52	−0.34	−0.32
San Francisco, Calif	+0.49	+0.43	+0.37	+0.04	+0.12	0.00	−0.35	−0.40	−0.22	−0.20
Fort Stevens, Oreg	+0.84	+0.78	+0.72	+0.39	+0.47	+0.35	0.00	−0.05	+0.13	+0.15
Tongue Point, Oreg	+0.89	+0.83	+0.77	+0.44	+0.52	+0.40	+0.05	0.00	+0.18	+0.20
Seattle, Wash	+0.71	+0.65	+0.59	+0.26	+0.34	+0.22	−0.13	−0.18	0.00	+0.02
Anacortes, Wash	+0.69	+0.63	+0.57	+0.24	+0.32	+0.20	−0.15	−0.20	−0.02	0.00

On the coast of the Pacific Ocean, starting at San Diego, Calif., where mean sea level is 0.40 meter higher than at Galveston, and proceeding northward the elevation of mean sea level at the following places is: San Pedro, Calif., +0.32 meter; San Francisco, Calif., +0.44 meter; Fort Stevens, Oreg., +0.79 meter; Seattle, Wash., +0.66 meter; and Anacortes, Wash., +0.64 meter.

The above values seem to indicate that along the coast of the Gulf of Mexico there is a general slope downward in the mean sea-level surface from west to east, and that along the Atlantic and Pacific coasts there is a general slope upward from south to north.

The table above gives for each tidal station the elevation of mean sea level with respect to that at each of the other tidal stations. Comparing mean sea level on the Pacific coast with mean sea level on the Atlantic coast, it is found that at San Diego, Calif., it is 0.59 meter

above that at Fernandina, Fla.; at San Francisco, Calif., it is 0.49 meter above that at Atlantic City, N. J.; and at Seattle, Wash., it is 0.59 meter above that at Portland, Me. The leveling thus indicates that mean sea level on the Pacific coast is higher than at approximately the same latitude on the Atlantic coast. This result agrees in sign with that shown by the leveling across the Isthmus of Panama, where it was found that mean sea level on the Pacific coast is 0.583 foot (0.178 meter) higher than on the Atlantic coast.

The values given for the differences in level of mean sea level at the various places are from the results of the leveling on the basis that the tidal observations determine the actual mean sea-level surface. The leveling is of such accuracy that on an average a correction of only about 0.15 millimeter per kilometer is necessary to close the circuits formed by the more modern lines. It is believed therefore that the differences in level found by the adjustment are real differences and that they are not due to any peculiarities in the leveling.

This adjustment was made solely for the purpose of study, and the results will not be used in assigning elevations to the bench marks.

The entire question of the variation of the mean sea-level surface from an equipotential surface is of such interest to geodesists, geophysicists, and oceanographers that it is hoped that other countries will make a similar study of the mean sea-level determinations along their coasts.

REPORT ON THE READJUSTMENT OF THE FIRST-ORDER TRIANGULATION NET OF THE WESTERN PART OF THE UNITED STATES

By Oscar S. Adams, *Mathematician, United States Coast and Geodetic Survey*

This report forms a continuation and supplement to the report published in United States Coast and Geodetic Survey Serial No. 350, which was issued in 1926, and which gives some account of the method employed in the readjustment.

The observations in two sections of the net remained to be made at the beginning of the season of 1926. These were the western end of the forty-ninth parallel, extending from the junction point numbered 25 to that numbered 26, and the arc in southern California and Nevada joining the junction points 11 and 13. (See fig. 10.) The field work on these arcs was finished in due time, although serious difficulties had to be overcome in the work along the forty-ninth parallel. The office work for the figure adjustment of these two sections was advanced as rapidily as posible, since it was desired to adjust the closures at as early a date as possible so that the data for carrying the positions northward into Alaska might be available.

After all of the sections were adjusted for figure, length, and azimuth the closures of the loops in latitude and longitude were computed in meters. The total closure in meters is, of course, equal to the square root of the sum of the squares of these two closures. Figure 7 shows these loop closures in meters together with the approximate number of kilometers in the loop, and below the line is given the approximate proportional part. Only two of these closures are greater than 1 part in 200,000, the largest one being 1 part in 162,000. The mean of all of the closures is approximately 1 part in 450,000. The closure around the entire outer boundary is 10.1 meters in a distance of 8,504 kilometers, or approximately 1 part in 842,000. The total length of the arcs in the adjustment is approximately 20,000 kilometers.

Some idea of what these closures mean may be obtained when we consider that they are the result of a combination of various types of measurements which have been made under conditions in the field that are oftentimes very unfavorable. The base measurements form one element of control, and the angle measurements serve to carry the length through the arcs from base to base, and finally the astronomic measurements furnish the azimuth control of the various arcs. Some of this work was done as much as 50 years ago, but the greater part has been done in the past 25 years.

In the network included in this adjustment the length is controlled by 50 bases, and the orientation is maintained by 74 Laplace azimuths, both classes of control being more or less evenly distributed throughout the various sections of the net.

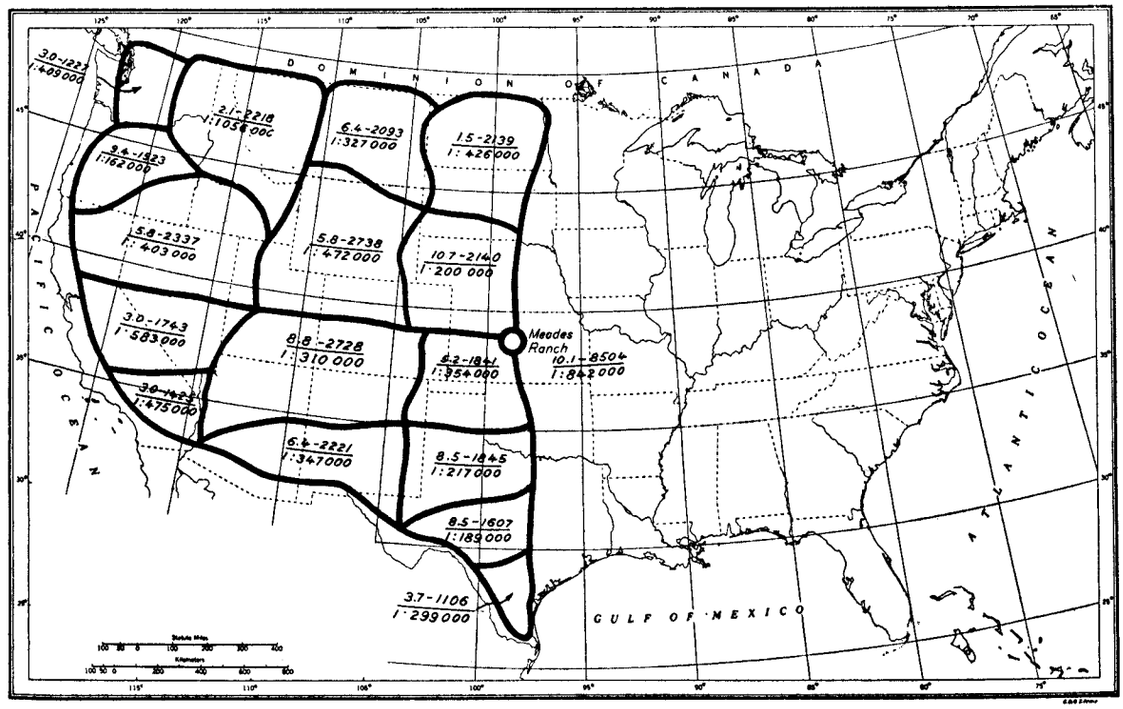

FIG. 7.—Loop closures resulting from readjustment

The first number above the line is the total closure in meters and the second number the approximate length of the loop in kilometers. Below the line is the approximate proportional part of the whole circuit represented by the closure.

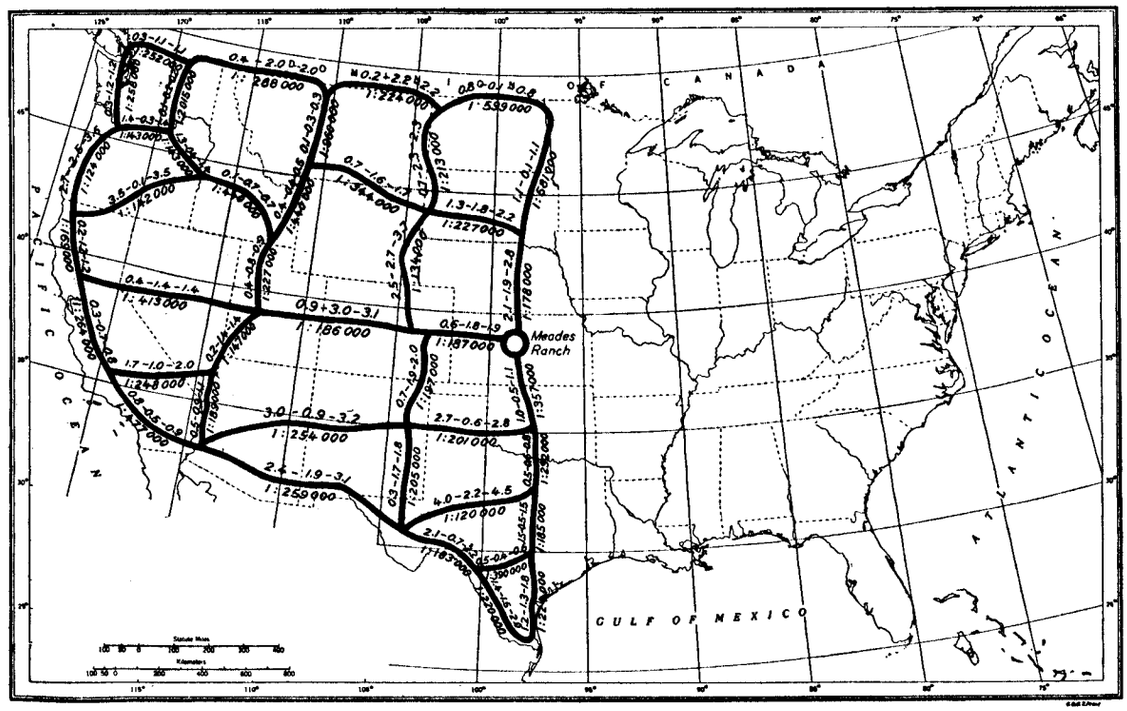

FIG. 8.—Section closures resulting from apportionment of loop closures

The first number above the line is the closure in latitude in meters, the second number the closure in longitude in meters, and the third number the total closure in meters. On the other side of the line representing the section is the approximate proportional part of the length of the section represented by the total closure.

The 50 bases have been measured within the past 50 years with various types of measuring apparatus. The older bases were measured with base bars or rods, and those measured in the first decade of the present century were measured with steel tapes. For approximately the past 15 years tapes made of invar metal have been used. With these three types of apparatus different methods of measurement were employed. In spite of these facts the circuit closures which have resulted demonstrate clearly that the general accord of bases is even much better than could be expected, and the fitting together of the various sections is such as to be, on the whole, satisfactory in every way.

After the preliminary adjustment of the sections was finally finished a solution was made of the equations for the adjustment of the closures and for the apportionment of the closures to the various sections. The solution of these equations resulted in the determination of the final geodetic position of a station in each one of the 26 junction figures. A list of these positions is given on page 34. The positions of all of these same stations that had been previously adjusted

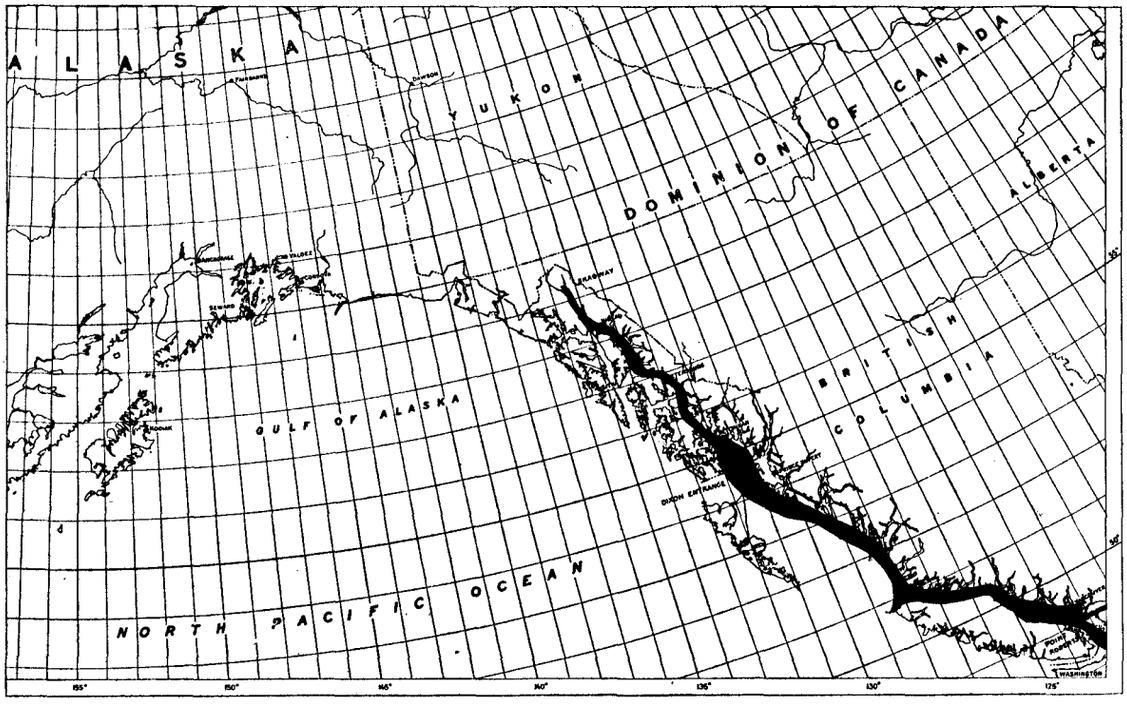

FIG. 9.—First-order triangulation, Point Roberts, Wash., to Skagway, Alaska

are also given, together with the amount of change of each brought about by the readjustment. It will be noted that junction point No. 26 has changed $-1''.056$ in latitude and $-1''.374$ in longitude, or something like 30 meters in both latitude and longitude. This is the point that controls the data that will be carried northward into western Canada and Alaska.

Figure 8 gives the amounts in meters of latitude and longitude discrepancies that have to be absorbed by each section. It also gives the total closure in length that has to be adjusted into each section and finally the approximate proportional part of the section that this closure represents. It will be seen that no closure in position in any section is greater than 1 part in 120,000, and that the great majority of the sections have closures of 1 part in 200,000 or better. This means that these closures can be absorbed by the sections when the conditions for closure in latitude and longitude are introduced, without any violence being done to the work in any of its parts. The whole network will therefore be fitted together in a rigid system, without undue strain in any of its parts. Any short arcs that may be observed in the future between

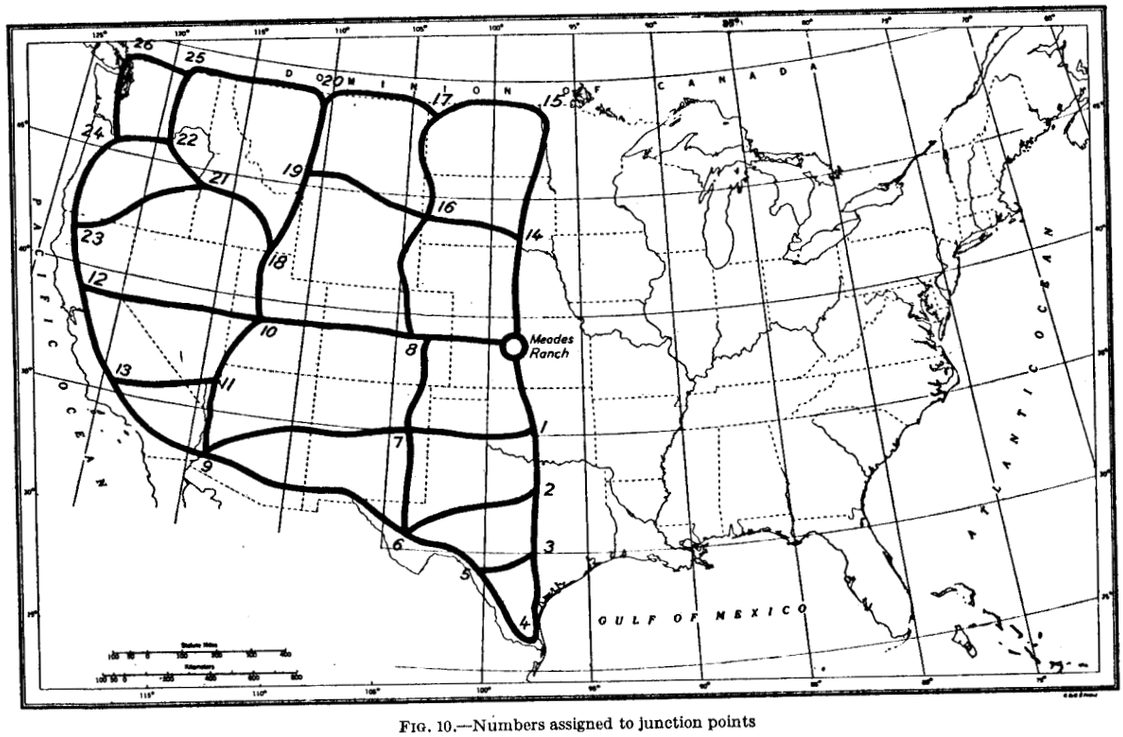

FIG. 10.—Numbers assigned to junction points

These numbers correspond to the numbers of the junction points as given in the table on page 34.

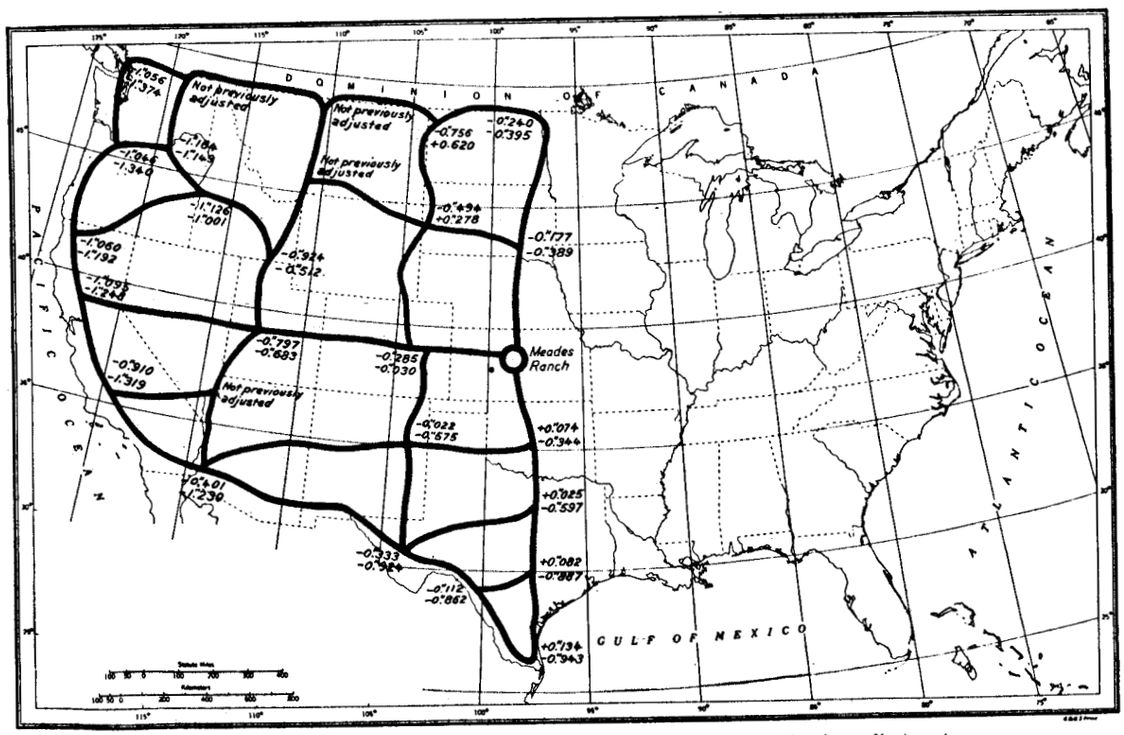

FIG. 11.—Changes in positions of junction points, previously adjusted, caused by the readjustment

The sign indicates in which direction the position was changed. The upper number is the change in latitude and the lower number the change in longitude.

sections of this framework should fit into the general scheme with comparatively small closure in position.

The United States Coast and Geodetic Survey and the Geodetic Survey of Canada have been cooperating in the extension of an arc of first-order triangulation from the vicinity of Point Roberts, on the forty-ninth parallel of latitude, northward to Skagway at the head of Lynn Canal, in latitude 59° 30′. (See fig. 9.) The new positions for the triangulation stations in the junction figure numbered 26 in Figure 10, at the northwest corner of the United States, have been furnished to the director of the Geodetic Survey of Canada. At the time of writing this report his office is engaged in the computation of the geographic positions on the North American datum of 1927 from the vicinity of Point Roberts to Dixon Entrance, along the western coast of British Columbia. As soon as this work has been completed by the Geodetic Survey of Canada the United States Coast and Geodetic Survey will compute the geographic positions on the North American datum of 1927, through the triangulation from Dixon Entrance northward to the vicinity of Skagway. (See fig. 9.)

A preliminary computation has been made to determine what change would be produced upon the positions at the northwest corner of the United States if Meades Ranch were held fixed on the Hayford ellipsoid and if the triangulation were computed continuously from that point up the ninety-eighth meridian and then westward along the forty-ninth parallel to the northwest corner of the State of Washington. It was found that the resulting latitude would be approximately 1″5 less than the value on the Clarke ellipsoid and the longitude approximately 2″1 less. It is expected in the near future to compute all of the junction points on the Hayford ellipsoid, and then to determine the geodetic positions of all of the astronomic stations on this ellipsoid so that they can be used in any future study of the figure of the earth.

Changes in positions of junction points caused by the readjustment

Number of junction	Station	Final latitude and longitude resulting from the readjustment	Latitude and longitude resulting from old adjustment	New minus old	Number of junction	Station	Final latitude and longitude resulting from the readjustment	Latitude and longitude resulting from old adjustment	New minus old
		° ′ ″	° ′ ″	″			° ′ ″	° ′ ″	″
1	Carson	35 16 24.922 97 57 32.416	35 16 24.848 97 57 32.760	+0.074 −0.344	14	Farmer	43 42 21.212 97 40 34.023	43 42 21.389 97 40 34.412	−0.177 −0.389
2	Kyle	32 49 18.039 98 19 11.612	32 49 18.014 98 19 12.209	+0.025 −0.597	15	States	49 00 01.447 97 07 39.343	49 00 01.687 97 07 39.738	−0.240 −0.395
3	Mission	29 42 52.843 98 09 52.109	29 42 52.761 98 09 52.996	+0.082 −0.887	16	Sundance	44 28 44.202 104 27 03.099	44 28 44.696 104 27 02.821	−0.494 +0.278
4	Donna	26 09 40.593 98 02 44.471	26 09 40.459 98 02 45.414	+0.134 −0.943	17	Norge	48 53 38.110 103 47 21.176	48 53 38.866 103 47 20.556	−0.756 +0.620
5	Peters	29 10 32.792 100 36 02.238	29 10 32.904 100 36 03.100	−0.112 −0.862	18	Oxford	42 16 10.842 112 05 49.460	42 16 11.766 112 05 49.972	−0.924 −0.512
6	Ingle	31 35 48.685 103 35 24.355	31 35 49.018 103 35 25.284	−0.333 −0.929	19	Mount Ellis	45 34 38.926 110 57 18.432	Not previously adjusted.	
7	Phillips	34 59 03.363 104 07 59.629	34 59 03.385 104 07 60.204	−0.022 −0.575	20	Goldstone	48 52 55.681 110 29 18.684	Not previously adjusted.	
8	Aroya	38 48 09.721 103 10 55.580	38 48 10.006 103 10 55.610	−0.285 −0.030	21	Dry	44 10 08.183 117 39 39.844	44 10 09.309 117 39 40.845	−1.126 −1.001
9	Whitetank	33 34 01.652 112 33 27.501	33 34 02.053 112 33 28.731	−0.401 −1.230	22	Alder	45 50 59.419 119 56 21.080	45 50 60.583 119 56 22.229	−1.164 −1.149
10	Mount Nebo	39 48 38.316 111 45 56.235	39 48 39.113 111 45 56.918	−0.797 −0.683	23	Bally	40 36 10.879 122 38 59.178	40 36 11.939 122 38 60.370	−1.060 −1.192
11	Black	35 55 51.689 115 02 35.556	Not previously adjusted		24	Red	45 56 06.140 121 49 11.100	45 56 07.249 121 49 12.344	−1.109 −1.244
12	Mount Diablo	37 52 54.387 121 54 47.107	37 52 55.482 121 54 48.355	−1.095 −1.248	25	Oroville	48 53 44.203 119 20 12.879	Not previously	justed.
13	Tepusquet	34 54 36.522 120 11 08.335	34 54 37.432 120 11 09.654	−0.910 −1.319	26	Birch Point	48 56 30.854 122 49 12.021	48 56 31.910 122 49 13.395	−1.056 −1.374