U.S. DEPARTMENT OF COMMERCE

DANIEL C. ROPER, Secretary

COAST AND GEODETIC SURVEY

R. S. PATTON, Director

Special Publication No. 178

GEODETIC OPERATIONS IN THE UNITED STATES JANUARY 1, 1930, TO DECEMBER 31, 1932

[Report to the International Association of Geodesy of the International Union of Geodesy and Geophysics, International Council of Scientific Unions]

BY

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UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1933

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GENERAL STATEMENT

This report covers in a general way the geodetic operations in the United States from January 1, 1930, to December 31, 1932. It is, necessarily, impossible to give here minute details regarding the locations of the geodetic work accomplished, or of new instruments and methods that may have been adopted, or of improvements in old instruments and methods. The report, however, is supposed to give the reader a sufficient amount of information to enable him to communicate with the Director of the Coast and Geodetic Survey should he desire further details on any subject in which he may be interested.

During the 3-year period mentioned above, the Coast and Geodetic Survey has issued very few publications or reports. This is due to two causes, first, the readjustment of the leveling and triangulation nets and second, to the scarcity of funds which could be devoted to printing. As a result of the adjustments of the nets, all geographic positions and elevations previously published have been superseded. At present many of the new positions and elevations are ready for printing, and it is hoped that they may appear in reports in the very near future.

The 3-year period covered by this report has witnessed a great activity in the field of geodetic surveying. For many years geodetic surveys were considered to be of value only in controlling the geographic positions used for charting the coasts of our country and for scientific purposes, but in recent decades engineers and others have found the results of the geodetic surveys of great value to them in engineering, mapping, and other classes of work. In consequence of this increased interest there has been a demand on the part of many citizens of the United States for an increase in the rate at which the geodetic surveys are extended over our area. This interest on the part of individuals and organizations outside of the Federal Government has resulted in increased appropriations by Congress for the work in question.

Practically all the first- and second-order triangulation accomplished during the past 3 years has been done by the Coast and Geodetic Survey. (See p. 25 for description of work by another organization.) Much work of a detailed character, mostly third-order triangulation, traverse and leveling has been done by the Corps of Engineers of the United States Army and its several branches, and by the United States Geological Survey. This detailed work is designed to control topographic mapping or engineering works along our water courses. It is connected at intervals with the higher grade work of the Coast and Geodetic Survey.

The Coast and Geodetic Survey measured many first-order base lines in the United States during the 3-year period covered by this report and also made the astronomical observations required for geodetic purposes. During about 8 months of 1932 gravity observations were made in the field with a new apparatus, described briefly on page 24, which gives satisfactory results in a short time and at a small cost. Other gravity observations have been made by some of the corporations engaged in the production of petroleum, but details regarding methods and apparatus used and results obtained are not now available. Necessarily a corporation engaged in commercial work cannot well afford to reveal the methods and instruments it may use or the results that it may obtain. It is hoped, however, that in the near future more information regarding the gravity work and results obtained by petroleum companies may become generally known.

A large amount of work has been done in the office at Washington in the computation and adjustment of field observations. It is, of course, essential that the office work involved in geodetic operations should not lag far behind the field work. Also, as far as practicable, the resulting data should be analyzed with a view to making them of use in other lines of investigation such as are found in the geophysical and geological fields.

This brief statement is designed to give the reader in a few words a general idea of what geodetic work has recently been carried on in this country. Each of the items will be treated more fully under separate headings, and at the back of this report will be found some special articles by workers in the several branches of geodesy.

FIRST-ORDER TRIANGULATION

During the 3 years covered by this report 8,160 miles of arcs of first-order triangulation have been executed in the United States. These arcs are shown in figure 1. The practice explained in Special Publication No. 166, entitled "Geodetic Operations in the United States, 1927–29", has been followed in carrying on the recent work. It may be said that the observations are such as to make the average closing error of the triangles of an arc not greater than about 1 second. As a matter of fact, for any single arc the average seldom exceeds 1 second and in most cases it is somewhat less. The maximum allowable closing error of a triangle used in deriving the R_1's is 3 seconds. Since practically all arcs of first-order triangulation are composed of quadrilaterals and central point figures, it is believed that the R_2 triangles may be allowed a slightly larger maximum closing error than 3 seconds without materially affecting the results. As a matter of fact, the observers in the field are permitted to omit the longer diagonal of the quadrilateral, if the ends of that line are not intervisible, rather than to incur expense of time and money in increasing the height of the towers involved. It can be readily seen that if it is permissible to omit an occasional long diagonal, it is not more serious to retain the two triangles formed by a long diagonal, even though they have closing errors somewhat larger than the specified limit. When such closing errors occur, the observations made on the long diagonal can be omitted from the office adjustments if the triangle closures exceed the 3 seconds by more than a small amount.

SECOND-ORDER TRIANGULATION

A considerable amount of second-order triangulation has been executed during the period covered by this report. Besides the special triangulation executed in California to serve as a basis for determining the extent of earth movements (see p. 9), second-order work was done along portions of the Atlantic, Gulf, and Pacific coasts, and in New York City.

Upon the completion of the first-order arcs required for the horizontal control net, more attention can be given to the second-order work. It has been thought best to concentrate efforts on the first-order triangulation in order that no place in the country will be far from horizontal control stations established by this class of work. Insofar as possible, the needs of the United States Geological Survey in topographic mapping are met by running arcs in or near areas where they are operating.

TRIANGULATION IN THE HAWAIIAN ISLANDS

Only a small amount of new triangulation was executed in the Hawaiian Islands during the past 3 years. The principal work done in connection with the triangulation of these islands was the placing of permanent monuments over a number of the stations. One of the two types of signals used on the more important stations was described and illustrated in Bulletin Geodesique, no. 29, January-February-March 1931, and also in an article entitled "The Survey of Hawaii" which appeared in the Military Engineer of January-February 1930. These two articles were by Hugh C. Mitchell, senior mathematician, United States Coast and Geodetic Survey.

FIGURE 1.—Triangulation in the United States.

CONNECTION OF THE TRIANGULATION NETS OF MEXICO AND THE UNITED STATES

During the early part of 1931, observers of the Department of Geographical and Climatological Research of Mexico and of the United States Coast and Geodetic Survey made observations in the vicinity of Juarez, Mexico, and El Paso, Tex., to connect the triangulation of the two countries. The work was successfully accomplished and a brief report on the connection appeared in the Bulletin Geodesique, no. 31.

TRIANGULATION INSTRUMENTS

Although the standard theodolite for the first-order triangulation of the Coast and Geodetic Survey is the 9-inch Parkhurst, described briefly in Special Publication No. 166, other types of Coast and Geodetic Survey theodolites and theodolites of private manufacture have also been used. Experience has shown that the Parkhurst 9-inch theodolite gives results that are entirely satisfactory at a small expense of time and money. The observations can be made with it with great rapidity.

No changes have been made in the electric signal lamps upon which observations are made. In nearly all cases the observations are made at night because of the greater steadiness of the atmosphere, but observing has been done on cloudy days when the lines are short enough for the lights from the electric lamps to be seen. As has been mentioned in other reports of the Coast and Geodetic Survey, it has been found that an arc of triangulation for which observations have been made only at night does not swerve from its true direction as much as an arc which depends upon observations made upon heliotropes. The lamps used on the triangulation are described in Special Publication No. 120.

BILBY STEEL TOWER

The Bilby steel tower for triangulation was mentioned in Special Publication No. 166 and described in detail in Special Publication No. 158. This tower has been modified only slightly since 1929. Modifications involved the strengthening of certain members without any change in the design.

The Bilby steel towers have proved to be of the greatest service in triangulation. They can be hauled on automobile trucks and can be erected very rapidly. Five men can erect a 103-foot tower within 5 hours. This includes the time required to dig the holes for the anchors of the legs of the tripods. Some of the original towers, first used in 1927, are still in service, and a few of them have been erected at as many as 100 stations or more. It is readily seen that the use of the steel in place of the wooden towers results in great economy. In fact, if it were not for the Bilby steel tower it would have been impossible to carry triangulation, except at enormous expense, along certain parts of our coasts and the Mississippi River where the ground is flat and the trees are high.

STATISTICAL DATA FOR TRIANGULATION EXECUTED

A list of the arcs of triangulation which have been executed in this country during the period covered by this report, together with the name of the chief of party and the year, is given below.

Arcs of first-order triangulation

[Jan. 1, 1930, to Dec. 31, 1932]

	Miles
Shreveport to Vicksburg, La., P. A. Smith, 1931	160
Vicksburg to oblique arc, Mississippi and Alabama, P. A. Smith, 1930-31	245
Oblique arc to Atlanta, Ala. and Ga., P. A. Smith, 1930	175
Point Reyes to Great Valley, Calif., G. L. Bean, 1930	45
La Crosse to Fond du Lac, Wis., I. T. Sanders, 1930	150
Forty-second parallel, Nebraska, Iowa and Illinois, H. W. Hemple, 1930	550

	Miles
Cairo to Belleville, Ill., P. A. Smith, 1930	125
Cairo to Nashville, Ill., Ky., and Tenn., P. A. Smith, 1930	160
Poplar Bluff to Cairo, Mo., P. A. Smith, 1930	110
Ninety-fourth meridian, Arkansas, Louisiana, and Texas, P. A. Smith, 1930–31	350
Mobile to New Orleans, Ala., Miss., and La., F. L. Gallen, 1930–31	150
Donaldsonville to Beaumont, La., and Tex., F. L. Gallen, 1930–31	265
Beaumont to Corpus Christi, Tex., F. L. Gallen, 1930–31	285
Mississippi River, Ill., Mo., Iowa, Wis., and Minn., H. W. Hemple, 1931	640
Laguna Madre connection, Texas, F. L. Gallen, 1931	30
Mexican connection, New Mexico and Texas, R. L. Pfau, 1931	70
Monterey Bay to Mariposa Peak, Calif., G. L. Bean, 1930	35
Reno to Lakeview, Calif., Nev., and Oreg., J. Bowie, Jr., 1931	175
San Joaquin Valley, Calif., J. Bowie, Jr., 1931	325
Billings to Grand Junction, Mont., Wyo., Colo., and Utah, C. I. Aslakson, 1931	425
Grand Traverse Bay to Sturgis, Mich., H. W. Hemple, 1931	250
Texas-Oklahoma boundary, Texas and Oklahoma, C. I. Aslakson, 1931	175
Amarillo to Del Rio, Tex., C. I. Aslakson, 1932	325
Norfolk to Brunswick, Va., N. C., S. C., and Ga., C. D. Meaney, 1931–32	575
Sacramento and San Joaquin Rivers, Calif., J. Bowie, Jr., 1931–32	75
Suisun Bay to San Francisco Bay, Calif., J. Bowie, Jr., 1931–32	125
Indiana-Ohio boundary, Indiana and Ohio, H. C. Warwick, 1932	200
East shore Lake Michigan, Mich., H. C. Warwick, 1932	260
San Luis Obispo, Calif., F. G. Johnson, 1932	65
Providence to Cape May, R. I., Conn., N. Y., and N. J., C. D. Meaney, 1932	325
Cape May to Norfolk, Del., Md., and Va., C. D. Meaney, 1932	215
Grand Traverse Bay to Hillsdale, Mich., H. C. Warwick, 1932	475
Augusta to Beaufort, Ga. and S. C., H. C. Warwick, 1932	120
Brunswick to Jacksonville, Ga. and Fla., H. C. Warwick, 1932	75
James River, Va., R. D. Horne, 1932	175
San Fernando to Bakersfield, Calif., F. G. Johnson, 1932	110
Vicinity of Taft, Calif., F. G. Johnson, 1932	15
Arlington to Bend, Oreg., F. G. Johnson, 1932	130
Total	8, 160

MEASUREMENT OF BASE LINES

During the past 3 years 39 first-order bases, totaling 253.6 miles in length or of an average length of 6.5 miles, have been measured in the United States by engineers of the Coast and Geodetic Survey.

The invar 50-meter tapes have been used in the measurements. The restandardization of the tapes have been made at frequent intervals by the division of weights and measures of the United States Bureau of Standards. It has been found desirable to have the tapes standardized frequently because of uncertainty in their lengths. The invar is not a stable alloy but excellent results can be obtained if one is careful to watch the tapes in the field by comparing measurements made with different tapes. As soon as any changes develop, the tapes should be restandardized.

The process used in measuring base lines is the same as that given in detail in Special Publication No. 120 except that, when measurements are made on the rail of a railroad track, the tape is supported at its ends and at the 12½-and at the 37½-meter points. The intermediate supports, which are frictionless rollers, are of such a height (6 inches) that the tape swings free approximately 1 inch above the rail at the center of the tape. All standardizations must be made under exactly the same conditions as to height and type of support as were used in the field and, hence, the distance between the ends of the tapes as determined by the standardization is used in computing the field observations. With the method of support described above it is certain that greater accuracy is secured in base measurement when the work is done over the rail. Where the tape is in contact with the rail there is a certain amount of friction or adhesion which is certain to affect the measurements.

The table given below furnishes data regarding the base lines that have been measured during the past 3 years.

First-order bases measured in the United States

[Jan. 1, 1930, to Dec. 31, 1932]

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—
East Prairie, Mo	16, 598. 4176	±4. 9	3, 400, 000	Pass Christian, Miss	6, 002. 5153	±2. 3	2, 600, 000
Stovall, Miss	11, 519. 9682	±4. 3	2, 700, 000	Schriever, La	5, 921. 3342	±2. 4	2, 500, 000
Chicot, Ark	9, 397. 3457	±3. 2	2, 900, 000	Baldwin, La	6, 160. 2873	±3. 7	1, 700, 000
Mounds, La	8, 611. 3191	±3. 4	2, 500, 000	Lake Arthur, La	10, 943. 8287	±2. 4	4, 600, 000
New Roads, La	10, 937. 2796	±6. 2	1, 800, 000	Winnie, Tex	17, 189. 0198	±4. 4	3, 900, 000
Gramercy, La	12, 006. 690	±4. 6	2, 600, 000	Palacios, Tex	16, 115. 0519	±3. 3	4, 900, 000
New Orleans, La	7, 613. 0755	±1. 8	4, 200, 000	Sturgis, Mich	10, 451. 4111	±4. 9	2, 100, 000
Rogersville, Mo	19, 535. 1504	±4. 6	4, 500, 000	Ferris, Ill	8, 002. 1489	±3. 3	2, 400, 000
Corydon, Iowa	8, 070. 5544	±3. 4	2, 400, 000	Palo Alto, Calif	10, 998. 0319	±2. 9	3, 800, 000
Rogers, Nebr	12, 588. 9376	±4. 1	3, 100, 000	Santa Ana, Calif	1, 594. 2592	±. 47	3, 400, 000
Liberty, Iowa	9, 740. 7969	±3. 8	2, 600, 000	Do	1, 594. 2640	±. 36	4, 400, 000
La Salle, Ill	8, 132. 2906	±2. 4	3, 400, 000	Howard City, Mich	11, 965. 1008	±3. 3	3, 700, 000
Belleville, Ill	6, 712. 3428	±1. 6	4, 200, 000	Pittsville, Md	10, 033. 1583	±1. 7	5, 900, 000
Pembroke, Ky	9, 868. 6955	±3. 3	3, 000, 000	Norfolk, Va	10, 608. 8716	±2. 4	4, 400, 000
Hamilton, Ga	14, 018. 5016	±4. 6	3, 050, 000	Richmond, Va	7, 113. 1918	±2. 2	3, 200, 000
Union, Ala	17, 408. 0289	±3. 2	5, 400, 000	Rocky Mount, N.C	15, 353. 8057	±3. 3	4, 650, 000
Forest, Miss	14, 013. 7226	±4. 1	3, 400, 000	Durham, N.C	7, 436. 2362	±2. 1	3, 500, 000
Monroe, La	9, 007. 7292	±3. 3	2, 700, 000	New Bern, N.C	9, 593. 5457	±2. 7	3, 600, 000
Shreveport, La	10, 406. 7273	±2. 1	5, 000, 000	Southport, N.C	10, 132. 6612	±2. 1	4, 800, 000
Ashdown, Ark	14, 731. 5288	±4. 9	3, 000, 000				

PLANS FOR TRIANGULATION NET

For some years the Coast and Geodetic Survey has been following a plan which calls for the spacing of arcs of first-order triangulation at intervals of approximately 100 miles, with cross arcs for use in adjusting the net. Second-order arcs were then to be run through the centers of the spaces between the first-order arcs. This plan was supposed, when adopted, to meet the requirements for topographic mapping, boundary surveys of political subdivisions of the country, and for other purposes. Recently, however, there has been a large increase in the demand for results of geodetic surveys, the outcome of which has been the adoption of a plan calling for the spacing of the second-order arcs at intervals of about 25 miles in the spaces lying between the first-order arcs. Since an arc of triangulation has a width depending upon the character of the terrain, it has been decided to place first-order arcs at intervals of about 120 miles. When three intermediate arcs of second-order triangulation are then run, the interval between each two of the contiguous arcs will be about 25 miles.

It is not intended that the fundamental triangulation net should cover the country in the form of a grid with the arcs following meridians and parallels. In making the reconnaissance for the arcs, which usually is completed about 6 months ahead of the field party making the angular measures, routes are selected which will space the arcs at approximately the intervals called for in the general plan and at the same time follow as closely as possible main highways in order to facilitate the transportation of equipment and steel towers. Inasmuch as many of the arcs were placed to meet particular requirements of other Government bureaus and other interests the result has been to form a net far from a regular pattern.

Owing to the large area of this country it has been deemed advisable to run triangulation in arcs across country without establishing supplemental points to any great extent for location purposes. It would, no doubt, be economical if, when the first-order triangulation is done, many stations could be established in the area within the arcs and to the sides. To do this, however, would require much more time to complete a given length of arc, and, until the network of arcs is much farther extended, it is believed that only a limited number of supplemental stations should be established. Eventually, the whole country will, no doubt, be covered by triangulation of various grades of accuracy, but it is absolutely essential in the first place to have the fundamental arcs available as soon as possible to furnish the basis for the detailed work.

TRIANGULATION ADJUSTMENTS

One of the most important pieces of office geodetic work undertaken by the United States Coast and Geodetic Survey has been the readjustment of the triangulation net of the country. In Special Publication No. 166, a report was made on the readjustment of the triangulation net of the western half of the country. Since that publication was issued the readjustment of the triangulation net of the eastern half of the country has been completed. Details regarding the readjustment of the eastern triangulation net are given in an article by Dr. O. S. Adams, senior mathematician, Coast and Geodetic Survey, on page 18.

The results of the readjustment of the national triangulation net are of such character that it is believed that all additional triangulation which may be done in this country can be fitted into the arcs of the adjusted net without changing any of the geographic positions that have been fixed by the net adjustment.

At the time of writing this report work was in progress on the adjustment of the new arcs of triangulation extending along the Atlantic coast and arcs connecting this coastal arc with the eastern oblique arc. A number of new arcs in the western part of the country, run since the completion of the western adjustment, have been fitted to the adjusted net in those sections. The triangulation computations and adjustments made in the office of the Coast and Geodetic Survey are covered by an article on page 17 of this report written by Walter F. Reynolds, chief of the section of triangulation.

FACTORS FOR COMPUTING GEOGRAPHIC POSITIONS ON INTERNATIONAL SPHEROID

Computations to furnish the factors that are necessary in computing geographic positions on the international spheroid have been in progress for some time and are now nearly completed. The factors will cover the range of latitude from the Equator to the pole. These tables will probably be published in a short time.

It would be of interest to compute the geographic positions of some of the triangulation stations of the United States triangulation net on the international spheroid in order to learn what differences in positions would be found from those of the Clarke spheroid. It would be especially desirable to learn how much areas are affected by the computation of triangulation on a spheroid somewhat in error.

FIRST- AND SECOND-ORDER LEVELING

The level net of the United States, involving lines of first- and second-order accuracy will eventually have first-order lines spaced at intervals of about 100 miles with cross lines to secure stronger results in the adjustments. The intermediate areas will be crossed by second-order leveling. The first general plan for the leveling called for the combined first- and second-order lines to be spaced at intervals of 50 miles but, recently, because of greater use of the leveling data by engineers and others, the plan has been modified, and the first- and second-order leveling will be so spaced that eventually no place in the country will be more than 10 or 15 miles from an accurately established bench mark.

First-order leveling is run in both directions. The specifications as to accuracy conform at least to the requirements of the specifications for that class of work as adopted by the International Geodetic Association.

Second-order leveling consists, in general, of a line run in one direction only but with the same degree of precision that is employed in running a first-order line. The same instruments are used in the second-order leveling as in the first. The greater possibility of making a blunder in second-order than in first-order leveling has been recognized by officials of the Survey and the engineers engaged in field work, and they have endeavored to devise methods which will make undetected blunders exceedingly rare.

There has been great activity in the field of leveling during the past 3 years, the observers of the Coast and Geodetic Survey having run 16,469 miles of first- and second-order leveling. At the close of the year 1932 there were 69,700 miles of first-order leveling and 2,900 miles of second-order leveling in the level net of the country.

In addition to the first- and second-order leveling, many miles of third-order leveling have been run by other agencies of the Government and by private engineers and corporations. For the leveling accomplished by the United States Geological Survey and the Corps of Engineers, United States Army, see pages 9 and 15, respectively.

Statistics for the first- and second-order leveling run by the Coast and Geodetic Survey during the past 3 years are given below. The new leveling is shown by broken lines on figure 2.

Leveling lines run by the U.S. Coast and Geodetic Survey

[Jan. 1, 1930, to Dec. 31, 1932]

Project	Chief of party	Length of line
		Kilometers
Shelbyville to Vincennes, Ind	John Bowie, Jr	239
Washington to Petersburg, Ind	do	26
Wabash to Huntington, Ind	do	31
Washington to Indianapolis, Ind	do	180
Warsaw, Ind., to Leipsic, Ohio	do	*166*
Highlands to Pleasantville, N.J	W. R. Porter	189
Eugene to Redmond, Oreg	J. H. Brittain	186
Rainier, Oreg., to Kelso, Wash	do	23
Sea Isle Junction to Camden, N.J	W. R. *Porter*	*162*
Elkhart, Ind., to Walton, Mich	John Bowie, Jr	486
Pendleton to Mount Vernon, Oreg	Charles Pierce	196
Rockton, Ill., to Escanaba, Mich	J. P. Lushene	547
Mount Vernon to Vale, Oreg	Charles Pierce	217
Grayling to Detroit, Mich	John Bowie, Jr	326
Hebo to Salem, Oreg	J. H. Brittain	100
Drain to Reedsport, Oreg	do	92
Minneapolis, Minn., to Glasgow, Mo	J. D. *Thurmond*	932
Ottumwa to Muscatine, Iowa	do	131
Mount Vernon to Arlington, Oreg	Charles Pierce	256
Astoria to Newport, Oreg	J. H. Brittain	254
Newport to Albany, Oreg	do	114
Ladysmith to Green Bay, Wis	J. P. Lushene	319
Wisconsin Rapids to La Crosse, Wis	do	175
Jackson, Ky., to Morristown, Tenn	W. R. Porter	392
Murfreesboro, Tenn., to Stevenson, Ala	A. J. Hoskinson	145
Lathrop to Bakersfield, Calif	Charles Pierce	373
Farwell to Sweetwater, Tex	J. D. Thurmond	361
Moccasin Gap to Roanoke, Va	W. R. Porter	300
Vicinity of San Pedro, Calif	E. E. Stohsner	3
Washington to Bellevue, D.C	A. L. Wardwell	8
Niland to Jacumba, Calif	Charles Pierce	137
El Centro, Calif., to Yuma, Ariz	E. E. Stohsner	97
Seligman, Mo., to Kensett, Ark	J. P. Lushene	295
Nashville, Tenn., to Florence, Ala	A. J. Hoskinson	209
Grants Pass, Oreg., to Eureka, Calif	J. H. Brittain	289
Tullahoma to Rockwood, Tenn	A. J. Hoskinson	196
Harpers Ferry, W.Va., to Harrisburg, Pa.	do	170
Arcata to Redding, Calif	E. E. Stohsner	245
Josephine to Blairsville, Pa	A. J. *Hoskinson*	21
Clarksburg to Saltsburg, Pa	do	20
Butler to Callery, Pa	do	32
Abilene to Del Rio, Tex	J. D. Thurmond	539
Philadelphia, Pa., to Lewes, Del	A. L. Wardwell	333
Crescent City, Calif., to Reedsport, Oreg.	E. E. Stohsner	318
Medford to Chinchalo, Oreg	do	163
Winnemucca, Nev., to Crane, Oreg	Curtis Le Fever	403
Brady to Camp San Saba, Tex	J. D. Thurmond	22
Kirk to Bend, Oreg	H. J. Oliver	167
Vicinity of Seattle, Wash	Charles Pierce	2
Carlton to Aitkin, Minn	A. J. Hoskinson	110
Twin Rivers to Olympia, Wash	Charles Pierce	269
Bemidji to International Falls, Minn	A. J. Hoskinson	178
Prineville to Dayville, Oreg	H. J. Oliver	141
Glendive, Mont., to Bismarck, N.Dak	G. R. Fish	359
Bemidji to Crookston, Minn	A. J. Hoskinson	125
Forsyth to Malta, Mont	J. D. Thurmond	363
Canyon City to Burns, Oreg	H. J. Oliver	131
Valley Falls to Lapine, Oreg	do	205
McKenzie, N.Dak., to Glyndon, Minn	*G. R. Fish*	338
Klamath Falls to Klamath Junction, Oreg.	H. J. Oliver	97
Klamath Falls to Dairy, Oreg	do	32
Vicinity of Wolf Creek, Oreg	do	4
Dillard to Coquille, Oreg	do	105
Twin Brooks to Roscoe, S.Dak	G. R. Fish	227
Cle Elum to Molson, Wash	Charles Pierce	382
Lakeview, Oreg., to Fernley, Nev	Curtis Le Fever	392
Malone to Troy, N.Y	W. M. Gibson	461
Laurier to Spokane, Wash	Charles Pierce	214
Utica to Weedsport, N.Y	W. M. Gibson	126
Great Falls to Mossmain, Mont	J. D. Thurmond	372
Shirley to Hoxie, Ark	G. R. Fish	224
Wilmington, Del., to Susquehanna Bridge, Md.	W. M. Gibson	63
Sioux Falls *Junction*, S. Dak., to La Crosse, Wis.	A. L. Wardwell	515
Kensett to Little Rock, Ark	G. R. Fish	105
Pine Bluff to Camden, Ark	do	135
Camp San Saba to San Antonio, Tex	J. D. Thurmond	222
Portsmouth, Va., to Southport, N.C	W. M. Gibson	497
Navassa to Chadbourn, N.C	do	80
Chadbourn to Fayetteville, N.C	do	102
Roseboro to Plymouth, N.C	do	302
Rocky Mount to Weldon, N.C	do	61
Suffolk to Old Point Comfort, Va	do	65
Richmond to Clarksville, Va	do	172
Clarksville, Va., to Manson, N.C	do	43
Suffolk to Richmond, Va	do	138
Orange to Tenaha, Tex	J. D. Thurmond	245
San Jacinto to Aguanga, Calif	Curtis Le Fever	50
Releveling, Los Angeles area, Calif	do	608
Longvale to Dos Rios, Calif	H. J. Oliver	23
Ukiah to Marysville, Calif	do	107
Palestine to Houston, Tex	J. D. Thurmond	246
Eureka to San Francisco and San Jose, Calif.	H. J. Oliver	597
Crossett to Montrose, Ark	G. R. Fish	155
Lampasas to Brownwood, Tex	J. D. *Thurmond*	167
Grady to Hazen, Ark	G. R. Fish	126
Mammoth Springs to Shirley, Ark	do	155
Fort Smith to Lewisville, Ark	A. L. Wardwell	371
Willow *Creek to Hornbrook*, Calif	H. J. Oliver	262
Forrest City to Newport, Ark	G. R. Fish	115
Mount Ida to Russellville, Ark	A. L. Wardwell	128
Helena to Wheatley, Ark	G. R. Fish	117
Smithton to Boles, Ark	A. L. Wardwell	185
Harrison to Clarksville, Ark	G. R. Fish	142
Sterling to Cayuga, N.Y	W. M. Gibson	70
Ithaca to Elmira, N.Y	do	83
Salida to Bishop, Calif	*Curtis Le Fever*	406
Port Jervis, N.Y., to Reading, Pa	W. M. Gibson	265
Redding to Alturas, Calif	H. J. Oliver	249
Lines on Long Island, N.Y	W. M. Gibson	355
Cape Girardeau, Mo., to Hoxie, Ark	J. D. Thurmond	226
Truckee to Sacramento, Calif	G. R. Fish	273
Sacramento to Oakland, Calif	do	248
Red Bluff, Calif., to Flanigan, Nev	H. J. Oliver	278
Westwood to Keddie, Calif	do	63
Doyle, Calif., to Reno, Nev	do	86
Reno Junction to Richvale, Calif	do	250
Knoxville, Tenn., to Dillsboro, N.C	W. M. Gibson	200
Dillsboro, N.C., to Spartanburg, S.C	do	204
Atlanta, Ga., to Dillsboro, N.C	A. L. Wardwell	253
Spartanburg, S.C., to Lynchburg, Va	W. M. Gibson	527
Mayport to Archer, Fla. (part)	A. L. Wardwell	286
Bowie to Clemenceau, Ariz. (part)	A. C. Thorson	70
El Paso, Tex., to Vaughn, N.Mex. (part).	E. E. Stohsner	117
Junction to Fort Stockton, Tex. (part).	*Curtis Le Fever*	53
Robstown to Laredo, Tex. (part)	J. Laskowski	33
Hopland to Albion, Calif. (part)	H. J. Oliver	77
Miscellaneous leveling in fragments too small to be listed separately.	Various	2
Total		26,505

Special leveling executed in California to detect earth movements is described below under the heading "Special Geodetic Work in California."

TIDAL STATIONS AND OBSERVATIONS

The elevations of the bench marks in the leveling net of the country are based upon mean sea level as determined at tidal stations along the coasts of the Atlantic Ocean, the Gulf of Mexico, and the Pacific Ocean. Observations are now being made at 26 primary tidal stations along these coasts, and a number of these stations have been in operation for some years.

SPECIAL GEODETIC WORK IN CALIFORNIA

Beginning in 1923 the Coast and Geodetic Survey extended some special geodetic work in California for use in detecting earth movements which take place between earthquakes or during their occurrence. In each year since the project was started, some geodetic work has been done. In some years only triangulation or leveling was done but in other years both classes of work were carried on.

Plans for this special geodetic work are made by the Advisory Committee in Seismology of the Carnegie Institution of Washington, of which Dr. Arthur L. Day is the chairman, and by the officials of the Coast and Geodetic Survey working in conferences. This geodetic work supplements seismological investigations and observations that are being made in California.

An arc of triangulation of the special type designed for this study consists of a main scheme of first-order accuracy and a second-order scheme over the same area with stations spaced quite close together. The distances between the stations are made exceptionally small where such an arc passes over a fault zone.

During the period covered by this report five such arcs, involving a total distance along the axis of 270 miles, have been run. In the course of this work 63 main-scheme and 220 supplemental stations were established. All of these special arcs are connected with the adjusted triangulation net of the country.

Some of the lines of levels in California have been rerun to strengthen the net and to reduce the closing errors of loops that seem to be larger than could be accounted for by the accidental errors of leveling. Only one line was rerun for the purpose of determining whether movement had occurred during an earthquake in the Imperial Valley. A comparison of the results of this releveling showed that a few of the bench marks near the determined epicenter had undergone changes in elevation of a few centimeters each.

All the triangulation and leveling of the country can be used for determining earth movements when an earthquake occurs on or close to an arc of triangulation or a line of levels. It is especially important that we learn the extent of the area that is affected during any earthquake. There are two schools of thought on the earthquake problem, the first believing that the cause or causes of earthquakes involve great volumes of the earth's crust and a great extent of the earth's surface, and the second, that the cause or causes of an earthquake are local in character. It is believed that a comparison of geodetic data obtained before and after an earthquake may throw some light on the problems involved.

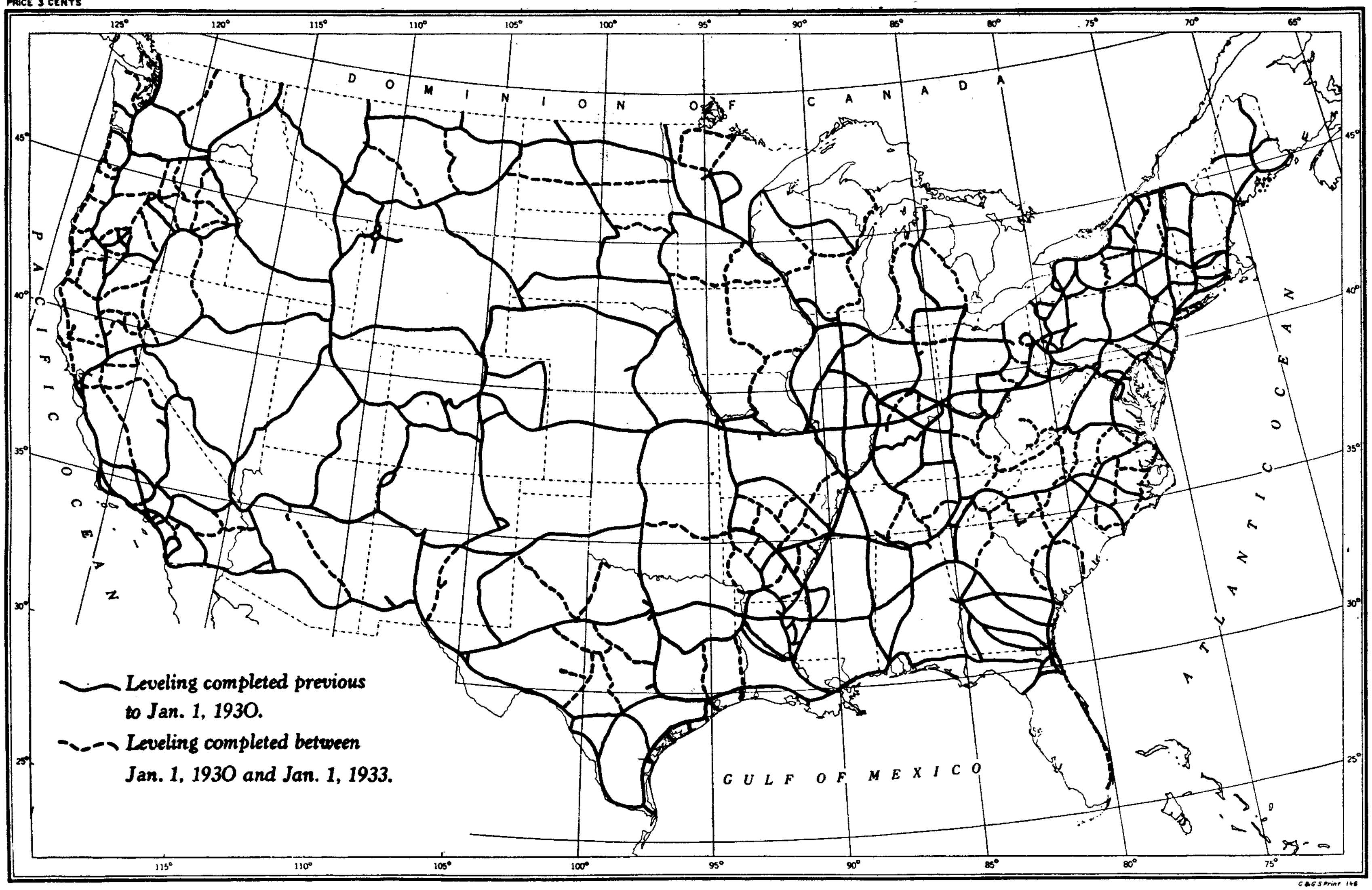
GEODETIC SURVEYING BY THE UNITED STATES GEOLOGICAL SURVEY AND BY THE CORPS OF ENGINEERS, UNITED STATES ARMY

There is quoted below a portion of a report on horizontal and vertical control surveys of the United States Geological Survey made by W. C. Mendenhall, director of that organization.

> The control surveys of the United States Geological Survey, triangulation, traverse, leveling, and aerial photographic, are executed primarily for use in its topographic surveys. Control of third-order accuracy, as defined by the United States Board of Surveys and Maps, is adequate for that purpose and control of first- or second-order accuracy is executed by the Geological Survey only where it is urgently needed to strengthen its third-order surveys.
>
> During the calendar years 1930, 1931, and 1932, control surveys were carried on in 38 States and in Hawaii. During that period 624 triangulation stations were occupied and marked; 17,492 miles of transit traverse and

FIRST AND SECOND ORDER LEVELING

PRICE 3 CENTS



C&GS Print 146

FIGURE 2.—First- and second-order leveling in the United States.

25,065 miles of levels were run. Permanent marks were established approximately every 3 miles along transit-traverse and level routes. The geodetic coordinates of all permanent marks and of many described intermediate points of transit-traverse lines were computed, and numerous intermediate bench marks were established along level routes. All tapes and rods used on control surveys were carefully calibrated each season.

Funds made available for printing and binding were insufficient, after providing for essential requirements, to permit the publication of control data in bulletin form. Work of assembling and compiling data, however, is going forward with a view to publication as soon as practicable.

The geodetic work in the form of triangulation, traverse and leveling executed during the 3 years covered by this report by the Corps of Engineers is described in the section of this report (see p. 15) which was prepared by W. H. Crosson, captain, Corps of Engineers, chief, intelligence section of that organization. The Corps of Engineers and the Coast and Geodetic Survey have cooperated on several projects during the 3-year period. In Special Publication No. 166, mention is made of the arc of triangulation executed along the Mississippi River from Cairo, Ill., to New Orleans, La. Since that report appeared, an arc has been extended northward from Cairo to the vicinity of St. Paul, Minn. The field work and office computations were done by the Coast and Geodetic Survey and the larger part of the money needed on that work was supplied by the Corps of Engineers. Another cooperative arc of triangulation was along the eastern shore of Lake Michigan. The Corps of Engineers furnished the funds for the field expenses of this arc. An arc of first-order triangulation with many supplemental stations was also executed for the Corps of Engineers along the San Joaquin River in California. Several lines of levels were run by the Coast and Geodetic Survey for the Corps of Engineers during the 3 years. For all these projects most of the funds were furnished by the Corps of Engineers.

The detailed triangulation which had been executed along the Mississippi River by the Mississippi River Commission, a branch of the Corps of Engineers, is being adjusted in the office of the United States Coast and Geodetic Survey in order that final positions for all the stations involved may become available. The pay of the computers engaged upon this work is furnished by the Corps of Engineers.

ASTRONOMICAL WORK

Astronomical work of interest to geodesists is carried on by the Coast and Geodetic Survey and by the Naval Observatory at Washington, D.C.

FIELD ASTRONOMY

During the period covered by this report astronomical observations were made, along the new arcs of triangulation, for the purpose of furnishing the deflections of the vertical in the prime vertical at triangulation stations where it was desired to use Laplace azimuths. In general, the observations on Polaris for azimuth are made by the observer engaged on the triangulation. The astronomical observations for the determination of latitude and longitude are made by a special party. During the 3-year period, astronomical determinations in the field consisted of 115 azimuths, of which 67 are Laplace azimuths, 76 longitudes, and 74 latitudes.

No changes of special importance were made in the apparatus or methods used in the field astronomical work.

The observers of the United States Naval Observatory have continued those operations which are of interest and value in geodesy. An article entitled "The U.S. Naval Observatory Time Service" by Mr. Paul Sollenberger is included in this report. (See p. 21.)

It should be stated that the time service of the Naval Observatory is of the utmost value to the observers of the Coast and Geodetic Survey. At the close of 1932, time signals were being sent six times daily while early in January of 1933 an additional time signal was sent for use in gravity surveys in Cuba. It is expected that in the future a still larger number of signals will be sent out from the Observatory. The time service of that organization is used in many branches of industry as well as by geologists and geophysicists.

VARIATION OF LATITUDE

Observations with the Ross reflex photographic zenith tube have been continued at the United States Naval Observatory. A statement on this work furnished by Capt. F. B. Littell, mathematician, United States Navy, reads as follows:

During the period January 1, 1930, to December 31, 1932, the observations for variation of latitude, which were begun in 1915, have been continued with the Ross reflex photographic zenith tube.

The results for the years 1929, 1930, and 1931 were published in the Astronomical Journal of March 15, 1930, September 8, 1931, and June 14, 1932, respectively. Those for the year 1932 are in preparation for publication.

After some preliminary experiments, the photographic zenith tube has been modified slightly so as to permit the observations to be used also for the determination of time. The results indicate practically the same degree of accuracy for the time determination as for the latitude determination. The method of determining time from these observations is described in the Astronomical Journal of November 6, 1929.

The United States Coast and Geodetic Survey has continued variation of latitude observations during the 3-year period at the station at Ukiah, Calif. The station at Gaithersburg, Md., which became inoperative in 1914, was reconditioned by the Coast and Geodetic Survey in 1931, and observations were resumed there in the spring of 1932.

GRAVITY DETERMINATIONS

Gravity observations have been made by the Coast and Geodetic Survey on land at a number of points in the United States and on islands of the Bahama group. Observations at sea have been made by Dr. F. A. Vening Meinesz, member of the Dutch Geodetic Commission, in the waters of the West Indies. The expedition to the West Indies was a cooperative one by the United States Navy which furnished a submarine and a boat to accompany it, the International Expeditions to the West Indies of which Prof. Richard M. Field is the chairman, and Dr. Vening Meinesz who furnished the instrument and made the observations. During this expedition, which occupied about 2 months in January, February, and March 1932, 54 determinations of gravity were made. A description of that expedition, together with the results obtained and the location of the stations, will undoubtedly be given by Dr. Vening Meinesz in his report on gravity determinations at sea to the International Association of Geodesy at its meeting in Lisbon.

The reduction of the stations for topography and isostatic compensation was made at the office of the Coast and Geodetic Survey. It is expected that a report on this subject, which will give all of the results and perhaps an interpretation of some of the data, will appear very soon as a publication of the Hydrographic Office, United States Navy.

That office issued a chart on which were shown the land and sea gravity stations of the Caribbean Sea and Gulf of Mexico regions and the epicenters which had been well determined for earthquakes that have occurred in those regions during recent years. Copies of this chart can be secured by addressing either Prof. Richard M. Field of Princeton University, Princeton, N.J., or the Hydrographer, United States Navy, Washington, D.C.

The gravity work of the Coast and Geodetic Survey is covered by a section of this report under the heading "Gravity and Isostasy" by C. H. Swick, senior mathematician of that organization. (See p. 23.)

COMPUTATION OF TABLES FOR REDUCING GRAVITY OBSERVATIONS TO THE SPHEROID

In the latter part of 1932, computations were begun on tables which will make it possible to reduce gravity stations from the sea level or geoid surface to the spheroid. This is a matter of importance, and it has been the subject of resolutions adopted by the International Association of Geodesy. It is expected that computations for these tables will be completed by the middle of 1933. Already General Perrier, secretary of the association, has offered to have the tables printed as a special number of the Bulletin Geodesique.

It is hoped that, after these tables are available, all gravity stations at sea and on land can be referred to the spheroid. When this has been done, the data for water and land stations should be comparable, and the combined data can then be used for the derivation of a gravity formula which should be close to the truth. The reductions in question should also make it possible to study the isostatic condition of the continental and oceanic areas with more effectiveness than is possible at present.

An outstanding difference has been found between the isostatic gravity anomalies for water areas and those for land areas. The former have a tendency to be positive and fairly large. It is anticipated that at least some of this difference will be accounted for by the difference in distance from the center of the earth of the geoid and spheroid surfaces. An article by C. H. Swick, on page 23, touches on the question of these tables.

GRAVITATIONAL WORK AT THE BUREAU OF STANDARDS

Special Publication No. 166 contains a statement by Dr. Paul R. Heyl, chief of the sound section of the Bureau of Standards, describing his work in obtaining an absolute value of gravity at the Bureau of Standards. There is quoted below a statement from Dr. Heyl which covers his work along this line during the past 3 years:

> The Bureau of Standards, at the request of the United States Coast and Geodetic Survey, has undertaken an absolute determination of gravity at Washington. There has never been made in this country any determination of this nature which can qualify as a precision measurement according to modern standards. The Potsdam determination of 25 years ago has been the ultimate standard of reference for gravity work in the United States.
>
> In the work at present being carried out, the three essential lengths involved—the pendulum, the standard scale, and the backbone of the comparator—are all of fused silica, thus almost eliminating temperature corrections.
>
> Especial attention is being paid to the flexure correction. Three pendulums of different flexibilities are being used, giving progressively different values of *g*. A short extrapolation to zero flexibility gives the corrected value of *g*.

ISOSTASY

Isostasy continues to be a subject of interest and importance, and it is being given more consideration by geophysicists and geologists than ever before. The subject may have an important practical value for, by applying corrections to gravity and deflection-of-the-vertical data to account for the compensation of topography, results are obtained which indicate the presence of abnormally heavy or light rock near by. Such information is of especial importance in geological and geophysical investigations designed to discover petroleum and ores. The article by C. H. Swick on page 23 tells of the isostatic reductions of gravity stations that have been made during the past 3 years.

The division of geology and geography of the National Research Council issued in 1932, in multigraphed form, a paper entitled "Comments on Isostasy." This paper gives quotations from articles and books by 65 different authors. Any statement that was definite regarding isostasy was included in the paper. Necessarily, some of the opinions quoted were adverse to isostasy, although the large majority were favorable.

PROJECTIONS FOR MAPS

Very little was accomplished in the field of projections for maps during the past 3 years. A brief statement regarding the subject by Oscar S. Adams, senior mathematician, Coast and Geodetic Survey, is quoted below:

> A wall map of the United States on the Albers equal area proportion has been issued by the United States Geological Survey. This is to be the official wall map of this country hereafter and is to replace the one previously in use.
>
> A new edition of the United States Coast and Geodetic Survey Special Publication No. 68, Elements of Map Projection, appeared in May 1931. In it was included an addition giving the mathematical theory of the parabolic equal-area projection which was suggested by Col. J. E. E. Craster in the Geographical Journal for November 1929. A map of the world on this projection was constructed by Charles H. Deetz and a plate of the same is added to the new edition. A map of Pan America is being constructed on this projection by some cartographers of the United States Coast and Geodetic Survey to be used for statistical purposes by the Department of Genetics of the Carnegie Institution of Washington.

SECTION OF GEODESY, AMERICAN GEOPHYSICAL UNION

The American Geophysical Union, which has sections corresponding to those of the International Geodetic and Geophysical Union, has, during the past 3 years, continued to assist in coordinating the efforts of many individuals and organizations dealing with geophysical matters. The Union has its annual meeting the latter part of April of each year, and shortly after each annual meeting the transactions of the Union are published.

The geodetic section of the Union has been quite active during the past 3 years, and its membership has shown a live interest in geodetic subjects.

On December 13, 1932, the officers of the Union were:

President, W. J. Humphreys.
Vice president, A. H. Clark.
General secretary, John A. Fleming.

Officers of the section of geodesy were:

President, H. G. Avers.
Vice president, D. C. Barton.
Secretary, C. H. Swick.

BOARD OF SURVEYS AND MAPS OF THE FEDERAL GOVERNMENT

The Board of Surveys and Maps, with 23 member organizations, has continued its activities during the past 3 years. As a result of its work, there has been a close coordination of various classes of surveying and mapping by the branches of the Federal Government, and the results of these activities have been more widely distributed to the citizens of the country who can profit by them. Requests for information regarding the surveying and mapping work of the Federal Government should be addressed to Maj. J. H. Wheat, chief, map information office, Interior Department Building, Washington, D.C.

SURVEYING AND MAPPING DIVISION, AMERICAN SOCIETY OF CIVIL ENGINEERS

The surveying and mapping division, American Society of Civil Engineers, was organized in 1926. This divison has been very active during its existence. Undoubtedly, as a result of its efforts, there is a greater appreciation today than ever before in the United States of the economic advantages of improved surveying and mapping practices, and a better realization that there are very few activities of a nation that do not, in some way, depend on accurate maps. Geodetic surveys, in the form of triangulation, traverse, and leveling, and topographic surveys by both land and air methods are required, of course, in the production of such maps.

Articles on surveys and maps, which have appeared in the publications of the American Society of Civil Engineers, have helped to expand the use of geodetic surveys in engineering and other work. The endorsement of geodetic surveys by engineers of the country has resulted in larger appropriations being made to the Coast and Geodetic Survey for extending its triangulation and leveling.

GEODETIC PUBLICATIONS ISSUED SINCE JANUARY 1, 1930

NATIONAL RESEARCH COUNCIL

Physics of the Earth—II. The Figure of the Earth. (Several authors.) Bulletin No. 78. 290 pages, octavo. 1931.

U.S. COAST AND GEODETIC SURVEY

First-Order Triangulation in Southeast Alaska. Walter F. Reynolds. Special Publication No. 164. 163 pages, octavo. 1930.

Geodetic Operations in the United States, January 1, 1927, to December 31, 1929. William Bowie. Special Publication No. 166. 42 pages, quarto. 1930.

First-Order Leveling in Alaska. Howard S. Rappleye. Special Publication No. 169. 31 pages, octavo. 1930.

Tables for a Polyconic Projection of Maps and Lengths of Terrestrial Arcs of Meridian and Parallel Based upon Clarke's Reference Spheroid of 1866. (Fifth edition.) Special Publication No. 5. 189 pages, quarto. 1930.

World Longitude Determinations by the U.S. Coast and Geodetic Survey in 1926. Clarence H. Swick. Special Publication No. 171. 31 pages, octavo. 1931.

First-Order Leveling in New Jersey. Howard S. Rappleye. Special Publication No. 172. 35 pages, octavo. 1931.

Latitude Redeterminations. Frederic W. Darling. Special Publication No. 173. 22 pages, octavo. 1931.

Triangulation. Serial 529. 20 pages, octavo. 1931.

First- and Second-Order Triangulation in Oregon (1927 datum). Clarence H. Swick. Special Publication No. 175. 92 pages, octavo. 1932.

First-Order Leveling in Michigan. Howard S. Rappleye. Special Publication No. 176. 69 pages, octavo. 1932.

Leveling in Oregon. Howard S. Rappleye. Special Publication No. 177. 247 pages, octavo. 1932.

U.S. GEOLOGICAL SURVEY

Boundaries, Areas, Geographic Centers, and Altitudes of the United States and the Several States. (Second edition.) Edward M. Douglas. Bulletin 817. 272 pages, octavo. 1930.

SPECIAL ARTICLES

GEODETIC OPERATIONS, CORPS OF ENGINEERS, UNITED STATES ARMY

By W. H. Crosson, *Captain, Corps of Engineers, Chief, Intelligence Section*

Relative to geodetic operations in the United States for the period from January 1, 1930, to December 31, 1932, the following reports have been submitted by the United States Lake Survey, Detroit, Mich., and the president, Mississippi River Commission, Vicksburg, Miss.

UNITED STATES LAKE SURVEY

In 1932 an arc of first-order triangulation extending along the east shore of Lake Michigan from the vicinity of Michigan City to Little Traverse Bay was executed by the Coast and Geodetic Survey, the cost being borne by the Lake Survey.

Geodetic control on Lake Champlain has been reestablished. Existing triangulation stations were recovered and remarked, and new stations were established to replace missing stations.

In 1932 search was made for all triangulation stations in the Lower Peninsula of Michigan for the purpose of preserving all that were still in existence.

In 1930 a line of first-order levels was run from Fort Gratiot Lighthouse at the head of the St. Clair River to St. Clair Flats Canal, connecting with all existing bench marks and establishing many new ones. In 1931 first-order levels were run from Lake Erie at Buffalo to Tonawanda, N.Y., along the Niagara River, checking the elevations of existing bench marks and establishing new ones where needed. In 1932 a line of first-order levels was run from Windmill Point on Lake St. Clair to Monroe, Mich., and to Amherstburg and Bar Point, Ontario, connecting with all existing bench marks, and establishing elevations on a great number of the harbor-line reference marks and other new bench marks. New bench marks were established by first-order leveling in Milwaukee, Wis., and in Cleveland, Ohio.

Continuous graphic records of water levels on the Great Lakes and connecting rivers are being obtained at the following stations:

Marquette, Mich.	Port Huron, Mich. (two stations).	Monroe, Mich.
Mackinaw City, Mich.	Roberts Landing, Mich.	Cleveland, Ohio.
Milwaukee, Wis.	St. Clair Flats, Mich.	Buffalo, N.Y. (two stations).
Harbor Beach, Mich.	Fort Wayne, Detroit, Mich.	Cape Vincent, N.Y.

A staff gage is being read three times daily at Windmill Point, Detroit. Records of self-registering gages at Sault Ste. Marie, Mich. (two), Calumet Harbor, Ill., and Amherstburg, Ontario (two), and of staff gages at Duluth, Minn., Houghton, Mich., and Oswego, N.Y., are being furnished to the Lake Survey by other Engineer districts on the Lakes.

The records of the various gages are the basis for determining the causes and extent of fluctuations of lake levels, changes in regimen of interlake and outflow rivers, the effect on lake levels of diversions through artificial outlets, the effect of improvements of navigation channels, and the design of compensating works to offset such effects. They also afford means of determining the direction and rate of tilting of the earth's surface in the lake region.

MISSISSIPPI RIVER COMMISSION

Memphis District

The survey work (third-order or higher) in which this district has been engaged during the past 3 years is listed below:

Location	Triangulation	Traverse	Levels
	Miles	*Miles*	*Miles*
Survey of alluvial valley (71 quadrangles)		3,740	1,800
General river surveys	336		130
Birds Point-New Madrid survey	0	185	185
Wolf River-Nonconnah Creek survey	0	43	0
Total	336	3,968	2,115

In addition to the items listed above, 615 miles of leveling were connected with and included in the adjustment of levels on the alluvial valley survey.

In this connection attention is invited to report covering geodetic operations during the period January 1, 1927, to December 31, 1929, previously rendered. Under section II of the Flood Control Act, 813 miles of traverse and 700 miles of levels were run, and 435 miles of traverse and levels were run on the low-water survey.

Vicksburg District

Geodetic work performed by the Vicksburg district during the 3-year period consisted of completing the general low-water survey of the Mississippi River which was begun in 1929; a survey of the Yazoo River backwater area; a survey of the Red River backwater area; a survey of Red River Valley from Alexandria to the Oklahoma State line; a survey of the alluvial valley of the Mississippi River to furnish data for 61 quadrangle maps; and surveys for bank protection along the Mississippi River. The number of permanent marks established by these surveys, together with the corresponding miles of third-order traverses and third-order levels, are shown in the following tabulation:

Operations, 1930–32

Locality	Permanent marks established	Third-order transit traverse	Third-order levels
	Number	*Miles*	*Miles*
Mississippi River, general low-water survey	66	328	328
Mississippi River, bank protection surveys	131	211	211
Yazoo River, backwater area survey	91	341	253
Red River, backwater area survey	98	386	350
Red River Valley survey	135	622	479
Alluvial valley quadrangle survey	359	1,008	1,101
Total	880	2,896	2,722

Attention is invited to report previously rendered for this district for the 3-year period ending December 31, 1929. Reliable data for many surveys then under way were not available at that time and the report of that date is now revised to read as follows:

Revised operations, 1927–29

Locality	Permanent marks established	Third-order transit traverse	Third-order levels
Yazoo Basin:	*Number*	*Miles*	*Miles*
Tallahatchie, Yazoo, Yalobusha, Skuna, Little Tallahatchie, and Cold Water Rivers surveys	133	313	489
Boeuf Basin surveys	89	496	496
Mississippi River, general low-water survey	64	115	115
Total	286	924	1,100

Second New Orleans District

The summary of geodetic work accomplished by this district during the 3-year period ending December 31, 1932, is as follows:

First-order levels were run from the vicinity of St. Gabriel, La., to New Orleans, La.; from Simmesport, La., to Alexandria, La.; from New Orleans, La., to Mandeville, La.; and from New Orleans, La., to Little Woods, La., a total distance of about 230 miles. Permanent bench marks were established at about 3-mile intervals throughout this work.

Eighteen permanent ranges were established across the Atchafalaya Basin below Krotz Springs, La., and ground surface elevations referred to mean Gulf level determined at 50-foot intervals.

The automatic tide gage near Biloxi, Miss., on the Gulf of Mexico, was maintained during the period covered by this report.

ADJUSTMENT OF THE TRIANGULATION ON THE NORTH AMERICAN DATUM OF 1927

By Walter F. Reynolds, *Chief, Section of Triangulation, United States Coast and Geodetic Survey*

During the period January 1, 1930, to December 31, 1932, considerable progress was made in the adjustment of the triangulation of the United States on the North American datum of 1927. A brief discussion of the readjustment of the first-order triangulation east of the ninety-eighth meridian is given by Dr. O. S. Adams on page 18 of this report. All other adjustments are considered in this article.

The following five arcs of triangulation in California located in earthquake regions and vicinity were rigidly adjusted: (1) Newport Beach to thirty-fifth parallel, the field work of which was done in 1929, (2) vicinity of Point Reyes, the field work of which was started in 1929 and completed in 1930, (3) Monterey Bay to Mariposa Peak, the field work of which was done in 1930, (4) vicinity of San Luis Obispo, the field work of which was done in 1932, (5) San Fernando to Bakersfield, the field work of which was done in 1932. The field work for a sixth arc in the vicinity of Taft was executed in 1932, but the adjustment of it has not been made.

Each of these arcs consists of a scheme of triangulation of first-order accuracy, which controls another scheme of triangulation of second-order accuracy that has a close grouping of stations near the fault zones that are crossed by the arcs. When the observations along these arcs are repeated after an interval of years, and adjusted, the results will be used in detecting any horizontal movements in these areas.

The following arcs of first-order triangulation, of which the field work was executed during the years 1931 and 1932, have been adjusted: (1) San Joaquin Valley, Calif.; (2) Sacramento and San Joaquin Rivers, Calif.; (3) Suisun Bay to San Francisco Bay, Calif.; (4) Reno to Lakeview, Calif., Nev., and Oreg.

Another noteworthy accomplishment during this period was the completion of the adjustment of the second- and third-order triangulation executed by the Mississippi River Commission along the Mississippi River from Cairo, Ill., to St. Paul, Minn., from St. Paul to Brainerd, from Brainerd to Bemidji and from Brainerd to Aitkin, Minn., and the adjustment of the traverse from Bemidji to Grand Rapids to Aitkin, Minn.

In 1931, at the request of the Chief of Engineers, United States Army, the United States Coast and Geodetic Survey executed an arc of first-order triangulation along the Mississippi River from Cairo, Ill., to St. Paul, Minn., for the purpose of controlling the maps and existing triangulation of the Mississippi River Commission in this area. During the execution of this triangulation, ties were made to the second-order triangulation of the Mississippi River Commission at an average interval of 12 miles. In some instances the second-order stations were chosen as stations for the first-order scheme, new observations of first-order accuracy being made at them. This arc of triangulation was not included in the general readjustment of the triangulation east of the ninety-eighth meridian, since the field observations for it were not completed at the time that adjustment was planned. However, after the junction figures of the triangulation in the eastern half of the country were finally fixed, those arcs, to which the Mississippi River triangulation is connected, were adjusted. Then the Mississippi River arc was adjusted in four sections to these completed arcs.

After the completion of the adjustment of the first-order triangulation, those stations of the Mississippi River Commission which were directly connected to the first-order work were adjusted. These stations were held fixed in position, length, and azimuth and then the Mississippi River Commission second-order triangulation was adjusted in sections. Finally the third-order triangulation was adjusted to the second-order scheme. It is hoped to have published, during the present year, the geographic positions and descriptions of the approximately 2,500 triangulation stations made available by these adjustments.

In Special Publication No. 166, "Geodetic Operations in the United States January 1, 1927, to December 31, 1929", a report was made on the adjustment of the triangulation in southeast Alaska on the North American datum of 1927 to the end of the calendar year 1929. Further progress has been made on this work so that now all triangulation executed in southeast Alaska since 1912, and a large part of the work done before that date, have been adjusted to this datum.

There have been measured since December 31, 1929, 38 first-order bases which are used for the control of the lengths in the first-order triangulation net of the United States. With a few exceptions the computations of these bases have been completed.

During the years 1930–32, progress has been made also in the computation and adjustment of the second- and third-order triangulation along the Atlantic and Pacific coasts of the United States on the North American datum of 1927. This triangulation has been executed primarily for the control of hydrographic and topographic surveys used in making nautical charts.

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

By OSCAR S. ADAMS, *Senior Mathematician, United States Coast and Geodetic Survey*

A report on the readjustment of the triangulation net in the western part of the United States by the Bowie method was presented at the meeting of the International Geodetic and Geophysical Union at Prague in 1927. The present report is on a similar adjustment of the first-order arcs in the eastern part of the country. The arc along the ninety-eighth meridian was included in the western section and hence was held fixed in this adjustment.

All of the older arcs that had been previously adjusted in this part of the country were included with the various new arcs that were observed to strengthen the network by filling up the gaps existing in the older work. All of these new arcs are included in the tabulation of the triangulation work done during the past 3 years. (See p. 4.)

The method followed in the adjustment was the same as that previously described in the report to the International Geodetic Association, an account of which is given in the United States Coast and Geodetic Survey Special Publication No. 159, The Bowie Method of Triangulation Adjustment. The total network formed 26 loops with 55 sections between junction figures. After excluding the junctions with the ninety-eighth meridian arcs, which were held fixed, there were a total of 29 junction figures in which the positions could be adjusted.

After all of the sections between junction figures were adjusted for figure, length, and azimuth, the closures of the loops in latitude and longitude were computed in feet. The total closure in feet is, of course, equal to the square root of the sum of the squares of these two closures. Figure 3 shows these loop closures in feet together with the approximate proportional part of the total length that this closure represents. Those loops that include a portion of the ninety-eighth meridian arc are proportionately greater in closure because this arc was held fixed and could not

FIGURE 3.—Loop closures in feet resulting from adjustment of triangulation net of eastern United States.

absorb a portion of the closure. Only one loop has a closure greater than 1 part in 100,000, and this is one that includes a portion of the ninety-eighth meridian arc. Most of the closures are near 1 part in 150,000 or better and the mean of the whole number of loops is 1 part in 193,000. These closures on the whole are not quite as good as were those in the western part of the country, mainly because the loops are smaller and partly because the ninety-eighth meridian arc had to be held as fixed by the previous adjustment.

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 astronomical measurements furnish the azimuth control of the various arcs. Some of the work was done 50 years or more ago, but the greater part has been done in the past 25 years.

In the network included in this adjustment, the lengths are controlled by 62 bases together with 7 lengths that were held fixed in the junctions with the ninety-eighth meridian arcs. The orientation is controlled by 101 Laplace azimuths, more or less equally distributed throughout the various sections of the network.

The 62 bases have been measured within the past 100 years with various types of apparatus. The older bases were measured with base bars or rods, and those established in the first decade of the present century were measured with steel tapes. For approximately the past 20 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 various methods, the circuit closures which have resulted demonstrate clearly that the general accord of bases is even better than could be expected, and the agreement of the various sections in the network is such as to be, on the whole, satisfactory in every way.

After the preliminary adjustment of the sections was completed, 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 29 junction figures. These positions furnish the data for the determination of the closures in latitude and longitude of the 55 sections of the complete net of the triangulation. In the table on page 21 these results are given in feet. The first column gives the number of the section, which can be located by reference to figure 3 on which the various sections are numbered as given in the table. The second column gives the closure in feet in latitude; the third column gives the similar closures in longitude; and the fourth column gives the total closure in feet. Finally, the last column gives the approximate proportional part of the total length of the section that this closure represents. The worst closure is on section 11, which is 1 part in 66,000. Forty-three sections of the 55 close better than 1 part in 100,000.

After the preliminary adjustments were finished and the values of the junction positions were determined, the Director of the Geodetic Survey of Canada and the Director of the United States Coast and Geodetic Survey agreed upon a joint adjustment of the United States work north and east of section 19, together with the Canadian arcs in eastern Canada, so that all of the work in this area might be on the same datum.

In fact, in the earlier adjustment, sections 14 and 15 were arcs of the Geodetic Survey of Canada which were included to strengthen our positions in New England. This supplementary adjustment was made but it did not materially change the positions already determined for the junction figures in this region.

The position of station Chamcook, in eastern Maine, differs $-0''.767$ in latitude and $-0''.130$ in longitude from the old position on the North American datum. At station Fort Morgan, in southern Alabama, the change is $-0''.220$ in latitude and $+0''.470$ in longitude. At other points the changes lie somewhere between these limits.

A subsequent arc along the Mississippi River from Cairo, Ill., to Minneapolis and St. Paul, Minn., was observed and adjusted into the net with very satisfactory closures at the junctions with the arcs of the general net. Also more recently a first-order arc has been observed extending from Providence, R.I., to Jacksonville, Fla., following the Atlantic coast line. Connections with the first-order arcs of the eastern adjustment were made at New York, at Princeton, N.J., and at the thirty-ninth parallel in the vicinity of Cape May. The work has been adjusted to this point with very satisfactory closures. From that point southward, there is a spur arc from Norfolk, Va., to join the oblique arc in the vicinity of Rapidan, Va., with two other spur arc connections further south. The work is at present under adjustment as far south as the southern boundary of South Carolina. This work will form the basis of the control of all of the second- and third-order work along the Atlantic coast.

Closures of sections

Section (See fig. 3)	Closure in latitude	Closure in longitude	Total closure of section	Proportional part of length of section. One part in—	Section (See fig. 3)	Closure in latitude	Closure in longitude	Total closure of section	Proportional part of length of section. One part in —
	Feet	*Feet*	*Feet*			*Feet*	*Feet*	*Feet*	
1	2.1	0.6	2.2	192,000	29	2.5	2.3	3.4	404,000
2	2.4	2.0	3.1	477,000	30	5.7	.8	5.8	182,000
3	1.7	1.3	2.1	251,000					
4	4.6	2.5	5.2	142,000	31	9.2	8.7	12.7	79,000
5	2.5	0	2.5	317,000	32	5.7	2.3	6.1	130,000
					33	3.4	0	3.4	171,000
6	8.9	2.2	9.2	126,000	34	2.4	2.1	3.2	165,000
7	1.1	2.6	2.8	245,000	35	4.8	2.3	5.3	159,000
8	4.0	2.9	4.9	248,000					
9	4.9	1.0	5.0	105,000	36	1.4	5.6	5.8	91,000
10	3.5	.4	3.5	166,000	37	.7	6.9	6.9	76,000
					38	4.2	.9	4.3	233,000
11	15.0	14.3	20.7	66,000	39	11.1	4.7	12.1	109,000
12	2.2	11.5	11.7	126,000	40	1.4	4.2	4.4	240,000
13	5.7	7.9	9.7	120,000					
14	2.7	2.1	3.4	311,000	41	1.4	4.2	4.4	240,000
15	12.1	9.4	15.3	97,000	42	4.0	3.6	5.4	108,000
					43	3.2	7.1	7.8	74,000
16	3.1	6.1	6.8	78,000	44	.3	.6	.7	128,000
17	1.3	2.7	3.0	173,000	45	3.9	8.5	9.4	79,000
18	1.3	3.0	3.3	400,000					
19	2.6	7.7	8.1	163,000	46	8.6	2.3	8.9	119,000
20	5.6	2.8	6.3	91,000	47	6.7	14.5	16.0	79,000
					48	4.0	10.8	11.5	69,000
21	1.1	1.5	1.9	277,000	49	3.2	8.0	8.6	141,000
22	8.4	2.2	8.7	127,000	50	1.5	2.3	2.7	196,000
23	2.1	3.6	4.2	239,000					
24	4.6	2.2	5.1	155,000	51	5.9	.1	5.9	125,000
25	3.7	2.1	4.3	245,000	52	7.3	1.8	7.5	211,000
					53	4.0	1.5	4.3	282,000
26	9.4	11.7	15.0	88,000	54	8.0	7.4	10.9	121,000
27	4.2	5.2	6.7	126,000	55	0	.6	.6	440,000
28	2.8	1.6	3.2	116,000					

THE UNITED STATES NAVAL OBSERVATORY TIME SERVICE

By PAUL SOLLENBERGER, *Astronomer, United States Naval Observatory*

An increased demand for more frequent time signals has been evident during the past 3 years. The need has been particularly urgent in scientific and technical work. Because of this demand, the United States Naval Observatory increased the number of its daily time transmissions from three to six, beginning October 1, 1931. It is now possible for field parties to receive time signals both before and after their star observations, and to make two independent determinations of longitude in one night. Moreover the signals are spaced at intervals such that gravity pendulums may be kept swinging from one time transmission to the next, thus greatly expediting the work. However the number of signals is still inadequate for many purposes, and plans are under way for a further increase in the schedule of transmissions.

In order to facilitate the work of sending out and recording so many time signals, as well as to increase the accuracy, complete new time service equipment has been designed. Part of this is already installed and the remainder is under construction. A new clock vault, designed to house seven standard clocks, was put into service during March 1932. In addition to the three Riefler clocks, which have been in service for a number of years, two new Shortt clocks have been installed, and a third has been ordered. A new type of chronograph, designed and built at the Naval Observatory, is now being used for the recording of time signals. It permits making simultaneous records of the signals from the sidereal clock, the transmitting clock, and a number of radio stations. These records may be read without the use of a scale, and more rapidly and accurately than is the case with the old style astronomical chronograph. For the purpose of receiving and recording the radio signals, nine new radio receivers of special design are under construction at the radio material school of the United States Naval Research Laboratory at Bellevue, D.C.

Probably the most important new apparatus is the new automatic transmission equipment, consisting of two units. The first unit is a Piezo-electric crystal controlled oscillator, which is nearing completion at the Naval Research Laboratory. This oscillator is of new and improved design. The vibrations of the quartz crystal are flexural, its frequency being 1,000 cycles per second. The feed back is acoustic. Unusual precautions have been taken to eliminate the effects of tube aging, as well as all other known sources of variation. The designers of this equipment anticipate that its performance will set a new standard, surpassing the records previously established by both pendulum and crystal controlled timekeepers. The output of this oscillator will be used to drive an elaborate program device. The latter unit is being designed and constructed at the Naval Observatory. It will automatically transmit time signals at any predetermined hours of the day. Provision will be made for rapidly and easily comparing any clock or time signal with the program device. Such comparisons, accurate to the thousandth of a second, may be read off at any time. If the program device is found to be fast or slow, it may be corrrected by a differential device, without disturbing the oscillator. Although it will still be necessary to keep an operator on duty, it is believed that his duties will be greatly simplified, and the accuracy of the transmissions increased.

Although efforts have been made to issue the final time signal corrections more promptly than heretofore, it has not been found possible to speed up the service as much as would be desirable. Fortunately there are several classes of users who need corrections only on a relative rather than an absolute basis, and they are the ones whose work requires the most speed in applying the corrections. To meet their needs the Naval Observatory began, in January 1930, to issue "Immediate Corrections" three times weekly. They give the corrections to the signals as referred to one another, but not on an absolute basis. They are computed by predicting the rates of the standard clocks, in advance of the final reductions of the star observations. In all work involving only rates they make possible rapid reduction of the results. The radio and electrical companies use this type of corrections extensively in radio-frequency work. The rates so computed differ from those which are based on the final corrections by an amount which averages about 1 part in 15,000,000.

The recording of French and British time signals has continued, and in addition signals from Germany and Argentina are now recorded when conditions permit.

As a result of the installation of new apparatus and refinement in the methods, there has been a gradual decrease in the errors of the signals. Previously the best record which had been attained in the mean errors as computed at the Naval Observatory was about $0^s.03$. This has recently decreased, the record for the calendar year 1932 being $0^s.018$. The improvement is more noteworthy because the errors were previously computed with respect to the time of emission from the Naval Observatory, while the more recent values are for the time of emission by radio on 113 kilocycles. It is believed that improved methods of making and reducing the star observations, and the excellent running of the new clocks were the principal causes of the reduction in the size of the errors.

The naval radio station at Mare Island, Calif., began to operate as a part of the Naval Observatory system during the year 1930. At first the signals were sent by local transmitting clocks which were set by comparison with Arlington signals, but during the last 2 years the signals have been picked up from Arlington and automatically retransmitted. While the system has operated very well for the most of the time, there have been a sufficient number of failures to justify some change. Accordingly an order has been placed for a crystal controlled transmitting device, similar to that which is to be installed at the Naval Observatory. It will make possible the transmission of time signals simultaneous with those from Arlington and of the same order of accuracy. When the installation has been completed, it will be possible to compare the transmitting device visually with the Arlington signal, and to set it in a few seconds to the nearest thousandth of a second.

GRAVITY AND ISOSTASY

By C. H. Swick, *Chief, Section of Gravity and Astronomy, United States Coast and Geodetic Survey*

Most of the work in gravity measurements and isostatic investigations during the period covered by this report was done in the last 1 of the 3 years involved. This was partly because the efforts of the Coast and Geodetic Survey in the gravity field were concentrated to a considerable extent during the first 2 years of the period in the development of an improved type of gravity apparatus. Such an apparatus, called the Brown gravity apparatus in honor of E. J. Brown, who designed it, was finally perfected early in 1932, and before the end of the year had been used very successfully in making gravity measurements at 75 stations in the United States. The accuracy obtained with the new instrument is fully as high as that possible with the old type of gravity apparatus, and at least four times as many stations on the average can be determined with it in a given time as with the former type. A brief description of this apparatus is given on page 24.[1]

In the Stockholm report[2] is given a brief discussion of the first gravity-at-sea work done by the United States. Another United States expedition for determining gravity at sea was carried out early in 1932 by the cooperation of Dr. F. A. Vening Meinesz of Holland, the United States Navy, and other governmental organizations under the auspices of the International Expeditions to the West Indies, Dr. R. M. Field of Princeton University, director. More than 50 gravity measurements were made by Dr. Vening Meinesz and his assistants north and south of Cuba and in the waters surrounding the Bahama Islands during the two months of the expedition. The isostatic anomalies at these stations were computed by the Coast and Geodetic Survey. A report of this work is in preparation by the United States Hydrographic Office and will probably be published soon.

To supplement the gravity-at-sea work in this area, the Coast and Geodetic Survey has cooperated with the International Expeditions to the West Indies in making 18 land gravity determinations in the Bahama Islands, 6 in 1930 and 12 in 1932. Another important project in the West Indies was started early in 1933 and will be discussed in the next report to the International Association of Geodesy. It consists of an intensive gravity survey which will be made of certain parts of Cuba in an effort to learn more about the structural geology of that island. It is being done by the cooperation of the Coast and Geodetic Survey and the Atlantic Refining Co. of Cuba under the auspices of the Committee on Geophysical and Geological Study of Oceanic Basins and Their Margins, American Geophysical Union.

The 75 land stations in the United States determined with the Brown apparatus are nearly all in three rather limited regions which are all of considerable interest to geologists and geodesists. About a fourth of the stations are within 150 miles of Washington, D.C. They help to define more closely the area of positive isostatic anomalies in and near the District of Columbia which was discovered a number of years ago. About half of the new stations are in the northern half of Wyoming, in the Black Hills-Big Horn region. Their locations were selected by W. T. Thom, Jr., of Princeton University, chairman of a committee of geologists who have been making an intensive geological study of this area. The isostatic anomalies have been found to have a striking correlation with the geological formations in this region.

The remainder of the 75 stations are in Alabama, near the southern extremity of the Appalachian Mountain system. Geologists have long been interested in finding an explanation of the sudden termination of these mountains, and some have suggested the possibility of a buried ridge as a prolongation of the system. An attempt was therefore made to find some indication of buried structure in this area, but the results so far obtained are not conclusive. More stations are needed before any satisfactory solution of the problem based on gravimetric data is possible.

[1] See also Transactions of the American Geophysical Union, thirteenth annual meeting, Apr. 28 and 29, 1932, published by the National Research Council, 1932, pp. 54–57.

[2] Special Publication No. 166, pp. 29–32.

Early in 1933, work was started on tables for the Bowie geoid correction. This correction is to take account of the fact that gravity observations are necessarily referred to the geoid while theoretical values, computed by any of the numerous gravity formulas, are based on the spheroid. The correction has been discussed at previous meetings of the International Association of Geodesy, and the desirability of having tables by which it may be computed has been realized by geodesists for several years. It is only by the use of such tables that isostatic anomalies on land can be properly correlated with sea anomalies. Perhaps, too, the much-discussed longitude term will become smaller or disappear after the Bowie corrections have been applied in the isostatic reductions. A more detailed report on this subject can be made at the next meeting of the association.

At the request, early in 1932, of Dr. F. A. Vening Meinesz of the Netherlands Geodetic Commission, mathematicians of the Coast and Geodetic Survey computed the isostatic anomalies at 242 sea stations in the Dutch East Indies which were determined by Dr. Vening Meinesz in 1929 and 1930. This work was done outside of office time and was paid for by Dr. Vening Meinesz and the Netherlands Geodetic Commission. The complete results of the computation were sent to Dr. Vening Meinesz during the latter part of 1932.

In December 1932 work was begun on a new connection of the United States gravity base station with the world base station at Potsdam, Germany. A base station at the United States Bureau of Standards, at which absolute gravity determinations are being made, will also be connected with Potsdam. A report of this work will be made at the next meeting of the association.

IMPROVED GRAVITY APPARATUS

About the middle of March 1932 the improved gravity apparatus of the Coast and Geodetic Survey was taken to the field for a thorough test. It had previously been used at three stations in Washington and vicinity where satisfactory results were obtained with it.

The gravity apparatus of this Bureau which has been used during the past 40 years or more is described in detail in Coast and Geodetic Survey Special Publication No. 69. A number of changes and improvements have been made in this apparatus from time to time, but no attempt had been made to redesign the apparatus until recently, as it has given very satisfactory service. New developments in radio, however, furnished the incentive for attempting rather radical changes in the apparatus and methods. The new design was worked out 2 years or more ago by E. J. Brown, and the construction was carried out in the instrument shops of this Bureau by A. Heim under the direction of D. L. Parkhurst, chief of the instrument division.

The new apparatus makes use of the same pendulums and knife edge as were employed in the old apparatus but in other respects is almost entirely a new design. The receiver is different, the coincidence flash apparatus is replaced by an automatic recorder, and most of the auxiliary apparatus is new.

There were two principal objects in view in changing the form of the apparatus. First, it was desired to have a clamping device inside of the receiver which could be operated from the outside and which would lift the pendulum off its knife edge and hold it in a safe position for transportation without the necessity for letting the air into the receiver and removing the pendulum. The second object was to be able to compare automatically the oscillations of the pendulum and the time signal ticks of the Naval Observatory in order to obtain a more accurate timing of the pendulum than is possible when the comparison is made by means of an auxiliary chronometer.

Since a clamping device could not readily be adapted to the old form of receiver, it was decided to try out an entirely new form in which the receiver hangs from foot screws near the top instead of being supported in the usual way. Much heavier foot screws with large hemispherical bearing surfaces were also used. It was hoped in this way to materially decrease the effect of flexure, or the weaving of the receiver caused by the oscillations of the pendulum, and tests show that this object has been accomplished.

The automatic device for recording the oscillations of the pendulum depends, as might be surmised, upon the photoelectric cell. A beam of light is directed on a mirror attached to the top of the pendulum and after reflection from this and another mirror, which is adjustable, strikes the cell and causes an electric impulse at each oscillation of the pendulum. After being sufficiently amplified this impulse is made to operate a relay and the oscillation of the pendulum is thus recorded on a chronograph. The recording device is arranged to give as nearly as possible a constant lag and to eliminate the effect of change of speed in the passage of the light beam across the photoelectric cell.

An important part of the new apparatus is the new gravity truck. The radio apparatus, chronograph, control switches, etc., are mounted permanently in the truck. On reaching a new station only the gravity apparatus itself, the part of the recorder which fits on top of it, and the gravity tent need to be unloaded. A hole is dug in the ground about a foot deep and the brass box in which the receiver is mounted is set in plaster of paris in this hole. A tent is erected over the apparatus, electric circuits completed between it and the truck, and a short antenna erected. These operations complete the major preparations.

Instead of 1 station a week which was about the average rate with the old apparatus, a progress of from 4 to 6 stations a week is now possible. The progress necessarily depends upon the weather, the distances to be traveled between stations, and the character of the roads.

The United States Naval Observatory is now sending a special radio time signal at 10 a.m. on each day of the week except Sunday, and this greatly facilitates the work. The pendulum is usually swung from the time this signal is received until the 4 p.m. or 7 p.m. signal is received. As a check on the work the pendulum is also compared with the noon signal. The value of gravity may be determined with a 6-hour swing with an accuracy of about 0.001 gal.

FIRST-ORDER TRIANGULATION AND LEVELING OF THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

By Floyd W. Hough, *Geodetic Engineer*

During the years 1931 and 1932 the Metropolitan Water District of Southern California executed an arc of first-order triangulation extending approximately 150 miles from Riverside, Calif., to the Colorado River. This work serves as control for surveys of the Colorado River Aqueduct. It consists of two schemes, the lines of the main scheme varying from 15 to 30 miles in length and those of the smaller scheme, which lies within the main scheme, varying from 3 to 10 miles in length.

The larger arc consists of a series of quadrilaterals and central point figures and extends between San Jacinto-Butte and Chemehuevis-Powell, first-order lines of the Coast and Geodetic Survey triangulation. The lengths are controlled by these two lines and two measured lines, Coxcomb and Parker bases. A Laplace azimuth was observed at station Lard.

The first-order scheme was adjusted in one piece at the Washington office of the Coast and Geodetic Survey. The smaller scheme was adjusted to the larger arc under the direction of the writer, the lengths being controlled by the fixed lengths of the principal scheme and by six measured first-order bases.

The surveys executed by this organization also include several lines of first-order levels run with instrumental equipment and under instructions such that the work when finished was well within the limits of accuracy for leveling of high precision. In all about 430 miles of first-order levels were run and the lines were connected with previously established first-order bench marks of the Coast and Geodetic Survey at six different places. The Coast and Geodetic Survey is including the above leveling in the general level net of the United States and has since connected with the lines run by the Metropolitan Water District at three additional points.

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