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GEODETIC OPERATIONS IN THE UNITED STATES JANUARY 1, 1933, TO DECEMBER 31, 1935

[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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GEODETIC OPERATIONS IN THE UNITED STATES JANUARY 1, 1933, TO DECEMBER 31, 1935

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

GENERAL STATEMENT

The 3 years covered by this report were very notable ones for geodetic surveying and geodetic research in the United States. A comparatively large increase in the appropriation for geodetic surveying had been made each year from 1930 to 1932 and late in 1932 emergency funds were also allotted to the Coast and Geodetic Survey for the geodetic surveying. In 1933 and again in January 1935 large amounts of emergency funds were made available for the geodetic work. The total appropriation of funds, both regular and emergency, for the geodetic work of the Bureau from January 1, 1933, to December 31, 1935, was approximately $4,500,000.

It has been possible to secure these emergency funds for the geodetic surveying because of the widespread interest shown in the results of the triangulation and leveling by engineers, planners and others throughout the country. It is realized that a knowledge of position, distance, direction, and elevation is needed for almost all classes of engineering work. Such data are absolutely essential for making accurate maps and in the establishment and location of national boundaries and the boundaries between subdivisions of the country. It is expected that eventually the monuments of all State boundaries and of many of the county boundaries will be determined by triangulation or traverse that is extended to the boundary monuments from nearby triangulation stations.

With the additional funds it was possible to organize many field parties and also to engage a large personnel in making computations and adjustments. When the field work was at its height 76 leveling instruments and 51 theodolites were kept in daily operation. On January 1, 1933, there were 72,600 miles of lines of levels and 37,000 miles of arcs of triangulation in the United States. There are now in this country 67,000 miles of triangulation and 261,000 miles of leveling. It will be seen that the triangulation was almost doubled during the 3-year period covered by this report and the leveling was increased nearly 4 times.

The field work carried on with emergency funds during the past 2 years together with the office work had to be discontinued upon the exhaustion of those funds in August 1935. In consequence of this a large amount of computing and adjusting of triangulation and leveling remains to be done. It is expected that funds will be made available for this office work.

Practically all of the first- and second-order triangulation and leveling accomplished in this country during the past 3 years was done by engineers and observers of the Coast and Geodetic Survey but there was some work of a detailed character carried on by other agencies such as the United States Geological Survey, the Corps of Engineers, United States Army, the Reclamation Service, the Forest Service, and the Soil Conservation Service. Wherever this detailed work was done and fundamental triangulation stations and leveling bench marks were available the detailed work was started from the fundamental stations.

TRIANGULATION AND LEVELING NETS

The Coast and Geodetic Survey is following a very definite plan which calls for the spacing of arcs of triangulation and lines of levels of the fundamental nets at intervals of approximately 25 miles over the 3,000,000 square miles of our area. The first-order arcs and lines are spaced at approximately 100 miles apart, and in the intermediate areas the leveling and triangulation is of second order. So far as triangulation of second order is concerned it is almost as strong as that of first order. The same kind of monuments are used and the observations are nearly as numerous as at the first-order stations. However, the observer may consider all stations of the second order completed after observations have been made over the lines radiating from the station with 12 positions on the horizontal circle of the theodolite. Then again on the second-order arcs more single triangles are used than on the arcs of the first order. On the second-order arcs the triangulation closures may be as great as 4 seconds without the requirement that stations must be reoccupied for strengthening the angle measurements. As a matter of fact, on the second-order arcs that have already been run the average closing error is approximately 1.1 seconds. For the arcs of first-order triangulation the average closing error is between 0.9 second and 1 second. On the second-order arcs very few base lines and Laplace azimuths are needed as they are fitted into previously adjusted work where the positions of the junction stations and the azimuth and distances between them are held fixed in the adjustment of the second-order arcs.

In addition to the first-order triangulation that has been done along the coast and the first- and second-order triangulation in the interior of the country there has been carried along a part of the coasts of this country detailed triangulation, which is second order in accuracy, to furnish closely spaced stations for use by engineers and observers collecting hydrographic and topographic data for navigational charts.

At present the 25-mile spacing of the leveling net is practically completed to the eastward of the 102d meridian. To the west of that meridian the first-order lines spaced at intervals of about 100 miles have been completed and a considerable amount of work has been done on the 25-mile spacing of the level lines. The first-order work involves lines that are run in both directions. The second-order leveling is done with exactly the same instruments and by the same methods as is the first-order leveling except that the line is run in only one direction unless the line is involved in a loop that fails to close within a prescribed limit. The bench marks are of the same type on the second-order leveling as on the first. It is found that approximately 10 percent of the lines of second order have to be rerun in order to find mistakes that have been made or to strengthen the line because of an accumulation of accidental errors.

It is estimated that 50,000 miles more of second-order leveling will be needed in order to reach the objective of a spacing of 25 miles over the whole country for the fundamental leveling net. There may, however, be a few areas in inaccessible mountains where the spacing of the lines of levels will be slightly more than 25 miles.

It is realized that much more control surveying than the 25-mile spacing of the arcs of triangulation and lines of levels will have to be done in order to meet all practical needs. It is assumed that for topographic mapping the horizontal and vertical control survey stations will have to be spaced at intervals of approximately 5 or 6 miles over the country.

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 is given below.

Arcs of first- and second-order triangulation

[January 1, 1933, to December 31, 1935]

First-order arcs:	Length, miles
Jacksonville to Tallahassee, Fla	170
Tallahassee, Fla., to Columbus, Ga	150
Vicinity of Big Sur, Calif	60
Oblique arc triangulation, Va., to Jacksonville, N. C	230
Goldsboro, N. C., to Little River, S. C	130
Marietta to Lincolnton, N. C	140
Jacksonville to Port Inglis, Fla	140
Loup City, Nebr., to Laramie, Wyo	330
Mount Airy to Murphy, N. C	210
Pasco, Wash., to Orofino, Idaho	165
Colfax to International Boundary, Wash	135
Dunnellon to Tallahassee, Fla	160
Roxboro, N. C., to Weldon, N. C., to Richmond, Va	130
Moyock to Kinston, N. C	180
Washington to Pamlico Sound, N. C	85
Newport to Core Sound, N. C	25
Asheville to Murphy, N. C	80
Delaware River, N. J., Pa., and Del	100
Laramie, Wyo., to Pocatello, Idaho	390
Uniontown to Wellsboro, Pa	185
Newport Beach northeastward, Calif. (reobservations)	45
Bristol, Tenn. and Va., to Argo, Ky., to Charleston, W. Va	130
Klamath Falls to Bend, Oreg	125
Prineville to Burns, Oreg	100
Washington, D. C., to Freeland, Md	95
Washington, Pa., to Greenville, Ohio	255
Murdo, S. Dak., to North Platte, Nebr	185
Ogallala, Nebr., to Sharon Springs, Kans	150
Russell Springs, Kans., to Perryton, Tex	165
Inyokern to San Bernardino, Calif	140
Tonopah to Las Vegas, Nev	240
Vicinity New York City, N. Y. and N. J	30
Chesapeake Bay, Md	40
Hermann, Mo., to Lonoke, Ark	245
Charlotte, N. C., to Augusta, Ga	130
Louisville, Ky., to Nashville, Tenn	175
Nashville, Tenn., to Corinth, Miss	140
Newberry to Georgetown, S. C	145
Dunnellon to Naples, Fla	205
Las Cruces to Belen, N. Mex	180
Las Vegas, Nev., to Niland, Calif	160
Langtry to Hot Wells, Tex	305
Hot Wells to El Paso, Tex	110
Lordsburg, N. Mex., to Grand Junction, Colo	540
St. Augustine to Miami, Fla	320
Crowley to Ruston, La	160
McIntyre, Fla., to Mobile, Ala	235
Niland, Calif., to Calexico, Calif., to Yuma, Ariz	130

First-order arcs—Continued.	Length, miles
Hot Wells, Tex., to Santa Rosa, N. Mex	265
Union City, Ind., to Quincy, Ill	295
Havana to Jacksonville, Ill	45
Hartshorne, Okla., to Lawrence, Kans	270
Topeka, Kans., to Nebraska City, Nebr	110
James River, Va., to Washington, D. C	135
Johannesburg to Bishop, Calif. (Owens Valley)	110
Hanna, Wyo., to Rosebud, Mont	285
Lakefield to Alexandria, Minn	150
Aitkin to Roosevelt, Minn	190
Havana to Belleville, Ill	55
Topeka, Kans., to Blair, Nebr	60
Potomac River, Md. and Va	50
Chesapeake Bay, Md	100
Johannesburg to Bridgeport, Calif. (Owens Valley)	80
Hanna, Wyo., to Opheim, Mont	185
Hermann, Mo., to Wykoff, Minn	360
Alma to Marinette, Wis	220
Hayward, Wis., to Princeton, Minn	115
St. Paul, Minn., to Ladysmith, Wis	125
Wellington to Sweetwater, Tex	160
Sweetwater to Brackettville, Tex	210
Blair, Nebr., to Adrian, Minn	140
Whitewater to Hardin, Mont	260
Austin, Nev., to Caldwell, Idaho	300
Crisfield to Elkton, Md	190
Helena to Missoula, Mont	145
Minot, N. Dak., to Presho, S. Dak	300
Cottonwood, S. Dak., to Scottsbluff, Nebr	150
Picacho, N. Mex., to Slaton, Tex	140
Sarles, N. Dak., to Chamberlain, S. Dak	355
Salina, Utah, to Grand Canyon, Ariz	240
Columbia River, Wash. and Oreg	90
White Sulphur Springs, Mont., to Belfield, N. Dak	330
Hopkinsville, Ky., to Washington, Ind	135
New Freedom to Scranton, Pa. (Susquehanna River)	180
McClenny, Fla., to Columbus, Ga., and Satilla River spur	280
Boulder Dam, Nev., to Grand Canyon, Ariz. (Colorado River)	180
Ada, Okla., to Abilene, Kans	290
Hartford, Ark., to Pittsburg, Kans	170
Abilene, Kans., to Columbus, Nebr	160
Havana, Ill., to White Creek, Wis	225
Columbus, Nebr., to Sioux Falls, S. Dak	155
Hawthorne to Sulphur, Nev	190
King Hill to Kimama, Idaho	70
Martinsburg, W. Va., to Newville, Pa	85
Danville to Brooksville, Ky	85
Franklin to Parks, Nebr	150
Towanda, Pa., to Syracuse, N. Y	85

First-order arcs—Continued.	Length, miles
Fairmount to Reeder, N. Dak	290
McCracken, Kans., to Cordell, Okla	270
Hobart, Okla., to Cisco, Tex	130
Cisco to Hondo, Tex	200
Scottsbluff, Nebr., to Hugo, Colo	200
Sharon Springs, Kans., to Texhoma, Tex	160
Felt, Okla., to Fort Stockton, Tex	390
Hondo to Mission, Tex	210
Sherburn, Minn., to Kansas City, Mo	315
Harrisonville, Mo., to Pittsburg, Kans	85
McAlester, Okla., to Palestine, Tex	210
Palestine to Bay City, Tex	190
Moscow, Tenn., to Slidell, La	335
Gulfport to Corinth, Miss	270
Yuma to Stewart Dam, Ariz	185
Phoenix to Winkelman, Ariz	95
Florence to Tucson, Ariz	90
Tucson to Nogales to Ajo, Ariz	150
Lake City to Lakes Stearns, Fla	240
Sarasota to Stuart, Fla	130
Miami to Key West, Fla	135
Appling, Ga., to Live Oak, Fla	250
Osgood to Canton, Mo	80
Vicinity of Washington, District of Columbia, Maryland, and Virginia	15
Catesby, Okla., to Anthony, Kans	120
Chamberlain, S. Dak., to Broken Bow, Nebr	170
El Centro to San Diego, Calif	60
Broken Bow, Nebr., to Wakeeney, Kans	160
Jacksboro to Texarkana, Tex	240
Boulder Dam, Nev., to Yuma, Ariz. (Colorado River)	220
Riceboro to Atlanta, Ga	220
Alice to Encinal, Tex	100
Lampasas to Leon Powell, Tex	190
Lubbock to Seymour, Tex	135
Newport to Freehold, N. J	90
Woodville, Tex., to Reddell, La	95
Jacksboro, Tenn., to Albany, Ky	65
Franklinville, N. Y., to New Castle, Pa	150
Greentree, Tenn., to Rowland, Ky	125
Navasota to Woodville, Tex	95
Boulder Dam, Nev., and Ariz	13
Austin to Navasota, Tex	100
Watertown, S. Dak., to Cedar Lake, Minn	155
Lancaster, Pa., to Elkton, Md	45
Zion City, Ill., to Sinsinawa, Wis	130
Guttenberg to Waverly, Iowa	65
Rothsay to Frazee, Minn	35
Belfast to Hornell, N. Y	30
Harrisburg to Boalsburg, Pa	70
Watertown to Gettysburg, S. Dak	145
Buena Vista to Antonito, Colo	140
Parks, Nebr., to Longmont, Colo	160
Hackettstown, N. J., to Staten Island, N. Y	95
Featherville to King Hill, Idaho	20
Missoula to Charlo, Mont.; Missoula, Mont., to Headquarters, Idaho; Grave Peak to Lookout Mountain, Idaho	175
Sulphur, Nev., to Andrews, Oreg	100
Tigerville to Douglass, S. C	70
Total first order	25, 138
Second-order arcs:	
Winchester to Lynchburg, Va	215
Smithville, Tenn., to Huntsville, Ala	95
New Orleans to Buras to Houma, La	115
Lebanon, Tenn., to Florence, Ala	130
La Fayette, Ga., to Bristol, Tenn	245
Boone, N. C., to Bluefield, W. Va	95
Clarksville, Tenn., to Corinth, Miss	160
Saulsbury to Silerton, Tenn	25
Lucerne Valley to Needles, Calif	130
Rice to Kingston, Calif	100
Saulsbury, Tenn., to Princeton, Ky	130
Paducah, Ky., to Martin, Tenn	50
Sparta, Tenn., to Gadsden, Ala	130
La Fayette, Ga., to Union City, Tenn	240
Greenville, Fla., to Hartwell, Ga	260
Delaware River, New Jersey and Delaware boundary	10
Superior National Forest, Minn	100
Chancellor, Tex., to Clayton, N. Mex	360
Silver City, Ga., to Hardeeville, S. C	200
Huntington, W. Va., to Pennington Gap, Va	140
Beattyville, Ky., to Roanoke, Va	200
Reidsville to Rentz, Ga	50
Reddell to Napoleonville, La	140
Chappell to Charleston, S. C	150
Lowndesville, S. C., to Gastonia, N. C	110
Americus, Ga., to Monticello, Fla	110
Sahuarita to Paradise, Ariz	105
Osceola to Bucksport, S. C	130
Texhoma to Thurston, Tex	400
Allendale, S. C., to Odum, Ga	90
Jasper to Wheaton, Minn	125
Stepstone to Louisville, Ky	105
Veseli to Troy, Minn	80
Sherburn to Hector, Minn	65
Vicinity of Portland, Oreg	70
Potomac River, D. C. and Virginia boundary	10
Total second order	4, 870
Grand total	30, 008

SKETCHES

Figure 1 shows the location of all the arcs of first- and second-order triangulation in the United States which compose the horizontal control net. The triangulation which has been run in the period covered by this report is shown by a distinctive symbol.

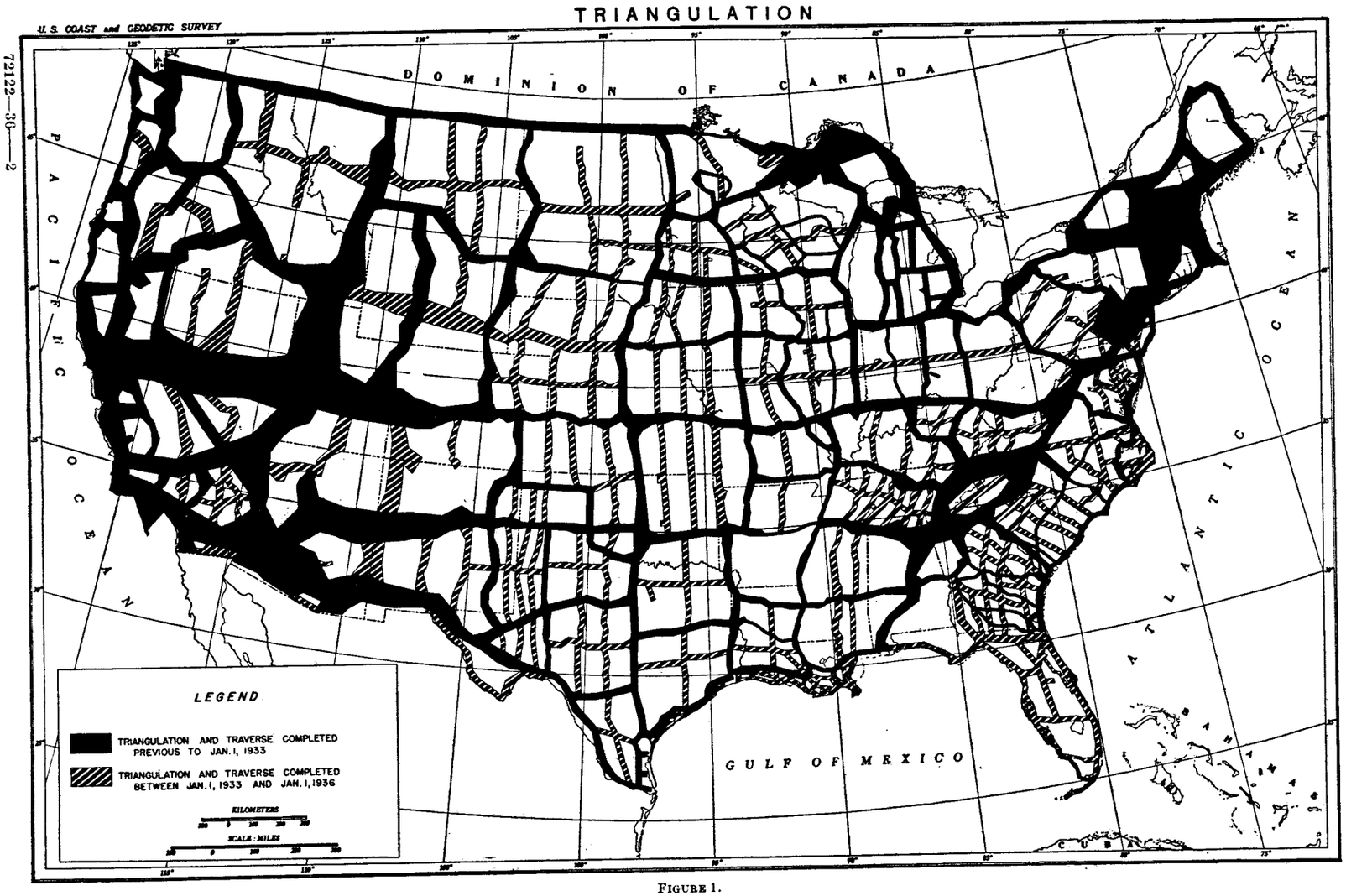

FIGURE 1.

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Figure 2 shows the location of all the first-order leveling in the United States. The leveling run during the period covered by this report is shown by a distinctive symbol.

In addition to the first-order leveling there are 154,000 miles of second-order leveling which could not be shown because of the small size of the sketch.

So many new lines of leveling have been run during the past 3 years that tabular data giving the names and lengths of the new lines will not be given in this report.

TRIANGULATION METHODS

As has been the practice in the past practically all of the observations for the principal stations of the first- and second-order triangulation were made at night. The objects sighted upon were the lights furnished by electric lamps. Very seldom was the heliotrope used as the object to sight upon for the principal angles of the triangles. On cloudy days the observer frequently used electric lamps. The light from one of these lamps could be seen on a cloudy day up to a distance of 12 miles without difficulty when the atmosphere was fairly clear. The observations made during cloudy days on lamps are not subject to the systematic errors that seem to be present in observations made upon heliotropes. It is believed that all of the observations on a long arc of triangulation could be made during cloudy days on the lights from signal lamps without having any swerving of the arc such as is found when heliotropes are used. Of course the work could only be done when the lines are short enough for the lights to be visible during the day.

A change has been made in recent years in regard to the lengths of the triangle sides. In the early days it was desirable to extend arcs through great areas in which there was no triangulation with as few stations as possible in order to get the maximum length of arc at a given cost. This resulted in some very long lines in mountainous regions and in regions that were undulating where stations at considerable distances apart were intervisible. Now, however, the object is to furnish stations rather closely spaced for use in topographic surveying and in many other classes of work. So far as is practicable the triangle sides have a maximum length of approximately 15 miles. If the character of the terrain is such that a longer triangle side than this is essential or desirable, additional stations are placed within the area covered by the triangles in order that more points will be available for local control.

It is probable that in future triangulation there will be many supplemental stations established when an arc of first- or second-order triangulation is executed. As remarked earlier in this report, it is necessary to have horizontal survey stations at intervals of some 5 to 6 miles for use of engineers engaged on topographic surveys. If the triangle sides are more than 6 miles in length then additional stations should be established for the use of the topographers. It is probable that a supplementary station will be placed within each triangle or each quadrilateral of the main arc and that there will also be placed over to the sides of the arc additional stations, say one on each side of the arc for each quadrilateral. These side stations would be placed at distances of from 4 to 7 or 8 miles from the side of the arc, depending upon the character of the terrain. While establishing these supplemental stations would increase somewhat the cost per unit distance along an arc, yet it is believed that the total cost of making the control surveys of the country would be ultimately reduced. It would avoid having to work over the same area a second time in order to furnish the closer spacing of the control stations.

MEASUREMENT OF BASE LINES

During the period covered by this report 47 first-order and 2 second-order bases, totaling 306.4 miles in length or an average of 6.3 miles, have been measured in the United States by engineers of the Coast and Geodetic Survey.

Bases are measured at intervals of 100 to 200 miles along arcs, depending upon the strength of the figures. The allowable limit for the summation of R_1, the minimum sum of the strength factors of the individual figures between bases, for first-order triangulation is 80 and for

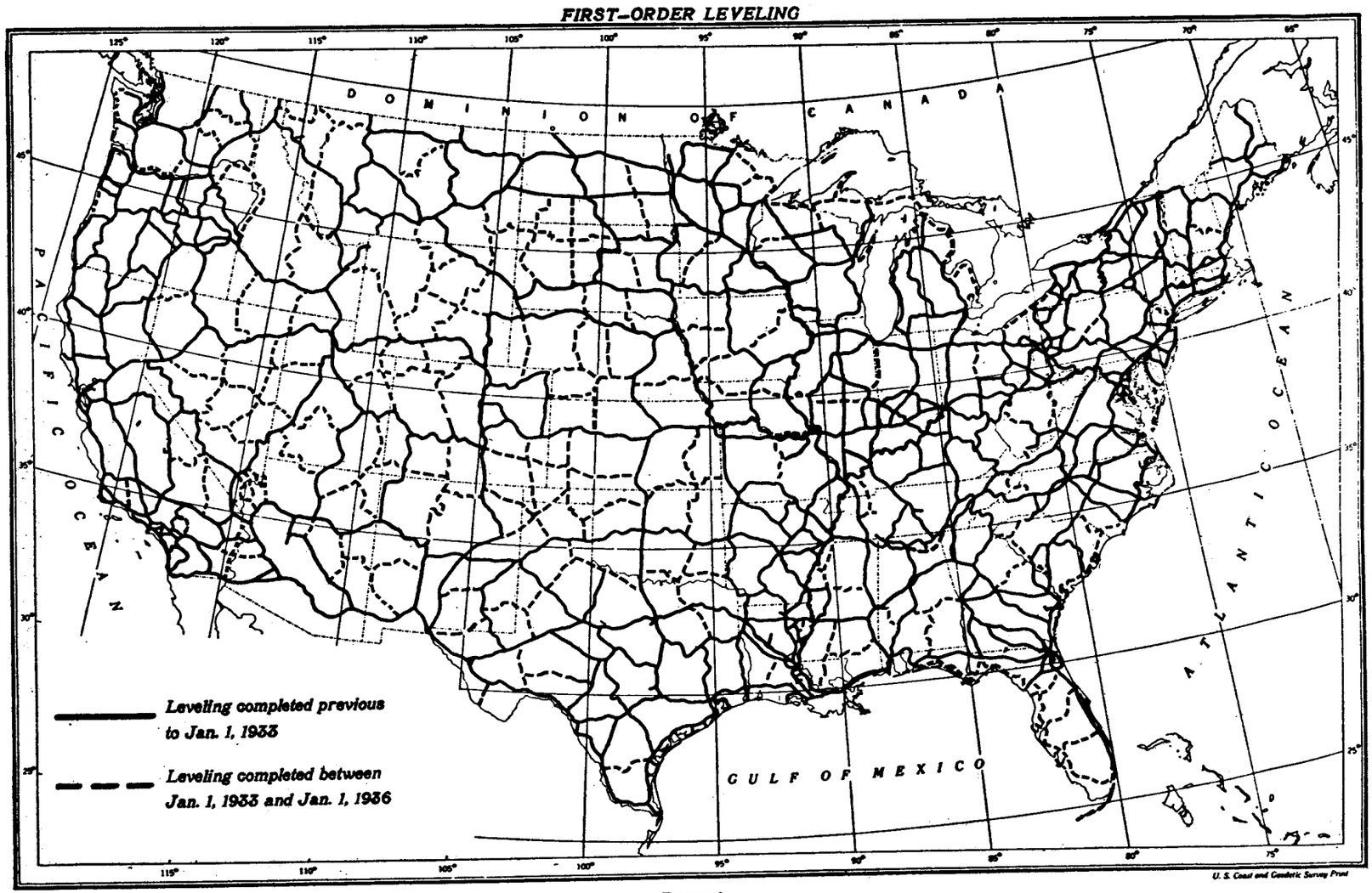
FIRST-ORDER LEVELING
DOMINION OF CANADA
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
Leveling completed previous to Jan. 1, 1933
Leveling completed between Jan. 1, 1933 and Jan. 1, 1936
U. S. Coast and Geodetic Survey Print

FIGURE 2.

second-order 100. Where a base site cannot readily be found these limits may be exceeded by 25 percent.

Most of the bases have been measured along railroad tracks using the rail to support the tape. The supports are at the ends of the tape and at the 12½- and 37½-meter points. The intermediate supports, which are frictionless rollers, are 6 inches in height and allow the tape to swing freely approximately 1 inch above the rail at the center of the tape. Invar tapes 50 meters in length are used. They are restandardized at frequent intervals by the division of weights and measures of the National Bureau of Standards.

A few of the bases are direct measurements between triangulation stations in a main arc and thus form one of the triangle sides. The usual base, however, is within or to the side of the main arc and connected with it by an expansion figure.

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

Base lines measured in the United States

[January 1, 1933, to December 31, 1935]

Location	Name of base	Length in miles	Probable error (1 part in—)
Arkansas	Lonoke	9.3	3,100,000
California	Taft (2d-order)	0.7	930,000
	Oceanside (2d-order)	2.8	2,100,000
Colorado	Romeo	6.3	4,000,000
Florida	Dunnellon	5.8	4,200,000
	Titusville	6.7	6,500,000
	Delray	6.4	7,100,000
	Tamiami	9.1	3,400,000
	Estero	6.9	5,600,000
	St. Petersburg	8.2	3,300,000
	Okeechobee	7.6	2,500,000
	Salem	7.2	3,000,000
	McIntyre	6.0	3,500,000
	Point Washington	10.4	4,100,000
	Perky	4.5	3,200,000
	Duval	5.5	9,600,000
	Live Oak	4.9	2,800,000
Georgia	Ogeechee	5.1	3,600,000
	Colquitt	10.9	5,800,000
Illinois	Chandlerville	6.0	3,900,000
Kentucky	Smiths Grove	5.6	3,600,000
Louisiana	Alexandria	5.3	5,300,000
Minnesota	Shooks	5.2	2,500,000
Missouri	Edina	5.5	970,000
	Asbury	4.9	3,700,000
Montana	Angela	5.4	2,900,000
	Missoula	5.3	2,600,000
Nebraska	Lewellen	6.8	4,300,000
Nevada	Battle Mountain	7.1	3,000,000
	Elko	4.3	3,300,000
	Reed	5.5	2,400,000
New Mexico	Arabella	6.0	2,250,000
North Carolina	South River	10.0	5,000,000
	Dillon	7.9	4,400,000
North Dakota	Pingree	8.9	4,800,000
	Huff	5.5	2,500,000
Ohio	Union City	8.4	3,700,000
Oklahoma	Lenapah	5.8	3,700,000
	Arard	4.2	2,700,000
	Newkirk	7.5	5,300,000
Pennsylvania	Berwick	6.8	4,200,000
South Carolina	Charleston	5.9	3,700,000
	Augusta	5.5	4,700,000
	Columbia	4.2	1,600,000
South Dakota	Aberdeen	7.5	5,500,000
Texas	Presidio	4.2	2,200,000
	Petty	5.6	3,300,000
Wisconsin	Antigo	6.5	3,600,000
	Hayward	4.8	3,500,000

THEODOLITE TESTS

During the 3 years the greatest improvement that has been made in the theodolites resulted from the regraduation of the circles of the old theodolites and the graduation of the circles for new theodolites by the National Bureau of Standards. It was found that many of the circles of the old theodolites had systematic and accidental errors that would be reduced by regraduations. Different types of metal have been used for these circles. Some of them are made entirely of silver and others of Duralumin. The graduation points on the circles have a very high degree of accuracy, thus resulting in improvements in the field observations.

In the basement of the Department of Commerce Building at Washington a room has been used for testing circles under conditions that are close to those found in field work. A pier separated from the floor of the building has been installed for supporting the theodolite. Four collimators have been established on the walls of the building, and observations are made on them with 16 positions of the circle of the theodolite. By noting the values for the directions to the collimators for these 16 positions one is able to arrive at a very accurate estimate as to the

excellence of the circle graduations. For many of the circles no repetition of the observations had to be made because of large residuals for individual determinations of the direction to a collimator. Thus we may assume that for the circles involved there were not any accidental or systematic errors of troublesome dimensions.

PLANE-COORDINATE SYSTEMS

The leveling data secured by the engineers and observers of the Coast and Geodetic Survey have been extensively used for many years but there has not been a corresponding large use of triangulation data. This apparently is due to the difficulty that is encountered by the engineer engaged on a local project in making the computations of the spherical coordinates. This difficulty, however, has been overcome by the devising and adoption of plane-coordinate systems for each one of the States of the Union. It has been found that a single-plane system can be used for a portion of the earth's surface that is not greater in width than 158 miles in the north-south or east-west direction without introducing a scale factor greater than one part in 10,000. A special article on Projections and Plane-Coordinate Systems by Dr. O. S. Adams, who devised and supervised the computing of the plane-coordinate systems for each of the States, appears in this report on page 17.

LOCAL CONTROL SURVEYS

Late in 1933 emergency funds were made available to relieve unemployment among engineers and others by employing them upon supplemental control surveys. It was realized that this work would have to be done in a large measure by many persons who had not had previous training in geodetic surveying. However, the project was initiated with a representative of the Coast and Geodetic Survey in each one of the 48 States.

More than 40,000 miles of traverse with an accuracy at least as great as 1 part in 10,000 and an equal number of miles of levels of second order have been accomplished with these emergency funds designed primarily to relieve unemployment. This adds a large amount of valuable control survey data to the fundamental horizontal and vertical nets. It is expected that this work will be continued by at least some of the States for an indefinite time. The object should be to have a sufficient amount of the supplemental control surveys to furnish the basis for all topographic mapping and also to furnish data which may be used in engineering construction, the location of highways, and also in property or cadastral surveying. A special article on Local Control Surveys by Lieut. H. W. Hemple appears in this report on page 18.

TOPOGRAPHIC MAPPING

There is a widespread sentiment throughout this country in favor of completing the topographic mapping. While 47 percent of the area of the United States is covered by sheets of the topographic map, yet not more than half of these map sheets are adequate for modern uses. Some of the old ones had to be done in a very sketchy way because of the lack of funds and besides the requirements of the map users 30 or more years ago were not as exacting as they are today. In consequence of this situation, it is safe to say that not more than 25 percent of the area of this country is adequately mapped and it is quite certain that most of the existing good maps must be revised in order to show all the cultural features as they now exist.

Topographic maps are needed for many purposes. Not only in engineering operations where structures must be located according to the character of the terrain but in such work as soil conservation, reforestation, flood prevention of rivers, and the search for minerals, including coal, oil, gas, and underground waters, the topographic map is invaluable. This sentiment has been expressed in a report prepared by the Federal Board of Surveys and Maps which outlines a plan which if followed would result in the completion of the topographic mapping of the country within 10 years. This plan has received the endorsement of the National Resources Committee and has the endorsement of engineering and scientific societies. It is probable that this plan will be initiated in the near future. A copy of this plan can be secured upon application to the

chairman of the National Resources Committee, Washington, D. C. This plan was reprinted from the original report, in the February 1935 number of Civil Engineering, a journal of the American Society of Civil Engineers.

SPECIAL GEODETIC WORK IN CALIFORNIA

The Coast and Geodetic Survey has continued during the past 3 years its cooperation with the Advisory Committee in Seismology of the Carnegie Institution of Washington of which Dr. Arthur L. Day is the chairman. This work consisted in the establishment of arcs of triangulation and lines of levels in regions that are considered by that committee to be subject to seismic disturbances in the future. A rerunning of some of the old lines of levels and reobservations at some of the previously established triangulation stations were made in order to detect earth movements should they have occurred between the earlier and later work. A very close spacing of bench marks was made along eight short lines of leveling in southern California that run across fault zones. These lines vary in length from 6.8 to 15.6 miles with a total length of 80.3 miles. Very close to the most recent faults the bench marks are spaced at intervals of 100 feet. This spacing is increased as the lines extend away from the fault. On this 80 miles of special leveling 1,300 bench marks were established. The chairman of the Advisory Committee in Seismology has requested the determination of the geographic positions of these bench marks. It is hoped that this work may be undertaken during the coming year.

It has been found by releveling that an area surrounding San Jose, Calif. (latitude 37°20′, longitude 121°54′) has been sinking. Since 1912 the maximum change in the elevation has been 5.0 feet (1.52 meters). There is a divided opinion as to whether this change in elevation is due to tectonic causes or to a sinking of the area resulting from the excessive pumping of ground waters. Already some of the lines of levels in the San Jose area have been run five times and at the time of writing this report a party was in the field making a fourth rerunning of the complete San Jose net. The results of releveling are of importance to engineers who use the leveling data in the San Jose area. The data secured will of course be of much geological and geophysical importance.

TRIANGULATION ADJUSTMENTS

Since the completion of the adjustment of the triangulation net of the United States all the new arcs of triangulation have been fitted to the previously adjusted work. With a few exceptions the 1927 triangulation net and the subsequently adjusted arcs have been so well fixed in geographic position that this method has proved very satisfactory. The corrections to the new work resulting from fitting it in have not been larger on an average than the corrections that this class of work receives when adjusted as a network in which there are more arcs through which the closures can be distributed.

The details of the triangulation computations and adjustments made in the office of the Coast and Geodetic Survey are covered in an article on page 15 of this report written by Walter F. Reynolds, chief of the section of triangulation.

FACTORS FOR COMPUTING GEODETIC POSITIONS ON THE INTERNATIONAL ELLIPSOID

Computations of the factors for computing positions on the international ellipsoid which were begun more than 3 years ago were finished in the office of the Bureau prior to the writing of this report. Special Publication No. 200 giving those factors has appeared and may be secured upon application to the Superintendent of Documents, Washington, D. C.

GEODETIC PUBLICATIONS ISSUED SINCE JANUARY 1, 1933

MISSISSIPPI RIVER COMMISSION

Triangulation along the Mississippi River, Cairo, Ill., to Headwaters by the United States Coast and Geodetic Survey and the Corps of Engineers, U. S. Army. 601 pages, 15 illustrations, octavo. 1934.

Triangulation along the Mississippi River, Cairo to Barfield to Memphis by the United States Coast and Geodetic Survey and the Corps of Engineers, U. S. Army. 221 pages, 9 illustrations, octavo. 1935.

UNITED STATES COAST AND GEODETIC SURVEY

Geodetic Operations in the United States, January 1, 1930, to December 31, 1932. William Bowie. Special Publication No. 178. 28 pages, 3 illustrations, quarto. 1933.

First-order triangulation in Kansas (1927 datum). O. P. Sutherland. Special Publication No. 179. 73 pages, 8 illustrations, octavo. 1934.

Plane coordinate systems. Oscar S. Adams. Serial 562. 6 pages, octavo. 1933.

Leveling in Massachusetts, Rhode Island and Connecticut. Charles J. Clifford. Special Publication No. 181. 67 pages, 4 illustrations, octavo. 1934.

Leveling in New Hampshire and Vermont. Charles J. Clifford. Special Publication No. 182. 27 pages, 4 illustrations, octavo. 1934.

First-order triangulation and traverse in Louisiana (1927 datum). O. P. Sutherland. Special Publication No. 183. 173 pages, 15 illustrations, octavo. 1934.

Leveling in Maine. Charles J. Clifford. Special Publication No. 184. 69 pages, 4 illustrations, octavo. 1934.

Leveling in Florida. Howard S. Rappleye. Special Publication No. 185. 106 pages, 4 illustrations, octavo. 1934.

Triangulation in Missouri (1927 datum). Walter F. Reynolds. Special Publication No. 186. 182 pages, 17 illustrations, octavo. 1934.

First-order triangulation and traverse in Arkansas (1927 datum). Walter D. Sutcliffe. Special Publication No. 187. 101 pages, 9 illustrations, octavo. 1934.

Leveling in Arkansas. Howard S. Rappleye. Special Publication No. 188. 162 pages, 4 illustrations, octavo. 1934.

First-order triangulation in Texas (1927 datum). Hugh C. Mitchell. Special Publication No. 189. 435 pages, 48 illustrations, octavo. 1935.

First-order triangulation in Oklahoma (1927 datum). Leslie E. Shmidl. Special Publication No. 190. 149 pages, 18 illustrations, octavo. 1935.

First- and second-order triangulation and traverse in North Carolina (1927 datum). Oscar S. Adams. Special Publication No. 192. 414 pages, 21 illustrations, octavo. 1935.

Manual of plane-coordinate computations. Oscar S. Adams and Charles N. Claire. Special Publication No. 193. 275 pages, 65 illustrations, octavo. 1935.

Manual of traverse computation on the Lambert grid. Oscar S. Adams and Charles N. Claire. Special Publication No. 194. 240 pages, 48 illustrations, octavo. 1935.

Manual of traverse computation on the transverse Mercator grid. Oscar S. Adams and Charles N. Claire. Special Publication No. 195. 201 pages, 31 illustrations, octavo. 1935.

First- and second-order triangulation in Tennessee (1927 datum). H. P. Kaufman. Special Publication No. 198. 344 pages, 22 illustrations, octavo. 1935.

Formulas and tables for the computation of geodetic positions on the international ellipsoid. Walter D. Lambert and Clarence H. Swick. Special Publication No. 200. 122 pages, 4 illustrations, octavo. 1935.

Control surveys and their uses. J. H. Brittain. Serial 583. 13 pages, octavo. 1935.

GRAVITY DETERMINATIONS

Gravity observations have been made in the United States proper and also on the island of Cuba during the 3-year period. Certain improvements have been made in the pendulum apparatus and in addition, the Coast and Geodetic Survey has purchased an apparatus of the Holweck-Lejay type, which at the time of preparing this report, was being standardized and tested in the Office of the Coast and Geodetic Survey in Washington. In 1933 a determination of the difference in the value of gravity at Potsdam, Germany, and Washington, D. C., was made by the late E. J. Brown, an engineer of the Coast and Geodetic Survey. The results of this determination appear in Coast and Geodetic Survey Special Publication No. 204—A Determination of the Relative Values of Gravity at Potsdam and Washington.

COMPUTATIONS OF TABLES FOR REDUCING GRAVITY OBSERVATIONS TO THE SPHEROID

The computations begun late in 1932 of the tables for use in reducing gravity observations to the spheroid were completed during the past 3 years. The results have appeared in a publication of the Coast and Geodetic Survey entitled Tables for Determining the Form of the Geoid and its Indirect Effect on Gravity, Special Publication No. 199.

TIDAL STATIONS AND OBSERVATIONS

The Coast and Geodetic Survey has now in continuous operation 33 primary tide stations for the purpose of furnishing basic datums and for the control of hydrographic surveys. These primary tide stations furnish the initial points for the leveling net of the country and furnish also the data which will permit the determination of the relative changes that are taking place in the relation of land to sea. A special article on Variations in Yearly Sea Level by Paul Schureman appears in this report on page 23.

ISOSTASY

Isostasy seems to have received more attention during the past 3 years than previously. Many geophysical, geodetic, and geological books and articles appearing in technical and scientific journals have included discussions of isostasy. While in general the comments are favorable there are still some writers who feel that isostasy is not a factor that must be considered in geological and geophysical investigations. However, most of the writers have the opposite view.

There is a great deal of interest now in geophysics and in geodesy on the part of investigators dealing with the scientific discovery of petroleum, natural gas, salt domes, etc. Many of these people are realizing the importance of the principle of isostasy in their work. The chief geophysicist of one of the large petroleum companies in this country informed the writer of this report that he would recommend to his higher officials that the isostatic reductions be made of the gravity stations being established by his company in order to correlate the gravity data secured for widely separated areas. He realized, he informs me, that for a very local area the Bouguer reductions of the gravity stations are all that are ordinarily required. This is because the effect of the compensation of the local topography will be almost the same for each of the stations that may lie in a restricted area.

One of the important contributions to the literature on isostasy is the chapter on this subject in the book entitled The Deformation of the Earth's Crust by Walter H. Bucher, Princeton University Press, Princeton, N. J., 1933.

FEDERAL BOARD OF SURVEYS AND MAPS

As mentioned earlier in this report, the Board of Surveys and Maps outlined a plan for completing the topographic mapping of the country within 10 years. As a part of that plan geodetic surveys in the form of triangulation, traverse, and leveling, were called for, with a spacing of the stations sufficiently close to serve as a basis for the topographic mapping. The Board, composed of representatives from each of the 23 map-making and map-using agencies of the Government, met each month except during June, July, and August during the past 3 years. At these meetings there were general discussions of surveying and mapping problems and reports were made on work accomplished by the member organizations. The Board does not issue any published report or journal but from time to time it presents special articles and minutes of its proceedings in multigraphed form which are furnished to the members of the Board and to certain individuals and organizations outside the Board. One of the principal functions of the Board is to provide for friendly cooperation among the organizations of the Government dealing with surveying and mapping, either as makers or users, and to secure information as to the needs of the engineers and others outside the Government in surveying and mapping activities. It is believed that the Board has done very good work and has avoided, through its friendly advice and actions, duplications that otherwise would surely have existed.

The Board maintains a map-information office in the Interior Department, Washington, D. C., in charge of J. H. Wheat. This office keeps in close touch with organizations making and publishing maps and maintains quite a large file of maps for consultation purposes. Inquiries addressed to the map information office, in case they cannot be answered directly, are forwarded to the proper agency for attention.

SECTION OF GEODESY, AMERICAN GEOPHYSICAL UNION

The American Geophysical Union was organized as a committee of the National Research Council, with headquarters at Washington, D. C. It has sections corresponding to those of the International Geodetic and Geophysical Union.

Meetings of the Union are held annually late in April or early in May. Meetings of the several sections are held at the same time, at which papers are presented and reports are made on the work accomplished during the year. The proceedings of the Union and the sections appear as bulletins of the National Research Council.

On December 31, 1935, the officers of the Union were: Chairman, N. H. Heck; vice chairman, R. M. Field; general secretary, J. A. Fleming. The officials of the section of geodesy were: Chairman, C. L. Garner; vice chairman, P. H. Underwood; secretary, C. H. Swick.

SURVEYING AND MAPPING DIVISION, AMERICAN SOCIETY OF CIVIL ENGINEERS

The surveying and mapping division, American Society of Civil Engineers, was organized in 1926. This division 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.

SPECIAL ARTICLES

GEODETIC OPERATIONS, CORPS OF ENGINEERS, UNITED STATES ARMY

By F. S. Besson, *Lt. Col., Corps of Engineers, Chief, Intelligence Section*

Relative to a report on geodetic operations in the United States for the 3-year period ending December 31, 1935, 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

A summary of the geodetic work accomplished by the Lake Survey in the 3-year period ending December 31, 1935, follows:

a. In 1934, a line of first-order levels was run from Point Iroquois on Lake Superior to Detour on Lake Michigan, establishing bench marks for use in connection with improvement work on the St. Marys River.

b. In 1935, permanent bench marks were established in every harbor of the United States on the Great Lakes by water-level transfer.

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

Marquette, Mich.	Port Huron, Mich. (two stations)	Cape Vincent, N. Y.
Point Iroquois, Mich.	Roberts Landing, Mich.	Ogdensburg, N. Y.
Mackinaw, Mich.	Detroit, Mich.	Amherstburg, Ontario (three stations)
Milwaukee, Wis.	Cleveland, Ohio	Wyandotte, Mich.
Calumet Harbor, Ill.	Buffalo, N. Y. (two stations)	Monroe, Mich.
Harbor Beach, Mich.	Niagara Falls, N. Y.	
	Oswego, N. Y.	

d. A comprehensive study of movements of the earth's crust in the Great Lakes region is being made, based on the records of these gages.

MISSISSIPPI RIVER COMMISSION

A summary of the geodetic work accomplished by the Mississippi River Commission in the 3-year period ending December 31, 1935, is furnished by districts as follows:

Memphis district

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

Operations, 1933–35

Location	Triangulation	Traverse	Levels
	Miles	*Miles*	*Miles*
General river surveys	85	785	725
Nine reservoir surveys in Arkansas, Missouri, and Oklahoma		820	680
Wolf River Harbor extension survey		50	65
Bridge levels on tributary streams in west Tennessee			65
Total	85	1,655	1,535

In addition to the items listed above, approximately 800 miles of levels were run along the Mississippi River to connect with existing bench marks and to establish new bench marks in localities where they had been destroyed; and approximately 1,500 miles of levels were run within the alluvial valley to complete the adjustment of the level lines within this area.

Vicksburg district

Geodetic work performed by the Vicksburg engineer district during the 3-year period consisted of basic control (precise levels, third-order levels, third-order traverse) in Mississippi, Louisiana, and Arkansas; a levee stationing survey of the Mississippi and Arkansas River levees; a levee profile of the Mississippi and Arkansas River levees; Yazoo Basin reservoir surveys; a slope profile of the Mississippi River; a survey of the alluvial valley of the Mississippi River to furnish data for quadrangle maps; a levee location survey on the Ouachita River from Monroe to Sandy Bayou; a survey of Mississippi River cut-offs; 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, third-order levels, and precise levels, are shown in the following tabulation:

Operations, 1933–35

	Permanent marks established	Third-order transit traverse	Third-order levels	Precise levels
	Number	*Miles*	*Miles*	*Miles*
Basic control in Mississippi, Louisiana, and Arkansas	134	150		1,423
Mississippi and Arkansas River levee-stationing survey	199	307	307	
Mississippi and Arkansas River levee profile			307	
Yazoo Basin reservoir survey	30	101	13	
Mississippi River slope profile	9		502	
Alluvial-valley quadrangle survey	19	123	104	
Ouachita River levee location		78	48	
Mississippi River cut-off surveys		130	47	
Mississippi River bank-protection survey		48	48	
Total	391	937	1,376	1,423

Second New Orleans district

The summary of geodetic work accomplished by this district during the 3-year period ending December 31, 1935, is as follows:

a. First-order levels: First-order levels were run from Vicksburg, Miss., to Torras, La., and from Krotz Springs, La., to Plaquemine, La., via Atchafalaya and Upper Grand Rivers, a total distance of about 215 miles.

b. Alluvial-valley quadrangle control: Third-order transit traverse of about 165 miles and 825 permanent markers set.

c. Levee and hydrographic control: Third-order transit traverse of about 210 miles and permanent markers set at all levee angles.

d. Atchafalaya River Channel improvements: Third-order hydrographic control traverse of about 85 miles. Permanent marks are to be set. This work is not yet complete.

e. Grand Lake hydrographic survey (Atchafalaya Basin): About 200 square miles of third-order triangulation. Permanent marks were set at all tower stations.

f. Lake Pontchartrain hydrographic survey: About 550 square miles of third-order triangulation. About 15,000 soundings were taken. Permanent marks were set at all tower stations.

g. Automatic tide gages: Two automatic gages were established in Grand Lake (Atchafalaya Basin) in July 1933. One automatic gage was established at Morgan City, La., in July 1933. These gages, as well as the automatic tide gage at Biloxi, Miss., have been maintained to date.

GEODETIC OPERATIONS OF THE UNITED STATES GEOLOGICAL SURVEY

By W. C. Mendenhall, *Director, United States Geological Survey*

Geodetic surveys, including spirit leveling, transit traverse, and triangulation, are made by the United States Department of the Interior, Geological Survey, with the primary object of establishing control for its topographic mapping. The greater part of the geodetic work done by this Survey is of third-order accuracy, as defined by the Board of Surveys and Maps of the Federal Government. First- and second-order levels are run only when it is necessary to extend the work a considerable distance away from lines of the basic first-order net. In this work the Geological Survey establishes permanent marks which are available to define standard datum in any local engineering surveys for which third-order control is sufficiently accurate.

During the calendar years 1933, 1934, and 1935, control surveys were conducted in all of the 48 States, and in Alaska and Puerto Rico. In these 3 years 1,573 triangulation stations were occupied and marked, and 34,174 miles of transit traverse and 33,229 miles of leveling were run.

The totals just given include work done for special projects in the Tennessee River Basin, and in South Carolina, and Puerto Rico. The object of the first of these projects, the work for which is still in progress in cooperation with the Tennessee Valley Authority, is to furnish topographic maps of the basin. To meet the urgent needs of the Authority, planimetric maps are being prepared first, and these will later form the base for final standard topographic maps showing the relief by contours. The horizontal control, now completed, that was done for this mapping project alone involved the establishment of 854 occupied triangulation stations supplemented by 424 intersected stations, and approximately 13,000 miles of transit traverse. The area so controlled covers about 45,000 square miles. About 110 of the 60-square mile map units were completed by January 1, 1936, and many more were in various stages of preparation.

In South Carolina the United States Geological Survey conducted control surveys in all unmapped parts of the State, thus paving the way for mapping when that can be done. For this project 9,548 miles of transit traverse and 7,948 miles of third-order leveling were run.

The practice in executing control surveys, particularly those that are made for the direct control of topographic mapping, has been influenced greatly by the requirement that control points must be established that can be identified in the airplane photographs which are made for use in photogrammetric methods of mapping. A large part of the 71,430 square miles of topographic mapping done by the United States Geological Survey in 1933, 1934, and 1935 was facilitated by the use of such pictures.

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, 1933, to December 31, 1935, more progress was made in the adjustment of the triangulation of the United States than in any other 3-year period in the history of the United States Coast and Geodetic Survey.

At the beginning of the year 1933 the adjustment on the North American datum of 1927 of the framework of all the first-order triangulation of the United States had been completed. During that year the adjustment of the Atlantic coast arc, which consists of first-order triangu-

lation extending from Providence, R. I., to Jacksonville, Fla., and connected by a number of cross arcs to the Eastern Oblique Arc, was completed. Rapid progress has been made also in adjusting those arcs of first- and second-order triangulation which have been executed to divide the areas between the arcs of the framework.

Owing to the expanded program of field work caused by allotments of funds to the Coast and Geodetic Survey from the Public Works Administration and the Civil Works Administration the personnel engaged on the computation and adjustment of triangulation was increased from the normal force of 25 to 98 mathematicians and computers in the Washington office. In addition during practically all this period there was in operation a suboffice in New York, N. Y., in which there were 50 computers engaged on triangulation computations and adjustments.

The number of arcs of first- and second-order triangulation for which computations and adjustments have been made during this period is so large that it is not possible in this paper to list them by name. It is sufficient to state that there were adjusted 63 arcs, varying in length from 15 to 645 miles and located in 26 States.

The following lines of first-order traverse were adjusted: Sanford, N. C., to the Virginia boundary; Sanford to Wilmington, N. C.; Sanford to Osborne, N. C.; Little Rock, Ark., to Memphis, Tenn.; and Mansfield to New Roads, La.

Considerable progress has been made in the adjustment of the second- and third-order triangulation executed under the direction of the Mississippi River Commission along the Mississippi River. At the close of the year 1932 the triangulation extending from Cairo, Ill., to the Headwaters in Minnesota had been completely adjusted. During the period covered by this report the adjustment of the triangulation has been made in the following sections: Cairo, Ill., to Memphis, Tenn.; Memphis, Tenn., to Vicksburg, Miss.; and New Orleans to the Mississippi Delta. It is hoped that the adjustment of the triangulation in the remaining section, Vicksburg, Miss., to New Orleans, La., will be completed within another year. When this is finished, final results in the form of geographic positions, plane coordinates, and descriptions of triangulation stations will be available along the Mississippi River from the Delta in Louisiana to the Headwaters in Minnesota.

The results of these computations and adjustments are being printed at the engineer reproduction plant of the Corps of Engineers, United States Army, Washington, D. C., and will appear in five volumes. The first volume containing the results from Cairo, Ill., to Headwaters, Minn., appeared in 1934. The second volume which contains the results from Cairo, Ill., to Memphis, Tenn., appeared in 1935. It is expected that two more volumes will be issued within the next year, the manuscript for them having already been prepared.

Since December 31, 1932, 44 first- and second-order bases which are used for the control of the lengths in the triangulation net of the United States have received final office computation.

The computation and adjustment of the second- and third-order triangulation along the Atlantic, Pacific, and Gulf coasts of the United States which have been executed primarily for the control of hydrographic and topographic surveys used in making nautical charts have been greatly advanced during the years 1933–35. There have been 104 arcs of first-, second-, and third-order coastal triangulation adjusted.

Practically all triangulation in Southeast Alaska of which the field work has been done since 1907 has been completely adjusted on the North American datum of 1927. Since very little new field work is being executed in this section it is possible to keep the adjustments up to date.

One of the most important developments during this period was the establishment of plane-coordinate systems for every State in the United States. The private engineer or surveyor usually has difficulty in understanding and computing geodetic coordinates. In order that the results of the triangulation might be of more value to the city, county, State, or private engineer, it was decided to establish plane-coordinate systems for each State, so that the computations might be made in the various States and their subdivisions by means of plane instead of geodetic

coordinates. A discussion of the plane-coordinate systems for the States is given below by Dr. O. S. Adams.

The Coast and Geodetic Survey has adopted the plan of computing the plane coordinates as well as the geodetic coordinates of its triangulation stations. It is also planned to include both sets of coordinates in the publication of the final results of the adjustment of the triangulation. The first volume to include such data was the publication issued in 1935 containing the final results of the first- and second-order triangulation in the State of Tennessee. Similar publications for the States of California and Minnesota will appear in 1936.

The demand from private corporations and engineers for the adjusted geographic positions of triangulation stations became so great that it was necessary to devise some system whereby copies of them could be readily distributed to the public previous to the publication of the results. The plan of making photolithographic prints of the geographic positions was adopted in 1933. As soon as an arc of triangulation has been adjusted, prints of the geographic positions are made. Copies of these prints are sent out in answer to requests for information until the final results are available in printed form.

With the rapidly growing demand for commercial airplanes there has been increased need for speed-trial courses. This has resulted in a number of requests from the National Aeronautic Association and its branches for the lengths of the courses over which the planes fly. In the determination of most of these courses it was necessary to make inverse computations between the geographic positions of established points.

PROJECTIONS AND PLANE-COORDINATE SYSTEMS

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

For some time engineers and surveyors who are interested in local projects have felt the need of some general systems of plane coordinates that would make possible the computation of surveys on the plane and at the same time allow the projects to be extended for considerable distances without the need of establishing independent systems. Due to the depression, public works activities in all of the States became unusually active in 1933 and 1934 and hence the demand for plane coordinates became more insistent. Accordingly the United States Coast and Geodetic Survey undertook to establish such coordinate systems in the various States in the latter part of 1933 and the work was completed in the first 3 months of 1934.

Since most local surveys are limited to the individual States, it was decided to set up the systems by States. If the State was too large for a single system, it was divided into two or more zones and a separate computation was made for each zone. For surveys of this nature the accuracy required is in general a closure of 1 part in 10,000 or, for less accurate work, of 1 part in 5,000. It was decided to limit the departure from true scale to the higher limit of 1 part in 10,000. With this limit it was found that a zone of approximately 254 km in width could be included in one system.

Since for all purposes, the conformal projections are better suited to serve as bases for such plane-coordinate systems, it was decided to make use of the Lambert conformal conic projection with two standard parallels for zones with greatest extent in an east-and-west direction and to use a modified form of the transverse Mercator projection for zones of greatest extent in a north-and-south direction. Because of the fact that counties are political divisions in the States, it seemed best to have every county in a single division. The division line between the zones was therefore established along county boundaries and the result is that this division is in general a broken line. In a few cases the arrangement of counties caused the adoption of one of the methods even when a better result could have been obtained by the other method if the division could have been made to consist of a straight line. In some few cases the limit of 1 part in 10,000 departure from true scale was exceeded in certain outlying regions.

In the tables that were computed the departure from true scale is tabulated for every minute of latitude in the Lambert system and for every 5,000 feet distance from the central meridian in the transverse Mercator system. By making use of this scale factor the departure

from true scale can be taken into account and accurate computation can be made even when the scale factor is greater than 1 part in 10,000.

The tables that were computed give just enough data to make it possible to compute the coordinates of a station when the latitude and longitude of it are given. The United States Coast and Geodetic Survey plans to compute the coordinates of all stations of its control surveys on the grids of the respective States. This will make the control surveys immediately available for local engineers and surveyors and it is found that this is a great advantage in local work.

These plane-coordinate systems have been established in each of the 48 States and in addition there are two separate systems, one for Long Island, N. Y., and another for the islands of Nantucket and Martha's Vineyard in Massachusetts.

In the recent work executed by the United States Coast and Geodetic Survey it is the practice to set an azimuth mark at every station at a distance of a fraction of a mile from the station. With the coordinates of the main station and the plane azimuth to this azimuth mark the local surveyor has all the data needed for starting a traverse to be connected at the end with some similar control station. In course of time it is the intention to have all of the control surveys of the country computed in terms of these plane coordinates, as well as in terms of latitude and longitude.

In the State of New Jersey a legal adoption has been made of the system of plane coordinates that this Bureau has devised for that State. As a result of this law, it is permissible to define the corners of property by coordinates on the State system and such definition will have full legal standing in the courts. The surveying and engineering units in this State have in progress the computation of the coordinates for the minute intersections of the parallels and meridians so that coordinates of a station may be computed from latitude and longitude by a mere interpolation in the table. A good share of this table has already been completed and it is expected the whole work will be finished probably by the time of the appearance of this report.

The establishment of these systems of coordinates throughout all of the States was a large and important undertaking and in course of time it is expected that they will do much to encourage the use of control surveys in local surveying and engineering work. This will tend to improve this class of work and, if the coordinates of the local surveys are preserved, they in turn can be used as control for further work. As a consequence, it is considered that this accomplishment forms the basis for great improvement in local surveys.

LOCAL CONTROL SURVEYS

By H. W. Hemple, *Chief, Section of Civil Works Surveys, United States Coast and Geodetic Survey*

As a measure for the relief of unemployment among engineers, the United States Coast and Geodetic Survey was asked in November 1933 to administer a local control survey project as a part of the Civil Works Administration program of the Federal Government. The project contemplated the establishment of lines of horizontal and vertical control at not more than 7-mile spacing. The regular program of control surveys of the Coast and Geodetic Survey calls for fundamental control lines at a spacing of 25 miles. The local control surveys thus supplemented the regular program of operations, was in addition thereto, and did not conflict with such work.

The horizontal control consisted principally of traverse surveys of an accuracy of one part in ten thousand although a small amount of triangulation was accomplished. The program of traverse was decided upon because a larger personnel could be employed more advantageously at such work than could be engaged upon triangulation. Also, the survey monuments would be spaced at shorter intervals, and in places not easily accessible for triangulation. The survey monuments would thus be more accessible to local users.

The vertical control surveys were made with the dumpy or wye level and the Philadelphia type of rod reading to 0.001 foot. Third-order accuracy of 0.05 foot $\sqrt{\text{distance in miles}}$ was specified and obtained without difficulty. The leveling was carried over the same monuments established for the traverse work.

The instruments used on the traverse work were the 100-foot steel tape; various types of transits which in few instances were graduated to read to a greater refinement than 30 seconds; clinometers for determining the angle of slope; thermometers; and spring balances. Such instruments were used because the magnitude of the project precluded the use of instruments of a greater refinement of graduation since only a small number of the latter were available. Yet by writing rigid instructions for surveys with the types of instruments used, the necessary accuracy of the traverses could be obtained.

The alinement of the traverse line was made with the transit. A definite tension was applied and the thermometer read for each tape length. The data to reduce to horizontal lengths were obtained either with a hand level or a clinometer. Measurements were usually made over portable tripods, the tape being supported at the ends. In some cases the traverse was carried on along railroad tracks the tape being supported throughout its length on the rail. A master tape standardized at the Bureau of Standards for methods of support similar to those used on the field work, was furnished to each State. The field tapes were compared with the standard at frequent intervals and the corrections noted and applied in the computation of lengths. Taping was done both forward and backward over the line. Angular measurements were, in most cases, made by the repetition method. Three or four sets of 6 D/R were required at each main station.

Monuments were placed at not more than 2-mile intervals along the traverse line. At each station, unless an azimuth was available to a prominent nearby object, a concrete mark was placed one-fourth mile or more distant from the station mark, which serves as an azimuth mark. The monuments were usually made of concrete and extended below the frost line.

There were many transits and leveling instruments owned by public and private organizations and concerns which were not in use at the time this project was started, because of the conditions of depression in business. It was decided that an appeal would be made for the gratuitous use of such idle instruments on the contemplated work, acquainting the owners with the fact that unemployed engineers could be placed at gainful operations and at a work for which their technical training fitted them. The response to this appeal was very gratifying and major surveying instruments were loaned by engineering concerns, engineering schools and colleges, various State, city, and municipal organizations and individual engineers. The Coast and Geodetic Survey agreed to keep these instruments in repair and to return them to the owners at the expiration of the project in as good condition as when received, ordinary wear and tear by use excepted.

Since the work was to be started immediately, and since the project was of such magnitude, and also because most of the money available was to be used for the payment of salaries of the individuals employed, it was impossible for the Coast and Geodetic Survey to purchase the necessary transportation facilities. Many of the engineers employed on the project, however, agreed to use their own personal automobiles on the work providing the necessary expenses for the purchase of gasoline and oils were paid from Government funds. The Government assumed responsibility for any accidents to these cars except those due to careless driving. Such arrangements were made throughout the country with private individuals employed on the project.

The first step after the project was approved was the appointment of an engineer in each State to have direct charge of the surveys. This man was without exception an outstanding engineer, in most cases being a professor of engineering in one of the leading State engineering colleges. This engineer was to devote but part of his time to administering these surveys. He appointed supervisors who were to have charge of the work and were to be directly responsible to him. Most of the details of organization were attended to by the supervisors. The parties consisted of 10 men, and traverse and leveling were carried on concurrently. The localities of the work were so chosen that the workers could live at their homes and not be subjected to unusual expenses due to living in camps or at boarding houses.

The project was approved by the Federal Administration on November 27, 1933, and on February 15, 1934, in excess of 10,000 men were employed on the project. About 50 percent

of these men were engineers. Many of the others were men with college degrees, who were employed in the subordinate positions. On February 15, 1934, by act of Congress the project was removed from the jurisdiction of the Coast and Geodetic Survey, and since that time has been carried on in several of the States as a local project for the relief of unemployment, under the control of State relief organizations. The Coast and Geodetic Survey is permitted to act in an advisory capacity to assure that the results obtained are in accordance with the standards prescribed so that the work may be included in the national net of control surveys.

The salaries now being paid on this project are much lower than obtained on engineering employment in private industry. The principle underlying the creation of the Works Progress Administration is that persons who have been on a direct relief status may obtain employment on projects authorized by that organization, at a salary lower than would be paid in private industry, with the expectation that, as opportunity permits, more lucrative employment in private industry will be accepted. The result is that there is a considerable turnover in personnel, with a consequent loss of efficiency and economy. The unit costs of the surveys accomplished on the relief program are somewhat higher than would obtain were the surveys executed by our own forces as a part of our regular program.

To date, over 40,000 miles of traverse and a like number of miles of leveling have been accomplished. The traverse data are being placed on the State plane-coordinate systems adopted by the Bureau. Such data will then be readily adaptable for the use of local engineers and surveyors. By tying into such monuments the surveyors can use the simple methods of plane surveying in adjusting their own field work.

The project has been of value in acquainting many engineers with the utility of geodetic surveys. In the past many surveyors engaged on cadastral or other local surveys have failed to connect their work to the stations of the national net of control surveys. As a result much difficulty has resulted in attempting to rerun such surveys at a later date, especially in those cases where the original markings had been poorly set and possibly lost. These men are now becoming aware that by connecting to the national scheme of horizontal and vertical control, their own work is perpetuated, and they are making use of the monuments established.

The project has placed many engineers, who would otherwise be unemployed, at a work for which they were fitted by their education and training. Many men of this type have, during the depression, been forced to accept employment at whatever sort of work was offered to them. Those who were employed on the surveys felt that they were engaged on work for which they were trained, and consequently their morale was higher than that of their less fortunate brothers who accepted any employment available. The Census of 1930 showed 226,136 engineers were registered. These were of all types, civil, mechanical, chemical, electrical, etc. In 1929 there were 115,205 engineers belonging to engineering or allied technical societies. At the lowest point of the depression in January and February 1934, the employment on the local control surveys project numbered in excess of 10,000 men, the larger percentage of whom were engineers. The project lends itself readily to the relief of idle engineers, and has been valuable in relieving an acute situation in unemployment among this class of professional men.

The project, by breaking down the 25-mile spacing of the fundamental net, has made the monuments more readily available, and has thereby increased their use by local engineers and surveyors. This is especially true since the data concerning horizontal control surveys is now expressed in the form of plane coordinates, which the local user finds better adapted to his needs than the use of spherical coordinates with involved mathematical formulas.

The many engineers employed on this work have found that accurate surveys can be made with the ordinary type of surveying instrument in use in this country. The use of transits graduated to a greater refinement than 30 seconds is not general in the United States. Our need of accurate surveys in the past has not been great, except in certain metropolitan areas, because land has been relatively cheap, and farm conditions are not overcrowded. There is gradually developing a realization that as the population increases, land will become more

valuable, and accurate surveys will be a necessity. At such a time, transits and theodolites graduated to 10 seconds and less, will have a greater use in private industry than now occurs. This project has been an educational factor in acquainting engineers with the methods of doing accurate surveying, and has taught them that by following certain instructions, accurate work can be accomplished with instruments not graduated to the degree of refinement ordinarily required on geodetic operations

THE UNITED STATES NAVAL OBSERVATORY TIME SERVICE AND VARIATION OF LATITUDE WORK

By Paul Sollenberger, *Astronomer, United States Naval Observatory* (Communicated by the Superintendent, U. S. Naval Observatory)

Early in the year 1934, the Naval Observatory discontinued the use of meridian transit telescopes for the regular determination of time. Since that date the Ross reflex photographic zenith tube has been used for the simultaneous determination of variation of latitude and of time. Care was taken to avoid systematic discontinuity in the signals as a result of this change. In order to render the time work more accurate, a new motor, screw, and gearing for driving the plate were provided. The motor is of the synchronous type, operating from the 1,000-cycle output of a crystal-controlled oscillator. Study of the results obtained so far indicates that the new method has substantially decreased the errors of time determination.

The crystal-controlled transmitting equipment, referred to in the last report, was put into service in May 1934, and has been used since that date. In addition, similar equipment has been installed at Mare Island. The latter equipment is synchronized with the Washington signals at the time of transmission, with the result that the accuracy of the Mare Island signals is now almost equal to that of the Washington signals. Similar equipment is also in process of manufacture for installation at Pearl Harbor.

The number of time transmissions on 113 kilocycles was increased on September 7, 1934, to 20 daily, and the number of transmissions on high frequency from Arlington was increased on August 4, 1935 to 13 daily.

The following table will give an idea as to the accuracy of the time signals. The first column gives the mean of the corrections, taken without regard to signs, to the signals on 113 kilocycles, as computed by the Naval Observatory. The second column gives the mean error of the corrected signals, as determined by le Bureau International de l'Heure at Paris. These errors were determined by comparison with signals from other countries, and are therefore affected not only by the errors of the Naval Observatory signals, but also, to a certain extent, by the errors of the foreign signals. In order to show the progressive improvement in the accuracy of the signals, the quantities are given for 6 years, except that the Paris report for 1935 has not yet been received.

Year	Naval Observatory corrections	Foreign corrections
	s	s
1930	0.038	0.022
1931	.023	.010
1932	.021	.012
1933	.015	.012
1934	.014	.008
1935	.011	

The latitude work has been continued in practically the same manner as formerly. The results have already been published in the Astronomical Journal through the year 1934, and the results for 1935 are ready for publication. The computations are now completed as rapidly as possible, so that the final results for any date are available within 2 or 3 months thereafter.

GRAVITY AND GEODETIC ASTRONOMY

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

GRAVITY DETERMINATIONS

The 3 years covered by this report have witnessed a considerable increase in the gravity work of the Coast and Geodetic Survey. The number of determinations in this period is greater than the total number during the preceeding 40 years. This speeding up the work has been due to a very great extent to the use of the new Brown gravity apparatus. Twenty stations per month are now as easily occupied as were five per month with the apparatus previously in use by his Bureau.

The total number of determinations in the 3 years is 447. These were made in 15 States and on the islands of Cuba and Oahu. The major part of the work was done in Cuba, Florida, Wyoming, Montana, Southern New England, and Pennsylvania. Much of it was in the nature of intensive surveys over limited areas for the purpose of investigating underground geologic structures. Enough success has attended these efforts to interest many geologists in the United States, who are constantly requesting the Coast and Geodetic Survey to do more gravity work in areas in which they are interested.

Practically all of the stations mentioned above have been isostatically reduced and the remaining stations will be computed at an early date. Although the isostatic computations require considerable time, it is felt the results justify the labor involved. The isostatic anomalies are not only very useful in scientific studies of the earth's crust but they are also valuable in geophysical investigations. Where the area to be studied is quite small and the topography is not too rugged then perhaps the free air or Bouguer anomalies are all that are needed, but where larger areas are involved the isostatic anomalies give a much better picture of the structural conditions over the whole area than do the others.

Within the past year, gravity tables for the indirect or Bowie effect have been completed and they are now available in United States Coast and Geodetic Survey Special Publication No. 199. These tables make it possible to compute the approximate difference in elevation of geoid and spheroid for any point, according to the theory of isostasy, and to apply a correction to gravity for the effect of this layer. Corrections for this indirect effect have been computed for practically all United States gravity stations and for both land and sea stations in the West Indies. In general the effects are smaller than were anticipated. They do tend however to decrease the systematic difference between land and sea stations as regards the isostatic anomalies.

ASTRONOMICAL MEASUREMENTS

Very few astronomical determinations for geodetic purposes were made by the Coast and Geodetic Survey during the first half of the 3-year period covered by this report. In the second half of the period, however, one astronomical party was in the field continuously and a second party about half the time. Work was done in 36 different States and included determinations of 162 longitudes, 147 azimuths, and 125 latitudes, all at Laplace stations. The latitude observations were, of course, not needed for the Laplace work but they could ordinarily be made at very small additional expense and so were omitted only when weather conditions were unfavorable and the party would be considerably delayed to obtain them.

It has been the recent practice of the Coast and Geodetic Survey to space Laplace stations from 6 to 10 quadrilaterals apart along the arcs of triangulation, the average spacing being about 8 quadrilaterals. Experience has indicated that this interval between Laplace stations is small enough to furnish adequate azimuth control for the arcs of triangulation. All of the recent Laplace stations are on new arcs of triangulation which have been done since the main net adjustments were made. The fact that these new arcs were connected to the main net at rather close intervals made the number of Laplace stations much less than would otherwise have been required. Many of the large areas where triangulation has been lacking have now

been broken up by intermediate arcs and therefore only occasional Laplace stations will be needed along future arcs.

The Coast and Geodetic Survey took part in the international longitude campaign in October and November of 1933 by making the necessary observations at Niu, near Honolulu, one of the stations of the 1926 net. Time observations were made on 36 nights, and radio signals recorded daily from several transmitting stations. As was done in 1926, a gravity pendulum was used as a substitute for a precision astronomical clock, since neither such a clock nor the proper housing for it were available. This expedient again proved to be quite satisfactory. Although not as convenient as a clock, the gravity pendulum gave the requisite accuracy in carrying time. Unfortunately, the method increased the complexity of the computations quite materially. The results of the work have not yet been published. They will be included in the publication covering the entire world net which will be issued in the near future by le Bureau International de l'Heure, Paris.

The two international variation-of-latitude observatories which are located at Ukiah, Calif., and Gaithersburg, Md., have been in continuous operation during the 3 years. The records for these stations have, as in the past, been sent directly to Professor Kimura, chairman of the joint international committee.

VARIATIONS IN YEARLY SEA LEVEL

By Paul Schureman, *Senior Mathematician, United States Coast and Geodetic Survey*

The variation in sea level from year to year is a matter of considerable interest to the geodesist. At some of the tide-gage stations maintained by the Coast and Geodetic Survey, observations have been continued over many years thus affording an opportunity for a study of these variations. Accompanying tables give average sea-level values for the principal long series tide observations taken in the United States and Alaska. There are included the results from the tide station at Honolulu, Hawaiian Islands, and also yearly averages for Cristobal and Balboa, Canal Zone, furnished by the Chief of Surveys of the Panama Canal.

The observations by the Coast and Geodetic Survey were taken by means of the standard automatic tide gage such as described in Special Publication No. 196, Manual of Tide Observations. The record from this gage is referred to a fixed staff or tape-gage zero through daily comparative readings, while the constancy of the staff or tape-gage zero is checked from time to time by levels to a system of benchmarks. Corrections are applied for any changes in the elevation of the zero.

The datum or zero to which the tabular heights at each station are referred is an arbitrary one, and in general the datums for the different stations have no particular relation to each other. In most cases, original tide staff zero was adopted as the datum for the tabulations. The datum used for Fort Hamilton and Whitehall Street, N. Y., is a plane 5 feet below the Sandy Hook sea-level datum, the latter being the standard reference plane for first-order leveling in this area. The heights at Cristobal are referred to a plane 0.138 foot below the "final precise level datum" of the Canal Zone, and the heights at Balboa to a plane 0.036 foot above the same datum.

The tide observations at Atlantic City, N. J., were taken at the Million Dollar pier during the years 1912 to 1920, and at the Steel pier from 1923 to the present time. The results from both series have been referred to a common datum through spirit-leveling connections. At Key West, Fla., the sea-level values for the years 1913 to 1925, inclusive, are from a gage located at Curry's wharf, and the values for the subsequent years from a gage at the naval base, all heights being referred to the tide staff at the latter place. For Galveston, Tex., the results are based upon observations at Fort Point from January 1, 1903, to June 30, 1908, and upon observations at the foot of Twentieth Street in Galveston Harbor from July 1, 1908, to end of series.

Sea level is derived by averaging the hourly heights of the tide. It is to be distinguished from half-tide level which is obtained from high- and low-water heights. The difference between the two planes is generally small. At Fort Hamilton, the tabular sea-level values for the years 1921 to 1932 were inferred from the half-tide level values by applying the average difference of 0.04 foot to the latter.

An examination of the yearly sea-level elevations shows irregular fluctuations from year to year which at times may amount to several tenths of a foot. Obviously, the meteorological effects are not entirely averaged out even by taking an entire year of observations. Table 3 has been prepared in which sea-level elevations for a number of the longer series are determined from 10-year periods. Even with this length, outstanding irregularities will be found in the tabular means.

It is an interesting question as to whether the average sea level for the entire world varies from year to year. In order to determine this, tide stations should be distributed more or less uniformly over all of the oceans. While the present compilation is inadequate for a study of the sea level as a whole, when taken in connection with similar data which may have been secured by other countries, it offers an opportunity for a more thorough study of the subject.

TABLE 1.—*Variations in yearly sea level, Atlantic coast*

Year	Portland, Maine	Boston, Mass.	Fort Hamilton, N. Y.	Whitehall Street, New York City	Atlantic City, N. J.	Baltimore, Md.	Charleston, S. C.	Fernandina, Fla.	Key West, Fla.	Cedar Keys, Fla.	Pensacola, Fla.	Galveston, Tex.	Cristobal, C. Z.
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1893			4.94										
1894			4.98										
1895			4.91										
1896			4.99										
1897			5.06										
1898			5.08					6.11					
1899			5.07					6.26					
1900			4.93					6.04					
1901			5.16					6.14					
1902			5.20					6.15					
1903			5.13			4.16		6.34					
1904			4.98			3.96		6.24				3.34	
1905			4.94			4.02		6.20				3.37	
1906			5.05			4.05		6.28				3.38	
1907			5.00			4.02		6.02				3.43	
1908			4.97			4.06		6.22				3.39	
1909			5.10			4.08		6.18				3.48	0.23
1910			5.16			4.15		5.98				3.22	.18
1911			5.11			4.10		6.05				3.35	.16
1912	3.08		4.93		6.01	4.00		6.10				3.51	.17
1913	3.03		4.98		6.08	4.03		6.10	4.94			3.63	.20
1914	3.09		5.11		6.20	4.06		6.16	4.90			3.57	.25
1915	3.17		5.16		6.26	4.17		6.16	4.90	4.77		3.45	.34
1916	3.13		5.12		6.17	4.13		5.99	4.94	4.75		3.50	.20
1917	3.14		5.15		6.18	4.11		5.92	5.00	4.74		3.25	.09
1918	3.14		5.13		6.23	4.21		6.03	4.91	4.79		3.33	.20
1919	3.23		5.30		6.37	4.30		6.33	4.91	4.84		3.70	.26
1920	3.19		5.23		6.31	4.17		6.09	4.83	4.74		3.59	.25
1921	3.14		5.24			4.25		6.28	4.97	4.85		3.92	.35
1922	3.02	8.09	5.14			4.15	4.98	6.11	4.93	4.88		3.72	.28
1923	3.07	8.08	5.15		6.19	4.17	4.91	6.08	4.86	4.84		3.78	.14
1924	3.08	8.10	5.10		6.22	4.21	4.98		4.87	4.66	8.40	3.50	.08
1925	3.00	8.03	5.05		6.13	4.08	5.05		4.89	4.80	8.48	3.48	.12
1926	2.98	8.06	5.03		6.17	4.10	4.83		4.83		8.53	3.50	.24
1927	3.10	8.17	5.18		6.33	4.21	4.90		4.95		8.57	3.77	.26
1928	3.02	8.07	5.04	5.05	6.16	4.10	4.92		4.88		8.52	3.58	.18
1929	3.00	8.09	5.00	5.10	6.18	4.12	4.94		4.93		8.80	3.99	.21
1930	2.98	8.09	5.06	5.06	6.20	4.08	4.90		4.96		8.49	3.69	.24
1931	3.09	8.24	5.30	5.21	6.38	4.18	4.81		4.82		8.42	3.49	.22
1932	3.12	8.22	5.30	5.20	6.37	4.21	4.98		4.97		8.64	3.73	.13
1933	3.19	8.30		5.30	6.49	4.33	5.12		5.08		8.77	3.91	.08
1934	3.04	8.12		5.15	6.30	4.21	4.91		4.93		8.51	3.63	.09
1935	3.15	8.25		5.29	6.44	4.27	5.10		5.03		8.58	3.79	

TABLE 2.—*Variations in yearly sea level, Pacific coast*

Year	Balboa, C. Z.	San Diego, Calif.	La Jolla, Calif.	Los Angeles, Calif.	San Francisco, Calif.	Seattle, Wash.	Ketchikan, Alaska	Seward, Alaska	Honolulu, Hawaii
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1898					8.30				
1899					8.44	3.94			
1900					8.50	4.10			
1901					8.46	3.88			
1902					8.57	4.06			
1903					8.53	3.99			
1904					8.63	4.10			
1905					8.65	4.08			4.14
1906		6.50			8.58	4.11			4.27
1907		6.56			8.66	4.17			4.29
1908		6.46			8.43	4.08			4.23
1909	0.69	6.40			8.53	4.12			3.95
1910	.60	6.43			8.42	3.98			4.10
1911	.85	6.63			8.61	3.96			4.04
1912	.60	6.50			8.49	3.96			4.14
1913	.75	6.52			8.51	3.96			4.23
1914	.77	6.66			8.81	4.16			4.41
1915	.79	6.63			8.69	4.23			4.51
1916	.68	6.42			8.52	4.08			4.35
1917	.56	6.44			8.48	3.88			4.29
1918	.82	6.69			8.70	4.18			4.14
1919	.65	6.55			8.61	4.08	4.31		4.40
1920	.74	6.56			8.54	3.99	4.25		4.64
1921	.79	6.52			8.58	4.02	4.29		4.49
1922	.79	6.52			8.55	3.94	4.12		4.36
1923	.77	6.64			8.52	4.00	4.26		4.32
1924	.65	6.50		6.36	8.42	3.90	4.21		4.25
1925	.83	6.62	6.61	6.46	8.62	4.10	4.28		4.41
1926	.58		6.72	6.46	8.63	4.11	4.41	8.30	4.36
1927	.77		6.61	6.40	8.60	4.14	4.26	8.01	4.26
1928	.80		6.67	6.42	8.58	4.08	4.26	8.14	4.20
1929	.81		6.71	6.47	8.55	3.89	4.08	7.95	4.25
1930	.87		6.73	6.60	8.72	4.08	4.24	8.00	4.36
1931	.72		6.74	6.53	8.62	4.10	4.45	8.31	4.40
1932	.87		6.67	6.45	8.68	4.12	4.37	8.10	4.39
1933	.74		6.51	6.27	8.52	4.13	4.32	7.94	4.34
1934	.75		6.60	6.42	8.63	4.17	4.39	8.20	4.23
1935			6.60	6.40	8.72	4.13	4.27	7.94	4.41

TABLE 3.—*Sea level for 10-year periods*

Period of observations	Portland, Maine	New York Harbor (Fort Hamilton and Whitehall Street)	Baltimore, Md.	Key West, Fla.	Galveston, Tex.	Cristobal, C. Z.	Balboa, C. Z.	San Francisco, Calif.	Seattle, Wash.	Honolulu, Hawaii
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1893–1902		5.03								
1894–1903		5.05								
1895–1904		5.05								
1896–1905		5.05								
1897–1906		5.06								
1898–1907		5.05						8.53		
1899–1908		5.04						8.54	4.05	
1900–9		5.05						8.55	4.07	
1901–10		5.07						8.55	4.06	
1902–11		5.06						8.56	4.06	
1903–12		5.04	4.06					8.55	4.06	
1904–13		5.02	4.05					8.55	4.05	
1905–14		5.04	4.06					8.57	4.06	4.18
1906–15		5.06	4.07					8.57	4.07	4.22
1907–16		5.06	4.08					8.57	4.07	4.22
1908–17		5.08	4.09					8.55	4.04	4.22
1909–18		5.10	4.10		3.43	0.20	0.71	8.58	4.05	4.22
1910–19		5.12	4.13		3.45	.20	.71	8.58	4.05	4.26
1911–20		5.12	4.13		3.49	.21	.72	8.60	4.05	4.32
1912–21	3.13	5.14	4.14		3.54	.23	.71	8.59	4.05	4.36
1913–22	3.13	5.16	4.16	4.92	3.57	.24	.73	8.60	4.05	4.38
1914–23	3.13	5.17	4.17	4.92	3.58	.23	.74	8.60	4.06	4.39
1915–24	3.13	5.17	4.19	4.91	3.57	.22	.72	8.56	4.03	4.38
1916–25	3.11	5.16	4.18	4.91	3.58	.20	.73	8.55	4.02	4.36
1917–26	3.10	5.15	4.18	4.90	3.58	.20	.72	8.56	4.02	4.37
1918–27	3.10	5.16	4.18	4.90	3.63	.22	.74	8.58	4.05	4.36
1919–28	3.08	5.15	4.17	4.89	3.65	.22	.74	8.56	4.04	4.37
1920–29	3.06	5.13	4.16	4.89	3.68	.21	.75	8.56	4.02	4.35
1921–30	3.04	5.11	4.15	4.91	3.69	.21	.77	8.58	4.03	4.33
1922–31	3.03	5.11	4.14	4.89	3.65	.20	.76	8.58	4.03	4.32
1923–32	3.04	5.11	4.15	4.90	3.65	.18	.77	8.59	4.05	4.32
1924–33	3.06	5.13	4.16	4.92	3.66	.18	.76	8.59	4.06	4.32
1925–34	3.05	5.13	4.16	4.92	3.68	.18	.78	8.62	4.09	4.32
1926–35	3.07	5.16	4.18	4.94	3.71			8.62	4.10	4.32

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