CHAPTER 2

Available Technical Data

In its long history of surveying and charting the coastal regions of the United States and possessions, the Coast and Geodetic Survey has accumulated a vast reservoir of precise facts of an engineering and scientific nature. These technical data often play an important role in the delimitation and demarcation of waterfront boundaries, and the engineer or lawyer who has to deal with such problems should have knowledge of the pertinent data available in the Bureau and have an understanding of the principles on which such data are based. The purpose of this chapter is to provide that understanding. Not all of the technical data available are described, but only those that are essential for the establishment of shore and sea boundaries with accuracy and permanence. These comprise, primarily, geodetic control data, topographic and hydrographic data, and tidal data.

21. GEODETIC CONTROL DATA

As its name indicates, the Coast and Geodetic Survey is the Bureau of the Federal Government which makes the geodetic control surveys. It was recognized at an early period in the history of the Survey that an undertaking of such vast magnitude could not be attacked as a problem in ordinary surveying, but had to be accomplished by methods which took into account the shape and size of the earth. Such surveys are termed geodetic surveys and represent the highest form of survey engineering. They include the determination of the latitudes and longitudes, and elevations above sea level, of numerous points throughout the country, and involve astronomic observations, measurement of base lines, and measurement of the force and direction of gravity. In addition, they include the computation and final adjustment of all field observations required for the establishment of a consistent network of marked points on a single basic horizontal control datum for latitudes and longitudes, and a single vertical control datum for elevations.

The basic geodetic networks of the country have many important uses. They serve to locate national, state, county, and private boundaries; provide rigid frameworks for all types of accurate maps, such as the topographic maps of the U.S. Geological Survey; make possible greater precision in the surveys of large cities than can be obtained by other methods; and coordinate into a single related system all local surveys connected to them, and help to assure the perpetuation of the positions of any marks established by such surveys.

Originally, the geodetic surveys in this country were made for the control of surveys along the Atlantic coast and to provide a proper base for the nautical charts of the coastal waters. By congressional action in 1871, these activities were expanded to furnish basic control for the interior of the country, including a geodetic connection between the Atlantic and Pacific coasts.[1] Since then, the Bureau has been actively engaged in extending triangulation and precise levels in the interior of the country for the purpose of establishing a federal framework on which all land surveys and engineering projects can be based.

For many reasons, it is in the best national interest to have all surveys, both public and private—no matter how localized they may be—tied in with the national control network. The extent to which this ideal is reached will depend upon the availability of control points to the local surveyor and engineer. The aim of the Bureau's geodetic program has therefore been to establish closely spaced control points as rapidly as possible, the distribution varying in accordance with the requirements of each region.

211. Horizontal Control Data

To span the country from coast to coast and from north to south, widely spaced arcs of triangulation were first established.[2] This gave a preliminary framework. Intermediate arcs, spaced 40 to 60 miles apart, provided control for boundary determinations and general purposes of the various states. The next logical step has been followed in the last two decades by filling in the areas between these arcs with "area" triangulation (*see* fig. 10).

An attempt is made to establish at least one triangulation station in each 7½-minute quadrangle area, with stations averaging about 4 miles along the main highways in agricultural areas and closer spacing in metropolitan areas and at towns, colleges, and airports. To coordinate local urban surveys, at least

1. Act of Mar. 3, 1871 (16 Stat. 495, 508).

2. Triangulation is a very efficient method for making surveys over extensive areas. It consists of a system of connected triangles with all angles carefully observed (*see* fig. 9), but with only an occasional length actually measured on the ground. Each measured length is known as a *base*. From these measured angles and bases, the lengths of all other sides of the connected triangles may be computed by trigonometric methods. If the latitude and longitude of one point are known, together with the azimuth to one of the other stations, the latitudes and longitudes of other points and the azimuths of all other lines may also be derived. Horizontal Control Data 1, Special Publication No. 227, U.S. Coast and Geodetic Survey (1957).

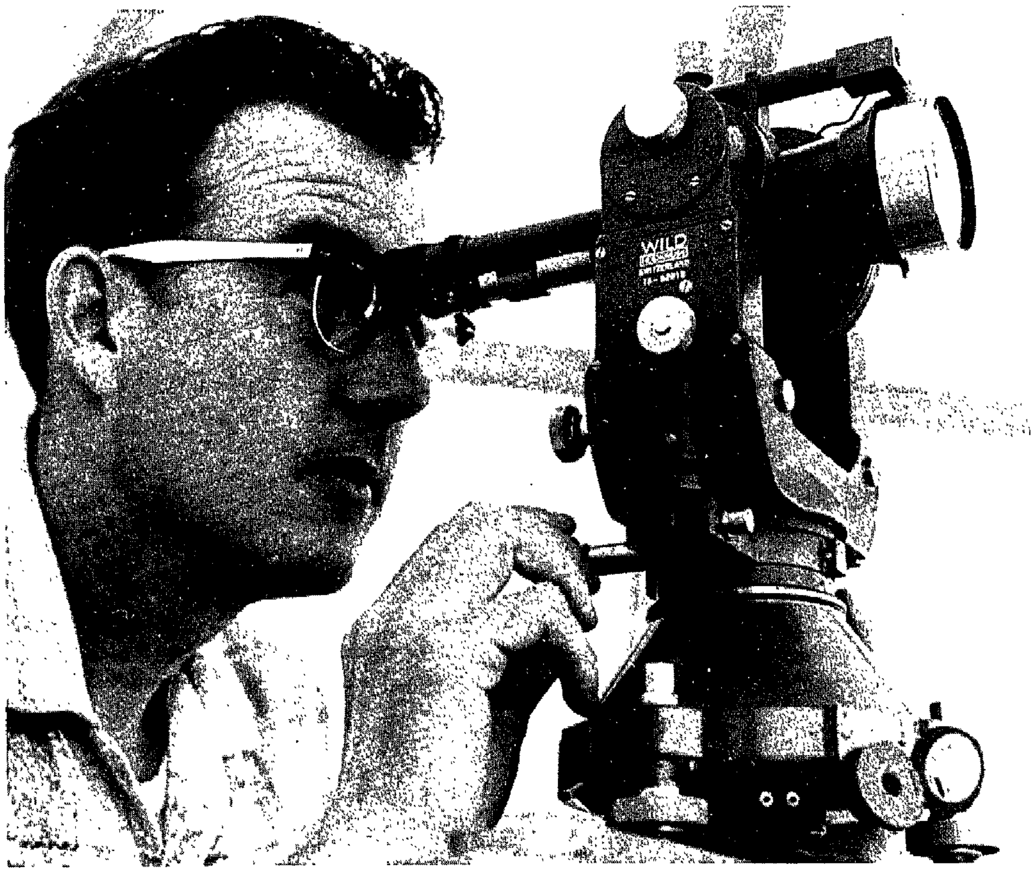

FIGURE 9.—Observer using a Wild T–3 theodolite in triangulation work.

one federal base is being established in metropolitan areas of 100,000 population or over.

2111. *A Network of Monumented Points*

Latitudes and longitudes have thus been determined for many thousands of marked stations scattered over the United States.[3] Surveys of small areas may be based on any of these marked points with the assurance that they will be correctly coordinated in position with all precise surveys and maps of the entire country and with all local surveys so connected. The permanency of surveys thus connected to the national triangulation network is also assured because any marked points that are destroyed may be relocated on the ground from their

3. As of May 1963, there were 170,400 permanently marked (*see* fig. 11) or otherwise identifiable stations in the United States, most of which can be used as starting points for all mapping and engineering projects in which geographic location is a consideration.

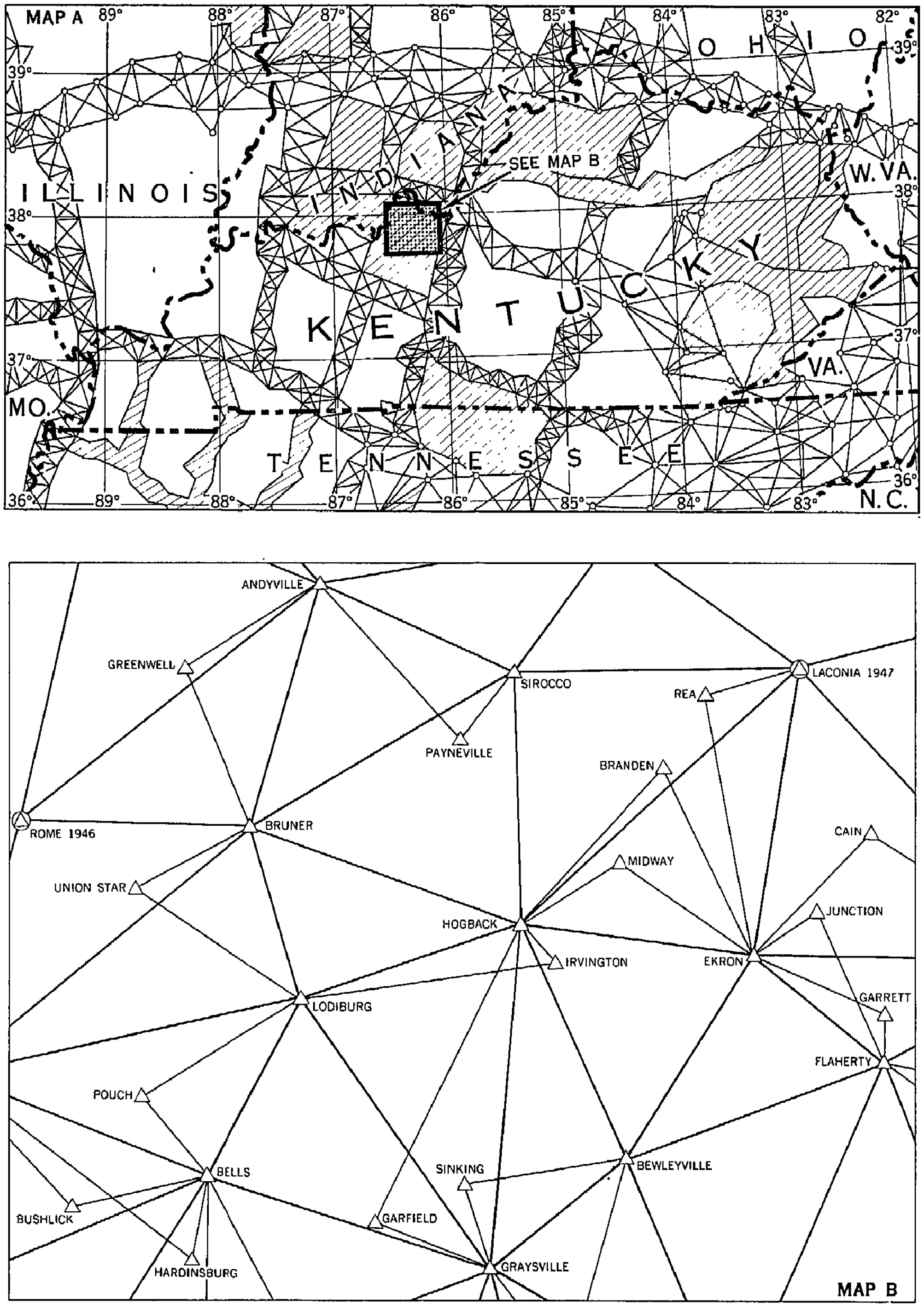

FIGURE 10.—"Area" triangulation is now used to fill in gaps between main arcs.

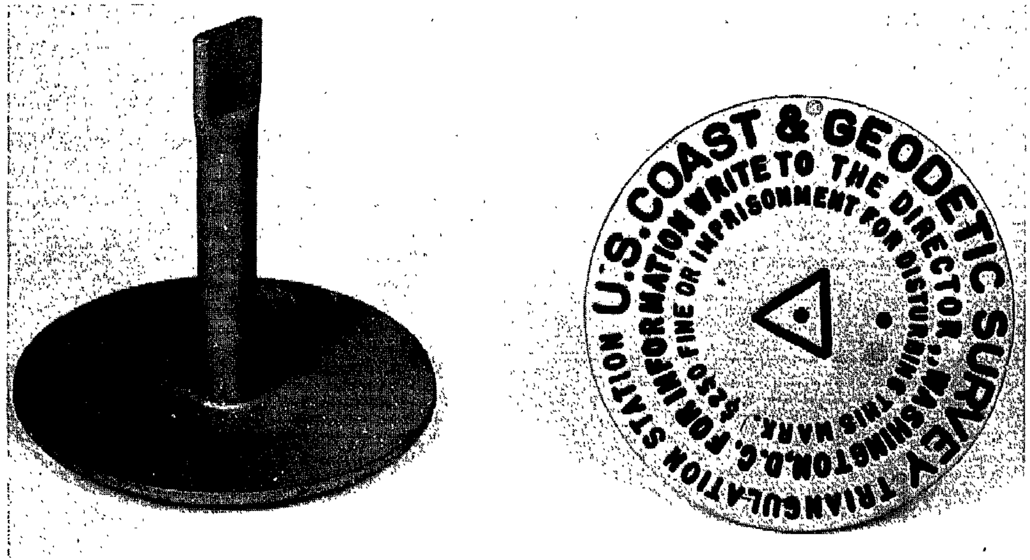

FIGURE 11.—Bronze marker used to identify a triangulation station.

relation to other marked points. To facilitate the use of the triangulation stations by local surveyors and engineers, a nearby azimuth mark is established which gives directional control and avoids the need of establishing a true meridian line.

2112. *Accuracy of Horizontal Control*

Control surveys are classified as nearly as possible according to the accuracy of the resulting lengths and azimuths of the lines. Since the absolute errors of these quantities cannot be ascertained, indirect gages must be used. For triangulation, the principal criterion is whether the discrepancy between a measured base and its length as computed through the network from the next preceding base is less than a certain fraction of the length of the base itself. For the basic first-order work, the computed length must agree within 1 part in 50,000, as a minimum, and should average about 1 in 75,000, or better.[4]

Another important indirect gage of the accuracy of the final results of the triangulation is the average closure of the triangles. After allowance has been made for spherical excess, that is, for the slight increase in the angles due to the spherical shape of the earth, the sum of the three angles of a triangle should be exactly 180°. The permissible variations from 180° are different for the different

4. Base lines are measured with the Geodimeter in one direction, observations being made on at least two nights. They are generally from 4 to 8 miles long with a probable error for the mean of the measurements averaging about 1 in 2,000,000.

classes of triangulation. For first-order work, the requirements are an average closure not in excess of 1 second.[5]

Although the base-to-base checks show an average discrepancy of the order of 1 part in 75,000, the loop closures developed in the 1927 adjustment of the triangulation in the United States (*see* Part 2, 225) indicate a much higher accuracy. In the adjustment of the western half of the United States, the average closure for 16 loops was 1 part in 450,000, with a maximum of 1 part in 162,000 (*see* fig. 12).[6] In the adjustment of the eastern half, the closures for 25 loops averaged 1 part in 193,000, the largest being 1 part in 94,000 (*see* fig. 12). In the figure, the number above the line is the total closure in feet; the number below the line is the approximate proportional part of the whole circuit represented by the closure.[7]

It is apparent then that for first-order triangulation involving very large loops, the average precision of the lengths of the arcs appears to be a little better than 1 part in 200,000. On the other hand, it has been found that for a small extension of triangulation in which two or more bases have been provided for length control (such as city work) it is difficult to exceed, for a certainty, an accuracy of 1 part in 100,000 as a base-to-base check.[8]

In 1960, a remarkably accurate horizontal control survey was carried out by the Bureau in east-central Florida, in connection with the test of an electronic missile-tracking device by the Air Force. The survey covered an area of approximately 4,000 square miles (*see* fig. 14), and while the requirements called for an accuracy of 1 part in 400,000, the final results indicated a probable error of 1 part in 1,300,000.[9] This project demonstrated clearly that with careful planning and great attention to details in the field, a very high degree of accuracy is attainable. It does not follow, however, as a result of this work,

5. For second-order work, the average closure does not exceed 3 seconds, and for third-order work the average does not exceed 5 seconds. A table of accuracy requirements for horizontal control, including closures and other specifications, are given in HORIZONTAL CONTROL DATA (1957), *op. cit. supra* note 2, at 10–11.

6. A more rigid test would probably be the closures of the sections forming the loops after the junction positions have been adopted, as these reflect to a greater extent the interrelations existing in the triangulation as a whole. For 42 sections (*see* fig. 13), the average closure was 1 part in 317,000, with a maximum of 1 part in 120,000.

7. The average closure for 55 sections was about 1 part in 175,000, with a maximum of 1 part in 66,000 (*see* fig. 13). In the figure, the number above the line is the total closure in feet; the number below the line is the approximate proportional part of the length of the section represented by the total closure.

8. Simmons, *How Accurate Is First-Order Triangulation?* 3 JOURNAL, COAST AND GEODETIC SURVEY 53 (1950). This paper also includes an empirical formula for determining the proportional accuracy of distances determined by triangulation. *Id.* at 54.

9. This was due in part to the numerous lines that were measured with the Geodimeter. Of the 200 lines in the triangulation net, 43 were thus measured. This was possible only because a special test demonstrated the feasibility of operating the Geodimeter from the top of a Bilby steel tower.

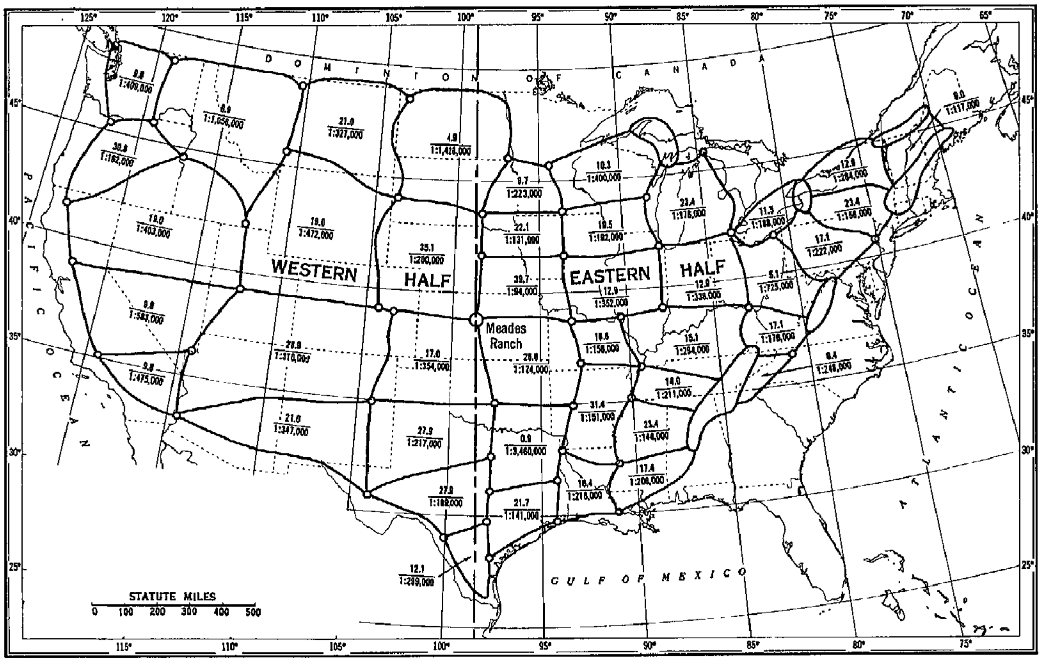

FIGURE 12.—Loop closures resulting from adjustment of the United States triangulation.

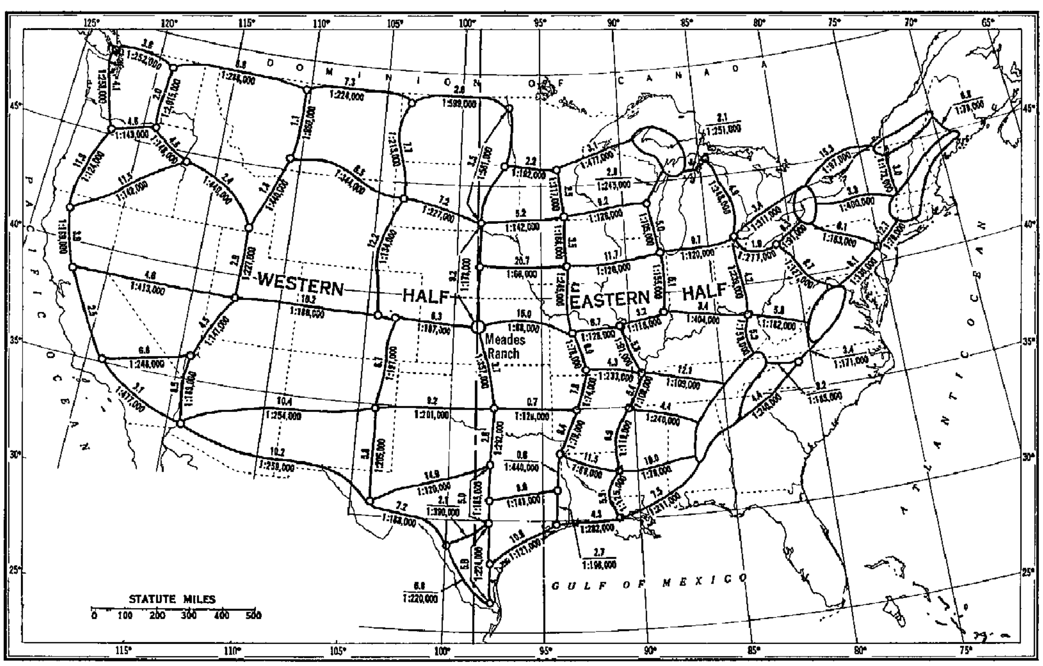

FIGURE 13.—Section closures resulting from apportionment of loop closures.

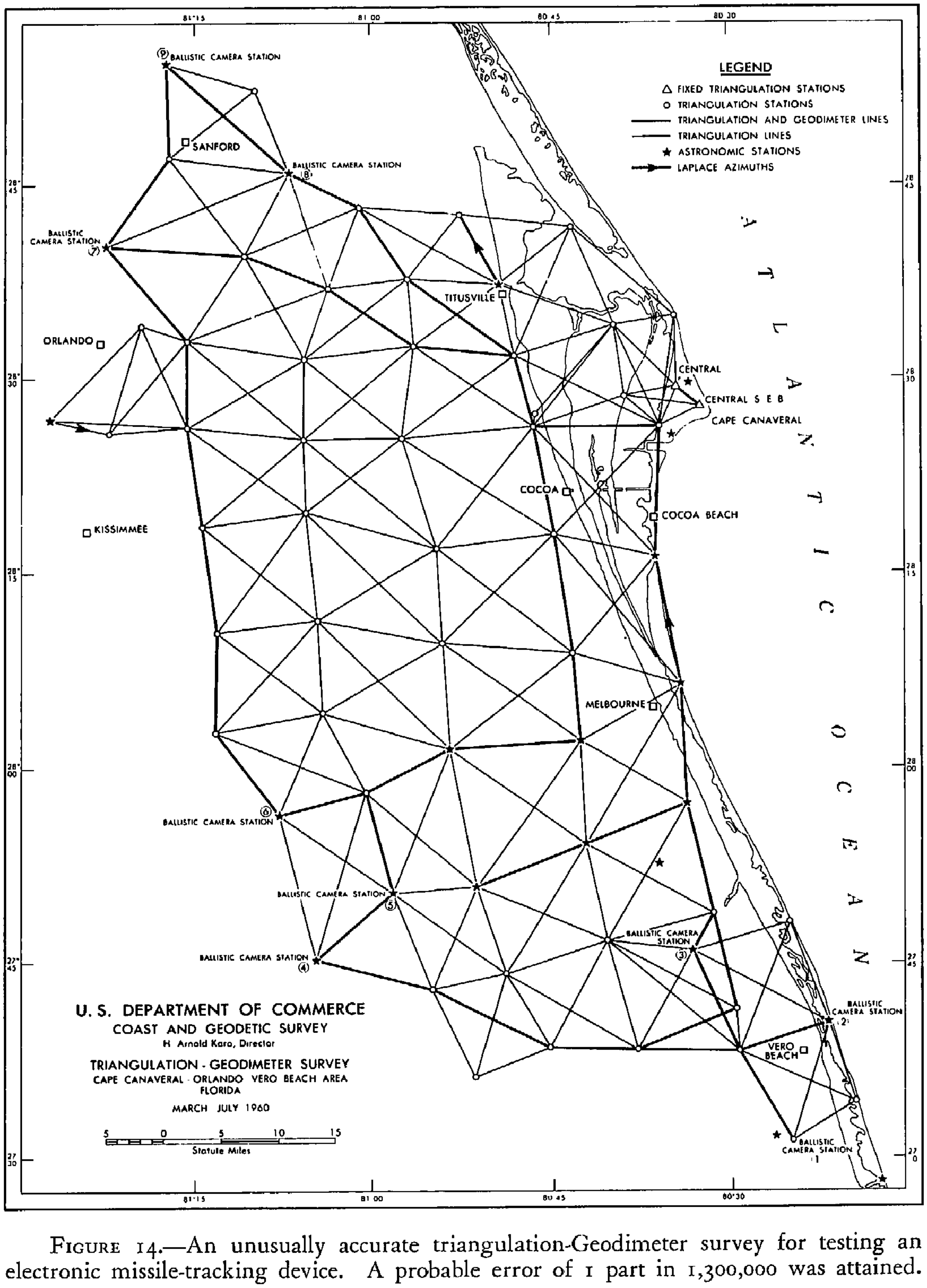

FIGURE 14.—An unusually accurate triangulation-Geodimeter survey for testing an electronic missile-tracking device. A probable error of 1 part in 1,300,000 was attained.

that comparable accuracies can be obtained everywhere. The conditions in Florida are singularly favorable to high precision of operations.[10]

2113. *Types of Available Horizontal Data*

The data for all triangulation and traverse stations established by the Coast and Geodetic Survey are available for the use of engineers and surveyors, either in the form of geographic coordinates or as plane coordinates.

A. GEOGRAPHIC COORDINATES

Data defining the locations of stations in terms of geographic coordinates include their latitudes and longitudes and the lengths and azimuths of the lines between contiguous stations. In this system of computations, account is taken of the earth's curvature when extensive surveys are involved, and the computations are made on a spheroidal surface—the mathematical surface that represents the shape of the earth (*see* Part 2, 21). One advantage of this system is its universality . Each triangulation station has a definite position on the surface of the earth with reference to the equator and to the prime meridian of Greenwich. Any point located in this system is definitely related to any other point in the same system.

B. STATE PLANE COORDINATES

Data defining the locations of stations in terms of State Plane Coordinates include their plane coordinates and the plane or grid azimuth to an azimuth mark.

For many engineering and property surveys, a rectangular system is used in which the plane of projection is a tangent plane, and the curvature of the earth is neglected. Surveys in such a system are started at a selected origin and conducted and computed as though all the observations were made on a flat surface. Such a system is adequate if it does not extend too far from the origin.

Where the survey covered a more extensive area, a system of rectangular coordinates was used in which the plane of projection was a tangent plane, but correction was made for the curvature of the earth. The plane coordinates resulting therefrom had an accuracy of 1 part in 50,000 at a distance of 25 miles from the origin of the system. The origin was usually a triangulation station whose latitude and longitude were known. In this method of computation the

10. For a detailed discussion of the planning, operations, and results of this project, *see* Simmons, *A Singular Geodetic Survey,* Technical Bulletin No. 13, U.S. Coast and Geodetic Survey (1960).

plane coordinates were derived from prepared tables.[11] As the distance from the origin went beyond 25 miles, a rapid decrease in accuracy resulted which could not be easily determined and allowed for. Where such reduced accuracy became intolerable, a new origin of coordinates had to be established, and for an extensive area even several origins were necessary, with resulting computational difficulties.

The State Coordinate Systems overcame these limitations. The unit of area became, in general, the state, and a single origin could be used which would give satisfactory results for most purposes. The systems provide the advantages of plane coordinates and at the same time make possible a perfect coordination of the work of different engineers throughout the whole region for which one system is adequate.

The establishment of a State Coordinate System not only simplifies the use of control data but it gives a permanent general grid for the whole or a large part of a state. County boundaries, township boundaries, property boundaries, intersections of roads and streets, and any prominent features of a region can be accurately located with definite X and Y coordinates. Such coordinates can readily be transformed into latitudes and longitudes, and any point can thus be definitely located in the network of meridians and parallels that serve to locate points on the earth's surface.[12]

In these systems two types of projections are used on which the plane coordinates are computed—the Lambert conformal conic, and the transverse Mercator which is also conformal.[13] The first is used for states whose greatest extent is in an east-west direction because the properties of this projection are such that the extent to which it can be carried in longitude is not limited and the scale on any parallel of latitude is the same throughout its entire length. The second projection—the transverse Mercator—is used for states having their predominant extent in a north-south direction.[14]

In order to avoid too great an error being introduced in the work when passing from geographic coordinates to plane coordinates, states are often divided

11. This system is fully described in REYNOLDS, RELATION BETWEEN PLANE RECTANGULAR COORDINATES AND GEOGRAPHIC POSITIONS, SPECIAL PUBLICATION NO. 71, U.S. COAST AND GEODETIC SURVEY (1936).

12. The first statewide plane coordinate system was established in 1933 for the State of North Carolina. MITCHELL AND SIMMONS, THE STATE COORDINATE SYSTEMS VI, SPECIAL PUBLICATION NO. 235, U.S. COAST AND GEODETIC SURVEY (1957). This publication is a manual for surveyors and deals comprehensively with the principles of the State Coordinate Systems and their use.

13. The projections are mathematical devices to permit the use of ordinary plane surveying methods and computations over much larger areas than would be permissible on a strictly local system of coordinates.

14. The transverse Mercator projection is the normal Mercator rotated through 90° so that it is based on a meridian instead of the equator (*see* Part 2, 613), thus making it an excellent projection for narrow bands extending in a north-south direction. The characteristics as to scale are identical to those of the normal Mercator, except that the scale is now dependent on distances east or west of the meridian instead of north or south of the equator (*see* Part 2, 6412).

into zones with a new origin for each zone and in such a manner that the error in any part of the system seldom exceeds 1 part in 10,000. This permits a single zone to cover a distance of 158 miles in a north-south direction on the Lambert projection and in an east-west direction on the transverse Mercator before a new origin is required. Sometimes the shape and extent of a state is such that both systems of projection are used. In Florida, for example, the Lambert projection is used for the northern part of the state, and the transverse Mercator with two zones for the southern part.

In the practical field use of state plane coordinates, the engineer needs only the plane coordinates of the triangulation stations and the plane or grid azimuth to an azimuth mark within the area covered by his survey, and need not concern himself with their conversion from geographic coordinates. These data are available to him in the Coast Survey, and are sufficient for him to run and adjust his traverse using the ordinary methods of plane surveying.

While scale errors exist in the state systems, the fact that they are based on definite projections with determinable scale factors makes it possible to bring the computations to geodetic accuracy—if such refinement should be necessary or desired—by applying corrections for scale errors and for elevation above sea level. This is not possible with a system of plane coordinates based on a tangent plane. With the limitation of error of 1 part in 10,000 imposed on the state systems, corrections for scale error can usually be ignored for ordinary surveying purposes.[15]

212. Vertical Control Data

The second major constituent of geodetic control data is the vertical control or leveling data, that is, the elevations of numerous marked points (known as bench marks) in the country which provide starting points for all surveying and engineering operations where elevation is a significant factor.[16]

To define completely the location of any point on the surface of the earth, it is necessary to determine not only its geographic coordinates (*see* 2113 A)

15. As of April 1963, the following 26 states had adopted legislation legalizing the use of State Coordinate Systems for boundary descriptions and other purposes (the date following the name of the state is the year of adoption): Alabama (1945), California (1947), Connecticut (1945), Delaware (1945), Georgia (1945), Indiana (1951), Louisiana (1944), Maine (1947), Maryland (1939), Massachusetts (1941), Minnesota (1945), Nevada (1945), New Jersey (1935), New Mexico (1957), New York (1938), North Carolina (1939), Ohio (1945), Oregon (1945), Pennsylvania (1937), Rhode Island (1945), South Dakota (1947), Tennessee (1947), Texas (1943), Vermont (1945), Virginia (1946), Washington (1945), Mitchell and Simmons (1957), *op. cit. supra* note 12, at II, 53.

16. Leveling, in general, may be defined as the operation of determining differences of elevation between points on the surface of the earth. It may also be considered as the determination of the elevations of such points relative to some arbitrary or natural level surface called a datum. Control Leveling 1, Special Publication No. 226, U.S. Coast and Geodetic Survey (1961).

but its elevation as well. However, it is seldom that the latitude and longitude *and* the elevation of a particular point are known. This is the result of the entirely different methods used in determining geographic positions and elevations. Triangulation stations are located on the highest and most commanding points in order that they may be visible from other similar points, whereas bench marks for which elevations are determined are usually placed adjacent to well-established transportation routes and are seldom located on summits.

In providing for the vertical control of the country, the Coast and Geodetic Survey followed a program starting with widely spaced first-order lines 100 miles apart, later supplemented by second-order lines spaced at approximately 50- and 25-mile intervals. In some regions, area leveling was established which consisted of second-order lines spaced about 6 miles apart and connected to the wider-spaced lines in a consistent network of levels. However, the Bureau's main responsibilty is to keep the 25-mile spacing net up to date, and a releveling of these lines which are 25 years or more of age is planned. Bench marks are set at 1-mile intervals along each line, except in cities and towns and in areas of vertical change studies, where the spacing averages about one-half mile. There are now (in May 1963) 187,374 miles of first-order leveling and 285,461 miles of second-order leveling in the United States and 422,619 bench marks leveled over (*see* fig. 15).

First-order leveling represents the most exact method of determining elevations. Lines are run in both directions and the two runnings must be such that in a 100-mile circuit the error of closure is on an average about 2 inches.[17] Second-order leveling is run in one direction, except where lines are 25 miles or more in length, when they are double-run. For a 25-mile circuit, the error of closure is on an average about 2 inches.

The accuracy of the leveling executed by the Coast Survey is well within the specifications adopted by the Bureau of the Budget. Its first-order work satisfies the requirements of the International Union of Geodesy and Geophysics for "leveling of high precision," while the second-order work is equivalent to that classified as "leveling of precision." [18]

17. In the Coast Survey, elevations are measured in meters above the mean sea-level surface. Afterward, when the data have been computed and adjusted, the metric elevations are converted to feet for general use. *Id.* at 1.

18. *Id.* at 4–5. Until 1922, control leveling in the Coast Survey was all first order. In 1923 and 1927, a small amount of second-order work was done. Since 1932 it has been standard practice to subdivide the areas within the loops of first-order leveling with leveling of second-order accuracy. *Id.* at 2. The classification of leveling in the Bureau and the specifications that must be met in each class are given in *id.* at 20.

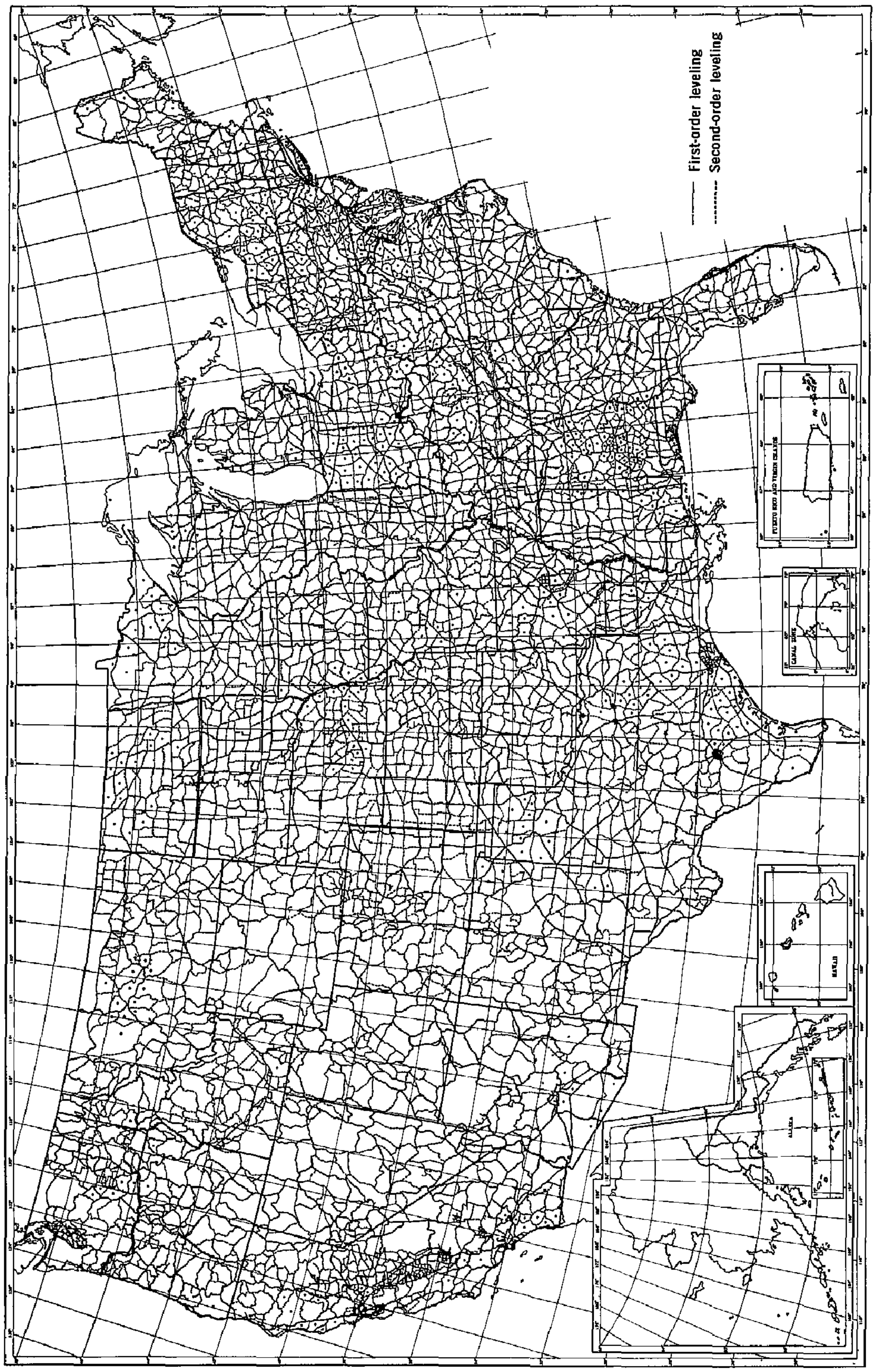

FIGURE 15.—Leveling network of the United States. As of May 1963, there were close to a half million miles of lines leveled over, and over 400,000 bench-mark elevations for use in topographic mapping and engineering projects.

2121. *Brief History of the Level Net*

First-order leveling was first undertaken by the Survey in 1878 when field work was begun on the line of precise levels which was to follow the transcontinental arc of triangulation extending from Chesapeake Bay to the Golden Gate, approximately along the 39th parallel of latitude.[19] The primary purpose of this first line of levels was to furnish accurate spirit level control for the vertical-angle leveling done in connection with the triangulation for use in reducing the observed horizontal directions to sea level. However, during the course of this leveling, bench marks were established at intervals of several miles and at most of the important towns along the route for the use of engineers and surveyors in initiating additional leveling on a sea-level datum. By 1899, the net had developed a total of 25 circuits, either all spirit leveling or spirit leveling between sea-level connections at tide stations. Closing errors were becoming troublesome to such an extent that an adjustment of the net was decided upon.[20]

About 1900, a new type of leveling instrument—the Fischer level—was designed in the Survey. The introduction of this instrument permitted levels of even greater accuracy to be run at much greater speed and stimulated the leveling work of the Bureau. With but comparatively slight changes, this has continued to be the standard instrument used for geodetic leveling since that time (*see* fig. 16).

During the years 1903, 1907, and 1912, adjustments in the level net became necessary in order to absorb the new leveling that had accumulated and the connections to sea level that had been made at Seattle, Wash., and at San Diego, Calif. The 1907 and 1912 adjustments were not strictly general adjustments because, after the rigid adjustments had been completed, certain areas showed such small changes from the former results that it was decided to hold fixed a considerable portion of the net as previously adjusted in order to avoid a large number of very small corrections to the elevations of the bench marks.[21]

Additional leveling was added to the net at a fairly steady rate in the decade and a half following the adjustment of 1912, but most of the new leveling fitted

19. The leveling was extended from a tide station at Sandy Hook, N.J., and elevations were published for a considerable time as "above mean tide level at Sandy Hook." RAPPLEYE, MANUAL OF LEVELING COMPUTATION AND ADJUSTMENT 1, SPECIAL PUBLICATION NO. 240, U.S. COAST AND GEODETIC SURVEY (1948).

20. The adjustment was made and the results published in the Annual Report (Appendix 8), U.S. Coast and Geodetic Survey (1899), under the title "Precise Leveling in the United States." This contained, in addition to the details of the various studies and the adjustment, the descriptions and resulting metric elevations of all bench marks established along the lines in the net. CONTROL LEVELING (1961), *op. cit. supra* note 16, at 7.

21. *Id.* at 7–8. References may be found here to the publications in which the results of the several adjustments are published.

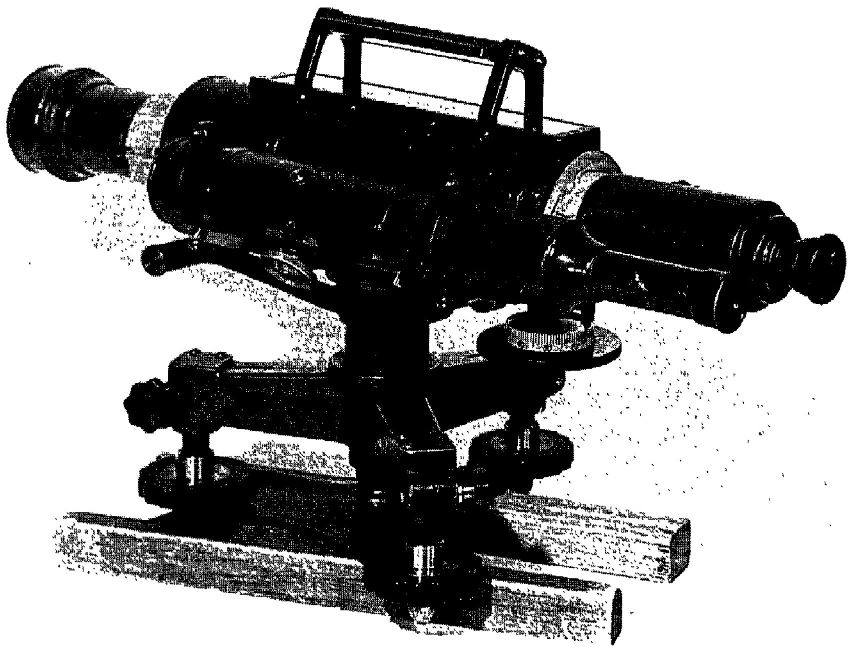

FIGURE 16.—Geodetic level used in first- and second-order leveling work. The observer is able to see the extremely sensitive bubble with his left eye and read the rod with his right eye without moving about the instrument.

into the net as adjusted without great difficulty, and it was not until 1927 that the need of an additional adjustment was felt. During this 15-year period, the only marked change in instrumental equipment was the introduction in 1916 of a new and improved type of leveling rod in which the fine graduations were placed on a strip of invar. This greatly reduced the difficulties experienced due to temperature changes and resulted in a further increase in the accuracy of the work.[22]

(*a*) *The 1927 Special Adjustment.*—In 1927, a special adjustment of the level net was undertaken. This resulted in an adjustment (for theoretical purposes) which is known as the 1927 Special Adjustment. Only the closed circuits of spirit leveling, including water leveling in the Great Lakes region, were adjusted, no sea-level connections being held fixed. After the net had been made

22. The orthometric correction to elevations, which takes into account the spheroidal shape of the earth and brings the elevations to their true heights above mean sea level, was not applied prior to about 1910. In the 1912 adjustment, it was applied only to the leveling lines west of the Mississippi River. It is now taken into account in all first- and second-order leveling. *Id.* at 9. For a complete explanation of this correction, *see* RAPPLEYE (1948), *op. cit. supra* note 19, at 43.

consistent internally by the adjustment, the difference of elevation between mean sea level at Galveston and the junction bench mark at Houston was used to determine the elevation of the latter. From that starting point the elevations of all other junction points were computed.

Using differences of elevation between the mean sea-level planes at the various tide stations and the nearest junction points, elevations were computed for the mean sea-level planes at the other tide stations. These elevations were independent of the local tide observations but were based on the mean sea-level surface at Galveston as carried to the other tide stations through the adjusted network.

The results indicated that the actual mean sea-level surface as defined by the tide observations tends to slope upward to the north along the Atlantic and Pacific coasts and upward to the west along the Gulf coast (*see* note 25 *infra*). The investigation also disclosed that sea level on the Pacific coast stood appreciably higher than that on the Atlantic coast.[23]

A. THE 1929 GENERAL ADJUSTMENT

By 1929, the level net had been extended until it included approximately 45,000 miles of first-order leveling. Many additional tide stations had been connected to the net and a number of connections had been made to the leveling net of the Dominion of Canada. A general adjustment was therefore undertaken in order to produce the best available elevations for all bench marks and to permit the adjustment of a large amount of leveling added since 1912 without the excessive rates of correction which were sometimes necessary in fitting the new work to that already adjusted.

The adjustment was completed in 1929 and included the combined level nets of the United States and Canada. Sea level was held fixed as observed at 26 tide stations—21 in the United States and 5 in Canada. The total length of the lines of levels actually used in the adjustment was about 60,000 miles—40,000 in the United States and 20,000 in Canada. This is identified as the 1929 General Adjustment.[24]

To make a further test of the variation of mean sea level from a level surface, all closed land circuits in the combined nets and the water leveling in the Great

23. CONTROL LEVELING (1961), *op. cit. supra* note 16, at 9–10. The results of the study are found in BOWIE, GEODETIC OPERATIONS IN THE UNITED STATES 29, SPECIAL PUBLICATION NO. 134, U.S. COAST AND GEODETIC SURVEY (1927).

24. The results of this adjustment have not been and probably never will be published in a single publication. Descriptions of bench marks with their elevations based on this adjustment are published in lithographed lists by lines. The present policy is to republish all leveling data by 30-minute quadrangles. This conversion is now taking place. CONTROL LEVELING (1961), *op. cit. supra* note 16, at 10.

Lakes area were adjusted without holding any sea-level connections. Then, as in the 1927 Special Adjustment (*see* 2121(*a*)), elevations based on Galveston, Tex., were computed for the mean sea-level planes at the other tide stations. This adjustment is identified as the 1929 Special Adjustment. The results verified and extended the findings of the 1927 adjustment.[25]

B. SEA LEVEL DATUM OF 1929

A sea level datum, as used in the Coast Survey, is a determination of mean sea level that has been adopted as a standard datum for heights. Sea level is subject to some variations from year to year, but because the permanency of a datum is of prime importance in engineering work, once a sea level datum is adopted it is generally maintained even though it may differ slightly from later determinations of mean sea level based upon longer series of observations. The sea level datum now used in the Coast and Geodetic Survey level net is officially known as "Sea Level Datum of 1929," the year referring to the last general adjustment of the net (*see* 2121 A).

As a result of the rapid expansion of the net during the years 1934 and 1935 and thereafter, together with the fact that some releveling disclosed areas where movements of marks had taken place either as a result of earthquakes or the removal of underground water, oil, and gas, or other factors, many supplementary adjustments became necessary in order to fit the new work to the old. These elevations were characterized as "Standard elevations based on the 1929 General Adjustment through the medium of the _______ Supplementary Adjustment." This caused confusion and resulted in a change of characterization for all elevations, whether based on the 1929 General Adjustment or the supplementary adjustments, and the establishment of a policy with regard to the readjustment of the net, as follows:

> Elevations based on the 1929 General Adjustment be held fixed, with some possible exceptions, and that the datum be officially designated as "Sea Level Datum of 1929." [26]

25. *Ibid.* The results of this adjustment are found in BOWIE, GEODETIC OPERATIONS IN THE UNITED STATES 23, SPECIAL PUBLICATION No. 166, U.S. COAST AND GEODETIC SURVEY (1929). Both the 1927 and the 1929 Special Adjustments were based upon the best available values for sea level at the different tide stations. These were not always for the same tidal epoch. Recent theoretical studies (in 1963) using the same epoch for all the tide stations indicate a more uniform slope for sea level than was revealed by the earlier studies.

26. CONTROL LEVELING (1961), *op. cit. supra* note 16, at 11. Exceptions to this policy are (1) where releveling discloses different results from the previous leveling, and (2) where repeated relevelings are made in areas of vertical change. In the first case, a limited portion of the net is readjusted in order to avoid an undue burden being placed on the new leveling; in the second case, readjustments are made based on "anchor" marks that are indicated by the releveling as stable, and the data are published in tabular form showing the bench-mark elevations at the date of each leveling.

A special problem is presented where new tidal stations and connections have been introduced into the net. In such cases, local mean sea level is not held at zero unless the newly determined tidal plane is considered properly consistent with values held in the 1929 General Adjustment. The alternatives are either to keep readjusting the net, especially along its edges, or else to admit that an actual difference exists between the geodetic datum and the local tidal planes. The latter seems to be the only practical approach and represents the present procedure in the Bureau.

The Sea Level Datum of 1929 must not be confused with local mean sea level. While both are of tidal definition, the first is an adjusted datum arrived at by holding sea level fixed as observed at a selected number of tide stations (*see* 2121 A), whereas the second is derived entirely from observations made at the local tide station. The difference between the two may be of significance under certain conditions of foreshore slope. In the demarcation of tidal boundaries, whether it be a high-water boundary or a low-water boundary, it is the intersection of the local datum with the shore that delimits the boundary. Hence, where only a geodetic bench mark (one that is part of the national level net) is available in an area where a tidal boundary is to be established, a correction must be applied to the geodetic elevation to bring it into harmony with the local datum plane.[27]

2122. *Bench Marks—Descriptions and Elevations*

In the early days of the Bureau's activity in control leveling, the bench marks established along the lines of levels were of various types. Many were chiseled squares and chiseled crosses, often flanked or surrounded by lettering cut in the masonry on which the mark was established. In the period prior to 1905, small copper or bronze bolts were often leaded or cemented into masonry structures to serve as bench marks.

The first bench-mark disks or tablets of a character at all similar to those now in use were cast of bronze.[28] Bench-mark tablets have been gradually improved, the type used at present in first- and second-order leveling being a

27. This was pointed up in a case that came to the Bureau's notice where the mean high-water line was established in one of the Texas bays from a geodetic bench mark whose elevation was 2.8 feet above the Sea Level Datum of 1929. No tides had been observed at that particular place, but from tide observations and geodetic leveling determinations in a nearby bay, it was determined that local mean sea level was 0.3 foot higher than the Sea Level Datum of 1929. When this difference was applied to the elevation of the first geodetic bench mark, an entirely different mean high-water line was obtained. Neither the attorney who was handling the case nor the engineer who established the original line was aware of this.

28. At one time the Bureau used bronze caps fastened on the tops of iron pipes set in the ground, but this was soon discontinued because of the difficulty encountered from rusting at or near the surface of the ground.

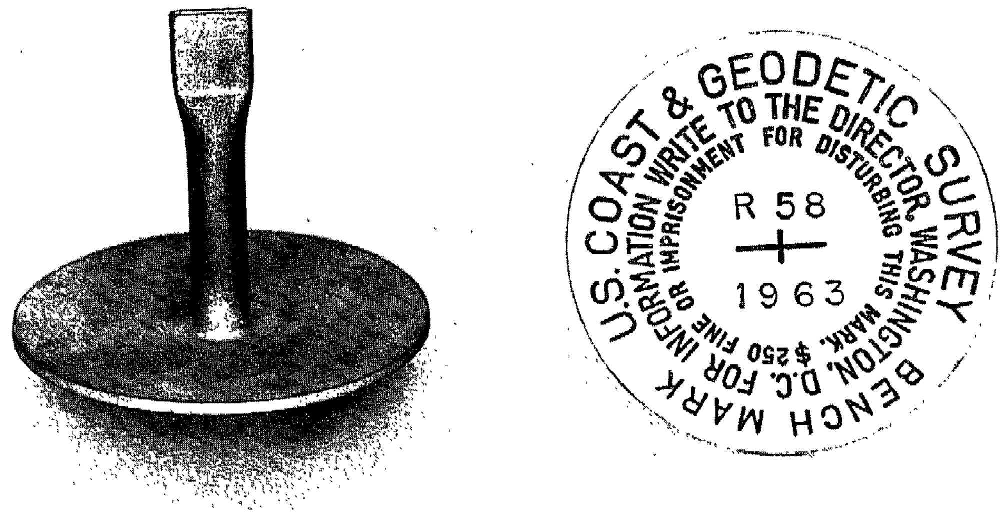

FIGURE 17.—A standard bench-mark tablet, set in masonry structures, rock outcrops, boulders, or concrete posts so that only the inscribed disk is visible.

tablet 3⅜ inches in diameter and a 3-inch shank, with the surface of the tablet slightly rounded so as to give a definite high point in the center to which the elevation is referred (*see* fig. 17). When these marks are set vertically (shank horizontal) in walls, the elevation refers to the center of the horizontal line in the center of the disk.[29]

Bench marks of the metal-tablet type have their designations stamped on them with dies. The system in use for numbering bench marks is as follows: The first mark established in a state is designated "A," the next "B," the next "C," and so on through the alphabet, to and including "Z." The next marks are stamped "A1," "B1," "C1," etc., to and including "Z1." The number is increased by one each time the alphabet is used. At first the letters "I" and "O" were used but they were so often confused with the numerals one and zero that later these letters were omitted from the bench-mark designations. In addition to these designations, the year of establishment is also stamped on the disk.

29. It was formerly the practice to stamp elevations on bench marks, but this was discontinued in Nov. 1956, except in Kentucky where the stamping of elevations was well advanced. The decision to discontinue was based upon a number of reasons among which were: changes in elevations due to earth movement, changes due to readjustments, and the difficulty of changing the stamping. *Discontinuance of Stamping Elevations on Bench Marks,* 7 JOURNAL, COAST AND GEODETIC SURVEY 120 (1957).

213. Index Maps and Control Survey Data

In the past, separate horizontal and vertical control index maps, indicating the locations of triangulation stations and the routes of level lines, were published by states mostly on a scale of about 1 : 667,000, with large-scale insets where necessary. Beginning in 1960, these separate state maps were being replaced by a new series covering 1° of latitude and 2° of longitude on a 1 : 250,000 scale, showing both horizontal and vertical control.[30] These index maps contain all the necessary information for identifying specific horizontal or vertical control data in an area, and for requesting particular control data from the Bureau. Horizontal control data available on request are the geographic positions (latitudes and longitudes) of triangulation and traverse stations, with azimuths and distances to nearby observed stations; the corresponding State Plane Coordinates in feet with plane azimuth to azimuth marks; and the descriptions for actually finding the control stations on the ground. Vertical control data available on request are the descriptions for finding the bench marks on the ground and their elevations above Sea Level Datum of 1929.

22. TOPOGRAPHIC AND HYDROGRAPHIC DATA

Topographic surveys of the Bureau have been used in the study of beach evolution, in the study of coastal erosion and protection, and frequently in the courts in the investigation of original land titles. Hydrographic surveys are basic tools for the geologist in his study of the origin and formation of the continental shelves and slopes.[31]

Topographic surveys of the coastal area and hydrographic surveys of the adjacent waters have been in progress since 1834 (*see* Part 2, 43, 52). In many areas, periodic surveys have been made in order to reflect the changeable nature of the coastline and the underwater topography. These represent a unique and comprehensive record of conditions as they existed at particular dates and of the changes that have occurred from both natural and man-made

30. This is a cooperative undertaking with the U.S. Geological Survey, and in most areas will show control surveys by both agencies. All Coast Survey work is shown in black and data are furnished by this Bureau. All Geological Survey control is shown in red and data are furnished by that agency.

31. A significant contribution to the study of submarine geology was made a few years ago by the Geological Society of America, when it prepared a series of submarine contour charts of the Atlantic continental shelf. These were based on detailed surveys of the Bureau and brought to light for the first time the highly dissected submarine topography of the northeast continental margin and the many submarine canyons that indent the continental slope. Veatch and Smith, Atlantic Submarine Valleys of the United States and the Congo Submarine Valley (1939).

causes. Besides their use in the production and maintenance of the nautical charts of the Bureau, these records find application in a variety of other uses by the public and by agencies of government.

Topographic and hydrographic surveys are made separately and are indexed in two parallel numbering systems (*see* Part 2, 1241). For studies of the shoreline and adjacent land areas, topographic surveys should be used; for studies of water depths, hydrographic surveys are appropriate. Scales of topographic surveys and the corresponding inshore hydrographic surveys are nearly always at either 1:10,000 or 1:20,000. Offshore hydrographic surveys are at smaller scales. A limited number in harbor areas are at 1:5,000 scale.

This section deals primarily with the general character of such surveys and the form in which the data are available; their interpretation is discussed in Part 2, chapters 4 and 5.

221. Topographic Surveys

Topographic surveys, as the name implies, are surveys of the topography or the land features of an area. They may vary both in coverage and in content. The area of coverage generally follows the chart needs at the time of the survey. On the early planetable surveys this varied from 1 to 10 miles. On photogrammetric surveys made from aerial photographs, coverage may extend from the shoreline inland for as much as 5 or more miles, or up to the 7½-minute quadrangle limit. Many show only the shoreline and planimetric features immediately adjacent thereto; others are complete planimetric maps; and still others are complete topographic maps.[32] From 1835 to 1927, practically all the topographic surveys were made by planetable. Since 1927, aerial photographs and photogrammetric methods have been utilized increasingly to provide the required topographic information along the coast. In recent years, most of the topographic surveys are recorded in the form of manuscript maps compiled from aerial photographs and ground survey data.

From the standpoint of waterfront boundaries, the most significant feature on a topographic survey is the mean high-water line (the dividing line between

32. Under a Memorandum of Understanding, dated Mar. 25, 1947, between the Coast and Geodetic Survey and the U.S. Geological Survey, a procedure was established whereby the activities of the two agencies would be more closely integrated so as to avoid overlapping and duplication in survey operations, but without any change in the responsibilities of either agency. To this end, it was agreed that a line be established around the coastal area of the United States, which shall, in general include the 7½-minute quadrangles touching the coastal waters. Where topographic information adequate for use in preparing nautical charts does not already exist within the area outlined, and it is determined that the Geological Survey will not be able to supply the needed information in time, the Coast Survey will make the required surveys to the inland borders of the 7½-minute quadrangles concerned. The results of such mapping are furnished the Geological Survey in a form mutually agreed upon for each particular project.

land and sea) which the topographer delineates without recourse to the running of levels (*see* Part 2, 4421). On some surveys the low-water line is also fully delineated but generally it merely represents the topographer's estimate of its location without waiting for low tide (*see* Part 2, 4461).

222. Hydrographic Surveys

Hydrographic surveys are surveys of the water area. They show principally the depths of water (in feet or fathoms) taken during the field survey but referred to a particular plane of reference or sounding datum (mean low water along the Atlantic and Gulf coasts, and mean lower low water along the Pacific coast). Besides the water depths or soundings, a completed hydrographic survey contains other data necessary for a proper interpretation of the survey, such as depth curves or depth contours, bottom characteristics, submerged and exposed rocks, and control stations.[33] Many of the surveys show a delineation of the zero depth curve, which corresponds to the sounding datum of the area, although surf conditions and the range of tide usually control the inclusion of such information.

Until the advent of echo sounding following World War I, inshore hydrographic surveys were made with the handlead and line or with a graduated sounding pole (*see* Part 2, 541). Since that time, some form of echo sounder (visual or graphic recorder) has been used. Today, nearly all sounding is done with a graphic recording type of instrument which traces a continuous profile of the sea bottom from which the depths to be shown on the survey sheet are scaled. Modern hydrographic surveys therefore exhibit a far more intensive development of the submarine relief than are found on the earlier surveys.

223. Copies of Field Surveys

Photographic copies of field topographic (planetable) and hydrographic surveys, and of topographic surveys compiled from aerial photographs, are

33. The full extent of a complete hydrographic survey may be described as consisting of a systematic coverage of the area with depth measurements (soundings) sufficient to ensure that all dangers to navigation have been found; a development of all underwater features of special significance to navigators, such as channels, reefs, banks, shoals, and characteristic submarine features; a determination of the least depths on all dangers to navigation; the location of the soundings, dangers, and submarine features so that they can be charted correctly with reference to the adjacent land features, or by latitude and longitude; contemporary tide observations from which the soundings may be reduced to a reference plane, and often for the determination of this plane; and supplemental operations to locate and obtain the descriptions of numerous features, such as rocks, reefs, wrecks, aids to navigation, and landmarks, that must be charted and described in the *Coast Pilots* published by the Bureau. Adams, Hydrographic Manual 191, Special Publication No. 143, U.S. Coast and Geodetic Survey (1942).

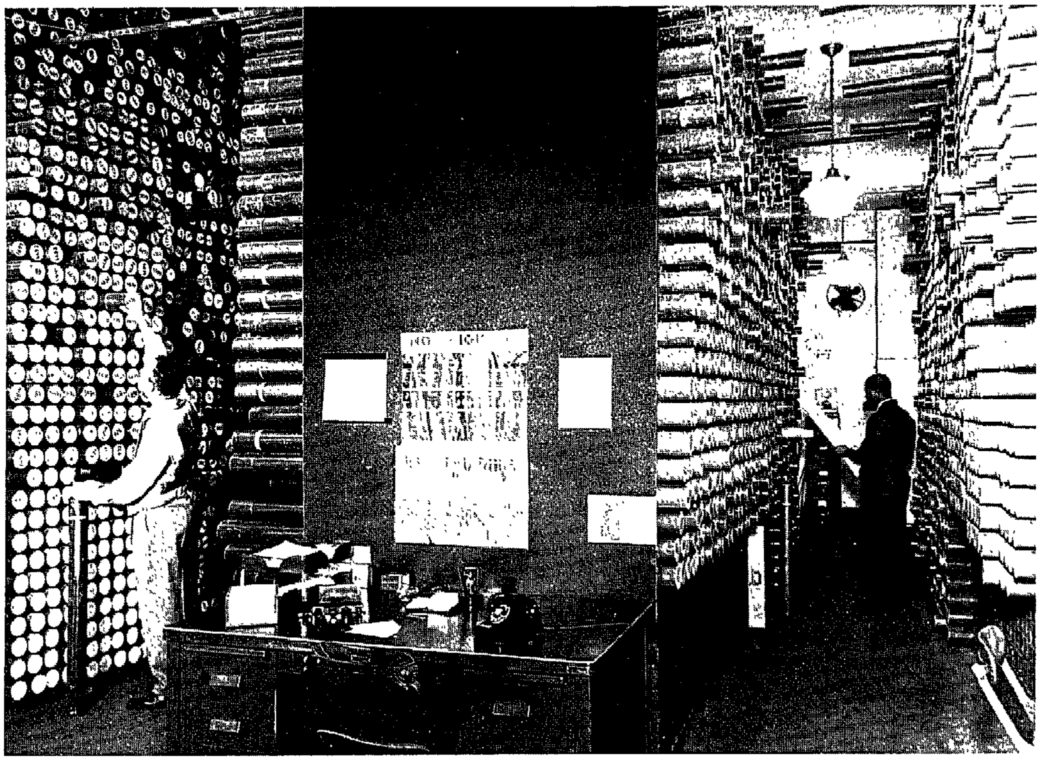

FIGURE 18.—A fireproof vault houses more than 18,000 topographic and hydrographic surveys that are used for keeping nautical charts of the Coast Survey current, and for other purposes. The earliest survey dates back to 1834.

available at the nominal cost of reproduction.[34] Photostatic copies are limited to 18 by 24 inches in size and can include only a section of a planetable or a hydrographic survey. Not more than two adjacent photostats of one survey will be made. When a copy of the entire survey is desired and it cannot be included in two photostats a bromide copy is made in one sheet.[35] A few surveys might require more than one bromide, depending on size and available negative.

A photostat is normally a negative in that the background is black and the detail is white, but the copy is otherwise correct. Positive photostats may be made from the negatives and have white backgrounds, but this is a double

34. As of May 1963, there were 5,400 planetable surveys, 8,800 hydrographic surveys, and 4,400 surveys compiled from aerial photographs on file in the Bureau archives (*see* fig. 18).

35. Photostating is a direct photographic process and no intervening film or plate is required. The bromide process requires the original to be first photographed at a reduced scale on a film or glass negative, and then making an enlargement on bromide paper to the scale desired but usually at approximately the same scale as the original. The bromide paper does not come in contact with the negative.

process. Bromides are always positive with black lines and figures on a white background. Upon request, a survey will be enlarged photographically to any scale up to twice the scale of the original or will be reduced to any scale no smaller than one-half the scale of the original.

Photographic copies of topographic surveys compiled from aerial photographs by photogrammetric methods are furnished as ozalid prints,[36] unless enlargements are requested in which case a film negative is first made and a photographic print furnished from the negative. Contact prints, reductions, and enlargements can also be furnished on materials such as the plastics to meet special needs.

Where required, certified photographic copies of original surveys for use in judicial proceedings may be obtained at a small additional cost.

2231. *Survey Indexes*

Two series of index sheets, which show the date, area covered, and scale of each survey, are available for the planetable and the hydrographic surveys along the Atlantic, Gulf, and Pacific coasts (exclusive of Alaska and Hawaii). An independent index series is available for the photogrammetric surveys which differentiates by color the classification of the surveys (planimetric maps, shoreline surveys, topographic maps) and furnishes information on area covered, scale, and date of aerial photographs upon which the surveys are based. Index sheets are published letter size and are available on request.

2232. *Aerial Photographs*

Original aerial photographs, from which the photogrammetric maps are prepared, form a valuable source of information for use in many fields of investigation. The wealth of information and fullness of detail embraced in good quality aerial photographs cannot be matched by any practical method of mapping from the ground. But aerial photographs are not maps in that they are perspectives and not orthographic projections of the ground on the spheroid of reference. To convert them to map form requires not only the use of special instruments and methods but extensive ground control as well in order to correlate the photographs with geographic position, elevation, scale, and orientation. Also, an aerial photograph never fits those on either side exactly, except over perfectly flat ground and after rectification.

36. Ozalid prints are photographic contact prints prepared in much the same manner as blueprints. The developed print shows a colored line on a white background. These prints are developed by a dry process and have a low distortion percentage.

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When used with an understanding of these limitations, they provide documentary evidence of existing conditions that would be difficult to controvert. Practically all of the coastline has been photographed several times in connection with keeping the nautical charts of the Bureau up to date.

The Coast and Geodetic Survey uses several single-lens mapping cameras and until recently made extensive use of a nine-lens camera specially designed for coastal photography. Prints of nearly all of the Bureau's aerial photography are available to the public and prices are furnished on request. Prints of nine-lens photographs are approximately 36 by 36 inches in size and have to be prepared in accordance with the scale of the aerial negatives. Ratio prints (enlargements or reductions) cannot be furnished for nine-lens photographs.

Most of the single-lens photography available at present is panchromatic photography. However, both infrared and color photography have been used in recent years and the use of color is increasing rapidly. Either contact prints or ratio prints (enlargements or reductions) can be furnished for single-lens panchromatic and infrared photography. Only contact prints can be furnished for color photography.

Aerial photography is usually indexed on 1:250,000 scale base maps, photographic copies of which are also available at a nominal cost.

23. TIDAL DATA

To a maritime nation like the United States with its extensive coastline, a knowledge of tidal phenomena is essential. Concentrated in the coastal areas tributary to tidal waters is a vast wealth of resources and facilities, intimately associated with and influenced by the ceaseless action of the tide. In order that these tidal movements may be better understood and utilized, the Coast and Geodetic Survey has been engaged for many years in a continuing program of tidal study and investigation. This program had its origin in the need for reducing to a common level, or datum plane, soundings taken at different stages of the tide during hydrographic surveying operations so that nautical charts will show all depths referred to a common datum. The further needs of the mariner were met with the publication of *Tide Tables* giving the predicted times and heights of the tide annually in advance. In recent years, greater emphasis has been placed on the needs of the land surveyor engaged in the demarcation of waterfront boundaries determined by tidal definition. It is with this last category that this section primarily deals, but only insofar as the data available to him in the Bureau are concerned.

231. The Tidal Program of the Bureau

The Coast and Geodetic Survey, as the federal agency most concerned with tidal studies, is being called upon with increasing frequency for special tidal investigations. Its tidal program must therefore be sufficiently comprehensive to serve the dual purpose of providing the tide observations and processed results for conducting its own survey operations and for meeting the additional demands for special data. This program includes the operation of a system of control tide stations at which continuous records of the rise and fall of the tide are maintained; the determination of tidal datum planes for surveying and other engineering purposes; the prediction of tides and the preparation and publication of annual *Tide Tables* in advance; the study of mean sea level and its long-period variation; the study of methods of observing tides and reducing tidal observations; and the study of tidal phenomena in general.

2311. *Control Tide Stations*

Any place where continuous tide observations have been taken or are expected to be taken over a number of years has been designated a *control tide station* (formerly called a primary tide station), and it is from this source that most of the basic tide data are obtained.[37] Control tide stations serve a number of purposes. They furnish data on the height of the tide at any particular time, thus permitting the determinations of mean sea level at these stations, which are then used as starting and tie-in points for the precise level net of the country (*see* 2121 A); they permit the precise determination of other tidal datum planes at these stations and make possible the correction to mean values of short-series tide observations at subsidiary stations; furnish data on the slow changes taking place in the relative elevations of land and sea; and provide the basic data for the study and advancement of the subject of tides generally.[38] The number and distribution of control tide stations depend on several factors, the more important of which are the tidal characteristics involved (type, range, interval, annual variation, etc.), the particular needs of the area for tidal data,

37. The first control tide station in the United States was established at Governor's Island, N.Y., in 1844. The tide station in longest operation is at the Presidio at the entrance to San Francisco Bay, and has continuously recorded the rise and fall of the tide since July 1897 (*see* Part 2, 543 note 36).

38. This is accomplished through the operation of an automatic tide gage that records on a roll of paper the rise and fall of the tide in the form of a curve, the abscissas of which represent the time and the ordinates the height. The Bureau is in the process of converting the majority of the tide stations so that the record will be a punched tape with readings every 5 minutes. This will take between 5 and 10 years to complete.

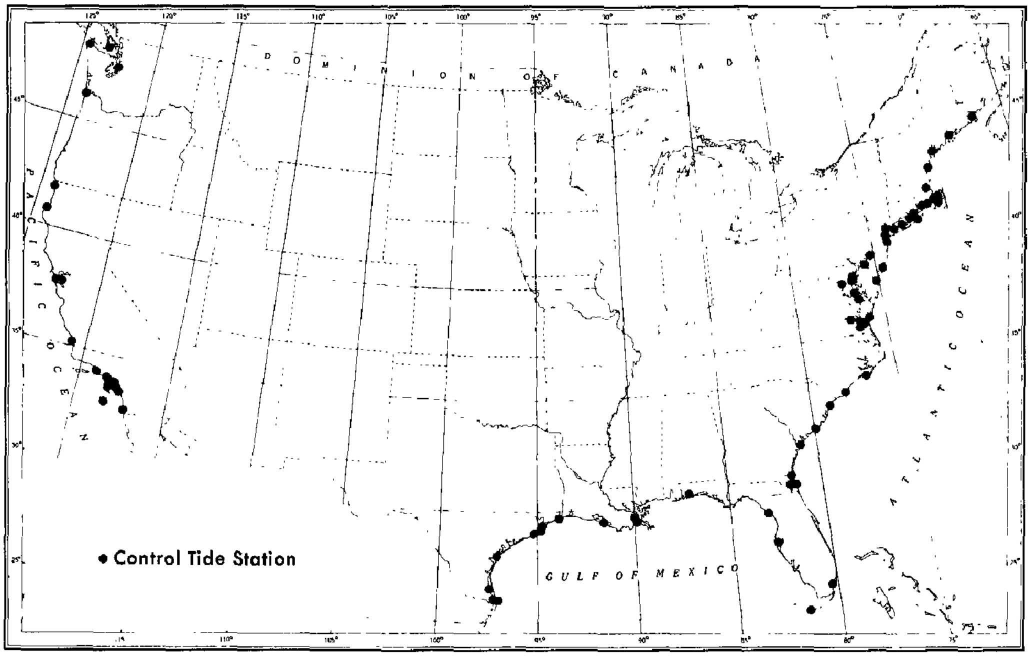

FIGURE 19.—Control tide stations in the United States (1963). These stations house automatic gage equipment that records a continuous record of the rise and fall of the tide from which most of the basic tide data are obtained.

and the facilities available for station installation and operation.[39] The principal ports and developed areas are the favored locations for the control tide stations of the Coast and Geodetic Survey, as it is here that the necessary facilities can be most readily found and the resulting tide data used to best advantage. The number of control tide stations has been gradually increased until it now (in June 1963) includes more than 100 within the United States and possessions (*see* fig. 19).

A. THE 19-YEAR CYCLE

Although tidal constants and tidal datum planes may be established (within certain limits of accuracy) from observations extending over a month or a year, for the demarcation of valuable tidelands or for scientific purposes continuous observations extending over a period of 19 years are required. This period is generally reckoned as constituting a full tidal cycle because the more important of the periodic tidal variations due to astronomic causes will have gone through

39. The selection of sites for control tide stations on the basis of tidal characteristics alone, while an excellent procedure from one standpoint, would frequently result in locations that would be impracticable when the other two factors are taken into consideration.

complete cycles, and because the variations of a nonperiodic character resulting from meterological causes may be assumed to balance out during this epoch.[40] It is therefore customary to regard results derived from 19 years of tide observations as constituting mean values.

This, however, is not the whole answer. If the mean level of the sea remained constant over long periods of time and if the coast were absolutely stable, then sea level determined at any place from one 19-year series would be the same as that derived from another such series, even if separated by a number of years. But long-period observations indicate slow, secular changes in the relation of land and sea.[41] While averages obtained from two overlapping 19-year epochs, for example, 1924–1942 and 1925–1943, exhibit an inconsequential difference, those obtained from two independent 19-year epochs, for example, 1903–1921 and 1930–1948, may show a difference great enough to be of significance where precise determinations are required.[42] Therefore, in defining tidal datums it is necessary to identify them with a particular 19-year series. To make datums comparable at all localities the same group of years must be used. Beginning with 1943, it was in general the practice of the Coast Survey to refer tidal datum planes to the 19-year period encompassing the years 1924–1942. The 19-year period used at the present time covers the years 1941–1959.

2312. *Short-Series Tide Stations*

In addition to the long-series control tide stations operated by the Bureau, tidal observations are made at short-series tide stations established as a necessary part of its hydrographic survey operations in order to provide the data required both for the determination of the reference datum and for the reduction of the soundings to that datum. In planning for these surveys, the locations of the tide stations are so selected as to also provide data of general utility for other pur-

40. The 19-year cycle reflects the full effect on the time and range of the tide due to the variation in the longitude of the moon's node which has a period of 18.6 years.

41. Systematic tide observations have provided quantitative data for the study of such changes. Along the Atlantic coast, investigations indicate that in the last 40 years the relative rise of sea level has been 0.011 foot per year; along the Pacific coast, it has been 0.005 foot per year; and along the Gulf coast, based on three stations in Florida, it has been 0.011 foot per year (at Galveston, the rate of rise has been 0.021 foot per year, due probably to land subsidence in the area). On the other hand, in Southeast Alaska, a 1959 special tidal survey indicates land emergence rather than a falling of sea level, the average change being of the order of 0.05 to 0.09 foot per year (*see* Part 2, 5654 note 81).

42. At New York, sea level from the 1930–1948 series is 0.29 foot higher than from the 1893–1911 series; at Baltimore, the 1930–1948 series gives a value 0.26 foot higher than the 1903–1921 series; and at Galveston, the 1930–1948 series shows a value 0.39 foot higher than the 1909–1927 series. MARMER, TIDAL DATUM PLANES 63–64, 104–105, SPECIAL PUBLICATION NO. 135, U.S. COAST AND GEODETIC SURVEY (1951).

poses.[43] The lengths of these series depend upon the time it takes to complete the hydrographic operations in a given area. The results from such stations are brought to the equivalent of 19-year means by comparisons with simultaneous observations at suitable control stations where mean values are available from long-series records. In their corrected form they can be utilized in *Tide Tables,* tidal notes for nautical charts, and in the determination of tidal datum planes.[44]

2313. *Special Area Tide Surveys*

In some areas a need has developed for more detailed tidal information than is provided by the nearest control stations and by the short-series stations. To supplement these sources, special tide surveys have been made in selected areas. Originally, these surveys were limited to ports and harbors and consisted mainly of short series of observations for the verification and improvement of existing data. Later, they evolved into comprehensive regional surveys through which tide-gage records were obtained simultaneously at 10 to 20 stations for periods of a year or more. This provided data to determine the varying times and heights of high and low water at critical points. Equipment, installation, and operation were the same as at the control station. Also, the usual leveling operations at the individual stations were extended to include connection with the first-order level net, thus providing a common reference datum for correlating tidal heights and planes throughout the area of the survey. The first of such systematic surveys was begun in New York Harbor in 1922. This was the pilot project by which all others were patterned.[45] This program was discontinued just prior to World War II, and as of June 1963 had not been resumed.

2314. *Establishment of Bench Marks*

All along the coast, wherever tides are observed, the Coast Survey establishes tidal bench marks, the elevations of which are determined with reference

43. During the years 1954–1958, the average number of short-series tide stations established each year was 73.

44. Two methods are available for establishing tidal datum planes from short-series observations: (1) comparison of simultaneous observations, and (2) correction by tabular values. The accuracy attainable depends upon the length of the series used. The second method is used when tides are observed at a place remote from a suitable control station. However, the present network of stations assures a suitable one for use with the first method. An explanation of the methods for determining the datum of mean high water is given in Marmer (1951), *op. cit. supra* note 42, at 87–95.

45. Marmer, Tides and Currents in New York Harbor, Special Publication No. 111, U.S. Coast and Geodetic Survey (1935). The following area surveys have been completed and the results included in special publications: Portsmouth Harbor; Boston Harbor; Narragansett and Buzzards Bays, and Nantucket and Vineyard Sounds; Long Island and Block Island Sounds; Hudson River; Delaware Bay and River; Chesapeake Bay; San Francisco Bay; and Southeast Alaska.

to the planes of local high water, mean sea level, low water, and other tidal planes. The practice is to establish three or more such marks for any series of observations, no matter how short. The zero of the tide staff is connected by spirit levels to these marks. This makes it possible to replace the staff at the same elevation during the progress of the observations, should it become destroyed or should its elevation be changed by accident. The bench marks also serve the further purpose of preserving for future use the datum planes that are determined from the tidal observations.[46] The standard tidal bench mark of the Bureau consists of a brass disk, about 3 inches in diameter, with a shank about 2½ inches long for insertion into a building or other substantial support.[47] Since bench marks are subject to disturbance and destruction through construction or building activities and the operation of natural forces, the Bureau conducts a bench-mark recovery program for periodic inspection of these marks. Where necessary, new bench marks are established and descriptions of existing bench marks revised.[48]

A complete record is kept of each tidal bench mark, including its original and revised descriptions, dates of establishment and recoveries, and its elevations referred to the tide staff for each successive leveling connection. For the control stations, where leveling connections between staff and bench marks are checked periodically, compilations are prepared showing the relative elevations of the different bench marks for each leveling operation. These compilations provide information on the relative stability of individual bench marks, indicating those that are most suitable for long-period reference and others that must be replaced as too unstable to fulfill their function. To permit datum correlation of surveys of different dates, a record is kept that shows for each hydrographic survey the relation of the reference datum to the tide staff and specified bench marks.

232. Engineering Aspects of Tides

The rise and fall of the tide is a continuing phenomenon and varies from day to day and from place to place. Thus, at New York the mean range is about 4.5 feet while the maximum range may be 7 feet. At the Atlantic entrance to the Panama Canal the range is less than a foot while at the Pacific

46. The bench marks and zero of the tide staff are connected by a double line of levels run in opposite directions. Coast Survey instructions prescribe that the forward and backward differences in the elevations of two tidal bench marks must not differ by more than 0.035 $\sqrt{K}$ feet, K being the distance in statute miles leveled between the two bench marks. Marmer (1951), *op. cit. supra* note 42, at 25.

47. The same type of disk is used for the tidal bench marks as is used in the vertical control network (*see* fig. 17). The year of establishment is stamped on the disk, as is the identifying number, but the latter follows a different numbering system from that used in the vertical control.

48. Many of the earlier tidal bench marks were of such temporary nature that they were not long recoverable and the planes that they originally referenced can no longer be positively identified.

entrance it averages 12.5 feet. On the other hand, at Anchorage, Alaska, a rise and fall of approximately 35 feet may be encountered on certain days.

Tides also differ in the character of the rise and fall. At New York, for example, there are two tides a day of approximately equal range; at San Francisco, there are two tides a day of unequal range; and at Pensacola, there is but one tide a day.

These and other aspects of the tidal phenomenon are matters which the engineer must take into account in planning or designing waterfront structures or in establishing waterfront boundaries based on tidal definition.

2321. *Establishment of Datum Planes*

The simplicity of its definition, the accuracy of its determination, and the certainty with which it may be reproduced at some future time, give value to the tidal datum as a plane of reference. There is no one natural or basic tidal datum, although the datum of mean sea level is frequently so designated because it is the plane about which the tide oscillates. There are a number of datums which may be derived from tidal observations, the selection of the most satisfactory one being dependent upon the specialized purpose which the datum is to serve and the type of tide existing in a particular locality.

In its work along the coasts of the United States and in the interior of the country, the Coast Survey utilizes the following principal tidal datums: mean sea level, mean high water, mean low water, and mean lower low water. In addition, it recognizes the tidal datums of mean higher high water, and half tide level, or mean tide level, as of value to the engineer and foı which the relationship to the other datums is determined (*see* 2332).

A. MEAN SEA LEVEL—A BASIS FOR THE LEVEL NET

Sea level as a basis for the level net of the country has been previously discussed. It was pointed out that the Sea Level Datum of 1929, on which the elevations in the interior are based, is an adjusted datum and may differ from local mean sea level (*see* 2121 B).

Mean sea level at any place is the mean level of the sea at that place. It is the primary tidal datum plane and may be defined as the average height of the surface of the sea for all stages of the tide for a 19-year period, usually determined from hourly height readings.[49] Sea level is the level of the sea from which the tide rises and falls, that is, it is the level of the sea freed from the rise and fall

49. Mean sea level is generally assumed to constitute an equipotential surface, but as derived from tide observations at different places it deviates somewhat from such a surface because of the effects of winds and variations in barometric pressure. A wind blowing from the sea—an onshore wind—tends

of the tide. Or stating this in another way, the daily rise and fall of the tide, which is of astronomic origin, is superimposed upon the daily variation in sea level brought about primarily by changing meteorological conditions. It is important that this concept be kept in mind (*see* fig. 20).[50]

In order to distinguish the average level to which the sea rises during various periods from *mean sea level,* sea level derived from observations extending over a period of 1 day, 1 month, 1 year, is referred to as daily, monthly, and annual sea level, respectively. At any point on the coast, sea level varies from day to day, from month to month, and from year to year. From one day to the next, sea level may vary by a foot or more, and within the same year two values of daily sea level may differ by 5 feet or more. Monthly sea level is subject to variations of both periodic and nonperiodic character so that within a year, sea level for two different months may differ by as much as a foot. Yearly values may differ by as much as one-tenth or two-tenths of a foot from one year to the next and in addition may be subject to a slow progressive rise or fall. The term *mean sea level* is reserved for the value obtained from averaging the hourly height values of the tide over a period of 19 years, this being considered as constituting a full tidal cycle and is regarded as a primary determination (*see* 2311 A).[51]

Observations covering a period of 19 years are obtained at but relatively few places along the coast. At all other places where mean sea level is required, satisfactory secondary determinations can be made by means of observations covering much shorter periods, if the results are corrected to a mean value by comparison with the determination at some suitably located control tide station. The precision with which mean sea level can be derived by this method depends upon the length of the series used in the comparison. In general, it may be taken that mean sea level determined from 1 day of observations will give a value correct to within 0.25 foot; 1 month, to within 0.1 foot; and 1 year, to within 0.05 foot.[52]

to raise the level of the sea along the coast; while a wind blowing from the land—an offshore wind—tends to lower it. This wind effect is brought about not by any effect on the tide-producing forces, but by the effect of the wind on the level of the sea; the amount of tidal rise or fall is changed by the wind only as this rise or fall takes place from a higher or lower level of the sea. The effect of variations in barometric pressure is to depress the level of the sea with a rising barometer and to raise the level with a falling barometer, the water thus behaving approximately as an inverted water barometer.

50. From this it follows that changes in sea level are independent of the range of tide. It is sometimes assumed that at stations having a large range of tide greater variations in sea level are to be expected than at stations having a small range. That there is no basis for this assumption is brought out by the fact that at Boston the range of tide is more than twice that at Atlantic City, yet the magnitude of the changes in daily sea level is much the same at both places. MARMER (1951), *op. cit. supra* note 42, at 49.

51. *Id.* at 63. For a detailed discussion of mean sea level in general, and daily, monthly, and annual sea level at various points along the coasts of continental United States, *see id.* at 45–63.

52. *Id.* at 65–67. A 3-year period has been found to give a value correct to within 0.03 foot, and 9 years to within 0.016 foot.

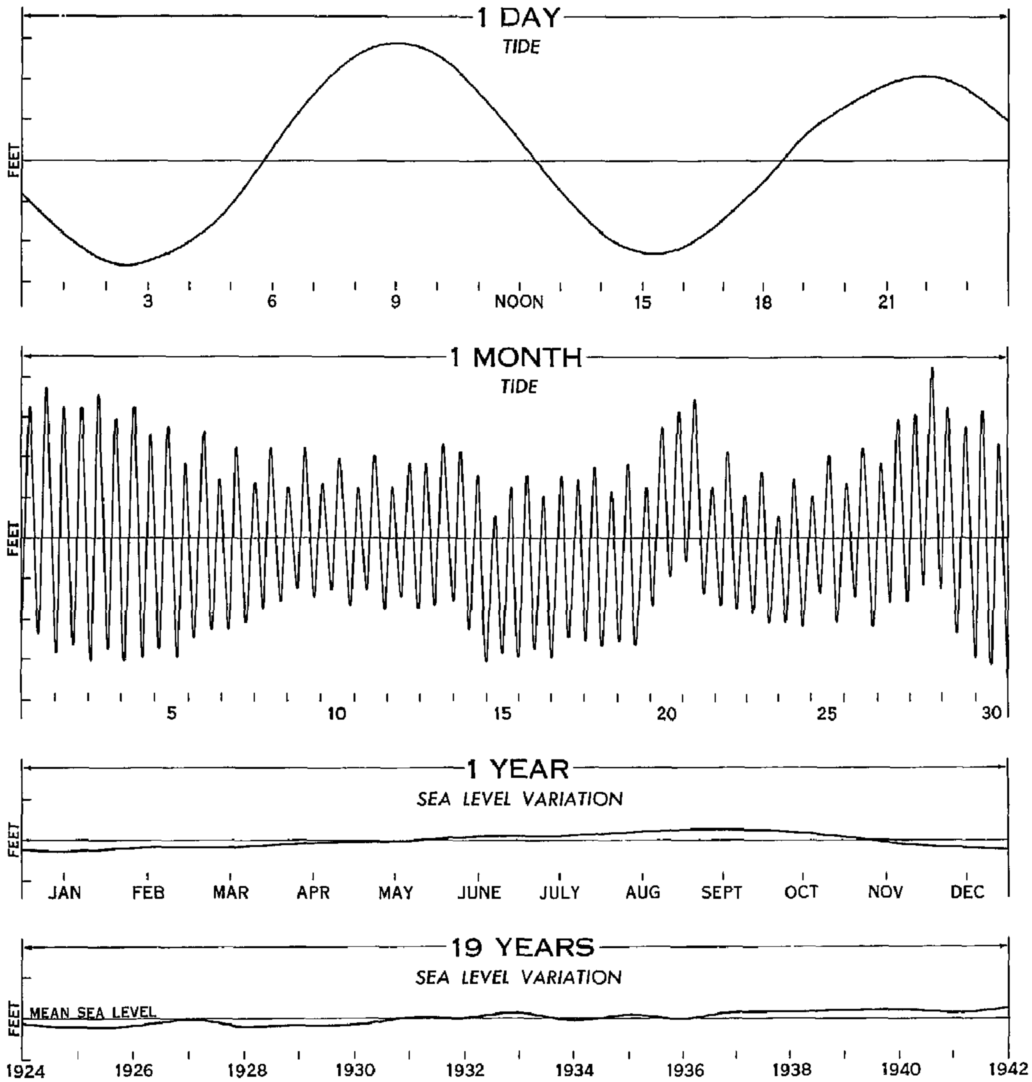

FIGURE 20.—Sea surface variation from Coast and Geodetic Survey tide station at Atlantic City, N.J.

B. OTHER DATUM PLANES

Besides the datum of mean sea level, other datum planes are established from tide observations for use on the surveys and nautical charts of the Coast and Geodetic Survey, and for boundary purposes.

(*a*) *For Shoreline and Alongshore Features.*—Along all coasts, the datum of mean high water is used as the plane of reference for the shoreline—the dividing line between land and sea—and for elevations of alongshore features on the topographic surveys and nautical charts of the Coast Survey.

(*b*) *For Soundings on Surveys and Charts.*—As a reference plane for soundings on the hydrographic surveys and nautical charts of the Bureau a low-water datum is used because of its practical utility to the navigator. The aim is to provide him with a margin of safety consistent with prevailing conditions. From the standpoint of navigation, the critical part of the tidal cycle is at the time of low water. At such time, depths in a channel or over a shoal area are at a minimum. If a datum higher than low water were to be used as a reference plane, depths shown on the nautical charts would be greater than actually exist at the time of low water. This might result in giving the mariner a false sense of security, particularly in areas where the controlling depth approaches the draft of his vessel. Another practical advantage of a low-water datum is that tidal corrections given in the *Tide Tables,* which the mariner uses in conjunction with the chart to find the depth at a specified time and place, will be mostly additive values. It is for these reasons that low-water datums have been adopted for the nautical charts of the Coast Survey.

But even low-water datums differ on the different coasts of the United States, depending upon the prevailing type of tide. Along the Atlantic coast, where the tide is of the semidiurnal type with two tides a day of approximately equal range and successive low waters differ but slightly, the adopted datum is mean low water, which is the mean of all the low waters in a given area. This also applies to the Gulf coast where the tide is predominantly of the diurnal type with but one high and one low water in a tidal day. On the Pacific coast, where the tide is of the mixed type with two tides a day of unequal range and successive low waters exhibit a marked inequality, the adopted datum is mean lower low water, which is the mean of the lower of the two low waters each day.

The advantages of using a mean lower-low-water datum over a mean low-water datum for Pacific coast charts are similar to those described above for low-water datums. The important point to keep in mind is that the selection is dictated by the practical needs of navigation. Its use should be so appraised.[53]

(*c*) *For Riparian Boundaries.*—Boundaries determined by the course of the tides involve two engineering aspects: a vertical one, predicated on the height reached by the tide during its vertical rise and fall, and constituting a tidal plane or datum; and a horizontal one, related to the line where the tidal plane

53. The datum of mean low water along the Pacific coast and in Alaska is not to be confused with the datum of mean lower low water. The first is the mean of all the low waters (higher lows and lower lows) occurring each tidal day over a period of 19 years; the second is the mean of only the lower lows over the same period. The two are technically distinct datums and cannot be equated any more than mean high water can be equated with mean higher high water.

intersects the shore to form the tidal boundary desired. In this section only the vertical aspect will be considered.

As a basis for riparian boundaries determined by tidal definition, the datums of mean high water and mean low water are the ones generally encountered.[54] High water and low water are subject to periodic variations from day to day, from month to month, and from year to year. In addition, they are subject to the nonperiodic variations found in sea level (*see* 2321 A).

In view of these variations, the datum of mean high water at any place may be defined simply as the average height of the high waters at that place over a period of 19 years; and the datum of mean low water as the average height of the low waters for the same period. In tides of the semidiurnal and mixed types no problem arises in determining either of these datums from the definition stated. But in applying the definition to tides which are predominantly diurnal—as is the case with tides in the Gulf of Mexico—the question arises whether to include or exclude from the tabulations the secondary tides which occur every fortnight and the tide curve exhibits two high and two low waters during a tidal day. These secondary tides have small ranges and are frequently difficult to detect on the tide record because of the disturbing effects of wind and weather. Therefore in tabulating tides of the diurnal type the secondary tides are completely disregarded in determining the datums of mean high water and mean low water, and on the days when two tides occur only the higher high water and the lower low water are used.[55]

2322. *Prediction of Tides*

In the days of shallow-draft vessels advance knowledge of the state of the tide was of little importance. With the increased size and draft of modern vessels, operating on exacting schedules, such advance information became of considerable interest to the navigator, for the state of the tide determines when certain harbors may be entered, when bars may be safely crossed, and when short cuts over shoal places may be attempted. It was in recognition of these needs that the Coast Survey undertook to provide such data in the form of *Tide Tables*.[56]

54. In almost all the states the boundary between the privately owned upland and the state owned tidelands is the high-water line. In a few states, the general rule has been modified and the boundary is the low-water line.

55. MARMER (1951), *op. cit. supra* note 42, at 86–87, 104. For a further discussion of this phase of riparian boundaries set in the context of the Submerged Lands Act (67 Stat. 29 (1953)), *see* Volume One, Part 2, 1613.

56. The procedure of publishing *Tide Tables* was initiated by the Bureau in 1853. These were first published in the annual reports in an abbreviated form without the daily predicted values that are given today. Prior to 1853, charts of the Coast Survey included tide notes which gave limited information for

Besides their use in navigation, tide predictions find application in a variety of activities connected with a modern port. The engineer engaged in harbor improvements, in the building of wharf structures, or in the placing of bridge spans, must be cognizant of the tidal conditions likely to be encountered. And the surveyor may utilize predicted tides for establishing an approximate high- or low-water boundary line that may be adequate for certain purposes and under certain conditions.

A. THE TIDE TABLES

The *Tide Tables* are published a year in advance and furnish information on the times and heights of high and low water for every day of the year for the more important ports of the world. By means of *tidal differences,* derived from a comparison of tide observations at a reference port and at a subsidiary station, the approximate times and heights of high and low water for a large number of other ports may be obtained. Each tide table includes a table of tidal differences with full explanation for its use.[57] In such a table it is the usual practice to refer the tides at a number of places to the tides at the nearest principal port for which daily predictions are given. This is based on the fact that, as a rule, the tides at nearby places are of the same type, this being one of the principal considerations in using a table of differences.[58] The tidal datum from which the predicted heights are reckoned is the same as that used for the largest-scale charts of the locality. In the United States, these datums are mean low water for the Atlantic and Gulf coasts and mean lower low water for the Pacific coast.

The table of differences also gives the *mean range,* the *spring range,* and the *diurnal range* of the tide at the various places listed, as well as the value of *mean tide level.* Mean range is the difference in height between mean high water and mean low water. Spring range is the average semidiurnal range occurring semimonthly as a result of the moon being new or full; it is larger than the mean range where the type of tide is either semidiurnal or mixed, and is of no

determining the height of mean high water and the time with reference to the moon's meridian transit. In 1867, the annual report tables were discontinued and separate tables of predictions published (*see* note 57 *infra*).

57. High water is the maximum height reached by each rising tide, and low water is the minimum height reached by each falling tide. The first tables to include predictions for each day were for the year 1867, and gave the times and heights of high waters only for 19 reference stations and tidal differences for 124 subsidiary stations. A few years later predictions for the low waters were also included, and for the year 1896 the tables were extended to include the entire maritime world, with full predictions for 70 ports and tidal differences for about 3,000 stations. The present tables contain daily predictions for 195 reference ports and tidal differences for about 6,000 stations. TIDE TABLES 1964, EAST COAST OF NORTH AND SOUTH AMERICA 4, U.S. COAST AND GEODETIC SURVEY.

58. Where differences in type of tide occur at nearby stations it becomes necessary to use a distant port as a reference station which has a similar type of tide. The tides at a number of islands in the Bering Sea are referenced to the tide at San Diego, rather than to the tide at nearer stations, such as Sitka or Kodiak.

practical value where the type of tide is diurnal. The diurnal range is the difference in height between mean higher high water and mean lower low water. Mean tide level (half tide level) is a plane midway between mean low water and mean high water.

In addition to the table of differences, the *Tide Tables* contain information for determining the height of the tide at any time. This applies to both the reference stations and the subsidiary stations. Two methods are available—a numerical one which makes use of a published table of corrections, and a graphical one which involves the construction of a predicted tide curve for the day in question.[59] The numerical method is fully explained in the tables and can be easily followed. The graphical method is also described but not illustrated. It is therefore included here.

(*a*) *Graphical Method of Finding Height of Tide at Any Time.*—This method of finding the height of the tide at any time is known as the *one-quarter, one-tenth rule,* so named because of the method of construction. The procedure is as follows:

(1) On cross-section paper (*see* fig. 21) plot the low- and high-water points—for example, *A* and *E* in the figure—in the order of their occurrence for the day, measuring time horizontally and height vertically. These are the basic points for the curve.

(2) Draw straight lines connecting the points representing successive high and low waters.

(3) Divide the connecting lines into four equal parts (points *B*, *C*, and *D* in the figure). The halfway point of each line gives another point for the curve.

(4) At the quarter points adjacent to low water and to high water (*B* and *D* in the figure) draw vertical lines below and above the respective quarter points at a distance equal to one-tenth the range of the tide (*B′* and *D′* in the figure).

(5) Draw a smooth curve through the high- and low-water points and the intermediate points (*A*, *B′*, *C*, *D′*, *E* in the figure), making the curve well rounded near high and low water. This curve will closely approximate the actual tide curve, and heights for any time of the day may be readily scaled from it.

B. THE TIDE PREDICTING MACHINE

The tide at any place is the direct result of the tide-producing forces of the moon and the sun, which are known. Its time of occurrence and magnitude, however, are greatly affected by the hydrographic features of an area, so that, strictly speaking, the tides as they occur in nature are the result of the varying responses of the different ocean basins to the tide-producing forces, as modified by local terrestrial features. This accounts for the variation in the tide from place to place (*see* 232). It is therefore necessary, as a first step in

59. Both methods are based on the assumption that the rise and fall of the tide conform to simple cosine curves. The heights obtained will therefore be approximate, the roughness of approximation varying as the tide curve departs from a cosine curve.

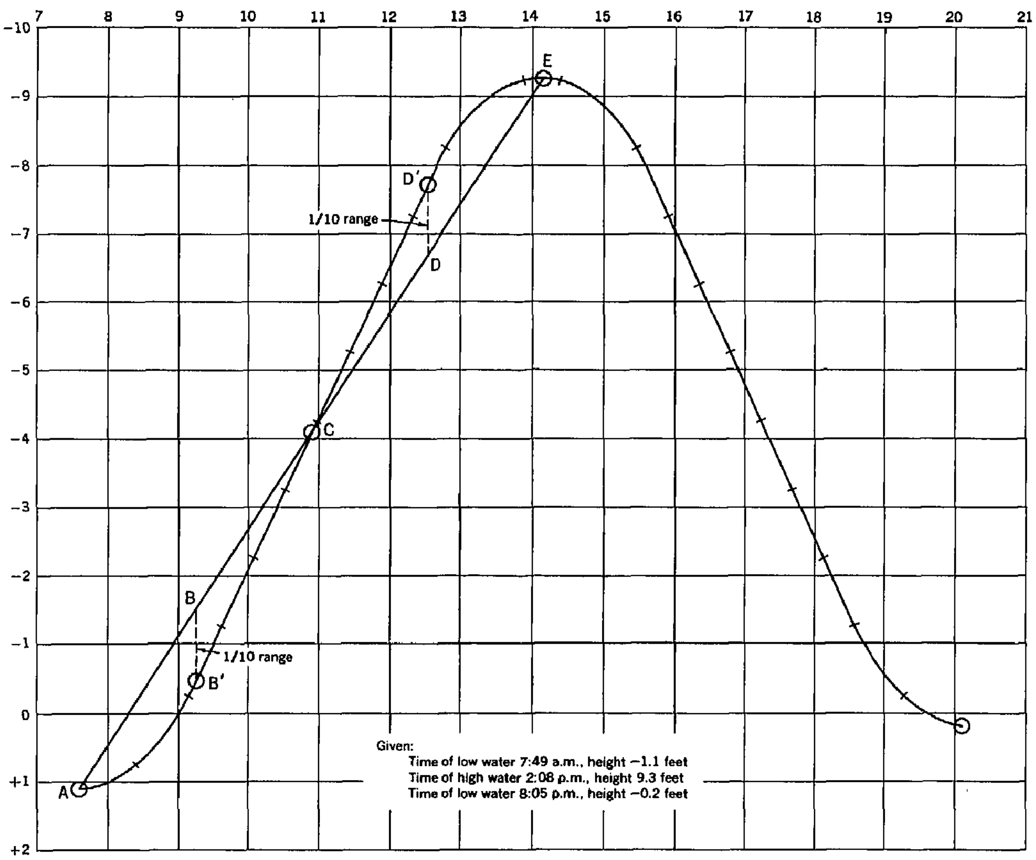

FIGURE 21.—Graphical method of finding the height of the tide at any time from the *Tide Tables* by the *one-quarter, one-tenth rule.*

tide prediction for a given place, to have a series of tide observations to learn the characteristics of the tide at that place—the longer the series the better, but it usually extends over a period of at least a year. Without such preliminary series, tide prediction would be impossible. But once a series has been observed and tidal constants determined, predictions can be made for any future time.

For predicting the times and heights of high and low water for use in the *Tide Tables,* two different methods have been employed—a nonharmonic one and a harmonic one. The latter came into use after the introduction of the harmonic analysis and is the method used today.[60]

60. The nonharmonic method is an approximate method. It is based on the principle that "the tide follows the moon" and makes use of the close relationship that exists between the time of tide at most places and the moon's meridian passage. For a full description of this method, *see* MARMER, THE TIDE 173–178 (1926).

In the harmonic method, the observed tide is subjected to a harmonic analysis, that is, the complicated motions of the moon and sun are replaced by a number of hypothetical moons and suns, which with respect to the earth as center have circular orbits in the plane of the equator. Each of these hypothetical bodies is regarded as generating a tide of its own. The actual tide at any place is thus regarded as made up of a number of simple tides, each of which is due to a hypothetical tide-producing body. Their combined tide must be the same as the actual tide of moon and sun.

The harmonic analysis separates the observed tide curve into cosine curves called constituents. Each constituent is represented by an amplitude which takes account of the height of the constituent and is one-half its range, and an epoch which takes account of the time element (time of occurrence reckoned from a fixed origin). These constituents, once determined, are used to predict the tidal curve for any future time. The resultant predicted curve represents a summation of all the constituent curves. The tide predicting machine (*see* fig. 22) performs this summation mechanically.[61]

Before beginning the predictions for any port, the constants, representing the different components of each constituent tide, are set on the proper cranks and dials of the machine which are so arranged that when the machine is set in motion by means of a crank and gears it will sum up the effects of all these constituent tides and produce the tide in nature. It provides for summing 37 constituents.[62]

C. ACCURACY OF TIDE TABLES

To test the accuracy of the *Tide Tables,* comparisons have been made for different ports between predicted tides and observed tides. These tests indicate that, under normal weather conditions, the predicted tides closely approximate the actual tides in both time of occurrence and height. At Los Angeles, for example, where the tide is of the mixed type with a mean range of 3.8 feet, a full year of comparisons showed that 90 percent of the predicted times of high and low water agreed within 5 minutes of the observed times; 98 percent of

61. Up to and including the *Tide Tables* for the year 1884, all the tide predictions were laboriously computed by means of auxiliary tables and curves constructed from the results of tide observations at the different ports. From 1885 to 1911, inclusive, the predictions were generally made by the Ferrell Tide Predicting Machine. From 1912 to the present time, the Coast and Geodetic Survey Tide Predicting Machine No. 2 has been used. TIDE TABLES (1964), *op. cit. supra* note 57, at 4. For a note on the development of tide predictions in the Bureau, *see* Finnegan, *Historical Note on Tide Predictions,* 5 JOURNAL, COAST AND GEODETIC SURVEY 100 (1953).

62. The machine not only traces a continuous curve showing the variation of the tide hour by hour throughout the year, but also indicates by dials the time and height of each high and low water. A recent addition to the machine is an attachment which automatically types the predictions in the format of the *Tide Tables,* thus permitting direct reproduction by offset printing. Including the time for setting the machine, daily predictions for a year can be made in about 7 hours.

FIGURE 22.—Tide Predicting Machine, designed in the Coast Survey, for predicting the times and heights of the tide for any port in the world and for any year. Astronomical equations involving as many as thirty-seven factors are solved mechanically to produce the tide in nature. Not shown in the view is a recent attachment which automatically types the predictions in the format of the *Tide Tables*.

the predicted heights agreed within half a foot of the observed heights; and 59 percent agreed within one-tenth foot. Exact agreement cannot be expected between predictions and actual times of occurrence, since the times and heights of the tide will be modified by the prevailing meteorological conditions, which may not be normal. This is particularly true of the upper reaches of rivers subject to freshet conditions, and also of comparatively shallow bays with a small range of tide.

233. Types of Tidal Data Available

Besides the published tables and the tide predictions that are included with the Small-Craft charts, there are other types of tidal data that are available to the public on request. Those which are used frequently by many people are furnished in the form of processed material—state index maps; tidal bench-mark data; relation between sea level datum and hydrographic datums; and tables of mean and diurnal ranges and highest and lowest tides—while those required for a special purpose covering a specific period of time are furnished in the form of photostats of the original records—hourly heights; high and low waters; and monthly, yearly, and cumulative means.

2331. *State Index Maps*

Special index maps are available for each coastal state showing by symbol and numbered position the localities for which tidal bench-mark data may be obtained (*see* fig. 23). On the reverse side of these maps more specific information is given as to where the bench marks are located for each numbered position on the index map, both of which are to be used in requesting bench-mark data.

2332. *Tidal Bench-Mark Data*

It has been previously noted that Coast Survey practice is to establish at least three bench marks for any series of observations (*see* 2314). Data for such bench marks are published separately for each station in loose-leaf form that permits ready expansion and revision. These compilations include the descriptions of all bench marks at each tide station (for ready identification on the ground), and their elevations above the basic hydrographic or chart datum for the area—mean low water on the Atlantic and Gulf coasts and mean lower low water on the Pacific coast, or some special low-water datum. The date and length of the tidal series on which the bench-mark elevations are based are also given. An accompanying table shows the relations between the basic datum

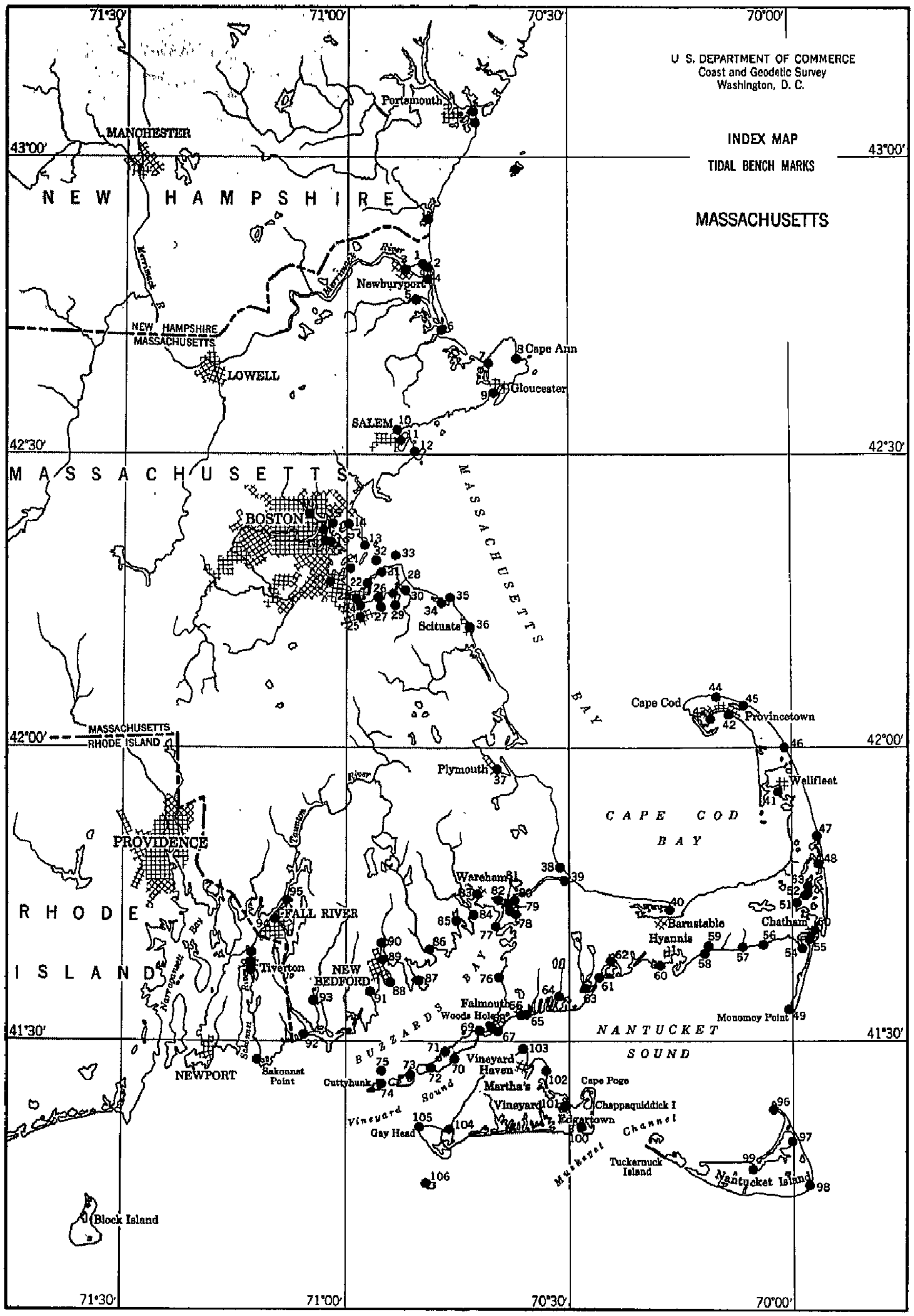

FIGURE 23.—Index map of tidal bench marks in Massachusetts. The dots and numbers indicate the localities for which tidal bench-mark data are available. On the reverse side are the place names corresponding to the numbers.

and other tidal datums in general use—mean higher high water, mean high water, half tide level, mean low water, and mean lower low water. In addition, heights of observed or estimated highest and lowest water levels in relation to the basic datum are also included with the dates of occurrence of these abnormalities (*see* 2334).

2333. *Relation Between Sea Level Datum and Hydrographic Datum*

In the process of its extension, the precise level net of the country has come to include tidal bench marks at many localities in addition to those where tide observations originally established the Sea Level Datum of 1929 (*see* 2121 B). However, there are still about 900 stations out of a total of about 1,700 in conterminous United States where there are no spirit-level ties between the geodetic bench marks and the tidal bench marks, and consequently the elevations of the tidal bench marks referred to the Sea Level Datum of 1929 have not been established.

For each coastal state where spirit-level connections have been made, a table is available showing the relation between Sea Level Datum of 1929 and the hydrographic datum. By subtracting the tabular value at each station from the published elevation above mean low water (or mean lower low water), the bench-mark elevation above the Sea Level Datum of 1929 is obtained. From this the vertical relationship between a geodetic bench mark and a tidal bench mark can be derived (*see* 2121 B note 27).

2334. *Mean and Diurnal Ranges and Highest and Lowest Tides*

Also available to the public on request is a leaflet consisting of two tables (Table 1 and Table 2). Table 1 applies to the Atlantic coast and gives the mean range of the tide, together with the height of the highest tide above mean high water and the lowest tide below mean low water, as recorded at the various control stations through the year 1961. Table 2 applies to the Pacific coast and Alaska and furnishes similar information as Table 1, except that the diurnal range is given and the highest and lowest tides are referenced to mean higher high water and mean lower low water, respectively. Both tables also give the average yearly highest and lowest tides for each station.

2335. *Hourly Heights and High and Low Waters*

Initial processing of tide records from control tide stations consists of a complete and systematic scaling of the hourly heights and the times and heights of high and low waters. The hourly height records have three distinct and basic applications. They provide data for the computation of the basic tidal plane of mean sea level, from which is derived the datum for the level net of the country; for the computation of the harmonic constants used in the prediction and classification of tides; and for a compact and condensed file record for future reference and reproduction. From the high- and low-water records are obtained basic data on time and height relationships, including lunitidal intervals, ranges, diurnal inequalities, high- and low-water datum planes, half-tide level or mean tide level, and mean and extreme heights.

2336. *Monthly, Yearly, and Cumulative Averages*

For each control tide station, compilations are prepared of monthly averages obtained from the hourly height and high- and low-water records (*see* 2335). These compilations are further processed to show yearly averages, cumulative averages, and averages by successive and overlapping 19-year periods, each new year as available becoming the last year of a 19-year group. Included in these summarized compilations are also the dates and heights of the highest and lowest tides recorded each month. These extreme heights are generally the result of meteorological disturbances superimposed on the normal periodic tide, and are of particular value to the navigator and to the coastal engineer. During periods of extreme low water, the actual depths of water may be noticeably less than shown on nautical charts. The lowest tide to be expected, as referred to the chart datum, is therefore a necessary part of the tidal information included on the nautical charts of the Survey (*see* Part 2, 658 and 6581). Knowledge of the heights of extreme tides—high and low—that have occurred or that may be expected to occur in any locality is an indispensable factor in planning and designing waterfront structures, and the long-period tide records of the Bureau are in constant demand for this purpose.

Photostat copies of the hourly heights and high and low waters and of the monthly, yearly, and cumulative averages are available for public distribution at the cost of reproduction.