Control Leveling

Special Publication No. 226 (REVISED 1961)

U.S. DEPARTMENT OF COMMERCE
Luther H. Hodges, Secretary
COAST AND GEODETIC SURVEY
H. Arnold Karo, Director

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 – Price 15 cents

Contents

	Page
Introduction	1
Instrumental equipment and methods	2
Computations and adjustments	5
History of the level net	7
Fischer level	7
1903 adjustment	7
1907 adjustment	8
1912 adjustment	8
Further development of the net	9
New design for leveling rods	9
Orthometric correction	9
1927 special adjustment	9
1929 special and general adjustments	10
Rapid expansion of the net	11
Bench marks	11
Designations of bench marks	14
Requests for leveling data	15
Elevations of cities and towns	16
Cooperation in preserving bench marks	17
Reports on condition of marks	17
Stamping elevations on bench marks	18
Relocation of bench marks	19
Specifications for vertical control	20
Classification	20

Illustrations

Figure	
1. Fischer first-order level	3
2. First-order leveling rods	4
3. *A first-order leveling party in action*	6
4. Level party moving between setups	6
5. A standard bench-mark tablet	12
6. Standard marks of the Coast and Geodetic Survey	14
7. Facsimile of Form 685, Report on Condition of Survey Marker	17
8. Facsimile of Form 86, Report on Relocation of Bench Mark	18

INTRODUCTION

Leveling may be defined as the operation of determining differences of elevation between points on or relatively near the surface of the earth. It may also be considered to be the determination of the elevation of such points relative to some arbitrary or natural level surface called a datum. There are few surveying or civil engineering operations which do not require the use of leveling in some form.

In order to define completely the location of any point on the earth, it is necessary to determine not only its geographic coordinates but its elevation. Geographic coordinates are expressed in terms of latitude and longitude. Geographic latitudes are measured, in degrees, minutes, and seconds, north or south from the Equator, while geographic longitudes are measured, in the same units, east or west from the meridian of Greenwich. The United States Coast and Geodetic Survey measures elevations in meters above the mean-sea-level surface. When the leveling data have been computed and adjusted, the metric elevations are converted to feet for general use.

The horizontal-control surveys of the Coast and Geodetic Survey (triangulation and traverse) result in the establishment of numerous marked points throughout the country and for each of these the latitude and longitude are known. The vertical-control surveys (leveling) result in the establishment of numerous other marked points and for each of these the elevation is known. It is seldom that the latitude and longitude and the elevation are known for the same survey station. This is due to the fact that entirely different methods are used in determining geographic positions and elevations. Triangulation and, to some extent, traverse stations are located on the highest and most commanding points in order that they may be visible from other similar points often located many miles away. The bench marks are usually found to be adjacent to well-established transportation routes and are seldom located on summits, because the lines of levels run to determine their elevations follow the easiest grades for reasons of economy.

In order to initiate a survey, the surveyor may obtain a start by connecting with the nearest triangulation or traverse stations, and the nearest bench marks.

Barometric leveling will serve to determine approximate differences of elevation. Vertical-angle or trigonometric leveling will yield results of greater accuracy. The ordinary engineer's level and rod, when properly used, are capable of considerable precision in the determination of differences of elevation. On the other hand, the use of geodetic equipment and methods in spirit leveling will permit the determination of differences of elevation between widely separated points with a remarkable precision.

For the guidance of the various governmental agencies in the classification of their work, the Budget Bureau adopted standard specifications for leveling of various grades of accuracy. These specifications will be found on page 20 of this publication.

Until 1922 the control leveling run by the Coast and Geodetic Survey was all first-order leveling. In 1923 and in 1927 a small amount of second-order leveling was done. Since 1932 it has been standard practice in this Bureau to subdivide the areas within the loops of first-order leveling with leveling of second-order accuracy.

Instrumental Equipment and Methods

The principal instrumental equipment used by this Bureau for first-order and second-order leveling consists of the leveling instrument and the leveling rods. The instrument consists essentially of a telescope carrying a delicate two-second spirit level mounted in such a manner on a portable tripod that it may be quickly and readily placed in a horizontal position. Various types of instruments have been used for first-order leveling, some of them being nearly like the "wye" level used extensively by engineers on construction work, and others differing widely from it.

The second-order leveling and practically all of the first-order leveling run since 1900 has been done with the instrument illustrated in figure 1. The principal characteristics of this form of first-order level are: The absence of "wyes"; the rigid fastening of the level vial to the top of the telescope in the barrel of which it is countersunk; the construction of the telescope, and its adjacent parts, of stainless steel (invar was used prior to about 1923); the protection of the level vial and the middle part of the telescope from sudden and unequal changes in temperature by encasing them in an outer tube; and an arrangement by which, without any change of the observer's position, the level bubble can be clearly seen by his left eye at nearly the same instant the rod is observed through the telescope by his right eye.

The readings are made upon a graduated strip of invar about 1 inch wide which fits loosely in a groove in a flat wooden rod (see fig. 2) about 10 feet long. The invar is free to expand or contract when the temperature changes, being fastened rigidly only at the bottom of the rod. The bottom of the rod is made of steel and terminates in a flat base of hardened steel about 1 inch in diameter.

The rods are placed on two stable points, the instrument being midway between them. The instrument is roughly leveled with a circular vial and finely leveled by centering the main bubble by manipulating the micrometer screw. The telescope is sighted first on one rod, where the observer reads the value for each of three crosshairs, and the procedure is repeated on the other rod. The difference of the readings of the rods is the difference in height between the two points. The length of sight is not to exceed 75 meters even under the most favorable conditions. By repeating the operation at successive instrument stations the difference of elevation of widely separated points may be determined.

For a complete description of the instrument, the rods, and the method of graduating the rods, see Coast and Geodetic Survey Special Publication No. 334, Geodetic Leveling Instruments. This publication gives a very detailed technical description of the instrument as

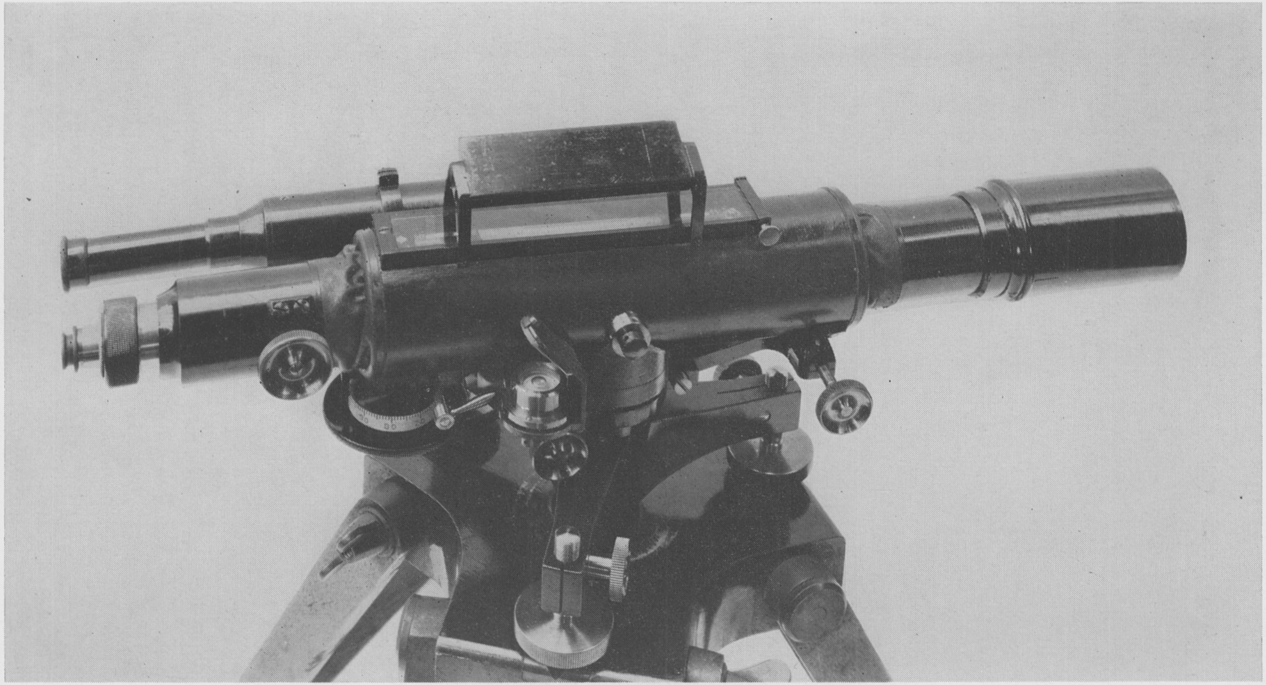
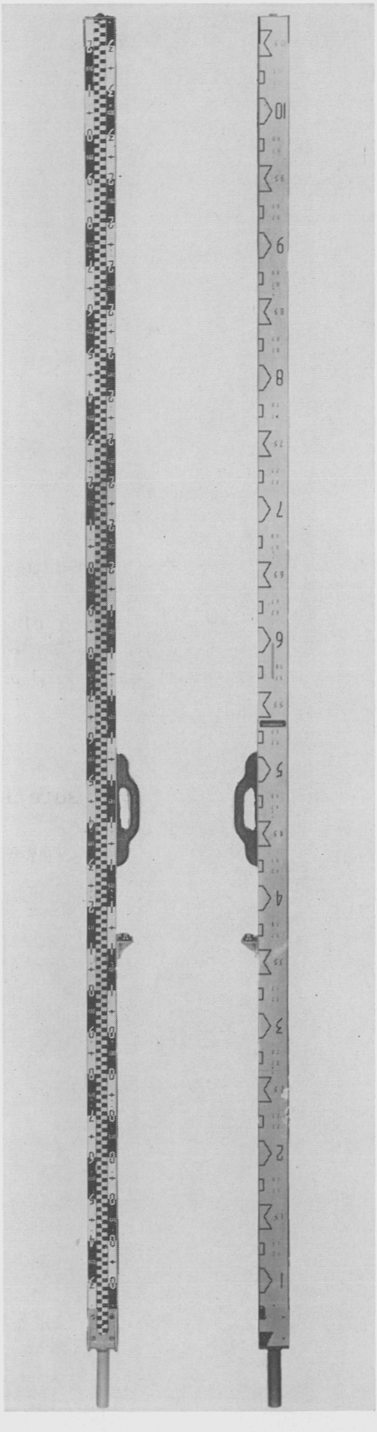


Figure 1.—Fischer first-order level.

This instrument has an extremely sensitive bubble and is so constructed that the observer may see the bubble with the left eye and read the rod with the right without moving about the instrument.



originally designed by E. G. Fischer and as later modified by D. L. Parkhurst.

The first- and second-order leveling of the Coast and Geodetic Survey is run, almost without exception, along railroads, highways, or roads. Automobile trucks are used for transporting the leveling party to and from the working grounds, for transporting the subparty setting bench marks, and for other miscellaneous duties. Generally during the actual leveling along a railroad the party walks. The truck is used to transport the party between setups when leveling along a highway. When leveling along a railroad, the top of a spike, which serves to hold the rail in place, is used as the rod support; off the railroad the rod is supported by a steel pin driven in the ground.

In leveling of first-order accuracy the line is divided into sections by temporary or permanent bench marks and the levels are run forward and back until two runnings in opposite directions agree within the specified limit. (See p. 20.) Second-order leveling is run continuously in one direction, though on most of the second-order lines already run the leveling on alternate days was run in opposite direction with regard to the general direction of progress. Second-order lines are double-run when they are 25 miles or more in length.

The accuracy of first- and second-order leveling executed by the Coast and Geodetic Survey is well within the specifications for first- and second-order leveling as adopted by the Budget Bureau. If an excessive rate of correction is applied to a line in adjusting it to the net, the fact is

Figure 2.—First-order leveling rods.

Both the face and the back of the rods are shown. Three wires are read on the face of the rod and the middle one of the three is read on the back as a rough check.

noted in the introductory paragraphs of the published list of descriptions and elevations of bench marks, with a caution that later leveling may require changes in the published elevations.

The first-order leveling of the Coast and Geodetic Survey comes within the specifications of the International Union of Geodesy and Geophysics for "leveling of high precision," the most rigid classification yet recognized for spirit leveling; while the second-order leveling is equivalent to that classified as "leveling of precision."

Computations and Adjustments

The records forwarded to the office by the field parties engaged in control leveling consist of the original notebooks in which the observations are recorded, the field computations, and the original descriptions of the bench marks.

The office computations include the checking of the field computations to see that the differences of elevation have been correctly carried from the record books to the computation sheets. The various corrections are then computed and added to the field-computation sheets. With modern equipment and methods these corrections are usually quite small.

An office abstract is made, using the corrected differences of elevation, and the preliminary elevations of the marks become available. The next step is the testing of the circuit closures and, if serious discrepancies are not uncovered at this stage of the work, the leveling is ready for adjustment.

When the adjustment consists simply of fitting a new line between known elevations at each end of the line the discrepancy or closure is simply distributed in proportion to the distances of the marks from the starting point of the line. When the new leveling consists of three or more lines radiating from one new junction point to fixed elevations at the ends of the radiating lines, a weighted mean is used for determining the elevation of the new junction point and the adjustment of each line is then handled as in the case of a single line. When the supplementary net to be fitted to the fundamental net becomes more complicated than either of the two cases outlined above, it is necessary to use the method of least squares, or some other method of adjustment which produces the same results, in adjusting the new leveling to the fixed elevations involved.

After the adjusted elevations are determined by distributing the closure corrections through the various links being adjusted, the standard elevations become known, but these elevations are in meters and the last step in the computations is the conversion of the metric elevations to feet. This is accomplished by multiplying each metric elevation by the conversion factor 3.2808333.

The original descriptions which are forwarded to the office on printed forms are prepared for publication. A separate list containing adjusted elevations is prepared and the material is ready for reproduction and distribution.

Figure 3.—A first-order leveling party in action.

The umbrella is to protect the instrument from the heat of the sun rather than for the comfort of the observer. One of the two rodmen does not appear in the picture.

Figure 4.—Level party moving between setups.

History of the Level Net

First-order leveling was first undertaken by the Coast and Geodetic Survey in 1878 when field work was begun on the line of precise levels which was to follow the Transcontinental Arc of Triangulation. This arc of triangulation extended across the United States from Chesapeake Bay to the Golden Gate approximately along the thirty-ninth parallel of latitude. 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 the leveling along the transcontinental line 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 the extent that an adjustment of the net was decided upon. The adjustment was made and the results were published in appendix 8, Report for 1898–99, under the title "Precise Leveling in the United States," which 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.

Fischer Level

About 1900 a new type of leveling instrument was designed by E. G. Fischer, then chief of the Instrument Division of the Coast and Geodetic Survey. This level, with comparatively slight changes, has continued to be the standard instrument used by this Bureau for geodetic leveling since that time. (See p. 3.)

The introduction of the new type of leveling instrument, which permitted levels of even greater accuracy to be run at much greater speed and consequently less cost, stimulated the leveling work of the Bureau. The network of lines of levels was extended more and more rapidly and developed an increased appreciation on the part of the engineering profession of the value of a common datum for levels, readily accessible at many places throughout the country.

1903 Adjustment

The amount of leveling added to the net by 1903 had been so great that it became necessary to make a second adjustment of the net in order to absorb the leveling added since 1899.

The details of the adjustment and the resulting metric elevations were published in appendix 3, Report for 1903, under the title "Precise Leveling in the United States, 1900–1903, with a Readjustment of the Level Net and Resulting Elevations." The descriptions of all bench marks added to the net since the publication of the results of the first adjustment were given in this publication, but for the descriptions of the bench marks included in the net at the time of the first adjustment reference was made to appendix 8, Report for 1898–99.

1907 Adjustment

Progress in first-order leveling continued to be quite rapid during the period from 1903 to 1907. It was during this period that the first spirit-level connection across the United States between the Atlantic and the Pacific Oceans was completed. Although by 1907 nine tide stations on the Atlantic and Gulf coasts had been connected to the level net, the one at Seattle, Wash., was the first on the Pacific coast to be connected by spirit leveling to the first-order level net.

The additional leveling and the connection to mean sea level on the Pacific coast made it desirable to readjust the net in order to absorb the new leveling and to take full advantage of the greater strength realized from the Pacific coast connection to sea level.

After the rigid adjustment had been completed certain areas showed such small changes from the results of the 1903 adjustment that it was decided to hold fixed a considerable portion of the net as adjusted in 1903 in order to avoid a large number of very small corrections to the elevations of the bench marks. For this reason the adjustment as finally published cannot be considered a strictly general adjustment.

The results of the 1907 adjustment were published in "Precise Leveling in the United States, 1903 to 1907, with a Readjustment of the Level Net and Resulting Elevations." In this publication may be found the descriptions and elevations of all bench marks brought into the net after the publication of the results of the 1903 adjustment. Elevations determined in 1903 but changed by the 1907 adjustment were also included. For elevations not changed by the 1907 adjustment, it was necessary to refer to appendix 3, Report for 1903. For the descriptions of the bench marks included in the adjustments of 1899 and 1903 reference was made to appendix 8, Report for 1898–99, and appendix 3, Report for 1903.

1912 Adjustment

By 1912 the net was greatly strengthened by another connection to sea level on the Pacific coast at San Diego, Calif., and by numerous additional lines, particularly in the West.

Like the 1907 adjustment, the adjustment of 1912 was not a strictly general adjustment because, after the rigid adjustment had been completed, the elevations of certain junction bench marks that showed only slight changes from the results of the last two previous adjustments were held fixed as previously adjusted.

The results of the 1912 adjustment were published in Coast and Geodetic Survey Special Publication No. 18, Fourth General Adjustment of the Precise Level Net in the United States and Resulting Standard Elevations. In this publication may be found the elevations, in both meters and feet, for all bench marks in the net at the time of the adjustment. The descriptions for all bench marks brought into the net since the 1907 adjustment were also included. At that time it was necessary to refer to the three previous publications for the descriptions of the marks brought into the net up to 1907. An index by States in Special Publication No. 18 shows where all descriptions and elevations of bench marks in the net in 1912 are to be found.

Further Development of the Net

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 into the net as adjusted without great difficulty and it was not until 1927 that the need of an additional adjustment was felt.

New Design for Leveling Rods

During this period of about 15 years the only marked change in instrumental equipment was the introduction in 1916 of a new and improved type of rod in which the fine graduations were placed on a strip of invar. This greatly reduced the difficulties experienced as a result of temperature changes and permitted further increase in the accuracy of the work.

Orthometric Correction

Because the earth is an oblate spheroid, level surfaces at different elevations are not parallel but tend to converge slightly toward the poles of the earth. This necessitates the application of an orthometric correction to the observed differences in elevation so that the resulting elevations of the bench marks may represent their true heights above mean sea level. This correction reaches a maximum on north-and-south lines run at high elevations, and it is zero on east-and-west lines. It is small on lines run in any direction at low elevations. For a more complete explanation of the orthometric correction, see Coast and Geodetic Survey Special Publication No. 240, Manual of Leveling Computation and Adjustment, Appendix C, pages 155 to 160.

The orthometric correction was not applied prior to about 1910 and in the 1912 adjustment it was applied only to the leveling along lines west of the Mississippi River. It is now applied to all first- and second-order leveling included in the net.

1927 Special Adjustment

In 1927 a special study of the level net was undertaken. This resulted in an adjustment (for theoretical purposes) which is known as the 1927 Special Adjustment. In that 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 entirely consistent within itself by the adjustment, the difference of elevation between mean sea level at Galveston, Tex., and the junction bench mark at Houston, Tex., was used to determine the elevation of the junction bench mark at Houston. From that starting point the elevations of all other junction points in the net were computed.

Using differences of elevation between the mean-sea-level planes at the various tide stations and the nearest junction points in the net, 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 seemed to indicate that the actual mean-sea-level surface as defined by the tide observations tends to slope upward to the north along the coasts of the Atlantic and Pacific Oceans and upward to the west along the Gulf coast. The actual mean-sea-level surface on the Pacific coast appears to stand appreciably higher than the similar surface on the Atlantic coast. The results of the study may be found in Coast and Geodetic Survey Special Publication No. 134, Geodetic Operations in the United States, January 1, 1924, to December 31, 1926 (*now out of print*).

1929 Special and General Adjustments

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 Geodetic Survey of Canada. It was decided that a general adjustment was needed 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.

It was believed that greater strength and theoretically better results could be obtained if the first-order level net of the United States and that of the Dominion of Canada could be combined and adjusted as a unit. Noel J. Ogilvie, director of the Geodetic Survey of Canada, placed at our disposal the results of the first-order leveling by that organization and in 1929 an adjustment of the combined level nets of the United States and Canada was made.

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 Lakes region were adjusted without holding any sea-level connections. Then, as in the 1927 Special Adjustment, elevations based on Galveston, Tex., were computed for the mean-sea level planes at the other tide stations. This adjustment was called the 1929 Special Adjustment.

Then the equations for all circuits involving connections to tide stations were added, and a new solution resulted in the 1929 General Adjustment in which sea level was held fixed as observed at 26 tide stations, 5 in Canada and 21 in the United States.

The total length of the lines of levels actually used in the adjustment was about 60,000 miles; 40,000 miles in the United States and 20,000 miles in Canada.

The results of the 1929 Special Adjustment verified and extended the findings of the 1927 Special Adjustment and were published in Coast and Geodetic Survey Special Publication No. 166, Geodetic Operations in the United States, January 1, 1927, to December 31, 1929 (now out of print).

The results of the 1929 General Adjustment have not been and probably never will be published in a single publication.

Descriptions of bench marks with their elevations based on the 1929 General Adjustment are published in lithographed lists by lines. The present policy is to republish all level data by 30-minute quadrangles.

Rapid Expansion of the Net

In the years 1934 and 1935 extremely rapid progress was made. This resulted from the use of emergency funds for the relief of unemployment and permitted prompt completion of field work which, in the normal course of events, would have taken many years to complete.

The present program for the development of the fundamental vertical-control net calls for first-order lines at approximately 100-mile intervals and the subdivision of the areas bounded by first-order lines by the use of second-order levels with lines spaced at approximately 50- and 25-mile intervals. In certain sections additional development has been carried out by using second-order levels to subdivide the smaller areas, with lines from 5 to 10 miles apart.

After the 1929 General Adjustment was completed the elevations of the marks were published in one form or another as rapidly as possible and they were characterized as "Standard elevations based on the 1929 General Adjustment."

As a result of the rapid expansion of the net and the resulting mass of new leveling which had to be fitted to the net, many supplementary adjustments became necessary. Also, 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. These conditions made further supplementary adjustments necessary. The confusion caused by characterizing the elevations resulting from the supplementary adjustments as "Standard elevations based on the 1929 General Adjustment through the medium of the ____________ Supplementary Adjustment" resulted in a change of characterization for the standard elevations and the definite establishment of a policy with regard to the readjustment of the net as follows:

> It is recommended that elevations based on the 1929 General Adjustment be held fixed with the possible exceptions outlined below, and that the datum be officially designated as "Sea Level Datum of 1929."
>
> 1. The case where new leveling discloses blunders in the old work and necessitates readjustment of a limited portion of the net, in order to absorb the blunder.
> 2. The readjustment of limited portions of the net, as a result of earthquakes, or other earth movements which are proven to have taken place.
> 3. The question of the introduction of new tidal stations and connections into the net should be handled by fitting the new work to the net in the usual manner, but not necessarily holding the tidal datum planes in determining the geodetic elevations. * * *

Bench Marks

In the early days of the activity of this Bureau in control leveling, the bench marks established along the lines of levels were of various types. Many of the marks were chiseled squares and chiseled crosses, often flanked or surrounded by lettering cut in the masonry on which the mark was established. These marks were established at rather infrequent intervals. After the lapse of some years they became rather inconspicuous and they were frequently destroyed by construction operations without even being noticed. When some of the marks on

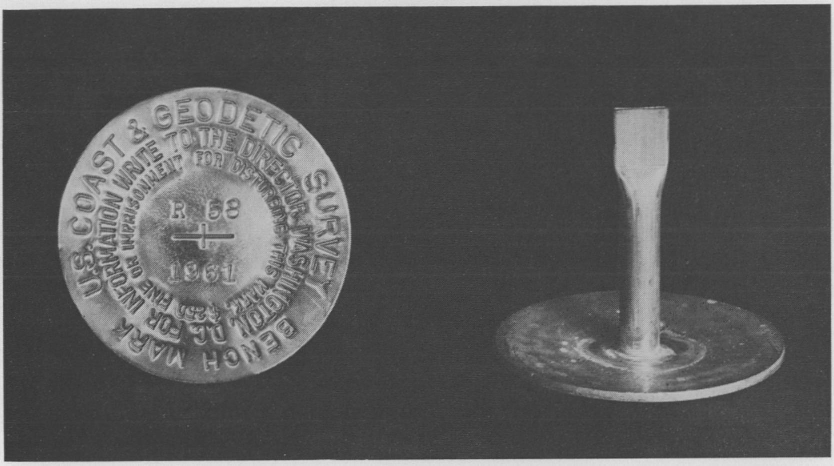


Figure 5.—A standard bench-mark tablet.

This tablet is set solidly in masonry structures, rock outcrops, boulders, or concrete posts so that only the inscribed disk is visible.

a line of levels, already widely spaced, are destroyed the spacing becomes altogether too wide. On some of the older lines the marks still in existence are so far apart as to cause great difficulty in securing a checked start for new leveling.

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 difficulty with this type of mark was that, although they were more conspicuous than the chiseled squares or chiseled crosses, there was nothing on the mark to indicate its use and many of them were destroyed through lack of knowledge on the part of those who encountered them in the way of construction, repair, or maintenance projects.

The first bench-mark disks or tablets of a character at all similar to those now in use were cast of bronze. They were about 3¼ inches in diameter and had a round shank centered in the back, ⅞ inch in diameter and 3 inches long. This shank was split and a wedge was inserted to spread it and thus give greater holding power. The disk itself had a depression in the center, about 2½ inches in diameter and ½ inch deep. Around the rim of the depressed portion were the raised letters "U.S.C. & G.S." Within the ring of letters was a smooth, flat, circular, raised portion, 1½ inches in diameter, which was the spot on which the rod was held and represented the portion of the disk to which the elevation of the mark referred. These marks were not used very long as it was soon found that they filled up with dirt, were hard to recover, and required a thorough cleaning out before they could be used.

Since that time the type of bench-mark tablet has been gradually improved until now the standard type of bench-mark disk for use on first- and second-order leveling is as shown in figure 5. This tablet has a diameter of 3⅝ inches and a 3-inch shank, and the surface of the disk is slightly rounded so as to give a definite high point in the center to which the elevation is referred. When these marks are set vertically (shank horizontally) in walls the elevation refers to the center of the horizontal line in the center of the disk.

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

During the period 1933 to 1935, inclusive, separate organizations were developed in each State to carry on geodetic surveys of second- and third-order accuracy, using funds allotted by the Civil Works Administration and later by the Works Progress Administration, under the technical supervision of the Coast and Geodetic Survey, through State Representatives appointed in each State. The points established by these State organizations were usually marked by a specially designed bronze tablet similar in style to the standard bench-mark disk but bearing the legend shown in figure 6, No. 11. These disks were only 2⅞ inches in diameter and had 2½-inch shanks. Some of the State organizations used special disks of the same general type but of different appearance and size and with legends cast in them which differed considerably from that cast in the standard "State Survey" disks. Another type of mark sometimes used by these State organizations was a commercial, round-headed monel-metal rivet, ⅜ inch by 2 inches, set with only the round head exposed.

During the years just before, during, and for a short time after the expanded program of leveling, a cooperative program was in operation whereby the engineering organizations of various railroads established extra bench marks ahead of our leveling parties to increase the number of permanent marks along the lines of levels following the railroads. On this work the monel-metal rivets described above were used. Many marks already established by the railroads were tied in. The character of these marks varies widely from chiseled squares to much more elaborate marks of many different kinds.

In the past, the Tides and Currents Branch of the Coast and Geodetic Survey used a tablet quite similar in size and shape to the one used on the geodetic leveling but with a different legend cast in it, and a distinguishing mark in the center which consists of an outlined circle, about 1 inch in diameter, with a horizontal line through the center of the circle. (See fig. 6, No. 10.) At present the Tides and Currents Branch and the Leveling Branch use the same disk. (See fig. 6, No. 8.)

Several different types of disks with slightly varying legends cast in them have been used by the Coast and Geodetic Survey since early in the first decade of this century. However, most of them are of the same general size and shape as the present standard tablet and bear legends which are self-explanatory. They should be readily recognized by persons at all familiar with surveying operations.

During World War II, owing to a shortage of bronze, the Coast and Geodetic Survey used a considerable number of bench-mark tablets made of cast iron. These tablets were of the same size and shape as the standard bench-mark tablet shown in figure 5, but manufacturing difficulties required that a greatly simplified legend be used. The center device is the same as shown in figure 5, but the lettering is 0.7 inch high and reads simply "USC & GS BM." The use of these cast-iron tablets was an emergency measure and was abandoned as soon as bronze could again be obtained.

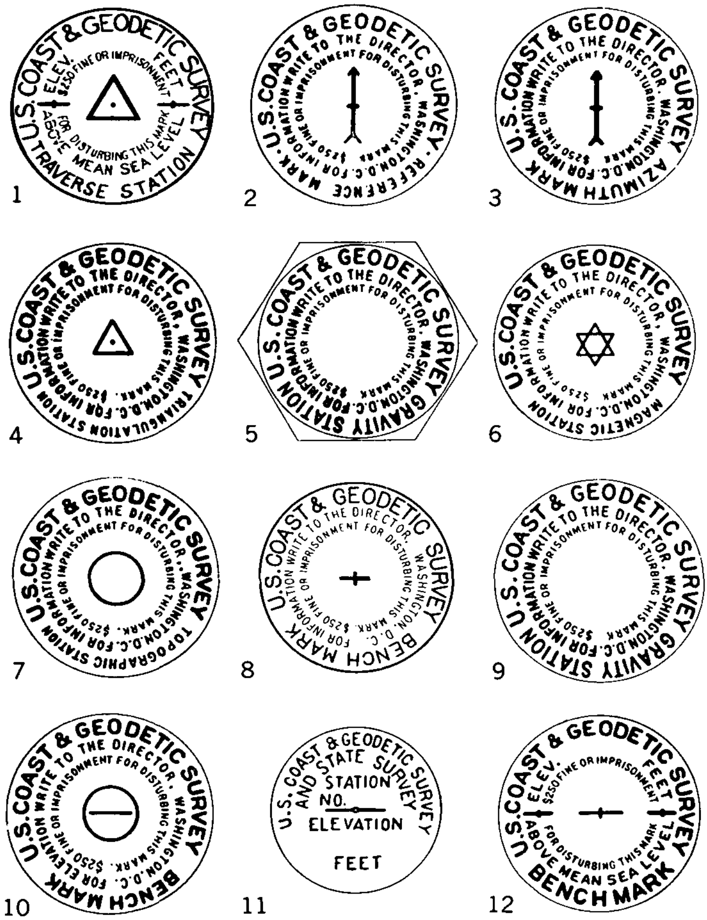


Figure 6.—Standard marks of the Coast and Geodetic Survey.

1. Traverse station mark.
2. Reference mark.
3. Azimuth mark.
4. Triangulation station mark.
5. Gravity station mark (old type).
6. Magnetic station mark.
7. Topographic station mark.
8. Geodetic bench mark (new type).
9. Gravity station mark (new type).
10. Tidal bench mark.
11. State Survey mark.
12. Geodetic bench mark (old type).

Designations of Bench Marks

The bench marks of the metal-tablet type have their designations stamped on them with dies. Theoretically there are no two bench marks stamped with the same designation in any one State. Practically, however, owing to the fact that mistakes have been made in the assignment of designations and in the use of assigned designations in the field, there are a few States in which one or more series of duplicate designations have been used.

The system in use by this Bureau 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 "A 1," "B 1," "C 1," etc., to and including "Z 1." The next marks are stamped "A 2," "B 2," etc., to and including "Z 2." 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 skipped in stamping the bench marks.

The State Survey disks (fig. 6, No. 11) are not ordinarily numbered in accordance with the above system but have various types of designations depending on the practice of the State organization which established them.

Requests for Leveling Data

It will readily be seen that it is necessary to be quite specific in stating character, designation, and location when asking for the elevation of a mark that has been found, because of the various types of marks that have been used by this Bureau and other organizations.

In order to avoid delay and confusion, a request for elevations of bench marks should give the letter, number, and year which is stamped on each disk; the State in which each disk is located; and to guard against duplicate designations, the distance and direction from the nearest town. Any other brief description of the character and location of the mark that may aid in its identification in the records on file at this office should be given. It is well to include rubbings or imprints of the marks with the request. A rubbing may be made by placing a piece of light- or medium-weight paper over the disk and then rubbing over the paper with a pencil, preferably a hard one, to bring out the legend cast in the disk and any letters or numbers stamped on the disk with dies, or an imprint of the disk may be made by placing a piece of aluminum foil, of the common household type, on the disk and pressing it with the hand or a soft eraser to transfer the letters and numbers to the foil. Other organizations sometimes use systems that correspond so closely to the system used by this Bureau in designating bench marks that confusion results unless we are sure of the name of the organization which is cast in the disk.

The procedure outlined above is of interest chiefly to one who may have found one or more bench marks and who desires the data concerning the mark or marks which have been found. On the other hand, an engineer or surveyor who is about to undertake field work in a given locality may wish to obtain data concerning all existing bench marks in the territory in which he is to work. Control diagrams have been published by States showing the routes of leveling and publication or line numbers. These State diagrams are being replaced by a new series covering 1° of latitude by 2° of longitude on a 1:250,000 scale showing both horizontal and vertical control. The vertical control data, until recently, were published by lines the numbers of which are shown on the State diagrams. New data are now being published and old data republished by areas covering 30 minutes of latitude by 30 minutes of longitude. Information concerning the form of publication of data for any particular area requested during the transition period will be furnished with the control diagrams.

The line numbers shown on the Control Leveling Index Maps have not been placed on all of the lists of descriptions and elevations of bench marks published by this Bureau. The indexes of line titles and numbers are published for the convenience of persons making use of our vertical-control data in correlating the unnumbered lists with the index map.

On the Control Leveling Index Maps the line numbers are assigned arbitrarily without regard to numbers assigned to lines in adjoining States. An interstate line usually has a different number in each State. For this reason, in ordering leveling data, it is necessary to give both the name of the State and the number of the line shown on the index map or list from which the number was obtained.

Because the editions of the various lithographed lists of descriptions and elevations of bench marks are small, requests for leveling data should be kept to a minimum consistent with the immediate needs of the user. Furthermore, this will serve the best interests of the user, since these lists are revised at rather frequent intervals in order to keep them as nearly up to date as possible.

Elevations of Cities and Towns

This Bureau often receives requests for the elevations or altitudes of towns, cities, or other relatively large areas. Usually no information is given as to whether the maximum, the minimum, or the average elevation is desired. Ordinarily, no reference is made to the use to which the information is to be put. Without some additional information of this sort, we are unable to comply with such requests in a manner which is at all satisfactory to us or to the person seeking the information.

Many inquirers seem to overlook the fact that the elevation of the ground surface, even in a small city, may vary as much as several hundred feet from point to point. Take, for example, the city of Washington, D.C. The Potomac River is a tidal stream to a point somewhat above the city. This means that the rise and fall of the tide is noticeable in the river opposite the city of Washington. The average level of the surface of the river is a fraction of a foot above mean sea level. The adjoining land will, of course, have varying elevations, depending on the steepness of the bank and the distance back from the river. Much of the flat part of the city around the Mall and the portion of the city known as the Federal Triangle is at an elevation of approximately 10 feet above sea level. The Washington Monument stands on a small hill having a summit elevation of about 40 feet. In the higher portions of the city there are elevations between 200 and 300 feet, while the maximum elevation of the District of Columbia is about 420 feet.

Obviously, if an inquirer asks for the altitude of Washington, we might truthfully say that it varies from a minimum of a fraction of a foot to a maximum of about 420 feet. This statement might or might not be useful to the person seeking the information.

Often approximate elevations are requested for use in deciding which of several places is best suited to some sort of recreation, to the search for health, etc. Sometimes elevations of a fairly high degree of accuracy are desired at particular locations in a city for the purpose of adjusting aneroid barometers. In many cases elevations of bench marks can be given with great accuracy. From these other elevations may be determined locally, with as high a precision as may be required or possible with the available equipment.

In writing to the Coast and Geodetic Survey for information as to elevations of towns, cities, or other places of considerable extent, the use to be made of the information should be stated in order that our reply may include all available information suited to the needs of the inquirer.

REPORT ON CONDITION OF SURVEY MARKER

Form Approved
Budget Bureau No. 41-R1923

Name or Designation: Z 33

State: Florida County: St. Lucie Established by: USC&GS Year 1933

Mark searched for or recovered by: Name - John Doe

Organization - Corps of Engineers, U.S. Army

Date of report 20 Sept. 60 Address - P.O. Box 4970, Jacksonville, Florida

Condition of marks: List letters and numbers found stamped in (not cast in) each mark.

Mark stamped:	Condition:
Z 33 30.249 1933	Good

Please report on the thoroughness of the search in case a mark was not recovered, suggested changes in description, need for repairing or moving the mark, or other pertinent facts:

Add to description:
"From County Court House at Ft. Pierce, go 3.3 miles south on Indian River Drive to No. 3701, the residence of Gregory Luke; thence about 700 feet west to railroad."

FORM 685 (9-8-58)

Figure 7.—Facsimile of Form 685, Report on Condition of Survey Marker.

Cooperation in Preserving Bench Marks

Reports on Condition of Marks

Obviously the final results of all the field and office work in connection with control leveling are represented by the marks themselves and the lists of the descriptions and elevations of them. A bench mark is useful only as long as it is recoverable. When changes occur, as they often do, in the surrounding natural and cultural features, with relation to which the mark is described, it becomes increasingly difficult to find the mark by means of the published description. Engineers and others who have occasion to visit any bench marks, established by this Bureau or other Government organizations, will be doing a public service if they will report the condition of the marks and make suggestions as to needed changes in the descriptions. Reports on the condition of bench marks are solicited and very much appreciated.

Form 685, Report on Condition of Survey Marker (see fig. 7) is a 5- by 8-inch card with blanks to be filled in when reporting the condition of a mark. Copies of this form will be furnished on request to anyone who may have occasion to search for or recover bench marks and who is willing to report their condition. The cards are self-addressed on the reverse side and require no postage.

Stamping Elevations on Bench Marks

This Bureau has discontinued the practice of stamping elevations on bench-mark disks. The reason for this is that there are many factors contributing to vertical change some of which are: frost action; varying moisture content of soil; removal of underground water, oil, and gas; fault lines; and earthquakes. A releveling will often indicate that a mark should have a new elevation based on the releveling. Also, new leveling may require a readjustment of previous lines.

Form 86 (8-24-55)

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

REPORT ON RELOCATION OF BENCH MARK
(See instructions on reverse side)

Designation of mark: J 152
State: California
County: Monterey

A. Description of original mark

2.1 miles southwest along the Southern Pacific Company railroad from the station at Castroville, at Nashua Siding, about 100 feet east of a Pacific Gas & Electric Company substation, and 35 feet west of Crossing EE 112.5. A standard disk, stamped "J 152 1933" and set in the top of a concrete post. (4.658 meters or 15.282 feet.)

B. Field notes

Date of leveling 5-4-61

Point	B.S.	H.I.	F.S.	Elevation	Remarks
	4.499	19.781		15.282	
	3.226	19.879	3.128	16.653	J 152 RESET
			4.596	15.283	

C. Description of new mark J 152 RESET 1961 - 2.1 miles southwest along the Southern Pacific Company Railroad from the station at Castroville, about 200 feet south of a Pacific Gas & Electric Company substation, and 325 feet southwest of Crossing EE 112.5, a standard disk, stamped "J 152 RESET 1961" and set in northerly end of concrete abutment at northwest end of S.P.R.R. Company Bridge No. 112.54.

J 152 to J 152 RESET = + 1.371 feet.

(Signed) John Doe, Road Commissioner

Figure 8.—Facsimile of Form 86, Report on Relocation of Bench Mark.

Relocation of Bench Marks

Frequently new construction or repairs to existing structures necessitates the destruction of bench marks, in spite of the fact that every effort has been made to place them where they will be as permanent as possible. If these marks are to be preserved for the use of all engineers and surveyors who may have occasion to use them, we must depend on the cooperation of engineers and others throughout the country for assistance in their preservation. Obviously, it is to the best interests of all concerned that bench marks be relocated rather than destroyed.

As soon as it becomes known that a mark must be moved, a letter should be sent to the Director, Coast and Geodetic Survey, U.S. Department of Commerce, Washington 25, D.C., stating the necessity for moving the mark, approximate time limitation, and giving its designation. The designation consists of the letters and numbers stamped with dies on the disk. It is desirable to furnish a rubbing of the disk as well. (See p. 15.) Upon receipt of this information, this Bureau will then, if possible, send a field engineer from a district office or field party to establish the replacement marks.

If one of our engineers is not near enough to move the mark within the time required, private engineers or engineers from other government agencies are often requested to establish replacements as a public service. This Bureau has no funds to pay these outside engineers for relocation work. This office will furnish a new disk properly stamped to show that it is a replacement.

The proper procedure, in most cases, is to establish the new mark in a safe place nearby and level from the old mark to the new one by means of an engineer's level and rod. The leveling should be run in duplicate to avoid the possibility of large errors, and all readings should be made to three decimal places in order to preserve the accuracy of the original surveys. It is not necessary that the new mark be established at the same elevation as the old mark.

The old mark should not be disturbed until the observations involved in the leveling have been checked by the observer or the recorder. An assumed elevation for the old mark may be used in the leveling if the elevation is unknown, since we are principally concerned with the difference of elevation between the old mark and the new one.

After the new mark has been established and leveled to, the old disk should be broken out and returned in a franked mailing sack which will be supplied for the purpose.

A complete report on the action taken, including a description of the location in which the new mark is established and a copy of the field notes involved in the transfer of elevation, should also be forwarded to this office in a franked envelope which will be furnished. The cooperation which individuals and organizations may extend to this Bureau in preserving bench marks will be a service, not only to this Bureau and other Government surveying organizations, but to all who may have occasion to use the marks in the future.

Specifications for Vertical Control

	First order	Second order		Third order
		Class I	Class II	
Spacing of lines and cross-lines	60 miles	25-35 miles	6 miles	Not specified.
Average spacing of permanently marked bench marks along lines, not to exceed	1 mile	1 mile	1 mile	3 miles.
Length of sections	½-1 mile	½-1 mile	½-1 mile	Not specified.
Check between forward and backward running between fixed elevations or loop closures, not to exceed	4 mm $\sqrt{K}$ or 0.017 ft. $\sqrt{M}$.	8.4 mm $\sqrt{K}$ or 0.035 ft. $\sqrt{M}$.	8.4 mm $\sqrt{K}$ or 0.035 ft. $\sqrt{M}$.	12 mm $\sqrt{K}$ or 0.05 ft. $\sqrt{M}$.

K is the distance in kilometers.
M is the distance in miles.

Classification

In first-order leveling the requirement is for a forward and backward running that agree within 4 mm. times the square root of the length of section in kilometers. If second-order leveling is run with the same equipment as first-order, it can be single run, with loop closures within the criterion 8.4 mm. times the square root of the distance around the loop. In remote areas where a second-order line is longer than 25 miles due to the fact that routes are unavailable for an additional network development, the line should be double-run. This is defined as Class I of Second-order. The single-run area leveling is defined as Class II of Second-order. Summaries of these classifications are listed in the table.

Third-order leveling should be used to subdivide the area surrounded by first- and second-order leveling and should be performed so that the standards in the table are satisfied. Trigonometric leveling may be considered as fourth-order leveling, and the elevations thus determined are listed with the triangulation data.

U.S. GOVERNMENT PRINTING OFFICE 740-625-h