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LEO OTIS COLBERT, *Director*

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MANUAL OF GEODETIC LEVELING

BY
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FOREWORD

United States Coast and Geodetic Survey Special Publication No. 140, "Manual of First-order Leveling" by Henry G. Avers, was first published in 1929 and was reprinted in 1935, 1939, and 1943, without revision except for the addition of a supplement containing changes in the General Instructions.

During the nearly two decades in which the Manual of First-order Leveling has been in use, changes have taken place in the total amount of leveling accomplished, the uses being made of the resulting data, and the spacing of the bench marks along the lines of levels. The wide use of second-order leveling for minor networks within first-order loops and other changes in field and office practice, resulting from experience gained since the manual was first issued, have made a revision of the publication necessary.

It has been decided to revise and expand Part I (Field Methods) of the Manual of First-order Leveling and to issue it under a new title, "Manual of Geodetic Leveling", as Special Publication No. 239. A revision and expansion of the material in Part II (Office Computations) of Special Publication No. 140 will be found in the "Manual of Leveling Computation and Adjustment", Special Publication No. 240.

The author wishes to acknowledge the help received from various members of the Section of Leveling in the detailed work of preparing the manuscript for this manual. Particular mention should be made of the advice and encouragement given the author by Commander Henry W. Hemple, Chief, Division of Geodesy, and the assistance of Mr. Lansing G. Simmons, Chief Mathematician, Division of Geodesy, who reviewed the entire manuscript and contributed many valuable suggestions for its betterment. Finally, it should be clearly understood that a considerable portion of the material in this publication has been taken directly from Special Publication No. 140, with only slight revision, and the author wishes to express his indebtedness to the late Henry G. Avers who, in his Manual of First-order Leveling, really laid the ground-work for this publication.

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DEPARTMENT OF COMMERCE,
UNITED STATES COAST AND GEODETIC SURVEY,
Washington, D. C.

The provisions of this Manual of Geodetic Leveling supersede all previous manuals, instructions and circulars on the subjects of first- or second-order leveling and, together with the Regulations of the United States Coast and Geodetic Survey, shall be complied with in the execution of all first- and second-order leveling by field parties of this Bureau unless divergence therefrom is authorized in the instructions issued for each project.

LEO OTIS COLBERT, *Director*

FIGURE 1.—A geodetic 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.

MANUAL OF GEODETIC LEVELING

INTRODUCTION

First-order leveling by the United States Coast and Geodetic Survey began with the transcontinental line of levels in 1878. Previous to that time the Bureau had done some leveling, but it was used mostly to control trigonometric leveling and, while it served its purpose, it was not of a high grade of accuracy compared with the standards of today. The transcontinental line of levels differed both in purpose and extent from former work of this kind for, besides furnishing vertical control for the great scheme of triangulation extending across the continent, it provided bench marks at frequent intervals for the use of engineers and others who might be in need of accurate elevations.

The instruments and methods used in 1878 were continued in use until 1899, when, as a result of an elaborate theoretical investigation, it was found that apparently the leveling was subject to a systematic error depending on the azimuth of the line of levels. About 4,300 miles of leveling had been done by this Bureau up to that time. The behavior of the systematic error was determined from an adjustment of all the first-order leveling by this Bureau and other organizations. The leveling of the Coast and Geodetic Survey was then corrected for the systematic error. Later developments have had a tendency to cast some doubt on the validity of the conclusions reached in 1899, but the systematic correction is still retained on the leveling to which it was applied at that time.

In 1898–99 the Superintendent of the United States Coast and Geodetic Survey, upon the recommendation of a committee on first-order leveling appointed by him, adopted the instruments and methods which, with relatively few changes, have remained in use up to the present time.

Leveling is of various degrees of accuracy, depending on the sensitiveness of the instruments used, the care with which the observations are made, and the refinement of the computations.

Leveling of the highest degree of accuracy is now designated first-order leveling to conform with the recommendations of the Federal Board of Surveys and Maps made in May, 1925. Previous to that time this class of leveling was designated "leveling of high precision" and "precise leveling", and those terms are still used by foreign countries and will be found in the older publications of this Bureau and in many textbooks on geodetic surveying.

The limits for errors in precise leveling were first fixed in 1867 by the Association for the Measurement of Degrees in Central Europe (later called the International Geodetic Association). Leveling was called precise if the probable error of the difference in elevation between two points one kilometer apart did not exceed 3 millimeters on an average and was not greater than 5 millimeters as a maximum.

In 1912 the International Geodetic Association at its meeting in Hamburg, Germany, introduced another class of leveling called "leveling of high precision", for which the limits of errors are plus or minus one millimeter per kilometer for the probable accidental error and plus or minus 0.2 millimeter per kilometer for the probable systematic error. This narrowing of the limits was due to important advances made in the art of leveling since the first limits were established.

The first-order leveling done by the United States Coast and Geodetic Survey since 1899 falls within the limits prescribed for "leveling of high precision" at the Hamburg meeting. In the 1912 adjustment of the first-order level net the average probable accidental error per kilometer was plus or minus 0.71 millimeter and the average probable systematic error was plus or minus 0.08 millimeter.

Although the necessary computations have not been made, the majority of the second-order leveling done by this Bureau undoubtedly should be classed as "precise leveling" as originally defined by the Association for the Measurement of Degrees in Central Europe and as retained by the International Geodetic Association in 1912.

At the Sixth General Assembly of the International Union of Geodesy and Geophysics, held at Edinburgh in September 1936, that association adopted a resolution redefining leveling of high precision and precise leveling. According to this definition a method of leveling comes within the international classification of high precision if its total probable error e, calculated by means of the adopted formulas, does not exceed two millimeters per kilometer. It is classed as precise leveling if this total probable error does not exceed six millimeters per kilometer.

Translations of the resolutions adopted at Hamburg in 1912 and at Edinburgh in 1936 will be found in the Manual of Leveling Computation and Adjustment (Special Publication No. 240).

Prior to 1932 very little second-order leveling had been run by the United States Coast and Geodetic Survey. When the basic network of lines of first-order leveling became sufficiently developed, particularly in that part of the country east of the Rocky Mountains, it became desirable to subdivide the circuits of first-order leveling with leveling of a lower order of accuracy, and second-order leveling was chosen for this purpose. Second-order leveling, as executed by the United States Coast and Geodetic Survey, is run with the same equipment and field methods as are required for first-order leveling except that normally, except for spur lines, the leveling is composed of single-run sections.

The following specifications for leveling were approved by the Board of Surveys and Maps of the Federal Government on May 9, 1933.

First-order leveling.—First-order leveling should be used in developing the main level net of the United States. The lines should be so placed that eventually no point in the country will be more than about 50 miles from a bench mark established by leveling of this order. All the lines should be divided into sections 1 to 2 kilometers in length, and each section should be run forward and backward, the two runnings of a section not to differ by more than 4 mm. $\sqrt{K}$ or 0.017 foot $\sqrt{M}$, where K is the length of the section in kilometers and M its length in miles.

Second-order leveling.—Second-order leveling should be used in subdividing loops of first-order leveling until no point within the area is more than 12½ miles from a first- or second-order mark. Second-order leveling will include lines run by first-order methods, but in only one direction, between bench marks previously established by first-order leveling, and all double lines of leveling whose sections, run in a backward and forward direction, check within the limits of 8.4 mm. $\sqrt{K}$ or 0.035 foot $\sqrt{M}$, where K is the length of the section in kilometers and M its length in miles.

Third-order leveling.—Third-order leveling may be used in subdividing loops of first- or second-order leveling, where additional control may be required. Third-order lines should not extend more than 30 miles from lines of first or second order; they may be

single-run lines but must always be loops or circuits closed upon lines of equal or higher order. Closing checks are not to exceed 12 mm. $\sqrt{\text{kilometers in circuit}}$ or 0.05 foot $\sqrt{\text{miles in circuit}}$.

Leveling of lower order.—Leveling that allows closure checks greater than the limit stated for third-order work, such as trigonometric leveling, barometric leveling, or "flying" levels, shall be considered as belonging to the lower order of work.

GENERAL INSTRUCTIONS FOR GEODETIC LEVELING[1]

METHODS

1. In general, a line of levels will begin and end on previously established bench marks. At least two bench marks which, as shown by the new leveling, have not changed their relative elevations must be recovered at each end of the line and at any intermediate junction of the line with previous leveling.

2. Failure of a first-order line, between two old first-order marks, to check the original observed difference in elevation within the limit ± 4.0 mm. $\sqrt{K}$ (where K is the distance between the bench marks in kilometers, measured along the route followed by the leveling) shall be construed to indicate movement of at least one of the marks.

3. Failure of the new leveling to check the original observed difference between two second-order bench marks (or between a first-order bench mark and a second-order bench mark) within the limit ± 8.4 mm. $\sqrt{K}$ (where K is the distance between the bench marks in kilometers, measured along the route followed by the leveling) shall be construed to indicate movement of at least one of the marks.

4. At the beginning or end of a line of levels and at any intermediate junction with previous leveling, ties to the old work shall be made with leveling of the same order of accuracy as the original leveling. In tying to old lines on which bench marks are widely spaced or where several marks have been destroyed, it is good practice to obtain checks in both directions from the junction of the new and old lines. This makes it possible to obtain a more accurate connection between the old work and the new.

5. Two bench marks located on the same structure or so close together that they may both be affected by the same disturbing influence are not to be considered as a proper check for beginning or ending a line or for a tie at an intermediate junction, even though the new observed difference in elevation may happen to check the old observed difference within the allowable tolerance.

6. Except when specific instructions to the contrary are given, all lines of first-order levels are to be leveled independently in both the forward and backward directions. Leveling of second-order accuracy will normally be run in one direction only, except on spur lines. Spur lines of second-order leveling must be leveled independently in both the forward and backward directions.

7. The backward measurement on any section of a line which is run in both directions should be made under different atmospheric conditions from those which occur on the forward measurement. It is especially desirable to make the backward measurement in the afternoon if the forward measurement was made in the forenoon, and vice versa. The observer is to secure as much difference of conditions between the forward and backward measurements as is possible without materially delaying the work for that particular purpose.

[1] Commonly referred to, throughout this manual, as "General Instructions."

8. The spaces between permanent bench marks of a line of levels should be broken into sections by the establishment of temporary bench marks only when the permanent bench marks are 1 kilometer or more apart. Ordinarily, with marks spaced at average intervals of a mile or less, there will be no reason to establish more than one temporary bench mark between two adjacent permanent bench marks. No temporary bench mark is to be established if its establishment will create a section of a length less than 0.5 kilometer, except as provided for in paragraphs 17 and 18; when the temporary mark is established to form the base of a spur line of levels; or when working along a route having a grade of 8 to 10 percent or more.

9. In general, when working along a railroad, the top of the spike on the inside of the rail, which holds the rail in place, should be used as a turning point. If the railroad is in poor condition and the spikes are loose, a nail should be driven in the center of a tie for a turning point. Nails thus used for turning points should not be driven down flush with the surface of the tie but should be left projecting about ⅛ inch above the surface of the tie to make sure that the rod will rest on the nail and not on some nearby portion of the surface of the tie. When working along a road or when running a spur line away from the railroad, metal pins, driven in the ground, should be used for turning points.

10. The instrument shall be shaded from the direct rays of the sun, both during the observations and when moving from one instrument station to another.

11. At each city along the line, the leveling should be connected with at least two stable bench marks which are connected with the city datum. Connection should be made with all stable bench marks of other organizations which may be found along the route. It should be kept in mind that every time a connection is made to the work of another organization the leveling of that organization can then be placed on a mean-sea-level datum. A half day spent in making a connection to a system of bench marks on an assumed datum may bring many miles of levels into agreement with the control net. When there is any question of the justification for the work necessary to make any connection not specifically provided for in the special instructions for the project, the matter should be referred to the Office for decision.

12. Leveling will be extended to such airports as may be listed in the specific instructions for the leveling project. At each airport leveled to, three bench marks will be established; one at the control tower, one on the administration building or hangar, and one at or near the entrance to the field. The elevation of the highest point of the useable landing area (usually a runway) will also be determined, as provided for in paragraphs 13 and 14 concerning rail and ground elevations. Since the bench marks and ground elevations provided for above may not completely satisfy the immediate need for elevations, the airport manager should be consulted regarding the determination of the elevation of some additional point or points on the runways. These extra points may or may not be marked, depending on the desire of the airport manager. Any such points leveled to but not marked in the manner prescribed for permanent bench marks should be adequately described in the record book (Form 257) to permit their recovery. However, no description on Form 638 (Revised 1946) is to be prepared for a mark of this class. Any extra points the elevations of which are determined and which are marked as permanent or semi-permanent bench marks should be described on Form 638 (Revised 1946).

13. In order that the results of our vertical-control surveys may be as widely useful as possible and especially in view of the increasing use of ground elevations in mapping from aerial photographs, the elevation of the top of the rail is to be determined, by means of extra foresights, in front of each railroad station, at the crossing of each public road

or highway, at points opposite intersecting fence lines defined by trees or brush, at points opposite sharp boundaries between cleared and wooded areas, and at bridges. When working through a city or a village where there are several road or highway crossings close together, it is not necessary to determine the elevation of the top of the rail at each crossing but only at the more important ones. In determining the elevation of the top of the rail at points located on curves, a note should be made in the record to show on which rail the rod was held, since the two rails on curves are not at the same elevation. (See paragraph 54.)

14. When working along a highway or well-defined road, the elevation of the surface of the road is to be determined, by means of extra foresights, at each intersecting railroad, road or highway; at principal forks; at well-defined angles in the road; at points opposite intersecting fence lines defined by trees or brush; at points opposite sharp boundaries between cleared and wooded areas; and at bridge floors. In determining elevations at road intersections the rod should be held at the intersection of the center lines of the traveled ways and notes in the record should state this fact or any deviation from standard practice. At complicated intersections, such as are now being constructed where main highways join, a sketch plan of the road junction, showing just where the rod was held, should be inserted in the record. (See paragraph 54.)

15. The temperature, to the nearest degree centigrade as shown by the rod thermometer, should be read and recorded for the rod coming up from the first backsight at the beginning of each section, as long as the leveling is continuous. When stopping for lunch, at the end of the day's work, or when for any other reason the leveling is interrupted for any considerable length of time, an additional temperature reading should be made and recorded at the end of the continuous leveling. If the interruption occurs during the running of a section, the temperature should again be read and recorded at the time the leveling is resumed. (See page 64.)

16. At least once each month, during the progress of the leveling, a test must be made of the adjustment of the plumbing levels on the rods. A statement should be inserted in the record, showing the manner in which the test was made, the error that was found, and whether or not an adjustment was made. With the bubble of the leveling rod held at the center, the deviation of the face and the edge of the rod from the vertical must be determined. If the deviation from the vertical in either direction exceeds 10 millimeters on a three-meter length of the rod, the rod level must be adjusted. In addition to the periodic tests provided for above, the test should be made at any time when the rod has been subjected to a severe jar or has met with any accident which might possibly have thrown the plumbing level out of adjustment.

17. When leveling has been completed to a point which is to hold the elevation of the line overnight, or longer, a check point should be established at least one setup of the instrument away. When the leveling is continued from or to such a pair of points, the instrument should be set up midway between them and rod readings taken on each point, in order to determine whether either of the points has been disturbed. If the new difference does not agree with the first determination (see paragraph 28), releveling must be extended to other points to verify the stability of the point used in carrying the elevation ahead through the line. When establishing a pair of points as provided for above, decide at the time they are established which one is to be the bench mark and which one is to be the check point. Then, to avoid confusion, carry the elevation forward over the point selected as the bench mark. The difference in elevation between the points of the pair should be at least a foot (more if possible) in order that, should con-

fusion occur in carrying the elevation ahead through the line, the blunder will be so large as to stand little or no chance of remaining undetected when the line is tied out or a circuit is closed.

18. Except in rare cases, the permanent bench marks should be established before or during the first running of the line. It is believed to be inadvisable to delay tying in permanent bench marks until after the line has been run, even if in only one direction. When it is impracticable to establish a permanent bench mark before or during the first measurement of the line, an acceptable manner of tying in the permanent bench mark or including it in the main line of levels is to establish a temporary bench mark and a check point on each side of the proposed location for the permanent bench mark and to leave the portion of the line between them un-leveled until the permanent mark has been set. The arrangement of the temporary bench marks and check points established for this purpose should be similar to that described in paragraph 17. This will provide for two points, the difference in elevation between which is known, on each side of the permanent mark, and the leveling between the two pairs of points makes a section in the main line of levels. A diagram showing the arrangement of the temporary bench marks, the check points, and the permanent bench marks is shown below.

$$-\mathrm{O}-\times-\Delta-\times-\square-\times-\Delta-\times-\mathrm{O}-$$

The positions of the instrument are shown by $\times$, the positions of the temporary bench marks by O, the check points by Δ, and the permanent bench mark by $\square$.

19. As far as possible, all permanent bench marks should be in the main line of levels and not on spur or branch lines. One of the exceptions to this rule is encountered when a triangulation station or a bench mark located off the route followed by the main line of levels is to be tied in. In such a case the spur or branch line is the more economical way of doing the work and will be satisfactory. Whenever a permanent bench mark is tied in by means of a spur or branch line, which has only one setup, the height of the instrument should be materially changed before making the second measurement. This will help to prevent any mistake in reading either one or both of the rods from escaping detection.

DETERMINATION OF LEVEL ERROR

20. Each morning, just before the leveling is begun or immediately after the beginning of the day's observations, the error of the level should be determined and the observations recorded in a separate opening of the record book, together with the date, the time of the observations, the instrument number, and the names of the observer and recorder. If the determination is made during the first setup of the line of levels and not before the leveling is actually started the following procedure should be used. After the ordinary observations at the instrument station are completed, transcribe the last foresight reading as a part of the record for the error determination; call up the back rodman and have the rod placed about 10 meters back from the instrument; read that rod; move the instrument to a position about 10 meters short of the front rod; read the front rod and then the back rod. (The two instrument stations are between the two rod points.) The rod readings must be taken with the bubble accurately centered. The required constant "C" to be determined, namely, the ratio of the required rod-reading correction to the corresponding subtended interval, is

$$C = \frac{(\text{sum of near-rod readings}) - (\text{sum of distant-rod readings})}{(\text{sum of distant-rod intervals}) - (\text{sum of near-rod intervals})}.$$

The total correction for curvature and refraction must be applied to each of the distant rod readings before using them in the above formula. The level should not be adjusted if "*C*" is less than 0.005. If "*C*" is between 0.005 and 0.010, the observer is advised not to adjust the level. If "*C*" exceeds 0.010 the adjustment must be made. If an adjustment of the level is made, "*C*" should at once be redetermined before proceeding even one setup further with the leveling. It is desirable to have the determination of "*C*" made under the usual conditions as to length of sight, character of ground, elevation of line of sight above the ground, etc. The adjustment of the instrument to reduce "*C*" must be made by moving the level vial and not by moving the reticle. Make sure that the date and time are recorded for each "*C*" determination, since this information is essential in computing the level corrections when making the office computation of the leveling. Should the instrument receive, at any time during the progress of the work, an especially severe bump or jolt which might disturb its adjustment, a new determination of the level error should be made at once and the level should then be adjusted if the new "*C*" is found to exceed 0.010. If the instrument is adjusted, another determination of "*C*" should be made at once as provided for above.

LENGTH OF SIGHTS

21. The maximum length of sight shall be 150 meters, and this maximum is to be attained only under the most favorable conditions. (See paragraph 23.)

22. The difference in length between the foresight and the backsight at any one instrument station must not exceed 10 meters. The difference is to be made as small on each pair of sights as is feasible, by the use of good judgement and care, without any expenditure of time for this particular purpose, unless the difference is found to exceed the 10-meter limit set forth above. The telescope should not be refocused between the two sights from a single instrument station if it can be avoided.

23. Observers should keep the length of sight great enough to make it necessary to do a moderate amount of rerunning. If an observer is extremely cautious and confines all his observations to sights sufficiently short to insure easy reading of the rod, it is possible to work month after month with almost no rerunning, but the progress will be slow. On the other hand, it is certain that an attempt to take sights of the limiting length, 150 meters, at all times would lead to a very large amount of rerunning and progress would not be rapid. It is believed that the maximum speed consistent with the required degree of accuracy will be secured by continually keeping the length of sight such that the amount of rerunning will be from 5 to 15 percent. An extremely small percentage of rerunning indicates an excess of caution on the part of the observer. The occurrence of a moderate amount of rerunning is due largely to an attempt on the part of the observer to obtain the maximum progress consistent with the required degree of accuracy and not to inability to secure such observations that little or no rerunning would be necessary. Observers have found that a convenient rule, in fixing the length of sight, is to shorten the sights whenever the upper and lower intervals subtended on the rod are found to differ frequently by more than a selected limit. Each observer should fix this limit from his own experience, by noting the relation between a provisional limit and the amount of rerunning found to be necessary while using it. Such a rule is based on the idea that the additional errors which are encountered when the length of sight is increased are, in the main, those due to the increased accidental errors in reading the rod. In second-order leveling which is not double-run the tendency should be toward the side of extreme caution rather than to risk the necessity for releveling whole lines when closures prove

to be outside allowable limits. If second-order leveling is run with the same care used in first-order leveling, the double-run second-order leveling will seldom require more than the two required measurements and circuits of single-run second-order leveling will seldom fail to close within the allowable tolerances. In the past, our chief trouble with second-order leveling has resulted from a tendency on the part of many observers to relax their care in observing and their attention to all details when doing second-order work. This should not be the case, since second-order leveling should be run with the same equipment, the same methods, and the same care as for first-order leveling, the only difference being that, with the exception of spur lines, the measurements are made in one direction only, instead of making both forward and backward measurements as in first-order leveling.

ALLOWABLE DIVERGENCE OF RUNNINGS

24. In first-order leveling, on all sections upon which the forward and backward measures of the difference in elevation differ by more than 4.0 mm. $\sqrt{K}$ (when K is the length of the section in kilometers), the leveling shall be repeated until any two runnings in opposite directions agree within the tolerance specified above. (See Table I, page 77.)

25. In double-run second-order leveling, on all sections upon which the forward and backward measures of the difference in elevation differ by more than 8.4 mm. $\sqrt{K}$ (when K is the length of the section in kilometers), the leveling shall be repeated until any two runnings in opposite directions agree within the tolerance specified above. (See Table II, page 78.) Closed circuits of single-run second-order leveling should close within the limit 8.4 mm. $\sqrt{K}$ (when K is the circumference of the circuit in kilometers). See paragraph 38 for discussion of requirements for releveling when developing subordinate networks of second-order lines in "area" leveling.

26. On all sections of first-order leveling which are 0.25 kilometer or less in length, a discrepancy of not more than 2.0 millimeters between the forward and backward measurements will be considered a satisfactory check, regardless of the limit provided by the formula in paragraph 24.

27. On all sections of double-run second-order leveling which are 0.25 kilometer or less in length, a discrepancy of not more than 4.2 millimeters between the forward and backward runnings will be considered a satisfactory check, regardless of the limit provided by the first of the two formulas in paragraph 25.

28. These special tolerances (paragraphs 26 and 27) should be regarded as applying to short sections of two or more setups in each direction and *not* to single-setup sections, especially when the sights are quite short. In such cases the checks between forward and backward runnings should seldom exceed 1.0 millimeter and should average 0.6 millimeter or less. (See paragraph 8.)

29. It is believed to be inadvisable to state definitely in these instructions the allowable limit on the rate of divergence between the forward and backward lines ($B-F$), but this should be kept as small as possible. If the accumulated B—F shows a marked tendency to increase steadily in either direction (plus or minus), an effort should be made to determine the cause of the accumulation and to take such steps as will correct the tendency. A steady accumulation of B—F in one direction is usually a good indication of the presence of some systematic error which should be eliminated if possible.

REJECTIONS

30. In first-order leveling, if any measurement of the difference in elevation for a section gives a result differing by more than ± 6.0 mm. $\sqrt{K}$ from the mean of all the

measured differences of elevation for that section, the measure shall be rejected. No rejection shall be made on account of a residual smaller than ± 6.0 mm. $\sqrt{K}$, unless there is some good reason for suspecting an error in that particular measurement. In such cases the reasons for the rejections must be fully stated in the record.

31. In double-run second-order leveling the provisions of paragraph 30 apply, except that the rejection limit is ± 9.0 mm. $\sqrt{K}$, instead of ± 6.0 mm. $\sqrt{K}$ as specified in paragraph 30.

MISTAKES

32. In first-order leveling, or in double-run second-order leveling, whenever a mistake, such as a misreading of 1 decimeter or 1 meter, or an interchange of sights (the backsight being recorded for the foresight, and vice versa), is discovered in any measure after its completion and the necessary correction is applied, such measure may be retained in computing the mean difference in elevation, provided there are at least two other measures over the same section which are not subject to any such uncertainty.

33. When doing single-run second-order leveling and a mistake, such as a misreading of 1 decimeter or 1 meter, or an interchange of sights, is discovered in any measure after its completion and the necessary correction applied, such measure may be retained and used in computing a mean difference of elevation for the section provided there is at least one other measurement over the same section which is not subject to any such uncertainty.

RELEVELING

34. When releveling lines or portions of lines of first-order leveling, whether for the determination of earth movement, the purpose of increasing the number of available bench marks on old lines, the elimination of excessive closures, or for the purpose of obtaining ties at the beginning or end of new lines or at intermediate junctions with old first-order lines, all releveling shall be strictly up to the specifications for first-order leveling as set forth in these General Instructions.

35. When releveling along old second-order lines, for any reason, the releveling will be by means of a single line, unless the new leveling between two consecutive bench marks fails to check the old work within the limit for second-order leveling, ± 8.4 mm. $\sqrt{K}$. If any sections are found on which the new leveling fails to check the original leveling within that limit, additional runnings are to be made until a check is obtained with the old work or until a forward and a backward running of the new leveling agree within second-order limits.

36. In releveling along old lines for any reason and regardless of whether the original leveling was first- or second-order, when the new elevation of a recovered mark fails to agree with its original elevation within the proper tolerance, depending on the accuracy of the leveling, the opinion of the observer as to why the mark failed to maintain its original elevation should be stated on the Form 685 A submitted for that mark.

AREA LEVELING

37. When preparing instructions for leveling by areas, reference is made to the best county and highway maps available in the Office. Upon receipt of instructions for this sort of leveling and as soon as possible after arrival in the field, a reconnaissance should be made to determine whether or not the most feasible routes have been proposed and

whether or not any additional routes exist that would bring about a more advantageous plan of development for each area network. If the reconnaissance shows that changes should be made, in order to bring about a better development of the area, recommendations should be submitted to the Office for approval. It should be remembered that the ideal spacing of lines in area leveling is approximately 7½ miles. In general the routes selected should comply with this ideal requirement to the extent that lines shall not be more than 10 miles apart nor less than 5 miles apart if feasible routes can be found. In recommending changes, the fact should be kept in mind that it is undesirable to have any circuit more than twice as long as it is wide. At times, available routes will not exist and this requirement cannot be complied with, but, in general, the circuits should not be allowed to become long and narrow.

38. In order that the leveling in an area may be properly adjusted as soon as possible after the field work has been completed, the circuits of single-run second-order leveling within the area should close within second-order limits. (See second formula in paragraph 25.) The observed elevations and distances along the lines surrounding each area assignment will be furnished to the field party, along with a sketch showing the existing closures of the circuits within which the new leveling will be done. From the observed elevations one may obtain observed differences for local tie purposes. The adjusted elevations, which will also be furnished when available, should be used as a start in carrying elevations through the field computations. The field computations (Form 45) should be kept closely up to date and circuit closures should be computed as soon as possible after each circuit is closed, to ascertain if there are any large closures in any of the newly developed circuits. If there are excessive closures of opposite sign on opposite sides of any line, it is good evidence that the line is in error and should be releveled. If any circuits are found that do not close, and there is any doubt as to just which lines should be releveled, forward the results to the Office for comment before undertaking any extensive releveling. In computing circuit closures, differences of elevation, taken in the sense from bench mark to bench mark, should always be accumulated in a clockwise order around the circuit.

PROGRAM OF OBSERVING

39. The program of observation at each instrument station is to be as follows: Set up and level the instrument. Read the three lines of the diaphragm as seen projected against the face of the No. 1 rod, each reading being taken to the nearest millimeter and the bubble being held continuously at the center of the graduations on the tube; that is, both ends reading the same. (See pages 29 and 35.) Then, after the rod has been turned, read the middle wire of the diaphragm, as seen projected against the back of the rod, to the nearest hundredth of a foot. As soon as possible thereafter repeat the operation with the telescope pointed at the No. 2 rod.

40. At instrument stations of odd numbers the backsight is to be taken before the foresight, and at those of even numbers the foresight is to be taken before the backsight. As the same rod is held on a turning point for both the foresight and the backsight, the effect of this method is that the same rod is read first at each setup, it being the rod used for the backsight at the first instrument station of the day's work.

PERMANENT BENCH MARKS

41. Permanent bench marks should be established at intervals not exceeding 1 mile except that, when transportation of materials is particularly difficult and there are no out-

crops of rock or existing structures of suitable character in which to set marks, this interval may be increased to 2 miles on the portion of the line where the unusual conditions are encountered. In determining the frequency of bench marks, all bench marks of other organizations, which are well and permanently marked in a manner closely similar to those established by this Bureau, may be counted in complying with the above requirements. Other types of marks, chiseled squares, bolts, rivets, unmarked points, etc., are not to be counted in complying with the above spacing requirements.

42. At places from which it is likely that future leveling will be extended, such as a railroad junction point, or the crossing of a main highway, at least three bench marks should be established within a radius of ½ mile, but far enough apart and in sufficiently varied types of structures so as not to be affected by the same disturbing cause or causes.

43. Every new permanent bench mark must be marked by a standard metal tablet, so fastened in rock, brick, stone or concrete as to resist extraction, change in elevation, or rotation.

44. Since paragraph 41 now requires that bench marks be established at 1-mile intervals, except when transportation difficulties are unusually great, it shall be considered good practice, when operating along routes where bench-mark trucks cannot be driven, and in the absence of rock outcrops, large well-imbedded boulders, or existing structures, to place bench marks at alternate mile intervals in trees. When bench marks are placed in trees, there should be two marks established from one to three setups apart. Both marks should be in the main line of levels rather than on spurs. The marks should be set in trees by boring a hole in the tree to a depth equal to the solid portion of the shank of the disk and of a diameter slightly less than that of the shank, and then driving the tablet in the hole till the disk is flush with a previously smoothed surface. The tablet should be set in a well-blazed area to delay the covering of the disk by later growth of the tree. The descriptions of bench marks of this type must be very carefully written so as to make recovery possible in future years. Reference marks consisting of copper nails or nails and washers driven in the centers of blazes on nearby trees should be established. Each reference mark of this character should be on the side of the nearby tree which faces the bench mark and the actual slope distance from the nail in the center of the blaze to the center of the bench-mark disk should be measured to the nearest 0.1 foot and recorded in the description. The approximate direction from each reference mark to the bench mark should also be stated in the description.

45. Triangulation and traverse stations, bench marks at tide stations, and marks of other organizations, which are within reasonable distances from the main line of levels and have been marked in a permanent manner, should be used as permanent bench marks. A traverse-station reference mark should not be used as a permanent bench mark since, as a rule, it is shallow and does not have the desired stability. However, when tying in triangulation stations, all reference marks and azimuth marks should be leveled over if they can be reached without an excessive amount of extra leveling. (See page 31.)

46. On all new leveling and on all releveling the requirements of paragraph 41 will be strictly complied with. In obtaining a tie to an existing line, where difficulty is encountered and it is found necessary to relevel a considerable distance along the old line to obtain a check, new marks should be established along the old line to bring the spacing of the marks up to present requirements. It is realized that this may at times be rather difficult, in as much as an observing unit will not know in advance just how much releveling along an old line will be necessary to obtain a check and the bench mark setting

crews will probably be at remote locations. However, the provisions of paragraph 41 should be complied with, even if it is necessary to interrupt the observing to enable the observing unit to set the necessary bench marks. Under these conditions, where suitable structures exist, the observing unit will be allowed to make use of them in establishing marks, and concrete-post marks may be kept to a minimum unless a nearby bench mark setting crew is available to help out in the work.

47. When concrete-post bench marks are established by the field parties of this Bureau, a 4- by 4-inch wooden post will be set nearby as a witness mark. These posts should be painted white and have the letters "U S B M" painted in black on the faces. The posts should be placed about 18 inches in the ground and should project at least 18 inches above ground. The use of these posts will aid in the recovery of the marks and will also prevent the unnecessary uprooting of the marks by contractors engaged in road or railroad changes or improvements. The description of each bench mark at which a witness post is set should include the distance and direction from the witness post to the bench mark. When permanent bench marks are established in cities or large towns and are so located that the establishment of the usual witness post is unnecessary and would constitute either a disfigurement or a hazard, the witness post should be omitted.

DESIGNATIONS OF BENCH MARKS

48. Permanent bench marks should be designated by a capital letter followed by a number, the letters to follow in alphabetical order and the numbers to change as each alphabet is exhausted. This designation, together with the year in which the bench mark is established, must be stamped on the tablet, preferably before it is set. The system of numbering is separate and distinct for each State. The chief of party will be furnished with an allotment of designations for use in each State in which he may work. If two or more parties are working in the same State, each party will be assigned a certain number of alphabets. Extreme caution should be exercised so as not to exceed the limits of an assigned group of designations. To do so will usually result in duplicate designations for bench marks in a given State and this can result in a great amount of confusion. The letters "I" and "O" should be omitted from each alphabet as they have been the source of considerable confusion in complying with requests for data concerning bench marks. Persons finding the marks often mistake the letters "I" and "O" for the numerals "1" and "0". The designations of two sets of three consecutive marks are given below for purposes of illustration.

H 2	J 2	K 2
1927	1927	1927
M 2	N 2	P 2
1927	1927	1927

The letter and number of the designation should be stamped on the tablet just above the center mark and the year of the establishment of the mark should be stamped just below the center mark. (See Figure 9.)

49. All recovered bench marks are to be referred to by their original designations, whether the bench marks were established by this or some other organization. In the records, computations and descriptions, the designation of a bench mark of another organization is to be followed by the initials, in parentheses, of the organization that established the mark.

50. Triangulation stations, traverse stations, reference marks, and azimuth marks connected with the leveling shall be referred to by their names and not be given letter-and-number designations.

51. Temporary bench marks are to be designated by arabic numerals only and are to be numbered continuously from "1" throughout the work of any one observing unit on any one line or area.

DESCRIPTIONS OF BENCH MARKS, AND RECOVERY NOTES

52. A description must be typed on Form 638 (Revised 1946) for each permanent bench mark established, or connected with, which is being brought into the leveling net for the first time. Temporary bench marks which may possibly be recovered for at least several years after their establishment should also be described on Form 638 (Revised 1946). No duplicates of the descriptions need be furnished.

53. Use Form 685 A for reporting on the condition of all old marks searched for in releveling old lines, in starting or ending new lines of leveling, or in making ties at intermediate junctions along the line. In general, Form 685 A will be used only for marks included in the list of original observed elevations furnished by the Office.

54. A brief description should be entered in the leveling record opposite the record of extra foresights at crossings and at other secondary points the elevations of which are determined by means of extra foresights, so that a person unfamiliar with the original field work may be able to identify positively the point on which the rod was held when the extra foresight was taken. Form 638 (Revised 1946) should not be used to describe points on which rail, highway or ground elevations are determined by means of extra foresights as called for in paragraphs 13 and 14.

RECORDS AND COMPUTATIONS

55. The record and field computation of the leveling must conform to the examples given on pages 63, 65, 66 and 67 of this publication.

56. The recorder shall keep a record of the rod intervals subtended by the extreme lines of the diaphragm on each backsight, together with the continuous sum of such intervals between each two consecutive bench marks (temporary or permanent), and a similar record shall be kept for the foresights. The two continuous sums shall be kept as nearly equal as is feasible, without the expenditure of extra time for that particular purpose, by setting the instrument beyond (or short of) the middle point between the back and front rods when the sums are unequal. The two continuous sums for a section shall not be allowed to differ by more than a quantity corresponding to a distance of 20 meters.

57. When working along a railroad, if the instrument is set up at some point other than on the railroad track, the number of the instrument station on the left-hand page of the record should be enclosed in parentheses. Similarly, on the right-hand page of the record, the number of the foresight rod shall be entered and enclosed in parentheses, if said rod is not supported on the railroad spike or on a nail driven into a tie. If the length of any portion of the level line run off the railroad is 25 meters or more greater than the railroad distance between the points of departure from and return to the railroad, the distance along the railroad track between these two points must be shown in the record. The purpose of these requirements is to furnish the Office a means of detecting blunders in the leveling, if necessary, by plotting the level line on a profile of the railroad.

58. The field computation should be kept up as the work progresses. As soon as the record books are out of use they should be sent to the Office by registered mail. The cor-

responding computation sheets must be retained until there is no possibility of their being forwarded in the same mail as the record books. No duplicates of the original records are to be made. (See page 20.)

59. Notes for future use in studying leveling errors shall be inserted in the record. These should give the time of the beginning and ending of the work on each section, weather conditions, especially as to cloudiness and strength of wind, and also the direction of the wind and sun with respect to the line of levels. Such other notes should be made as promise to be of value in studying errors.

60. The "Remarks" column in the record book is there to be used, and the more use that is made of it the better. When working over the records in the Office the only information available is the record and computations made in the field, and it often happens that a note in the "Remarks" column, made at the time some unusual circumstance occurred, is all that is needed to clear up some legitimate doubt in the mind of the computer working up the data in the Office.

61. In order to simplify the matter of handling the records, computations, descriptions, adjustments, etc., for the leveling run in developing control to the 7½-mile spacing, the following variations in the method of marking the records, computations and description cards should be observed:

(a) On Form 257 the "area" name should be entered on the cover and title page of each volume of record pertaining to that particular area. Do not have leveling for more than one area in a single volume.

(b) Inside the front cover of each volume of Form 257, make an index of the lines or parts of lines the records for which will be found in that particular volume.

(c) In preparing Form 45, fill in the line name in the usual place and at the top of each sheet place the name of the area in which the leveling shown on the computation form is located.

(d) Place the area name at the top of each copy of Form 638 (Revised 1946), above or to the right of the words "Description of Bench Mark." In each group of cards the positioning of the area name should be consistent throughout the group for the sake of improved appearance when the cards are reproduced by photolithography for publication.

(e) With the field computations will be submitted a sketch of each area, similar to the sample that will be forwarded from the Office as a guide. Each area line should be assigned a number which will appear on the sketch as well as on the computation sheets for that line.

If these instructions are observed carefully, there will be very little chance of any confusion in handling the records, computations, etc., in the Office, even though there are several lines or parts of lines in one volume, and in spite of the fact that in some cases a complicated network of lines will be represented in the computations for a single area.

MISCELLANEOUS

62. Should the experience of the chief of party indicate to him that a change or changes in these General Instructions would facilitate the work in the field, he is urged to communicate with the Office regarding such changes. However, no such changes shall be assumed to be in effect until they have been approved by the Office and the chief of party has been notified to that effect.

63. When cases arise which are not provided for by these General Instructions or by the specific instructions for the project, and the matter is not covered in material on the

following pages of this publication, the chief of party will use his own judgement in the matter.

64. The mileage statistics for the Director's annual report are prepared for publication by States. Therefore, in preparing the Monthly Report and Journal, the leveling accomplished during the month should be classified as first-order or second-order and reported with separate totals of each classification for each State in which leveling was done during the month.

65. About the middle of each month the chief of party will submit an informal report to the Office, detailing the progress made and giving any pertinent details concerning plans for future work. After the completion of each project, a season's report will be submitted. The season's report should follow the instructions on pages 61 to 62, inclusive, of this manual (Special Publication No. 239) and the provisions of the "Regulations of the Coast and Geodetic Survey" (Serial 685).

66. Permission will be obtained locally to operate along railroad rights-of-way or private roads. This should be done in ample time before actual field work is started along such routes. Descriptions of any available bench marks established by the railroads should be obtained from railroad officials in order that the marks may be leveled over during the progress of the work.

INSTRUMENTS

GEODETIC LEVEL

The geodetic level now in use is a modification of the one adopted by this Bureau in 1899 and fully described in Appendix 3, Report for 1903. A complete description of the new model is given in United States Coast and Geodetic Survey Special Publication No. 129, "Geodetic Level and Rod" by D. L. Parkhurst. This level was designed by E. G. Fischer, formerly chief of the instrument division, and the first one was constructed by him. Later, modification of the instrument was made by D. L. Parkhurst, chief of the instrument division.

The latest type of the geodetic level has a telescope made entirely of stainless steel (except for the eyepiece assembly and its holder) and this material is also used for the reticle ring, the bubble-vial holder and the adjusting screw for the latter. The telescope is mounted on cone-shaped pivots located in a plane passing through the vertical axis of the instrument. This permits the tilting of the telescope, by means of the micrometer screw, to bring the bubble to the center of its tube without changing the height of the instrument. The geodetic level as originally designed by Mr. Fischer had the pivots located about 9.7 centimeters forward of the vertical axis of the instrument and this introduced a systematic difference in the height of the instrument between the backsight and the foresight if the observer habitually leveled his instrument so that the vertical axis deviated slightly from the vertical in one particular direction.

Two views of the present type of geodetic level are shown in Figures 2 and 3.

ADJUSTMENT OF GEODETIC LEVEL

Length of bubble.—The level vial of the instrument has a small air chamber at one end, by means of which the length of the bubble can be controlled by properly tilting the instrument. To change the length of the bubble, remove the instrument from the tripod and hold it in the hands with one end down. It may be necessary in some cases to shake

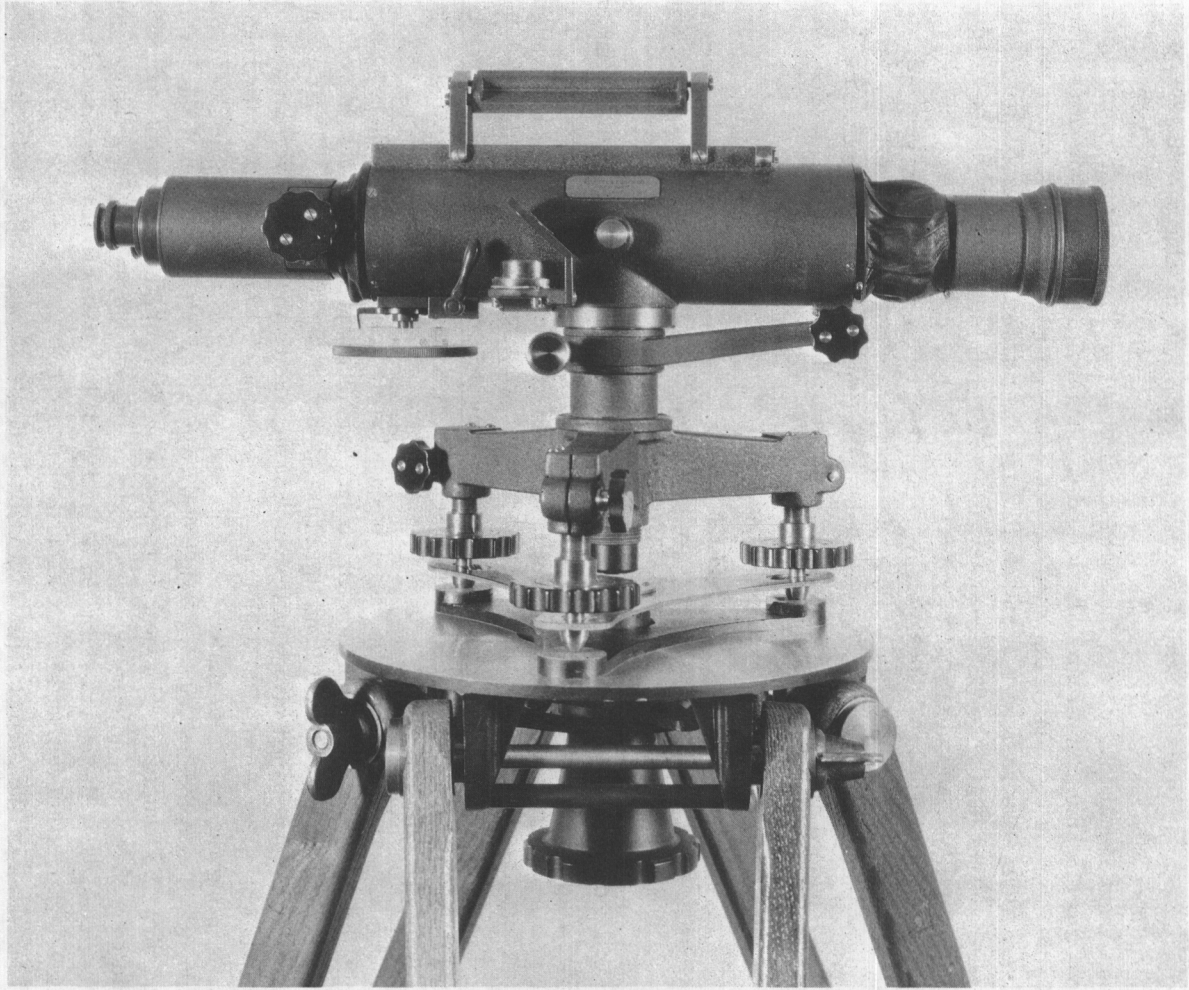


FIGURE 2.—Geodetic level, United States Coast and Geodetic Survey model, right side.

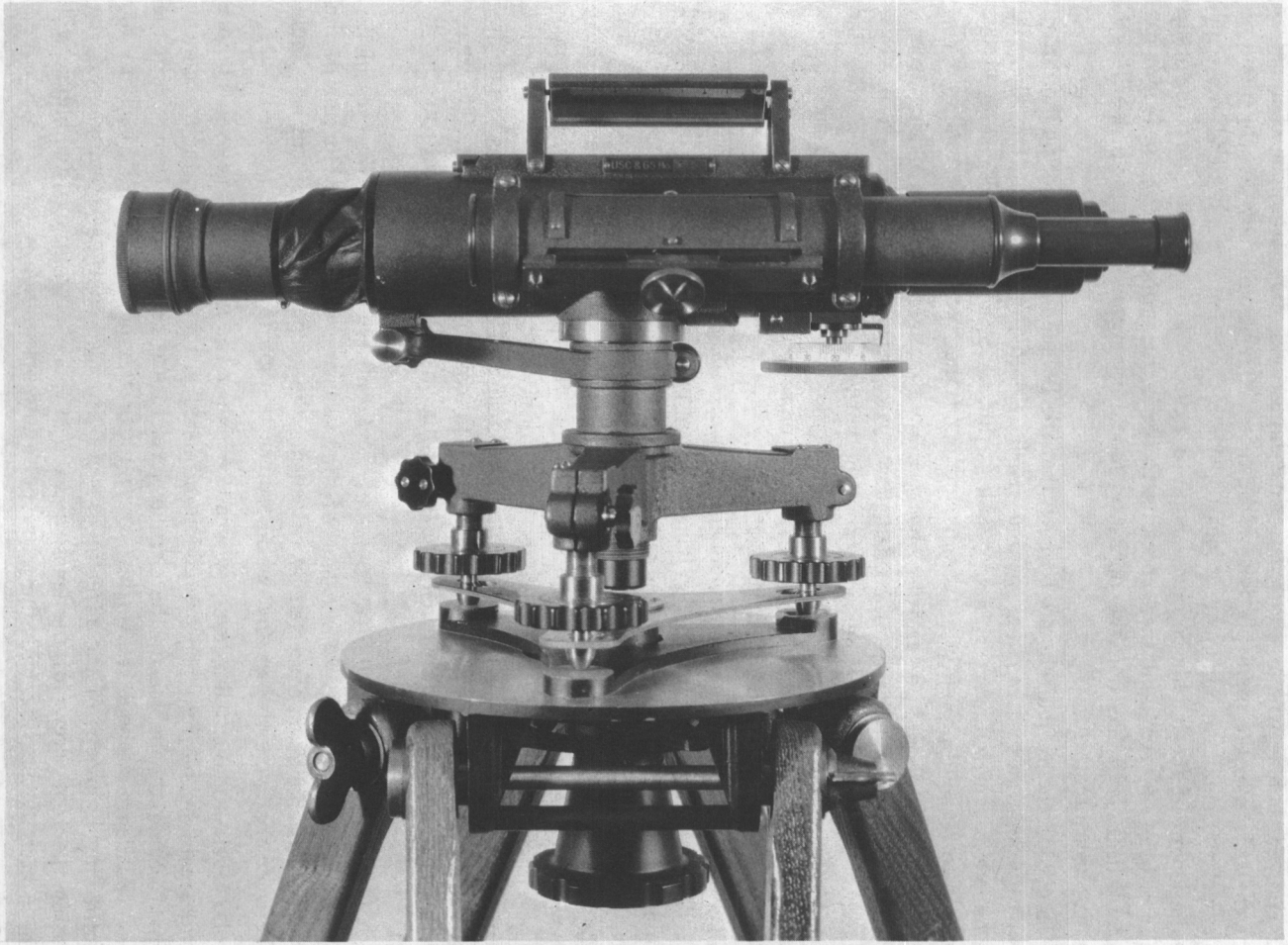


FIGURE 3.—Geodetic level, United States Coast and Geodetic Survey model, left side.

the instrument gently to insure passage of the liquid in the vial in or out of the chamber at the end. If the air chamber is at the lower end, bubbles will be seen to rise through the liquid in the vial, thus increasing the length of the bubble. If the air chamber is at the upper end, the bubble will be shortened, since liquid will flow from the chamber at the end of the tube into the main portion of the tube. A trial will show at which end of the bubble vial the small air chamber is located. If this location is memorized, the regulation of the length of the bubble becomes simply a matter of tipping the instrument up on end for a brief interval and then checking to see if the proper change in length has been accomplished. If it has not, the operation should be repeated until the proper length of bubble has been obtained.

The length of the bubble should be such that the bubble ends will not be more than one or two divisions away from the position marks (dotted graduations) on the vial when the bubble is centered. A very long bubble is difficult to control, and a short bubble is too sluggish to respond promptly to the movements of the micrometer screw.

This requirement should be carefully observed for the reason that, in making acceptance tests for level vials for use in geodetic levels, only that portion of the vial which is within two or three divisions either way from the position marks is considered, since the bubble is habitually used when centered. Acceptance tests of the vials are usually made with the bubble regulated so as to have a length not more than one division greater or less than the distance between the position marks.

Parallax.—Before using the instrument the telescope should be carefully examined for parallax. This is done by pointing the telescope toward the sky or any light-colored surface and focusing the eyepiece on the cross wires so that they appear sharp and black. Next focus the objective on a leveling rod placed about 100 meters distant and test for parallax by moving the eye slowly across the exit pupil. If the wires appear to move over the image of the graduations, parallax is present. The parallax may be due to poor focusing of either the eyepiece or the objective. To eliminate the parallax, refocus the objective until no parallax is present, then, if the image of the graduations is not distinct, move the eyepiece the small amount necessary to make it appear distinct. The image of the object (graduations) is now in the plane of the cross wires, and both are in the focus of the eyepiece.

This adjustment should be tested frequently while observing, for, as the eyes of the observer tire, the focal distance of the lens of the eye changes, causing a blurring of the cross wires, which should be corrected by refocusing the eyepiece. No refocusing should be done between the two sights at any one instrument station if it can be avoided.

Circular level.—The circular level, by means of which the instrument is leveled before bringing the main bubble into play, should be adjusted as follows: Set up the instrument on its tripod; bring the bubble of the circular level to the center of the ring; turn the instrument 180 degrees about its vertical axis; move the bubble halfway back to the center of the ring by means of the adjusting screws provided and the remainder of the way by using the foot screws of the level; and repeat this operation until the bubble will stay in the center of the ring with the telescope in any orientation.

Level vial.—The level adjustment, or what is commonly referred to as the determination of *"C"*, is made in accordance with the provisions of paragraph 20 of the General Instructions (page 6), where the procedure is given in sufficient detail.

A specimen of the record and computation of the determination of *"C"* is given in Figure 4.

Determination of "C" SPIRIT LEVELING

Date: *May 8, 1946* Forward—Backward (Strike out one word)

Sun:

From B. M.: To B. M.:

Wind: Time: *0840*

No. of Station	Thread Reading Back Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Rod and Temp.	Thread Reading Fore Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Remarks
	1603						1784					
	1593	15930		10			1628	16280		156	312	
	1583			10	20		1472			156		
	4779						4884					
	1547						1666					
	1537	15367		10	21		1510	15100		156	312	
	1526	31297		11	41		1354	31380		156	624	
	9389						9414	-12			-41	
								31368			583	
								31297				
								583)71	|-0.012			
								583				
								1270				
		Instrument adjusted										
	1547						1661					
	1536	15363		11	21		1505	15053		156	311	
	1526			10			1350			155		
	4609						4516					
	1587						1763					
	1576	15757		11	23		1609	16087		154	309	
	1564	31120		12	44		1454	31140		155	620	
	9336						9342	-11			-44	
								31129			576	
								31120				
								576)0.9	|-0.002			

Observer *J.C. Cowart*
Recorder *J.C. Chambers*
Instrument *G 71*
Rods *368 & 387*

Weather *Clear - Warm*

FIGURE 4.—Sample of record and computation of level constant *"C"*.

Each of the readings on the distant rods must be corrected for curvature and refraction. (See Table IV, page 79.) The two corrections may be combined as indicated in the specimen shown in Figure 4.

It should be noted that if the figures are transferred from page to page so that all subtractions are made right side up, a plus *"C"* will be worked out on the left-hand page and a minus *"C"* will be worked out on the right-hand page. Strict adherence to this system of recording and computing will tend to prevent mistakes in sign and will simplify later work in the Office.

"C" should be computed to the nearest unit in the third decimal place but no further.

When the instrument must be adjusted, because of too large a numerical value for *"C"*, the adjustment should be made by raising or lowering one end of the level vial and *not by moving the reticle.*

The adjustment is made as follows: Point to a distant rod, with the bubble centered, and read. Move the telescope, by means of the micrometer screw, so as to change the reading of the middle wire by an amount equal to *"C"* times the total rod interval in millimeters. The middle wire should be moved upward on the rod if *"C"* is plus or downward on the rod if the *"C"* is negative. Then with the telescope held in this position, bring the bubble to the center by raising or lowering the end of the level vial which is provided with the adjusting screw having a square projection on top and over which the adjusting wrench fits. To reach this it is necessary to slide the cover glass forward in its guides until access to the adjusting screw may be had.

In the example shown in Figure 4, the middle wire would be lowered on the rod by about 4 millimeters before bringing the bubble to the center by means of the adjusting screw.

Frequently, when an observing unit is working near the junction of two lines, it happens that the unit will work for part of the day on one line and the remainder of the day on the other line. This means that the record of the determination of the level constant *"C"* will be with the record for the line on which the party was working during the first part of the day. In such a case and despite the provisions of paragraph 58 of the General Instructions, a copy of the record for the *"C"* determination should be made in the record for the line worked on during the latter part of the day. This duplicate record should be plainly marked as a copy of the original record and a cross-reference should be made to show the name of the line, volume number, and page number where the original record may be found. This will enable the computers in the office to proceed with the processing of the records for the second line even if the records for the first line have not yet been received or, if received, they have been sent to another processing office located outside of Washington.

DETERMINATION OF STADIA CONSTANT

The stadia constant of the instrument should be carefully determined, since it is the factor by which the totals of the cumulative sums of the total intervals for both backsights and foresights are multiplied to obtain the lengths of the sections and these in turn are used in the formulas for computing the allowable divergences between forward and backward runnings of the various sections.

Stadia Constant SPIRIT LEVELING *Level No. G 47*

Date: *Nov. 7, 1945* Forward—Backward (Strike out one word)

Sun:

From B. M.:

Wind:

To B. M.:

Time: *10:00*

No. of Station	Thread Reading Back Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Rod and Temp	Thread Reading Fore Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Remarks
	1218											
75	1106			112			75	=	0.335			
	0994			112	224		224					
	1174											
85	1047			127			85	=	0.333			
	0919			128	255		255					
					479							
	1111											
95	0969			142			95	=	0.335			
	0827			142	284		284					
					763							
	1059											
105	0902			157			105	=	0.333			
	0744			168	315		315					
					1078							
	1018											
115	0846			172			115	=	0.334			
	0674			172	344		344					
					1422							
	0972											
125	0786			186			125	=	0.335			
	0599			187	373		373					
					1795							
600									6/2.005			
									0.334			

$$\frac{600}{1795} = 0.334$$

FIGURE 5.—Sample of record and computation for determination of stadia constant.

This should be done for each instrument received in the field and placed in use by the party. Furthermore, should new cross wires be installed in the field at any time, a redetermination of the stadia constant should be made at once.

The observations and computations for a stadia-constant determination should be recorded in a separate opening of the record book and the date and time of the observations should also be recorded. (See Figure 5.)

The determination should be made as follows: Select a suitable stretch of reasonably level track, roadway, or sidewalk, and place nails or other marks in a straight line at distances of 75, 85, 95, 105, 115, and 125 meters out from a point 0.6 meter toward these marks from the center of the instrument. Read the rod at each of the six points and record the readings in the record book. The bubble need not be accurately centered for these readings but should at least be free of the ends of the tube. The half-wire intervals should be computed as a check against erroneous readings. The sum of the total intervals for the six readings should also be computed. The stadia constant is then the sum of the measured distances (600 meters) divided by the sum of the six total wire intervals. As a check against gross errors in the measurement of the six rod distances, each separate observation should be computed and the average of the results of the six separate computations will serve as a numerical check on the computation called for above. Furthermore, any tendency for the six computed values to creep in one direction will be good evidence that some error in distance has been made between the point 0.6 meter out from the center of the instrument and the first of the six rod points. This may seem to be a useless precaution, but a case has actually come to light in which all six measured distances were in error by an even 10 meters.

RODS

The present type of geodetic leveling rod is only slightly different from the rod adopted in 1916. These rods are constructed in the shops of the United States Coast and Geodetic Survey.

The rod (see Figure 6) consists of a graduated metallic strip rigidly fastened to a metal foot piece, the latter being fastened to the wooden staff which supports the strip.

The graduated strip, 25 millimeters wide and 1 millimeter thick, is made of invar and has a thermal coefficient of expansion seldom exceeding 0.000001 per degree centigrade. It is fastened to the metal foot piece by a brass machine screw and two bronze dowel pins.

The staff is made of a single piece of well-seasoned, straight-grained white or sugar pine, free from knots or other defects. The metal foot piece is securely fastened to the staff by four bolts through the base. A shallow groove slightly wider than the invar strip is routed out through the entire length of the face of the staff and deep enough so that the strip is free to move underneath a number of brass washers recessed to set flush with the face of the staff. In order to eliminate any error due to sagging of the invar strip when the rod is held erect, it is placed under tension by a stiff spring, set into a recess in the top of the staff and bearing against a small brass angle plate attached to the top of the strip.

The staff serves to hold the graduated strip straight. On the face of the staff are the numbers indicating the meter and decimeter graduations, while the back of the staff carries graduations in feet and tenths which are used for making the check readings. A thermometer is mounted in the back of the staff, just back of the invar strip. A circular level enables the rodman to hold the rod vertically.

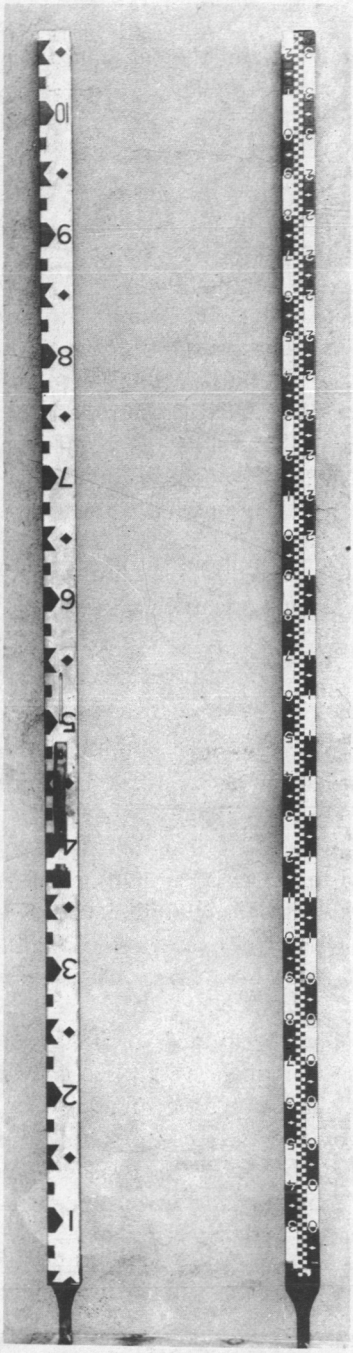


FIGURE 6.—United States Coast and Geodetic Survey leveling rod.

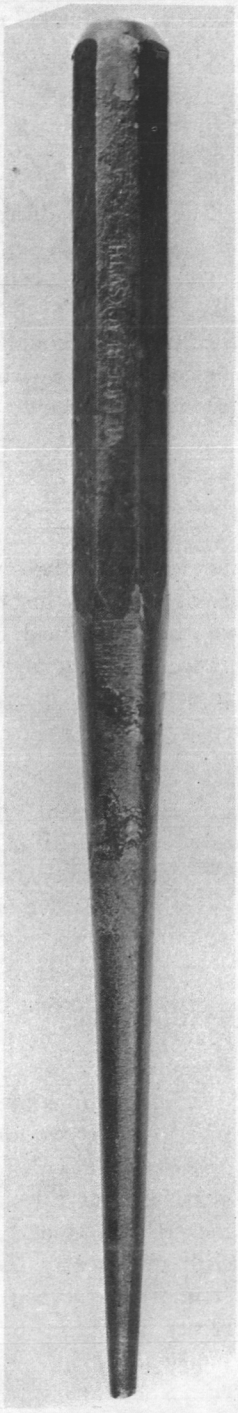


FIGURE 7.—Foot pin.

The wooden staff is painted thoroughly and the graduations which are on the wooden portion of the rod are put on by means of decalcomania transfers. The staff is then given a coat of clear lacquer as a further protection for the paint and graduations.

The invar strip carries the alternating black and white centimeter graduations of the usual form. The graduating of the strip is done by a machine and a process perfected by D. L. Parkhurst, chief of the instrument division, of the United States Coast and Geodetic Survey.

The foot piece is shaped so as to permit using as turning points the spikes which hold the rails to the ties.

A complete description of the rods and the process by which they are graduated is given in United States Coast and Geodetic Survey Special Publication No. 129, "Geodetic Level and Rod."

The leveling rods are standardized at the National Bureau of Standards, where both index and length corrections for the rods are determined. Having a large number of rods, it is possible to pair those of like characteristics for convenience in applying the various corrections when making the office computations. This accounts for the rods of a pair not having consecutive numbers. The rods are paired after standardization and, when the pairing has been decided upon, "pair marks" are painted on the edges of the rods. These make it unnecessary to refer to the records in order to select a matched pair when shipping rods to the field.

TURNING POINTS

When leveling along a railroad track the tops of the spikes which hold the rail to the ties should be used for turning points.

The spike selected for a turning point should be near the center of a rail in order to be away from the rail joints where, as a rule, the spikes are loosened by the passage of trains. Only spikes with well-defined high points should be used. The top of the spike should be made free of grease and dirt by the use of a steel brush or by scraping the sole of one's shoe over it. If the precaution of cleaning the top of the spike is neglected, the rod support may be lower for the backsight than for the foresight.

Also, the bottom of the rod may accumulate grease and dirt, making its surface irregular and thus affecting the length of the rod. The foot of the rod should always be wiped off before setting it on a turning point.

When the leveling follows a railroad, foot pins are used as turning points only when it is necessary to extend the line to a bench mark at some distance from the track or when it is found necessary to hold an elevation for a few minutes due to a passing train or other interruption to the work. When the leveling follows a highway, foot pins are used exclusively for turning points. The foot pin (see Figure 7) is a commercial rivet punch 14 inches in length.

CARE OF LEVEL AND RODS

The level and rods should at all times be accorded the care and attention that delicate scientific instruments of this type merit.

Keep the level in the box when it is not in use and when transporting it to and from the working grounds.

The telescope should not rest on the point of the micrometer screw when the instrument is being carried about or when it is in the box.

Keep the lenses of the telescope clean by the frequent use of a camel's-hair brush.

See that the object glass is firmly in place and, in removing or replacing the dust cap or sunshade over the objective, always use a clockwise twist so that, if there should be any tendency to drag on the objective cell, the twisting of the dust cap or sunshade will tend to tighten rather than loosen the mounting for the objective lens.

Keep the leveling screws and the micrometer screw clean by oiling and rubbing. The threads of the micrometer screw are extremely fine and great care should be exercised to see that no damage is done to them during cleaning and oiling.

The rods should be carried by the handles or face up on the shoulder. If the rods are always carried with the face down or up, they will become slightly bowed and the rod readings will be too large. In order to keep the rods straight, the rodmen should carry them in the natural position with the face down for a certain period of time and then shift the rods to their shoulders with the face up, and carry them in that position for a like period of time. Great care should be exercised to see that the graduations, especially those on the invar strip, are not subjected to friction in carrying or transporting the rods, since worn and thus indistinct graduations are not only very annoying to the observer but are a detriment to the quality of the observations.

In traveling to and from the working grounds the rods should be placed edges down on carrying brackets, with all the bearing parts heavily padded or cushioned and the faces of the rods separated by heavy cloth or burlap. It will usually be found best to fasten the box, in which the rods are shipped, to the truck in a secure manner and to transport the rods in the box. This not only protects them from moisture and dirt but reduces frictional wear to a minimum.

The foot piece, though firmly attached to the wooden staff, should be inspected frequently to make sure that it has not been bent so that the plane of the bottom of the foot piece is no longer normal to the face of the rod.

The rod, because of its length, is so easily struck against objects that the greatest care should be used in handling it. Striking the rod against poles, cables, walls, etc., will mar the graduations and tends to chip the paint off the wood and metal parts of the rod. A badly scarred rod means shorter sights, slower observing, greater unit costs, and decrease in accuracy. A rod should be returned for repainting as soon as the observer finds that it is scarred so badly as to interfere with the rapid reading of the rod.

ORGANIZATION AND EQUIPMENT OF PARTY

The present practice in the United States Coast and Geodetic Survey is to operate leveling parties as multiple units. Usually from two to four observing units and enough bench mark setting units to keep bench marks set ahead of the observing units will be under the supervision of one chief of party. With bench marks spaced at approximately one-mile intervals and so much of the leveling being single-run second-order work, the matter of keeping bench marks set ahead of the observing units requires careful planning and the organization of a sufficient number of bench mark setting crews.

For normal operation an observing unit consists of an observer, a recorder, an umbrellaman, and two rodmen. Abnormal conditions sometimes require the addition of one or two men to the unit for special duties.

The observer should have had at least the usual surveying courses given in a school of civil engineering or have had the equivalent in practical experience in surveying. He

should not be put in charge of an observing unit until after he has been given a period of training under the guidance of an experienced observer and has demonstrated his ability to make his observations properly, understands his instrument thoroughly, has become familiar with the General Instructions and the contents of this manual, and has demonstrated his ability to handle an observing unit successfully. Even then all observing units should be inspected frequently by the chief of party, in order that he may have personal knowledge that the leveling is being carried on in an approved manner and that the unit is functioning smoothly.

The recorder should have had at least a high-school education, should be able to keep a clear and legible record of the observations, and be extremely rapid and accurate in making the arithmetical calculations required in completing the record in the field. He should also understand the observer's work to such an extent that he may be able to call the observer's attention to any slips or oversights which, if noticed and corrected on the spot and before the instrument has been moved, may avoid the necessity for returning and releveling the section.

The umbrellaman should be possessed of sufficient physical strength to hold the large umbrella steady even in a stiff wind and act as an instrument carrier when required. He should also be able to make quickly and accurately the necessary conversions from meters to feet for comparing the middle-thread readings on the face and the back of the rod as an additional guard against blunders.

The rodmen should be able, not only to perform their usual duties of driving turning pins and holding their rods properly, but should understand the requirements for the selection of points on which extra elevations should be determined and be constantly on the alert to see that no such points are missed.

An observing unit is exactly what the name implies, *a unit,* and each man in the group, whatever his position, must be constantly on the alert to see that his duties are performed promptly and carefully. Complete and continuous attention to the details of the work should be required of *all* members of an observing unit if it is to operate smoothly and efficiently. Any member of the unit who is slow, careless, or indifferent can ruin the work of the whole unit and should not be retained in the unit if he does not constantly contribute his fair share to the operation of the group.

At times it may be necessary to add a windshield man to the party, but this should not be done unless it is evident that the increased progress resulting from the addition of this man will be sufficient to warrant the extra cost involved.

INSTRUMENTS AND OUTFIT

The minimum of instrumental equipment for an observing unit is as follows:

Adding machine	1
Compass, pocket	1
Fountain pen	1
Hammers (for driving turning pins)	2
Level, geodetic, including tripod	1
Level, hand	1
Rods, leveling, geodetic	2
Stationery case	1
Tape, pocket, steel (graduated in both meters and feet)	1
Turning pins	2

Typewriter 1
Umbrella (for shading instrument) 1
Watch (for use of recorder) 1

The equipment listed above should be obtained on requisition from the Washington office.

The minimum of instrumental and other equipment for a bench mark setting party is as follows:

Bench-mark tablets (additional tablets to be requisitioned as needed)	100
Compass, pocket	1
Dies, letter, set	1
Dies, number, set	1
Fountain pen	1
Hammer (for use with star drills)	1
Hammer, carpenter's	1
Post-hole digger	1
Saw, carpenter's	1
Shovel	1
Spade	1
Star drills (7/8-inch)	3
Stationery case	1
Tape, pocket, steel (graduated in both meters and feet)	1

Of the above, only the bench-mark tablets, compass, dies, fountain pen, stationery case and tape will ordinarily be obtained on requisition from the Washington office. The balance of the equipment will usually be purchased by the chief of party or obtained from storage.

When the wind is so strong as to require a windshield, an extra umbrella will often be found to be sufficient. However, it may be necessary to construct a windshield of canvas stretched on a suitable frame. This can be made by the party in the field. When leveling along a railroad in windy weather, observers have found it advantageous to set the instrument on the ground on the leeward side of the track and thus have the lower part of the tripod protected from the wind by the track and ballast. This procedure may be used when there is a brisk breeze blowing and no boiling is evident. When boiling is encountered the instrument should be set as high as possible above the track, which means setting up on the track. In extreme cases it may be found necessary to set up the instrument on the windward side of the track when boiling is bad, as with a very light breeze.

Until about 1930, most of the first-order leveling of the Coast and Geodetic Survey was run along railroads, since, in general, railroad work is most economical. In recent years, much of the first-order leveling and a large part of the second-order leveling has been run along highways, roads, and even trails. Along railroads the spikes holding the rails to the ties are used as turning points, thus obviating the necessity for driving turning pins. However, along highways and other routes the pins must be used.

The route to be followed is usually given in the instructions to the chief of party for the project, though in cases where "area" leveling is to be undertaken the selection of some of the routes is at times left to the judgement of the chief of party. When specific instructions are given as to the routes to be followed, changes should not be made without first securing the approval of the Director. In applying for approval for a change of route, the reasons for recommending the change should be clearly and completely stated in the letter in which the change is recommended.

Each observing unit and each bench mark setting unit should be provided with a truck which is suitable for the work on which it is to be used. Trucks have long been in general use for transporting the party to and from the working grounds, for moving equipment and baggage when changing headquarters, and at times it has been found advantageous to have the observing-unit truck right with the party during the leveling when working along highways in flat country.

Truck drivers should be experienced and careful men, not only for the good of the trucks but for reasons of safety as well.

The members of leveling parties may live in hotels, boarding houses, tourist camps, or in camps which they establish. The method of living is left almost entirely to the chief of party. If camps are established, tents, cots and bed tarps are provided for the men.

If tents are obtained from storage, each one should be carefully inspected and any needed repairs made. All weak ropes should be replaced. If the tents are old, it is advisable to have on hand a piece of canvas, sail needles, thread, and sewing palm for emergency repairs.

If new tents are to be purchased, they should be the standard type of center-pole tent, specifications for which can be obtained from the Office. These standard tents are more strongly reinforced than ordinary stock tents. The standard tent for leveling work is 9 by 9 feet, and it will comfortably hold two men or, in an emergency, three men. A center-pole tent can be pitched by one man even in very windy weather and will stand a strong wind better than a ridgepole tent. The center pole itself is usually made in two or three sections held together by ferrules of brass tubing, thus making it easy to pack.

MANAGEMENT OF PARTY AND PROCEDURE IN THE FIELD

The management of the party and the procedure in the field are governed largely by the route along which the levels are run, the available means of transportation, and the class of the leveling. The methods adapted to working along railroads are covered in detail in the following paragraphs, but it will be necessary later on to discuss the modifications of procedure for leveling to be run along highways, roads or trails. (See page 32.)

Instead of referring to the rods by their serial numbers, it is customary to designate one rod as the No. 1 rod and the man carrying it as the No. 1 rodman. The other is designated as the No. 2 rod and the man carrying it as the No. 2 rodman. The rods retain their respective designations throughout the season or until new rods replace them. However, a rodman's designation may be changed from rodman No. 1 to rodman No. 2, and vice versa, at will. Rod No. 1 is *always* read first at each instrument station. The designations "No. 1 rod" and "No. 2 rod" should not be confused with "front rod" and "back rod." One rod is always the "No. 1 rod" but it alternates from "front rod" to "back rod" or from "back rod" to "front rod" with successive instrument stations.

In starting the leveling from a bench mark the instrument is set up, usually between the rails, at a distance from the bench mark depending on the observing conditions. The No. 1 rodman is sent to the bench mark. The No. 2 rodman goes ahead of the instrument a distance equal to the distance from the bench mark to the instrument, where he makes a mark with chalk, keel, crayon or some other material, around the spike on the right-hand rail on which he is to hold his rod. While this is being done the observer levels his instrument.

In setting up the instrument the tripod should be placed with the points of two of the legs in a line parallel to the track and the point of the other leg in a line which is the

perpendicular bisector of the line between the other two. When standing at the instrument and looking toward the No. 1 rod the two legs should be next to the right-hand rail. Setting up the instrument in this way places the telescope in the best position for the observer in lifting the instrument to his shoulder after reading the No. 2 rod.

The leveling of the instrument is first done approximately with the small universal bubble attached to the side of the telescope housing, after which it is perfected with the level proper. The point on the head of the micrometer screw, called the reversing point, which indicates the required position of the micrometer screw to make the line of sight revolve in a horizontal plane when the instrument is leveled, is supposed to have been determined and marked with a soft pencil. In leveling the instrument at a station, the head of the micrometer screw is placed in that position and the telescope is turned at right angles to the railway track. The bubble of the universal level is then brought to the center, after which the adjustment in a plane perpendicular to the track is perfected with the leveling screw, which now lies under the eye end of the telescope, by bringing the bubble of the level proper to the middle of the tube. The telescope is then turned parallel to the track, directed toward the No. 1 rod, and the adjustment is perfected in that direction, using the two leveling screws that are in line parallel to the track. The telescope is now nearly in position for reading on the No. 1 rod, and, as stated above, the observer will be in position to lift the instrument when rod No. 2 has been read. If this method of setting up the instrument is followed, the number of separate motions required by the observer and the time needed at a station will be reduced to a minimum. It need only be remembered that the tripod should be set with two legs in a line parallel to the track and next to the right-hand rail when looking at the No. 1 rod; that is, the rod upon which the first reading at the station is to be made. By following this practice there is less liability of reading the No. 2 rod first, since to do so would seem awkward to the observer.

The preceding paragraph is exactly as published in Special Publication No. 140, "Manual of First-order Leveling" and it should be pointed out that, if the system as outlined for leveling the instrument is followed exactly, there is great danger that the instrument will be somewhat out of level in the cross-track direction at the time the readings are made on the rods. This comes about because it is practically impossible to turn the two footscrews which are in a line parallel to the track by exactly equal amounts in opposite directions and, if that is not done, the gain by using the main bubble in leveling in the cross-track position is lost unless the telescope is turned a second time to the cross-track position and the main bubble again brought to the middle of the tube by means of the one footscrew which is under the telescope when it is oriented at right angles to the track.

The paragraph referred to above as being quoted from the "Manual of First-order Leveling" was based on the practice necessary when the Fischer level had the telescope pivoted at a point considerably toward the objective from the vertical axis of the instrument. With the telescope pivoted in that manner any turning of the micrometer screw actually made a very minute change in the "height of instrument" or "H.I." as it is commonly called. On this account it was necessary to reduce to as small limits as possible the amount that the micrometer screw must be turned to perfect the centering of the main bubble at the time a reading was taken and to guard against a systematic accumulation of error from that source. However, since the instrument has been redesigned and the telescope pivoted at the vertical axis of the instrument, some of the provisions of the paragraph under discussion are no longer as necessary as they were before the design of the instrument was changed.

With the instrument in its present form, it is not considered necessary to make use of the main bubble in the rough leveling of the instrument, *PROVIDED* that the universal bubble is kept in good adjustment and the readings on the rod are made only when the vertical wire is on the rod somewhere between the invar strip and the edge of the rod. To have the vertical wire on the invar strip interferes with making the estimations but the vertical wire should be kept as close to the invar strip as possible, certainly within the space between the invar strip and the outside edge of the rod.

The observer is now ready to make the rod readings. He sights on the No. 1 rod, makes sure that the rod is in focus, brings the vertical wire on the wooden part of the rod, and then perfects the centering of the main bubble by means of the micrometer screw. He then reads the three horizontal cross wires, calling out the three readings to the recorder, thus: "Two three, four one; two one, two nine; one nine, one seven." Then, for a check, the first two figures of the middle wire are called out, thus: "Twenty-one." The check reading is called out loudly enough to be heard by the rodman, who then turns his rod for the reading in feet on the back of the rod. The observer has, in the brief interval between completing the readings on the face of the rod and beginning those on the back of the rod, shifted his attention to the main bubble to make sure that it is still centered. If it is he should read the back of the rod, thus: "Six, nine, eight", calling off the figures loudly enough so that he can be heard by the rodman, whereupon the rodman takes down his rod and starts forward to the next turning point. If the main bubble has not remained centered it should again be centered and the reading on the back of the rod should be called off only loudly enough for the recorder and umbrellaman to hear and the rodman should be signaled to show the face of the rod to the instrument again. The face of the rod is then read again and the record is changed if the recentering of the main bubble has produced readings differing from those already read and recorded. The centering of the bubble is again checked and, if it is still centered, the rodman is signaled to proceed forward along the line.

As the No. 1 rodman passes the instrument he is told the number of rails that will be used for the next length of sight. As he passes the No. 2 rodman he starts counting off on the left-hand rail double the number of rails that are to be used for the next length of sight. Having reached the place where the next turning point is to be selected he picks out a spike on the right-hand rail opposite the joint on the left-hand rail where he has completed his count. He then proceeds to mark the spike as did the No. 2 rodman for his first turning point and is then ready to show his rod to the observer when the observer is ready to observe upon it.

The No. 2 rodman, seeing that his rod is about to be read, perfects the plumbing of it on his turning point. The No. 2 rod is read and checked in a manner similar to that described above for the reading of the No. 1 rod.

At each instrument station the recorder and the observer should make certain that the back-of-rod reading is in agreement with the middle-wire reading on the face of the rod. It is believed that this can best be accomplished by providing the umbrellaman with a scale or table for converting from meters to feet. When the middle-wire reading on the face of the rod is called out by the observer the umbrellaman can then convert that reading to feet and know what the back-of-rod reading should be. Then, when the observer actually reads the middle wire on the back of the rod, the umbrellaman should call "check" if the called reading agrees with his conversion within one or two hundredths of a foot. In case the called reading from the back of the rod fails to check his conversion of the metric reading within the prescribed one or two hundredths of a foot, he should call "no" and the matter

should be investigated right then and there and before proceeding further with the leveling. The converted metric reading of the middle wire on the face of the rod should usually be checked by the middle-wire reading on the back of the rod within one hundredth of a foot. However, since the back of the rod is read principally for the purpose of checking against gross errors or blunders, it is not thought to be necessary to hold the check to the nearest hundredth. However, any persistent tendency for the back-of-rod readings to fail to check the converted metric readings by two hundredths of a foot or more should be thoroughly investigated and the cause determined and corrected if possible.

The recorder makes sure that there are no errors or omissions in the readings and calls "check." The observer, or whoever is to carry the instrument, picks it up and proceeds to the next station.

The procedure at each instrument station is the same except that when the observations have been completed at the instrument stations of even number the No. 2 rodman goes ahead and establishes the new turning point for the next instrument station.

To guard against the harmful effects of the rodman shifting his position or of the observer moving about his instrument, the rodman should not stand on the tie holding the spike that is being used as a turning point and the legs of the tripod of the instrument should not rest on a tie. All members of the party should be cautioned that in moving forward along the track they should avoid stepping on any tie that holds a spike which is in use as a turning point.

In connecting with the bench mark at the end of a section, it usually happens that the length of sight must be changed from what has been used regularly throughout the section. The rodman who is going to the bench mark should count the rails from the last turning point to the bench mark and call back the number to the observer, who will then be able to place the instrument midway between the last turning point and the bench mark; or, if the sum of the lengths of the backsights for the section differs too much from the corresponding sum of the lengths of the foresights, he can place his instrument in such a position as to even up the two sums. (See paragraph 22, page 7 and paragraph 56, page 13.)

The line of sight should be kept as far away as possible from intervening objects, and the umbrellaman should be extremely cautious in holding the umbrella to keep it well away from the line of sight.

Paragraphs 24 and 25 of the General Instructions specify the allowable tolerance between the forward and backward runnings and, in the case of second-order leveling which is not double-run, the loop closure. Paragraphs 2 and 3 of the General Instructions specify the tolerances that must be adhered to in getting checks at the beginning or end of a line and at intermediate junctions along the line. These specifications should be rigidly adhered to and in no case where the divergence is beyond the specified limits shall the work be allowed to stand without further leveling, even though the divergences are only very slightly over the specified limits.

On some of the early leveling by this Bureau, some of the bench marks established were stone posts with a square hole in the top. The bench mark is the bottom of the square hole. In leveling *to* a mark of this type, when the square hole is too small to allow the foot of the rod to rest on the bottom of the hole, a small block should be placed on the turning point next preceding the bench mark when the backsight is being taken upon it. Then if the same block is carried forward and placed between the bottom of the square hole and the foot of the rod when the foresight is taken to the rod on the bench mark, the difference in elevation will be the same as if the rods had stood directly on the turning

point and on the bottom of the square hole. In leveling *from* a mark of this type, use the block in the hole while taking the backsight on the bench mark and then carry the same block and place it on the next turning point while the foresight is being taken. Then, if the block is removed from the turning point before the next backsight is taken on it, the correct difference in elevation will be determined. A ¾-inch length of ½- or ⅝-inch dowel stick, or a similar piece of round metal rod, makes an excellent block for such use. *DO NOT* use a square stick or rod from which to cut the block, since a nearly cubical block may introduce errors in the line by being turned in moving so that the same faces would not be used in the two positions. A cylindrical block will always be placed so that the same dimension is vertical. Notes in the "Remarks" column of the record book should indicate clearly just what was done in each and every case which is handled in accordance with the provisions of this paragraph.

In tying to U. S. Geological Survey leveling, as provided for in paragraph 11 of the General Instructions (see page 4), many secondary or semi-permanent bench marks. such as copper nails in tree roots and tree trunks, square cuts on boulders and bridges, etc., will be encountered. These may be readily recognized in the U. S. Geological Survey publications as their elevations are given to only two decimal places in feet, while the elevations of the standard marks are published to three decimal places in feet. While the marks in the tree roots and tree trunks are perfectly good marks and some excellent recoveries have been made, even after a period of from 15 to 20 years, they are, nevertheless, hard to recover. In most cases, the tree bark and wood fibre will have grown over the mark, making recovery difficult. Men attempting the recovery of marks of this type should first look for a possible scar and then dig into the bark and wood carefully. If care is not used in attempting to uncover the mark, the mark may be destroyed in the attempt to recover it. Marks of this type will not be counted in complying with the spacing requirements of paragraph 41 of the General Instructions (see page 10), but should be leveled to if possible.

Descriptions of triangulation stations, which are located near lines of levels called for in the special instructions for any leveling project, will be furnished to the chief of party, along with a sketch of the triangulation net. During the progress of the work, levels will be run to any triangulation station which can be reached by the expenditure of not more than one-half day's time of an observing unit. In leveling to any triangulation station the leveling should also touch on all reference and azimuth marks, if such marks exist and can be reached without making the additional leveling consume more than the one-half day specified above.

No attempt should be made to level to the underground mark at a triangulation station. Extreme care should be exercised in recording the designations, in writing the descriptions, and in making the records for the leveling to the marks in the group at a triangulation station, so that there will be no chance of confusion in the elevations of the marks in the group. (See page 11.)

Any spur lines which are run to tie in triangulation stations should, of course, be double-run and the check limits between forward and backward runnings should be those for first- or second-order leveling, depending upon the order of accuracy of the main line from which the spur line is run.

When leveling along the coasts or in the vicinity of tidal estuaries and when groups of tidal bench marks are located on or near the routes followed by the observing units, all recoverable tidal bench marks should be touched upon by the leveling and a connection

should also be made to the tide staff itself, if one is in place and it is possible to level to it. Descriptions of bench marks at tide stations located close to a leveling project will be furnished to the chief of party as a part of the data transmitted to the field at the beginning of the season.

It is a distinct advantage for the observer to know where the permanent bench marks are located. These are usually established by the bench mark setting party, but the observer should have a copy of their descriptions so that he can regulate the length of his sights when approaching them. The bench mark setting party should make a mark on the tie or rail opposite the bench mark in order that it may be found easily. A paint mark or other mark on a pole or on the end of a tie a constant number of rails both ways from the bench mark is of considerable assistance to the observing unit. The bench mark setting party should be cautioned, however, that a great deal of diffculty has been caused in the past by the use of paint and large, unsightly marks. Paint should be used sparingly and the marks should be carefully and neatly made so as not to disfigure structures or right-of-way. Paint or any other markings which will not be obliterated in the matter of a few months by normal weathering should not be used on any permanent structure.

In working along highways or roads, the procedure is essentially the same as when working along a railroad, except that there are no rails to regulate the lengths of the sights. The lengths of the sights have to be regulated by pacing, and where the grades of the highway are not uniform it is sometimes economical to have an extra man to pace distances and mark locations for turning points and instrument stations. Locating turning points at the proper elevations is accomplished by the use of a hand level. When working along modern concrete highways the expansion joints in the pavement can often be used in lieu of rails in keeping sight lengths equalized.

Each chief of party will use his own judgement as to the best method of moving his party and equipment from one headquarters to another. The usual practice is to transport men and equipment by means of the trucks furnished for the use of the party.

In order that the lines and circuits of leveling may be properly adjusted after the office computations have been completed, it is important, when obtaining ties at the beginning or end of a line or at an intermediate junction along the line, that proper checks be obtained. A "proper check" does not merely mean that the field party should obtain a check within the prescribed limits between two marks and consider the matter closed, except where a check is obtained between the first two bench marks of the old line between which new levels were run and no other old marks have to be leveled over.

A "proper check" means more than this when the field party has failed to obtain a check on the first attempt and finds it necessary to do further releveling along the old line.

To illustrate by means of an actual example: A line of second-order levels was run in 1935 from Sperryville to Quicksburg, Va., and in the vicinity of Massanutten, Va., bench marks were established in sequence along the line and having the following designations: Q 10, R 10, S 10, T 10, and U 10.

In 1938, in attempting to tie out another line of second-order levels from Grove Hill to Massanutten, Va., the party releveled from S 10 to T 10, failed to check within the prescribed tolerance and then ran from T 10 back to S 10. The second 1938 running agreed with the first 1938 running, but the mean of the two failed to agree with the single running made in 1935 between the same marks by the amount of 41.9 mm., when the allowable divergence for a check would have been only 13.8 mm.

Obviously either one of two things had happened. There may have been an error in the 1935 leveling from S 10 to T 10 or at least one of these marks had not maintained its original elevation from 1935 to 1938.

Not having obtained a check between S 10 and T 10, the party releveled from S 10 to R 10 and obtained a check between the new and the old leveling of 1.1 mm., on a section of such a length that a divergence of 8.8 mm. would have been within the prescribed tolerance. Obviously, they obtained a good check between S 10 and R 10 and, in so doing, verified the stability of S 10.

This leaves a doubt as to the stability of T 10 or the accuracy of the original (1935) leveling from S 10 to T 10 and, as no further releveling along the 1935 line was done in 1938, the doubt still exists. The party leveling in 1938 should have leveled from T 10 to U 10 and onward until the matter had been cleared up.

Two things might have happened had the releveling been extended to U 10. First, if the new leveling showed a failure to check between T 10 and U 10 but a check from S 10 to U 10, movement of T 10 would have been indicated and a new elevation for T 10 could have been published, based on the new leveling from S 10 over T 10 to a check on U 10. Second, if the leveling (1938) obtained a check against the old (1935) leveling from T 10 to U 10, the stability of both T 10 and U 10 would have been indicated and the result would have been the disclosure of an error in the 1935 leveling from S 10 to T 10.

In beginning or ending lines of levels or in making ties to old lines at intermediate junctions along a new line, sufficient releveling should be done to leave no doubt as to the proper treatment of the leveling during adjustment. In other words, if the releveling of a section of an old line fails to check the old work, the releveling should be continued in both directions along the old line until checks within prescribed limits are obtained.

ERRORS OF LEVELING

The General Instructions for Geodetic Leveling by the United States Coast and Geodetic Survey (pages 3 to 15 of this publication) are designed to minimize or eliminate from a line of levels all known sources of accidental and systematic errors. It is the purpose of this section of this manual, however, to explain those paragraphs of the General Instructions which are not considered to be in sufficient detail, to point out those errors which have been found to occur most frequently, and to suggest the precautions that observers should take to make their results of the required accuracy in the minimum time and at the lowest unit costs.

Many of the sources of errors in leveling of any kind are self-evident, and the observer will guard against them by properly adjusting his instrument and rods and by the use of firm rod supports.

MISTAKES OR BLUNDERS

Mistakes or blunders are especially to be guarded against, as they may cause great expense and annoyance on engineering projects before they are discovered. It may also be necessary to rerun the line to locate the error. Mistakes are usually caused by—

1. Reading a rod 1 meter or 1 decimeter wrong on both the forward and backward runnings of a section.
2. Undetected disturbance of a temporary bench mark.
3. The recorder reversing the backsights and foresights at a station on each of two runnings of a section.

4. Carelessness in connecting a permanent bench mark with the line of levels after the main line has been run.

Special care should be exercised to guard against mistakes or blunders in single-run second-order leveling, since they are much more likely to escape detection than when made on double-run leveling. Undetected blunders necessitate the releveling of a complete line instead of a single section, in order to make the necessary correction, when an excessive closure is developed.

A mistake in a rod reading is most likely to occur at a decided change in grade or when changing at a bench mark from the forward to the backward running, or vice versa. The General Instructions provide that after the first running to a bench mark the second must not be immediately started back from that mark without changing the position of the instrument enough to make a real difference in the rod readings.

While running on a long even grade both the observer and recorder should be on the alert for a change in grade, because the reading for the foresight, and possibly for the backsight also, may fall on a different meter space on the rod from where it had been made for a number of previous stations. A mistake of a whole meter is the one most likely to occur at the change in grade. The backs of the rods are graduated in feet and by reading the backs of the rods at each station on *at least* one running it is believed that the probability of an undetected mistake of a meter or decimeter is very small. However, it should be kept in mind that such mistakes have occurred in the past and may do so in the future unless carefully guarded against.

The General Instructions (paragraph 17, page 5) state that any temporary bench mark which is required to hold the elevation of the forward end of the line, or any detached piece of the line, should have a check point at least one setup of the instrument away. Both points are connected with when the leveling is advanced from them later, and any discrepancy between the original and the new difference in elevation is noted and investigated before proceeding. With this method any disturbance of the temporary bench mark is detected. When the new difference between a temporary bench mark and its check point fails to agree with the original difference in elevation between the same two points, by more than the usual tolerance for a one-setup section, the failure to check should be investigated thoroughly, before continuing the line of levels, even to the extent of repeating the leveling of preceding sections to obtain proper checks.

The transposition of backsight and foresight will probably remain undetected only very rarely in double-run leveling, for it is not customary on the second running of a section for the rods to be held at the same points as on the first running. On single-run work the greatest possible care should be exercised to prevent such transpositions. Under no circumstances should any section of a single-run line in which a transposition is even remotely suspected be allowed to stand without another running over the section, preferably in the opposite direction to that in which the first running was made.

The precautions to be observed, in the relatively rare case when it is necessary to postpone the establishment of a permanent bench mark until after the levels have been run past the site of the mark, are fully covered in paragraph 18 (page 6) of the General Instructions. However, this scheme should be resorted to as infrequently as possible. The best practice is to have the marks established ahead of the leveling.

ACCIDENTAL AND SYSTEMATIC ERRORS

With an accurately adjusted instrument of the type of the Coast and Geodetic Survey level, with the plumbing levels on the rods carefully adjusted, and with firm rod

supports, there would seem to be no source of systematic error in the mean of the forward and backward runnings of a line of levels, if the observing is done in accordance with the General Instructions and the other provisions of this manual. Closing errors of the circuits show, however, that the systematic errors are not entirely eliminated, and the divergence of the backward and forward runnings of lines of double-run levels clearly indicates some systematic error in a single forward or backward line, though the mean of the two may be close to the truth.

In paragraph 39 of the General Instructions (page 10) and throughout this manual, where reference is made to the position of the level bubble during observations, the observer has been instructed to hold the bubble continuously in the middle of the tube. The difficulty of obtaining this ideal position of the bubble, except with the expenditure of a large amount of time for the purpose, is apparent to any observer who has used a sensitive bubble under the conditions prevailing in our field work.

Although the bubble can easily be brought to the middle of the vial and held there, by means of the micrometer screw, until the beginning of the rod readings, it is often found to be slightly off center when the observer checks its position after making the three wire readings on the face of the rod. This creep of the bubble should not cause too great concern as long as it is small. A change of 0.1 division in the position of the bubble will change the rod readings by approximately 0.1 millimeter on a sight 100 meters in length. Since this creep may be in either direction its effect is largely accidental.

It is not intended to suggest that leveling of the required accuracy can be obtained by deliberately keeping the bubble off center, but if there is a creep of the bubble during the observations the observer should know how much creep can be permitted before it is necessary to relevel and repeat the rod readings. If any relationship should develop between the bubble creep and the accumulation of $B—F$, or the percentage of rerunning, the limiting value of the bubble creep should be revised accordingly.

Accidental errors will be present under any method of operation, and, other things being equal, they will increase with the increase in the rapidity of the progress of the work beyond a certain normal amount. The observers in the United States Coast and Geodetic Survey are directed to do as much leveling as possible of a certain order of accuracy (as indicated by the agreement of the two separate measures of each section of a line or the loop closures in networks of single-run lines) rather than a smaller amount of leveling of greater accuracy. They make the lines of sight as long as the atmospheric conditions will permit, up to the prescribed maximum of 150 meters. The greatest sources of accidental error are believed to be in estimating the tenths of the centimeter graduations on the rod and in the varying vertical refraction on the backsights and foresights. Another source of error (probably entirely accidental under the method of leveling prescribed) is the inertia of the liquid in the level vial. The observer should bring the bubble to rest at the center of the tube and then wait a few seconds to see whether or not it creeps to another position. If it moves away from the central position, it should be brought back before making the rod readings. An error, probably mostly accidental, may be caused by refocusing the rod image between the two sights at an instrument station. This probably changes the relation between the axis of the bubble and the line of collimation.

The Coast and Geodetic Survey type level, being incapable of rotation about the axis of the telescope, as is the case with a "wye" level, must be collimated in the shop before it is assembled and the collimation adjustment cannot be checked easily in the field. To

check the collimation of the telescope it is necessary to take the telescope out of the housing in which it is pivoted and place it in a pair of "wyes" on a test stand where it can be rotated about its longitudinal axis and tested against a collimator or a distant signal.

The telescopes of the geodetic levels are carefully adjusted and checked for collimation error before reassembly after an overhaul in the shop and usually maintain their adjustment in collimation very well. However, a severe jolt in transportation or in use may disturb the collimation adjustment and cause serious trouble in the field.

If the instrument is quite badly out of adjustment as far as collimation is concerned, this fact can be established by the following simple procedure. Set up the instrument and at least rough-level it. Point on a distant rod and focus sharply on it. Then by means of the focusing screw move the whole eyepiece and cross-wire assembly slightly in and out past the point at which focus is sharp. If the wires have a tendency to crawl first one way and then the other along the rod as the focusing screw is turned, the instrument is obviously in need of a collimation adjustment and should be returned to the shop for an overhaul.

If it is necessary to keep the instrument in operation until a replacement can be obtained, care should be taken to see that the instrument is set so nearly midway between the rods at each instrument station that it will not be necessary to change the focus of the telescope between the two sights at a single instrument station.

Paragraph 29 of the General Instructions refers to the accumulation of the discrepancy or divergence between the elevations carried by the forward and backward runnings of a line of levels. It is rarely the case that both runnings are made on the same half-day but the interval between them is very seldom more than one week.

It has been our experience that early in a line of levels run by a new party the value of the discrepancy between the forward and backward measures ($B-F$) in millimeters per kilometer tends to be large, but that after about the first 20 kilometers it begins to decrease. About 0.25 millimeter per kilometer, as the line progresses, is a good value, tending to decrease to the end of the line. Any noticeable tendency of the discrepancy to be of one sign is a thing to be guarded against, studied, and, if possible, counteracted.

There is no reason for the office computation to affect the value of $B-F$ systematically in either direction. The two principal corrections for rod length and for temperature are usually about equal on the backward and forward lines and, therefore, do not greatly affect the $B-F$.

The effects of the sun, the grade of the line, the average temperature, and the azimuth of the line on the accumulation of $B-F$ are not known. Therefore the methods are designed to eliminate them from the observations or at least to reduce them by providing that the running of the backward and forward lines shall be under different conditions. Any rapid accumulation, in most cases, has been found to be due to the habits of the rodmen or to the methods of supporting the rods.

When the accumulation is large the observer should make various experiments, such as

(1) when working along a railroad, use foot pins for turning points for a few miles,

(2) a change of rodmen,

(3) requiring the rodmen to try various changes in their methods of holding their rods, especially requiring them to be unusually careful in placing the rod on the highest point of the spike and in avoiding the placing of an excess of pressure on the rod by leaning on it or in bracing against wind pressure, and

(4) changing the program of running forward in the forenoon and backward in the afternoon to backward in the forenoon and forward in the afternoon.

The observer should then study the relation of the accumulated *B—F:* first, to each of the above-mentioned changes; second, to the weather; third, to changes in the character of the ballast; and fourth, to changes in the grade of the railroad. By such studies the source of the trouble will probably be located or else the accumulation will cease without the reason for its doing so being discovered.

It is believed that the larger accumulated discrepancies cannot possibly arise from any systematic error in reading the rods. Especially is this true in leveling such as that called for by the General Instructions (paragraph 40, page 10) where the backsight is read first at stations of odd numbers and the foresight first at the remaining stations. This makes it practically a symmetrical process insofar as the observer is concerned. The primary purpose of this feature of the program is to eliminate from the computed elevations any systematic tendency of the instrument to rise or settle during observations and to balance out the effect of varying refraction.

There is a possibility of an accumulated discrepancy being produced by refraction on lines having steep grades. If the conditions in regard to refraction be the same on the two runnings of a line, there would be no divergence from that cause; but it is probable that the refraction is different on the higher sight than on the lower one and that this difference changes during the day as the relative temperatures of the ground and air vary. The refraction on the higher sight (up the slope) is no doubt different in the morning with a rising temperature from what it is in the afternoon with a falling temperature, while the lower sight (down the slope) which comes well above the surface of the ground will not vary so much between the forenoon and afternoon. Consequently, if the observer systematically levels forward early in the day and backward late in the day, refraction might cause an accumulation of *B—F*. If it does, there should be a change in the sign of the discrepancy when the program is reversed by leveling backward in the morning and forward in the afternoon. Also, without a change of program, a change of sign should occur after passing a summit or the lowest point in a valley.

It is difficult to see how a large accumulated discrepancy could be caused by errors due to a difference in the appearance of the rods, one being more brightly illuminated than the other, but if such is the case a change in the program of forward in the morning and backward in the afternoon to backward in the morning and forward in the afternoon would tend to change the sign. The discrepancy, if due to the appearance of the rods, would not increase on portions of a line run in both directions on cloudy days, and the change of program would probably not be effective on a line running north and south.

A test similar to that mentioned above might be made to show whether the accumulation is due to the tendency of the bubble to crawl toward the source of heat—the sun.

In this connection it should be mentioned that, in running through tunnels or in other places where it is so dark that artificial illumination of the bubble must be resorted to, great care should be exercised to get a diffused light on the bubble. It has been demonstrated that with one of the level vials, such as are used in the Coast and Geodetic Survey type geodetic level, the bubble can be made to creep up and down the vial for a considerable distance merely by playing the beam of a two-cell focusing flashlight on first one end of the bubble and then the other. This trouble can be almost completely overcome by placing a cap consisting of two or three layers of ordinary tissue paper over the front

of the flashlight, holding the paper in place with a rubber band, and thus diffusing the light so that it cannot be concentrated in a small area.

Among the cases of large accumulations of discrepancy between the two runnings of a line are:

(1) A section of the line from Ogden, Utah, to Pocatello, Idaho, where a discrepancy of 63.4 millimeters occurred on 138.4 kilometers, a rate of 0.46 millimeter per kilometer.

(2) On the line Red Desert to Azusa, Wyo., there was an accumulated discrepancy of 89.1 millimeters on 170.4 kilometers of line, or 0.52 millimeter per kilometer.

If there is a systematic error due to the direction of running, which causes the accumulated discrepancy, it is probable that this error, with different signs in the two runnings, is practically eliminated from the mean of the two runnings.

If there is a systematic error in a line, due to its having been run in the forenoon, which is of the same size but of different sign from a systematic error in the same line, caused by its having been run in the afternoon, then, if there are no other sources of error, the two lines will differ by twice the systematic error in a single line, but the mean will be free from this error. Now, if one-half of the above line is measured forward in the forenoon and the other half forward in the afternoon, and if the backward running is made half in the forenoon and half in the afternoon, then the difference in elevation of the ends of the line from each of the two runnings will be free from the systematic error and they will give the same difference in elevation for the two ends of the line. It seems to be reasonably certain that, insofar as errors due to forenoon and afternoon runnings and to the direction in which the line is run are concerned, the amount of the accumulated discrepancy is not an indication of the size of the systematic error which may be present in the line, for the systematic errors in each of the forward and backward runnings due to these causes may be made to accumulate or eliminate themselves by a change of program without affecting the difference in elevation as given by the mean of the two lines.

In making certain astronomic observations where extreme accuracy is required it has been found that most observers have a personal equation in bisecting a star with a wire. This may be called the "bisection error." This error is eliminated from the results by means of a reversing prism, which reverses the image formed on the retina of the eye, and one half of the observations are made in each of the two positions. It is no doubt true that there is an "estimation error" for some observers in reading the fractions of the divisions on the level rods, but as the same error would presumably be made on both the front and back rods these errors would not come into the line of levels. It may be the case, however, that the "estimation error" on a rod illuminated by the direct rays of the sun is different from that on a rod the face of which is in shadow. It is possible that this phenomenon is one of the causes or the cause of the accumulation of the difference $(B-F)$ between the forward and backward runnings of a line when one of the runnings has been made entirely toward the sun, while the other has been made in a direction away from the sun. On an east and west line, the effect of this error (if it exists) will probably be eliminated by the mean of the two runnings, but this would not be the case on a line which is nearer north and south than east and west. It may be desirable where extreme accuracy is required to have a reversing prism on the level and to have readings made on the rod in both positions of the prism.

After an observer has taken every known precaution to eliminate the effects of errors on the elevations of a line, it will usually be found that the closing error of the

loop or loops involving the line will be greater than can be attributed to purely accidental errors. There must be some systematic errors in the leveling which affect the mean of the forward and backward runnings, although the instrument may be in perfect adjustment, the constants of the rods accurately determined, the rod supports entirely satisfactory, and the two runnings made on different days and under different atmospheric conditions as far as rising and falling temperatures are concerned.

ERRORS DUE TO ATMOSPHERIC CONDITIONS

There is usually some systematic error in a single running of a line, the size and sign of which probably depend upon the direction of the running with respect to the sun, the time of day, the movement of the air, or possibly upon all three of these causes combined. Observers have reported that the two runnings of a section on a clear day or days agree more closely when the wind has a decided velocity than when the wind is very light or it is calm. This is probably due to the fact that when the air is in motion the temperature is more likely to be uniform throughout the layers through which the line of sight passes, and the refraction should be more nearly the same for the backward and forward sights.

The errors, other than instrumental or observational, which may affect a single running in a systematic manner can be made to act as accidental errors by leveling the second running under opposite conditions. For instance, if the first running has been made in the forenoon with a rising temperature and the sun to the eastward, the second measure should be made in the afternoon with a falling temperature and the sun to the westward. This does not apply to cloudy days, when it is believed the systematic errors due to atmospheric conditions are negligible.

It is possible that there is an error in the mean of the two measures of a section where one running is made on a clear day and the other on a cloudy day, but it would be difficult to show that this is true, for any systematic error on a short section of line (say 1 kilometer) is very small compared with the accidental errors.

SYSTEMATIC ERRORS ON SLOPES

It is believed that systematic errors are more likely to occur on steep grades if the observing is done at times when the surface of the ground and the air have different temperatures. If the air has a uniform temperature, or temperatures varying uniformly with height above sea level, then the density of any layer of air at a certain elevation above sea level will be the same throughout the layer. The effect of barometric pressure and the hygrometric condition of the atmosphere at different points within the distance considered (300 meters between the two rods) may be considered as having no effect in causing a different density in the layer. Under this condition of uniform temperature, or temperatures varying uniformly with regard to elevation above sea level, there will be the same amount of refraction on the backsights and foresights when these are of equal length. But when the air and the surface of the ground have different temperatures, the layer of air in contact with the surface of the ground will assume a temperature nearly that of the ground, and consequently the density of the air will tend to vary with its distance from the surface of the ground instead of with the elevation above sea level. (This will, of course, be true for only a short distance from the ground, say 1 or 2 meters.) If the ground is level, there will be no difference in the amount of refraction on the two sights, but if the ground is sloping, the sight up the slope will pass through layers of air of different densities, while

the lower sight will go through air in a normal state so far as the arrangement of its densities is concerned. The effect of the refraction on the rod reading on the upper sight will be of one sign if the surface of the ground is colder than the air, and of the opposite sign if the surface of the ground is warmer than the air. These errors are no doubt smaller when the wind is blowing and the air is stirred. On cloudy days the temperature of the air and the surface of the ground are supposed to be nearly the same, and consequently the refraction error on the slope would not be so large as on a clear day. The refraction error on a clear day should be at a minimum during the several hours in the middle of the day, when the temperatures of the air and the surface of the ground are nearly the same, and greatest in the morning and late afternoon, but should have opposite signs during these two periods.

As stated above, this refraction error should be entirely absent if the ground is level or nearly so and the backsights and foresights at a station are equal in length. It should reach a maximum on steep grades where the line of sight up the slope comes very close to the bottom of the rod. This error may be made small by never letting the line of sight come near the ground. It is impossible to predict what the safe height is, but it is believed that if the lower one of the three wires reads more than 30 centimeters above the ground most of the trouble will be avoided.

BENCH MARKS

PERMANENT BENCH MARKS

The value of a line of levels depends upon the distribution and permanency of the bench marks established or tied in during the leveling. The bench marks are the only visible evidence of the work, and the necessary time and money should be spent to perpetuate the line by making the marks of a substantial character and by placing them in locations where they will be as free as possible from the usual causes of disturbance or destruction.

Obviously, a bench mark, if improperly constructed or carelessly located, will often change its elevation by settling in soft ground, or by heaving as a result of frost action. It may settle by reason of being placed on a sliding hillside or may even be moved by man because it is in the way of improvements or additions to existing structures. A mark which settles or heaves from natural causes, or is moved by man without additional leveling to determine its new elevation, is not only useless as a bench mark but worse than useless because it is positively misleading.

Bench-mark setters can do much to insure the long life and continued usefulness of the bench marks established in the course of the leveling by giving careful thought to the location of the marks and taking pains to see that they are carefully constructed from properly selected materials.

The type of bench mark established by this Bureau consists, almost without exception, of a standard metal disk, on the back of which is a split shank which serves to fasten it to the structure in which it is set. (See Figure 9.) It is a well-designed tablet and will, if properly set, have a long life and resist all ordinary attempts to dislodge it.

The structures in which these disks are set vary in size and character through the full range from large monumental buildings to the relatively small and inconspicuous concrete posts, cast in place in holes in the ground, which are used to support a large percentage of the bench-mark disks established by the field parties of this Bureau. The choice

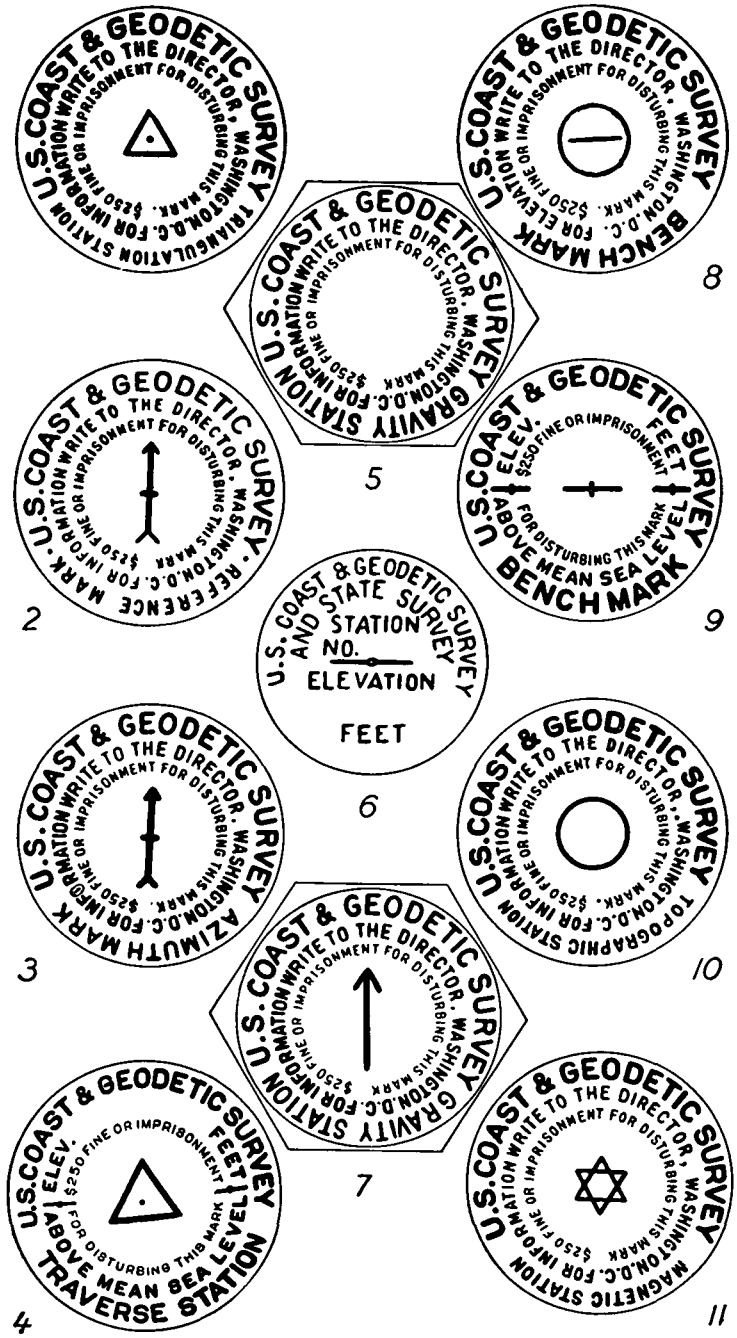


FIGURE 8.—Standard marks of the United States Coast and Geodetic Survey.

1. Triangulation station mark.
2. Reference mark.
3. Azimuth mark.
4. Traverse station mark.
5. Gravity station mark.
6. State Survey mark.
7. Gravity station reference mark.
8. Tidal bench mark.
9. Geodetic bench mark.
10. Topographic station mark.
11. Magnetic station mark.

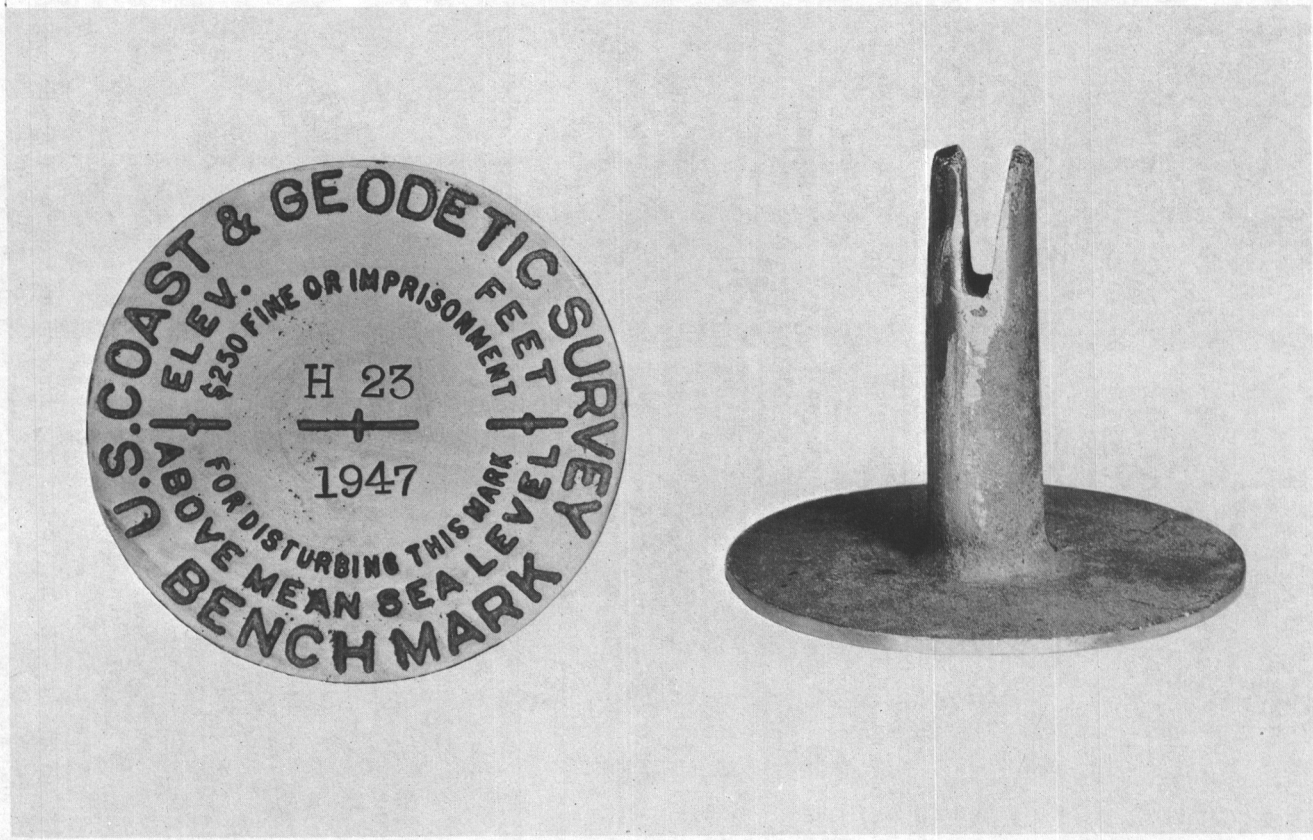


FIGURE 9.—Geodetic bench-mark tablet, showing method of stamping designation on the mark.

of the location for a bench mark is often a very large factor in prolonging its life and the site for a bench mark should not be selected hastily and without thought.

This discussion cannot provide for every possible situation that may arise in connection with the establishment of bench marks, but aims to call attention to the proper solution of problems that will arise frequently and to suggest lines of thought that will serve to aid the bench-mark setter in properly handling unusual situations in the selection of sites and the construction of marks as they may be encountered in the course of the work.

Buildings—In general, public buildings, buildings of a memorial character and churches have a longer life than do commercial buildings. On the other hand a new and modern bank building in a city or large town is apt to remain undisturbed longer than an antiquated city hall or county courthouse, unless the old structure has a historical significance which may insure its remaining untouched for that reason. Railroad stations in growing communities are frequently demolished or rebuilt to provide added station facilities for increasing traffic.

A bench mark set in the wall of a building is less apt to be disturbed than one set in a step or portico, since these portions of the structure are more frequently changed than the building itself. Bench marks should not be placed on steps or other projecting portions of buildings unless these portions are supported on massive foundations to prevent settlement or heaving from frost action. Bench marks are frequently destroyed or rendered inaccessible by reason of additions being made to the buildings on which they are set. For this reason placing bench marks on the sides of buildings where additions are possible should be avoided.

Monuments—Many monuments or memorials offer excellent locations for bench marks and, of course, if such sites can be utilized without defacing or damaging the structure, afford sites for the establishment of marks with a long expectation of life.

Bridges—Large and well-constructed bridges usually offer excellent sites for bench marks as they are usually very well founded and will in all probability remain undisturbed for long periods of time. Small bridges, which will soon have to be widened on account of increased traffic, or antiquated bridges not strong enough for modern loads, are poor places for bench marks and should be avoided when possible.

Culverts—Culverts are usually poorly constructed and liable to disturbance, except along main-line railroads and the most highly improved modern highways. Good judgement in estimating the probable stability and length of life of culvert structures can greatly reduce the number of casualties among bench marks.

Tower, Semaphore and Tank Foundations—These are usually quite stable, since they must remain accurately in place to insure the stability of the superstructure, but in the case of small towers and semaphores, the structures, being of relatively low cost, are frequently changed in location with the result that many bench marks are lost, not from the settling or heaving of the structure on which they are located, but because of the demolition of the structure. In the case of semaphores, these structures are often picked up bodily and moved to new locations during the rearrangement of a signaling system or the rearrangement of trackage.

Curbs, Sidewalks, Pavements, etc.—These are particularly poor places for bench marks because they are subject to settlement and heaving through lack of deep foundations and also because they are frequently changed with the resultant disturbance or destruction of the marks.

Concrete posts—Concrete posts are perhaps the type of structure most frequently used for supporting bench-mark disks. They can be constructed at almost any desired location, and if properly located and carefully constructed will remain undisturbed for long periods of time.

In working through cities and towns, probably the safest place for the location of a concrete post is in a public square, or other reserved area, far enough removed from street lines to be safe from street widening or minor changes in grade or alignment as well as free from disturbance by trenching for public utility services such as water-mains, sewers, underground telephone conduits, etc.

In working along highways, care should be taken to locate concrete posts well away from existing pavement, near the edge of the right-of-way, and far enough from intersecting roads to be free from new construction in rounding corners and in grade separations. Curves are more often flattened than sharpened and for this reason a site on the outside of a curve is more apt to insure long life for a mark than one on the inside of a curve.

On railways double-tracking will often destroy a large number of marks unless they are set well out toward the right-of-way lines or fences. Easement of curves results in frequent destruction of bench marks established on the inside of sharp curves along railroads as well as along highways. In cities the construction of additional spur tracks, sidings and passing tracks is frequently the cause of the destruction of bench marks, and in selecting a site for a concrete-post type bench mark the bench-mark setter should try to visualize possible future changes and so locate his mark as to be as free as possible from future disturbance from foreseeable causes.

Often it will be difficult to decide what is the best location for a mark at a given place along a line of levels. The specifications for spacing bench marks sometimes require their construction in places where ideal conditions are not obtainable. In general, however, it is well to avoid steep banks or hillsides, as sliding will be almost sure to disturb the mark in elevation. Close proximity to the banks of streams should also be avoided on account of the danger of undercutting the mark. It is also well, in placing marks along railroads or highways, to stagger them first on one side and then on the other side so that no single widening or double-tracking project will take out a whole row of bench marks at one time.

Construction of concrete posts—The specifications (see page 46) are quite definite regarding the type of concrete post to be cast as a support for a bench-mark disk. Several things, however, must be taken into consideration in the construction of a concrete-post type bench mark if the best results are to be obtained.

Frost action will heave a post which does not go deep in the ground. An enlarged foot on the post serves to reduce the possibility of heaving. The posts should be free from projecting corners which may assist the frost to lift the post and thus destroy the accuracy of the elevation of it.

The upper part of the post is molded in a form the sides of which are battered to reduce the effect of frost action and to improve the appearance of the post. This form should be placed in the hole and supported by sticks nailed crosswise of the form before the placing of the concrete is begun; for, if the form is placed after part of the concrete has been put in the hole, dirt will nearly always fall down into the concrete and produce a weak seam across the post which will make it unable to withstand a severe shock.

In low latitudes where frost seldom occurs a post extending 3 feet into the ground is ordinarily sufficient, but in high latitudes, where frost goes deep in the ground, 5 or

even 6 feet is not too great a depth for the post to extend into the ground. The enlarged foot should always be made on the post as an anchor against frost as well as to secure a better bearing even where frost action never becomes severe.

Choice of materials—Only the best of materials, good cement, clean sand and gravel, free from dirt, should be used. They should be properly and carefully proportioned, thoroughly mixed with the proper amount of water and the concrete should then be carefully placed in the hole to prevent the admixture of dirt from the sides of the hole since this certainly will weaken the post.

When the post has been poured, the disk, which has been previously stamped and has had the split shank spread slightly, should be carefully inserted in the top of the freshly cast post. The disk should be truly horizontal and should be pressed down in the concrete so that a chisel or bar cannot be inserted at the edge. This is to guard against its removal by malicious or heedless persons after the concrete has set. Cover the freshly cast post with paper or grass to prevent the sun from drying the concrete too quickly or a shower from spoiling the appearance of the post. The top of the post should be troweled slightly to improve its appearance.

Spacing of bench marks—Paragraphs 41 to 45, inclusive, of the General Instructions pertain to the establishment of bench marks and specify that, except under unusual conditions, permanent bench marks shall be established at intervals of one mile or less along the lines of levels. In complying with this specification it is well, when it is necessary to establish a mark or a series of marks in structures or locations which are apparently likely to be subject to some disturbance within a period of from 10 to 15 years, to give such marks a weight of one-third or one-half in counting them toward compliance with the one-mile spacing requirement. It should be remembered that the cost of an extra mark, established at the time the original leveling is done, is so small, compared with the cost of replacing a mark at a later date or the cost of long stretches of releveling in obtaining ties to old work, that it is logical in case of doubt to tend toward the establishment of more marks than the minimum number actually required by the General Instructions.

Bench-mark disks may be set either horizontally (shank vertical) or vertically (shank horizontal) but, when they are set vertically, they are much less convenient to use since a leveling rod cannot be placed on them and it is usually necessary to use a tape in lieu of a rod in leveling to or from a disk set vertically. If disks are set vertically care should be taken to see that the tablet, because of its weight, does not loosen itself before the cement has set firmly.

In setting a tablet in a rock outcrop, the bench-mark setter should make sure that the rock in which it is set is hard and that it is a part of the main ledge and not a detached fragment. When bench-mark tablets are set in boulders one should be as sure as possible that the boulder is of durable rock and that, in the matter of size and depth below the surface of the ground, it is at least the equivalent of the standard concrete post. Boulders (not outcropping rock) located on steeply sloping hillsides should be avoided, as they tend to slide downhill with the passage of time.

When a concrete post is to be constructed as a support for a bench-mark disk, the disk will be set horizontally in the top of the post and not vertically in the side of the portion of the post which projects above the ground.

It may be found that, in some localities, the availability of stone posts will recommend their use instead of concrete posts, particularly as they are often more durable than the concrete posts. When stone posts are used they should be not less than 8 inches

by 8 inches in cross-section and extend to the depth required for concrete posts. Furthermore, when setting stone-post bench marks, they should be imbedded in concrete placed in the bottom of the hole to a depth of at least six inches.

STANDARD CONCRETE-POST BENCH MARKS

(1) **Shape.** —The bench mark shall be larger at the base than at the surface of the ground. It may take the form of the frustum of a pyramid or cone or be a square or cylindrical post with an enlarged base. If it is built in the form of a frustum, there should be a batter of not less than 1 inch to 1 foot. It is believed that a post with an enlarged base will offer just as great resistance to the lifting effect of freezing and thawing as a conical post and will be more economical of concrete. The base should be not less than four inches larger in horizontal cross-section than the post itself, and the enlarged portion should be not less than 6 inches thick vertically. The portion of the mark above the frost line should be molded to lessen the lifting effect of the surface layers of the ground when freezing. These molds may be made of sheet iron or wood and should have a slope or batter of at least 1 inch to 1 foot. The sheet iron may be cut to proper size and shape, bent for a lock seam, and carried flat until needed.

Extreme care should be taken that the molded portion of the concrete post has no projecting corners, which would increase the lifting effect of freezing. The concrete beneath the mold should have a sufficiently large area so that no portion of the mold extends outside of the concrete on which it rests.

(2) **Material.**—The main considerations in making concrete are to have clean materials, mix them well before adding water, have the mixture not too wet, and tamp well into the form. Each streak of dirt in concrete means a line of cleavage. Where rough aggregate is available, the proportions may very well vary from 1-2-4 to 1-3-5, but the top 12 inches of the mark should be of a considerably richer mixture. Where only cement and sand are available the mark should be proportioned 1 part of cement to 3 parts of sand, and the upper part should be 1 part cement to 2 parts of sand.

With a mark of proper size it will not be necessary to reinforce the concrete with metal rods or wire. To avoid cracking of the concrete, due to too rapid drying, it should be covered with a paper or cloth and then with earth or other material for a period of at least 48 hours.

(3) **Size and depth.**—Where lack of transportation does not make the cost prohibitive, the post should be not less than 12 inches in least cross-section dimension except at the top where it is shaped by the mold, and that should be not less than 10 inches. The top should extend from 2 to 4 inches above the surface of the ground. The mark should not be placed in a line of traffic.

The mark should extend to a depth such that the enlarged base will be lower than the depth to which frost habitually penetrates during the most severe part of the winter. This depth should be ascertained by inquiry from local engineers, water works superintendents, grave diggers or others who may have accurate knowledge of the depths to which frost regularly penetrates in a given region. The minimum depth below the surface of the ground for any post shall be 36 inches.

SUPPLEMENTARY BENCH MARKS

As stated in paragraph 8 of the General Instructions (page 4) each line of levels may be broken into sections. The ends of these sections, when not marked by permanent

bench marks, are to be marked by supplementary bench marks consisting of spikes in poles, bolts on bridges, or chisel marks on masonry.

Railroad spikes have been in general use for supplementary bench marks, but it is believed that a lagscrew makes a much better mark. It can be easily identified, especially if the letters "C & G S" are stamped on the head of it, and it has an exceptional permanency when driven, by means of a wrench, into a milepost, telegraph pole or tree.

Chisel marks on masonry should be in the form of square cuts, outlined squares, or crosses, cut sufficiently deep into the stone or concrete to insure their being easily found for a number of years. However, caution should be exercised, in establishing this form of mark, not to deface a structure of any kind. This type of mark should be cut in a relatively inconspicuous place so as not to mar a smoothed or polished surface with an unsightly mark.

DESCRIPTIONS OF BENCH MARKS

PERMANENT BENCH MARKS

The descriptions of the permanent bench marks are of the greatest importance, for it is only by means of them that the marks can be recovered.

The description of a bench mark should be clear, concise and complete. It should be written as nearly as possible in the form used in our publications and lithographed lists which were issued prior to the introduction of the method of reproducing by photolithography from the original description cards turned in by the field parties.

The first part of a description should enable one to go with certainty to the immediate vicinity of the mark, while the latter part, the detailed description, by means of its measured distances and directions from reference points or objects, must inform the searcher as to the exact location of the mark and make its identification certain. (See page 71.)

The original description should be written by the bench-mark setter while at the mark and at the time the mark is established. The description is then used by the observing unit to find the mark during the leveling. The description should be thoroughly checked by the observing unit at the time the levels are run to the mark.

The description is then typed on Form 638 (Revised 1946) and, since the original description cards turned in by the field party are now reproduced by photolithography in the publication of the results of the leveling, the necessity for a well-written description should be apparent. The typewriter used in typing the descriptions should be in good condition, the type should be kept well cleaned, and the ribbon (always a *black* record ribbon) should be discarded and a new one installed when good, clean, sharp, black typing is no longer obtainable from the old ribbon.

A single copy only of each description need be sent to the Office. These are then photostated for the permanent record in the library and archives and the original typed copies on Form 638 (Revised 1946) become the working file in the Section of Leveling, for lithographic reproduction and for ready reference in the section.

Complete descriptions should be typed on Form 638 (Revised 1946) for all new permanent bench marks established by the leveling party and for all bench marks of other organizations that are being leveled to for the first time by this Bureau.

Bench marks of other organizations should be designated in accordance with the practice of the organization which established them and should not be given letter-and-number designations of our series. The description of a bench mark established by another organi-

zation should state clearly the name of the organization which established it, all letters and numbers found to have been stamped on it with dies, and its exact character and condition at the time it was touched upon by the new leveling.

Descriptions of any marks touched upon in leveling to a triangulation station for the first time should be forwarded to the Office and each mark tied in should be described on a separate copy of Form 638 (Revised 1946), since to describe them by groups, as they are described in the triangulation-station descriptions, will not fit in well with the filing system in the Section of Leveling.

Form 638 (Revised 1946) is so arranged that, if properly filled out, all the essentials of a good description will be present.

The distance from the nearest town should be given to the nearest tenth of a mile, and the direction from the nearest town should be given to the nearest half-quadrant, i.e., N., NE., E., etc. The route along which the distance is measured and the initial point in the town should be given. Sometimes it happens that the point used as a reference is not on the direct route of the leveling and in such a case the distance from the point of reference to the highway, railroad, or other route followed by the leveling should be given. All descriptions should be written so as to decrease the possibility of following the wrong route to the bench mark. When the leveling follows unmarked or unnumbered roads, special care should be used in describing the route followed. If there are alternative routes which would give varying distances from the reference point or town to the bench mark, the one followed should be clearly indicated in the description of the mark.

Usually the distance is measured from the nearest town having a post office or railroad station, but very often small, named communities are passed without being mentioned in the description. References to these places would be helpful in following the routes to the bench marks, particularly if the larger towns are widely spaced and if there is more than one road between them.

When changing the reference from one town to another, it is desirable to include a distance and direction from the previous town in the first description using the new reference town, so that the mark may be readily located when approaching it from either direction.

In the first part of the description of a bench mark, when the aim is to lead the person trying to recover it to the vicinity of the mark, some of the longer distances may be given in various units, such as decimals of a mile, rails, poles, and yards.

In the latter part of the description, when the aim is to take the searcher to the exact location of the mark, all distances should be measured with a tape and should be given to the nearest tenth of a foot, if they are measured from a sharply defined point or object such as a rail, the edge of a concrete pavement, or the corner of a building. Distances measured from trees, poles, or other objects, when there is no sharply defined point from which to measure, should be given to the nearest half-foot. Distances measured to the nearest tenth of a foot should be given in feet and decimals, but those measured to the nearest half-foot should be given in feet and fractions.

The direction of the bench mark from the track, the highway, or other reference object or point must be a true direction given to the nearest half-quadrant. It must never be assumed that the railroad or highway follows an arbitrary direction, with all other directions referred to that direction. A compass should always be used to determine directions when there is the slightest doubt as to the orientation of the route along which

the levels are being run in the vicinity of the mark. When the magnetic declination is large, compass readings should be corrected to give true directions.

When a witness post is set near a bench mark, state definitely the distance and direction from the witness post to the bench mark.

The errors most commonly occurring in descriptions are errors of direction. Therefore, all directions should be carefully determined and thoroughly checked. The terms "right" and "left" are never to be used. The term "opposite" is also confusing. It is better to use the expressions "across the track (or highway) from" and "on the same side of the track (or highway) as".

In preparing the detailed part of the description, where there is a choice as to the reference points or objects used, the most permanent objects should be chosen, so as to afford the maximum probability of the future recovery of the mark. The person writing the description should attempt to visualize possible future cultural changes, and should choose such references and make such measurements as will insure the recovery of the mark 20 or 25 years later.

The possibility that a mark may be covered by debris from a fill or hillside, or overgrown by grass, weeds, or brush, should be kept in mind. The description should include at least two, preferably three, references and measurements of such character as to permit the recovery of the mark without extensive digging or search through tall grass or weeds.

Where cultural objects are limited in number, descriptions should contain references to prominent topographical features. Names of streams should be used when they can be learned. Numbers on railroad bridges are also of material assistance in finding marks.

In the States where the land has been divided into townships and sections, references to section and other corners should be made and should include section, township and range numbers when these can be ascertained.

In the detailed portion of the description emphasis should be on specific distances and directions and the distinguishing features of reference objects.

Not only the character of the mark but also where it is set should be stated. Especially if the references are to building corners, it is very often impossible to tell whether the mark is on the building or in a post close to the building.

In stating the character of a mark, such as our standard bench-mark tablet or other similar mark, the mark should be referred to as a "disk", since that is all that is visible to the person trying to recover it. If the mark is set with the disk in a horizontal position so that the rod can be stood on it, it is not necessary to state that the disk is horizontal. However, if the mark is set in the wall of a building or is placed in a vertical position in any type of structure, so that a rod cannot be stood on it when leveling to or from the mark, this fact should be stated in the description.

The letters and numbers stamped on the disk with dies should always be stated in the description, but it is not necessary to quote the legend cast in a bench-mark disk except in those unusual cases where ties are being made to marks of little-known organizations or marks of unusual type. Rather than repeat the legend over and over in the descriptions of bench marks frequently encountered, a statement in the season's report concerning the exact character of any new types of marks encountered will be sufficient. If possible, rubbings of any unusual types of marks of other organizations that may be tied in should be made and included in the season's report.

Form 638 (Revised 1946), after being completely filled out, should be read over carefully to see that there are no reversed directions or omitted measurements, that the description is complete, and that in no way is it vague, ambiguous or erroneous. Typographical errors and errors of spelling should be corrected, especially now that the original cards are reproduced by lithography for publication.

With the group of cards—Form 638 (Revised 1946) and/or Form 685 A—submitted for a line of levels, whether that line is a part of an area development or a separate line, the top card should be a plain, white, 5- by 8-inch card on which the following information is typed:

(1) Area name and line number (if the line is a part of an area development).

(2) Title of the line.

(3) A paragraph stating in detail the route followed by the leveling. Examples of paragraphs of the type desired will be found at the beginning of most lithographed lists of descriptions of bench marks sent to the field with the starting data for a project.

RECOVERED BENCH MARKS

Form 685 A should be used in reporting recoveries of bench marks previously established or tied in by this Bureau. The foregoing paragraphs on the typing of descriptions on Form 638 (Revised 1946) also apply to the material typed on Form 685 A, since these reports also are often reproduced by lithography.

For use in recovering bench marks on previously run lines, the field paty is furnished descriptions, which are either photostats of the original cards or are ditto, mimeographed. or lithographed lists, which in many cases have been revised since the original list was published. When recovery notes state simply "Recovered as described", it is frequently difficult to ascertain which of these types of descriptions was used for the recovery. Therefore, wording similar to the following should be used: "Recovered as described in lithographed list of August 12, 1941", etc.

If the description furnished no longer fits the facts, a complete new description must be written, repeating such parts of the old description as are still applicable. It is not sufficient to state that the mark was recovered as described and then note the exceptions to the furnished description. If *any* changes are required a complete new description should be written, *except* when adding a reference from a newly installed witness post.

Whenever a mark is reported as being in "fair" or "poor" condition, a brief statement of the reasons for considering it to be in the condition reported should be included in the recovery note.

A complete report as to all letters and numbers found stamped on the disk with dies should be included in the recovery note. This feature should be accurately and carefully stated as it often happens that stamping has been added to the disk since the description was written and published and it is not sufficient to take the stamping on the disk from the original description without checking it carefully in the field.

When preparing recovery notes for old bench marks along a line that is being releveled, care should be taken to correlate the descriptions of the old marks with the descriptions of the new marks established during the releveling. Very often the old descriptions refer to different towns than those used in the new descriptions and, therefore, sufficient information should be furnished to make the descriptions of the old marks consistent with those of the new marks. (See also page 72.)

SUPPLEMENTARY BENCH MARKS

Supplementary bench marks need be described on Form 638 (Revised 1946) only when there is a possibility of their being recoverable for a number of years, and when they are so placed that good descriptions of them are possible. Descriptions of supplementary marks, if submitted at all, should be as complete as those for permanent bench marks. The different character of the designations of the supplementary marks will insure against their being confused with or treated as permanent bench marks.

PICTURE POINTS AND EXTRA ELEVATIONS

Picture points and points on which rail and ground elevations are determined in accordance with the provisions of the General Instructions (paragraphs 13 and 14), need not be described unless the point on which the rod was held can be so exactly described that it would be classifiable as a supplementary bench mark. If the picture points and rail or ground elevations are taken on points not capable of sufficiently accurate description to be classified as supplementary bench marks, the descriptive material concerning them should be entered in the record book and transcribed to Form 45 as provided on pages 65 to 68 of this manual and no descriptions for such points will be prepared or forwarded on Form 638 (Revised 1946).

INSTRUCTIONS FOR RIVER CROSSINGS

With the tendency now toward the extension of first- and second-order level lines along rivers and over routes which were heretofore not generally used for this class of work, there arises more and more frequently the need for an accurate and economical method of carrying lines of levels across rivers and other spaces where ordinary lengths of sights are not sufficient.

The method described below is one that was devised when it became necessary to extend a line of levels across the Mississippi River in the vicinity of New Orleans, La. The river was about 1200 meters wide at the point where the crossing was made and no bridge over which levels could be run was in existence. The method has been used many times since with very satisfactory results.

In this method two fixed targets are used. It is essentially a modified form of the vertical-angle method of leveling into which the absolute values of the vertical angles do not enter.

The general scheme of this method of observing is that simultaneous reciprocal observations are made at each of two points, one on each side of the river. Instead of moving a single target into the line of sight, two targets are set on each rod, one above and the other below that point on the rod which is crossed by the middle horizontal wire when the bubble is centered. The graduated head of the micrometer screw is read with the telescope in each of three positions: First, with the middle horizontal wire bisecting the top target; second, with the telescope level (bubble centered); and third, with the middle horizontal wire bisecting the bottom target. The reading on the rod given by the line of sight when the telescope is level can be determined, for the distance from this point to the two targets will be proportional to the corresponding differences in the readings on the micrometer head.

Figure 10 illustrates the principle of the method. Let A and B be the positions of the upper and lower targets on the rod and let C be the point where the line of sight inter-

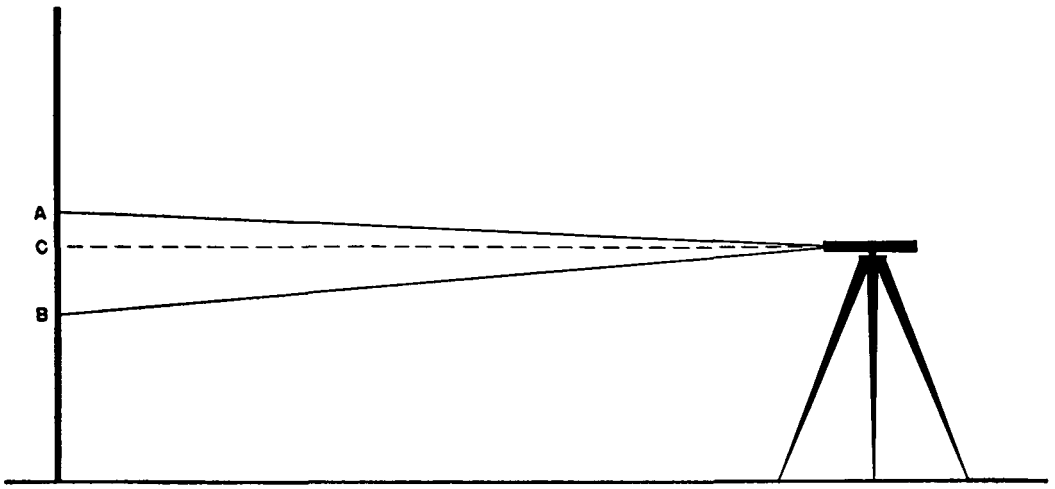


FIGURE 10.—River crossing, principle of the method.

sects the rod when the telescope is leveled by means of the main bubble. Let the readings of the micrometer head, when the telescope is pointed at A and B be 25.8 and 40.2, respectively, and let the reading of the micrometer head, when the telescope is level, be 30.6. Then, if the targets are at a distance of 0.4000 meter apart, the distance from target A to the point of intersection when the telescope is level will be

$$\frac{30.6-25.8}{40.2-25.8}(0.4000) = 0.1333 \text{ meter.}$$

If the setting of target A is 1.8930 meters, then the line of sight intersects the rod at 1.7597 meters.

The targets are cast aluminum and are 12 inches long and 6 inches wide. They are painted black with a horizontal white band 1 inch wide across the center. Figure 11 shows a front view and figure 12 a back view of the targets. These targets can be requisitioned from the Office as needed.

Each rod, with its targets, is guyed into place over the bench mark. The targets are set one above and the other below the line of sight, after the approximate intersection of the line of sight with the rod has been obtained, upon signal from the observer, by moving one of the targets along the rod. Figure 13 shows a rod with the targets in position. The targets should be spaced on the rod so as to require turning the micrometer head from 20 to 50 divisions to change the pointing of the instrument from one target to the other, but the targets, even on long crossings, should not be much over a meter apart if this can possibly be avoided.

The targets have a small rectangular hole machined through the center of each one. The center line of the hole is defined by means of narrow slots machined in the target. The center line of the hole is also in the center line of the white stripe. In setting a pair of targets on a rod, the positions of the targets on the graduations on the invar strip may be observed through these windows. However, since the back of the target is set out in front of the face of the invar strip by about 1 centimeter, care must be taken to see that parallax does not cause erroneous readings. In reading the position of a target on the rod it is necessary to make sure that the observer's height of eye is the same as that of the center of the target whose position on the rod he is reading at the moment.

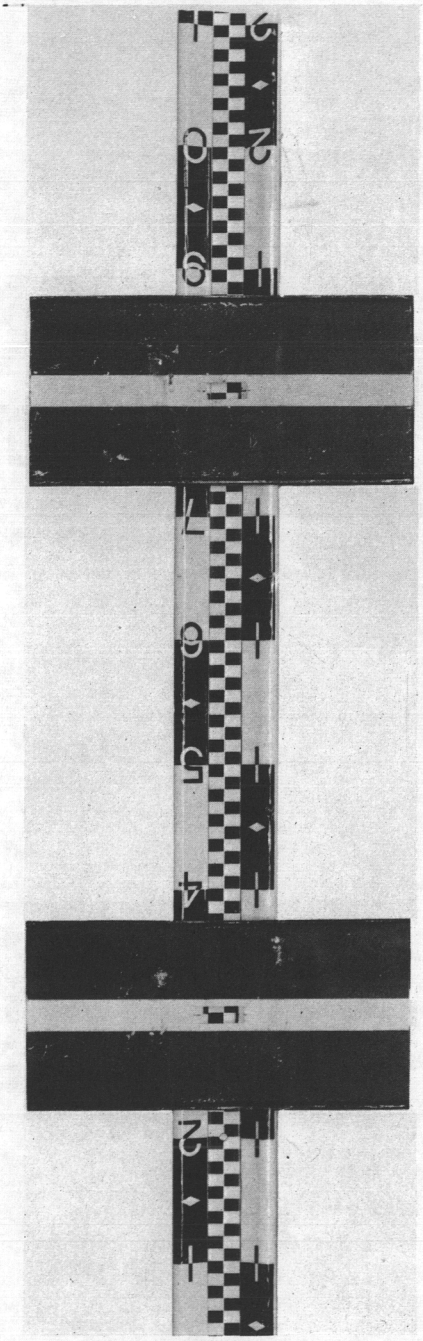


FIGURE 11.—Targets for river crossing, front view.

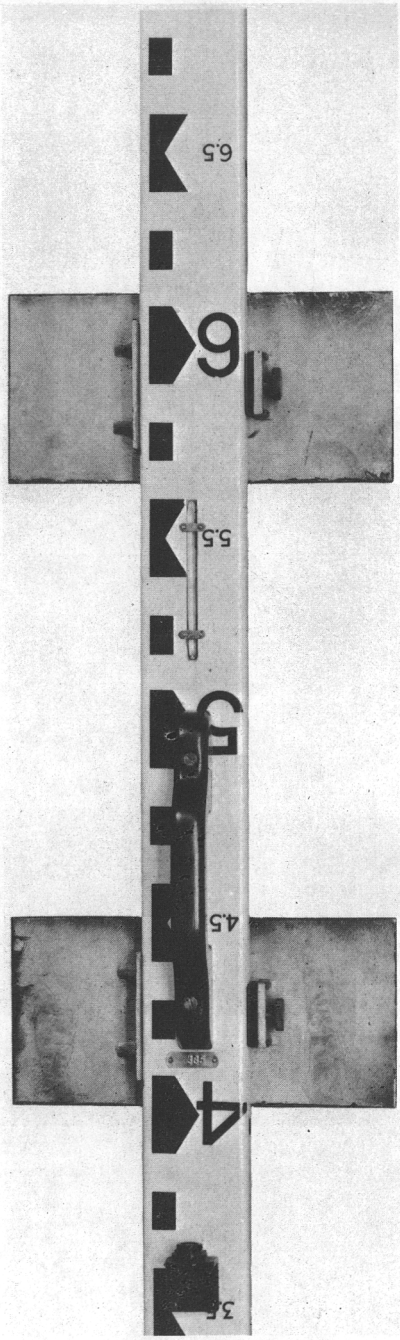


FIGURE 12.—Targets for river crossing, back view.

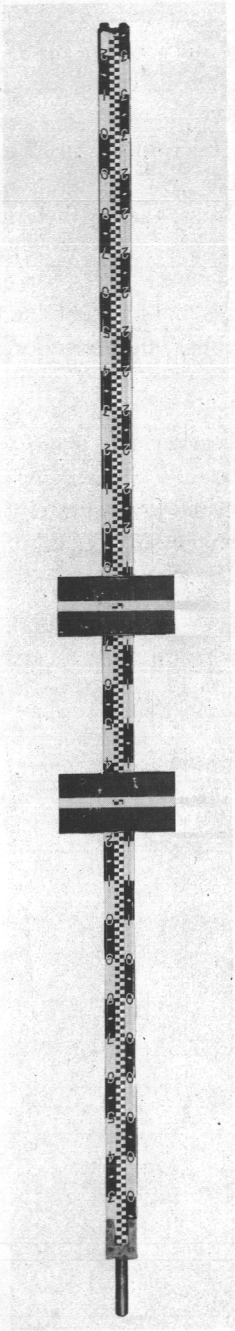


FIGURE 13.—Rod, with targets for river crossing in position.

The observations should be made in accordance with the following schedule:

Read the near rod once for each set of 25 observations on the distant rod.

Set the middle horizontal wire on the center of the white stripe on the top target and read the micrometer head.

Center the bubble and read the micrometer head.

Set the middle horizontal wire on the center of the white stripe on the bottom target and read the micrometer head.

These three readings of the micrometer head are to be repeated in the above order until 25 of each have been obtained.

The observers then change places, taking their instruments with them but leaving the tripods in place.

Four sets of 25 observations each (two sets for each observer at each station) constitute a day's observing. These sets should be obtained in the following order:

Let A and B be the two stations, one on either side of the river, and the numbers 1 and 2 represent the observers. Observer No. 1 will take a set of readings at station A, transport his instrument to station B, take two sets of readings, return to station A and take one set of readings. Observer No. 2, of course, will carry out a similar program, starting at station B.

The instrument should be adjusted as accurately as possible and the program of observing arranged to avoid all unnecessary changing of focus; that is, at the first station, read the near rod before taking the first set of observations and, at the second station,

SPIRIT LEVELING

Date: Feb. 28, 1946 Forward—~~Backward~~ (Strike out one word)

Sun: 1

No. of Station	Thread Reading Back Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Rod and Temp.
	0844					298
	0833	08330	273	11		18°
	0822			11	22	
	2499					

From T.B.M.: West To T.B.M.: East

Wind: 0 Time: 1022 to 1038

Thread Reading Fore Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Remarks
	Top	Level		Bottom	
1	22.8	490		72.8	
2	22.8	48.8		72.8	Bottom
3	22.8	48.7		72.8	Target at
4	22.8	48.8		72.8	1430
5	22.7	48.6		72.5	
6	22.5	48.4		72.4	Top
7	22.3	48.6		72.5	Target at
8	22.8	48.7		72.6	1930
9	22.5	48.1		72.3	
10	22.5	48.0		72.1	
11	22.2	48.1		72.0	
12	22.1	48.0		72.2	
13	22.1	48.0		72.1	West Side
14	22.1	48.1		72.0	
15	22.4	48.2		72.5	
16	22.1	48.1		72.1	
17	22.2	48.0		72.1	
18	22.2	48.0		72.1	
19	22.1	48.0		72.1	
20	22.1	48.1		72.3	
21	22.2	48.0		72.0	
22	22.3	48.1		72.1	
23	22.2	48.0		72.1	
24	22.1	48.2		72.1	
25	22.2	48.2		72.2	
26	22.1	48.0		72.0	
27	22.1	48.1		72.1	
28	22.2	48.2		72.1	
Σ	9.5	7.1		7.8	
Mean	22.339	48.254		72.279	

FIGURE 14.—Sample of record for river-crossing observations.

make the near-rod reading between the two sets of observations. The day's program for each observer will then be: Read the near rod, take set of observations, go to the second station, take set of observations, read the near rod, take set of observations, return to first station, take set of observations, read near rod.

These instructions as outlined are designed to cover the case where both men observe with practically the same rapidity. Observing should begin and end at each station at the same time. If it is found that the observers do not work with equal rapidity, the observing should start at the same time and continue until the slower observer has 25 sets of readings, both observers stopping at the same time although they do not have an equal number of readings.

Figure 14 shows the record for a reading on the near rod (on T.B.M. West) and the micrometer readings for a set of pointings on the rod (on T.B.M. East) across the river. The results of this set of readings, shown in this sample of the form of record for river-crossing work, show in the first two lines of the computation of the second day's observations in Figure 15. The entries in the remarks column of the sample record show the positions of the targets on the near rod (on T.B.M. West) and these appear in the second line of the second half of Figure 15; since these are the targets which were being observed upon simultaneously by the observer on the east side of the river whose instrument was near the rod on T.B.M. East.

The computation shown in Figure 15 is complete for the two-day series of observations involved in this particular river crossing. The means of the differences of elevation from T.B.M. West to T.B.M. East for the observations on the two days are in disagreement by only 2.2 mm., and, since the length of the crossing is 0.40 km., the allowable tolerance for a first-order crossing would be 2.5 mm. The observations, since they agreed within first-order limits, were properly considered to be complete and no further observations were made.

The computation shown in Figure 15 is complete and the following brief statement concerning the operations to be performed in completing one line of the computation should be sufficient to explain the whole, except for the system of taking out the means—which should be obvious from even a casual inspection of the figure.

As an illustration, take the first line of the second half of the computations shown. The date is February 28, 1946. The observations were started at the west end of the crossing at 1022 by observer Withrow, whose instrument (G 74) was set up near the rod mounted over T.B.M. West. The entries in the next three columns are the positions of the top and bottom targets on the rod on T.B.M. East and the interval between them. The entries in the next three columns are the mean micrometer readings on the rod over T.B.M. East (see Figure 14). The entries in the next two columns are the indicated differences between the various mean micrometer readings. The next entry is the computation of the length of rod which is included between the bottom target and the place at which the wire crosses the rod when the bubble is centered. This entry is

$$\frac{(24.025)\quad(0.5200)}{49.940} = 0.2502$$

according to the principle explained on page 52. The next entry comes directly from the record and is the backsight on the near rod (see Figure 14). The next entry is the sum of the rod reading for the position of the bottom target on the rod over T.B.M. East plus the rod length from that target up to the position of the middle wire on the same rod

Forward direction of line
TBM West to TBM East
Distance = 0.40 km.

Date & Time	Observer	River Side	Inst.	Target Settings Top	Target Settings Bottom	Target Interval	Mean Micrometer Readings Top	Mean Micrometer Readings Level	Mean Micrometer Readings Bottom
Feb. 27, 1946				First					
1146	Withrow	W	G74	1.3602	0.7896	0.5706	35.556	64.110	89.474
1145	Stohsner	E	G43	1.8600	1.4100	0.4500	86.920	105.688	131.536
1253	Stohsner	W	G43	1.3602	0.7896	0.5706	68.544	101.140	127.200
1254	Withrow	E	G74	1.8600	1.4100	0.4500	33.270	49.870	70.820
1326	Stohsner	W	G43	1.3602	0.7896	0.5706	67.124	99.460	125.860
1325	Withrow	E	G74	1.8600	1.4100	0.4500	31.725	49.150	74.364
1405	Withrow	W	G74	1.3602	0.7896	0.5706	23.013	52.427	77.847
1406	Stohsner	E	G43	1.8600	1.4100	0.4500	83.624	101.948	128.688
Feb. 28, 1946				Second					
1022	Withrow	W	G74	1.2700	0.7500	0.5200	22.339	48.254	72.279
1022	Stohsner	E	G43	1.9300	1.4300	0.5000	87.896	112.852	136.956
1104	Stohsner	W	G43	1.2700	0.7500	0.5200	76.982	105.782	129.379
1104	Withrow	E	G74	1.9300	1.4300	0.5000	20.380	43.684	68.192
1127	Stohsner	W	G43	1.2700	0.7500	0.5200	78.808	106.816	130.492
1127	Withrow	E	G74	1.9300	1.4300	0.5000	20.416	43.940	68.328
1232	Withrow	W	G74	1.2700	0.7500	0.5200	1.712	27.676	52.552
1232	Stohsner	E	G43	1.9300	1.4300	0.5000	82.052	107.456	131.124

Releveling - Long Beach Area, Calif.

1945

Micrometer Interval Top-Bottom	Micrometer Interval Level-Bottom	Rod Length Level-Bottom	Back-sight	Fore-sight	Diff of Elevation	Mean	Mean of Pair	Mean of Set
			Set					
53.918	25.364	0.2684	0.8910	1.0580	-0.1670			
44.616	25.848	0.2607	1.8550	1.6707	+0.1843	-0.1756		
58.656	26.060	0.2535	0.8893	1.0431	-0.1538		-0.1686	
42.550	25.950	0.2744	1.8537	1.6844	+0.1693	-0.1616		
58.736	26.400	0.2565	0.8893	1.0461	-0.1568			-0.1698
42.639	25.214	0.2661	1.8537	1.6761	+0.1776	-0.1672		
54.834	25.420	0.2645	0.8850	1.0541	-0.1691		-0.1711	
45.064	26.740	0.2670	1.8680	1.6770	+0.1810	-0.1750		
			Set					
49.940	24.025	0.2502	0.8330	1.0002	-0.1672			
47.060	24.104	0.2457	1.8563	1.6757	+0.1806	-0.1739		
52.397	23.597	0.2342	0.8363	0.9842	-0.1479		-0.1656	
47.812	24.508	0.2563	1.8530	1.6863	+0.1667	-0.1573		
51.684	23.676	0.2382	0.8363	0.9882	-0.1519			-0.1676
47.912	24.388	0.2545	1.8530	1.6845	+0.1685	-0.1602		
50.840	24.876	0.2544	0.8317	1.0044	-0.1727		-0.1696	
49.072	23.668	0.2412	1.8567	1.6712	+0.1855	-0.1791		

-0.1687

FIGURE 15.—Computation of river-crossing observations.

when the line of sight is level, thus:

$$0.7500 + 0.2502 = 1.0002.$$

This constitutes the foresight and is subtracted from the backsight (0.8330) to obtain the difference in elevation, −0.1672.

It will be noted that the individual differences of elevation vary quite considerably. This is because the various readings (backsights and foresights) have not been corrected for level error nor has the total correction for curvature and refraction been applied. On long sights these corrections become large. However, the whole observing program is so arranged that these effects are automatically eliminated from the means in the column headed "Mean of Pair."

On the first day the two separate means differ by 2.5 mm., which would be just within the allowable tolerance for a first-order crossing 0.4 km. in length, except for the provision (see below) that no river crossing is to consist of less than two days of observations. It will be noticed that the results of the two separate halves of the observations on the second day differ by 4.0 mm., but that the means for the two days disagree by only 2.2 mm., or 0.3 mm. within the allowable limit.

It has been found from experience that in most cases, when observing conditions are not too bad, a very accurate determination of the difference in elevation can be obtained from the results of two days of observations. If for any reason the results of the two day's work differ by more than the prescribed tolerance, for a line of levels of equal length and of a grade of accuracy as prescribed for the line in which the river crossing occurs, the observations shall be continued on succeeding days until the work on two different days agrees within the prescribed tolerance.

In other words, if the crossing is one kilometer in length and first-order accuracy is required, the observing should be continued until the results of two separate days of observations agree within 4.0 mm. If the crossing is one kilometer in length and occurs in a second-order line the observing should be continued until the results of two separate days of observations agree within 8.4 mm.

The success of the method, like that of all reciprocal leveling, depends to a large extent on the equality of the refraction over the line in opposite directions. To secure this equality, the conditions on the two sides of the river should be as nearly the same as possible, with the line of sight at least ten feet above the surface of the water. If topographic conditions are reasonably good, boiling is not too bad, and the observations are made with care, the results of the first two days of observations will usually agree within the prescribed tolerance and no further observations will be required. However, if the required agreement is not obtained between the results of the first two days of observations the observing should, in every case, be continued until the results of two days of observations do agree within the proper limits. If such agreement is not obtained at the end of four days of observations, a change of site for the crossing should be considered. If that is not feasible the matter should be referred to the Office for study and further instructions. In any case where the crossing is not completed within the space of four days of observations a complete report and an abstract of results should be forwarded to the Office with a request for advice and further instructions.

It should be kept in mind that it takes a half day's observing in accordance with the schedule outlined above to make one determination of the difference in elevation between the bench marks located on opposite sides of the river. The second half day's work then makes another complete observation. The two may be considered and abstracted as

a forward running and a backward running. However, the importance of a crossing of this type and the uncertainties as to refraction on the long sights make it necessary that more than a single forward and backward running be made even though they may happen to agree within the prescribed tolerance.

SEASON'S REPORT

After the completion of a leveling project, or at such time as the project is discontinued, the chief of party should submit a season's report, covering in detail the following points in connection with the work:

1. Purpose and scope of the work, as shown by excerpts from instructions or by a condensed statement.
2. Locality, with description of such topographic, climatic, and transportation conditions as affected the organization or progress of the party.
3. Organization of party—personnel, equipment, transportation, etc.
4. Chronology of progress of the work.
5. Progress sketch and statistics of field work (Form 21).
6. Statement of costs.
7. Recommendations, or special features.

The report should be clearly written, logically arranged, and concise. It may vary in length from a short report, covering a routine piece of work carried out under normal conditions, to a long detailed report illustrated with photographs when unusual features were encountered and should be reported on. Attention should be called to all matters connected with the work which, in the judgement of the chief of party, will help others to execute leveling of the required accuracy at smaller unit costs. Even a short report, however, will necessarily embrace the features listed in the outline above, although the text relating to some of the items may be condensed to a single paragraph or sentence.

The progress sketch should show the routes followed by the leveling and the towns passed through, but it is not necessary to indicate the locations of the individual bench marks. Parallels of latitude and meridians of longitude should be shown on the sketch. Sections of one or more State maps of convenient scale may be used for the basis of the sketch. The progress sketch must be done in india ink on tracing cloth so that it may be duplicated by the blue-print or similar process.

A statement of costs is an essential part of the report on any leveling project. In order to secure uniformity and to insure that the statement shall contain all of the necessary data, it is suggested that the arrangement of the sample given below be followed as closely as possible.

Truck statistics

Total of all trucks:	
Season's mileage	103,590
Cost of operation	$2,551
Cost of depreciation	$1,427
Total cost of (operation and depreciation)	$3,978
Cost per mile	$0.038

Cost data

Total miles of second-order levels		2,523
Total number of permanent bench marks set		1,963
Total number of permanent bench marks leveled over		2,309
Party expenses (including pay and per diem)		$52,542
Party expenses (truck operation and depreciation)		$3,978
Officers' salaries	$5,230	
Amount for prorated leave (officers)	$ 429	
Total		$5,659
Amount for prorated leave (men)		$3,480
Total		$65,659

	Party operating expenses	Prorated leave officers	Truck operation	Prorated leave men	Officers' salaries	Truck depreciation	Total
Cost per mile	$20.83	$0.17	$1.01	$1.38	$2.07	$0.56	$26.02
Cost per bench mark	22.76	0.19	1.10	1.51	2.26	0.62	28.44

The above unit costs are rather high due to the fact that this assignment was over difficult terrain and involved a number of widely separated short lines.

FIELD RECORDS AND COMPUTATIONS

All observations of either first- or second-order leveling are recorded in Form 257, Spirit Level Observations.

The following examples of the record will serve to illustrate the method of recording and also to explain some details of the method of observation. The record should be made in ink and should be as neat and clear as possible. By this is meant neatness of arrangement and legibility rather than mere beauty. Entries belonging in a single column should be kept lined up so that figures in each succeeding entry will be directly below the corresponding figures in the preceding entries in the column and not zig-zag down the column. A neatly arranged record is easier to compute and materially reduces the chances of mistakes being made.

No erasures should be made. If a figure or entry is found to be wrong, that figure or entry should be crossed out neatly and the correct entry made above it.

Figure 16 shows the record of leveling between bench marks Y 159 and T.B.M. 2. The top of the right-hand page has been filled out to indicate that the leveling recorded at that opening of the book was run from Y 159 to or toward T.B.M. 2, regardless of whether or not the running was forward or backward with regard to the general direction of progress along the line. Then since Y 159 is nearer the beginning of the line than bench mark T.B.M. 2, the running is a forward running and at the top of the left-hand page the word "Backward" has been struck out. The backward running of this same section would be headed, on the right-hand page, "From T.B.M. 2 to B.M. Y 159" and the word "Forward" would be struck out on the left-hand page.

CAUTION: It should always be remembered that on a spur line the forward running is the one made in the direction from the base, or point on the main line from which the spur takes off, toward the free end of the spur. This convention is general and bears no relation to the geographical direction of the spur with relation to the geographical direction of the progress along the main line. It may so happen that a spur line may

SPIRIT LEVELING

Date: Aug. 14, 1946 Forward—~~Backward~~ (Strike out one word)

Sun: 5

From B. M.: Y 159 To B. M.: Z 2

Wind: 1 Time: 1330

No. of Station	Thread Reading Back Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Rod and Temp.	Thread Reading Fore Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Remarks
	1651					37.5	1384					
53	1549	15490	508	102	204	33°	1282	12820	420	102	204	
	1447			102			1180			102		
	4647						3846					
	1716						1459					
54	1615	16150	530	101	202		1360	13597	445	99	199	
	1514	31640	1038	101	406		1260	26417	865	100	403	
	9492						7925					
	1667						1559					
55	1569	15687	513	98	197		1459	14590	478	100	200	
	1470	47327	1551	99	603		1359	41007	1343	100	603	
	14198						12302					
	1690						1267					
56	1591	16907	521	99	199		1167	11667	382	100	201	
	1491	63234	2072	100	802		1066	52674	1725	101	804	
	18970						15802					
	1823						1885					
57	1723	17227	564	100	201		1784	17840	585	101	202	
	1622	80461	2636	101	1003		1683	70514	2310	101	1006	
	24138						21154					
	1422						1575					
58	1322	13220	433	100	200		1476	14757	483	99	199	
	1222	93681	3069	100	1203		1376	85271	2793	100	1205	
	28104	85271	2793				25581				1203	
	25581	+0.8410 m	2.76 ft = 0.84 m.								2408 = 0.80 km.	
	3/2523											
	+0.8410 m.											

FIGURE 16.—Sample of record for leveling observations.

double back in such a manner that the geographical direction of a forward running on the spur line may be almost exactly the same as the geographical direction of a backward running on the main line from which the spur originates.

In other words, if one thinks of leveling in the sense of carrying an elevation from a known point at the beginning of a line through the line to determine new elevations, as the work progresses, the forward runnings are from known elevations to new ones being determined and the backward runnings are from newly determined elevations back to the previously known elevations for a check.

The explanation of the numbers used after the words "Sun" and "Wind" is given at the bottom of Form 45. (See Figure 18.) These values are to be entered for their possible value in connection with office studies of the effect of direction of running with relation to sun and wind encountered along the line.

The unit (one in the last place) in the columns headed "Thread Reading Backsight," "Thread Reading Foresight," "Thread Interval" and "Sum of Intervals" is the millimeter. The entries in the columns headed "Mean" are carried one place further than the readings themselves. The unit (one in the last place) in the column headed "Middle-thread Reading Back of Rod" is one hundredth of a foot. The reading of the middle thread to hundredths of feet on the back of the rod is only for checking purposes and it is not used otherwise in the computations.

The instrument stations (not turning points) are numbered consecutively throughout the day, as shown in the column headed "No. of Station."

The columns headed "Thread Interval" and "Sum of Intervals" show the interval between the upper and middle threads as seen projected on the rod, the interval between the middle and lower threads, the total interval or sum of the two "half intervals" and

the continuous sum of the total intervals. As these values are proportional to the sums of the backsight distances and foresight distances, respectively, they enable the observer to keep these sums nearly equal at all times as required by the General Instructions and for the purpose of eliminating certain instrumental and other errors. (See paragraphs 22 and 56 of the General Instructions, pages 7 and 13.)

The columns headed "Mean" show the means of the three thread readings for each rod reading. The recorder uses, as a short method of computing the mean of the three thread readings, the fact that the difference between the upper and lower "half intervals" when divided by three is the correction to be applied with the proper sign to the middle thread reading to give the mean of the three.

The rod number and its temperature are recorded for the first backsight in each section. If it is found that the readings of the two thermometers differ, the number of each rod and its thermometer reading should be recorded, but the number and temperature of the rod that is in backsight should be recorded first. A rod once placed at a turning point is kept there, for both the foresight from one instrument station and the backsight from the next, each rodman being alternately front rodman and back rodman. To carry out the requirement of the General Instructions, that at stations of odd numbers the backsight is to be taken before the foresight and that at even-numbered stations the foresight is to be taken first, it is only necessary to remember that this is equivalent to the statement that one particular rodman must always show his rod first after each placing of the instrument.

Such portions of the computation as form a part of the record (see Figure 16) are kept up by the recorder as the work progresses. The instrument is not to be moved forward from any station until the recorder announces that the readings at the station, as shown by the rod intervals, check properly.

The difference in elevation for the ends of each section is computed in the record. This difference is equal to the sum of the backsights minus the sum of the foresights, the sign of the difference being plus if the sum of the backsights is the larger. The difference between the sums of the columns headed "Mean" equals the difference in elevation, but, as a check, the difference in elevation is also computed by subtracting the sum of the foresight thread readings from the sum of the backsight thread readings and dividing the difference by three. The difference in elevation for each section as computed from the sums of the thread readings should be checked at the time the data are transferred from the record book (Form 257) to the computation sheets (Form 45) since it frequently happens that the difference in elevation thus computed seems to check the difference in elevation computed from the sums of the mean readings, when actually errors have been made in addition, subtraction, and division by three. Should this check reveal differences which have been erroneously computed in the field, care should be taken to return to the line and relevel any sections that are found to have divergences between the forward and backward runnings which are not within the permissible tolerances.

The difference in elevation computed from the sums of the thread readings may differ from that computed from the sums of the mean readings, especially on sections having a large number of setups, by several tenths of a millimeter, depending upon the number of hundredths of a millimeter dropped or added in computing the means of the thread readings for the sights. However, a quick inspection of the last figures in the "Mean" column will show by how much the differences should fail to agree. Any small difference, which cannot be accounted for by hundredths dropped or added during

the computing of the means, should be investigated before considering the computations completed.

As an additional check upon the difference in elevation for a section and to guard against erroneous readings on the rods in the meters and in the decimeters, a reading of the middle thread is made, as already explained, on the back of the rod, which is graduated in feet. The difference in elevation is computed from these readings and the conversion made from feet to meters as indicated in Figure 16. This difference, however, is not carried over to Form 45.

Quite frequently the first backsight or the last foresight of a section is made on a tape. This is the case when the bench mark is in the wall of a building and it is impossible to hold a rod on it. The record should indicate clearly what readings were made on a tape and should also include the number of the tape.

SPIRIT LEVELING

Date: Aug. 15, 1946 Forward—~~Backward~~ (Strike out one word)
Sun. 0

From B. M.: 4 To B. M.: B160
Wind: 1 Time: 1130

No. of Station	Thread Reading Back Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Rod and Temp	Thread Reading Fore Sight	Mean	Middle Thread Reading Back of Rod	Thread Interval	Sum of Intervals	Remarks
	0952					375	2056					
44	0806	08053	263	146	294	23°	1910	19097	626	146	293	
	0658			148			1763			147		
	2416						5729					
	0772						2603					
45	0622	06217	203	150	301		2462	24617	807	141	283	
	0471	14270	466	151	595		2320	43714	1433	142	576	
	4281						13114					
	1676						0865					
46	1514	15140	496	162	324		0706	07053	231	159	320	
	1352	29410	962	162	919		0545	50767	1664	161	896	
	8823						15230					
46	(F)	Center of 50' concrete bridge & State Highway #15					1444					
							1405	14050	461	39		
							1366			39		
	3186						1467					
47	3030	30297	992	156	313		1309	13087	429	158	317	
	2873	59707	1954	157	1232		1150	63854	2093	159	1213	
	17912						19156	59707	1954		1232	
							17912	-0.4147 m.	139 ft = 0.42 m		2445 = 0.82 km	
							3/1244 -0.4147 m					

FIGURE 17.—Sample of record for leveling observations, showing method of recording extra foresights.

Figure 17 illustrates the method of recording an extra foresight, such as is made to obtain the elevation of the top of the rail in front of a depot or in the middle of a bridge, etc. The readings for the extra foresight are recorded on the right-hand page and are set off from the regular foresights by means of horizontal lines above and below the extra-foresight readings as shown. Neglect of setting off extra foresights from the regular foresights is apt to result in the extra foresights being added in to the cumulative totals of the foresights, thus causing confusion and increasing the chances of a blunder being made.

The space on the left-hand (backsight) page, which is opposite the readings for the extra foresight, is a good place to enter the brief description of the point on which the rod was held while the extra foresight was being taken.

The number of the instrument station from which the extra foresight was taken should always be shown in the record, as it is the only way one can be sure from the record to connect the extra foresight with the corresponding backsight, the fact that the

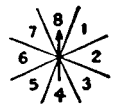
DEPARTMENT OF COMMERCE
U.S. COAST AND GEODETIC SURVEY
Form 45
Rev. Ed. Sept. 1934

COMPUTATION OF FIRST-ORDER LEVELS

Line Warsaw, Ind., to Goshen, Ind. Rods 370 & 375

Date (1)	Designation of Section (2)	Forward or Backward (3)	Time (4)	Sun (5)	Wind (6)	Temp. of Rods (7)	Length of Section (8) km.	Distance from B.M. J8 (9) km.	ROD READINGS Σ B (10) meters	ROD READINGS Σ F (11) meters	Difference of Elevation Each Section (12) meters	DIVERGENCE (B—F) Partial (13) mm.	DIVERGENCE (B—F) Total Accumulated (14) mm.
	I 8												
8-14	to J 8	B	11^{25}	5	1	30	0.30		6.2987	6.7557	−0.4570		
8-14	J8 to	F	11^{50}	1	1	30	0.58		6.7290	9.8898	−3.1608		
8-14	TBM 1	B	11^{00}	7	1	30	0.57	0.57	8.2274	5.0664	+3.1610	−0.2	−0.2
8-14	TBM 1	F	13^{00}	4	1	32	0.77		6.2071	7.9444	−1.7373		
8-14	to Y159	B	10^{30}	7	1	30	0.77	1.34	8.1344	6.3948	+1.7396	−2.3	−2.5
8-14	Y159 to	F	13^{30}	5	1	34	0.80		9.3681	8.5271	+0.8410		
8-14	TBM 2	B	10^{10}	7	1	30	0.80	2.14	8.2094	9.0515	−0.8421	+1.1	−1.4
8-14	TBM 2	F	14^{10}						4.5884	4.6054	−0.0170		
8-14	to EFS	B	10^{00}						3.2447	3.2247	+0.0200	−3.0	
8-14	TBM 2	F	13^{15}	4	1	33	0.93		10.8355	12.6758	−1.8403		
8-14	to Z159	B	9^{45}	7	1	30	0.93	3.07	10.9845	9.1401	+1.8444	−2.6	−4.0
8-14		B	14^{20}	1	1	34	0.93		12.6672	10.8258	+1.8414		
8-14	Z159 to	F	15^{00}						2.9920	1.1610	+1.8310		
8-14	EFS	B	9^{40}						0.8350	2.6647	−1.8297	−1.3	
8-14	Z159 to	F	15^{00}	4	1	34	0.87		12.1111	7.4304	+4.6807		
8-14	TBM 3	B	9^{25}	7	1	28	0.87	3.94	7.1931	11.8748	−4.6817	+1.0	−3.0
8-14	TBM 3	F	16^{35}						1.5530	1.5560	−0.0030		
8-14	to EFS	B	9^{20}						2.8000	2.8010	−0.0010	+4.0	

Abbreviations for sun: O=cloudy. With sunshine, show direction of progress in relation to sun by numbers in diagram.
Abbreviations, strength of wind: O=calm; 1=moderate; 2=strong.



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extra foresights should always follow the regular foresight at an instrument station not being sufficient.

It will be noticed that "(F)" has been entered on the left-hand page and to the right of the setup number "46" opposite the extra foresight. This indicates that the point on

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Mean Difference of Elevation (18) meters	Designation of Bench Mark (16)	Elevation of Bench Mark (17) meters	CORRECTIONS Index Error (19) mm.	Length of Rod (20) mm.	Temp. of Rod (20) mm.	Level (21) mm.	REMARKS (22)
	I 8	251.8860					Check data: between I8 & J8
+0.4570	J 8	252.343					Old difference 0.4572
							New " 0.4570
							divergence 0.0002
-3.1609	TBM 1	249.1821					
-1.7384	Y159	247.4437					
+0.8416	TBM 2	248.2853					
							0.5 mi N of Y159 1.2 mi. N. of Warsow Top of E rail of main N.Y.C.R.R. &
-0.0185	EFS	248.2668					N. end of easterly siding
-1.8416	Z159	246.4437					
							At Z159 1.9 mi N of Warsow Top of E rail of N.Y.C.R.R.
+1.8304	EFS	248.2741					& E-W gravel road
+4.6812	TBM 3	251.1249					
							0.5 mi N of Z159 2.4 mi N of Warsow Top of E rail N.Y.C.R.R. & E-W
-0.0010	EFS	251.1239					gravel road.

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FIGURE 18.—Sample of field computation.

Note: The numbers in parentheses at the top of the various columns have been added for convenience of reference in the text. These numbers should not appear on a computation made in the field and forwarded to the Office.

which the extra foresight was taken was located along the line between the instrument and the regular foresight at setup 46. Had the point on which the extra foresight was taken been located at a point along the line between the instrument and the regular backsight at setup 46, the entry would have been "(B)" instead of "(F)".

If a regular foresight is upon a point whose elevation is to be determined as an extra elevation, a brief description of the point on which the rod was held should be entered in the "Remarks" column in somewhat the following form: "F. S. – S. U. 31, on nail in tie at center of bridge No. 341-A." This, being translated, would read, "The rod which was in foresight at instrument station No. 31 was held on the head of a nail driven in a tie at the center of bridge No. 341-A". It is good practice to put such entries in the "Remarks" column in such a position that the entry begins on the same horizontal line on which the middle one of the three thread readings occurs.

Where the level line follows the same railroad for a considerable distance, it is not necessary to insert the name of the railroad when giving the name of the depot in recording the extra foresight for the top of the rail, but where there can be any doubt as to which depot is referred to, the name of the railroad should also be given in addition to the depot or station name.

Form 45 (Figure 18) should show the separate results of each running over each section of the leveling, together with the date and time of the running, the position of the sun, the strength of the wind, the mean temperature of the rods, the length of the section, and the distance of the second bench mark of the section from the initial bench mark of the line.

On this form the sections are arranged in their order along the line. The spur lines and the elevations determined from extra foresights follow the bench marks of the main line with which they are connected. Do not assemble spur lines and the results of leveling for supplementary elevations on separate sheets. The computation of a line of levels is a progressive calculation and to have all the sections in their proper order will not only facilitate the computation, but will make errors in the computed elevations much less likely to occur.

All entries on Form 45, whether pertaining to spur lines to bench marks or spur lines resulting from the taking of extra foresights, which show runnings not in the main line of levels should be made in red ink if possible. Should it happen that red ink is not available, the entries may be made in the same ink as for the entries concerning the runnings in the main line, but all entries pertaining to spurs of any character should then be set off in boxes, as shown in Figure 18.

The brief description of the point on which the rod was held should be entered in the "Remarks" column for spurs resulting from extra foresights or similar cases. When a spur line is run to a point or points described on Form 638 (Revised 1946), the entry "Spur Line" should appear in the "Remarks" column of Form 45.

The lengths of the sections are obtained by multiplying the total of the two sums of the rod intervals for each section by the stadia constant of the instrument. (See page 20.) The length of each section, whether in the main line or on a spur line should be given, but it is not necessary to give the lengths involved in the determination of elevations of points by means of extra foresights. It is well, though, to show the time with entries of this sort, as this provides an easy means of finding the observations in the record book if one needs to go back to them.

The entries in columns 10, 11, and 12 (Figure 18) are transcribed directly from the record book (Form 257), the figures being those obtained by using the means of the thread readings.

In computing the mean difference in elevation shown in column 15, when abstracting double-run leveling, the mean difference in elevation is simply the arithmetic mean of the

two differences shown in column 12, but the sign of the difference is that of the forward running, with the possible exception of a case where the difference in elevation is so small that both the forward and backward runnings are of the same sign. (See last section abstracted in Figure 18.)

In abstracting single-run leveling the entry in column 15 will be the same as that in column 12, except that the sign will be reversed if column 12 shows the difference for a running made in the backward direction.

When double-run leveling is being abstracted and any section has been leveled more than twice, a straight arithmetic mean of all the differences for that section in column 12 should be taken. Any observed differences, which depart from the others to such an extent as to indicate blunders, should not be used in computing this mean. Then, if any of the remaining differences depart from the mean by more than ± 6.0 mm. $\sqrt{K}$ (K being the length of the section in kilometers) they shall be rejected before computing the mean difference in elevation to be entered in column 15.

After the necessary rejections have been made, the final mean difference in elevation to be entered in column 15 is to be computed as follows:

(1) Take the mean of all forward runnings which were not rejected.

(2) Take the mean of all backward runnings which were not rejected.

(3) Take the mean of the two means provided for in (1) and (2) as the mean difference in elevation to be entered in column 15.

The following example will serve to illustrate the process of making rejections and computing the required means. To be sure, this example is not a strictly typical case but it has been chosen to illustrate in one example all the points which may be encountered at this step in the computation of the levels.

Assume that first-order differences in elevation have been observed, as shown below, for a section 1.15 kilometers in length.

F	+1.4473
B	−1.4420
F	+1.4523
B	−1.4430
F	+1.4441

The indiscriminate mean of all five runnings is then found to be 1.4457. The rejection limit is ± 6.0 mm. $\sqrt{1.15}$ or ± 6.4 mm. Thus any differences lying between 1.4521 and 1.4393 shall not be rejected. In this case we reject the third running, +1.4523.

The mean of the retained forward runnings is +1.4457 and the mean of the retained backward runnings is −1.4425. The mean to be entered in column 15 is

$$\frac{(1.4457 + 1.4425)}{2} = +1.4441$$

the plus sign being the sign of the forward runnings. The partial is the difference between 1.4457 and 1.4425 or 3.2 mm. This partial, of course, will be −3.2, since, except in the unusual case to be discussed later, the partial takes the sign of the smaller of the two differences used in computing it.

In the case of double-run second-order leveling the rejection limit is ± 9.0 mm. $\sqrt{K}$, when K is the length of the section in kilometers.

If, for any reason, a running is rejected for any cause other than excessive divergence from the indiscriminate mean of all the runnings for that section, the reason for the rejection should be clearly stated in column 22 of Form 45.

It sometimes happens, as in the case of the leveling from T.B.M. 3 to E.F.S. (see Figure 18), that the difference in elevation is numerically smaller than the allowable divergence and both forward and backward runnings yield differences in elevation of the same algebraic sign. In such a case the mean difference in elevation and the partial should be computed as follows:

Take the case of the last item in Figure 18. In this case the forward running resulted in a difference in elevation from T.B.M. 3 to E.F.S. of −0.0030 meter, while the backward running resulted in a difference of elevation from E.F.S. to T.B.M. 3 of −0.0010 meter. The mean difference of elevation to be entered in column 15 is obtained by changing the sign of the backward running and taking the mean of the two runnings thus:

$$\frac{-0.0030 + 0.0010}{2} = -0.0010.$$

The partial is obtained by carrying an assumed elevation, say 1.0000 meter, for T.B.M. 3 through the forward running to E.F.S. and then through the backward running back to T.B.M. 3. The partial is then the correction that must be applied to the elevation brought back to T.B.M. 3 to make it agree with the assumed elevation which was first used for T.B.M. 3. Numerically the partial in this case is computed as shown below:

Assumed elevation of T.B.M. 3	1.0000
Forward running, T.B.M. 3 to E.F.S.	−0.0030
Computed elevation of E.F.S.	0.9970
Backward running, E.F.S. to T.B.M. 3	−0.0010
Computed elevation of T.B.M. 3	0.9960
Correction necessary to get back to assumed elevation of T.B.M. 3	+0.0040 = partial
Assumed elevation of T.B.M. 3	1.0000 (check)

That this procedure in computing the partial is in agreement with the standard procedure in less unusual cases, is illustrated by the following example:

Assume F +1.4732
B −1.4715.

The usual rule, the difference of the two runnings with the sign of the smaller difference, gives a partial of −1.7 mm.

Assumed elevation of first point	1.0000
Forward running	+1.4732
Computed elevation of second point	2.4732
Backward running	−1.4715
Computed elevation of first point	1.0017
Correction necessary to get back to assumed elevation of first point	−0.0017 = partial
Assumed elevation of first point	1.0000 (check)

Column 16 contains the designations of the marks at the forward end of each section and the computed elevations of each of these marks are entered on the same line in column 17.

The elevation to be used for the initial bench mark of a line is always furnished to the chief of party, and the elevations in column 17 are computed using the successive differences, section by section, as given in column 15.

Columns 18, 19, 20 and 21, are for office use only, as none of these corrections forms a part of the field computation.

The elevations of all permanent bench marks whose designations appear on the left-hand side of Form 45 should be computed and shown on the right-hand side of the form. Also, all elevations computed in a single field abstract should be consistent. After deciding upon the junction mark at the beginning of the line, the elevation furnished by the Office for that mark should be used for computing all other elevations in the line, including those of all of the other check marks.

INSTRUCTIONS FOR STAMPING ELEVATIONS ON BENCH MARKS

From time to time the Coast and Geodetic Survey places recovery-and-stamping parties in the field to go about recovering bench marks, reporting on their condition at the time of recovery, and, in any case in which the character of the mark permits and the standard elevation is available, stamping the elevation on the tablet. This work cannot be carried on by the observing units for the reason that the final elevations of the marks are never known until after the office computations and adjustments have been completed. Furthermore, adjusted elevations resulting from preliminary or tentative adjustments should never be stamped on the tablets. Not until standard elevations are available is it permissible to stamp the elevation on any mark.

The following is a slightly revised set of instructions for the recovery and stamping of bench marks, which were issued under date of January 12, 1937, and were based on our experience during an intensive campaign of recovery and stamping of bench marks carried out in 1934 and 1935.

After all of the field and office work of geodetic leveling has been completed there are just two things that are of real use, aside from possible scientific by-products which need not be considered here.

1. The bench marks themselves.
2. The published descriptions and elevations which enable engineers and surveyors to find and use the marks.

All of the details of setting the marks, the observing, computation, adjustment, publication, etc., are merely a means to an end—the marks and their published descriptions and elevations. Obviously, no matter how permanent a bench mark may be, if it cannot be found when it is needed it might as well never have been established.

At first thought, it might seem to be a very simple task to so describe a given bench mark that a stranger might, when given the published description and elevation, find and make use of it. However, it has been our experience, in handling thousands of bench mark descriptions, that description writing is not as simple a matter as it seems from a merely casual consideration of the subject.

In general, a good description should lead a person from some place with which he is familiar, or which he can locate without any aids other than those available to all, gradually and by properly ordered and easy stages to the immediate locality of the mark. Having been led to a point from which the mark, if still in place, is visible, he should then be told exactly what to look for, in order that the mark may be positively identified.

Practical considerations which must be taken into account in publishing descriptions of bench marks are as follows:

1. The description should be as brief as is consistent with clearness and certainty of recovery.

2. Sketches cannot be used except under the most unusual conditions.
3. For the sake of uniformity a more or less standard form must be followed.
4. The descriptions must be readable and not written "telegraph" style.
5. Only generally accepted abbreviations should be used.
6. The order in which the various items in the description are arranged should be such as to lead the person who is trying to recover the mark to the desired spot with as little lost motion as possible.

Description writing is not a hard-and-fast routine. The character of the description will vary greatly with the character of the mark, its location and the abundance or scarcity of natural or cultural objects to which it can be referenced. A description of a mark located in the Union Station at Washington, D.C., would be a very different affair from the description of a mark located in an outcrop of rock alongside the trail up Mt. Whitney. To describe a mark in a public park in a city requires a very different sort of treatment than is best for the description of a mark in a field beside a railroad many miles from the nearest station or town.

REPORT ON CONDITION OF BENCH MARK

For each and every bench mark searched for, whether recovered or not, a report (Form 685)[2] will be sent to this Office. This report consists of a 5- by 8-inch card of light-blue color, on which there is a printed form with blanks to be filled in with data required concerning the mark, its location, the date on which search was made, the name of the party making the search, the condition of the mark, etc.

The first blank to be filled in is the one following the words "Designation of mark" and, in general, the entry in this blank will be that combination of letters and figures with which the description of the mark begins. Certain typical designations, taken more or less at random, are as follows: D 14, 2813 (U.S.G.S.), 2723.52 (A.H.D.), RV 10 (S.P.), MILLSTEAD, and T.B.M. 86. In other words, the designation is usually that part of the very beginning of the description which precedes the ".--" or the ".-", when mimeographed or printed descriptions are furnished or, when photostat or lithographic copies of original description cards are furnished, the entry in the blank following "Designation of bench mark."

The other two entries on the same line of Form 685 are the State and county in which the *mark* is located.

The entries on the next line give the name of the nearest town and the distance and direction from that town.

The blanks for the name, occupation and address of the person making the recovery need only be filled in completely on the first card of the group of cards pertaining to a given line of levels. The date on which the bench mark is visited should appear on each report. The *signature* of the person making the recovery will be *on each and every report* and will serve to tie the cards of a group together and avoid the necessity for filling in the items—name, occupation and address on any except the first card in each group.

The entry following "Present condition of the mark" will depend entirely on whether the mark is recovered or not and, if it is recovered, the condition in which it is found. Some typical entries in this blank, together with their meanings, as accepted by this Office, are as follows:

[2] Form 685A should be used by geodetic leveling parties of this Bureau for reporting on bench marks recovered during the course of their work. (See page 50.) In all other cases use Form 685.

1. Destroyed.—To be used only in cases where the mark has been actually, and can be proved to have been, destroyed.

2. Not recovered on this date.—To be used in cases where, after thorough search has been made, the mark has not actually been recovered, but not actually proven to have been destroyed.

3. Good.—To be used in cases where the mark is recovered in its original condition, unmutilated and showing no evidence of having been disturbed.

4. Moved.—To be used in cases where evidence is uncovered which proves that the mark has been actually moved from its original location to another by a deliberate act of man.

5. Disturbed.—To be used in cases where the mark shows evidence of having moved from its original location by accident or natural forces, as for example: Having been tilted as a result of a caving bank or from having been struck by a truck, wagon, grader, etc.

6. Mutilated.—To be used in cases where the original stamping or lettering has been battered so as to become illegible. A mark may have been mutilated and yet be perfectly suitable for use as a bench mark.

Following the entry "Letters or numbers found stamped on (not cast in) the mark," any letters or numbers found to have been stamped with dies on the disk prior to your recovery of it will be entered. Any letters or numbers stamped by you on the disk will be entered in the large blank space in the lower part of the card by writing the word "stamped" followed by the letters or numbers, stamped by you on the disk in quotation marks, thus: Stamped "3786.612". For example, suppose you arrive at and recover bench mark N 52, established in 1932, and find that the designation and date are already stamped on the disk. The entry on the blank provided opposite "Letters or numbers found stamped on (not cast in) the mark" would then be "N 52 1932" and if you stamped the elevation 3786.612 on the disk in the appropriate place, the entry in the lower part of the card would be as follows: Stamped "3786.612".

You will find on Form 685 that the large blank space at the lower part of the card is topped with the following: "Use the following space for reporting upon the thoroughness of the search in case mark was not recovered, or for suggesting needed changes in the published description, if the mark was recovered" and this part of the form should be used as indicated by its heading. Completeness and thoroughness concerning the extent of the search made in case a mark was not recovered or in commenting on the published description when the mark is recovered are essential. In cases where numerous changes are needed to revise the description, it may be well to write a complete new description. Do not write on the back of the card—use more than one card, if necessary, and pin or staple them together.

MISCELLANEOUS COMMENTS CONCERNING REPORTS

The mere fact that a bench mark is readily recovered from the published description does not necessarily mean that the description is accurate in all its details or that the mark will be as readily recoverable in future years. All items in the published bench-mark descriptions should be carefully checked and such additions should be made to the description as may serve to increase the period of time that the bench mark may be readily recovered from the description as revised.

Care should be used in selecting reference objects, where more than enough are available, so as to use in the description those that are most permanent. Directions to refer-

ence objects from the bench mark should not be given. It is better to give the direction from the reference object to the mark itself since that is the information desired by the person searching for the mark.

If difficulty is encountered in recovering the mark by means of the information contained in the published description, it is prima facie evidence that the description as published is either incorrect, inadequate, or both. In this event, care should be taken to make sufficient changes, corrections, or additions to produce a thorough and adequate description.

Where the marks are posts or pipes set in the ground, the height to which the mark projects above the surface of the ground should be stated. This information will be valuable to persons searching for the mark in the future, especially if it be located where tall grass or weeds are apt to grow up around it.

In addition to calling attention to errors in facts in the original descriptions, report on any needed changes in spelling, capitalization, grammar, punctuation, etc.

In all cases, use accepted engineering or dictionary terminology in preference to localisms or railroad, highway, and construction "lingo." Many errors have been made in naming railroad and highway structures. Bridges are frequently confused with culverts, piers with abutments, and head walls, parapets, railings, and wing walls are oftentimes hopelessly confused.

Ordinarily no attempt should be made to give the distance from a town closer than the nearest tenth of a mile and the directions need only be given to the nearest half quadrant, i. e., N., NE., E., SE., etc. Where possible the route along which the distance is measured and the *point of departure* should be given in this item.

On some lines directions will be found to follow "railroad convention" instead of being given as true directions. In all cases where this occurs the directions following the "railroad convention" should be changed to true directions in accordance with the above paragraph.

Along highways, the speedometer in your car or truck will often be used to check distance references from towns. An appreciable systematic error may exist in your speedometer, and it should be checked against a known distance so that a proportional correction may be applied to the readings if necessary.

Short distances should be given in suitable units, such as poles, rails, yards, feet, etc.

Measured distances should be given to the nearest tenth of a foot if they are measured from some sharply defined object, such as a rail, the edge of a concrete pavement, the face of a building, etc. Distances measured from trees, poles, and other objects, where no sharply defined point is available from which to measure, should usually be given to feet only, though ½ foot may be used to advantage at times. Paced distances should be given in yards and distances determined by counting poles or rails may be given in ½'s, or ¼'s, but a finer subdivision of the rail or pole unit is rather fictitious accuracy.

In giving distances which are measured to the nearest tenth of a foot, use feet and decimals. If distances are not measured closer than the nearest half or quarter of a foot use fractions instead of decimals. The last decimal place or fraction in the recorded distance should be a clue to the accuracy of the measurement itself.

The possibility, that the mark may be covered over by a fill, overgrown by weeds or brush, or otherwise obscured, should be kept in mind in rewriting the description. Usually, where it is at all possible, at least two references should be included which are

of such character as to permit of so nicely locating the mark that extensive digging or search through tall grass and weeds will not be necessary.

Generally the tendency of a man in the field is to write the description "backwards." In other words, he is standing at the mark and the nearest reference objects are noticed first and the more distant ones later. He usually writes them down in this order. The person searching for the mark usually wants the longer distances first and the minute details later. Of course, the relative order of the items can be changed in the Office but this requires an immense amount of extra work where thousands of descriptions are being edited for publication.

Because of the fact that, after the mark is set, the disk is all that is visible to the person recovering the mark, it is better practice to refer to the mark as a disk. A disk set horizontally (shank vertical) is the normal position for a bench mark disk and unless otherwise noted in the description they will be considered as having been set so that a rod can be held on the top of the disk. A disk set vertically (shank horizontal) in a vertical wall should be noted as having been set vertically since it is the more unusual position.

Unusual marks are often tied in and for those extra care should be taken to so describe the mark that a person entirely unfamiliar with it may recognize it and be able to make a positive identification of the point on which the rod was held.

It is obvious that a description, to be useful, must be clearly and accurately written. The leveling is of no value if the marks cannot be found. This thought should be kept in mind at all times. Reports should be accurate, definite and complete.

An example of a vague description corrected by a good report is as follows:

Original description:

> 192.3 (?).— About 3 miles west of Pittsfield, Henry County, on the Texas & New Orleans Railway, about ½ mile west of a road crossing, and in the west end of a bridge. A chiseled mark.

Description as corrected by report:

> 192.3 (U.S.G.S.).—In Adams County, about 3.2 miles southwest along the Texas & New Orleans Railroad from the station at Pittsfield, Henry County, about 0.5 mile east of milepost 26, about 0.4 mile west of the crossing of State Highway 42, at a bridge over Holly Creek, and in the top of the north end of the west abutment. A chiseled square.

PREPARATION OF RUBBINGS

In all cases where elevations are furnished to you as being based on the Sea-level Datum of 1929, and where the mark is a United States Coast and Geodetic Survey standard bench-mark disk, the elevation, in feet, as given with the description should be stamped with 3/16-inch dies in the place provided for it on the disk.

In some cases, the elevations will already be found stamped on the disk. In such cases this should be checked, and if found to be in error, the erroneous figures should be cut out with a small cold chisel, the indentation thus made smoothed out either with a light ball-peen hammer, emery cloth, or both, and the correct figures stamped in place of those which were cut out.

In all cases, after the stamping is complete, a rubbing should be made of enough of the disk to show *all* the stamped figures and enough of the cast legend to positively identify the type of disk. A rubbing can be made by placing a piece of light- or medium-

weight paper over the disk and then rubbing over the paper with a hard pencil to bring out the legend cast in the disk and especially the letters and numbers stamped on it with dies.

In some cases it will be found that a rubbing cannot be made which will be clear in all details, owing perhaps to depressions where figures have been cut out and restamped, or in cases where disks have been mutilated. Such details can be penciled in but this should not be resorted to unless absolutely necessary.

After the rubbing has been made the designation of the mark should be written on it and it should be forwarded to this Office with the copy of Form 685 also pertaining to the same mark.

Only Coast and Geodetic Survey and U. S. Geological Survey disks should be stamped with the elevation during the course of your work. We have no authority to stamp our elevations on disks of any other organizations. Of course, in the case of marks such as chiseled crosses, chiseled squares, metal bolts, rivets, etc., there will be no place on which to stamp an elevation and no attempt should be made to stamp marks of this type. On the other hand, a report (Form 685) must be turned in for each and every mark visited and all marks in any line covered by your work should be at least thoroughly searched for and a proper report concerning your findings made.

You will frequently encounter cases where elevations to the nearest foot have already been stamped on bench marks. Where these figures are still correct, it will be merely necessary to add the decimal point and the figures to the right of it.

In cases where the last figures of the elevations already stamped are no longer correct, it will be necessary to cut out the erroneous figures and restamp them in accordance with the elevations furnished to you.

In all cases where you stamp U.S. Geological Survey bench marks, duplicate rubbings must be furnished with your report (Form 685), in order that we may furnish to the U.S. Geological Survey one of the rubbings showing exactly what stamping has been added to the disk.

TRANSMITTAL OF RECORDS

In addition to a supply of Form 685, dies, 4H pencils and 5- by 8-inch paper, you will be furnished with a supply of manila envelopes addressed to the Director, U.S. Coast and Geodetic Survey, Washington, D.C., and stamped for the attention of the Section of Leveling, Division of Geodesy. Your reports and rubbings should be allowed to accumulate in your possession until you have completed the work on a line or such part of the line as may lie within your territory, at which time the accumulated reports and rubbings should all be forwarded at once in one or more envelopes, as may be necessary. A brief summary, stating the number of marks visited, the number recovered, the number found to have been destroyed, the number remaining unrecoverable, and the number on which elevations were stamped, should be included with each shipment of reports and rubbings. This brief summary should be headed with the name of the line for the purpose of identifying not only the summary but the group of cards with which it is shipped. This summary should be attached to the first card in the group for the line. In cases where a shipment consists of more than one envelope, a post-card notice should be sent with the shipment stating the number of envelopes comprising the shipment, or, should it be found more convenient, the envelopes may be numbered in the order in which they are sent to the Office, numbering your first envelope 1 and continuing to number them consecutively as long as you are engaged on this class of work.

From time to time, you may be furnished with lists of descriptions of bench marks for which no elevations are given, or on which will appear a caution that the elevations are doubtful and possibly subject to change when future leveling is completed. In all cases of this sort, you will go over the lines, recover if possible, and report on all marks on the list, but will stamp no elevations, even though the marks are our own standard disks and not already stamped. Rubbings will be prepared in all cases where possible, even though no additional stamping is done. All marks of a character which will permit of a rubbing being taken will be so treated, and the rubbing furnished with the report on Form 685.

TABLE I.—Allowable divergence between forward and backward runnings of a section of first-order levels. (4.0 mm. $\sqrt{K}$)

Length of section Kilometers	Allowable divergence Mm.	Length of section Kilometers	Allowable divergence Mm.
0.00 to 0.26	2.0	0.98 to 1.02	4.0
0.27 to 0.28	2.1	1.03 to 1.07	4.1
0.29 to 0.31	2.2	1.08 to 1.12	4.2
0.32 to 0.34	2.3	1.13 to 1.18	4.3
0.35 to 0.37	2.4	1.19 to 1.23	4.4
0.38 to 0.40	2.5	1.24 to 1.29	4.5
0.41 to 0.43	2.6	1.30 to 1.35	4.6
0.44 to 0.47	2.7	1.36 to 1.41	4.7
0.48 to 0.50	2.8	1.42 to 1.47	4.8
0.51 to 0.54	2.9	1.48 to 1.53	4.9
0.55 to 0.58	3.0	1.54 to 1.59	5.0
0.59 to 0.62	3.1	1.60 to 1.65	5.1
0.63 to 0.66	3.2	1.66 to 1.72	5.2
0.67 to 0.70	3.3	1.73 to 1.78	5.3
0.71 to 0.74	3.4	1.79 to 1.85	5.4
0.75 to 0.78	3.5	1.86 to 1.92	5.5
0.79 to 0.83	3.6	1.93 to 1.99	5.6
0.84 to 0.87	3.7	2.00 to 2.06	5.7
0.88 to 0.92	3.8		
0.93 to 0.97	3.9		

TABLE II.—Allowable divergence between forward and backward runnings of double-run second-order levels. (8.4 mm. $\sqrt{K}$)

Length of section Kilometers	Allowable divergence Mm.	Length of section Kilometers	Allowable divergence Mm.
0.00 to 0.25	4.2	0.95 to 0.96	8.2
0.26	4.3	0.97 to 0.98	8.3
0.27 to 0.28	4.4	0.99 to 1.01	8.4
0.29	4.5	1.02 to 1.03	8.5
0.30	4.6	1.04 to 1.06	8.6
0.31	4.7	1.07 to 1.08	8.7
0.32 to 0.33	4.8	1.09 to 1.11	8.8
0.34	4.9	1.12 to 1.13	8.9
0.35 to 0.36	5.0	1.14 to 1.16	9.0
0.37	5.1	1.17 to 1.18	9.1
0.38 to 0.39	5.2	1.19 to 1.21	9.2
0.40	5.3	1.22 to 1.23	9.3
0.41 to 0.42	5.4	1.24 to 1.26	9.4
0.43	5.5	1.27 to 1.29	9.5
0.44 to 0.45	5.6	1.30 to 1.31	9.6
0.46	5.7	1.32 to 1.34	9.7
0.47 to 0.48	5.8	1.35 to 1.37	9.8
0.49 to 0.50	5.9	1.38 to 1.40	9.9
0.51	6.0	1.41 to 1.43	10.0
0.52 to 0.53	6.1	1.44 to 1.46	10.1
0.54 to 0.55	6.2	1.47 to 1.48	10.2
0.56 to 0.57	6.3	1.49 to 1.51	10.3
0.58	6.4	1.52 to 1.54	10.4
0.59 to 0.60	6.5	1.55 to 1.57	10.5
0.61 to 0.62	6.6	1.58 to 1.60	10.6
0.63 to 0.64	6.7	1.61 to 1.63	10.7
0.65 to 0.66	6.8	1.64 to 1.66	10.8
0.67 to 0.68	6.9	1.67 to 1.69	10.9
0.69 to 0.70	7.0	1.70 to 1.73	11.0
0.71 to 0.72	7.1	1.74 to 1.76	11.1
0.73 to 0.74	7.2	1.77 to 1.79	11.2
0.75 to 0.76	7.3	1.80 to 1.82	11.3
0.77 to 0.78	7.4	1.83 to 1.85	11.4
0.79 to 0.80	7.5	1.86 to 1.89	11.5
0.81 to 0.82	7.6	1.90 to 1.92	11.6
0.83 to 0.85	7.7	1.93 to 1.95	11.7
0.86 to 0.87	7.8	1.96 to 1.99	11.8
0.88 to 0.89	7.9	2.00 to 2.02	11.9
0.90 to 0.91	8.0		
0.92 to 0.94	8.1		

TABLE III.—Allowable divergence between forward and backward runnings of a section of first-order levels when special instructions call for special accuracy. (3.0 mm. $\sqrt{K}$)

Length of section Kilometers	Allowable divergence Mm.	Length of section Kilometers	Allowable divergence Mm.
0.00 to 0.26	1.5	0.97 to 1.03	3.0
0.27 to 0.30	1.6	1.04 to 1.10	3.1
0.31 to 0.34	1.7	1.11 to 1.17	3.2
0.35 to 0.38	1.8	1.18 to 1.24	3.3
0.39 to 0.42	1.9	1.25 to 1.32	3.4
0.43 to 0.46	2.0	1.33 to 1.40	3.5
0.47 to 0.51	2.1	1.41 to 1.48	3.6
0.52 to 0.56	2.2	1.49 to 1.56	3.7
0.57 to 0.61	2.3	1.57 to 1.64	3.8
0.62 to 0.66	2.4	1.65 to 1.73	3.9
0.67 to 0.72	2.5	1.74 to 1.82	4.0
0.73 to 0.78	2.6	1.83 to 1.91	4.1
0.79 to 0.84	2.7	1.92 to 2.00	4.2
0.85 to 0.90	2.8		
0.91 to 0.96	2.9		

TABLE IV.—Total correction for curvature and refraction

[This table of total correction for curvature and refraction is for use in computing "*C*" and in general wherever the total correction is required. In computing this table the refraction was assumed to be equal to one-eighth the curvature]

Distance *Meters*	Correction to rod reading *Mm.*	Distance *Meters*	Correction to rod reading *Mm.*
0 to 27	0.0	160	—1.8
28 to 47	—0.1	170	—2.1
48 to 60	—0.2	180	—2.3
61 to 72	—0.3	190	—2.6
73 to 81	—0.4	200	—2.8
82 to 90	—0.5	210	—3.0
91 to 98	—0.6	220	—3.3
99 to 105	—0.7	230	—3.7
106 to 112	—0.8	240	—4.0
113 to 118	—0.9	250	—4.3
119 to 124	—1.0	260	—4.7
125 to 130	—1.1	270	—5.0
131 to 136	—1.2	280	—5.4
137 to 141	—1.3	290	—5.8
142 to 146	—1.4	300	—6.2
147 to 150	—1.5		

TABLE V.—CONVERSION TABLES

Lengths—Feet to meters (from 1 to 1,000 units)

[Reduction factor: 1 foot = 0.3048006096 meter]

Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters
0	0.0	50	15.24003	100	30.48006	150	45.72009	200	60.96012
1	0.30480	1	15.54483	1	30.78486	1	46.02489	1	61.26492
2	0.60960	2	15.84963	2	31.08966	2	46.32969	2	61.56972
3	0.91440	3	16.15443	3	31.39446	3	46.63449	3	61.87452
4	1.21920	4	16.45923	4	31.69926	4	46.93929	4	62.17932
5	1.52400	5	16.76403	5	32.00406	5	47.24409	5	62.48412
6	1.82880	6	17.06883	6	32.30886	6	47.54890	6	62.78893
7	2.13360	7	17.37363	7	32.61367	7	47.85370	7	63.09373
8	2.43840	8	17.67844	8	32.91847	8	48.15850	8	63.39853
9	2.74321	9	17.98324	9	33.22327	9	48.46330	9	63.70333
10	3.04801	60	18.28804	110	33.52807	160	48.76810	210	64.00813
1	3.35281	1	18.59284	1	33.83287	1	49.07290	1	64.31293
2	3.65761	2	18.89764	2	34.13767	2	49.37770	2	64.61773
3	3.96241	3	19.20244	3	34.44247	3	49.68250	3	64.92253
4	4.26721	4	19.50724	4	34.74727	4	49.98730	4	65.22733
5	4.57201	5	19.81204	5	35.05207	5	50.29210	5	65.53213
6	4.87681	6	20.11684	6	35.35687	6	50.59690	6	65.83693
7	5.18161	7	20.42164	7	35.66167	7	50.90170	7	66.14173
8	5.48641	8	20.72644	8	35.96647	8	51.20650	8	66.44653
9	5.79121	9	21.03124	9	36.27127	9	51.51130	9	66.75133
20	6.09601	70	21.33604	120	36.57607	170	51.81610	220	67.05613
1	6.40081	1	21.64084	1	36.88087	1	52.12090	1	67.36093
2	6.70561	2	21.94564	2	37.18567	2	52.42570	2	67.66574
3	7.01041	3	22.25044	3	37.49047	3	52.73051	3	67.97054
4	7.31521	4	22.55525	4	37.79528	4	53.03531	4	68.27534
5	7.62002	5	22.86005	5	38.10008	5	53.34011	5	68.58014
6	7.92482	6	23.16485	6	38.40488	6	53.64491	6	68.88494
7	8.22962	7	23.46965	7	38.70968	7	53.94971	7	69.18974
8	8.53442	8	23.77445	8	39.01448	8	54.25451	8	69.49454
9	8.83922	9	24.07925	9	39.31928	9	54.55931	9	69.79934
30	9.14402	80	24.38405	130	39.62408	180	54.86411	230	70.10414
1	9.44882	1	24.68885	1	39.92888	1	55.16891	1	70.40894
2	9.75362	2	24.99365	2	40.23368	2	55.47371	2	70.71374
3	10.05842	3	25.29845	3	40.53848	3	55.77851	3	71.01854
4	10.36322	4	25.60325	4	40.84328	4	56.08331	4	71.32334
5	10.66802	5	25.90805	5	41.14808	5	56.38811	5	71.62814
6	10.97282	6	26.21285	6	41.45288	6	56.69291	6	71.93294
7	11.27762	7	26.51765	7	41.75768	7	56.99771	7	72.23774
8	11.58242	8	26.82245	8	42.06248	8	57.30251	8	72.54255
9	11.88722	9	27.12725	9	42.36728	9	57.60732	9	72.84735
40	12.19202	90	27.43205	140	42.67209	190	57.91212	240	73.15215
1	12.49682	1	27.73686	1	42.97689	1	58.21692	1	73.45695
2	12.80163	2	28.04166	2	43.28169	2	58.52172	2	73.76175
3	13.10643	3	28.34646	3	43.58649	3	58.82652	3	74.06655
4	13.41123	4	28.65126	4	43.89129	4	59.13132	4	74.37135
5	13.71603	5	28.95606	5	44.19609	5	59.43612	5	74.67615
6	14.02083	6	29.26086	6	44.50089	6	59.74092	6	74.98095
7	14.32563	7	29.56566	7	44.80569	7	60.04572	7	75.28575
8	14.63043	8	29.87046	8	45.11049	8	60.35052	8	75.59055
9	14.93523	9	30.17526	9	45.41529	9	60.65532	9	75.89535

Lengths—Feet to meters (from 1 to 1,000 units)—Continued

Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters
250	76.20015	300	91.44018	350	106.68021	400	121.92024	450	137.16027
1	76.50495	1	91.74498	1	106.98501	1	122.22504	1	137.46507
2	76.80975	2	92.04978	2	107.28981	2	122.52985	2	137.76988
3	77.11455	3	92.35458	3	107.59462	3	122.83465	3	138.07468
4	77.41935	4	92.65939	4	107.89942	4	123.13945	4	138.37948
5	77.72416	5	92.96419	5	108.20422	5	123.44425	5	138.68428
6	78.02896	6	93.26899	6	108.50902	6	123.74905	6	138.98908
7	78.33376	7	93.57379	7	108.81382	7	124.05385	7	139.29388
8	78.63856	8	93.87859	8	109.11862	8	124.35865	8	139.59868
9	78.94336	9	94.18339	9	109.42342	9	124.66345	9	139.90348
260	79.24816	310	94.48819	360	109.72822	410	124.96825	460	140.20828
1	79.55296	1	94.79299	1	110.03302	1	125.27305	1	140.51308
2	79.85776	2	95.09779	2	110.33782	2	125.57785	2	140.81788
3	80.16256	3	95.40259	3	110.64262	3	125.88265	3	141.12268
4	80.46736	4	95.70739	4	110.94742	4	126.18745	4	141.42748
5	80.77216	5	96.01219	5	111.25222	5	126.49225	5	141.73228
6	81.07696	6	96.31699	6	111.55702	6	126.79705	6	142.03708
7	81.38176	7	96.62179	7	111.86182	7	127.10185	7	142.34188
8	81.68656	8	96.92659	8	112.16662	8	127.40665	8	142.64669
9	81.99136	9	97.23139	9	112.47142	9	127.71146	9	142.95149
270	82.29616	320	97.53620	370	112.77623	420	128.01626	470	143.25629
1	82.60097	1	97.84100	1	113.08103	1	128.32106	1	143.56109
2	82.90577	2	98.14580	2	113.38583	2	128.62586	2	143.86589
3	83.21057	3	98.45060	3	113.69063	3	128.93066	3	144.17069
4	83.51537	4	98.75540	4	113.99543	4	129.23546	4	144.47549
5	83.82017	5	99.06020	5	114.30023	5	129.54026	5	144.78029
6	84.12497	6	99.36500	6	114.60503	6	129.84506	6	145.08509
7	84.42977	7	99.66980	7	114.90983	7	130.14986	7	145.38989
8	84.73457	8	99.97460	8	115.21463	8	130.45466	8	145.69469
9	85.03937	9	100.27940	9	115.51943	9	130.75946	9	145.99949
280	85.34417	330	100.58420	380	115.82423	430	131.06426	480	146.30429
1	85.64897	1	100.88900	1	116.12903	1	131.36906	1	146.60909
2	85.95377	2	101.19380	2	116.43383	2	131.67386	2	146.91389
3	86.25857	3	101.49860	3	116.73863	3	131.97866	3	147.21869
4	86.56337	4	101.80340	4	117.04343	4	132.28346	4	147.52350
5	86.86817	5	102.10820	5	117.34823	5	132.58827	5	147.82830
6	87.17297	6	102.41300	6	117.65304	6	132.89307	6	148.13310
7	87.47777	7	102.71781	7	117.95784	7	133.19787	7	148.43790
8	87.78258	8	103.02261	8	118.26264	8	133.50267	8	148.74270
9	88.08738	9	103.32741	9	118.56744	9	133.80747	9	149.04750
290	88.39218	340	103.63221	390	118.87224	440	134.11227	490	149.35230
1	88.69698	1	103.93701	1	119.17704	1	134.41707	1	149.65710
2	89.00178	2	104.24181	2	119.48184	2	134.72187	2	149.96190
3	89.30658	3	104.54661	3	119.78664	3	135.02667	3	150.26670
4	89.61138	4	104.85141	4	120.09144	4	135.33147	4	150.57150
5	89.91618	5	105.15621	5	120.39624	5	135.63627	5	150.87630
6	90.22098	6	105.46101	6	120.70104	6	135.94107	6	151.18110
7	90.52578	7	105.76581	7	121.00584	7	136.24587	7	151.48590
8	90.83058	8	106.07061	8	121.31064	8	136.55067	8	151.79070
9	91.13538	9	106.37541	9	121.61544	9	136.85547	9	152.09550

Lengths—Feet to meters (from 1 to 1000 units)—Continued

Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters
500	152.40030	550	167.64034	600	182.88037	650	198.12040	700	213.36043
1	152.70511	1	167.94514	1	183.18517	1	198.42520	1	213.66523
2	153.00991	2	168.24994	2	183.48997	2	198.73000	2	213.97003
3	153.31471	3	168.55474	3	183.79477	3	199.03480	3	214.27483
4	153.61951	4	168.85954	4	184.09957	4	199.33960	4	214.57963
5	153.92431	5	169.16434	5	184.40437	5	199.64440	5	214.88443
6	154.22911	6	169.46914	6	184.70917	6	199.94920	6	215.18923
7	154.53391	7	169.77394	7	185.01397	7	200.25400	7	215.49403
8	154.83871	8	170.07874	8	185.31877	8	200.55880	8	215.79883
9	155.14351	9	170.38354	9	185.62357	9	200.86360	9	216.10363
510	155.44831	560	170.68834	610	185.92837	660	201.16840	710	216.40843
1	155.75311	1	170.99314	1	186.23317	1	201.47320	1	216.71323
2	156.05791	2	171.29794	2	186.53797	2	201.77800	2	217.01803
3	156.36271	3	171.60274	3	186.84277	3	202.08280	3	217.32283
4	156.66751	4	171.90754	4	187.14757	4	202.38760	4	217.62764
5	156.97231	5	172.21234	5	187.45237	5	202.69241	5	217.93244
6	157.27711	6	172.51715	6	187.75718	6	202.99721	6	218.23724
7	157.58192	7	172.82195	7	188.06198	7	203.30201	7	218.54204
8	157.88672	8	173.12675	8	188.36678	8	203.60681	8	218.84684
9	158.19152	9	173.43155	9	188.67158	9	203.91161	9	219.15164
520	158.49632	570	173.73635	620	188.97638	670	204.21641	720	219.45644
1	158.80112	1	174.04115	1	189.28118	1	204.52121	1	219.76124
2	159.10592	2	174.34595	2	189.58598	2	204.82601	2	220.06604
3	159.41072	3	174.65075	3	189.89078	3	205.13081	3	220.37084
4	159.71552	4	174.95555	4	190.19558	4	205.43561	4	220.67564
5	160.02032	5	175.26035	5	190.50038	5	205.74041	5	220.98044
6	160.32512	6	175.56515	6	190.80518	6	206.04521	6	221.28524
7	160.62992	7	175.86995	7	191.10998	7	206.35001	7	221.59004
8	160.93472	8	176.17475	8	191.41478	8	206.65481	8	221.89484
9	161.23952	9	176.47955	9	191.71958	9	206.95961	9	222.19964
530	161.54432	580	176.78435	630	192.02438	680	207.26441	730	222.50445
1	161.84912	1	177.08915	1	192.32918	1	207.56922	1	222.80925
2	162.15392	2	177.39395	2	192.63399	2	207.87402	2	223.11405
3	162.45872	3	177.69876	3	192.93879	3	208.17882	3	223.41885
4	162.76353	4	178.00356	4	193.24359	4	208.48362	4	223.72365
5	163.06833	5	178.30836	5	193.54839	5	208.78842	5	224.02845
6	163.37313	6	178.61316	6	193.85319	6	209.09322	6	224.33325
7	163.67793	7	178.91796	7	194.15799	7	209.39802	7	224.63805
8	163.98273	8	179.22276	8	194.46279	8	209.70282	8	224.94285
9	164.28753	9	179.52756	9	194.76759	9	210.00762	9	225.24765
540	164.59233	590	179.83236	640	195.07239	690	210.31242	740	225.55245
1	164.89713	1	180.13716	1	195.37719	1	210.61722	1	225.85725
2	165.20193	2	180.44196	2	195.68199	2	210.92202	2	226.16205
3	165.50673	3	180.74676	3	195.98679	3	211.22682	3	226.46685
4	165.81153	4	181.05156	4	196.29159	4	211.53162	4	226.77165
5	166.11633	5	181.35636	5	196.59639	5	211.83642	5	227.07645
6	166.42113	6	181.66116	6	196.90119	6	212.14122	6	227.38125
7	166.72593	7	181.96596	7	197.20590	7	212.44602	7	227.68606
8	167.03073	8	182.27076	8	197.51080	8	212.75083	8	227.99086
9	167.33553	9	182.57557	9	197.81560	9	213.05563	9	228.29566

Lengths—Feet to meters (from 1 to 1,000 units)—Continued

Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters
750	228.60046	800	243.84049	850	259.08052	900	274.32055	950	289.56058
1	228.90526	1	244.14529	1	259.38532	1	274.62535	1	289.86538
2	229.21006	2	244.45009	2	259.69012	2	274.93015	2	290.17018
3	229.51486	3	244.75489	3	259.99492	3	275.23495	3	290.47498
4	229.81966	4	245.05969	4	260.29972	4	275.53975	4	290.77978
5	230.12446	5	245.36449	5	260.60452	5	275.84455	5	291.08458
6	230.42926	6	245.66929	6	260.90932	6	276.14935	6	291.38938
7	230.73406	7	245.97409	7	261.21412	7	276.45415	7	291.69418
8	231.03886	8	246.27889	8	261.51892	8	276.75895	8	291.99898
9	231.34366	9	246.58369	9	261.82372	9	277.06375	9	292.30378
760	231.64846	810	246.88849	860	262.12852	910	277.36855	960	292.60859
1	231.95326	1	247.19329	1	262.43332	1	277.67336	1	292.91339
2	232.25806	2	247.49809	2	262.73813	2	277.97816	2	293.21819
3	232.56287	3	247.80290	3	263.04293	3	278.28296	3	293.52299
4	232.86767	4	248.10770	4	263.34773	4	278.58776	4	293.82779
5	233.17247	5	248.41250	5	263.65253	5	278.89256	5	294.13259
6	233.47727	6	248.71730	6	263.95733	6	279.19736	6	294.43739
7	233.78207	7	249.02210	7	264.26213	7	279.50216	7	294.74219
8	234.08687	8	249.32690	8	264.56693	8	279.80696	8	295.04699
9	234.39167	9	249.63170	9	264.87173	9	280.11176	9	295.35179
770	234.69647	820	249.93650	870	265.17653	920	280.41656	970	295.65659
1	235.00127	1	250.24130	1	265.48133	1	280.72136	1	295.96139
2	235.30607	2	250.54610	2	265.78613	2	281.02616	2	296.26619
3	235.61087	3	250.85090	3	266.09093	3	281.33096	3	296.57099
4	235.91567	4	251.15570	4	266.39573	4	281.63576	4	296.87579
5	236.22047	5	251.46050	5	266.70053	5	281.94056	5	297.18059
6	236.52527	6	251.76530	6	267.00533	6	282.24536	6	297.48539
7	236.83007	7	252.07010	7	267.31013	7	282.55017	7	297.79020
8	237.13487	8	252.37490	8	267.61494	8	282.85497	8	298.09500
9	237.43967	9	252.67971	9	267.91974	9	283.15977	9	298.39980
780	237.74448	830	252.98451	880	268.22454	930	283.46457	980	298.70460
1	238.04928	1	253.28931	1	268.52934	1	283.76937	1	299.00940
2	238.35408	2	253.59411	2	268.83414	2	284.07417	2	299.31420
3	238.65888	3	253.89891	3	269.13894	3	284.37897	3	299.61900
4	238.96368	4	254.20371	4	269.44374	4	284.68377	4	299.92380
5	239.26848	5	254.50851	5	269.74854	5	284.98857	5	300.22860
6	239.57328	6	254.81331	6	270.05334	6	285.29337	6	300.53340
7	239.87808	7	255.11811	7	270.35814	7	285.59817	7	300.83820
8	240.18288	8	255.42291	8	270.66294	8	285.90297	8	301.14300
9	240.48768	9	255.72771	9	270.96774	9	286.20777	9	301.44780
790	240.79248	840	256.03251	890	271.27254	940	286.51257	990	301.75260
1	241.09728	1	256.33731	1	271.57734	1	286.81737	1	302.05740
2	241.40208	2	256.64211	2	271.88214	2	287.12217	2	302.36220
3	241.70688	3	256.94691	3	272.18694	3	287.42697	3	302.66701
4	242.01168	4	257.25171	4	272.49174	4	287.73178	4	302.97181
5	242.31648	5	257.55652	5	272.79655	5	288.03658	5	303.27661
6	242.62129	6	257.86132	6	273.10135	6	288.34138	6	303.58141
7	242.92609	7	258.16612	7	273.40615	7	288.64618	7	303.88621
8	243.23089	8	258.47092	8	273.71095	8	288.95098	8	304.19101
9	243.53569	9	258.77572	9	274.01575	9	289.25578	9	304.49581

Lengths—Meters to feet (from 1 to 1,000 units)

[Reduction factor: 1 meter=3.280833333 feet]

Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
0		50	164.04167	100	328.08333	150	492.12500	200	656.16667
1	3.28083	1	167.32250	1	331.36417	1	495.40583	1	659.44750
2	6.56167	2	170.60333	2	334.64500	2	498.68667	2	662.72833
3	9.84250	3	173.88417	3	337.92583	3	501.96750	3	666.00917
4	13.12333	4	177.16500	4	341.20667	4	505.24833	4	669.29000
5	16.40417	5	180.44583	5	344.48750	5	508.52917	5	672.57083
6	19.68500	6	183.72667	6	347.76833	6	511.81000	6	675.85167
7	22.96583	7	187.00750	7	351.04917	7	515.09083	7	679.13250
8	26.24667	8	190.28833	8	354.33000	8	518.37167	8	682.41333
9	29.52750	9	193.56917	9	357.61083	9	521.65250	9	685.69417
10	32.80833	60	196.85000	110	360.89167	160	524.93333	210	688.97500
1	36.08917	1	200.13083	1	364.17250	1	528.21417	1	692.25583
2	39.37000	2	203.41167	2	367.45333	2	531.49500	2	695.53667
3	42.65083	3	206.69250	3	370.73417	3	534.77583	3	698.81750
4	45.93167	4	209.97333	4	374.01500	4	538.05667	4	702.09833
5	49.21250	5	213.25417	5	377.29583	5	541.33750	5	705.37917
6	52.49333	6	216.53500	6	380.57667	6	544.61833	6	708.66000
7	55.77417	7	219.81583	7	383.85750	7	547.89917	7	711.94083
8	59.05500	8	223.09667	8	387.13833	8	551.18000	8	715.22167
9	62.33583	9	226.37750	9	390.41917	9	554.46083	9	718.50250
20	65.61667	70	229.65833	120	393.70000	170	557.74167	220	721.78333
1	68.89750	1	232.93917	1	396.98083	1	561.02250	1	725.06417
2	72.17833	2	236.22000	2	400.26167	2	564.30333	2	728.34500
3	75.45917	3	239.50083	3	403.54250	3	567.58417	3	731.62583
4	78.74000	4	242.78167	4	406.82333	4	570.86500	4	734.90667
5	82.02083	5	246.06250	5	410.10417	5	574.14583	5	738.18750
6	85.30167	6	249.34333	6	413.38500	6	577.42667	6	741.46833
7	88.58250	7	252.62417	7	416.66583	7	580.70750	7	744.74917
8	91.86333	8	255.90500	8	419.94667	8	583.98833	8	748.03000
9	95.14417	9	259.18583	9	423.22750	9	587.26917	9	751.31083
30	98.42500	80	262.46667	130	426.50833	180	590.55000	230	754.59167
1	101.70583	1	265.74750	1	429.78917	1	593.83083	1	757.87250
2	104.98667	2	269.02833	2	433.07000	2	597.11167	2	761.15333
3	108.26750	3	272.30917	3	436.35083	3	600.39250	3	764.43417
4	111.54833	4	275.59000	4	439.63167	4	603.67333	4	767.71500
5	114.82917	5	278.87083	5	442.91250	5	606.95417	5	770.99583
6	118.11000	6	282.15167	6	446.19333	6	610.23500	6	774.27667
7	121.39083	7	285.43250	7	449.47417	7	613.51583	7	777.55750
8	124.67167	8	288.71333	8	452.75500	8	616.79667	8	780.83833
9	127.95250	9	291.99417	9	456.03583	9	620.07750	9	784.11917
40	131.23333	90	295.27500	140	459.31667	190	623.35833	240	787.40000
1	134.51417	1	298.55583	1	462.59750	1	626.63917	1	790.68083
2	137.79500	2	301.83667	2	465.87833	2	629.92000	2	793.96167
3	141.07583	3	305.11750	3	469.15917	3	633.20083	3	797.24250
4	144.35667	4	308.39833	4	472.44000	4	636.48167	4	800.52333
5	147.63750	5	311.67917	5	475.72083	5	639.76250	5	803.80417
6	150.91833	6	314.96000	6	479.00167	6	643.04333	6	807.08500
7	154.19917	7	318.24083	7	482.28250	7	646.32417	7	810.36583
8	157.48000	8	321.52167	8	485.56333	8	649.60500	8	813.64667
9	160.76083	9	324.80250	9	488.84417	9	652.88583	9	816.92750

Lengths—Meters to feet (from 1 to 1,000 units)—Continued

Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
250	820.20833	300	984.25000	350	1,148.29167	400	1,312.33333	450	1,476.37500
1	823.48917	1	987.53083	1	1,151.57250	1	1,315.61417	1	1,479.65583
2	826.77000	2	990.81167	2	1,154.85333	2	1,318.89500	2	1,482.93667
3	830.05083	3	994.09250	3	1,158,13417	3	1,322.17583	3	1,486.21750
4	833.33167	4	997.37333	4	1,161,41500	4	1,325.45667	4	1,489.49833
5	836.61250	5	1,000.65417	5	1,164.69583	5	1,328.73750	5	1,492.77917
6	839.89333	6	1,003.93500	6	1,167.97667	6	1,332.01833	6	1,496.06000
7	843.17417	7	1,007.21583	7	1,171.25750	7	1,335.29917	7	1,499.34083
8	846.45500	8	1,010.49667	8	1,174.53833	8	1,338.58000	8	1,502.62167
9	849.73583	9	1,013.77750	9	1,177.81917	9	1,341.86083	9	1,505.90250
260	853.01667	310	1,017.05833	360	1,181.10000	410	1,345.14167	460	1,509.18333
1	856.29750	1	1,020.33917	1	1,184.38083	1	1,348.42250	1	1,512.46417
2	859.57833	2	1,023.62000	2	1,187.66167	2	1,351.70333	2	1,515.74500
3	862.85917	3	1,026.90083	3	1,190.94250	3	1,354.98417	3	1,519.02583
4	866.14000	4	1,030.18167	4	1,194.22333	4	1,358.26500	4	1,522.30667
5	869.42083	5	1,033.46250	5	1,197.50417	5	1,361.54583	5	1,525.58750
6	872.70167	6	1,036.74333	6	1,200.78500	6	1,364.82667	6	1,528.86833
7	875.98250	7	1,040.02417	7	1,204.06583	7	1,368.10750	7	1,532.14917
8	879.26333	8	1,043.30500	8	1,207.34667	8	1,371.38833	8	1,535.43000
9	882.54417	9	1,046.58583	9	1,210.62750	9	1,374.66917	9	1,538.71083
270	885.82500	320	1,049.86667	370	1,213.90833	420	1,377.95000	470	1,541.99167
1	889.10583	1	1,053.14750	1	1,217.18917	1	1,381.23083	1	1,545.27250
2	892.38667	2	1,056.42833	2	1,220.47000	2	1,384.51167	2	1,548.55333
3	895.66750	3	1,059.70917	3	1,223.75083	3	1,387.79250	3	1,551.83417
4	898.94833	4	1,062.99000	4	1,227.03167	4	1,391.07333	4	1,555.11500
5	902.22917	5	1,066.27083	5	1,230.31250	5	1,394.35417	5	1,558.39583
6	905.51000	6	1,069.55167	6	1,233.59333	6	1,397.63500	6	1,561.67667
7	908.79083	7	1,072.83250	7	1,236.87417	7	1,400.91583	7	1,564.95750
8	912.07167	8	1,076.11333	8	1,240.15500	8	1,404.19667	8	1,568.23833
9	915.35250	9	1,079.39417	9	1,243.43583	9	1,407.47750	9	1,571.51917
280	918.63333	330	1,082.67500	380	1,246.71667	430	1,410.75833	480	1,574.80000
1	921.91417	1	1,085.95583	1	1,249.99750	1	1,414.03917	1	1,578.08083
2	925.19500	2	1,089.23667	2	1,253.27833	2	1,417.32000	2	1,581.36167
3	928.47583	3	1,092.51750	3	1,256.55917	3	1,420.60083	3	1,584.64250
4	931.75667	4	1,095.79833	4	1,259.84000	4	1,423.88167	4	1,587.92333
5	935.03750	5	1,099.07917	5	1,263.12083	5	1,427.16250	5	1,591.20417
6	938.31833	6	1,102.36000	6	1,266.40167	6	1,430.44333	6	1,594.48500
7	941.59917	7	1,105.64083	7	1,269.68250	7	1,433.72417	7	1,597.76583
8	944.88000	8	1,108.92167	8	1,272.96333	8	1,437.00500	8	1,601.04667
9	948.16083	9	1,112.20250	9	1,276.24417	9	1,440.28583	9	1,604.32750
290	951.44167	340	1,115.48333	390	1,279.52500	440	1,443.56667	490	1,607.60833
1	954.72250	1	1,118.76417	1	1,282.80583	1	1,446.84750	1	1,610.88917
2	958.00333	2	1,122.04500	2	1,286.08667	2	1,450.12833	2	1,614.17000
3	961.28417	3	1,125.32583	3	1,289.36750	3	1,453.40917	3	1,617.45083
4	964.56500	4	1,128.60667	4	1,292.64833	4	1,456.69000	4	1,620.73167
5	967.84583	5	1,131.88750	5	1,295.92917	5	1,459.97083	5	1,624.01250
6	971.12667	6	1,135.16833	6	1,299.21000	6	1,463.25167	6	1,627.29333
7	974.40750	7	1,138.44917	7	1,302.49083	7	1,466.53250	7	1,630.57417
8	977.68833	8	1,141.73000	8	1,305.77167	8	1,469.81333	8	1,633.85500
9	980.96917	9	1,145.01083	9	1,309.05250	9	1,473.09417	9	1,637.13583

Lengths—Meters to feet (from 1 to 1,000 units)—Continued

Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
500	1,640.41667	550	1,804.45833	600	1,968.50000	650	2,132.54167	700	2,296.58333
1	1,643.69750	1	1,807.73917	1	1,971.78083	1	2,135.82250	1	2,299.86417
2	1,646.97833	2	1,811.02000	2	1,975.06167	2	2,139.10333	2	2,303.14500
3	1,650.25917	3	1,814.30083	3	1,978.34250	3	2,142.38417	3	2,306.42583
4	1,653.54000	4	1,817.58167	4	1,981.62333	4	2,145.66500	4	2,309.70667
5	1,656.82083	5	1,820.86250	5	1,984.90417	5	2,148.94583	5	2,312.98750
6	1,660.10167	6	1,824.14333	6	1,988.18500	6	2,152.22667	6	2,316.26833
7	1,663.38250	7	1,827.42417	7	1,991.46583	7	2,155.50750	7	2,319.54917
8	1,666.66333	8	1,830.70500	8	1,994.74667	8	2,158.78833	8	2,322.83000
9	1,669.94417	9	1,833.98583	9	1,998.02750	9	2,162.06917	9	2,326.11083
510	1,673.22500	560	1,837.26667	610	2,001.30833	660	2,165.35000	710	2,329.39167
1	1,676.50583	1	1,840.54750	1	2,004.58917	1	2,168.63083	1	2,332.67250
2	1,679.78667	2	1,843.82833	2	2,007.87000	2	2,171.91167	2	2,335.95333
3	1,683.06750	3	1,847.10917	3	2,011.15083	3	2,175.19250	3	2,339.23417
4	1,686.34833	4	1,850.39000	4	2,014.43167	4	2,178.47333	4	2,342.51500
5	1,689.62917	5	1,853.67083	5	2,017.71250	5	2,181.75417	5	2,345.79583
6	1,692.91000	6	1,856.95167	6	2,020.99333	6	2,185.03500	6	2,349.07667
7	1,696.19083	7	1,860.23250	7	2,024.27417	7	2,188.31583	7	2,352.35750
8	1,699.47167	8	1,863.51333	8	2,027.55500	8	2,191.59667	8	2,355.63833
9	1,702.75250	9	1,866.79417	9	2,030.83583	9	2,194.87750	9	2,358.91917
520	1,706.03333	570	1,870.07500	620	2,034.11667	670	2,198.15833	720	2,362.20000
1	1,709.31417	1	1,873.35583	1	2,037.39750	1	2,201.43917	1	2,365.48083
2	1,712.59500	2	1,876.63667	2	2,040.67833	2	2,204.72000	2	2,368.76167
3	1,715.87583	3	1,879.91750	3	2,043.95917	3	2,208.00083	3	2,372.04250
4	1,719.15667	4	1,883.19833	4	2,047.24000	4	2,211.28167	4	2,375.32333
5	1,722.43750	5	1,886.47917	5	2,050.52083	5	2,214.56250	5	2,378.60417
6	1,725.71833	6	1,889.76000	6	2,053.80167	6	2,217.84333	6	2,381.88500
7	1,728.99917	7	1,893.04083	7	2,057.08250	7	2,221.12417	7	2,385.16583
8	1,732.28000	8	1,896.32167	8	2,060.36333	8	2,224.40500	8	2,388.44667
9	1,735.56083	9	1,899.60250	9	2,063.64417	9	2,227.68583	9	2,391.72750
530	1,738.84167	580	1,902.88333	630	2,066.92500	680	2,230.96667	730	2,395.00833
1	1,742.12250	1	1,906.16417	1	2,070.20583	1	2,234.24750	1	2,398.28917
2	1,745.40333	2	1,909.44500	2	2,073.48667	2	2,237.52833	2	2,401.57000
3	1,748.68417	3	1,912.72583	3	2,076.76750	3	2,240.80917	3	2,404.85083
4	1,751.96500	4	1,916.00667	4	2,080.04833	4	2,244.09000	4	2,408.13167
5	1,755.24583	5	1,919.28750	5	2,083.32917	5	2,247.37083	5	2,411.41250
6	1,758.52667	6	1,922.56833	6	2,086.61000	6	2,250.65167	6	2,414.69333
7	1,761.80750	7	1,925.84917	7	2,089.89083	7	2,253.93250	7	2,417.97417
8	1,765.08833	8	1,929.13000	8	2,093.17167	8	2,257.21333	8	2,421.25500
9	1,768.36917	9	1,932.41083	9	2,096.45250	9	2,260.49417	9	2,424.53583
540	1,771.65000	590	1,935.69167	640	2,099.73333	690	2,263.77500	740	2,427.81667
1	1,174.93083	1	1,938.97250	1	2,103.01417	1	2,267.05583	1	2,431.09750
2	1,778.21167	2	1,942.25333	2	2,106.29500	2	2,270.33667	2	2,434.37833
3	1,781.49250	3	1,945.53417	3	2,109.57583	3	2,273.61750	3	2,437.65917
4	1,784.77333	4	1,948.81500	4	2,112.85667	4	2,276.89833	4	2,440.94000
5	1,788.05417	5	1,952.09583	5	2,116.13750	5	2,280.17917	5	2,444.22083
6	1,791.33500	6	1,955.37667	6	2,119.41833	6	2,283.46000	6	2,447.50167
7	1,794.61583	7	1,958.65750	7	2,122.69917	7	2,286.74083	7	2,450.78250
8	1,797.89667	8	1,961.93833	8	2,125.98000	8	2,290.02167	8	2,454.06333
9	1,801.17750	9	1,965.21917	9	2,129.26083	9	2,293.30250	9	2,457.34417

Lengths—Meters to feet (from 1 to 1,000 units)—Continued

Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
750	2,460.62500	800	2,624.66667	850	2,788.70833	900	2,952.75000	950	3,116.79167
1	2,463.90583	1	2,627.94750	1	2,791.98917	1	2,956.03083	1	3,120.07250
2	2,467.18667	2	2,631.22833	2	2,795.27000	2	2,959.31167	2	3,123.35333
3	2,470.46750	3	2,634.50917	3	2,798.55083	3	2,962.59250	3	3,126.63417
4	2,473.74833	4	2,637.79000	4	2,801.83167	4	2,965.87333	4	3,129.91500
5	2,477.02917	5	2,641.07083	5	2,805.11250	5	2,969.15417	5	3,133.19583
6	2,480.31000	6	2,644.35167	6	2,808.39333	6	2,972.43500	6	3,136.47667
7	2,483.59083	7	2,647.63250	7	2,811.67417	7	2,975.71583	7	3,139.75750
8	2,486.87167	8	2,650.91333	8	2,814.95500	8	2,978.99667	8	3,143.03833
9	2,490.15250	9	2,654.19417	9	2,818.23583	9	2,982.27750	9	3,146.31917
760	2,493.43333	810	2,657.47500	860	2,821.51667	910	2,985.55833	960	3,149.60000
1	2,496.71417	1	2,660.75583	1	2,824.79750	1	2,988.83917	1	3,152.88083
2	2,499.99500	2	2,664.03667	2	2,828.07833	2	2,992.12000	2	3,156.16167
3	2,503.27583	3	2,667.31750	3	2,831.35917	3	2,995.40083	3	3,159.44250
4	2,506.55667	4	2,670.59833	4	2,834.64000	4	2,998.68167	4	3,162.72333
5	2,509.83750	5	2,673.87917	5	2,837.92083	5	3,001.96250	5	3,166.00417
6	2,513.11833	6	2,677.16000	6	2,841.20167	6	3,005.24333	6	3,169.28500
7	2,516.39917	7	2,680.44083	7	2,844.48250	7	3,008.52417	7	3,172.56583
8	2,519.68000	8	2,683.72167	8	2,847.76333	8	3,011.80500	8	3,175.84667
9	2,522.96083	9	2,687.00250	9	2,851.04417	9	3,015.08583	9	3,179.12750
770	2,526.24167	820	2,690.28333	870	2,854.32500	920	3,018.36667	970	3,182.40833
1	2,529.52250	1	2,693.56417	1	2,857.60583	1	3,021.64750	1	3,185.68917
2	2,532.80333	2	2,696.84500	2	2,860.88667	2	3,024.92833	2	3,188.97000
3	2,536.08417	3	2,700.12583	3	2,864.16750	3	3,028.20917	3	3,192.25083
4	2,539.36500	4	2,703.40667	4	2,867.44833	4	3,031.49000	4	3,195.53167
5	2,542.64583	5	2,706.68750	5	2,870.72917	5	3,034.77083	5	3,198.81250
6	2,545.92667	6	2,709.96833	6	2,874.01000	6	3,038.05167	6	3,202.09333
7	2,549.20750	7	2,713.24917	7	2,877.29083	7	3,041.33250	7	3,205.37417
8	2,552.48833	8	2,716.53000	8	2,880.57167	8	3,044.61333	8	3,208.65500
9	2,555.76917	9	2,719.81083	9	2,883.85250	9	3,047.89417	9	3,211.93583
780	2,559.05000	830	2,723.09167	880	2,887.13333	930	3,051.17500	980	3,215.21667
1	2,562.33083	1	2,726.37250	1	2,890.41417	1	3,054.45583	1	3,218.49750
2	2,565.61167	2	2,729.65333	2	2,893.69500	2	3,057.73667	2	3,221.77833
3	2,568.89250	3	2,732.93417	3	2,896.97583	3	3,061.01750	3	3,225.05917
4	2,572.17333	4	2,736.21500	4	2,900.25667	4	3,064.29833	4	3,228.34000
5	2,575.45417	5	2,739.49583	5	2,903.53750	5	3,067.57917	5	3,231.62083
6	2,578.73500	6	2,742.77667	6	2,906.81833	6	3,070.86000	6	3,234.90167
7	2,582.01583	7	2,746.05750	7	2,910.09917	7	3,074.14083	7	3,238.18250
8	2,585.29667	8	2,749.33833	8	2,913.38000	8	3,077.42167	8	3,241.46333
9	2,588.57750	9	2,752.61917	9	2,916.66083	9	3,080.70250	9	3,244.74417
790	2,591.85833	840	2,755.90000	890	2,919.94167	940	3,083.98333	990	3,248.02500
1	2,595.13917	1	2,759.18083	1	2,923.22250	1	3,087.26417	1	3,251.30583
2	2,598.42000	2	2,762.46167	2	2,926.50333	2	3,090.54500	2	3,254.58667
3	2,601.70083	3	2,765.74250	3	2,929.78417	3	3,093.82583	3	3,257.86750
4	2,604.98167	4	2,769.02333	4	2,933.06500	4	3,097.10667	4	3,261.14833
5	2,608.26250	5	2,772.30417	5	2,936.34583	5	3,100.38750	5	3,264.42917
6	2,611.54333	6	2,775.58500	6	2,939.62667	6	3,103.68833	6	3,267.71000
7	2,614.82417	7	2,778.86583	7	2,942.90750	7	3,106.94917	7	3,270.99083
8	2,618.10500	8	2,782.14667	8	2,946.18833	8	3,110.23000	8	3,274.27167
9	2,621.38583	9	2,785.42750	9	2,949.46917	9	3,113.51083	9	3,277.55250

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