TOPOGRAPHIC INSTRUCTIONS

of the

UNITED STATES

GEOLOGICAL SURVEY

Leveling

BOOK 2
CHAPTERS 2E1–2E5
1966

U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849

TOPOGRAPHIC INSTRUCTIONS

of the

UNITED STATES

GEOLOGICAL SURVEY

Leveling

Instructions for field operations and office computations

in second- and third-order leveling

BOOK 2—CONTROL SURVEYS

Part 2E—Leveling

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1966

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 50 cents

PREFACE

The Geological Survey Topographic Instructions describe the engineering standards, methods, and procedures used by the Topographic Division in the production of topographic quadrangle maps. Although the instructions are prepared primarily for the guidance of Survey employees, private individuals and organizations engaged in similar work find them a useful reference; therefore they are being published in a series of volumes. The preceding Topographic Instructions were published as Geological Survey Bulletin 788, in 1928. Since then, many supplements have been issued in the form of technical memorandums, and a considerable part of the present manual has been prepared in looseleaf form for use within the Topographic Division. Where applicable, all preceding instructions are incorporated into the present manual.

The Topographic Instructions are divided into five numbered books; each book contains one or more parts, designated by letters; and the parts are divided, in turn, into numbered chapters. In preparing the manual for publication the chapters have been grouped into volumes, in the established sequence, so that each volume covers a single subject or phase of activity, as nearly as possible. The series of volumes describes all the steps of map production, generally in the order in which they are carried out. The complete series will constitute a comprehensive manual of topographic surveying and mapping.

The volumes published and scheduled for publication are listed below, with the title, a short note on the contents, and the chapter or chapters included in each volume. For published volumes, this information is printed in boldface type, and the date of publication or revision is given. These volumes are for sale by the Superintendent of Documents, Government Printing Office, Washington, D.C., 20402.

The other listed volumes are being prepared but were not available for sale on the date this volume was published. When they are published, they will be announced in the monthly list "New Publications of the Geological Survey" (available free on request) and listed in "Price List 53" of the Superintendent of Documents.

LIST OF VOLUMES OF TOPOGRAPHIC INSTRUCTIONS

[Boldface type indicates published volumes]

BOOK 1. GENERAL POLICIES

THE NATIONAL TOPOGRAPHIC MAP SERIES

General specifications for publication scales, contour intervals, accuracy, and the portrayal of map features; a summary of mapping procedures. Chapters 1A1–1A5.

BOOK 2. CONTROL SURVEYS

TRIANGULATION FIELDWORK

Instructions for field operations in third-order triangulation surveys for topographic mapping. Chapters 2A1–2A7.

TRIANGULATION COMPUTATIONS

Instructions for computing third-order triangulation, including adjustment by variation of coordinates. Chapters 2B1–2B8.

TRANSIT TRAVERSE FIELDWORK

Instructions for field operations in second- and third-order transit traverse surveys for topographic mapping. Chapters 2C1–2C8.

TRANSIT TRAVERSE COMPUTATIONS

Instructions for computing second- and third-order transit traverse surveys, including the determination of geographic positions and State grid coordinates. Chapters 2D1–2D7.

LEVELING, 1966

Instructions for field operations and office computations in second- and third-order leveling. Chapters 2E1–2E5.

CONTROL SURVEYS WITH ELECTRONIC INSTRUMENTS

Instructions for field operations and office computations for electronic surveying instruments. Chapters 2F1–2F2.

SUPPLEMENTAL CONTROL SURVEYS

Instructions for planning supplemental control, photoidentifying control points, and establishing elevations by stadia traverse and vertical angle measurements. Chapters 2G1–2G3.

SUPPLEMENTAL CONTROL BY PHOTOGRAMMETRIC METHODS

Instructions for establishing photocontrol elevations by means of the phototheodolite and photoalidade. Chapters 2G4–2G5.

SUPPLEMENTAL CONTROL BY ALTIMETRY

Instructions for field and office procedures for determining photocontrol elevations by surveying altimeters. Chapter 2G6.

SUPPLEMENTAL CONTROL BY ELEVATION METER

Instructions for determining photocontrol elevations by means of an electromechanical meter, mounted in a carryall. Chapter 2G7.

PROCESSING CONTROL-SURVEY DATA

Instructions for adjusting control-survey data, interconverting geographic and plane coordinates, and tabulating results and filing records of control surveys. Chapters 2H1–2H4.

BOOK 3. MAPPING PROCEDURES

STANDARDS FOR THE TREATMENT OF MAP FEATURES

Instructions for selecting, classifying, and symbolizing the principal features shown on topographic maps. Chapters 3A1–3A9.

AERIAL PHOTOGRAPHY FOR MAPPING

Standards for mapping photography and photogrammetric aerial cameras; instructions for planning aerial photography and procuring aerial photographs. Chapters 3B1–3B4.

PHOTOGRAMMETRIC PHOTOLABORATORY OPERATIONS

Instructions for preparing diapositives for photogrammetric plotters and for preparing photomosaics for mapping bases. Chapters 3C1–3C2.

PHOTOGRAMMETRIC RECTIFICATION, 1961

Instructions for preparing equivalent vertical prints from tilted aerial negatives; a discussion of the theory of rectification. Chapter 3C3.

BASE SHEETS FOR STEREOCOMPILATION

Instructions for preparing base sheets for topographic map compilation; a discussion of map projections and State grid systems. Chapters 3D1–3D2.

AEROTRIANGULATION WITH TEMPLETS

Instructions for extending horizontal control by radial triangulation with vertical and trimetrogon photographs and instructions for stereotemplet triangulation with vertical and oblique photographs. Chapters 3E1–3E3.

TRAINING MANUAL IN PHOTOGRAMMETRY

Instructions in the elements of photogrammetry as applied to topographic mapping. Chapter 3F1.

STEREOPHOTOGRAMMETRIC COMPILATION

Instructions for compiling map manuscripts from stereoscopic models; use of pantograph attachment on stereoplotters. Chapters 3F2–3F3.

MULTIPLEX PLOTTER PROCEDURES, 1960

Instructions in the standard operating procedures for the multiplex plotter, including a description of equipment. Chapter 3F4.

KELSH PLOTTER PROCEDURES, 1960

Instructions in the standard operating procedures for the Kelsh plotter, including a description of equipment. Chapter 3F5.

ER–55 PLOTTER PROCEDURES, 1961

Instructions in the standard operating procedures for the ER–55 plotter, including a description of equipment. Chapter 3F6.

UNIVERSAL PLOTTER PROCEDURES

Instructions in the standard operating procedures for Zeiss Stereoplanigraph and Wild Autograph plotters, including a description of equipment. Chapter 3F7.

TWINPLEX PLOTTER PROCEDURES

Instructions in the standard operating procedures for the Twinplex plotter, including a description of equipment. Chapter 3F8.

PLANIMETRIC MAP COMPILATION WITH TRIMETROGON PHOTOGRAPHS, 1960

Instructions for preparing small-scale maps and charts from trimetrogon aerial photographs. Part 3G. Chapter 3G1.

ORTHOPHOTOSCOPE PROCEDURES

Instructions for converting perspective photographs to equivalent orthographic photographs by means of the Orthophotoscope, including a description of the instrument. Chapter 3G2.

ANALYTICAL AEROTRIANGULATION
Instructions for extending horizontal and vertical control by mathematical analysis of data derived from aerial photographs. Chapter 3G3.

PLANETABLE OPERATION
Instructions in the basic techniques of planetable surveys, including the adjustment and maintenance of equipment. Chapter 3H1.

FIELD MAPPING AND COMPLETION SURVEYS
Instructions for planetable surveys to contour, complete, or correct stereocompiled maps, including surveys to contour controlled photomosaics. Chapters 3H2–3H4.

ACCURACY-TESTING SURVEYS
Instructions for planning and executing surveys for testing the accuracy of topographic maps. Chapter 3H5.

MAP REVISION
Instructions for field and office operations to revise topographic maps that have become obsolete, including procedures for appraising the quality of topographic maps. Chapter 3H6.

BOOK 4. CARTOGRAPHIC PROCEDURES

TOPOGRAPHIC MAP SYMBOLS
Symbols for compilation manuscripts and published maps in the United States 7½-minutes and 15-minute series. Chapter 4A1.

TOPOGRAPHIC MAP LETTERING
Instructions for selecting and placing map lettering, using abbreviations and word compounds, and composing and arranging map marginal data. Chapters 4A2–4A4.

COLOR-SEPARATION SCRIBING, 1961
Instructions for preparing topographic map manuscripts for multicolor printing by scribing on coated plastic sheets. Chapters 4B1–4B3.

MAP EDITING AND CHECKING
Instructions for reviewing final drawings to assure that map information is accurate and complete and conforms to established standards. Chapters 4C1–4C3.

SPECIAL MAPS AND CARTOGRAPHIC PROCESSES
Instructions for preparing small-scale special maps, metropolitan area maps, and shaded relief maps and for other specialized cartographic operations. Chapters 4D1–4D5.

BOOK 5. TABLES AND REFERENCE INFORMATION

TABLES FOR COMPUTING GEOGRAPHIC POSITIONS
Tables of natural and logarithmic factors for computing geographic positions from triangulation and traverse surveys. Chapters 5A1–5A3.

CARTOGRAPHIC TABLES, 1964
Tables of quadrangle areas; instructions and tables for making and checking polyconic projections at selected scales. Chapters 5B1–5B2.

THE PUBLIC-LAND SURVEY SYSTEM
The system of rectangular cadastral surveys used in subdividing the public lands of the United States, including a review of the history of the system. Chapter 5C1.

DEFINITIONS OF TOPOGRAPHIC SURVEYING AND MAPPING TERMS
A dictionary of technical terms used in topographic mapping and a glossary of names for topographic forms. Chapters 5C2–5C3.

CONTENTS

ILLUSTRATIONS

CHAPTERS 2E1–2E5

LEVELING

ABSTRACT

Geodetic leveling by the U.S. Geological Survey provides a framework of accurate elevations for topographic mapping. Elevations are referred to the Sea Level Datum of 1929. Lines of leveling may be run either with automatic or with precise spirit levels, by either the center-wire or the three-wire method. For future use, the surveys are monumented with bench marks, using standard metal tablets or other marking devices. The elevations are adjusted by least squares or other suitable method and are published in lists of control.

CHAPTER 2E1. STANDARDS AND PLANNING FOR LEVELING

LEVELING STANDARDS

1. Objectives of leveling

The primary objective of geodetic leveling by the U.S. Geological Survey is to establish accurate elevations for control of topographic mapping. The basic framework of elevations determined by geodetic leveling is then expanded by supplemental-control surveys to provide the many photocontrol and spot elevations needed in detailed mapping operations.

In addition to its immediate usefulness in mapping, Survey leveling contributes toward the completion of the national network of basic control. Elevations of first-, second-, and third-order accuracy (see art. 3) are particularly useful to other engineers and surveyors because practically all surveying and civil-engineering operations require the use of accurate elevations. Most of the first- and second-order leveling in the United States is executed by the Coast and Geodetic Survey. The Geological Survey supplements the basic network with third-order leveling, and with second-order leveling where necessary to support the new third-order work.

2. Sea Level Datum of 1929

In the United States, geodetic elevations are referred to the datum of mean sea level, which is the level of the sea with all tidal variations averaged out. Mean sea level is determined by averaging the hourly heights of the sea over a long period of time, usually 19 years, to eliminate cyclic variations.

In 1878 the Coast and Geodetic Survey began work on the first transcontinental line of precise levels, to provide vertical control for the transcontinental arc of triangulation along the 39th parallel. As this line started from the tidal station at Sandy Hook, N.J., elevations determined by the line and other lines connected to it were for many years described as being on the "Sandy Hook Datum."

By 1899 the leveling net was extensive enough to warrant a general adjustment. Further expansion led to the readjustments of 1903, 1907, and 1912. The 1907 adjustment included the first tie to sea level on the Pacific coast, at Seattle, Wash., and the 1912 adjustment added a second Pacific-coast tie, at San Diego, Calif.

The Special Adjustment of 1927 was a theoretical investigation which apparently indicated that mean sea level slopes upward to the north along the Atlantic and Pacific coasts and to the west along the Gulf coast, and that mean sea level is appreciably higher on the Pacific coast than on the Atlantic coast. These indications were confirmed and extended by the Special Adjustment of 1929.

797-176 O—66——2

The subsequent General Adjustment of 1929 included 40,000 miles of first-order leveling and 21 tidal stations in the United States and 20,000 miles of leveling and 5 tidal stations in Canada. Since then, limited supplementary adjustments have been needed to remove the effects of earth movement, caused by earthquakes or subsidence, or occasional errors discovered in the older lines as new leveling was added. On the whole, however, the General Adjustment of 1929 has proved strong enough to accommodate subsequent leveling without excessive corrections to new work. Consequently, in 1937 the Coast and Geodetic Survey officially adopted the designation "Sea Level Datum of 1929" to describe the datum established by the 1929 General Adjustment.

3. Orders of leveling

Leveling is classified in four orders of decreasing accuracy, according to the limits specified for line and circuit closures and for the agreement between forward and backward runs, and also generally according to the methods and instruments used. The standards for leveling currently in effect were issued by the Bureau of the Budget in Exhibit C of Circular A–16, dated October 10, 1958.

a. First-order leveling.—Lines of first-order leveling are run in sections 0.5 to 1 mile long, with a forward and backward run over each section to agree within 0.017 ft $\sqrt{M}$ or 4 mm $\sqrt{K}$, where M is the length of the section in miles and K is the length in kilometers. The same limits apply to line and circuit closures. Monumented bench marks are established at intervals not to exceed 1 mile. The maximum spacing between first-order lines and cross lines is specified as 60 miles.

b. Second-order leveling.—This order of leveling is divided into two classes. Class I lines are double run in sections 0.5 to 1 mile long, with agreement between forward and backward runs within 0.035 ft $\sqrt{M}$ or 8.4 mm $\sqrt{K}$. The same limits apply to line and circuit closures. Spacing between lines and cross lines is limited to 25–35 miles. Monumented bench marks are established at intervals not to exceed 1 mile.

Class II second-order leveling is area leveling, with lines and cross lines spaced at intervals of approximately 6 miles. Lines may be single run if first-order equipment and methods are used. Closure limits and monumentation are the same as specified for Class I.

c. Third-order leveling.—This order of leveling is used to subdivide areas surrounded by lines of first- or second-order leveling. Third-order lines usually are single run, in loops or networks, with line and circuit closures not to exceed 0.05 ft $\sqrt{M}$ or 12 mm $\sqrt{K}$. Monumented bench marks are established at intervals not to exceed 3 miles.

The 25–35 mile limit on the spacing of second-order lines imposes a like limit on the length of third-order lines, and the Geological Survey prefers to limit the length of third-order lines to 30 miles. This limit, it should be noted, applies to the total length of the route followed, not to the airline distance from the midpoint to the nearest higher order leveling.

d. Fourth-order leveling.—Only the first three orders of leveling, with established standards, are considered geodetic leveling. Any leveling run with less précise methods or equipment, with closures larger than those allowable in third-order work, may be classified as fourth-order leveling. Trigonometric leveling and fly levels are examples of this type of leveling, which is used by the Survey mainly to provide supplemental control for photogrammetric mapping.

Except as noted below, no monumented bench marks are to be established in fourth-order leveling, and fourth-order elevations are not to be published in such a way that they might be confused with the results of geodetic leveling. In mountainous terrain difficult of access for geodetic leveling, standard tablets may be used to mark stations for which elevations are determined by trigonometric leveling, provided that the geographic positions for these stations are of third-order accuracy or better. The marks may be described and stamped as vertical-angle bench marks (VABM), and the elevations published in lists of triangulation or electronic-distance traverse.

PLANNING LINES OF LEVELING

4. Requirements for planning

As the Coast and Geodetic Survey is the agency primarily responsible for planning and executing first- and second-order control in the

United States, other Federal agencies, including the Geological Survey, cooperate with C&GS by preparing annual statements of foreseeable needs for geodetic leveling in the immediately succeeding fiscal years. These statements are submitted to C&GS, through the Bureau of the Budget; they consist mainly of index maps showing areas in which agency operations will need the support of geodetic leveling and the years in which the operations are planned or scheduled.

The Geological Survey does not need to plan and execute first-order leveling. Unexpected changes in priorities and schedules may, however, make it impossible for C&GS to carry out second-order leveling in time to meet Survey needs. In these circumstances the Survey must plan and extend enough second-order leveling to support the regular third-order work according to the standards established by the Bureau of the Budget (art. 3).

a. Planning for second-order leveling.—Where the distance between established first- or second-order leveling exceeds 30 miles, new second-order leveling must be considered by the planning unit. These additional lines, meeting the requirements outlined in article 3*b*, should complete the framework from which the third-order lines, located generally around the perimeters of 7½-minute quadrangles, can be extended.

The planning unit must consider the entire area bounded by available first- and second-order leveling, even though much of the area may lie outside the boundaries of current mapping projects. If the existing higher order lines are more than 50 miles apart, a master plan should be prepared, outlining the routes of second-order leveling needed to support the third-order circuits to follow eventually. The practice of expanding third-order circuits into extensive areas not controlled by higher-order leveling will thereby be eliminated, and the accumulation of error will be held to a minimum.

b. Planning for third-order leveling.—As Survey third-order leveling is intended primarily for vertical control of mapping, planning must take into account the specific requirements of the mapping project under consideration. New work must be coordinated with old work to provide a suitable distribution of elevations, and the new circuits must be tied to the old work so as to support and strengthen the leveling network as a whole. The first step in planning, therefore, is to prepare a base map on which all existing control can be plotted accurately and the new lines can be outlined. Information about the terrain and the most practical routes of access is essential to effective planning.

5. Source material for planning

The material needed for planning a leveling project includes a suitable planning map, lists of existing control, recovery notes, mapping specifications, and data on photogrammetric requirements.

Copies of the 1:250,000-scale series of geodetic control diagrams may be used for planning. These maps show the control lines and stations, both horizontal and vertical, already established by the Survey, C&GS, and some other agencies. They also show drainage and such cultural features as roads and railroads. With this information, individual bench-mark locations can be identified and plotted from their descriptions. The road pattern on these maps usually is accurate enough for planning the routes of new level lines.

If the project area extends beyond the bounds of a single control diagram, adjacent sheets can be mosaicked and the assembly trimmed to convenient size. If a larger scale is needed for the planning map, the base can be enlarged photographically, or available large-scale maps can be used.

For studying the terrain of the project area, the 1:250,000-scale diagrams should be supplemented by other available map coverage, such as topographic maps, highway maps prepared by the Bureau of Public Roads, Forest Service maps, and C&GS charts. Although these other maps may be used to compile planning bases if necessary, the geodetic-control diagrams are more suitable.

In the absence of geodetic-control-diagram coverage, present practice in some Areas is to make and assemble ozalid copies of the county highway maps for planning bases. Established control lines and stations and the proposed new level lines are then drawn on the bases. It is also advantageous to indicate any proposed new horizontal control. After paper autopositives

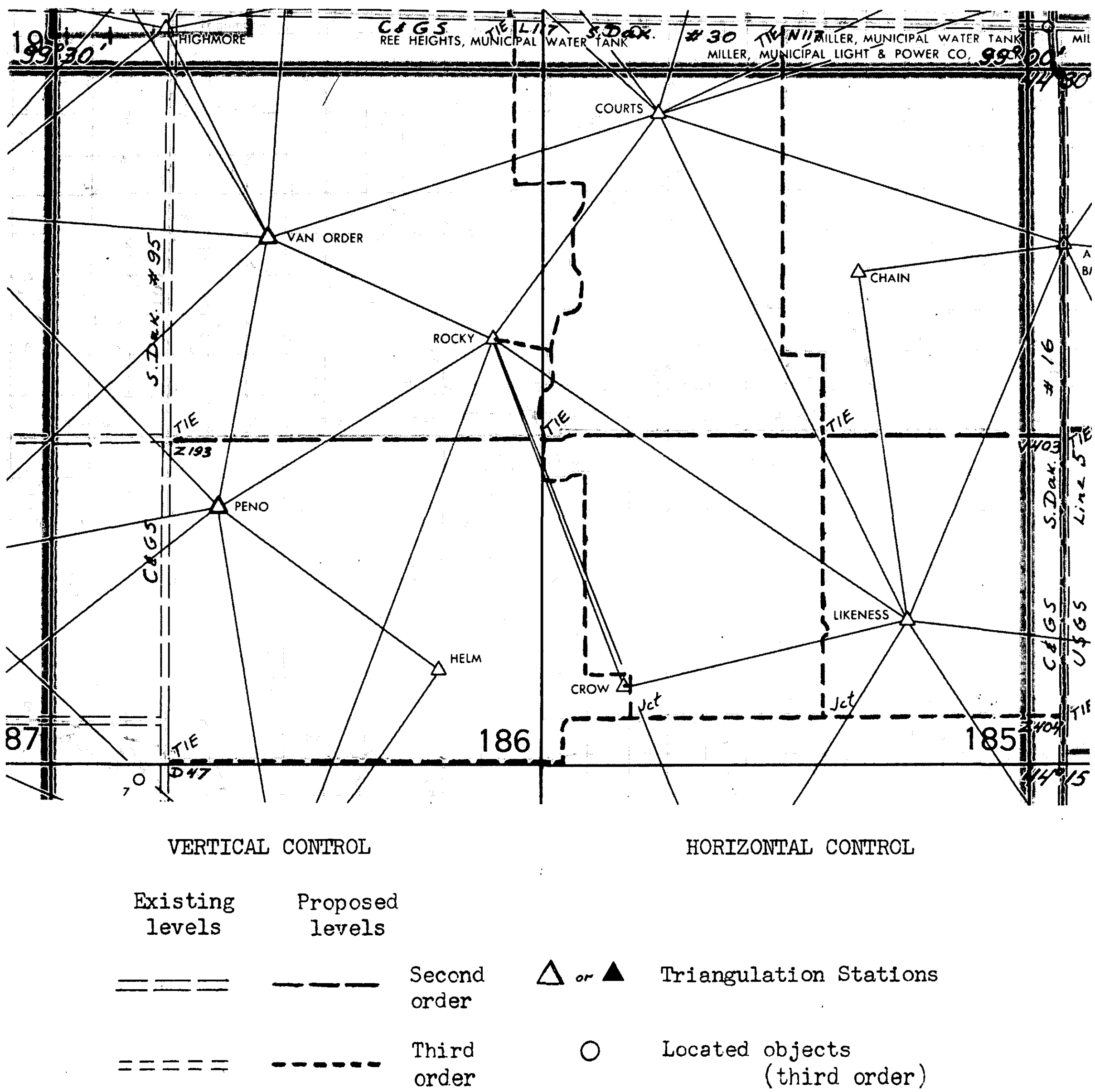


FIGURE 1.—Typical plan for leveling outlined on geodetic control diagram.

are prepared from the master drawings, the required number of copies are made by the ozalid process.

Figure 1 illustrates a typical plan supplied to the levelman. To make the proposed new lines stand out more clearly, they may be traced over with transparent colored ink or pencil, especially on the levelman's copy. As the planning maps are intended for internal use within the Area, established Area usage in line weights, symbolization, and other features should be followed.

6. Evaluation of existing level lines

The accuracy and the method of adjustment of existing lines of leveling should be carefully evaluated. Although one line may look as good as another on a control diagram, the actual lines may vary significantly in strength or utility. The evaluation should include the following elements:

Status of Coast and Geodetic Survey lines.
Complete closure diagram for existing Geological Survey lines.
Substandard lines that need releveling.
Indication of possible fault zones, subsidence areas, and areas where improvement projects are underway or expected.

The dates of leveling indicate in a general way the methods used and probability of recovering bench marks; but recent field reports, such as bench-mark recovery reports, provide specific information. Reconnaissance trips by district and project engineers offer ideal opportunities for scouting old lines and inquiring about planned road construction and other improvement projects. Recent aerial photographs also may provide evidence of construction work or road relocations along the old routes of leveling.

7. Selecting routes for new leveling

Preparing effective plans for new leveling is the responsibility of the control planning unit in the Area office, where most of the information needed for planning is readily available. The planning is done by men thoroughly familiar with the requirements for leveling and also well acquainted with field conditions and procedures. Although levelmen and project engineers are not directly concerned in preparing plans, they should understand the objectives and requirements of planning so that they can suggest or make suitable changes in the original plans where field conditions require them.

In selecting the particular routes for new lines of leveling, the control planner must consider many conditions and technical and economic factors. The new work must meet the established standards for geodetic leveling; it must be coordinated with other control surveys in the project area; and it must provide, at reasonable cost, the basic elevations needed in the later mapping phases. For some projects the fulfillment of all these requirements is almost routine. But for other projects, especially those in difficult terrain, the planner must compromise, departing from the most desirable location to one which is feasible.

a. Use of existing permanent marks.—New third-order lines must tie to established lines of the same or higher order. Ties to first- or second-order lines are particularly important in starting the planning diagram because third-order lines must not be extended more than 30 miles between ties to higher order leveling Any existing lines that were not shown on the control diagram should be plotted, whether they lie in the area to be mapped or extend into the surrounding area.

The proposed lines should be routed to take advantage of as many existing permanent marks as practicable. These marks usually are traverse or triangulation stations or marks established by local surveys, and isolated Geological Survey marks on obsolete lines. Dual use of permanent marks reduces the likelihood of confusing one mark with another and also lowers the cost of the new survey.

b. Coordination with other surveys.—As a rule, the horizontal and vertical control for a project should be planned concurrently so that both types of surveys can use the same permanent marks wherever practicable. Because the specific locations for new marks are determined mainly by local conditions, fieldmen on control surveys must cooperate with each other in placing marks at advantageous sites and in supplying descriptions of the new marks they set.

Elevations should be established on all triangulation stations, reference marks, and azimuth marks within practical reach of the leveling. This consideration is particularly important if supplemental control is to be established by vertical-angle observations in conjunction with triangulation or electronic-distance traverse. Even where it is not practical to run levels to the triangulation stations, levelmen can assist the triangulation parties by placing bench marks on divides or crests of ridges or in open areas that can be sighted from the triangulation stations, either directly or by means of auxiliary stations.

New leveling should tie in bench marks of other organizations if the marks were established by surveys of third-order accuracy or better. These ties generally should not entail more than about a mile of extra leveling unless special instructions are given by the Area office or the project engineer. The ties should be indicated on the planning diagram if the necessary information is available to the control planner.

Elevations should be established on water gaging stations of the Water Resources Division of the Geological Survey if the stations are within a mile or so of the new leveling. The control planner should obtain and supply to the levelman descriptions and other data concerning all water gaging stations in or around the project area.

Elevations also should be established on the highest points of runways at airports not more than a mile from the leveling routes if reliable elevations are not already available for these points. If the airports are more than a mile off the leveling routes, the elevations will be established during supplemental-control or field-completion phases.

c. Accessibility.—The cost and rate of progress of leveling depend greatly on the routes selected. Therefore, the most accessible and unimpeded routes should be selected for new lines insofar as this consideration is consistent with providing elevations where they are needed and maintaining the strength of the leveling network. Routes along railroads or modern highways provide the easiest grades, the longest sight distances, and therefore usually the opportunity for maximum progress. Moreover, the bench marks established will be most useful to the public if they are set along roads or railroads.

d. Type of terrain.—The characteristics of the terrain have an important influence on the placement of leveling routes. In mountainous terrain with few roads, for example, lines must follow the best or only routes available, regardless of quadrangle boundaries. In these areas, most of the elevations required for supplemental control are obtained by the vertical-angle method. Poor roads or trails should not be overlooked as possible routes for leveling through areas where elevations are needed.

Frequent crossings over mountains should be avoided whenever possible. Powerlines, pipelines, or cleared property lines often afford good routes through forested areas with few roads. Lines should be routed around, rather than through, large swamps unless good roads can be followed. In areas plentifully supplied with roads and railroads, however, the routing of new leveling consists mainly in spacing the lines approximately along quadrangle boundaries.

e. Use of water levels.—Sizable bodies of water of nearly constant elevation, such as lakes and large ponds, can be used as part of the leveling net. In areas without access roads they also may serve as transportation routes. Using a body of water in this way widens the applicability of an elevation to any point along the shoreline, as long as the stage of the water is taken into account.

8. Adapting level lines to mapping method

At the start of a mapping project, the control planner is supplied with information on the method of compilation, the contour interval, and the method to be used for supplemental control. He must consider the capabilities, limitations, and relative costs of the various methods to devise a comprehensive plan that can be expected to provide adequate control at an overall minimum cost.

Although mapping is now done in 7½-minute quadrangle units, control files are maintained in 15-minute units, and control usually is planned with reference to 15-minute quadrangles. In most areas of the Eastern and Midwestern States, placement of geodetic leveling around the perimeter of each 7½-minute quadrangle will provide adequate basic control for most methods of mapping and supplemental control.

This standard placement may have to be modified, however, to meet the requirements of special methods, such as the "scatter" system of supplemental control in conjunction with vertical bridging; elevation meter leveling, which normally is run in extensive networks; or photoalidade supplemental control. For suggestions on placement of lines in difficult terrain, see article 7*d*.

CHAPTER 2E2. EQUIPMENT FOR LEVELING

LEVELING INSTRUMENTS

9. Basic characteristics of leveling instruments

In geodetic leveling, the instrument used to determine differences of elevation is a level of intermediate or high precision. The level consists of a telescope for sighting and a leveling device for making and keeping the line of sight horizontal. The leveling device may be either a type of pendulum, which acts automatically through the force of gravity to level the sightline, or a bubble in a cylindrical vial, which requires manual orientation and adjustment by the observer.

When the instrument is leveled precisely and rotated about its vertical axis, the line of sight generates a horizontal plane. The difference in elevation between this plane and any nearby lower point, within the effective range of the telescope and within the length of a graduated rod held vertically on the point, is measured by sighting the rod and reading the graduation intercepted by the crosshair. Once the height of the instrument (HI) is established by adding the backsight reading to the elevation of a point of known elevation, the elevation of any point within range of the instrument and the rod can be determined by taking a foresight to the point and subtracting the reading from the HI.

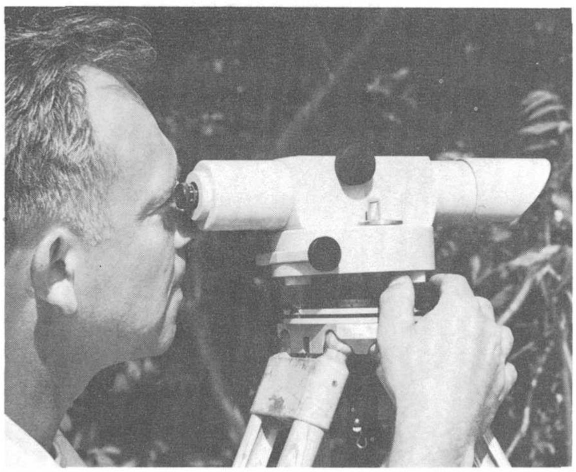


FIGURE 2.—Zeiss Ni2 automatic level.

For geodetic leveling the Geological Survey has adopted automatic (pendulum) and prism levels as standard instruments, because of their accuracy and speed of operation. Older levels, such as the dumpy level and wye level, are less satisfactory for geodetic work and therefore are used only in emergencies or occasionally for fourth-order leveling.

10. Automatic (pendulum) level

The distinctive feature of the Zeiss Ni2 (fig. 2) and Hilger & Watts Autoset automatic levels is an internal compensator that automatically levels the line of sight and keeps it level through the force of gravity. (The following discussion concerns the Ni2 level; however, the remarks are also generally applicable to the Hilger & Watts Autoset level.) As soon as the instrument is approximately leveled by means of the circular bubble, the movable component of the compensator swings free to a position that makes the line of sight horizontal despite any small tilt of the telescope. Subsequent small tilts or disturbances of the instrument will not move the line of sight from horizontal as long as there is sufficient clearance between the damping piston and chamber of the compensator.

In observing with a conventional spirit level, the levelman must be constantly alert to keep the bubble centered, especially in bright sunshine, in windy weather, or on unstable footings. A properly adjusted automatic level demands much less attention and is therefore easier to operate.

The Ni2 level has three leveling screws and may be mounted on a universal tripod. Protective housings shield the focusing, tangent, and leveling screws from dust and rain.

The compensator is completely housed within the telescope of the level. The reference used in setting up the level is a small circular bubble in a vial situated to the right of the telescope barrel and viewed through a reflecting prism. The bubble must be kept in good adjustment so that the compensating element is suspended free, near its center of swing, when the level is set up with the bubble centered in the bull's-eye.

The instrument is adjusted in the shop by first adjusting the circular vial. The reticle is mechanically centered in the instrument by means of a jig. The compensator is next adjusted to proper height so that it is centered in the optical axis. Then it is properly balanced and weighted. To maintain a high degree of sensitivity and repeatability, it is necessary to weight and balance the arm of the compensator so that with a fore-and-aft tilt from center there is some overcompensation, and when the pendulum unit is at rest, it is not truly in the vertical. Over a small range of tilt which does not exceed about 4 minutes, excellent repeatability can be obtained without overcompensation. However, if the range is as great as 8 minutes, some run or overcompensation may reasonably be expected. Each compensator unit has individual characteristics. Each requires slight differences in weighting and adjustment, and consequently has differences in behavior of run. While the run from a tilt directly fore and aft can be controlled by varying the weights and the positioning of the weights, a run from a tilt to the left or right is totally dependent on the length of the suspension wires, and no adjustment is possible. Therefore, very strict tolerances are maintained in selecting compensator units for these instruments. If the run exceeds 2 seconds for an 8-minute tip to the left or right, the compensator unit is not satisfactory.

All Ni2 levels are adjusted in the shop so that a slight decentering of the bull's-eye bubble will cause no deflection in the line of sight. However, in field use, the instrument is subjected to frequent jolts, dust, heat, and humidity which can cause a shift in the rest point of the pendulum when the bull's-eye bubble is centered. This shift could be caused by some disturbance of either the compensator unit or the circular vial. Small shifts are sometimes difficult to detect in the shop with special equipment; however, if proper field procedures are followed, these small changes will be tolerable. Frequently the changes are large and can be detected in the field. Field procedures for testing the compensator and adjusting the circular bubble are outlined in articles 14*a* and 14*b*.

11. Prism level

The Geological Survey prism (Staack) level is basically a tilting dumpy level which may be used for all orders of leveling. A prism-and-mirror viewing system enables the levelman to observe both ends of the main bubble and the image of the rod simultaneously.

Although the prism level was designed to reduce the effects of unequal expansion of component parts, the precise level vial and its metal housing are extremely sensitive to changes in temperature. The adjustable metal sunshade provides partial protection, but further shielding should be supplied by encasing the full length of the instrument with a polyurethane plastic foam cover, as shown in figure 3. Experiments have shown that insulation reduces thermal bubble creep by 50 to 70 percent. Polyurethane shielding is essential for prism levels that must be used in hot weather or in a wide range of varying temperatures.

A micrometer screw is provided for moving the eyepiece end of the telescope up or down to keep the bubble precisely centered. To avoid needless wear on the micrometer bearing point, some models of the prism level are equipped with a cam for lifting the telescope free of the micrometer screw while the instrument is not set up for observing.

The instrument is supported on three footscrews that rest in V-slotted pads which are part of the tripod head. The level is fastened to the tripod with a large threaded bolt working against spring pressure. (Some levels have been modified with a tribrach for use on a universal tripod.)

CARE AND ADJUSTMENT OF LEVELS

12. Field care of levels and tripods

Although a level is built to withstand continuous service, it cannot be subjected to mistreatment and remain in good adjustment. The levelman should note how the instrument is packed when received from headquarters. When the level is shipped by common carrier, all vacant space in the instrument box should be filled with tissue or soft paper to prevent shifting or rubbing and to prevent damage if a part should come loose. The instrument box should then be packed in an outer box or carton

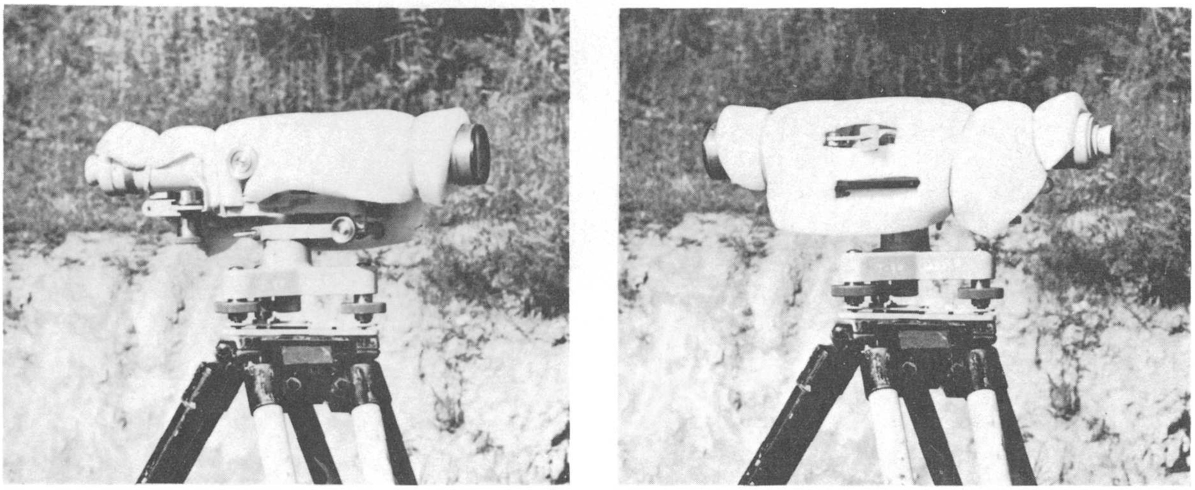


FIGURE 3.—*Geological Survey prism level with full-length foam shield.*

lined with excelsior or shredded paper to absorb the shocks of handling in transit.

The Ni2 level is a sensitive instrument and must be handled with care. It should be gently lowered into its box and protected from shock while being transported. The small suspension wires in the compensator can be stretched by hard or repeated shocks. In driving to and from work, especially over rough roads, the level box should be placed on a thick mat of foam rubber or other shock-absorbing material, or it should be carried in the lap of the recorder or rodman. It should never be carried on the bare floor of the truck.

In field use the level is normally carried over a shoulder, mounted on its tripod, from setup to setup. The tripod should be lowered gently to the ground and set firmly, with the legs far enough apart to assure stability.

In carrying a prism level, the telescope should be clamped and the telescope axis should be kept horizontal so that the length of the bubble will not be changed. If the level is equipped with a cam, the telescope should be lifted from the micrometer bearing between setups and also when the instrument is put in its box. The spring on the tripod mounting bolt should be kept tight enough to prevent the level from rocking on the footscrews.

The tripod should be handled carefully. The screws or bolts connecting the legs to the head should be set firm but not too tight. To check for proper tension, set the tripod on level ground, with the feet about a yard apart, and lift by the head; the legs should fold in only slightly. On the tripod for the automatic level, leg tension is adjustable. If a tripod is wet by a shower or otherwise exposed to moisture, the leg bolts should be loosened to prevent damage in case the wood swells. The pointed shoes on the feet should be kept tight.

13. Peg test for collimation adjustment

A basic requirement in geodetic leveling is that the line of collimation of the telescope must be perpendicular to the direction of gravity when the level is set up for observing. The accuracy of the results of leveling depend to a great degree on the fulfillment of this requirement. Although it is impossible to keep the level in perfect adjustment at all times, accurate results are possible by keeping backsight and foresight distances balanced. The peg test is a field means of checking the collimation of an instrument and serves to ensure that the reticle is centered in the optical train for the most efficient operation of the instrument.

The peg test, a standard procedure in surveying, consists of a short closed circuit of leveling that exaggerates the difference between backsight and foresight distances and produces a closure proportional to the collimation error of the level. The factor C, determined by the peg test, represents the fraction of a foot of vertical distance per 100 feet of horizontal distance by which the line of sight of the level diverges from

797-176 O—66——3

the horizontal. C is used to compute a corrected rod reading for adjusting the level.

a. Frequency of tests.—Peg tests are required at the beginning of each line and at weekly intervals during the course of a line. A series of short lines that can be completed in a single day need not have a peg test at the beginning of each line. A newly issued level should be peg-tested at 2- or 3-day intervals during the first few weeks it is used. If the level is found to remain in good adjustment, the frequency of testing may be reduced to once a week.

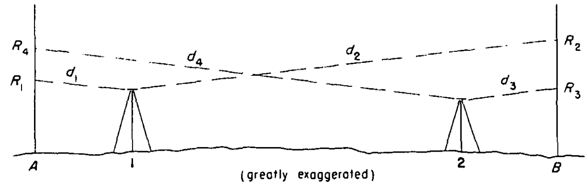
b. Effect of temperature on tests.—Laboratory tests of the Ni2 level have demonstrated that the collimation adjustment varies with changes of temperature. This variation can be large for older units of the Ni2, but the newer units have been temperature compensated and present a very small pattern of variation, averaging about 3 seconds of arc for each 10 degrees of temperature change (Fahrenheit scale).

As the C determined for an automatic level may vary considerably at different temperatures during the day, regular peg tests for this instrument should be taken at as nearly the same temperature as possible, and the ambient temperature used for testing should apply to most of the leveling in progress.

c. Peg tests on special points.—Peg tests may be made either on points specially selected for the purpose or at regular setups in a line of leveling, as described in article 13*d*. Special points are normally used for the first peg test of a newly issued level and for tests where local conditions make it inconvenient or impractical to use setups in the line.

An example of the record for a peg test on special points, with center-wire readings, is shown in figure 4. (The diagram illustrating the principle of the peg test is not needed in actual field records.)

After the rods have been stationed on firm points A and B, about 250 feet apart, the level is set up at point *1* about 25 feet from A for sights d_1 and d_2 to obtain readings R_1 and R_2. The level is then moved to point *2*, about 25 feet from B, for sights d_3 and d_4 to obtain readings R_3 and R_4. The levelman then calculates C (art. 13*e*) and adjusts the instrument if C exceeds the acceptable limit (0.006 ft). The peg test must be repeated after any adjustment to



BACKSIGHT			H. I. Yards	FORESIGHT		
Color Dist.	Check	Yards	Elev. Yards	Yards	Check	Dist. Color
d_1		R_1				
				R_2		d_2
d_3		R_3				
				R_4		d_4

R 25		1.360				
				2.020		250G
R 25		1.980				
50		3.340		1.380		250 R
		3 10.020		3.400		500
		-10.197		3 10.200		50
		-0.177		-.003* 10.197		550
		$C = 100 \left(\frac{-0.177}{550}\right)$		$= -0.032$		

* This is twice the curvature and refraction correction for a 250-ft sight

FIGURE 4.—Example of peg test, center-wire method.

check or refine the adjustment and determine a corrected value of C.

d. Peg tests in line.—Routine peg tests may be included in the line if local conditions are favorable. As illustrated in figure 5, only one extra turning point and one extra setup are needed to complete the test. Having taken a long foresight in the line from *1* to *b* (250–300 ft), the levelman uses the same data for foresight R_2 and waits for the rear rodman to come forward and establish extra turning point A which is used for backsight R_1. The level is then moved to the extra setup at *2*, where backsight R_3 is made to B and foresight R_4 is made to A. After calculating C, and adjusting the instrument if necessary, the levelman and rodman move forward along the line to the next regular setup, for which B is the backsight point.

e. Notes and computations for peg tests.—The field notebook records of peg tests must always indicate clearly where the tests were made and whether the level was adjusted. The notes for each test should be recorded at the point in

Date: May 20, 1965, ERD, Levelman. CWE, Recorder.

Line from Middletown via U.S. Hwy. 66, to Saltville 44

Checks	Thr. Rdg.	Thr. Int.	Sum. T. R.	H. I. Elev. Feet	Sum. T. R.	Thr. Int.	Thr. Rdg.	Checks	Fore Rod and Sta.
				485.464					
Y	3250	240				222	2093	G	
9.03	3010	240	9030		5613	222	1871	5.61	A
G	2770						1649	R	
Y	3018	183				201	1286	R	
8.50	2835	185	8503		3256	200	1085	3.25	B
G	2650						0885	B	
Y	3086	241				252	2042	G	
8.54	2845	241	8535		5372	250	1790	5.37	A
G	2604						1540	R	

Miles From B.M. H 12: 2.62 Brought forward from page 43

DESCRIPTIONS, COMPUTATIONS, AND REMARKS {Dry; Clear; Wet; Cloudy} Wind: Calm; moderate; strong.

Peg Test

BS (R_1 & R_3) FS (R_2 & R_4)

R	1787					2042	G
5.29	1762	25	5.286	5.372	252	1790	5.37
R	1737	25			250	1540	R
R	1874					2080	G
5.55	1849	25	5.548	5.490	250	1830	5.49
R	1825	24			250	1580	R
		50	10.834	10.862	501		
				−0.003	−50		
				10.859	451		
				10.834			

$C = 100 \frac{-0.025}{451} = -0.006$ − 0.025 ft = 0.008 yd

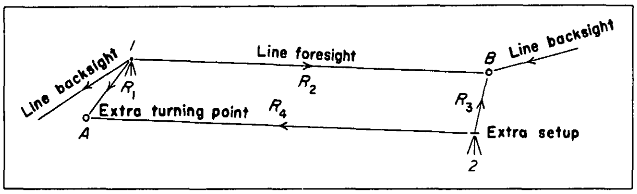
Correction to R_4: ½ × 0.008 = 0.004 (−)

1.830

1.826

Level adjusted 5/20/65

R	1874					2076	G
5.55	1849	25	5.548	5.478	250	1826	5.48
R	1825	24			250	1576	R
R	1927					2176	G
5.70	1902	25	5.706	5.778	250	1926	5.78
R	1877	25			250	1676	R
			11.254	11.256			
				−0.003			
				11.253			



Σ M.T.R. yds. × 3 ft. D_b Σ B. S. Elev.—Elev. B. S.—F. S. Σ F. S. D_f Σ M.T.R. yds. × 3 ft.

D_b+D_f= .... Feet= .... Miles .... Total miles.
$\frac{C(D_b-D_f)}{100}$= .... Cor. for Level and Collimation in feet.

FIGURE 5.—Example of peg test in line, three-wire method.

the line where the test was made; the practice of recording peg tests on the back pages of the notebook should be discontinued.

The collimation error factor C is computed by the formula

$$C = 100\frac{(R_1+R_3)-(R_2+R_4-\mathrm{CR})}{(d_2+d_4)-(d_1+d_3)},$$

where R_1 and R_3 are the backsight rod readings, R_2 and R_4 are the foresight rod readings, d_2 and d_4 are the foresight distances, d_1 and d_3 are the backsight distances, and CR is the sum of the curvature and refractions corrections for the two long foresights. Note that the value for CR is obtained by adding the two individual CR corrections for the foresight distances, not by taking the CR correction for the sum of the two distances. The table of CR corrections is found in back of both center-wire and three-wire fieldbooks. The algebraic sign of C is plus if (R_1+R_3) is larger than $(R_2+R_4-\mathrm{CR})$ and minus if $(R_2+R_4-\mathrm{CR})$ is larger. Rod readings must be converted to feet. With the center-wire method and yard rods, the sums of the pairs of backsight and foresight readings are multiplied by 3 to convert to feet, as shown in figure 4. With the three-wire method and yard rods, adding the three intercept readings for each pointing gives a mean reading in feet directly.

If C exceeds 0.006 ft, the instrument should be adjusted. The last long foresight (R_4) is used in adjusting the level. C is divided by 3 to convert to yards, and the yard value is multiplied by the number of hundreds of feet to the rod. The correction thus obtained is added to the center-wire reading of R_4 if C is plus, or subtracted if C is minus. The line of sight is then adjusted to give the corrected rod reading, as explained in articles 14d and 15f.

An alternative and simpler method of computing the correction to R_4 is to take half the difference between the sums of backsight and foresight rod readings, in yards, after the foresight sum has been corrected for curvature and refraction. The sign of the correction is the same as for C. (This method is illustrated in fig. 5.)

14. Adjustment of automatic level

The basic adjustments of an automatic level, pertaining to the functions of the compensator and optical system, as indicated by the field tests described in articles 14*b* and 14*c*, must be done in an instrument shop with special equipment. Only the circular bubble and the collimation can be adjusted in the field.

a. Adjustment of circular bubble.—The circular bubble needs adjustment if it will not stay centered in the bull's-eye as the telescope is turned about the vertical axis. In adjusting the bubble, the telescope is turned until the bubble displacement from center is at a maximum. The bubble is then brought halfway back to center by means of the footscrews and the rest of the way by means of the adjusting screws on the bubble mount. After two or three trials, the bubble should remain centered as the telescope is rotated through 360°.

In using the adjusting screws on the bubble mount, several precautions must be observed:

Turn the screws downward to maintain pressure on the base washer.

Do not adjust by retracting one screw and depressing another.

Do not force the vial tight against its base. If one or more screws are turned down to the limit of travel, retract all three and readjust by downward rotation.

After any adjustment to the circular vial, the test described in article 14*b* should be made to see whether the compensator has remained in good adjustment.

b. Field tests of compensator.—Because of the small clearance between pot and piston in the damping mechanism, the unit is sometimes subject to sticking or hanging. This seldom causes trouble, but the fieldman should be constantly on the alert to ensure that he does not take a reading when the unit is sticking. Tests have shown that this is particularly likely to occur after the slight displacement caused by centrifugal force in turning the telescope on its vertical axis.

This effect can be overcome by lightly tapping the tripod head or the body of the level near the compensator before a reading is taken and watching the apparent movement of the crosswires against the rod to see that the movement is smooth and unhampered. Although the normal shocks of setting up should be adequate to bring the pendulum to vertical for the first sight taken, it is preferable for the levelman to adopt the routine practice of lightly tapping the instrument before taking each reading.

Any change in reading after a tap constitutes evidence that the piston might be sticking. Repeated changes of the rod reading after a series of taps means that the level is not functioning properly and should be sent to the Property Maintenance Shop (in Silver Spring, Md.) for adjustment.

If no movement of the crosswire is noted, a further check should be made to be sure that the circular bubble and pendulum are properly coordinated. Place a 1 : 24,000 scale in a vertical position 10–20 feet from the instrument. Center the circular vial, sight the scale, and note the scale reading. Next, decenter the Ni2 by means of the footscrews in a forward tilt until the compensator comes to rest on the stop. Back up until the unit is swinging free and note the position of the bubble, with reference to the circle, and the scale reading. Then run the bubble in the opposite direction by means of the same footscrew until the compensator unit is against the stop. Back off again until the unit is swinging free and note the position of the bubble and the scale reading.

If the instrument is in good adjustment, the bubble should have about the same amount of run fore and aft from center, and the scale readings should vary about the same amount from the center reading. If the difference in run amounts to more than about one-fourth the diameter of the bubble, the relationship between the circular bubble and compensator has been disturbed, and the instrument should be sent to the Property Maintenance Shop for adjustment.

c. Check for loose prisms and lenses.—This test should be made while the instrument is set up for the test previously described. First, recenter the circular bubble of the Ni2 and note the scale reading. Then tap the instrument lightly on top of the compensator unit (just forward of the eyepiece), using a small screwdriver or other suitable object. Next, tap the instrument on the bottom side directly beneath the compensator unit. Any residual displacement of the crosswires is evidence that the instrument should be sent to the shop. If no residual displacement is noted, the tapping should be repeated above and below the objective lenses and the crosswires watched for movement. Any displacements will probably be very slight, and due care must be taken to be sure that the displacements are caused by the tapping and not by settling or movement of the instrument.

d. Collimation adjustment.—When the levelman has determined, by a peg test, that the collimation of the level needs adjustment, he computes a corrected rod reading for the second long foresight, R_4 (see art. 13*e*). The level is then brought to the corrected reading by means of the single capstan-head adjusting screw for the reticle. This screw is exposed by unscrewing the collar at the forward end of the eyepiece. Each time the reticle is adjusted, the peg test must be repeated to check the adjustment.

15. Adjustment of prism level

The field adjustments of the prism level concern the reflector, the length of the main bubble, the prism viewing mirror, the reversing point of the micrometer, the circular bubble, and the relationship between the line of collimation and the axis of the main bubble.

a. Reflector.—The reflector is a long thin stainless-steel strip with one polished and one dull surface. It is mounted horizontally, just below the main bubble vial, and can be adjusted as needed to give the most satisfactory illumination of the bubble.

b. Length of main bubble.—The bubble tube of the prism level contains an air chamber which is used to adjust the length of the bubble. Changes in temperature cause the liquid in the tube to expand or contract and thereby shorten or lengthen the bubble. In responding to movements of the footscrews, a short bubble is somewhat sluggish and a long bubble is hard to control. The bubble should be adjusted so that the images of the two ends match near the center of the viewing mirror.

To lengthen the bubble, hold the level with the telescope vertical, eye end down. Small bubbles will rise through the fluid, thus increasing the bubble length. To shorten the bubble, hold the telescope with objective end down. Light shaking may be needed to induce movement of air in the tube. To keep the bubble at its adjusted length and avoid "losing" it, the level should be carried with the telescope horizontal and the spindle clamped.

c. Prism viewing mirror.—The prisms above the main bubble provide a split double image of the two ends of the bubble when it is approximately centered in the tube. This image is reflected to the observer's eye by a mirror on a hinged arm that can be adjusted to the observer's interpupillary distance. Once the arm is adjusted, it will automatically stop at the proper viewing position when pulled out from its folded position.

To adjust the arm, loosen the screw holding the eccentric washer just behind the arm. Sight the rod through the telescope with the right eye, and move the mirror arm in or out until the bubble image, as seen with the left eye, seems to float just to the left of the rod image. Then turn the eccentric washer against the arm and tighten the holding screw.

d. Reversing point of micrometer.—In routine use, the micrometer screw should not be turned more than a small fraction of its run to center the main bubble after the telescope has been turned to the opposite rod. To avoid excessive use of the micrometer, the levelman should determine and use its reversing point, as follows:

Set up the instrument carefully.
Center the main bubble.
Note the reading on the micrometer scale.
Turn the telescope 180°.
Center the bubble with the micrometer and note the scale reading. Midway between the two scale readings is the reversing point; the micrometer should be returned to this point after each setup. (On micrometers with an adjustable ring, the scale can be set to read 0 at the reversing point.)

e. Circular bubble.—By keeping the circular bubble in good adjustment, the levelman saves time and effort in setting up. With practice in manipulating the tripod legs, both the circular and main bubbles can be brought almost to center before the leveling screws are touched.

To test the circular bubble, level the instrument by using the main bubble so that it remains centered for all pointings of the telescope (the micrometer must be set at its reversing point). If the circular bubble is displaced from the center of the bull's-eye, bring it to center by means of the three adjusting screws on the outer rim of the mounting.

f. Collimation adjustment.—When a peg test indicates an excessive value of C (art. 13), the prism level is adjusted by making the axis of the bubble tube parallel to the line of collimation. A corrected reading for the second long foresight, R_4, is computed as explained in article 13*e*. The center wire is set to this reading on the rod by means of the micrometer screw. The resulting displacement of the main bubble is then corrected by turning the two-way capstan-head screw on the prism housing until the two halves of the bubble image again match. (The capstan-head screw moves the viewing prisms, rather than the bubble, to correct the line of sight.) Each time the level is adjusted, the peg test must be repeated to check or refine the adjustment.

RODS AND OTHER EQUIPMENT

16. Yard rods

The quality of the leveling rods and the care given them contribute materially to the accuracy of leveling. The most recent design of the Geological Survey standard yard rod, illustrated in figure 6, consists of a supporting staff of magnesium to which is attached a precisely graduated strip of invar. One end of the strip is securely fastened to the shoe of the rod, and the other end is suspended from the top by a tension spring. The plastic facing, which screws to the front of the rod, holds the invar strip in place but should clear it by the thickness of a sheet of notebook paper. This construction permits the staff to expand or contract with changes of temperature without affecting the length of the invar strip.

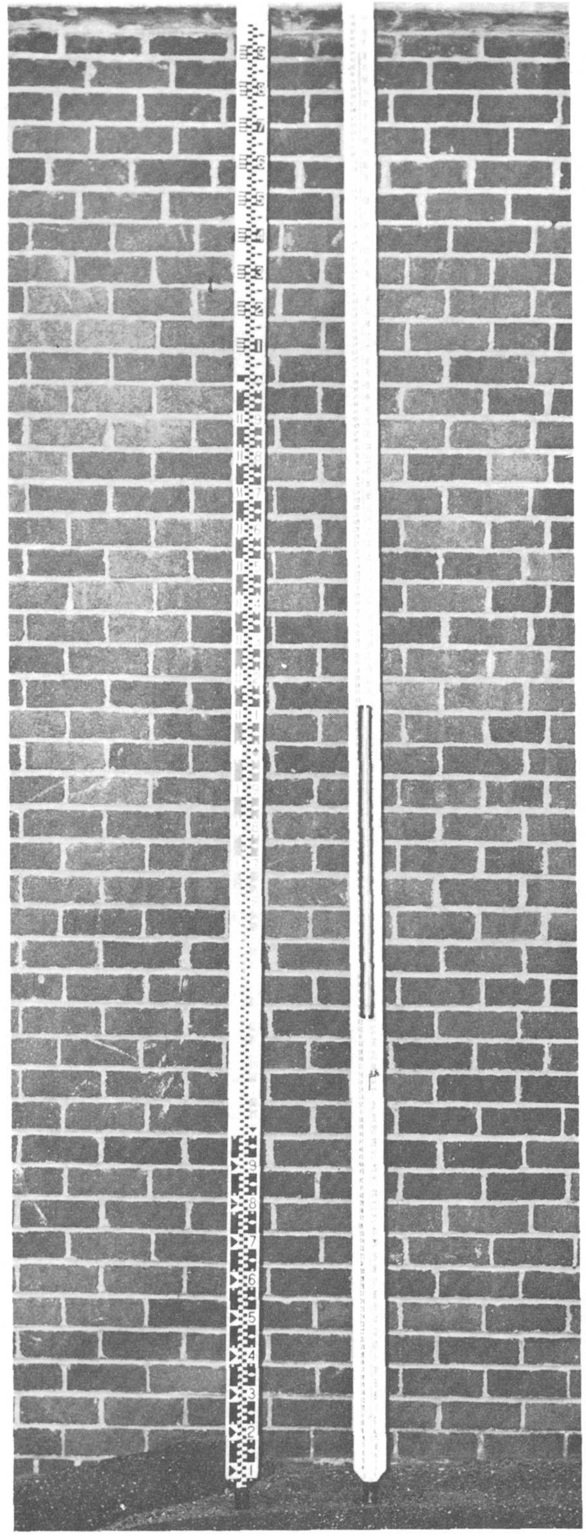


FIGURE 6.—Geological Survey standard yard rod with magnesium body and plastic face graduations.

The face of the rod is laminated plastic and is graduated in yards and tenths, from about 0.2 to 3.9 yards. The strip itself is graduated in hundredths of a yard. These rods are termed "self-reading" because they have no targets to be set by the rodman; they are read directly by the levelman, who estimates the cross wire intercept readings to a thousandth of a yard. Each yard has a different background color to provide a check on the whole-yard figure of a reading. Graduations in units of 0.02 yard, painted on the back of the rod, provide a check on center-wire readings; graduations in units of 0.1 foot, also painted on the back of the rod, provide a check on three-wire readings.

Some older magnesium rods have painted face graduations, but newer ones are equipped with the laminated plastic. Rods intended for use with the Ni2 level have erect figures, whereas those intended for use with the prism level have inverted figures.

a. Rod test.—The levelman should check the condition of each rod even if it is new. He should measure the distance from the bottom of the rod shoe to the first graduation on the invar strip to make sure that the strip has been accurately attached and that the metal shoe on the rod has been securely fitted. He should also check to see that the double-yard and tenth-foot scales match with the corresponding yard graduations on the face.

Any variations from normal measurements should be recorded in the field notebook so that index corrections can be applied where necessary. To prevent minor rod index errors from accumulating significantly as errors in elevation, the same rod used for the foresight to a turning point should always be used for the backsight from that point.

Although invar has a remarkably low coefficient of thermal expansion, research has shown that unannealed or improperly annealed invar can significantly and progressively change length with time. All new leveling rods made for Survey use will contain stabilized, annealed invar strips, but some of the older rods were made with strips of inferior invar. Therefore, the levelman should make the following check on all newly received rods:

Set up the level on a steep hillside.

Select 8 firm turning points on the hillside that will provide rod readings at approximate 0.5-yard intervals from the bottom to the top of the invar strip. Keep the distance between the instrument and rod to a minimum.

Level the instrument carefully and read the center wire, alternating the rods on the turning points so that both rods are read on each point.

The Area office should be notified if there is a difference greater than 0.001 yard between sets of comparison readings.

b. Adjustment of plumbing bubble.—Each rod is equipped with a circular bubble so that the rodman can plumb it accurately. The bubble must be checked frequently and adjusted as necessary, by holding the rod plumb and centering the bubble in the bull's-eye with the three adjusting screws. This can be done by alternately holding the face and an edge of the rod against a plumb wall or alongside a plumbline. At every setup, the levelman can observe the rods in relation to the vertical wire of the reticle, and he should be alert to notice a rod with a poorly adjusted bubble or one that is being held carelessly by a rodman.

c. Care of rods.—Improper handling of leveling rods will damage them and cause errors in reading. Special boxes or cases are provided to protect the rods when they are not in use or are being transported. In carrying a rod from one point to the next, the rodman should hold it either by the handle with the face down or over his shoulder with the face up; he should never carry it with the graduated face resting against his shoulder.

A rod should never be left leaning insecurely against a tree, a pole, or other prop because of possible damage if it should fall. When the rod is put aside temporarily, it should be supported uniformly if possible. It should never be laid on the ground face down, exposed to bad weather unnecessarily, or used for any purpose except its intended one. The shoe and invar strip must be kept clean.

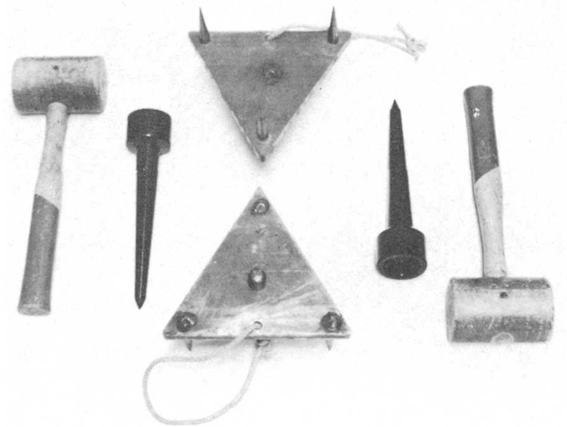


FIGURE 7.—Turning pins, turning plates, and rawhide mallets.

17. Turning pins and plates

The turning pins used in Survey leveling, illustrated in figure 7, are 10-inch steel spikes with cup-shaped tops that keep the rods from slipping off the points, especially in windy weather. A convex mound in the bottom of each cup provides a small, consistent bearing surface no matter which way the rod is turned. Turning pins are driven into the ground with rawhide mallets, which will not mar or damage the pins. The cups in the pins must always be kept clean.

Turning plates with spike feet are designed for use on loose, sandy, or unstable soil. A small convex projection in the center of each plate supports the shoe of the rod. To set the plate, the rodman places it over the selected point and presses the prongs into the ground with his foot until the plate is in firm contact with the surface.

Since rod displacement is an important source of error in leveling, due care should be exercised by the levelmen in selecting turning pins or plates. A turning pin or plate should be selected which will give the least amount of displacement in a particular type of soil.

18. Hand levels

Hand (or Locke) levels (fig. 8) are standard auxiliary equipment for the levelman and rodman, as an aid in determining favorable points on slopes, to obtain maximum sight distances and take advantage of the full usable span of the rods.

FIGURE 8.—Hand level with wrist strap.

The hand level is a metal tube 6–8 inches long, with an eyepiece at one end and a level bubble mounted near the objective end. Some have a focusing eyepiece. The bubble appears at one side of the field of view, in a 45° mirror or prism; the rest of the field is clear for sighting the rod or object. The instrument is used to determine the height or position of the object sighted in relation to the eye level of the observer.

The adjustment of the hand level is checked by setting up the regular level and identifying a distinctive mark 30–40 feet distant, at the same elevation as the line of sight. The hand level is then held beside the main level, at the same height, and the selected mark is sighted. If the bubble of the hand level is off center, the small screws holding the bubble vial are loosened, the vial is shifted forward or back until the bubble is centered when the mark is sighted, and the screws are tightened.

19. Itemized list of equipment and supplies for a leveling party:

1 level, automatic or prism
1 tripod
2 rods, yard
3 hand levels
2 turning pins
2 turning plates
2 mallets, rawhide
1 tape, 25-ft of 50-ft
1 compass, prismatic or pocket
1 set dies, 3/16-in. figures and letters
2 drills, rock, 7/8-in.
2 chisels, cold
1 hammer, 2½-lb
2 machetes with sheaths
1 axe, hand
1 posthole digger
1 crowbar (spudding bar)
1 typewriter

1 adding machine
50 bench-mark tablets
50 witness signs, USGS
25 witness signs, C&GS
100 copper nails and washers
100 identification tags
20 cans cement (or bag as needed)
12 lumber crayons (keel)
1 shovel
4 canteens
1 book bag
75 fenceposts, steel
1 fencepost driver (see p. 43)
Notebooks, center-wire method, Form 9–332.1, or
Notebooks, three-wire method, Form 9–332.2
Bench-mark descriptions, field summary, Form 9–1128
Summary sheets, Form 9–1128a
Recovery of permanent survey mark, Form 9–1165
Airport elevation, Form 9–332.6
Miscellaneous stationery and administrative forms.

CHAPTER 2E3. LEVELING OPERATIONS

OPERATION OF A LEVELING PARTY

20. Makeup of a party

Ordinarily, a full leveling party consists of four men, a levelman, a recorder, and two rodmen. (See figs. 9, 10.) If necessary, the levelman can record his own notes and operate with only one rodman. The levelman serves as chief of party, organizing and supervising the work. He is responsible for all controlled property issued for the use of his party and takes care of the required administrative reports and duties.

A good recorder, adept and accurate at figuring, can materially speed the progress of the party, especially when the three-wire method of

FIGURE 9.—Leveling party and equipment.

797–176 O—66——4

FIGURE 10.—Leveling party at work. Left to right: rear rodman, levelman, recorder, front rodman.

recording is used. In addition to keeping the notes and making the required checks for either method of leveling, he keeps the levelman informed of any imbalance between sums of backsight and foresight distances, drives the truck forward between setups, and helps in setting bench marks and writing descriptions.

The rodmen establish firm, stable turning points and hold the rods plumb for the observations. They pace the prescribed distances to the turning points to keep the sights balanced. They also help in setting bench marks, stamping tablets, and other miscellaneous work.

21. Basic procedures of leveling

In the process of differential leveling, a backsight is taken to a rod held on a point of established elevation (fig. 11). The rod reading is added to the known elevation to obtain the height of the instrument (HI). A foresight is taken to a rod held on a point forward along the line of progress. The elevation of the forward point is obtained by subtracting the foresight rod reading from the HI. The level is moved forward to a new setup, for which the established foresight point of the first setup serves as the backsight point, and the procedure of reading a backsight and a foresight is repeated.

The elevation is thus carried forward at each setup from backsight point to instrument to foresight point. To check the successive elevations along the line, the final foresight is taken on a point of established elevation, either the starting point or another point of known elevation. Subtracting the known elevation from the terminal elevation as carried through the line gives the error of closure (usually called simply "closure"), an indication of the accuracy of the leveling. A less satisfactory check is ob-

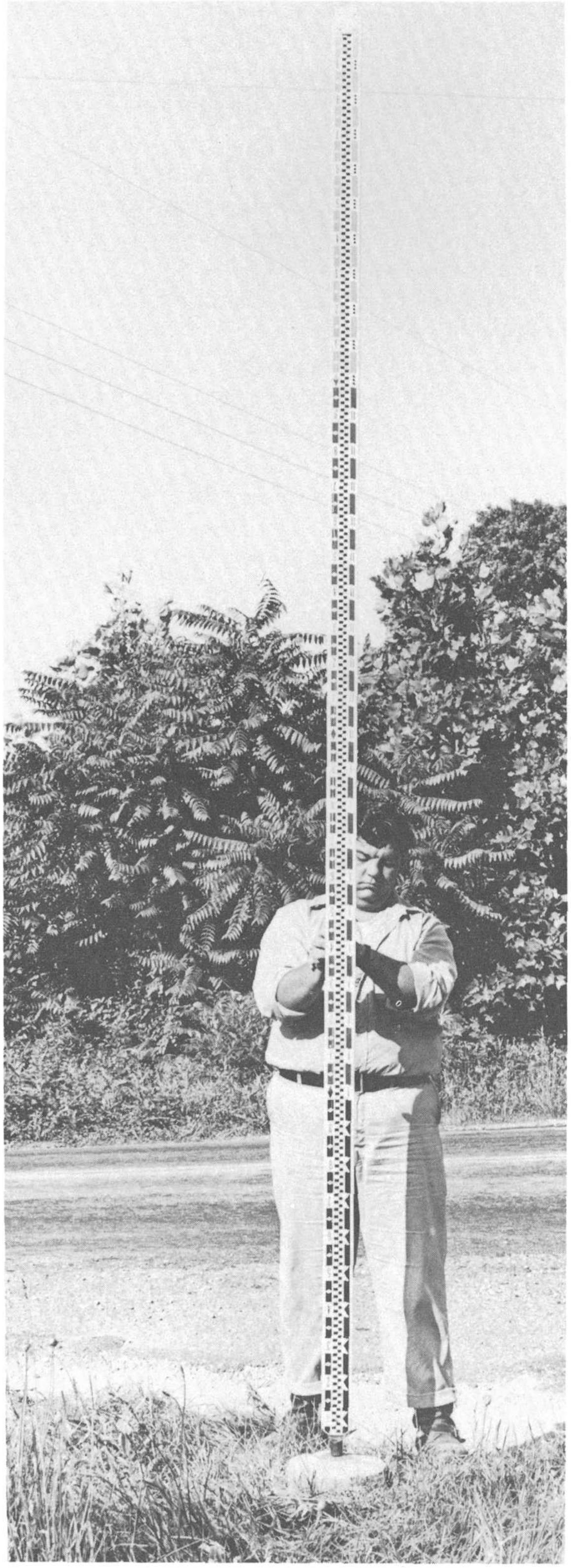


FIGURE 11.—Rodman giving backsight on a starting point.

tained on spur lines by running the line back from the farthermost foresight point to the starting point and comparing the two differences of elevation obtained between common points on both lines or runnings.

Experienced levelmen develop a systematic routine of operation, involving as few movements as possible and a minimum likelihood of mistakes. Great care must be taken to make each reading precisely and to avoid any systematic error. Although the effect of such error may be insignificant on a single sight, it may accumulate enough to produce an out-of-limits line closure.

All members of the party must realize that the rear turning point, the level, and the forward turning point are depended on, in turn, to hold the elevation as it is carried forward. If any one is moved or disturbed before the elevation is transferred from it, the line is broken and the party must return to the nearest marked point of known elevation and begin again. The length of time the instrument holds the elevation should be kept as short as practicable.

DETAILS OF THIRD-ORDER LEVELING

22. Starting and tie points

Lists of established control points furnished to the levelman are checked by the Area geodetic section for completeness, accuracy, and reference to proper datum. Each old bench mark to which new leveling is tied must be positively identified by checking the data stamped on the mark and any figures or letters marked nearby. Measurements to described reference points also must be checked carefully, and local inquiry sometimes may be needed to make sure that the mark has not been disturbed.

A third-order level line may be started from and tied to a single monumented bench mark at each end if the bench-mark elevation was established no earlier than the previous year and the levelman is reasonably sure that the marks have not been disturbed. Any available reference marks must be tied in to check the bench-mark elevations. If the levelman suspects that the starting elevation is in error, he must also tie in the next adjacent bench mark of the adjusted line. If the difference of elevation between the two old bench marks does not check within third-order limits, a third mark must be tied.

Similar precautions must be observed in closing a line. A double-run spur line must start from an elevation checked by a reference mark or adjacent bench mark, unless the starting elevation has recently been established on the same project and is known to be undisturbed.

23. Turning points

In leveling along roads and railroads, the rodmen can save time by using available firm points as turning points. The chief requirements are that the points must be stable and the identical point used for a foresight must also be used for the next backsight.

Along railroads, the tops of rails or preferably the heads of firm spikes make good turning points. Each point must be marked with keel before the rod is held on it for the foresight. No one should step on a crosstie while one of the spikes in it is being used as a turning point. On steeply banked curves, the higher side of the railhead should be used.

If no suitable turning points are available along the leveling route, turning pins or plates are used. They *must* be fixed solidly in place to minimize settlement between foresight and backsight readings. Extreme care must be used when handling the rod on the turning pins and plates. Only the normal weight of the rod should bear on the turning point; the rodman must take care not to exert extra pressure or weight on the point. The rod must not be removed from the plate or pin between foresight and backsight because the amount of settlement is not likely to be the same after it is replaced. The rod is rotated carefully without changing the weight it exerts on the pin or plate. If these precautions are not followed, the resulting systematic error can be significant.

Two recoverable turning points must be established when work is stopped temporarily without tying the line to a bench mark or other solid, durable mark. The two turning points provide a starting check when the line is continued.

24. Length and balancing of sights

The maximum length of sight permitted under ideal conditions is 300 feet, except at river crossings where longer sights may be unavoidable. The average length of sight in any level line must not exceed 200 feet. Sights must be shortened when visibility is impaired by heat waves or for any other reason. Rod readings must not be taken below 0.5 yard on the rod except for sights less than 60 feet in length. A sight more than 60 feet long must clear a crest by at least 2 feet.

Backsight and foresight distances should be approximately balanced on every setup. The imbalance at a single setup *must not exceed* 30 feet, and this amount must be removed within two setups. The total accumulated imbalance between foresight distances and backsight distances at any point between ties should generally be kept less than 10 feet. An imbalance greater than 30 feet must not be accumulated at any point in the level line.

Sight distances are measured by stadia and recorded in the field notebook. These are accumulated as the line progesses so that any imbalance can be detected.

25. Center-wire method

Two standard methods are available for reading the rod and recording fieldnotes—the center-wire method and the three-wire (thread) method. The three-wire method incorporates more checks, but it takes more time and requires an expert recorder. It is the method always used for first-order leveling with instruments not equipped with a parallel-plate micrometer and has been generally preferred for leveling in mountainous terrain, where mistakes would involve costly reruns. The center-wire method is much simpler and faster and is entirely adequate for third-order leveling. As each method has particular advantages, the one to be used, either regularly or for special projects, will be specified by the field surveys branch of the Area office.

The general procedure is the same for both methods. The level setups and turning points should always be set on firm and stable ground, not on such surfaces as bituminous-paved roads or marshy ground. The automatic levels, unlike spirit levels, do not give any indication of settlement by going out of level.

The errors caused by settling of the tripod or a turning point, and by unequal heating of the instrument by the sun, can be reduced by taking the foresight first at alternate setups. In this procedure, called the "alternate-setup method," the same rod is read first at every setup.

At each setup, the instrument is oriented so that one part of the tripod and the level always point to the same rodman. The bull's-eye bubble can be roughly centered by moving one of the legs. The instrument can then be precisely leveled by the leveling screws with minimum motion.

Thus, the attitude of tripod and instrument at every station is rotated 180° with respect to the attitude at the previous station. The observer then calls out the backsight or foresight readings, and the recorder enters them in the fieldbook and makes the required checks. The levelman then calls out the readings for the other rod. At setups where the backsight is read first, the rear rodman is signaled to come forward as soon as the figures for the backsight are checked and accepted. When the foresight is read first, both rodmen must hold their turning points until all readings are recorded and checked. The levelman and recorder then move forward to a new setup while the front rodman remains at his turning point to give the next backsight. This rodman should keep his rod on the turning pin or plate while the instrument is being moved, to minimize errors due to upheaval forces on the turning point.

As shown in figure 12, the reticle consists of one vertical and three horizontal crosswires. In the center-wire method, only the center-wire intercepts are read for elevation, as follows:

With an erecting eyepiece (automatic level), read up in the rod image; with an inverting eyepiece (prism level), read down.

Read stadia distance to the first rod. All prism levels and newer automatic levels have 0.3:100 half-interval wires, so that the reading is taken on the face of the rod, between the center wires and either the upper or lower stadia wire. Some of the earlier Ni2 levels have 1:100 full-interval stadia wires, so that the reading is taken on the foot check scale on the rear of the rod, between the top and bottom wires. The pendulum action in the automatic level does not permit the operator to set one of the stadia wires on an even graduation for reading stadia distance; therefore, both wires must be read. Most levelmen mentally subtract the difference and call out the result. Many levelmen prefer to do the same with the prism level even though one of the wires can be set on an even graduation with the rear footscrew or the micrometer.

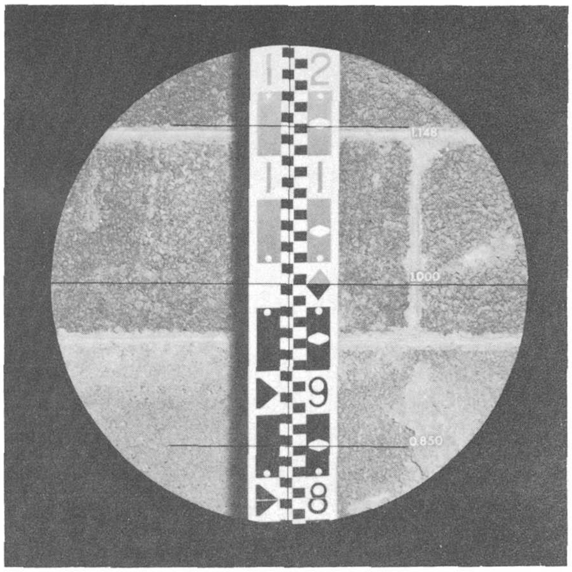


FIGURE 12.—Segment of rod as seen through telescope of level.

With the instrument leveled, tap the automatic level to check for free action of the compensator and call the yard color intercepted by the center wire.

Call the center-wire intercept reading, in yards, tenths, hundredths, and estimated thousandths.

Signal the rodman to display double-yard check scale; call the center-wire reading, estimated to thousandths. This reading must be unbiased.

When the recorder has checked and accepted the readings taken on the first rod, turn the telescope towards the other rod; then tap the automatic level or bring the bubble of the prism level to center with the micrometer.

Call the readings for the other rod as soon as possible after the telescope has been turned toward the other rod, especially when using the prism level. The stadia reading is taken last.

26. Three-wire method

Procedures are generally the same as for the center-wire method, described in article 25, except that the intercepts of all three horizontal wires are read and stadia is not read separately unless the level has 1:100 wires (earlier Ni2 levels). The following variations in procedure should be noted:

Call the yard colors intercepted by the top and bottom wires.

Call the intercept readings of the top, center, and bottom wires, in yards, tenths, hundredths, and estimated thousandths. Each reading must be made independently.

Signal rodman to display the foot check scale; call the center-wire intercept reading in feet, tenths, and estimated hundredths.

27. Establishing bench marks and useful elevations

The usefulness of geodetic leveling is extended and preserved by establishing bench marks and useful elevations along the lines of leveling. These are marked and described points which can be recovered for future surveys.

On third-order lines, monumented bench marks (art. 41) are established at intervals of approximately 1 mile whenever feasible. Where it is not feasible to adhere to the 1-mile spacing, monumented marks should be spaced at intervals of approximately 2 miles, and a nonmonumented bench mark established between the monumented marks. If 2-mile spacing is used, two monumented marks must be established at all junctions and probable future junctions—one at the junction and the other approximately a mile from it. For detailed instructions on setting marks, see articles 44–46.

UE's (useful elevations) may be established as desired, but they should be limited to points that are both photoidentifiable and mapworthy, so that they can be shown on the published map as checked spot elevations. All useful elevations must be established as turning points in the line, not as sideshots, and must be identified unmistakably in the fieldnotes.

As all marks should be placed at locations useful for subsequent phases of mapping, a careful study of the aerial photographs covering the proposed leveling routes will aid in selecting favorable sites; it can also obviate much field reconnaissance.

If a monumented bench mark cannot be set until after the line is run past the selected location, two reference marks that are turning points in the line must be left at the site. A checked elevation for the bench mark can then be determined later by two independent setups connecting the two reference marks, with the bench mark as midpoint. Space must be left in the fieldbook for recording the notes of these setups. An unchecked sideshot must never be used to establish the elevation of a bench mark.

a. Tying in marks of other surveys.—Survey marks of other organizations should be tied in wherever practicable if the ties do not require an unreasonable amount of extra leveling. If the marks are of substantial and permanent construction and are properly situated, they may be substituted for standard monumented bench marks. If data on the available marks are included in the material supplied to the levelman, he should recover as many of the marks as requested and establish elevations on them. If, however, he discovers marks of surveys that were unknown to the control planner, usually local surveys, he should obtain as much information about the surveys as he can and include it with the field data submitted to the office.

28. Airport ties

Elevations accurate to the nearest foot are an important requirement for all airports shown on aeronautical charts of the Coast and Geodetic Survey. Interpolation between contour lines on topographic maps is not accurate enough for this purpose. Special surveys and C&GS leveling parties have established elevations at most airports, but elevations are still needed for some civil and joint civil-military airports. The Geological Survey cooperates with C&GS in supplying these elevations.

If an airport is not more than 1 mile by road from a planned leveling route, the levelman should determine if an accurate elevation has been established for the highest point of the landing area. If so, he should record it in the field notebook, giving the authority for the elevation, and continue with his line. However, if no accurate elevation has been established or the source or reliability of an available elevation is uncertain, the levelman should proceed as follows:

Obtain permission from the airport management to run the necessary levels at the airport.

Using the level, identify the highest point on the usable landing area (that is, the portion of the runways or field on which takeoffs and landings are permitted, not including the overrun area used only for taxiing; on paved runways, the limits between the two areas are usually marked by painted chevrons).

Using standard third-order methods, determine the elevation of the highest point, either by including it in a closed circuit or by double running.

Prepare Form 9–332.6, Airport Elevation, in triplicate, including a sketch showing the location of the highest point in relation to the airport runways. (See fig. 13.) As soon as the line has been closed satisfactorily, put the blue copy of Form 9–332.6 in the quadrangle report folder and mail the original (white) and the yellow copy to the Area office. If the quadrangle report folder is not available, mail all three copies to the Area office.

In addition to the point at the highest elevation, a monumented bench mark should be established in a suitably protected location, unless there is a monumented bench mark within 0.5 mile.

29. River crossings

To carry an elevation across a stream more than 300 feet wide, reciprocal observations must be made between 2 turning points on opposite banks.

The plan of operation is shown diagrammatically in figure 14. The leveling is brought to the near bank of the river, and the levelman selects the location for setup *1* (fig. 14) where he can see across the river. Firm turning points *A* and *B* are then established at nearly the same elevation, one on each side of the river. The levelman sets up carefully at *1*, reads the backsight to the last previous turning point in the line, and reads foresights to points *A* and *B*. He makes three independent readings on the long foresight to *B*, tapping the automatic level before each reading, or running the bubble off center and releveling with the micrometer of the prism level. The mean of the three readings is adopted for the long foresight. As the check scales cannot be read at great distances, the three face readings provide a check.

The levelman then crosses the river and sets up at *2*, near turning point *B*. He reads backsights to *B* and *A*, using the same procedure for the long backsight to *A* as for the long foresight from *1* to *B*. The HI at *2* is the mean of the determinations by routes *1–A–2* and *1–B–2*. The line continues forward with the foresight at *2*.

Improvised targets should be used if the levelman cannot read the far rods clearly. The targets can be run up and down and set by the rodmen in response to the levelman's signals. The distant rods are read most easily on calm cloudy days or in the early morning or late afternoon with the sun behind the observer.

30. Extending elevations by water levels

In areas with lakes or large ponds, leveling often may be extended quickly and accurately by using the water surfaces. Water elevations should be established only while the surfaces are calm, at points more than 100 yards from any sizable inlet or outlet that might affect the water level. If the distance across the body of water is a mile or more, a monumented bench mark should be established at each side, where the leveling enters and leaves the water surface. If possible, the sights to these bench marks should be made on the same setups as the sights to the water level. Fieldbook entries should state the method used, the date and time, and should describe the points at which elevations are transferred to and from the water level.

A recommended method of establishing the elevation of the water surface is to backsight to the bench mark and read the foresight on a rod held exactly at water level, on a solidly embedded rock or on a stake firmly driven into the lake bed. A rodman is then sent to the opposite shore to mark the water level there on another rock or stake, at the specified time or signal. Simultaneously, the levelman notes and records any change in the water level between the original and later foresights. Moving to the opposite side of the lake, he uses the marked water level as the backsight to continue the line. Alternatively, hubs or rocks at water level can

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
FORM 9-332.6

COAST AND GEODETIC SURVEY

AIRPORT ELEVATION

STATE Wyoming COUNTY Sweetwater QUADRANGLE Alkali Lake, #126

AIRPORT NAME Wamsutter PRIMARY REFERENCE Wamsutter, 1.5 mi north of
(Direction and distance)

BM DESIGNATION AND ELEVATION 17 IWH 1961, 6870 FEET (If located) ELEVATION HIGH POINT 6875 FEET (On runway)

APPROXIMATE LATITUDE 41 ° 43 ' -- "

APPROXIMATE LONGITUDE 107 ° 59 ' -- "

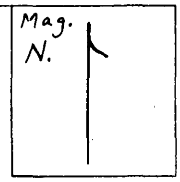
IDENTIFICATION ON PHOTO # 26 ROLL # 2

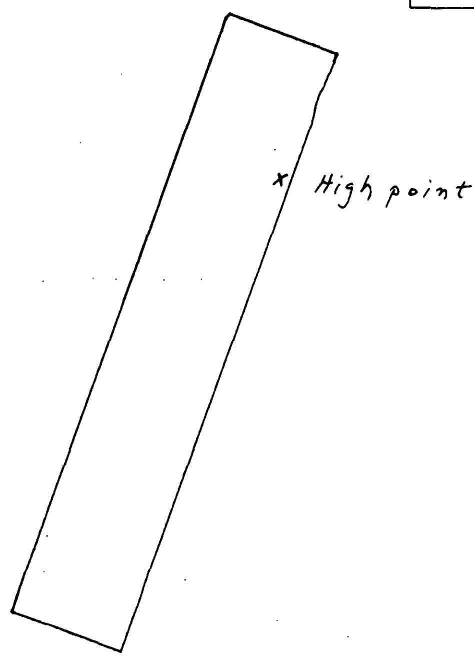
ELEVATION DETERMINED BY: LEVELS [X] CLOSED STADIA TRAVERSE [ ] .... (Other) [ ]

BRIEF DESCRIPTION OF HIGH POINT:

Near east edge of runway, 1050 ft south of NE. corner

SKETCH OF HIGHEST POINT WITH REFERENCE TO RUNWAYS: SCALE 1:12,000 ORIENTATION:





(Please prepare in triplicate)

SUBMITTED BY: IW Harper DATE August 26, 1961

TITLE Party Chief, Levels FIELD BOOK IWH Book 2, Red Desert Project

CHECKED BY: DO Blackwell PAGE 26

TITLE Project Engineer

Airports or landing fields having existing bench marks need not be reported.

16—75976-1—F GPO

FIGURE 13.—Example of completed Form 9-332.6, Airport Elevation.

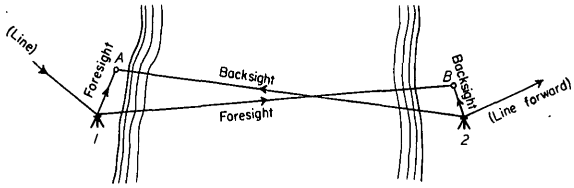


FIGURE 14.—Reciprocal sights for river crossing.

be established simultaneously by stationing men at the desired points in advance and setting the marks at a specified time. The lake also may serve as a junction point if three or more hubs and bench marks are set around the perimeter.

If the lake is controlled by a dam, a bench mark should be established on or near the dam unless this would entail more than a mile of extra leveling. The difference of elevation between the water level and the crest of the spillway should always be given, and an elevation should be established on the water gage (if there is one) at as nearly the same time as the other observations as practicable. The water level at the spillway and on both sides of the lake can be marked simultaneously by prearrangement, if desired.

RECORDING FIELDNOTES OF LEVELING

31. Center-wire fieldnotes

Notes for the center-wire method (art. 25) are recorded in the standard notebook, Form 9–332.1, Leveling Notes, Center-Wire Readings. The title page must be filled in before any notes are recorded, and the heading of each page must be filled in as it is used. An example of center-wire notes is shown in figure 15. Columns have been numbered in the illustration for easy reference in the following explanation.

The horizontal lines are grouped into pairs set

43

Date: Sept. 9, 1964, W.S.W. Lev. R.D.C. Rec. Line from See Pg. 35, via ...., to ....

① BACKSIGHT Color Dist.	② Check	③ Yards	④ H. I. Yards Elev. Yards	⑤ FORESIGHT Yards	⑥ Check	⑦ Dist. Color	⑧	⑨ Elev. Feet	Rod A - Jones Rod B - Smith DESCRIPTIONS
2980			363.291	Elevation brought forward from page 42		2980		1089.873	10.71
B 120 3100	171	0.342		2.015	1008	120 G 3100	A		
R 100 3200	716	1.432		1.972	986	80 R 3180	B		
B 80 3280	222	0.445		3.314	1657	100 Y 3280	A		
B 60 3340	261	0.521	354.958	3.772	1886	80 Y 3360	B	1064.874	UE: X-Rds; intersection of U.S. Hwy. 67 and east-west gravel road 10.85
	1370	2740		11.073	5537				
B 60 3400	216	0.432		3.754	1877	70 Y 3430	A		
B 40 3440	173	0.346		2.572	1286	30 G 3460	B		
B 50 3490	236	0.471		2.623	1311	40 G 3500	A		
B 50 3540	162	0.325		3.654	1827	40 Y 3540	B		
B 50 3590	228	0.456		3.163	1582	60 Y 3600	A		
G 150 3740	1007	2.014		1.124	562	140 R 3740	B		
Y 120 3860	1782	3.564		0.745	372	130 B 3870	A		
G 120 3980	1316	2.632		1.378	689	110 R 3980	B		
R 100 4080	786	1.572	344.968	2.789	1394	100 G 4080	A	1034.904	11.13 BM: Orfordville, 4.3 miles north of along U.S. Hwy. 67; near center SE ¼ sec. 26, T. 14 N., R. 22 W.; 120 ft north and 23 ft west of and 2 ft lower than T-rd east; 47 ft southwest of 32-inch oak tree standing on east side of hwy; in rock ledge, 5 ft west of witness post; std tablet stamped "12 WSW 1964."
SUMS FOR PAGE			ELEV.—ELEV.	SUMS FOR PAGE					PAGE CHECK MILEAGE
2980 1100 4080	7276 × 2 14.552	14.552	−18.323 B. S.—F. S. −18.323	32.875	16.437 × 2 32.874	2980 1100 4080		1089.873 1034.904 − 54.969	−18.323 3 −54.969 1100 1100 2800 = 0.42 10.71 0.42 11.13

FIGURE 15.—Leveling notes, center-wire method, Form 9–332.1.

off by red lines, and each pair contains the notes for one setup. The backsight and foresight readings are recorded on the upper line of a pair, and the elevation (in yards) of a marked or described point is recorded on the lower line along with the cumulative distances.

The color checks for unit yards (B=black=0, R=red=1, G=green=2, and Y=yellow or orange=3) and the stadia distances (in feet) are recorded in columns 1 and 7. Columns 3 and 5 contain the center-wire yard readings, to thousandths of a yard. The double-yard check-scale readings are recorded in columns 2 and 6; these readings must be made carefully and independently by the levelman. The recorder checks each yard reading by halving it and comparing the result with the corresponding check-scale reading; he should not call out half the reading and have the levelman verify it, as this would destroy the independence of the check reading. If the check reading and one-half the yard reading do not agree within 0.002 yard, after correction for any index error (art. 16*a*), both readings must be repeated.

In using the alternate-setup method, described in article 25, the recorder can organize his notes by recording in column 8 the designation of the rod held on the foresight. He must be very careful to enter the backsight and the foresight readings in their proper columns.

a. Computing forward elevations.—The entry at the top of column 4 is the elevation in yards carried forward from the previous page, or the starting elevation of the line, converted to yards, if the line begins on the page.

If a foresight is to a marked or described point, the elevation in yards is recorded on the second line of that setup. This elevation is then multiplied by 3 and entered in column 9 on the same line. The recorder is not required to compute the HI and the elevation of the foresight point for each setup; but he must compute the elevation of each marked or described point, or the final elevation on a page, by adding the backsight yard readings and subtracting the foresight yard readings from the preceding computed elevation. An adding machine may be carried in the truck for computing and checking elevations.

The rest of the page should be left blank after recording the elevation of a bench mark. At least two spaces (between red lines) should be left blank after each UE; if the UE is recorded on the lower part of a page, the rest of the page should be left blank.

b. Page checks.—The notes must be page-checked at each bench mark or UE and also before starting a new page. The sum of the readings in column 2 is multiplied by 2, and the result should approximately equal the total for column 3 (this check can be made exact by noting the discrepancies between individual yard and check readings; the algebraic sum should equal the discrepancy at the bottom of the column). Columns 6 and 5 are checked similarly. The difference between the first and last elevations in column 4 should equal the difference of the sums of columns 3 and 5. This difference multiplied by 3 should equal the difference between the first and last elevations in column 9.

Page-checking is facilitated if the recorder subtotals columns 2, 3, 5, and 6 every two or three setups. The subtotals are entered in small, light figures.

c. Distance record.—Backsight and foresight stadia distances are added cumulatively in columns 1 and 7, so that a close check can be kept on the balance between these distances. To avoid excessively large numbers, the cumulative sums usually start with zero at each monumented bench mark.

Cumulative mileage along the line is recorded along the right edge of the page. Subtotals of backsight and foresight distances are added at each computed elevation, the sum is converted to hundredths of a mile, and the increment is added to the mileage of the next previous computed elevation. Backsight and foresight distances and mileage are page-checked as shown in figure 15. Mileage is kept continuous from the beginning to the end of a line, because it is used in computing and adjusting lines of leveling and is shown in preliminary lists of elevations.

d. Day checks.—To guard against mistakes in carrying elevations forward, a day check should be made as follows:

Add the several sums of backsight readings shown in the page checks for the day's running (col. 3).

Substract the sums of foresight readings (col. 5).

Compare the result with the difference between the day's initial and final elevations (subtract initial from final elevation to obtain correct algebraic sign).

Any discrepancy must be thoroughly investigated and corrected.

32. Three-wire fieldnotes

Notes for the three-wire method (art. 26) are recorded in the standard notebook, Form 9-332.2, Leveling Notes, Three-Thread Readings. The title page must be filled in before any notes are recorded, and the heading of each page must be filled in as it is used. A sample of three-wire notes is shown in figure 16. Columns have been numbered in the illustration for easy reference in the following explanation.

The horizontal lines are divided into groups of four, set off by red lines, and each group is used for the notes of one setup.

The unit-yard check colors intercepted by the top and bottom wires (B=black=0, R=red=1, G=green=2, and Y=yellow or orange=3) are recorded in columns 1 and 9 together with the center-wire readings on the foot check scale (back of rod), to hundredths of a foot. Columns 2 and 8 contain the groups of three-wire (or thread) intercept readings, to thousandths of a yard. The interwire intervals, between the top and center wires, and center and bottom wires, are entered in columns 3 and 7. With standard 0.3:100 half-interval stadia wires, these intervals indicate horizontal distances in feet (decimal points are dropped, thereby multiplying the intervals by 1,000).

Ni2 levels with 1:100 full-interval stadia wires will give interwire intervals that are 67 percent too large for distance readings in feet.

Date: Sept. 9, 1964, TDW, Levelman. M.S.R, Recorder. Line from Middletown, via State Hwy. 64, to Saltville 44

① Checks	Backsight ② Thr. Rdg.	③ Thr. Int	④ Sum. T. R.	H. I. ⑤ Elev. Feet	⑥ Sum. T. R.	Foresight ⑦ Thr. Int	⑧ Thr. Rdg.	⑨ Checks		⑩ Fore Rod and Sta.	Temp.	Dif. Cor. O. & R.	Miles From B.M. E-44	Descriptions, computations, and remarks {Dry, Clear; Wet; Cloudy} Wind: ~~Calm~~; moderate; ~~strong~~ Rod A-Smith, Rod B-Jones
		4752		327.861		4742							4.02	Brought forward from page 43.
B	0675	81				89	3609	Y						
1.78	0594	82	1781	____	10560	89	3520	10.56		B				
B	0512	4833				4831	3431	Y						
B	0733	85				80	3379	Y						
1.95	0648	85	1944	____	9896	81	3299	9.89		A				
B	0563	4918				4911	3218	Y						
		166	3725		20456	169								
B	0700	97				100	3121	Y						
1.81	0603	97	1809	____	9063	100	3021	9.06		B				
B	0506	5015				5011	2921	G						
Y	3027	300		327.861		286	1115	R						
8.17	2727	302	8179	− 18.292	2486	287	0829	2.49		A				
G	2425	5315		309.569		5297	0542	B					4.23	UE: Painted circle at T-Rd south
		563	13719		32005	555								
	563 555 1118 = 0.21	____		____	13713 −18292	____								
Y	3180	140				153	2479	G						
9.12	3040	140	9120	____	6979	152	2326	6.98		B				
G	2900	5455				5450	2174	G						
G	2602	184		309.569		189	2369	G						
7.25	2418	184	7254	+ 2.855	6540	189	2180	6.54		A				
G	2234	5639		312.424		5639	1991	R					4.36	BM: Middletown, 4.3 mi east of along State Hwy. 64; 2.8 mi north of Pleasant Grove;
		324	16374		13519	342								17 ft north and 31 ft west of and 2 ft higher than crossroads; 38 ft east of 24-inch
	324 342 666 = 0.13	____	13519 + 2855	____		____								walnut tree; 2 ft south of fence; in concrete post, 2 ft west of witness post,
		____		____		____								projecting 4 inches; std. tablet stamped "18 TWD 1964"
		____		____		____								
Σ M.T.R. yds.	10.030	D_b	Σ B. S.	Elev.—Elev.	Σ F. S.	D_f	15.175	Σ M.T.R. yds.						D_b+D_f = 1784 Feet = 0.34 Miles 4.36 Total miles.
30.08	× 3	887	30087	−15.437	45.524	897	× 3	45.52						$\frac{C(D_b-D_f)}{100}$ = ... Cor. for Level and Collimation in feet.
ft.	30.090	ft.	ft.	−15.437 B. S.—F. S.	ft.	ft.	45.525	ft.						
	+3	5639				5639	+1							

FIGURE 16.—Leveling notes, three-wire method, Form 9-332.2.

To use these intervals for stadia distance would require multiplying each interval by 0.6. With these reticles, therefore, it is better to read stadia on the foot check scale.

In column 10, the designation of the rod held on the foresight is recorded to help the recorder to keep the notes straight, so that a backsight reading will not be recorded in the foresight column and vice versa.

Columns 4 and 6 contain the sums of each group of three yard readings, equivalent to the mean of these readings converted to feet. The entry at the top of column 5 is the elevation in feet carried forward from the previous page, or the starting elevation of the line if the line begins on the page.

Because of the considerable extra work involved in recording three-wire notes, it is preferable not to compute the HI and forward elevation for each setup. Elevations must, however, be computed for all marked or described points and at the bottom of each page, by adding the backsight readings and subtracting the foresight readings from the preceding computed or established elevation.

The rest of the page should be left blank after recording the elevation of a bench mark. At least one space (between red lines) should be left blank after each UE; if the UE is recorded on the lower part of a page, the rest of the page should be left blank.

a. Observation and fieldnote checks.—Three checks must be made for each setup:

The color symbols in columns 1 and 9 should check the unit-yard figures of the top and bottom yard intercepts in columns 2 and 8.

The interwire intervals in columns 3 and 7 should check the intercept readings of all three wires in columns 2 and 8 within 0.002 yard.

The center-wire check readings in columns 1 and 9 should check the corresponding sum entries in columns 4 and 6 within 0.02 foot, after correction for any index error (art. 16*a*).

All these checks must be satisfactory before the level is moved to the next setup.

A page check must be made at each bench mark or UE and also before starting a new page. The sums of columns 1 and 9 should check the sums of columns 4 and 6, allowing for the algebraic sum of discrepancies between individual readings. Likewise, the sums of the center-wire readings in columns 2 and 8, multiplied by 3, should equal the sums of columns 4 and 6 when allowance is made for the algebraic sums of the interwire interval discrepancies in columns 3 and 7. The difference between the sums of columns 4 and 6 should equal the difference between the initial and final elevations on the page in column 5.

To guard against mistakes in carrying elevations forward, a day check should be made by adding the several sums of mean backsight readings shown in the page checks for the day's running (col. 4) and subtracting the sums of mean foresight readings (col. 6). The result should check the difference between the day's initial and final elevations (subtract initial from final elevation to obtain the correct algebraic sign). Any discrepancy must be thoroughly investigated and corrected.

b. Distance record.—Backsight and foresight stadia distances are added cumulatively in columns 3 and 7, so that a close check can be kept on the balance between these distances. To avoid excessively large numbers, the cumulative sums usually start with zero at each monumented bench mark. Either one of a pair of interwire intervals may be used to figure the cumulative distance.

Cumulative mileage along the line is recorded in the distance column on the right-hand page Subtotals of backsight and foresight distances are added at each computed elevation. The sum is converted to hundredths of a mile, and the increment is added to the mileage of the next previous computed elevation. Mileage is kept continuous from the beginning to the end of a line; it is used in computing and adjusting lines of leveling and is shown in preliminary lists of elevations.

SECOND-ORDER LEVELING

Any second-order leveling called for by the control plan will consist of class I double-run lines. (See arts. 3*b*, 4*a*.) As the chief purpose of these lines is to strengthen the leveling network, they should be run over the routes that offer the most favorable conditions for accurate leveling whenever circumstances permit a choice of routes. Whenever possible, second-order lines should be run in advance of the third-order leveling. If advance second-order leveling is impractical, any third-order leveling over part of a route planned for a second-order line should conform to the procedures for forward runs of second-order leveling; subsequent backward runs will raise the coincident portion of the route to second order.

33. Procedures for second-order leveling

The specifications for class I lines of second-order leveling require double runs in opposite directions over sections of line 0.5–1.0 mile long. The separate runs should be made under different conditions—for example, sunny and cloudy or morning and afternoon. Differences of elevation obtained by the pair of runs over a section should agree within 0.035 ft $\sqrt{M}$. For convenient use, allowable closure or divergence limits for various lengths of line are tabulated in Form 332.1b. (See fig. 17.) If the initial pair of runs over a section do not check, the section must be rerun until agreement within limits is obtained between a pair of forward and backward runs. Each run must be completely independent; the final setup of one run must not be used as the first setup of a reverse run.

The cumulative divergence between forward and backward runs must be considered in addition to the allowable error for each section. If the divergence is caused principally by random or accidental errors, the errors will tend to compensate on long lines. In actual leveling, however, very small systematic errors due to imperfect equipment or techniques may sometimes cause the divergence to accumulate steadily in one direction, so that the line fails to close satisfactorily even though each section checks within limits. If the cumulative divergence shows a tendency to increase steadily in either direction (plus or minus), an effort should be made to determine the cause of the accumulation, and steps should be taken to correct the tendency. A steady accumulation of divergence in one direction is usually a good indication of systematic error, which should be eliminated if possible. (See art. 35.) The levelman must be on constant guard against excessive divergence, especially on long lines.

Owing to the greater importance and

Form 332.1b U. S. Geological Survey

ALLOWABLE CLOSURE LIMITS IN LEVELING
(or divergence between F & B runs)

SECOND ORDER				THIRD ORDER	
Closure (ft) = 0.035 $\sqrt{\text{Miles}}$				Cl. (ft) = 0.050 $\sqrt{M}$	
Miles	Cl. (ft)	Miles	Cl. (ft)	Miles	Cl. (ft)
0.08	0.010	8.2	0.10		
0.12	0.012	9.9	0.11	0.04	0.01
.16	.014	11.8	.12	.16	.02
.21	.016	13.8	.13	.36	.03
.26	.018	16.0	.14	.64	.04
.33	.020	18.4	.15	1.00	.05
0.40	0.022	20.9	0.16	1.44	0.06
.47	.024	23.6	.17	1.96	.07
.55	.026	26.4	.18	2.56	.08
.64	.028	29.5	.19	3.24	.09
.74	.030	32.7	.20	4.00	.10
0.84	0.032	36.0	0.21	4.84	0.11
.94	.034	39.5	.22	5.76	.12
1.06	.036	43.2	.23	6.76	.13
1.18	.038	47.0	.24	7.84	.14
1.31	.040	51.0	.25	9.00	.15
1.44	0.042	55.2	0.26	10.2	0.16
1.58	.044	59.5	.27	11:6	.17
1.73	.046	64.0	.28	13.0	.18
1.88	.048	68.7	.29	14.4	.19
2.04	.050	73.5	.30	16.0	.20
2.47	0.055	78.4	0.31	17.6	0.21
2.94	.060	83.6	.32	19.4	.22
3.45	.065	88.9	.33	21.2	.23
4.00	.070	94.4	.34	23.0	.24
4.59	.075	100.0	.35	25.0	.25
5.22	0.080	105.8	0.36	27.0	0.26
5.90	.085	111.8	.37	29.2	.27
6.61	.090	117.9	.38	31.4	.28
7.37	.095	124.2	.39	33.6	.29
8.16	.100	130.6	.40	36:0	.30

FIRST-ORDER tolerances are approximately one-half those shown above for corresponding distances.

Closure (ft) = 0.017 $\sqrt{\text{Miles}}$

63807

FIGURE 17.—Tabulated closure limits for second- and third-order leveling, Form 332.1b.

accuracy of second-order lines, monumented bench marks are established at intervals of approximately 1 mile. This spacing of monuments automatically breaks the line into sections of convenient length, except where difficult conditions (such as rough terrain) make it desirable to subdivide the intervals between bench marks. Nonmonumented bench marks are not required. UE's, however, may be established on selected photoidentifiable points along the line.

In general, the operational procedures for second-order leveling are the same as for third-order leveling. The normal third-order procedures are modified so that the maximum length of sight under good atmospheric conditions does not exceed 200 feet. The average length of sight in second-order leveling should not exceed 150 feet.

At any setup, the difference between the backsight and foresight distance must not exceed 10 feet. Any imbalance incurred should be reduced to less than 5 feet in the next 2 setups. The total imbalance in sights in a section of second-order leveling must not exceed 10 feet.

The temperature to the nearest degree, as shown by the rod thermometer, should be read and recorded on the first backsight at the beginning of each section. If for any reason the leveling is interrupted for a considerable length of time, additional temperature readings should be recorded at the end of the continuous leveling and at the time the leveling is resumed. If 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 used for a backsight should be recorded first.

The level, especially a spirit level, should be shaded from the direct rays of the sun by an umbrella or other suitable means during setups and should be covered with a white cloth hood during moves between setups. Extra care should be taken to set up the level firmly and to establish firm, stable turning points. The levelman should always tap the automatic level before each reading to make sure that the compensator is swinging freely.

Either the three-wire or center-wire method may be used for second-order leveling. With a recently adjusted automatic level, the center-wire method is adequate, and it is the more practical method if the level is equipped with a parallel-plate micrometer. (See fig. 18.) The method to be used will be specified by the Area office.

Peg tests must be made at the start of each line and at 2- or 3-day intervals during the course of the line. If the instrument receives a jolt or blow which might disturb the compensator, bubble, reticle, or other element, a peg test should be taken immediately to determine if adjustment is necessary. Attempts to keep an instrument in perfect adjustment are not necessary. Strict balancing of sights will completely eliminate small collimation errors. No adjustment for collimation is necessary if the factor C does not exceed 0.006 foot (art. 13).

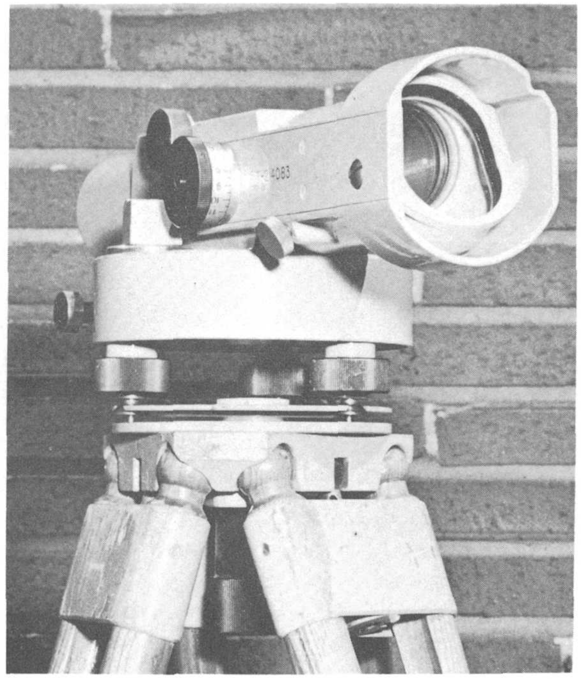


FIGURE 18.—Zeiss Ni2 automatic level with parallel-plate micrometer attachment.

The peg tests should be recorded at the points where they apply, and the date and time should be indicated. The recorded data should always show the value of C, after adjustment.

34. Recording fieldnotes of second-order leveling

Fieldnotes for second-order leveling are recorded in the standard notebooks, Form 9–332.1 for the center-wire method or Form 9–332.2 for the three-wire method. To avoid confusion among the multiple runnings, three books or sets of books should be used: one for the forward run, one for the backward run, and one for all reruns. The contents must be clearly specified at the beginning of each book.

The forward-run book contains elevations and complete descriptions of points along the line in continuous sequence from start to finish, exactly as for a single-run line. (See arts. 31, 32.) For convenience and simplicity, only the forward-run differences of elevation are used to carry preliminary elevations through the line. This enables the levelman or recorder to complete most of the bookwork without waiting for section closures. The preliminary elevations are not recomputed unless a serious mistake in the forward run is disclosed by subsequent runs. The notes for each individual section of the line should start on a fresh page.

The differences of elevation obtained from the forward and backward runs over each section are also tabulated in the forward-run book, on the page containing the description and elevation of the forward endpoint of the section (in the direction of progress). This tabulation together with the table in figure 17 makes it easy to compare the results of the runs and determine whether the section closure is satisfactory. Two sample tabulations are shown in figure 19.

The tabulation should include the divergence for the section and the cumulative divergence. The divergence for the section is added algebraically to the total carried over from the previous section to obtain the cumulative divergence at the end of the section. The mean elevation of the final point can be computed by

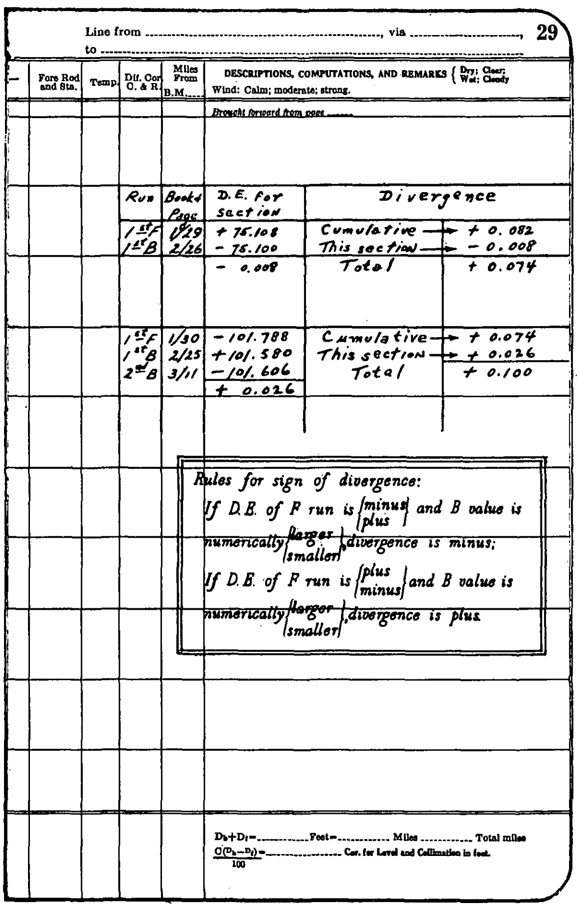


FIGURE 19.—Tabulating differences of elevation and divergence for sections of a second-order line.

adding algebraically half the cumulative divergence to the forward-run elevation of the point.

The second notebook contains the fieldnotes for the backward runs over the sections. Each section is recorded complete in itself and in the sequence of running, but not necessarily in the sequence shown in the forward-run book. As the forward-run book contains full descriptions of bench marks or other points marking the ends of sections, the descriptive notations in the backward-run book are abbreviated to the mileage determined by the forward run, the letters BM or SP (section point), the code stamping or the nature of the mark, and the elevation to the nearest 0.1 foot. For example,

27.12 mi, BM 27 WAL 1961, 807[2]

or 29.46 mi, SP copper nail and washer, 1016[8].

UE's are omitted on backward runs. If a significant mistake in the forward run is discovered, the UE's must again be tied in by the first rerun. This same system of recording is also used in the rerun notebook, which contains the notes for all additional runs needed to obtain satisfactory section closures. The separate runs over each section must be thoroughly cross-referenced in each notebook in which they appear.

If preferred, Form 9–332.7, Field Abstract, Level Notes, can be used instead of a tabulation in the fieldbook. (See fig. 20.) This form has the advantage of condensing onto one page the data for all the sections of the line.

The fieldbook page, section designation, mileage, and temperature are noted in the proper columns of the form. The sums of backsight readings and the sums of foresight readings are taken from the fieldbooks. The differences of elevation are computed for the forward and backward runs and the results compared to verify that they agree within limits. This form also has columns for the divergence between forward and backward runs and for the accumulated divergence over the line. The last column gives a brief designation of the bench mark for which the elevation is given in the observed elevation column.

35. Excessive divergence between runs

If the levelman encounters excessive divergence between runs, despite the usual precautions and refinements of procedure, he must

Form 9-332.7
November 1963

U.S. DEPARTMENT OF THE INTERIOR — GEOLOGICAL SURVEY

FIELD ABSTRACT, LEVEL NOTES

Page 1 of 18
Order 2nd Rod No. T-210191 Quadrangle Laramie 7½' State Wyoming
Level No. T-36273 Rod No. T-210192 Observer R. Jones Year 19 65

Complete Line from C&GS P-233 via U.S. Hwy. 287 to C&GS N-177

No. of Field Book and Page	1965 Date	Designation of Section: From B.M.	Designation of Section: To B.M.	Forward or Backward	Length of Section in Miles	Miles from B.M. P-233	F° Mean Temp. of Rods	Σ Mean Rod Readings in Feet for Section: Σ B.S.	Σ Mean Rod Readings in Feet for Section: Σ F.S.	Approximate Difference of Elevation in feet	Mean Difference of Elevation in feet (a)	2232.937 Observed Elevation Above Mean Sea Level in Feet	Divergence in Feet: Partial (b)	Divergence in Feet: Total Accumulated	Designation of B.M.
A-1	4/3	P233	1RJ	F	1.01	1.01	78°	56.733	44.501	+12.232	+12.226	2245.163	-.011	-.011	"1RJ 2245 1965"
B-5	4/3	1RJ	P233	B	1.02		81°	44.703	56.924	-12.221					
				F											
				B											
A-3	4/3	1RJ	2RJ	F	1.09	2.10	78°	101.325	60.781	Reject +40.544	+40.576	2285.739	+.024	+.013	"2RJ 2286 1965"
B-4	4/3	2RJ	1RJ	B	1.09		82°	60.781	101.369	-40.588					
B-6	4/3	1RJ	2RJ	F	1.09		83°	104.667	64.103	+40.564					
				B											
A-3	4/3	2RJ	3RJ	F	1.25	3.35	79°	60.712	55.376	+ 5.336	+ 5.335	2291.074	-.002	-.011	"3RJ 2291 1965"
B-3	4/3	3RJ	2RJ	B	1.24		82°	55.446	60.780	- 5.334					
				F											
				B											
A-4	4/3	3RJ	4RJ	F	0.95	4.30	80°	70.134	91.324	-21.190	Reject -21.198	2269.876	-.009	-.020	"4RJ 2270 1965"
B-2	4/3	4RJ	3RJ	B	0.96		81°	94.571	73.332	+21.239		Mean of 3			
B-7	4/3	3RJ	4RJ	F	0.95		82°	72.576	93.772	-21.196	-21.193	Forward mean			
B-8	4/3	4RJ	3RJ	B	0.95		82°	90.921	69.719	+21.202	+21.202	Backward mean			
				F											
				B											
				F											
				B											

(a) Enter forward mean, backward mean, and average mean, the last with sign of forward difference of elevation.
(b) Enter divergence in feet between mean forward and mean backward difference of elevation; this value takes sign of lesser difference of elevation.

Figure 20.—Field Abstract, Level Notes, Form 9–332.7.

investigate the cause. The following steps are suggested (they also may be applied in investigations of excessive closures in third-order leveling):

Determine whether the rodmen's procedures are faulty; check to see that they are holding on highest point of turning pin and are not exerting excessive force while holding rod.

Change from turning pins to plates, or vice versa, if type of ground permits.

Change the program of forward and backward runs over sections.

Check for settlement of tripod and loose tripod shoes. Check for sticking pendulum or sluggish bubble. Decrease length of sightlines.

The levelman should study the line, the conditions of running, and the cumulative divergence in relation to possible causes of small systematic errors, such as atmospheric conditions and the slope of the terrain. The effects of atmospheric conditions are difficult to analyze, but if heat waves are troublesome, making it difficult to estimate the thousandths readings, sight lengths should be decreased until a stable rod image is obtained in the telescope. The combined effect of slope and refraction may be significant on steep grades, if the air and ground are at different temperatures. The maximum error occurs when the sights up the slope are taken near the foot of the rod and the sights down the slope are taken on the upper part of the rod. The rules given in the first paragraph of article 24 are intended to obviate serious refraction error.

If the remedial steps suggested above fail to eliminate the excessive error, the levelman should consider his personal bias in estimating thousandths as a source of error. This error is similar to the personal equation in astronomic observations and horizontal angle measurements, which is compensated by proper instrumental techniques. Normally, estimation error tends to compensate, and it is effectively eliminated by the use of a parallel-plate micrometer. However, if the levelman suspects that estimation error may be causing excessive divergence, he should adopt the practice of reading doubtful thousandths either high or low. This methodical procedure, followed on both backsights and foresights, should reduce divergence due to estimation error.

FIELD REVIEW OF LEVELING NOTES

36. Checking fieldnotes

The levelman is responsible for the accuracy, completeness, legibility, and general appearance of the fieldnotes he submits to the Area office. Page checks and day checks are made as described in articles 31 and 32. After a line is completed, the levelman should make a line check, similar to the day check, by adding all the sums of backsights shown in the page checks throughout the line, subtracting all the sums of foresights, and comparing the result for identity with the quantity obtained by subtracting the initial elevation from the terminal elevation.

As the notes will be reviewed and transcribed perhaps several times in the office, they must be clear and easy to read to avoid mistakes or misinterpretation. It is axiomatic for all surveying fieldnotes that observed data must never be erased or copied, though neat erasing may be permitted in derived data, such as subtotals or page checks, or in descriptions. An erroneous entry is corrected by drawing a line through the wrong figures or letters and writing the corrections above or below. Faint recording and poorly formed figures and letters are always potential sources of misinterpretation and mistakes, no matter how accurately the line has been run.

37. Checking closures

If a level line starts from and ties to bench marks with adjusted elevations, the closure of the line is determined simply by subtracting the accepted elevation of the tie point from the terminal elevation as carried through the line. (Allowable closures are specified in art. 3 and tabulated in fig. 17.) Closures are the most important evidence in evaluating the accuracy of leveling, but they are not necessarily conclusive. Disturbed or reset bench marks, subsidence or settling, and previously undetected blunders in established lines are possible causes of out-of-limits closures that must be considered before a new line is definitely classed as faulty.

Moreover, third-order leveling is usually run in networks, often with a complicated pattern of junction points and ties to previous leveling. In these networks, individual closures are only tentative indications, and each network must be studied carefully before the new work is accepted as satisfactory or before any rerunning is undertaken. A line diagram of the new leveling and pertinent old leveling is prepared as the basis for study. Each levelman plots his own lines on Form 9–1128a, Summary Sheets of Bench Mark Descriptions and Elevations. For projects encompassing work by more than one levelman, a comprehensive diagram is prepared by, or under the supervision of, the project engineer.

An example of a line diagram for the work of an individual levelman is illustrated in figure 21. If each of the heavier blue lines on Form 9–1128a is taken to represent 5 minutes of latitude or longitude, each sheet will accomodate eight 15-minute quadrangles. Lines are sketched freehand in approximately correct position, with arrows to indicate the direction of running. The lines should be connected at a junction point if the same elevation is shown in

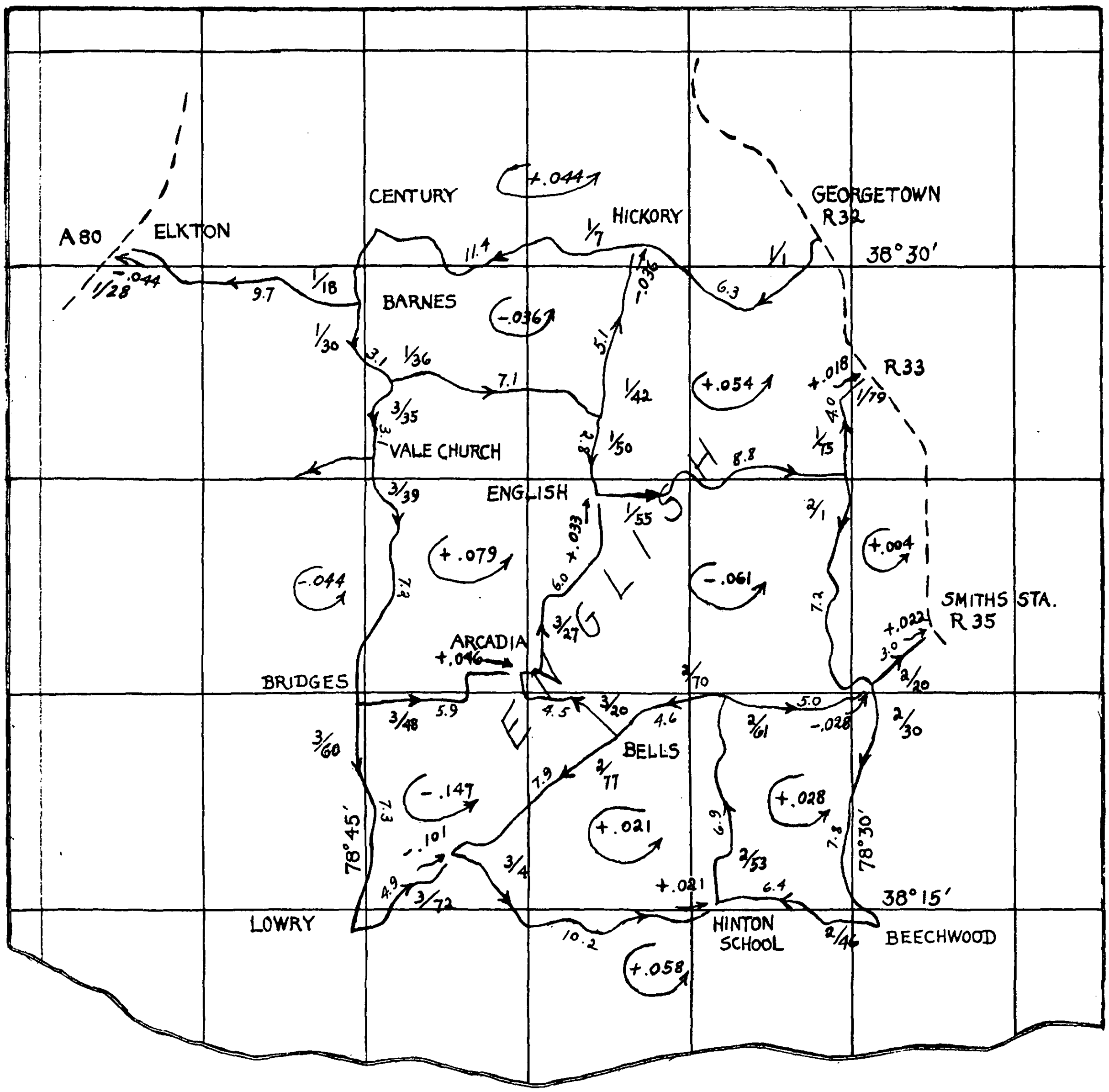


FIGURE 21.—Diagram of leveling lines, with line and circuit closures, Form 9–1128a.

each segment of line, but a break should be left before each closure. Fractional numbers near ties and junction points refer to the fieldbook pages on which the junctions and ties are recorded; for example, 3/72 indicates book 3, page 72. Towns and villages, especially those used as descriptive references, should be indicated to fix the general location of the leveling. Mileage between junctions, to the nearest 0.1 mile, is shown beside each segment of line.

Previously established lines should be shown in colored pencil, usually red for Coast and Geodetic Survey lines, green for Geological Survey lines, and blue for other lines. New lines should be shown in ink, with a distinctive color or symbol for the lines of different levelmen.

a. Line and junction closures.—In figure 21, line closures are shown at bench marks A 80, R 33, and R 35. Each of these closures was determined by subtracting the published elevation of the bench mark from the elevation as carried through the new line. For example, assume that the published elevation of A 80 was 436.290 and the elevation determined by the line tying from the English quadrangle was 436.246; therefore, $436.246 - 436.290 = -0.044$. A short arrow is drawn alongside each closing line, pointing toward the line or point closed upon, and the closure is written near the arrow.

Junction closures are similar to line closures, but the elevations closed upon are preliminary field elevations established by lines previously run in the network. Six junction closures are shown in figure 21. Each of them was determined by subtracting the previously established elevation of the junction point from the terminal elevation of the line closing on it.

b. Circuit closures.—In a leveling network, a circuit is a series of line segments forming a closed loop or connecting fixed points (in this latter situation, the loop may be considered as being closed by an imaginary line, with zero closures, between the terminal bench marks). A circuit closure is the algebraic sum of the junction or line closures in the circuit, reckoned counterclockwise around the circuit regardless of the direction in which the lines were actually run. In adding the closures, algebraic signs are retained if the closure arrows point counterclockwise in the circuit, but the signs must be changed if the arrows point clockwise. Circuit closures are recorded on the line diagram, inside their respective circuits and within counterclockwise arrows, as shown in figure 21.

Circuit closures provide an indication of the quality of the leveling. Comparing the total lengths of circuits against the respective circuit closures, with the aid of Form 332.1b (fig. 17), will reveal any circuits containing excessive error. Junction or line closures that at first seemed excessive may prove to be acceptable if the circuits in which they are included close well. Mistakes, blunders, and excessive accumulations of errors normally are indicated by adjacent circuit closures that are large (in comparison with other closures in the network) and approximately equal in magnitude but opposite in algebraic sign. Therefore, the circuit-closure diagram usually will point out the specific lines or segments of line needing investigation. In the office, the diagrams are helpful in preparing adjustment diagrams.

38. Field materials sent to the office

The levelman should carefully review fieldbooks and other materials before submitting them to the Area office. Descriptions should be complete and legible; Forms 9–1165 must be submitted for all bench marks needing changes in descriptions (including those previously established on the project by traversemen or other levelmen), for those not found, and for those evidently destroyed or disturbed. (See chap. 2E4 for detailed instructions.)

Fieldbooks should be sent to the office promptly, by registered mail, as soon as the lines have been tied satisfactorily. If the books are submitted regularly, there is no need for the levelman to copy descriptions and elevations on Form 9–1128, Bench Mark Descriptions, Field Summary, for this can be done more efficiently in the Area office. Each shipment of books must include a copy of Form 9–1128a showing the location and closures of the lines completed. Before releasing the books, the levelman must make a list of the field elevations for all points that may be used as junctions during the current field season. He should also prepare a list of elevations and abbreviated descriptions for use in supplemental control if basic and supplemental-control operations are concurrent.

At the conclusion of a project, the quadrangle reports and control folders should be reviewed to assure that all pertinent notations have been included. Any changes from the original plan of leveling, such as lines added in the field or those planned but not actually run, must be indicated on the planning map. All newly established permanent marks should be located on the planning map. These materials should be sent to the office by parcel post or regular mail.

RERUNNING LINES OF LEVELING

39. Preliminary investigation and report of excessive closures

Except for a simple line, without junctions between fixed bench marks, apparently faulty lines should not be rerun (though the fieldnotes should be thoroughly rechecked) until the surrounding circuits have been completed. It is assumed that starting and tie points were checked as prescribed in article 22. As explained in article 37, the closure diagram usually will indicate the specific segments of line that should be investigated.

As no reruns should be undertaken without prior authorization, the levelman should first consult his project engineer and prepare a report for the Area office. The report should include all pertinent details, such as the closure diagram; descriptions and elevations of starting and tie points; instrument, rod, and invar-strip numbers; rod comparisons; and any other information that might be helpful in analyzing the problem. If the questionable line is among the last to be run on a project, the office should be informed by telephone or telegraph in addition to the memorandum report.

40. Procedures for rerunning

Instructions from the Area office may request the levelman to subdivide a large circuit or make additional ties to localize the error, keep rerun mileage to a minimum, and provide more elevations in the project area. These extra lines should be run before rerunning is started.

In general, the procedures for reruns are the same as for regular third-order leveling, though fly levels or carefully run planetable leveling may be useful for locating a large blunder. The rerun ordinarily proceeds backward over the route of the original run, tying in all established bench marks and UE's. The fieldnotes may be recorded in the same book as the original run, if space is available, or in a separate book. Descriptions are abbreviated as in backward runs of second-order lines (art. 34), and the notes are cross-referenced.

Differences of elevation are compared for agreement at each point recovered. The error in the original line will be revealed either by a sudden discrepancy roughly equal to the line or circuit closure in magnitude (if the bad closure is due to an isolated mistake) or by a gradually increasing divergence between the first run and the rerun (if the bad closure is due to an excessive accumulation of small errors). If a break is discovered between two bench marks, a third run between the marks (in the forward direction) is needed to confirm the rerun. Otherwise, the rerun is extended back to the junction or tie point indicated by the closure diagram. If the rerun produces satisfactory closures when substituted for the original leveling, the first run is marked "void," appropriate cross-references are made to substitute the rerun, and no further rerunning is needed.

A full report on all reruns is attached to the comprehensive closure diagram on Form 9–1128a. If the excessive closures were caused by accumulation of small errors, the levelman should examine his instrument and review his field procedures to determine the most likely cause (see art. 35) and adopt whatever corrective measures seem advisable.

CHAPTER 2E4. BENCH MARKS

CLASSES OF BENCH MARKS

41. Monumented bench marks

The bench marks established in geodetic leveling are classed as monumented or nonmonumented. The distinguishing feature of a monumented bench mark is the standard metal tablet, disk, or cap used to mark the elevation. The tablet contains a cast or pressed inscription identifying the agency that established the mark, and it is hand stamped with a code designation and the elevation. The two latest designs of the Geological Survey tablets are shown in figure 22. Both carry the inscription shown in the top view of figure 22. Monumented bench marks have also been variously called "permanent," "formal," and "standard" bench marks. They are shown on published maps by the oblique cross symbol, the letters BM, and the elevation, all in black ink.

Standard tablets are commonly set in concrete or stone posts, firm rock, masonry structures, or buildings, depending on local conditons. More recently, tablets with modified shanks have been fastened to the tops of copper-coated steel rods, which have been driven in the ground to the point of refusal or to a depth sufficient to provide stability. Typical momumented bench marks are illustrated in figure 23. Normally the tablets are set with face horizontal, but occasionally they may be set vertically in a wall or rock cut.

Monuments of other organizations, already in place, may be substituted for new bench marks if they are in suitable locations and are of satisfactory quality. ("Satisfactory quality" means apparently stable and permanent.)

Geological Survey levelmen and traversemen use the same monumented stations wherever their routes coincide. The marks are placed by the first party to cover the route.

42. Nonmonumented bench marks

Bench marks established with geodetic precision and fully described, but not marked with standard tablets, are classed as nonmonumented bench marks. They may consist of chiseled squares, crosses, or circles on concrete or masonry structures; bolt or rivet heads in steel structures; metal pins or nails embedded in concrete; copper nails and washers in tree roots; or other specific, permanent, recoverable objects. These bench marks have also been variously termed "temporary," "intermediate," "supplementary," or "unmonumented" bench marks. They are shown on published maps with the oblique cross symbol and the elevation in black ink, but without the letters BM. Typical nonmonumented bench marks are illustrated in figure 24.

43. Useful elevations (UE's)

Useful elevations are distinguished from bench marks by the nature of the points and the precision with which the elevations can be recovered. UE's are established on features that can be photoidentified and that are shown on maps—such features as road intersections, fence corners, culverts, bridges, and railroad crossings. UE's are intended primarily for use in supplemental-control surveys and photogrammetric operations. Although the point where the rod was held may be marked with paint, an elevation accurate to a few tenths of a foot shoud be recoverable from the description alone after the temporary mark has disappeared. UE's are shown on the published map as checked spot elevations.

TYPES OF MONUMENTS

44. Concrete posts

Standard tablets are set in reinforced concrete posts if no solid rock or suitable masonry structures are available at the sites selected for bench marks. The posts may be either poured in place or precast. Each tablet is inserted immediately after the concrete is poured, with the lines of the fiducial cross oriented parallel to the sides of a square post. The tablet is tapped down lightly to expel air from beneath it and to embed it flush with the top of the post. Concrete is then smoothed over the edge of the tablet, without obscuring any of the lettering.

a. Posts poured in place.—If only a few posts are needed or it is difficult to obtain them on contract, the leveling party should pour them in place. A hole not less than 10 inches in diameter, enlarged at the bottom to form a bulb, is

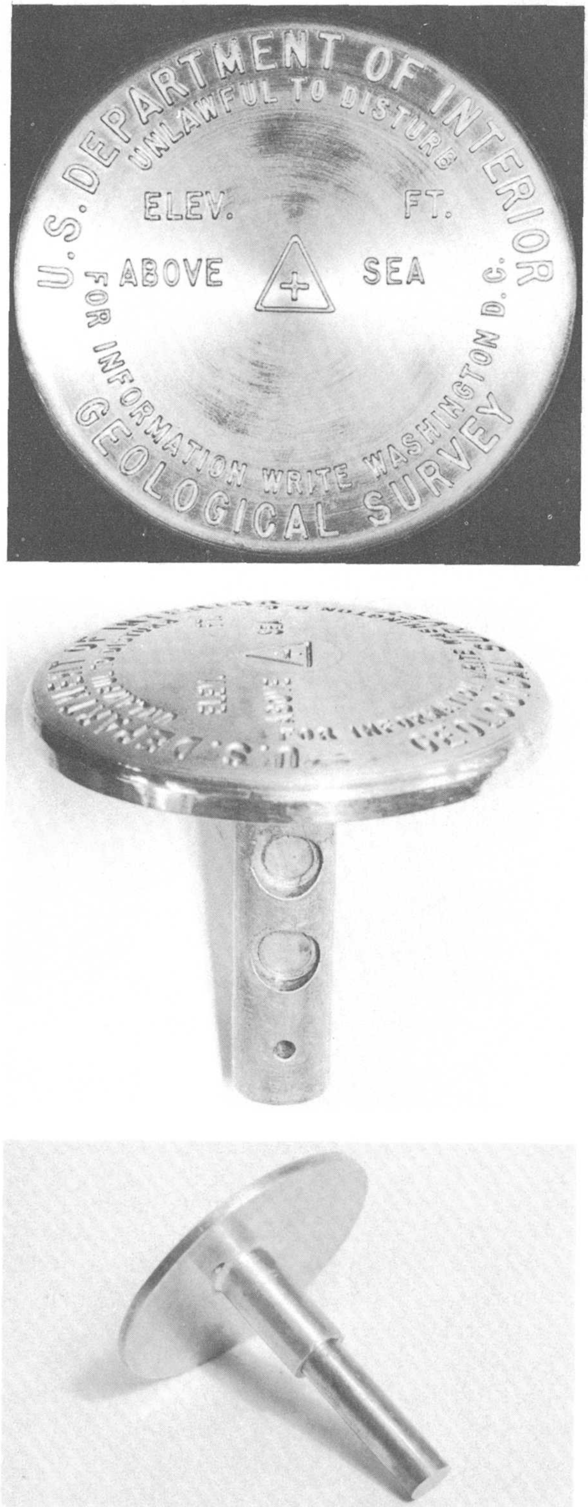


FIGURE 22.—Geological standard tablets. Top and center: die-cast aluminum tablets; bottom: stamped brass tablet designed for crimping to copper-coated rod (section of rod is shown inserted into hollow stem).

dug to proper depth below the frostline, but not less than 3 feet. A foot of concrete is poured in the bottom, and the reinforcing rods are inserted. More concrete is added to within a foot of the surface. A wooden form, a can with top and bottom removed, or a pipe or tile may be used to form the rest of the post and give a neat appearance. In the absence of better material, a cylindrical form may be made from impervious paper, such as tar paper or cement bags. The top of this form should be about an inch above the ground surface. When other types of forms are used, the projection above ground surface should be the same as specified in article 44*c*.

b. Precast posts.—On most projects it is more economical and efficient to have the bench-mark posts precast under contract with a local concrete plant, although the posts can also be made by leveling parties in weather unsuitable for leveling. Building contractors or ready-mix concrete distributors are often glad to make the posts, which can provide a profitable outlet for leftover concrete. In letting contracts, good workmanship and reliable delivery, as well as the lowest bid price, must be considered. Good judgment should be used in estimating the number of posts needed for a project, because surplus posts may be difficult to carry to the next project.

As the cost of forms is a substantial part of the total cost of posts, especially for small quantities, it may be advantageous to obtain a set of collapsible forms that can be carried from project to project. The forms can be loaned to contractors to obtain lower bids, or used by the party itself to make posts.

c. Setting precast posts.—Local conditions will limit the distance that posts should project out of the ground. In cleared land or along the edges of cultivated fields, posts should not project more than 2 or 3 inches. In wooded or waste land or at sites where leaves, silt, or debris might cover the marks, posts may project as much as 6 or 8 inches.

A post should be oriented so that the inscription can be read directly by one approaching from the road. If set away from a road or fence, it should be oriented to be read from the south. The bottom of the hole must be thor-

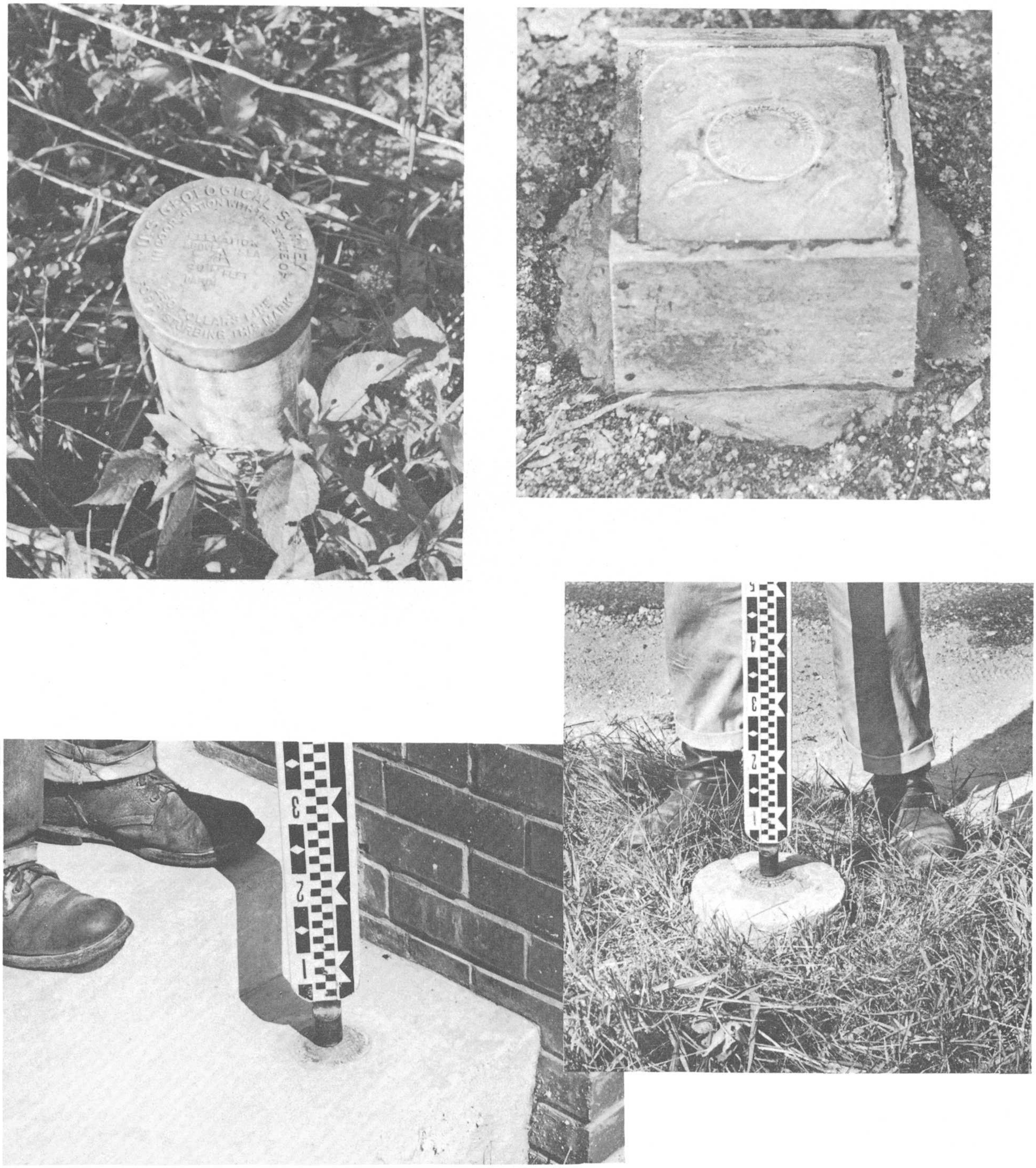


FIGURE 23.—Examples of monumented bench marks.

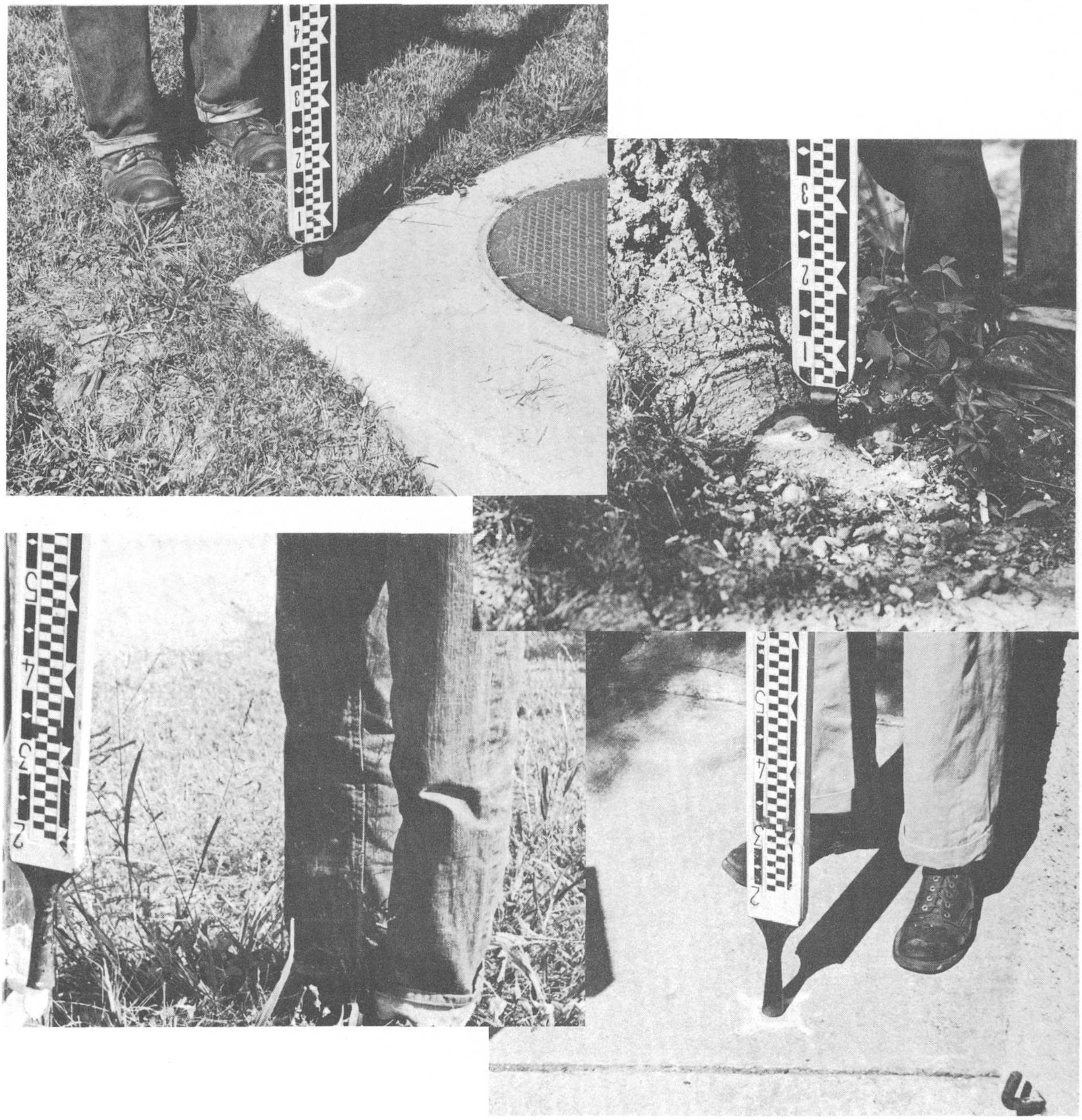


FIGURE 24.—Examples of nonmonumented bench marks.

oughly tamped to minimize settling, and the backfill must be well tamped to set the post firmly.

d. Specifications for precast posts.—Concrete posts may be cast either square or round in cross section. Acceptable minimum specifications are shown in figure 25. Posts should be long enough to extend below the frostline in the project area, varying from a minimum of 30 inches to a maximum of 5 feet, with a minimum section at the top of 7 inches square or 7 inches in diameter for third-order leveling. If frost penetrates below 5 feet (generally north and east of lat 43° N., long 110° W.), standard tablets should be set in solid rock ledges or in substantial concrete or masonry structures or foundations if at all practicable. However, if posts must be used in these areas, they should be poured in place in well-drained ground, not in wet or swampy ground.

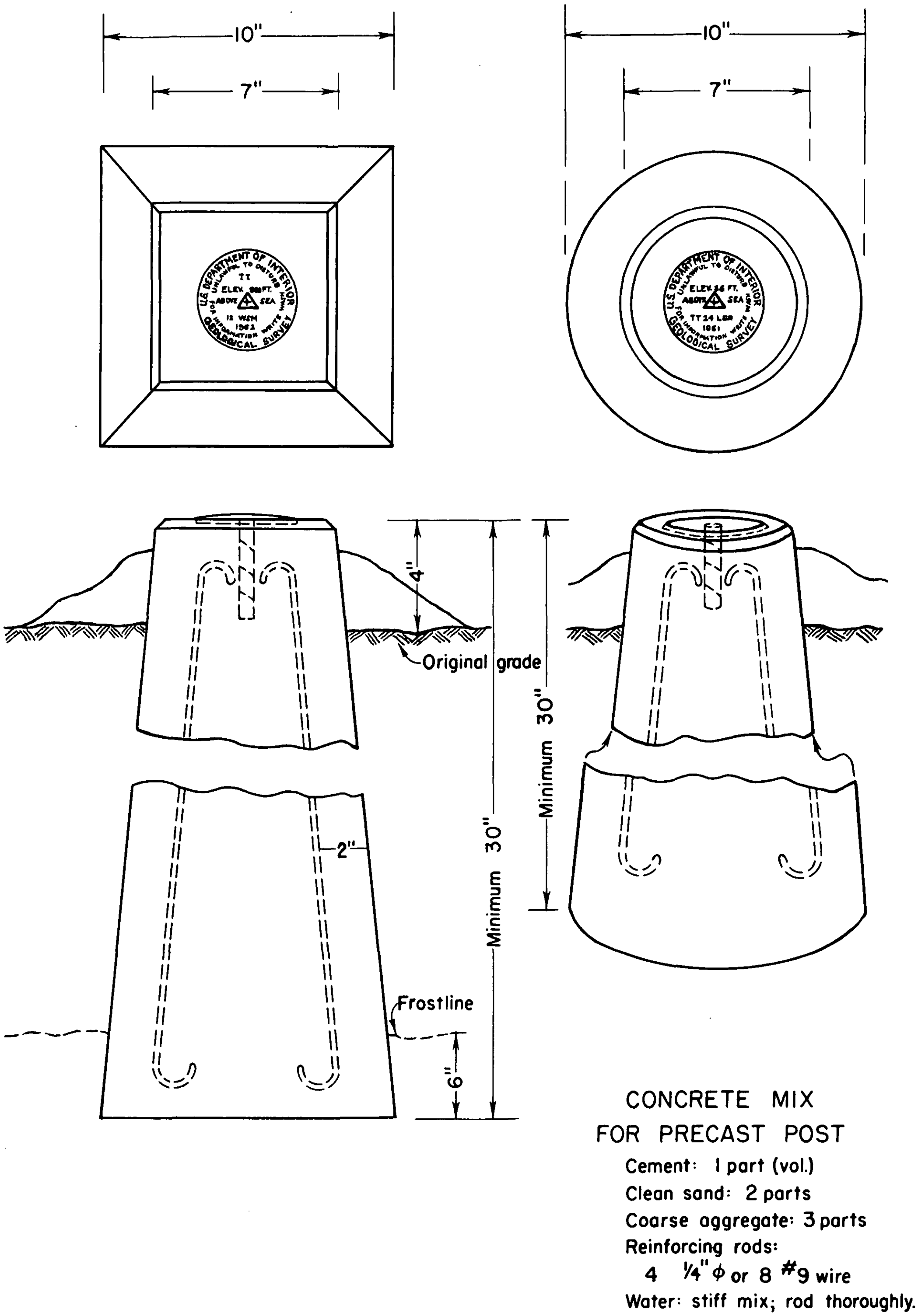


FIGURE 25.—Minimum specifications for precast concrete posts.

The posts are tapered, as shown in figure 25, to set firmly and resist heaving by frost action. Reinforcing rods or wires should be evenly distributed and at least 2 inches from any surface. The top edges should be beveled if practicable; after the forms are removed, the top 6 inches of the sides should be wire-brushed to give a neat and finished appearance to the portion projecting above ground.

45. Standard tablets in structures or rocks

Standard tablets may be cemented into holes drilled in heavy concrete, masonry, or brick structures or in solid rock found at the sites.

Holes for the tablets are drilled with hand drills and hammers or with special power drills. The holes should be drilled about 3½ inches deep (that is, a half inch deeper than the length of the tablet shank) to allow for countersinking the disk. The area to be covered by the disk should be chiseled out to a flat surface so that the disk will bear evenly and so that the top of the tablet is nearly flush with the adjacent surface. The tablet, drill hole, and chiseled area should be cleaned and wet before the cement is placed.

Cement (carried in small cans) is mixed with enough water to form a thick paste, which is placed in the drill hole and over the chiseled area. The tablet (already stamped except for elevation) is inserted and tapped down gently with a hammer handle until it is firmly embedded. Cement should cover the edge of the disk without obscuring any of the lettering. The tablet should then be covered with damp paper, burlap, or earth to prevent the mortar from drying too quickly.

a. Setting marks at temperatures below freezing.—Tablets should not be set in rock or masonry when temperatures are below freezing. During prolonged cold spells, locations suitable for the use of precast concrete posts should be chosen. If posts are not available, reference marks may be left at the sites and the tablets set later, in warmer weather. Alternatively, the rock or masonry can be heated with a fire before setting a tablet. After the tablet is set, it should be well covered to prevent freezing until the cement has set initially (about 2 or 3 hr). The fire must be completely extinguished before the party leaves the site. If it is necessary to set tablets in freezing weather, 2 percent of calcium chloride should be added to the mix.

46. Copper-coated steel rods

The use of copper-coated steel rods with standard tablets attached is still experimental, but the following rules can be stated as minimum requirements for establishing stable marks:

The rods must be driven at least to 10 feet or to refusal.

If refusal is encountered at a depth of less than 4 feet, a new site must be selected or a different type of bench mark used.

If the time required to drive a rod 5 feet, with a power hammer, is less than 2 minutes, additional sections must be added and driven until the rate of penetration for a 5-foot section is slower than 2 minutes.

STAMPING TABLETS AND MARKING SITES

47. Stamping code data and elevations

For unmistakable identification, code designations and elevations are stamped on monumented bench marks with steel dies. Tablets in precast posts are stamped when the posts are set in place, but tablets set in drill holes or in posts poured in place are stamped, except for elevation, before they are set. Special anvils are provided to hold the tablets for stamping.

Each levelman is assigned a personal letter code, usually based on his initials, which identifies all the standard tablets he sets on geodetic control surveys (horizontal as well as vertical if he is later assigned to traverse). A levelman's first tablet is stamped, for example, "1 WDE 1962," the second "2 WDE 1962," and so on.

To avoid confusion, the levelman must not use duplicate serial numbers in any one State during a given year. He should keep the numbering sequence (including the year number) continuous to the end of a project even if work extends beyond the end of a calendar year. Also, he should use only one number sequence if the project area lies in two or more States.

Elevations to the nearest foot are stamped on standard tablets, but they should not be stamped until the lines are closed satisfactorily. Elevations may be stamped as the leveling progresses on lines difficult of access, but they must be changed if the closure makes it necessary. With

Area approval, stamping may be deferred until the supplemental-control or field-completion phases. If a standard tablet was set and stamped with a code number by a traverse party, the only stamping to be added by the levelman is the elevation.

Figure 26 illustrates the proper methods of stamping tablets. In figure 26*A*, the code number and elevation were stamped by a levelman, and the traverseman who later used the tablet added the letters TT. (Instead of TT, the letters ET are used for electronic-distance traverse marks.) In figure 26*B*, the code number was stamped by a traverseman, and a levelman added the elevation when he used the monument as a bench mark.

No stampings are added to monuments established by other organizations, except for reset monuments. These are stamped "RESET (year)," and any stamped elevation that is changed by the resetting is either corrected or obliterated.

48. Aids for finding bench marks

As bench marks normally are used for map control soon after they are established, levelmen identify the sites with witness signs or metal tags so that subsequent users can find the marks quickly and easily. (See fig. 27.)

a. Witness signs.—The Geological Survey and the Coast and Geodetic Survey have metal signs that are placed near bench marks. These signs request that the mark not be disturbed; they also make recovery of the mark much easier (fig. 27, upper part). The signs are 6½ by 10½ inches and are usually bolted to steel fenceposts.

All monumented survey marks should be witnessed by one of these signs except in areas where the signs would be objectionable. In remote areas, where it is impractical to transport the posts, signs can be nailed to nearby trees. Witness signs identifying the agency should be set whenever new monumented bench marks are established. When previously set marks are recovered, a witness post should be placed nearby if its presence is not objectionable.

A tool made of steel tubing makes driving the posts comparatively easy. The tubing should be about 3 feet long, 2¼ inches inside diameter, with walls ⅛ inch thick. A plug should be

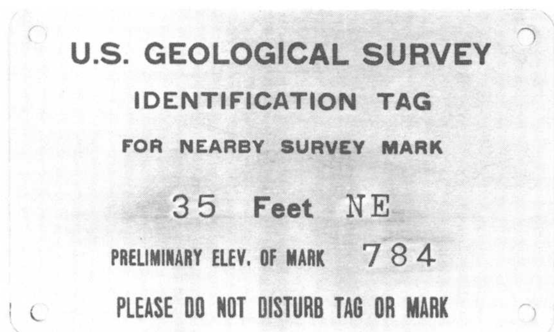


FIGURE 27.—Witness sign and metal tag for bench-mark site identification.

A *B*

FIGURE 26.—Examples of stamping on standard tablets.

welded in one end of the tube. A completed driver weighs about 15 pounds.

b. Metal tags.—Another method of identifying bench-mark sites, especially useful where witness signs might be objectionable, is to attach Geological Survey metal identification tags (fig. 27, lower part) to suitable nearby objects, such as trees, poles, posts, or witness stakes. On each tag are stamped the distance and direction to the bench mark and its elevation to the nearest foot. Tags should be placed with discretion, and the levelman should request permission to use them if there is any likelihood that they might be objectionable. Caution should be used in placing tags on utility poles so that they will not interfere with climbing.

CONSIDERATIONS IN CHOOSING SITES FOR BENCH MARKS

Although the standards for leveling specify an average spacing between bench marks, and general locations may be shown on the planning map, the levelman is responsible for choosing the specific locations at which the marks are placed, varying the spacing between marks to take advantage of good sites. In choosing the best site in the vicinity, he must consider several requirements, exercising good judgment and considerable foresight.

49. Maximum usefulness and permanence of location

Bench marks should be placed where they will be most convenient and useful for future surveys, particularly the horizontal and supplemental control surveys required for topographic mapping. Although the needs of other Geological Survey fieldmen are given primary consideration, the levelman must not forget that the marks are widely used by other Federal and State agencies and private companies, engineers, and surveyors.

As the bench marks must be identified on aerial photographs, either directly or in relation to nearby features, they should be placed at sites where photoidentification is simple and positive. Bench marks should be placed at easily described and recoverable locations, such as close to road junctions, at railroad stations or crossings, near public buildings, or in parks and cemeteries. The ease of placing a panel over bench marks for photoidentification must be considered.

From the notations on the planning map and consultation with other fieldmen and the project engineer, the levelman will generally know which of his bench marks are most likely to be tied in by horizontal control surveys. These marks should be located with special consideration for the requirements of horizontal ties. Locations on crests, in cleared areas, or with extensive open sights facilitate ties by taped or electronic-distance traverse and vertical-angle triangulation. Since portable towers may be used to obtain long sights, the marks should be set in positions over which towers can be erected without difficulty.

The most important consideration in placing bench marks, and the one that makes the greatest demands on the levelman's experience, judgment, and foresight, is selecting locations where marks will remain undisturbed indefinitely. In evaluating the probable permanence and safety of each prospective location, the levelman must consider such possibilities as erosion, the widening or realinement of roads, mowing of the right-of-way, grading of ditches, and construction or reconstruction of buildings, culverts, and bridges.

Figure 28 illustrates several possible locations for a bench mark at a T-road intersection. Location BM_1 is undesirable because a levelman would have to tie the mark by means of an extra setup unless, in place of the hedgerow, there is a fence of open-wire construction, free of bushes and other obstructions. Marks

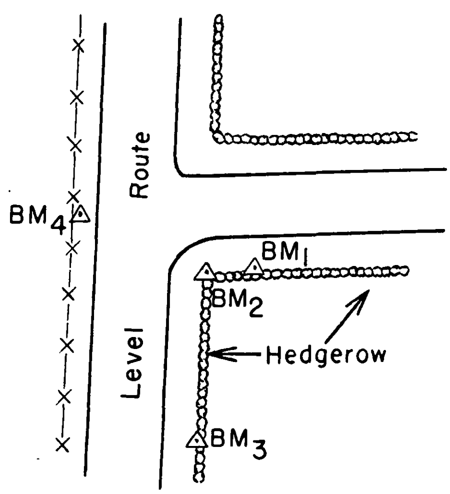


FIGURE 28.—Alternative locations for bench mark at road intersection.

along fences should be positioned so that transits and other instruments can be set up over them. (Overhanging obstructions that would interfere with holding a level rod plumb must also be avoided.) Location BM_2 offers extended sights along both roads, but it may be in danger from road maintenance equipment. Location BM_3, 200–500 feet from the intersection, is preferred because it is less subject to disturbance. A bench mark at any of these locations will be avoided by mowing equipment if properly marked by a witness sign. Location BM_4 is convenient, but a monument at this site will be destroyed, or will have to be reset, if the road is extended west.

50. Permission and good will of landowners

Sites used for bench marks include public buildings, parks, churchyards, and schoolyards. In rural areas, farmyards may provide ideal locations if the owners take a personal interest in having the marks on their property.

Before setting a bench mark on private property or in an exposed public place, the levelman must obtain permission from the owner or a responsible agent or official. The landowner must be told about the purpose and public usefulness of the mark once it is set. Usually, permission will be readily granted. However, if firm resistance or hostility is encountered, the levelman should choose another location rather than arouse local antagonism.

Once permission is obtained, the leveling party must maintain good will by placing the mark where it will not be a nuisance or a hazard; often the owner will help in choosing a satisfactory location. Marks set in lawns or parks should be flush with the ground to prevent damage to mowing machines. They must never be placed where they might cause damage to mechanical equipment or might be a safety hazard. The marks must be set neatly, and the party must leave the site clean and orderly.

DESCRIPTIONS OF RECOVERABLE ELEVATIONS

Monumented and nonmonumented bench marks must be described completely and exactly so that later users can find them easily and can be reasonably sure that the recovered marks have not been moved from their original positions. UE's are photoidentified and described briefly, but definitely enough for use in later phases of mapping.

51. Elements of descriptions

To assure uniformity and completeness in descriptions, the Survey has developed and adopted a standard format and style which is to be followed by all fieldmen in describing the marks they set. The standard description figuratively guides a person looking for a mark from some definite, well-known landmark to the site of the mark and then, by measurements from objects at the site, to the mark itself.

A standard description consists of four principal elements:

1. Distances and directions from landmark places or features
    a. Primary reference (inverted wording)
    b. Secondary reference (direct wording)
    c. Supplementary reference(s) (direct wording)
2. Distances and directions from nearby objects
3. Object in or on which mark is placed
4. Nature of mark and how stamped and witnessed

Note that the primary reference is always written in inverted order, with the name of the reference first, followed by the distance and direction from; for example, "Adkins, 2.5 mi. south of, thence 1.0 mi. east," or "Romanville, 3.6 mi. SW. of courthouse at, along State Highway 21." The secondary and supplementary references are written in ordinary direct wording.

52. Places, features, and objects used as references

Writing a satisfactory description requires good judgment in selecting place names, features, and objects which are not likely to change and from which a subsequent user can be expected to recover the mark. Railroad stations and hamlets may be abandoned, and an expanding city may cause surrounding communities to lose their value as place names. The names of rural schools, churches, and places may drop out of local usage through consolidation or other changes, thus requiring a search of historical records to determine the application intended in a description.

The primary reference should define a specific point or small area so that mileages do not become ambiguous in application. If a city or sizable town is the primary reference, a public building or other landmark should be specified as the point from which mileages are measured. In areas with few cities or towns, features prominent enough to be shown and named on topographic maps should be used as primary references. These features include railroad flag stations, churches, schools, lakes, ponds, fords, ferries, and parks. In the sparsely settled Western States, the headquarters of prominent ranches may be good primary references.

In the public-land States, the position of a mark by township, range, and section should always be given as a reference unless the mark is situated in an incorporated community. The land-net reference may be a primary, secondary, or supplementary reference, depending on local circumstances; in some areas it may be the most prominent and permanent reference available and therefore the logical primary reference.

a. Secondary and supplementary references.—The secondary reference ordinarily is equivalent to the primary reference in prominence and importance, so that either may be used as a starting point for finding the bench mark. On most leveling lines, several primary references are used in succession, as the line passes through or near the reference points. The first primary reference is used for several descriptions, then a new and closer primary reference is selected for the next several descriptions, and so on. At each changeover point, about equally distant from the two primary references, the new reference is introduced as a secondary reference and becomes the primary reference in succeeding descriptions.

For intermediate descriptions, in which a place or feature name would not ordinarily be cited as a secondary reference, the land-net position may be given as the secondary reference. To avoid excessive length and detail, a description should contain no more than one primary reference, one secondary reference, and two supplementary references. Distances between these references and the bench mark are given in miles, to the nearest 0.1 or 0.05 mile.

b. Reference objects at site.—The objects to be used as references at the site of a bench mark, in part 2 of a description, should be chosen with the same care and judgment as the references in part 1. The number of reference objects included should be enough to assure recovery of the mark even if some of them are destroyed by local changes or improvements. Large trees, especially along fence lines; definite corners of substantial buildings; specified parts of bridges or culverts; fence corners; mileposts; telephone or telegraph poles; and similar objects make good reference points. Measured distances, preferably taped, from roads, railroads, and other linear features should always be given.

Horizontal distances from reference objects to bench marks are given in feet, to the nearest foot, or nearest tenth of a foot if taped. If stadia distances are read to objects too far away for taping, the distances should be rounded off to the nearest 5 or 10 feet and qualified in the description by the word "about." Note that all directions are given *from* reference *to* mark. Distances described with a direction from a linear feature are considered as being normal to the centerline. Thus the phrase "16 ft north of ℄ RR." signifies a direction at right angles to the railroad but perhaps only approximately north. Compass directions ordinarily are given no closer than the cardinal directions or halfway between them—for example, north, northeast, or east.

53. Specimen descriptions

The descriptions included here are fictitious specimens which illustrate the required standard arrangement and style.

> Brownfield, 3.2 mi north of, along U.S. Highway 17; 3.8 mi south of Paris; near quarter corner between secs. 1 and 2, T. 14 S., R. 6 W.; 0.8 mi east of Peace Creek Church; 62 ft south and 24 ft east of and 3 ft higher than X-rd., 51 ft north of 36-inch oak tree on fence line, 45 ft NW. of NW. cor. of brick house, 2 ft west of fence and witness post; in concrete post set flush with ground; standard tablet stamped "ET 8 ERD 1965 2443."

This description illustrates the use of primary and secondary references. Brownfield has been the primary reference in preceding descriptions and is used here for the last time. Paris, nearly equidistant, is introduced as the secondary reference and will become the primary reference in the next several descriptions. The cross-reference supplies the distance between Brownfield and Paris and allows a searcher to use either town as a starting point for finding the bench mark. Note that the description gives the difference of elevation, as well as the horizontal distance, between the mark and the crossroads, a photoidentifiable point. The vertical relationship between the bench mark and a photoidentifiable feature should always be given, if possible. In expressing this relationship, the mark is described as being "higher than," "lower than," or "level with" the specified features. Note also that larger distances usually are given first, except in coordinate couplets (62 ft south and 24 ft east), in which north-south distances precede east-west distances.

> Central City, 4.2 mi east of post office at, along State Highway 18, thence 1.7 mi south along blacktop rd.; 0.3 mi SE. of entrance to plant of Jones Mfg. Co., 0.2 mi north of Mount Moriah Church; 152 ft SE. of RR. milepost 237, 3 ft south and 44 ft west of and 2 ft lower than rd. crossing Illinois Central RR., 32 ft SW. of south rail of main track, 28 ft NW. of ȼ rd., 3 ft south of telegraph pole 237–A to which is affixed a standard USGS identification tag; in concrete post projecting 6 inches above ground; standard tablet stamped "44 AD 1961 788 ET."

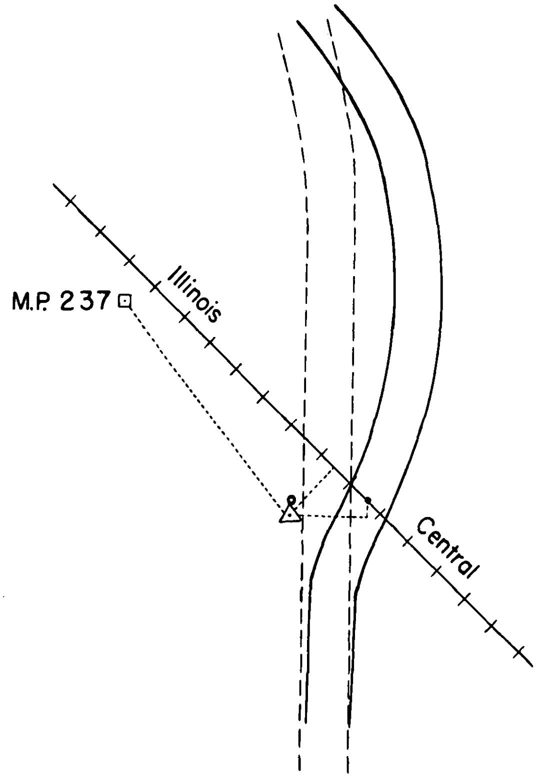


FIGURE 29.—Sketch illustrating specimen description.

This second description may at first seem unnecessarily long. However, the sketch (fig. 29) shows that the levelman used good judgment in recording this amount of information. If the road were to be rebuilt to eliminate the curve, as indicated by dashed lines, the bench mark might be covered by the toe of a fill or destroyed. The same change might also require a relocation of the telegraph pole. These changes would leave the distances from the milepost and the track as the only remaining exact measurements by which the location of the mark could be found or checked. Although the telegraph pole might be considered a superfluous reference, it enables the mark to be found quickly, without measuring.

In sparsely settled areas, primary references may necessarily consist of complicated route descriptions. Sometimes these route descriptions can be simplified by omitting all the minor changes in direction, as in the following example:

> Falls City, 17.5 mi SE. of, along U.S. Highway 67 to T-rd. SW., thence 10.4 mi southwesterly along Lost Creek Ranch rd.; about 0.4 mi SW. of NE. cor. sec. 5, T. 4 S., R. 5 E.; 0.5 mi west of cattle guard in fence, at highest point of north-south ridge; 57 ft south of and 4 ft higher than ȼ rd., 2 ft north of witness post; in solid rock outcrop; standard tablet stamped "14 ERD 1961 6591."

54. Specific terms and wording in descriptions

To avoid uncertainty and ambiguity in descriptions, certain terms and phrases must be used with particular care, and certain conventional assumptions must be clearly understood.

Use the term "highway" only in referring to numbered Interstate, Federal, or State highways; otherwise use "road."

"Intersection" denotes the point at which the centerlines of two or more roads, railroad tracks, or other linear features intersect.

"Junction" does not denote a specific point but merely the immediate locality in which two or more routes meet.

"Centerline" denotes a line equidistant from the sides of a linear feature having significant width, such as a road, railroad, or canal. Sometimes it is necessary to distinguish between the centerline of the traveled way and the centerline of the right-of-way.

"Center of" generally is superfluous and should be omitted from such expressions as "center of intersection," "center of crossroad," and "center of culvert." Never use the erroneous expression "centerline of intersection."

In such expressions as "crossroad," "T-rd. east," and "rd. crossing Illinois Central RR.," the fiducial point is understood to be the intersection of the centerlines unless the description states otherwise.

A point described as "crossroad" must be common to the centerlines in all four directions; if not, the description should read, for example, "T-rd. south at offset X-rd." to specify the particular one of two intersections.

A point described as "RR. opposite milepost 178," or semaphore or other railroad structure, refers to the top of the rail nearest the structure unless specified otherwise.

At overhead crossings of viaducts and bridges, specify the overpassing route, as "at south end of viaduct, Southern Ry. over hwy."

55. Abbreviations for field use

The following common terms may be abbreviated in field notebooks:

approximate	approx
centerline	℄
concrete	conc.
corner	cor.
crossing	X-ing
crossroad(s)	X-rd., X-rds.
foot, feet	ft (no period)
highway	hwy.
junction	jct.
mile(s)	mi (no period)
northeast	NE.
northwest	NW.
quarter corner	¼ cor.
railroad	RR.
railway	Ry.
range(s)	R., Rs.
road	rd.
road fork	rd. fk.
section(s)	sec., secs.
southeast	SE.
southwest	SW.
standard	std.
station	sta.
township(s)	T., Tps.
T-road	T-rd.
yard(s)	yd (no period)
Y-road	Y-rd.

Unusual abbreviations and those whose significance is not clear must not be used. Spell out "inch(es)," and, except in land-net references, the directions "north," "south," "east," and "west."

56. Sketches in field notebooks

Simple sketches showing the important features (north indicated by top of page or arrow) and measurements of bench-mark locations may be included with the descriptions in the field notebook. These sketches are not required and may be omitted from most descriptions, but they are sometimes useful in clarifying or checking statements in the descriptions. The levelman must not, however, rely on sketches as substitutes for complete, accurate, well-written descriptions because the sketches ordinarily are not seen by anyone but the levelman and the computer in the geodetic section who processes the fieldnotes for adjustment and duplication. Hence, the sketches cannot be expected to serve the same purpose as photoidentification sketches.

RECOVERING AND RESETTING BENCH MARKS

57. Reporting marks recovered or searched for

As practically all available control monuments are shown by symbol on published quadrangle maps, levelmen are expected to search for and report on the condition of previously established marks along or near their routes of leveling. The recovery reports also help the geodetic sections in maintaining accurate, up-to-date files of control data.

In the control folder, the levelman places a brief notation, the date, and his initials beside the published description of each mark he searches for. Examples of adequate notations include "recovered in good condition," "OK," "disturbed," "destroyed," "not found," "redescribed," and "description revised." For marks found in good condition, with descriptions still correct and complete, the notations in the control folder are all that are needed.

An additional report, on Form 9–1165, Report on Permanent Survey Mark, must be prepared for each mark that has been disturbed or destroyed, that was not found, or that needs a new or revised description. In the control folder, the notation "Form 9–1165 sent" should be added beside the descriptions affected, after the required reports have been forwarded to the Area office.

Instead of Form 9–1165, the Area office may provide a special form in the control folder, on which the fieldmen report the condition of all permanent control marks. New or modified descriptions should be included. The Area geodetic section will then extract the information recorded, prepare Form 9–1165 as required, and retain the special form and the quadrangle report for later reference.

a. Entries in field notebook.—To save time and avoid possible mistakes in copying, the levelman does not need to copy into his fieldbook the description of a mark listed in the control folder if he finds the published description complete and correct. Instead, he records a brief statement patterned after one of the following examples:

USC&GS standard disk stamped "H 77 1935," recovered in good condition as described in Michigan line 27, 22 ft south and 33 ft west of X-rd.

USGS standard tablet stamped "12 E 1948 311," recovered in good condition as described in Hilton quadrangle leveling list, Kansas 114, line 3.

USC&GS triangulation station "WARNER 1941," recovered as described in Norton quadrangle folder, Wyoming 232 (or "in C&GS list Waverly to Bald Eagle, page 4," if complete C&GS description list is included in folder).

This style of brief reference may also be used if a published description needs only one or two additions or corrections, as the changes are emphasized by being isolated from the complete descriptions. Examples:

USGS standard tablet stamped "4 ANS 1958 472," recovered as described in Addison quadrangle leveling list, Kentucky 32, line 2, except that tablet has been additionally stamped and now reads "4 ANS 1958 472 TT."

USGS standard tablet stamped "25 M 1937 627," recovered as described in Basswood quadrangle leveling list, Nebraska 323, line 5, except that mark is 24 ft *south*, not north, and 210 ft west of X-rd.

All changes must be additionally reported on Form 9–1165 or its substitute.

If the published description needs appreciable revision, or a description is not generally available (as for a local survey mark), the levelman must record a complete description in the notebook, incorporating the portions of the old description that still apply. The description should be preceded by the notation "New description" or "Revised description." The style of the original should be followed if the mark was set by another organization and the control list is widely available to the public; otherwise the decription should follow Geological Survey style. The description recorded in the fieldbook must agree exactly with the one reported on Form 9–1165.

When tying in horizontal-control monuments, whether listed in the control folder or recently set, the levelman must check the descriptions carefully. If a description of a recently set mark is correct, it is copied verbatim into the fieldbook (with the addition of the elevation data). If a description is not entirely correct, the levelman revises it as necessary, records it in the fieldbook with the notation "Revised description—Form 9–1165 sent," and prepares the usual report on Form 9–1165. He also supplies a copy of the revised description to the horizontal-control party, if the mark is new and they have not left the project, giving reasons for the changes.

58. Preparing reports on Form 9–1165

The required reports on Form 9–1165 (arts. 57, 59) are prepared in duplicate or triplicate, according to Area practice. Two copies are supplied to the Area office, one of them (yellow copy) for transmittal to the Map Information Office in Washington; the third copy is filed in the master control folder or the quadrangle report. The forms are to be filled out and submitted promptly, not left until the end of the project and submitted with the rest of the field material.

Examples of completed Forms 9–1165 are shown in figure 30. Both the name and control index number of the 15-minute quadrangle should be given. For Coast and Geodetic Survey bench marks, the number of the published level line should be shown in the upper right corner. Other entries are self-explanatory.

a. Use of the terms "destroyed" and "not found."—In reporting on marks that could not be recovered, the levelman must take care to use the terms "destroyed" and "not found" literally. "Destroyed" means either that a mark no longer exists or that it has been moved from its established location by an amount that cannot be determined. "Not found" merely means that the mark could not be found on the basis of the description and the limited effort expended in the

C&GS Line 57, Texas

U. S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
FORM 9–1165
(Rev. 3-60)

REPORT ON PERMANENT SURVEY MARK

AREA OFFICE

STATE Texas COUNTY Brazos QUADRANGLE Mineral, #113

QUOTE PRIMARY REFERENCE Milford, about 7.2 mi SW. of
(Direction and distance)

DESIGNATION { LISTED A 120 1934 / STAMPED }

TYPE OF MARK: BM X TT TRIANG.

Lat. ° ′ ″
Long. ° ′ ″
Elev. 219.779 feet

CONDITION: Disturbed ☐ Destroyed ☐ Not Found ☒

ESTABLISHED BY: USGS ☐ USBR ☐ USC&GS ☒ State GS ☐ USNPS ☐ USNFS ☐ USGLO/USBLM ☐ (Other) ☐

REMARKS ~~OR REVISED DESCRIPTION~~:

Mark not found; probably destroyed. Party searched 1½ hr, probing area around spot indicated by measurements from local objects. Area has been under cultivation 15-20 yr; owner bought property 10 yr ago and knows nothing about mark.

SUBMITTED BY A. H. Markel
TITLE Party Chief, Levels
AGENCY USGS

DATE January 15, 1962

Marks found in good condition need not be reported.

FILL IN ALL AVAILABLE INFORMATION

16—54252-4 (OVER)

Please prepare in triplicate and send to nearest (or indicated) address shown on reverse side.

U. S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
FORM 9–1165
(Rev. 3-60)

REPORT ON PERMANENT SURVEY MARK

AREA OFFICE

STATE Kentucky COUNTY Parks QUADRANGLE Wells, #301

QUOTE PRIMARY REFERENCE Hygiene, 1.2 mi north of post office
(Direction and distance)

DESIGNATION { LISTED 14 AC 1928 / STAMPED 14 AC 1928 TT }

TYPE OF MARK: BM X TT X TRIANG.

Lat. 36 ° 50 ′ 47.30 ″
Long. 87 ° 02 ′ 17.86 ″
Elev. 672.981 feet

CONDITION: Disturbed ☐ Destroyed ☒ Not Found ☐

ESTABLISHED BY: USGS ☒ USBR ☐ USC&GS ☐ State GS ☐ USNPS ☐ USNFS ☐ USGLO/USBLM ☐ (Other) ☐

REMARKS ~~OR REVISED DESCRIPTION~~:

Tablet and pieces of broken post found at site. Tablet battered and bent, but stamping still discernible. Site has been regraded for road widening. Impossible to recover original position and reestablish mark.

SUBMITTED BY John C. Carter
TITLE Party Chief, Field Completion
AGENCY USGS

DATE February 16, 1962

Marks found in good condition need not be reported.

FILL IN ALL AVAILABLE INFORMATION

16—54252-4 (OVER)

Please prepare in triplicate and send to nearest (or indicated) address shown on reverse side.

FIGURE 30.—Examples of reports on Form 9–1165.

search; the mark might still exist and could possibly be recovered after a more thorough investigation. The time and effort that should be spent in searching for a mark will depend on the importance of the mark to the searching party.

To state that a mark has been destroyed, the levelman must obtain satisfactory evidence of the fact and cite the evidence in his report. The evidence may be direct and physical, such as a broken post lying in a ditch, or an empty hole at the spot indicated by measurements from nearby references. The testimony of a responsible local person who knows the circumstances under which the mark was destroyed would also constitute satisfactory evidence. If found, the old tablet should be recovered and sent to the Area geodetic section.

If conclusive evidence of destruction cannot be obtained, the mark is reported "not found." For example, if measurements from local objects indicate that the location lies under a construction fill, the mark cannot, with certainty, be reported destroyed unless the county engineer or other responsible authority can state that the mark was destroyed and not merely covered by the new construction. Likewise, marks along streambanks and shorelines may become covered with sand, silt, or debris, and it may be difficult or impossible to find them; but they cannot, with certainty, be reported destroyed.

b. Reestablishing damaged or destroyed marks.—Sometimes marks that have been damaged or destroyed can be reestablished without extensive resurveying, or horizontal positions can be preserved even though the elevations are lost. For example, the hole for a destroyed or missing monument might be positively identified by fragments of the post or checked measurements from reference objects. A new post can be set in the same hole, or in a nearby safer location if the new mark is also likely to be damaged in the original location. A new elevation can be established if an intact reference mark is available. Reestablished marks are treated as reset marks, even if set in the original positions, and are stamped accordingly. (See art. 59.)

59. Resetting bench marks

Despite the care taken to place bench marks in safe, permanent locations, occasionally they must be moved and reset. Most commonly, resetting is necessitated by improvements in the vicinity, such as the widening or realinement of a road, the reconstruction of a bridge or culvert, or the erection of a new building, which would damage, destroy, or cover a monument.

Geological Survey levelmen may reset USGS monuments at their own discretion, or on request, if they have the proper equipment. Marks of other organizations should not be reset until permission and instructions are received from the responsible agency, through the Area office. An other-agency mark (not a boundary mark or a private survey mark) may be reset without prior authorization if delay would lead to the destruction of the mark; however, even in this case, it may be possible to establish two hubs nearby and set a new mark after permission has been obtained. Other qualified persons, such as county surveyors or highway engineers, may be authorized to reset Geological Survey marks if no Survey field parties are working in the surrounding area. Permission is granted on Form 9-1111, which also contains instructions for resetting marks and a report sheet for recording field data and a revised description for the reset mark.

a. Procedures for resetting marks.—If the mark to be reset has only an elevation, the levelman measures the difference in elevation between the original mark and the new mark, revises the description, and reports the original mark destroyed. This may be done directly by first setting a new tablet (in a post or existing structure), transferring the elevation by two independent setups, and then destroying the original mark. Alternatively, if it is preferable to move the original mark, two reference hubs are established, the monument is moved to its new location, the new elevation is transferred from the reference hubs, and the description is revised.

If the original mark has an established horizontal position, in addition to or instead of an elevation, the horizontal distance (to the nearest 0.1 or 0.01 ft) and the direction from the old to the new position must be measured. Depending on the instruments and data available, the direction may be determined by turning the angle, at the original mark, from a known azimuth reference point to the new point; by taking an observation on Polaris or the sun; by reading a compass bearing between the two positions; or by using the planetable to record sight rays from the old position to a known azimuth point (or magnetic north) and to the new position.

b. Stamping reset tablets.—A tablet reset in the same vicinity, whether the original or a new tablet, retains all the stamped data of the original, except the elevation, plus "RESET (year)." Examples:

"18 LHD 1935 RESET 1962 418"

"TT 8 RLH 1946 RESET 1962 176"

The elevation stamping must be corrected to agree with the reset elevation. The additional reset stamping is added also to marks of other agencies and is the only information Geological Survey fieldmen may stamp on these marks. Many Coast and Geodetic Survey bench marks are stamped with the elevation to the nearest thousandth of a foot. If one of these marks is moved, the original elevation stamping should be obliterated with the round head of a ball-peen hammer unless the levelman is specifically instructed to stamp a corrected elevation.

c. Reports on reset marks.—A levelman should record the fieldnotes and revised descriptions for reset marks in his regular field notebook. For each mark he resets, he also fills out a Form 9–1165, reporting the original mark destroyed. Under "Remarks or Revised Description," he includes a statement such as "Destroyed by resetting," gives the description and field elevation of the reset mark, and refers to the fieldbook page on which the data are recorded.

CHAPTER 2E5. LEVELING COMPUTATIONS

PREPARATION FOR ADJUSTMENT

60. Preliminary operations

As the fieldnotes for leveling are received in the Area geodetic section, the books are indexed and the lines of leveling are plotted on the control index maps.[1] The field notebooks and the computation folders are then sent to the vertical computations group for processing.

a. Preliminary lists of results.—Unadjusted elevations and unedited descriptions of points established by geodetic leveling are adequate for use in map compilation and may be needed immediately after the fieldwork has been completed. Therefore, preliminary lists of results usually are prepared before the fieldnotes are processed.[2] Ordinarily the fieldbook elevations are shown in preliminary lists. When time permits, mean elevations may be computed for multiple-run lines. Usually, however, only a comparison is made, to delete those runs that contain apparent blunders or large errors. Closures are noted for all junctions and ties, and a typing guide is prepared for each preliminary list.

b. Review of notes.—A careful review of the fieldnotes precedes the adjustment. The extent of the review depends on the time available and the reputation of the levelman for thoroughness and accuracy in prechecking his own notes. As a minimum, the computer reviews all field checks for completeness and accuracy. (See arts. 13, 16*a*, 31, 32, 34, 36, and 37.) He also compares the summary sheets with the fieldnotes to make sure that mileages and descriptions have been copied correctly, paying particular attention to directions and measured distances, and that elevations have been copied correctly and assigned to the proper descriptions.

61. Computation form

The descriptions of the bench marks are typed on Form 9–1128, Bench Mark Descriptions, Field Summary, as shown in the left half of figure 31. The back of the form (shown as the right half of fig. 31) is the standard computation and adjustment sheet for leveling. The sheets have been punched so that, when put in a loose-

[1] See Chap. 2H3, Indexing and filing control-survey records.
[2] See Chap. 2H4, Tabulating results of control surveys.

leaf notebook, the description page is on the left, facing a blank computation page with which it will be used. The paired pages are numbered identically.

62. Corrections for systematic errors

Differences in elevation measured in the field are subject to systematic errors which should be removed before the elevations are adjusted. Collimation errors are held to a minimum by keeping the instrument in accurate adjustment and by keeping foresight and backsight distances balanced (art. 24). The effect of the flattening of the earth towards the poles is compensated by the orthometric correction.

a. Rod corrections.—Errors introduced by variations in rod length due to temperature and humidity have been eliminated in modern leveling by the use of rods with graduated invar strips. Errors due to thermal expansion may be present in older leveling lines, but the data needed to correct them are seldom available. Temperature is recorded and corrections are made for second-order level lines. The correction is found as the product of the coefficient of expansion, the difference of elevation, and the difference between the temperature at which the rod was used and that at which it was calibrated. The coefficient of expansion and the rod calibration temperature are listed on the rod calibration sheet.

Errors caused by imperfect rod graduations are removed by applying a correction to each of the affected sights. The amount of the rod correction is determined from the calibration test data for the rods used. If the deviation in length is uniform over the entire rod, the correction is derived by meaning the total deviation for both rods and computing the deviation per foot. The correction is obtained by multiplying the difference of elevation for the section by the deviation per foot. If the deviation from true length is not uniform over the length of the rod, each reading must be corrected for length deviation.

Any rod index errors (art. 16*a*) should be corrected where necessary. When only one rod is used, the correction is zero. The rod used for a foresight should always be used for the backsight to the same turning point to prevent minor index errors from accumulating significantly as errors in elevation.

b. Orthometric correction.—In geodetic leveling, the surface defined by the level bubble, or the compensator, and the line of collimation of a perfectly adjusted telescope is a true level surface. Because of the ellipsoidal shape of the earth, level surfaces at different elevations are not parallel to each other or to the sea-level surface, except at the Equator and the poles. As illustrated in figure 32, the spacing between level surfaces varies continuously from a maximum at the Equator to a minimum at the poles. The total variation between Equator and pole is about 25 feet for each 5,000 feet of elevation. Thus, a continuous level surface with an elevation of 5,000 feet at the Equator is only about 4,975 feet above sea level at the poles. As a geodetic elevation represents an actual height above sea level at a particular point (h or h' in fig. 32), allowance must be made for this nonparallelism of level surfaces.

The orthometric correction, which compensates for the lowering of level surfaces toward the poles, depends on the latitude range of the level line, its average elevation, and its average latitude. In the Northern Hemisphere the correction reduces the elevations on northbound lines and increases them on southbound lines; it is not needed for east-west lines at any elevation and is usually insignificant at average elevations lower than 1,000 feet.

For second-order lines, the orthometric correction should always be investigated, and applied where it is significant; the correction is applied to third-order lines with an appreciable north-south component if their average elevation is 1,000 feet or more. For applying orthometric corrections, lines should be broken into sections of uniform general direction or slope, at points where abrupt changes in direction or slope occur. The maximum elevation range within a section should not exceed about 500 feet. The orthometric correction for each section of line is prorated among the bench marks of that section, as explained in article 62*c*.

Page 3 **BENCH MARK DESCRIPTIONS, FIELD SUMMARY** UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY 9-1128

Quads. Spanish Peaks No. 3 State COLORADO By J.E. Davis Date 1964

Bk.—Page	Miles	Adj.	Altitude by Field Book
1 15	7.3	Valdez, 3.0 mi west of along State Highway 12, thence 7.4 mi NW. along Zarcillo Canyon rd.; 75 ft south and 50 ft east of and 2 ft higher than Y-jct. of NW.-SE. rd. and rd. east, 65 ft. NE. of fence line, 3 ft. north of witness post; in large sandstone outcrop; std. tablet stamped "27 JED 1964 7217"	7217.366
17	8.0	Valdez, 3.0 mi west of along State Highway 12, thence 6.7 mi NW. Zarcillo Canyon rd.; 7 ft NE. of rd.; in SW. end of cattle guard; copper nail and washer	-67.183 7150.183
18	8.8	Valdez, 3.0 mi west of along State Highway 12, thence 5.9 mi NW. along Zarcillo Canyon rd.; 110 ft east of rd. at drain crossing; on top of large boulder; chiseled square	-109.949 7040.234 (-154.192)
20	9.4	Valdez, 3.0 mi west of along State Highway 12, thence 5.3 mi NW. along Zarcillo Canyon rd.; 72 ft east of and 7 ft higher than rd., 60 ft east of east end of wooden culvert; in large boulder, 2 ft west of witness post; std. tablet stamped "28 JED 1964 6996 "	-44.243 6995.991
21	10.2	Valdez, 3.0 mi west of along State Highway 12, thence 4.5 mi NW. along Zarcillo Canyon rd.; 220 ft SE. of ranchhouse, 30 ft NW. of wooden bridge, 12 ft SW. of and 1 ft lower than rd.; on top of boulder; chiseled square	-74.101 6921.890
23	11.0	Valdez, 3.0 mi west of along State Highway 12, thence 3.7 mi NW. along Zarcillo Canyon rd.; 9 ft east of rd.; at wooden bridge over drain, in SE. wingwall; copper nail and washer	-53.127 6868.763
24	11.5	Valdez, 3.0 mi west of along State Highway 12, thence 3.2 mi NW. along Zarcillo Canyon rd.; 9 ft SW. of and 2 ft lower than rd., at wooden bridge over drain; at west abutment, in SW. wingwall; std. tablet stamped "29 JED 1964 6820 "	-48.866 6819.897
		NOTE: Descriptions typed single-spaced for this illustration; in practice they are double-spaced.	

FIGURE 31.—Summary page.

COMPUTATION AND ADJUSTMENT

Page 3

Level No. T74190 Rod Nos. T203205/6

	Miles	Rerun ↑ 3/18 64	Mean ↓		Ortho.	Adjustment Correction	Adjusted Altitude (feet)
	7.3	7217.395	7217.366		+ .056	+ .014	7217.436
		+67.172	-67.178				
	8.0	7150.223	7150.188		+ .062	+ .011	7150.26
		+154.248	-109.965				
(Mean) -154.220	8.8		7040.223		+ .068	+ .008	7040.30
			-44.255				
	9.4	6995.975	6995.968	Jct., p. 12	+ .073	+ .006	6996.047
		+74.096	-74.098				
	10.2	6921.879	6921.870		+ .079	+ .003	6921.95
		+53.118	-53.122				
	11.0	6868.761	6868.748		+ .085	± .000	6868.83
		+48.883	-48.874				
	11.5	6819.878	6819.874		+ .089	- .002	6819.961

FIGURE 31.—Computation page.

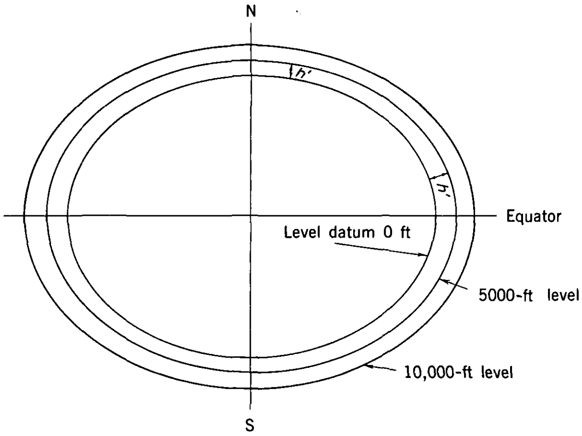


FIGURE 32.—Orthometric correction.

The orthometric correction is computed by the formula[8]

Correction$= -C\,h\,\Delta\phi$, in which

C= a factor depending on average latitude of section; values of C are listed in the table below, for each degree of latitude (in using the table, read over to the proper ten-degree column and down to the unit-degree line).

h= average elevation of section, in feet.

$\Delta\phi$= difference in latitude between the ends of the section (terminal minus initial), in minutes (scaled from a map or from the sketch on Form 9–1128a).

[8] For the theory and derivation of the orthometric correction, see Howard S. Rappleye, 1948, Manual of leveling computation and adjustment: U.S. Coast and Geod. Survey Spec. Pub. 240, app. C, p. 155–160.

Note that the correction is always opposite in sign to $\Delta\phi$. The nomogram illustrated in figure 33 (Form 333.1) also may be used for computing and distributing the orthometric correction.

To illustrate the computation of the orthometric correction, assume a line of leveling 20 miles long, extending southeast from lat 37°15′ to lat 37°00′ at a mean elevation of 7,000 feet. Factor C is taken from the table as 0.00000148; $\Delta\phi$ is $-15'$. The correction is therefore $-0.00000148 \times 7{,}000 \times (-15) = +0.155$ foot. This correction is positive because the line has a southerly component. The total correction is divided by the length of the line to obtain a rate of +0.00775 foot per mile for proration among the bench marks along the line, as shown in figure 31. The same computation is illustrated by the dashed lines on the nomogram in figure 33.

c. Continuity of corrections.—Because tabulated elevations on a computation sheet form a series on a continuous datum, a correction to any one elevation affects all that follow it in the line. Corrections for systematic errors are computed for the specific bench marks or portions of lines where the errors occur; however, the corrections must be applied cumulatively along the entire line. For example, the correction for any one elevation is the algebraic sum of the corrections for preceding elevations plus the specific correction for that elevation. The continuity of corrections is broken only at the end of a line or at a junction, where the line may be broken.

63. Computing mean lines

If a third-order line of leveling has been run two or more times, runs that agree within ac-

Orthometric correction factor C, in units of the 8th decimal place

Lat	0°	10°	20°	30°	40°	50°	60°	70°	80°
0°	0	52	99	133	151	152	133	99	52
1	5	57	103	136	152	150	131	95	47
2	11	62	107	138	153	149	128	91	42
3	16	67	110	140	153	148	125	86	37
4	21	72	114	142	154	146	121	82	32
5	27	77	118	144	154	145	118	77	27
6	32	81	121	146	154	143	114	72	21
7	37	86	124	148	154	141	111	67	16
8	42	90	127	149	153	138	107	63	11
9	47	94	130	150	152	136	103	58	5

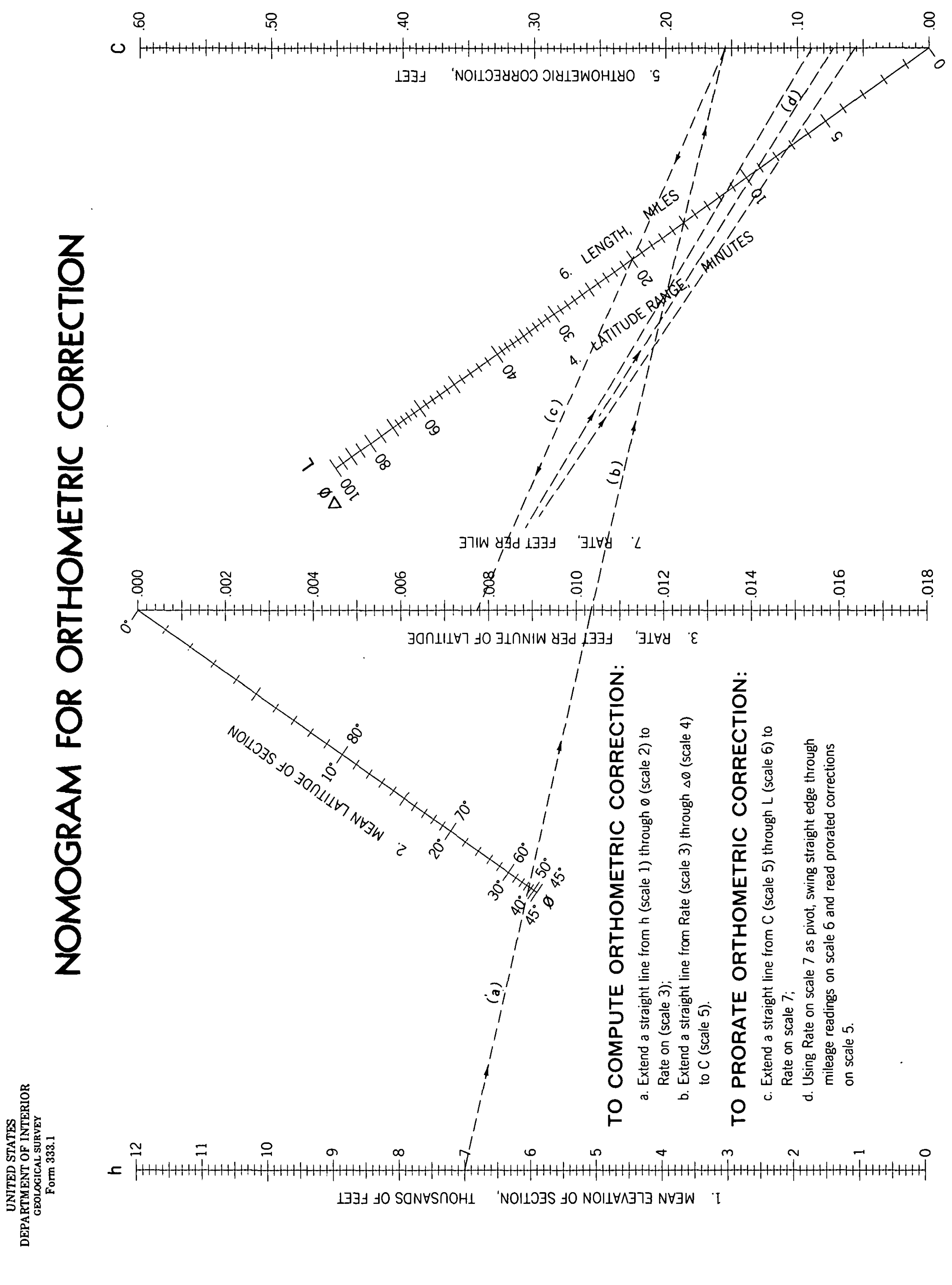


FIGURE 33.—Nomogram for computing and prorating orthometric correction, Form 333.1.

ceptable limits are averaged to form a mean line. Systematic error corrections are applied, as needed, to the original runs before the mean line is computed. The orthometric correction, which is independent of the field measurements, is then applied to the mean line.

As shown in figure 31, the Computation and Adjustment face of Form 9–1128 is used for entering the results of an acceptable rerun, obtaining mean elevations, and later applying the orthometric correction. The mileage for each mark is listed in the first column, opposite the original elevation on the left-hand page. Elevations from the rerun are listed on corresponding lines in the second column, and successive differences between these elevations are recorded between entries, as shown by the slanted entries in the figure. This column is headed with the book and page numbers for the rerun and a short arrow indicating its direction. If differences in elevation are available directly from the differences between backsight and foresight totals in the field notebook, they may be recorded without tabulating fieldbook elevations.

The means of the differences in elevation between successive bench marks and UE's determined from the original run and the reruns, are computed and recorded in the "mean" column. The short arrow in the heading indicates the adopted forward direction of the line, usually the direction of the first run. To obtain the mean difference for a point that was skipped on one of the runs, compute first the total mean difference in elevation between the two points on each side of, and adjacent to, the skipped point. Then, obtain the discrepancy between this mean and the sum of the measured partial differences, and prorate the discrepancy to the two partial differences in proportion to mileage. The sum of the corrected partial differences must equal the mean total difference.

In the example illustrated in figure 31, the bench mark at mile 8.8 was skipped in the rerun. The total mean elevation difference between the adjacent marks is $(-154.192 - 154.248)/2 = -154.220$. The sum of the measured partial differences is $-109.949 + (-44.243) = -154.192$, and the discrepancy is $-154.192 - (-154.220) = +0.028$. Then, the prorated mean deviations on each side of the omitted point are $(0.8/1.4) \times 0.028 = 0.016$ and $(0.6/1.4) \times 0.028 = 0.012$. The mean elevation differences are therefore $-109.949 - 0.016 = -109.965$ and $-44.243 - 0.012 = -44.255$.

To obtain mean elevations along the line, the mean differences are added algebraically in the forward direction, starting with the accepted fieldbook elevation of the initial point.

For a partial check on the mean line, the difference between the average of the several fieldbook elevations and the mean elevation for the initial point on the line should agree approximately with the corresponding difference for the final point. For example, in figure 31, the average of the initial fieldbook elevations on the page is $\frac{1}{2}$ (7217.366+7217.395) =7217.380; this differs from the mean, 7217.366, by +0.014. The average of the final fieldbook elevations on the page is $\frac{1}{2}$ (6819.897 +6819.878) =6819.888; this differs from the mean, 6819.874, by +0.014. These differences from the mean may differ by one or two thousandths because of roundoffs on the page.

Second-order leveling requires a computation of the mean of both lines run in opposite directions or the mean of all forward and backward runnings after rejections. Form 9–932a, Computation of Second-Order Levels, is used for computing second-order level lines.

ADJUSTMENT OF ELEVATIONS

64. Adjustment diagram

After the fieldnotes have been reviewed and all known systematic errors corrected, the closure errors remaining in the work are assumed to be due to accidental errors and are removed by adjustment. An essential requirement for any method of adjustment is a diagram showing the relationship between lines to be adjusted, junctions, and ties to fixed elevations. In showing this relationship, it may be necessary to distort the scale in parts of the diagram.

Information for preparing the adjustment diagram is obtained from the field summary and computation sheets, Form 9–1128, using the circuit diagram on Form 9–1128a as a guide. For this purpose, every junction elevation on Form 9–1128 is cross-referenced by page number to every other determination of the same elevation. A typical adjustment diagram is illustrated in figure 34.

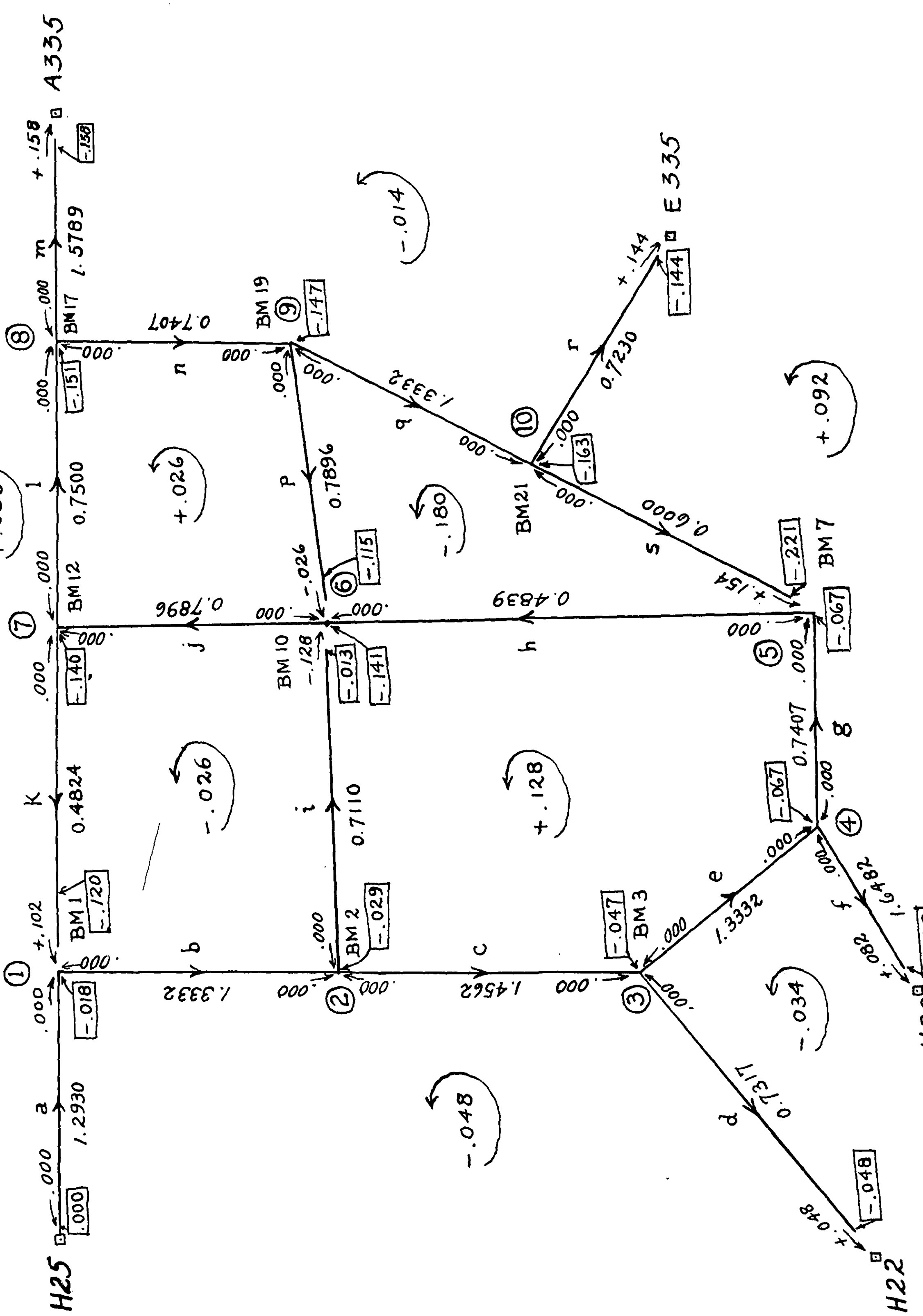


FIGURE 34.—Adjustment diagram.

Fixed bench marks and ties to previous work are labeled with identifying symbols, usually the code letters and numbers stamped on the tablets. Junction bench marks are similarly identified and also given a reference number, as shown in figure 34. A lowercase letter is placed near the middle of each line, with an arrowhead indicating the direction in which it was run. On a multiple-run line the arrowhead indicates the direction adopted for the mean line, normally the direction of the forward run. If the adjustment is to be made by either the circuit-reduction method or ESNA (art. 65), the length of each line is recorded opposite its designating letter; if a weighted-mean or machine adjustment is to be used, the weight of each line (inversely proportional to its length) is recorded.

a. Tabular line summary.—Some computers may find a tabular line summary (fig. 35) helpful in preparing the adjustment diagram. The fixed or controlling points are listed in the first section of the summary; the correctness of these elevations must be checked and their datum verified. In the second section are tabulated the data for all the lines to be adjusted. The initial and closing elevations of each line, listed in the second column, have been corrected for systematic errors and checked for accuracy.

b. Junction closures.—At each junction and tie point, an elevation must be assumed as the basis for adjustment. The assumed elevation for a fixed bench mark must, of necessity, be the previously adjusted elevation that is to be held fixed; at any other junction, the assumed elevation may, for convenience, be that determined on any of the lines entering the junction. For every other line entering the junction, or tying to the fixed bench mark, the closure is computed by subtracting the assumed elevation of the junction or bench mark from the elevation determined by the new line. The closure is recorded near the end of the line, with a short arrow parallel to the line and pointing to the junction or tie point. Zero closures may be omitted where there is no likelihood of confusion.

For an example of junction-closure computations, refer to junction 6, the common junction of lines h, i, j, and p, at BM 10 in figure 34. The assumed elevation of BM 10 is taken as 750.444 feet, as determined by line h; consequently, the closure of line h on the junction is zero. The elevation of BM 10 determined by line i is 750.316; therefore the closure of line i is $750.316-750.444=-0.128$. In line j the elevation of BM 10 is 750.444, producing a zero closure. The closure of line p is $750.418-750.444=-0.026$. Except at a fixed bench mark, it makes no difference in the final results which elevation is assumed as the basis for the adjustment, but the same value must be used in determining the closures for all lines entering the junction.

c. Circuit closures.—Circuit closures are computed after all the junction closures have been recorded on the diagram. Although the circuit closures are not used directly in some methods of adjustment, they do provide an indication of the quality of the work; furthermore, they enable the computer to detect blunders in the previous steps of the computation, to eliminate from the adjustment substandard lines that should be rerun, and to recommend additional ties needed to strengthen the net.

Each circuit closure is computed by adding all the junction closures counterclockwise around the circuit, changing the sign of each closure that is opposed to the counterclockwise route. To close a circuit containing two fixed bench marks, the line connecting them is assumed to have a zero closure.

In figure 34, the closure for circuit 9, 6, 5, 10, is computed as $-0.000+(-0.026)-0.000+0.000-(+0.154)+0.000-0.000+0.000=-0.180$. For circuit E 335, 10, 5, 4, H 20, E 335, the closure is $-(+0.144)+0.000-0.000+0.154-0.000+0.000-0.000+0.082+0.000$ (for the imaginary line between fixed bench marks H 20 and E 335) $=+0.092$. The circuit closure is recorded inside a counterclockwise arrow near the center of each circuit.

Each circuit closure and all its line and junction closures may be checked directly on an adding machine from the elevations recorded in the tabular line summary, figure 35. Proceeding counterclockwise around the circuit, the initial elevation reached on each line segment is subtracted and the terminal elevation added. Fixed bench marks are treated as the ends of an imaginary closing line. The net sum should exactly equal the circuit closure previously computed from the junction closures. For example,

FIXED POINTS

Bench mark	Elevation
H 25	873.272
H 22	805.464
H 20	776.534
A 335, C&GS	408.965
E 335, C&GS	379.458

LINE	ELEVATIONS	BOOK	PAGE	MILEAGE	BENCH MARKS
a	873.272 851.888	1 1	2 4	2.32	H 25 BM 1
b	851.888 835.286	1 1	5 8	2.25	BM 1 BM 2
c	835.286 822.349	1 1	9 12	2.06	BM 2 BM 3
d	822.349 805.512	1 1	13 17	4.10	BM 3 H 22
e	822.349 820.567	1 1	20 24	2.25	BM 3 BM 5
f	820.567 776.616	1 1	25 26	1.82	BM 5 H 20
g	820.567 782.134	1 1	27 30	4.05	BM 5 BM 7
h	782.134 750.444	1 1	31 41	6.20	BM 7 BM 10
i	835.286 750.316	1 1	55 60	4.22	BM 2 BM 10
j	750.444 577.643	1 1	42 48	3.80	BM 10 BM 12
k	577.643 851.990	1 1	50 54	6.22	BM 12 BM 1
l	577.643 491.816	1 1	62 67	4.00	BM 12 BM 17
m	491.816 409.123	1 1	68 73	1.90	BM 17 A 335
n	491.816 502.555	2 2	2 10	4.05	BM 17 BM 19
p	502.555 750.418	2 2	12 17	3.80	BM 19 BM 10
q	502.555 418.980	2 2	18 24	2.25	BM 19 BM 21
r	418.980 379.602	2 2	25 30	4.15	BM 21 E 335
s	418.980 782.288	2 2	32 39	5.00	BM 21 BM 7

FIGURE 35.—Tabular line summary.

the lines in circuit E 335, 10, 5, 4, H 20, E 335 are *r* (reversed), *s*, *g* (reversed), *f*, and H 20–E 335. The circuit-closure check from figure 35 is $-379.602+418.980-418.980+782.288-782.134+820.567-820.567+776.616-776.534+379.458=+0.092$, which checks the value obtained previously. As a further check, which should always be made, the sum of all the circuit closures in the net, excluding any circuits that overlap others, must be exactly zero. (A circuit is said to overlap others if it includes or encloses them within its confines.)

Each circuit closure should be tested for conformity to the specified standards (art. 3). If the closures of two adjoining circuits are excessive and approximately equal in magnitude but opposite in sign, the line common to these circuits probably contains excessive error or blunders. If the trouble cannot be discovered in the fieldnotes or computations, the line should be omitted from the adjustment (with the approval of the chief of the geodetic section) and recommended for rerunning. Excessive closures in two circuits that have only a common junction usually indicate that the junction bench mark has been misidentified or disturbed.

65. Choice of adjustment methods

The Geological Survey uses only those methods of adjustment that conform to the principle of least squares. Because several methods are available, depending on the size and configuration of the leveling net, and all yield practically the same results, the computer may choose the most appropriate and convenient one. Each method requires almost the same preliminary preparation, and the resulting corrections are applied in the same way. Explanations and instructions for the several available methods of adjustment are given in Chapter 2H1, Adjustment methods.

a. Simple proration.—To adjust a single line connecting two fixed bench marks, the closing bench mark is given a correction equal to, but opposite in sign to, the closure error; this correction is then prorated along the line according to the distance from the starting point. If a junction is determined by only two lines from fixed bench marks, the circuit closure is prorated between the lines in proportion to their lengths.

b. Weighted means.—The adjusted elevation of a junction determined by three or more lines from fixed bench marks may be computed as the weighted mean of the elevations brought in over the separate lines, or an adjustment correction may be determined as the weighted mean of the closures on an assumed elevation for the junction. The resulting corrections are then prorated along the lines according to their lengths. For this method of adjustment, the weight assigned to each line is inversely proportional to its length.

c. Circuit-reduction method.—Many nets of leveling consist of simple circuit patterns, or can be readily reduced to a combination of simple nets, that can be adjusted by the circuit-reduction method. This method is also called the Braaten method.

d. General methods.—For larger or more complicated nets, one of the general methods of adjustment that apply to all possible configurations should be used. If an ESNA (Electrical Survey-Net Adjuster) is available, it may be used to adjust large nets within the limits of its capacity. If an ESNA is not available or if the net is small, machine adjustment may be used.

The work required for machine adjustments increases at a much higher rate than the size of the net, varying almost as the square of the number of junctions in the net. The efficient limit of size for machine adjustments is about 15–20 junctions, depending on the skill and experience of the computer. Large nets may be adjusted in parts; however, the number of parts should be kept to a minimum because the adjustment of a large net in sections is somewhat weaker than a single adjustment.

66. Applying adjustment corrections

Regardless of the method used, the adjustment yields corrections to be applied to each end of every line in the net. These corrections are marked on the diagram in small rectangles with arrows pointing to the places in the lines where the corrections are to be applied (fig. 34). They are also entered and encircled in the "Adjustment Correction" column of Form 9–1128 (fig. 31).

a. Prorating.—The difference between the corrections applied at the ends of a line is the amount of correction to be prorated along the line in proportion to the distance from one end. For example, the length of line *i* (figs. 34, 35) is 4.22 miles, and its end corrections are −0.029 and −0.013. The correction to be applied at a point 2.71 miles from BM 2 is computed as $-0.029+[(0.013)-(-0.029)]\ (2.71/4.22) = -0.019$.

A convenient method of prorating this correction is to determine first the rate per mile. Thus, the total correction to be distributed is $(-0.013)-(-0.029)=+0.016$; this quantity divided by 4.22 miles equals +0.00379, the rate per mile. Then, the correction at any point is found by adding to the correction for the initial point the product of the rate per mile and the distance to the point. The correction as a distance of 2.71 miles is thus $-0.029+2.71\,(+0.00379)=-0.019$. These corrections are distributed only to points for which elevations have been determined; they are recorded in the "Adjustment Correction" column of Form 9-1128 (fig. 31).

b. Adjusted elevations.—Each adjusted elevation is obtained by algebraically adding the original fieldbook elevation (or mean elevation on a multiple-run line) and all the corrections, systematic and adjustment, recorded on the same line on the computation and adjustment sheet. The adjusted elevations are recorded in the final column of the form, to 3 decimal places of feet for tablets or rounded to 2 decimal places for other marked points. To check the application of the correction, the following test may be made on an adding machine or calculating machine:

Add all the original elevations (or mean elevations) on the page;

Add in all systematic and adjustment corrections;

Subtract all adjusted elevations.

The result should be zero, except for the accumulation of roundoffs. This accumulation may be expected to average around $0.0025\sqrt{n}$, where n is the number of rounded elevations on the page; it should never exceed $0.005\,n$.

c. Checking elevations of junctions.—After all the adjusted elevations have been computed and recorded, a final check is essential to see that the adjusted elevation of each junction is the same in each line entering it. Either the adjustment diagram or the tabular line summary may be used as a guide in making this check. Discrepancies must be investigated and corrected immediately.

U.S. GOVERNMENT PRINTING OFFICE: 1966 O—797-176

TOPOGRAPHIC INSTRUCTIONS • CHAPTERS 2E1–2E5 • LEVELING