Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A19

LEVELS AT STREAMFLOW GAGING STATIONS

By E.J. Kennedy

Book 3

APPLICATIONS OF HYDRAULICS

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, Jr., *Secretary*

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PREFACE

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The unit of publication, the Chapter, is limited to a narrow field of subject matter. This format permits flexibility in revision and publication as the need arises. Chapter A19 of Book 3 (TWRI 3–A19) deals with levels at streamflow gaging stations.

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TWRI 3–A9.[1] Measurement of time of travel in streams by dye tracing, by F.A. Kilpatrick and J.F. Wilson, Jr. 1989. 27 pages.
TWRI 3–A10. Discharge ratings at gaging stations, by E.J. Kennedy. 1984. 59 pages.
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TWRI 3–A19. Levels at streamflow gaging stations, by E.J. Kennedy. 1990. 31 pages.
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TWRI 3–B2.[2] Introduction to ground-water hydraulics, a programmed text for self-instruction, by G.D. Bennett. 1976. 172 pages.
TWRI 3–B3. Type curves for selected problems of flow to wells in confined aquifers, by J.E. Reed. 1980. 106 pages.
TWRI 3–B4. Regression modeling of ground-water flow, by Richard L. Cooley and Richard L. Naff. 1990. 232 pages.

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[1]This manual is a revision of "Measurement of Time of Travel and Dispersion in Streams by Dye Tracing," by E.F. Hubbard, F.A. Kilpatrick, L.A. Martens, and J.F. Wilson, Jr., Book 3, Chapter A9, published in 1982.
[2]Spanish translation also available.

TWRI 3–B5. Definition of boundary and initial conditions in the analysis of saturated ground-water flow systems—An introduction, by O. Lehn Franke, Thomas E. Reilly, and Gordon D. Bennett. 1987. 15 pages.
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TWRI 5–A1. Methods for determination of inorganic substances in water and fluvial sediments, by Marvin J. Fishman and Linda C. Friedman, editors. 1989. 545 pages.
TWRI 5–A2. Determination of minor elements in water by emission spectroscopy, by P.R. Barnett and E.C. Mallory, Jr. 1971. 31 pages.
TWRI 5–A3.[1] Methods for the determination of organic substances in water and fluvial sediments, edited by R.L. Wershaw, M.J. Fishman, R.R. Grabbe, and L.E. Lowe. 1987. 80 pages.
TWRI 5–A4.[2] Methods for collection and analysis of aquatic biological and microbiological samples, by L.J. Britton and P.E. Greeson, editors. 1989. 363 pages.
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TWRI 5–A6. Quality assurance practices for the chemical and biological analyses of water and fluvial sediments, by L.C. Friedman and D.E. Erdmann. 1982. 181 pages.
TWRI 5–C1. Laboratory theory and methods for sediment analysis, by H.P. Guy. 1969. 58 pages.
TWRI 6–A1. A modular three-dimensional finite-difference ground-water flow model, by Michael G. McDonald and Arlen W. Harbaugh. 1988. 586 pages.
TWRI 7–C1. Finite difference model for aquifer simulation in two dimensions with results of numerical experiments, by P.C. Trescott, G.F. Pinder, and S.P. Larson. 1976. 116 pages.
TWRI 7–C2. Computer model of two-dimensional solute transport and dispersion in ground water, by L.F. Konikow and J.D. Bredehoeft. 1978. 90 pages.
TWRI 7–C3. A model for simulation of flow in singular and interconnected channels, by R.W. Schaffranek, R.A. Baltzer, and D.E. Goldberg. 1981. 110 pages.
TWRI 8–A1. Methods of measuring water levels in deep wells, by M.S. Garber and F.C. Koopman. 1968. 23 pages.
TWRI 8–A2. Installation and service manual for U.S. Geological Survey monometers, by J.D. Craig. 1983. 57 pages.
TWRI 8–B2. Calibration and maintenance of vertical-axis type current meters, by G.F. Smoot and C.E. Novak. 1968. 15 pages.

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[1]This manual is a revision of TWRI 5–A3, "Methods of Analysis of Organic Substances in Water," by Donald F. Goerlitz and Eugene Brown, published in 1972.

[2]This manual supersedes TWRI 5–A4, "Methods for collection and analysis of aquatic biological and microbiological samples," edited by P.E. Greeson and others, published in 1977.

CONTENTS

FIGURES

METRIC CONVERSION FACTORS

The inch-pound system of units is used in this manual. For readers who wish to convert to the metric system of units, the conversion factors are listed below:

Multiply inch-pound units	*By*	*To obtain metric units*
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer

GLOSSARY

Backsight (BS). The reading on a leveling rod held on a point of known elevation.

Bench mark (BM). A permanent marker whose description and elevation above National Geodetic Vertical Datum of 1929 (NGVD of 1929) are included in lists compiled for public use by various agencies.

Collimation. Agreement of a surveying instrument's line of sight with its horizontal axis.

Collimation error factor (c). The inclination of a level's line of sight, in feet per 100 feet; positive when the line of sight points downward from the instrument.

***Curvature effect (C).** The increase in a leveling rod's reading caused by the curvature of the Earth.

***Curvature and refraction effect (CR).** The increase in a leveling rod's reading caused by the combination of the Earth's curvature and atmospheric refraction effects.

***Datum.** A level surface that represents a zero elevation.

Differential leveling. The determination of the difference in elevation of two points by use of an engineer's level and a leveling rod.

Elevation (Elev.). The vertical distance from a point to the datum.

Engineer's level. A surveying instrument consisting of a telescopic sight and a sensitive leveling device to make the line of sight horizontal.

Error of closure. The difference between the elevation of the starting point of a closed circuit of levels and the elevation of that same point as determined from the last leveling rod reading in the circuit.

Foresight (FS). The reading on a leveling rod held on a point whose elevation is to be determined.

***Gage datum.** The datum whose surface is at the zero elevation of all the gages at a gaging station.

Gaging station levels. Levels run (that is, carried out) in the vicinity of a gaging station in order to define and maintain a constant gage datum for the individual gages.

Geodetic bench mark levels. Relatively long lines of levels between bench marks, run at one of three orders of accuracy with special equipment and meticulous procedures designed to minimize systematic errors and keep errors of closure smaller than 0.017 $\sqrt{M}$ feet for first-order levels, 0.035 $\sqrt{M}$ feet for second-order levels, and 0.050 $\sqrt{M}$ feet for third-order levels, where M is the total distance run, out and back, in miles. Note: Fourth-order levels are similar to third-order levels but are run with ordinary equipment and procedures, for the purpose of referencing gaging-station datums to NGVD of 1929. Errors of closure may be larger than for third-order levels.

Height of instrument (HI). The elevation of the horizontal line of sight of an engineer's level.

***Horizontal.** A direction perpendicular to the force of gravity.

***Level.** A line or surface all of whose segments are horizontal. Also an engineer's level.

Leveling. The determination of elevations by surveying, usually with an engineer's level and a leveling rod.

Leveling rod (rod). A slender bar graduated on one face from the bottom, used to measure the height of a line of sight above a point on the ground.

***National Geodetic Vertical Datum of 1929 (NGVD of 1929).** A spheroidal datum in the conterminous United States and Canada that approximates mean sea level but does not necessarily agree with the mean sea level measured at a specific locality. The reference datum used for all national mapping activities.

Parallax. The relative movement of the image of the leveling rod with respect to the crosshairs as the observer's eye moves, caused by improper focusing of the objective lens.

Peg test. A procedure for checking that a level's line of sight is truly horizontal.
Reference mark (RM). A permanent marker, installed in the ground or on a structure in the vicinity of a gaging station, whose elevation above the gage datum is known.
Reference point (RP). A bolt, screw, or other object installed on or in the vicinity of a gage structure in order to set or check the gage by taping (that is, measuring the distance with a graduated tape) from the point to a gage graduation or the water surface.
***Refraction effect (R).** An error in the reading of a leveling rod caused by the bending of horizontal light rays toward the Earth's surface due to variation in atmospheric density at different elevations.
Reticle. A surveying instrument's crosshairs and their supporting ring.
Stadia. A method for measuring the horizontal distance between an engineer's level and a leveling rod by reading two horizontal crosshairs in the level's telescope; the difference in rod readings at the two crosshairs, multiplied by a constant, usually 100, is the length of the sight. Also the telescope feature that permits this method.
Turning point (TP). A temporary point of reference used in the leveling process.
***Vertical.** The direction of the force of gravity.

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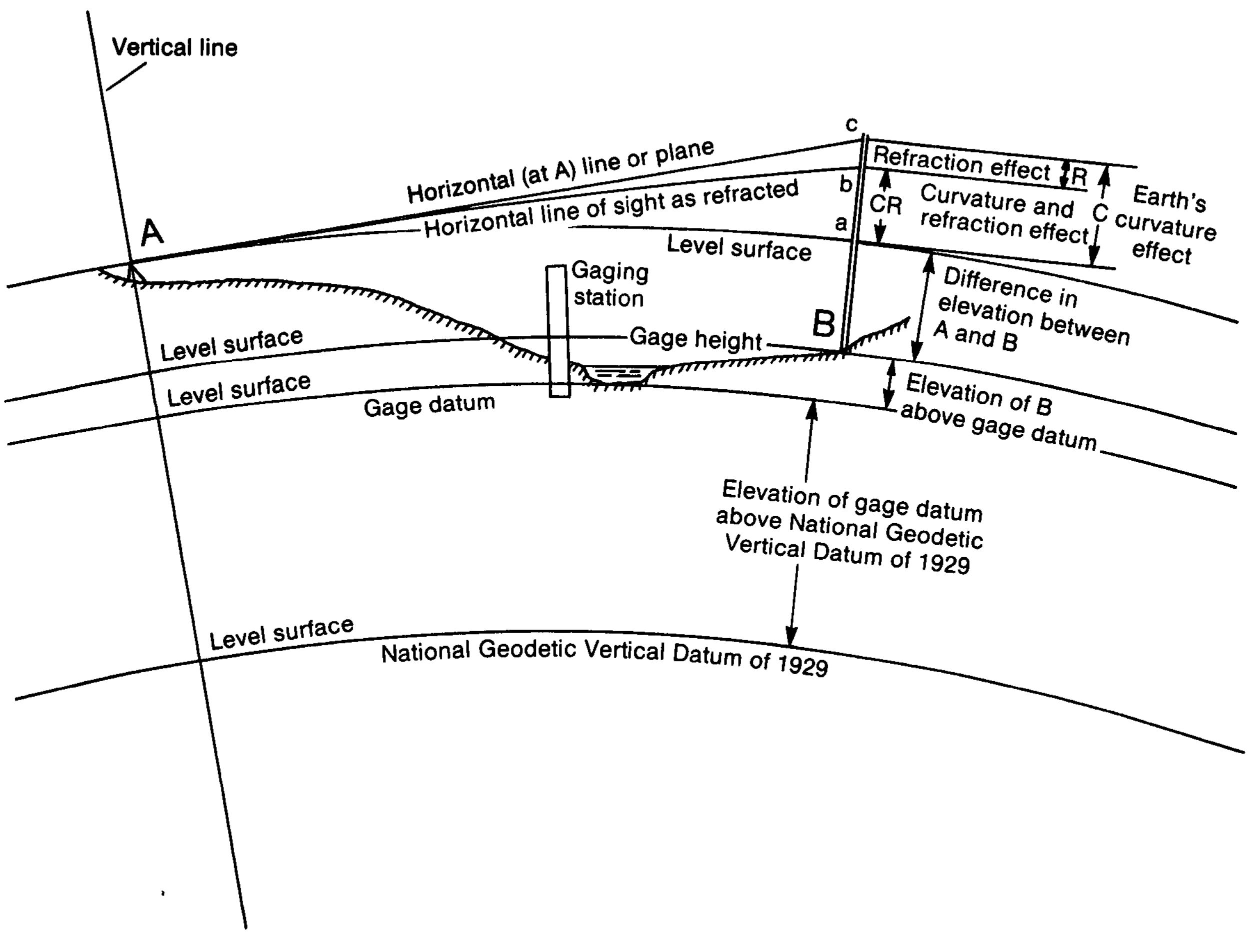
*See accompanying graphical illustration.



Leveling terms (curvature greatly exaggerated).

LEVELS AT STREAMFLOW GAGING STATIONS

By E.J. Kennedy

Abstract

This manual establishes the surveying procedures for (1) setting gages at a streamflow gaging station to datum and (2) checking the gages periodically for errors caused by vertical movement of the structures that support them. Surveying terms and concepts are explained, and procedures for testing, adjusting, and operating the instruments are described in detail. Notekeeping, adjusting level circuits, checking gages, summarizing results, locating the nearest National Geodetic Vertical Datum of 1929 bench mark, and relating the gage datum to the national datum are also described.

Introduction

The various gages at a newly established gaging station are set to register the elevation of a water surface above a selected level reference surface called the gage datum. The position of this datum is intended to remain unchanged throughout the life of the station. The gage's supporting structures—stilling wells, backings, shelters, bridges, and other structures—tend to settle or rise as a result of earth movement or battering by floodwaters and flood-borne ice or debris. Vertical movement of a structure makes the attached gages read too high or too low and, if the errors go undetected, may lead to increased uncertainties in streamflow records. Leveling, a procedure by which surveying instruments are used to determine the differences in elevation between points, is used to set the gages and to check them from time to time for vertical movement.

Leveling, done at intervals, usually between 1 and 4 years, determines the elevations of certain points located on or near the different gages by measuring the vertical distances between those points. When the levels are run (that is, the process of leveling is carried out), the gages are checked and reset where necessary. The checking usually is done by taping (that is, measuring with a graduated tape) up or down from reference points to graduations on the gages or to the water surface near them, or by sighting directly on the gage scales. The accuracy of the levels and the time required to run them depends on the weather, the type and condition of the instruments, the procedures used, and, especially, the skill of the leveling party. Gages are sometimes checked or reset during routine visits to a station without running levels, by measuring up or down from the reference points, using their elevations as determined from previous levels.

This manual was prepared to provide in one document pertinent information on all aspects of leveling related to gaging-station operation. It is intended for use in formal and informal training programs in which hydrographers can learn the approved techniques and develop the degree of skill needed to apply them. Procedures, instruments, and equipment, including the following, are covered: leveling concepts and terms; equipment selection, maintenance, and operation; checking of various types of gages; recording of field notes; adjustment of measured elevations by logical distribution of the measuring errors; and summarizing of results of leveling so they can be readily incorporated in discharge-record computations. The leveling techniques described agree with those outlined in surveying textbooks, with instructions prepared by the U.S. Geological Survey National Mapping Division (U.S. Geological Survey, 1966), and with instructions for gaging-station leveling developed by the U.S. Geological Survey Water Resources Division.

Leveling Method and Concepts

Differential leveling starts by using the telescope of an engineer's level to obtain a reading from a leveling rod held upright on a point of known elevation. The reading, that is, the value on the rod's graduations viewed at the telescope's crosshair, is the backsight

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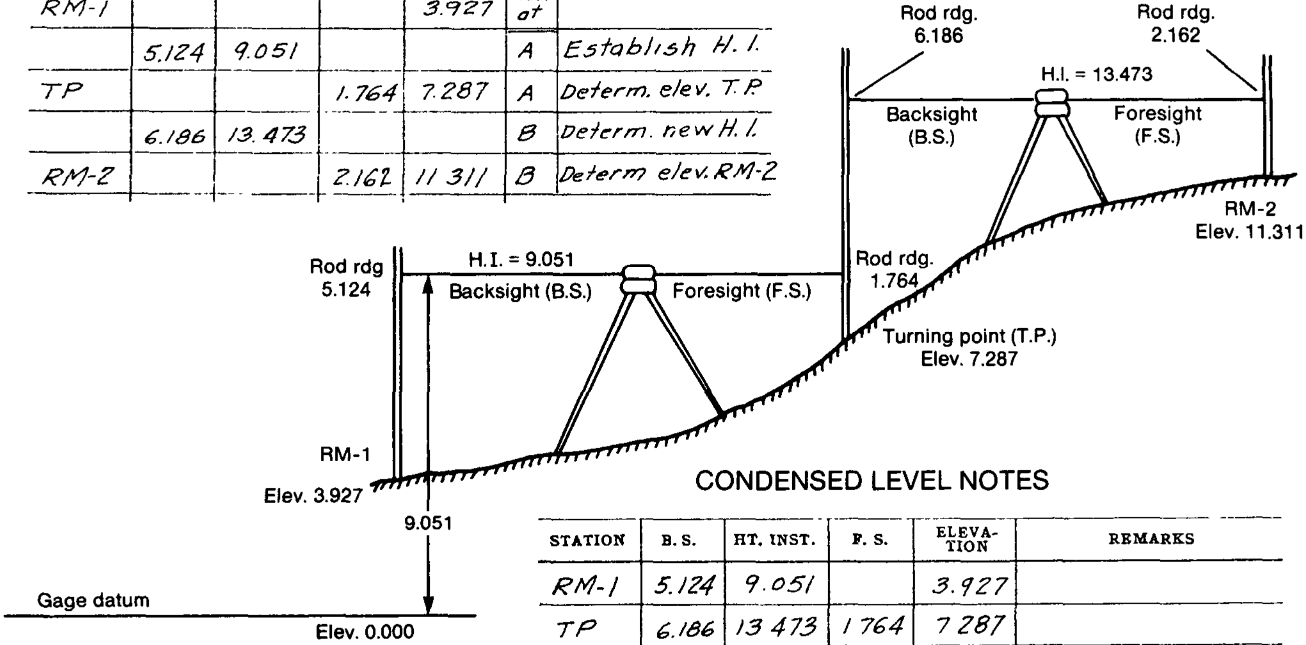
EXPANDED LEVEL NOTES

STATION	B. S.	HT. INST.	F. S.	ELEVATION	Instr at	REMARKS
RM-1				3.927		
	5.124	9.051			A	Establish H.I.
TP			1.764	7.287	A	Determ. elev. T.P.
	6.186	13.473			B	Determ. new H.I.
RM-2			2.162	11.311	B	Determ elev. RM-2



CONDENSED LEVEL NOTES

STATION	B. S.	HT. INST.	F. S.	ELEVATION	REMARKS
RM-1	5.124	9.051		3.927	
TP	6.186	13 473	1 764	7 287	
RM-2			2.162	11.311	

Figure 1.—Leveling procedure.

(BS); the backsight is added to the point's known elevation to obtain the elevation of the instrument's line of sight, or height of instrument (HI). The rod is then held on the next point whose elevation is to be determined, and a foresight (FS) is read. The foresight is subtracted from the height of instrument, and the result is the elevation of the point under the rod. That point then becomes a point of known elevation, and the level may be moved to a new location, usually halfway between the last leveled point and the next turning point. The process is repeated as often as necessary until the line along which leveling is done is complete. New elevations (Elev.) are computed by using the following equations: Known Elev.+BS=HI, and HI−FS=New Elev. Figure 1 illustrates the procedure and two notekeeping formats. The condensed version of the notes is commonly used.

The principal potential source of error in gaging-station leveling is variation of the level's line of sight from a true horizontal line, usually due to imperfect instrument adjustment. Few levels can be counted on to remain in close adjustment for much more than a week of normal use. Another source of error is atmospheric refraction, which curves the line of sight downward. However, errors from this source are usually negligible for the sight lengths used in gaging-station or ordinary bench mark leveling.

If the line of sight of an engineer's level is in perfect adjustment, it generates a horizontal plane (slightly distorted by refraction) when the telescope is revolved about its vertical axis. If a level has a faulty collimation adjustment, the surface defined by revolving the line of sight about its vertical axis is a shallow cone with its vertex at the top or bottom, depending on the direction of the collimation error. The cone corresponding to such a misadjusted level is illustrated in figure 2. The level is set up at "B," and its line of sight tilts downward at a slope of 0.010 foot in 100 feet (or a collimation error factor of +0.010). A backsight on "A" 100 feet away would be 0.010 foot too low, which would make the computed height of instrument 0.010 foot too low. A foresight on "C" 50 feet from the level would be 0.005 foot too low; this reading subtracted from the 0.010-foot-low height of instrument would give an elevation for "C" 0.005 foot too high. If the foresight were made on "D" 100 feet from the level, the rod reading would be 0.010 foot too low and, when subtracted from the 0.010-foot-low height of instrument, would give the correct elevation for "D." Note that the effect of the slope in the line of sight is

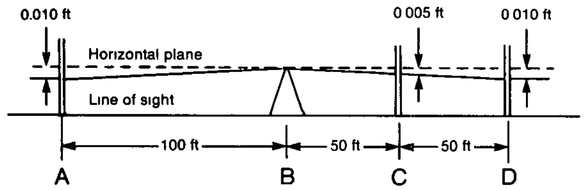
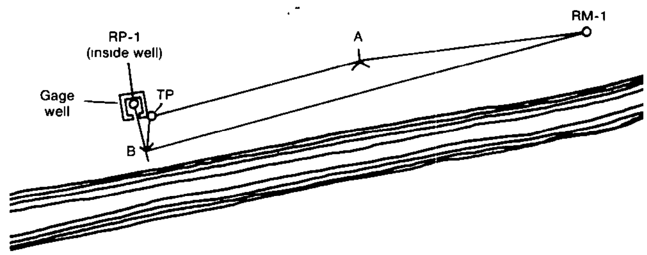


Figure 2.—Variation of effect of line of sight misadjustment with length of sight.

canceled out, and no error in elevation results, when the backsight and foresight distances are the same.

A level, even one kept in close adjustment, is used knowing that it may have been knocked out of adjustment since its last checking. Therefore, all sight distances should be balanced as closely as possible. An extra turning point can be used to balance the distances at a gaging station where the level must be set up at a fixed location. Figure 3 illustrates a situation in which the gages inside a well must be checked from a reference point inside the well. In most cases, the levels could be run from the reference mark (RM) directly to the reference point. In this situation, however, a rod held on the reference point can be sighted only through the cleanout door, from a level set up at "B." The backsight distance to the reference mark would be about 100 feet longer than the foresight distance to the reference point, and if the instrument were even slightly out of adjustment, the slope of the line of sight could cause a substantial error in the measured elevation of the reference point. The sight distances can be closely balanced by using a turning point outside of the well and measuring its elevation by setting up the level at "A." The reference-point elevation can then be measured accurately from "B" by using reasonably balanced sight lengths from the turning point and the reference point.



Levels from RM-1 to RP-1, using an instrument whose line of sight slopes downward 0.0001 ft/ft

STATION	BS	HT INST	FS	ELEVATION	REMARKS
Level set up at "B", 110 ft from RM-1 and 15 ft from RP-1					
RM-1	4.110	10 835		6.725	
RP-1	4.031	10.913	3.953	6.882	Measured elevation affected by instrument misadjustment
RM-1			4.188	6.725	closure 0
		—			
Level set up at "A", 55 ft from RM-1 and TP, and at "B", 15 ft from RP-1 and 10 ft from TP					
RM-1	4.092	10.817		6.725	
TP	3.817	10.623	4.011	6.806	
RP-1	3.882	10.774	3.731	6.892	True elevation, unaffected by instrument misadjustment
TP	4.102	10.908	3.968	6.806	closure 0
RM-1			4.183	6.725	closure 0
		—			

Figure 3.—Use of turning point to avoid unbalanced lengths of sight.

Curvature and refraction

Horizontal light rays bend when they travel through varying densities of the atmosphere. The bending is erratic when the air temperature is changing rapidly and also near the ground when heat waves are noticeable. Refraction also bends a horizontal line of sight slightly and smoothly downward from the instrument. When the effect of this refraction (R) is evaluated, it is usually combined with the curvature effect (C), the effect on the line of sight resulting from Earth's curvature. In the figure in the "Glossary," the horizontal line of sight from a level set up at "A" and pointed at a leveling rod held at "B" is refracted downward. If the Earth's surface were flat, and the line of sight straight, the rod would read "a." The rod actually reads "b," but "b" appears to be at "c." The distance "ab" represents the combined curvature and refraction effect (CR), which for stable conditions can be estimated by the formula $CR = 0.0206\ F^2$, where F is the length of the line of sight in thousands of feet.

Both curvature and refraction are negligible as long as sight lengths are less than 150 feet (110 feet for peg testing of a level, discussed later) and no heat waves radiating from the ground are visible through the telescope. The effect of heat waves can usually be eliminated by keeping the line of sight as high off the ground as practical and by shortening the sight lengths. When the curvature effect is consequential, as when referencing a gaging-station datum to National Geodetic Vertical Datum of 1929 (NGVD of 1929) with sight lengths of up to 300 feet, it can be minimized in the same way the effect of instrument misadjustment can be minimized—by balancing the lengths of the backsight and foresight for each setup of the level.

Precision

Precision is the degree of refinement to which measurements are carried out. Leveling precision depends on the type and quality of the instruments used. Nearly all engineer's levels and leveling rods support precision of rod readings to 0.001 foot for sight lengths of up to about 125 feet; precision is less when sight lengths are longer. Use of less than the maximum precision afforded by the equipment usually saves no time or cost of leveling, so maximum precision is recommended.

Accuracy

Accuracy is the degree of conformity of a measured value to its true value. In leveling, accuracy is usually expressed as plus or minus the square root of the length of the line over which leveling is done ($\sqrt{M}$), or the number of instrument setups ($\sqrt{n}$), multiplied by a value that is measured as explained below.

A line over which levels are run starts at a point of known elevation and follows a route that turns on all reference marks and selected points in the line until the farthest point is reached. The line then heads back to the starting point. The first backsight and last foresight are made on the starting point, thus completing a closed circuit. The difference between the starting elevation (as previously established) and that elevation computed from the final foresight is the error of closure, the principal measure of the accuracy of the levels in that circuit. Systematic leveling errors, such as those from faulty rod calibration, and some other errors related to unbalanced sights, may not be reflected in the error of closure.

Leveling classifications

Leveling is usually classified according to the use of the results, procedural specifications, and closure error tolerance. The two classes of leveling used at gaging stations are described in the following two sections.

Gaging-station levels

Gaging-station levels are levels run at a gaging station in order to set or check the gages. The levels are normally run with closure errors of less than 0.003 $\sqrt{n}$ foot, where "n" is the total number of instrument setups in the circuit. Sight lengths, usually less than 100 feet, are balanced by estimation where practical. The leveling rod, checked daily with a steel tape, is read to 0.001 foot. The level's line of sight is checked about weekly and again whenever there is reason to doubt its performance. Closure errors larger than 0.003 $\sqrt{n}$ foot may be tolerable when conditions are unfavorable, but excessive closure errors could be a sign of faulty equipment and technique.

Ordinary levels

All levels between bench marks, when run to less than third-order geodetic leveling specifications, are classified as fourth-order, or ordinary, levels (see "geodetic bench mark levels" in "Glossary"). Gaging-station datums are usually tied to NGVD of 1929 by ordinary leveling. Sight lengths are limited to 300 feet, and distances are estimated by pacing. Distances of foresights and backsights are approximately equal. Rods are read to 0.01 foot. Closure errors are kept under 0.05 $\sqrt{M}$ foot when possible, although closure errors as high as 0.10 $\sqrt{M}$ foot may be acceptable in rough or hilly country. The total length of the circuit, out and back, M, is measured in miles.

Adjustment of elevations

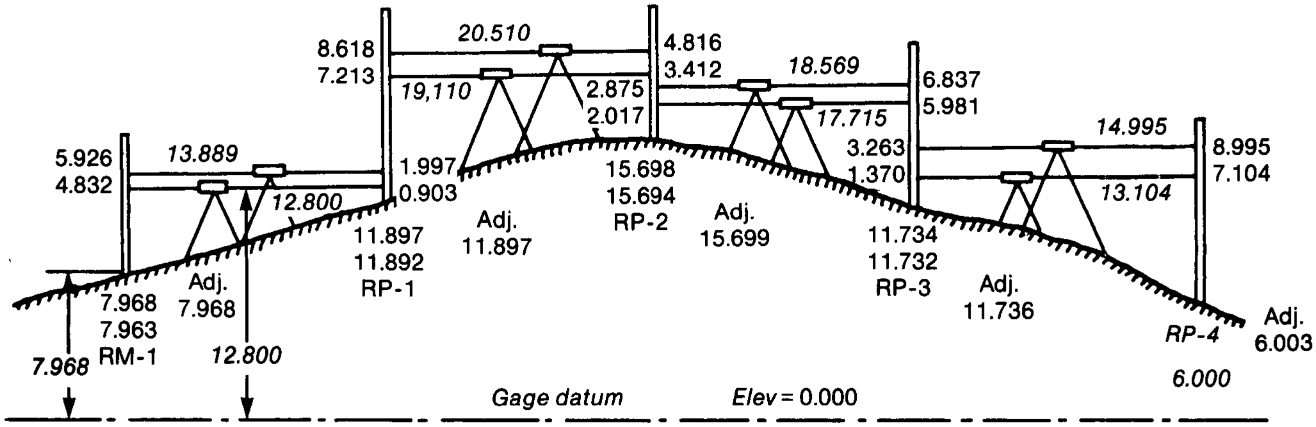
The several elevations in a circuit are adjusted by distributing the closure errors of parts of circuits. The method of doing this requires that each mark on which the leveling rod was read, other than the starting mark, be included in only one circuit and to be leveled to on both the outward and return paths of only that circuit. Two differences in elevation between each pair of adjacent points are determined, and the mean difference is used to compute each adjusted elevation. This procedure also identifies faulty readings indicating that a segment of a circuit needs to be rerun. Figure 4 illustrates a level circuit beginning at reference mark 1, turning on reference points 1–4, and returning to reference mark 1 by turning on the same points. Notekeeping and adjustment formats also are illustrated.

Engineer's Level

Nearly all engineer's levels are automatic, tilting, or dumpy models; each of these general types has many variations. Some of the more common models are illustrated in figure 5. Virtually all levels have stadia as standard or optional equipment. All modern levels permit levels to be run to any order of accuracy, but the proper choice of an instrument can have a profound effect on the time required to use and adjust it.

Automatic level

An automatic, or self-leveling, instrument levels itself precisely after being leveled manually with its insensitive circular (or bull's-eye) level. The precision leveling device, or compensator, is a system of prisms, one of which, suspended by wires, acts as a pendulum to keep the line of sight horizontal. Despite the level's



LEVEL NOTES

STATION	B. S.	HT. INST.	F. S.	ELEVATION
RM-1	4.832	12.800		7.968
RP-1	7.213	19.110	.903	11.897
RP-2	2.017	17.715	3.412	15.698
RP-3	1.370	13.104	5.981	11.734
RP-4	8.995	14.995	7.104	6.000
RP-3	6.837	18.569	3.263	11.732
RP-2	4.816	20.510	2.875	15.694
RP-1	1.997	13.889	8.618	11.892
RM-1			5.926	7.963

ELEVATION ADJUSTMENTS

Object	1st Diff.	2nd Diff.	Aver. Diff.	Elevation
RM-1				7.968
	3.929	3.929	+3.929	
RP-1				11.897
	3.801	3.802	+3.802	
RP-2				15.699
	3.964	3.962	-3.963	
RP-3				11.736
	5.734	5.732	-5.733	
RP-4				6.003

Error of closure = -0.005′

Allowable closure = $0.003\sqrt{8}$ = 0.008′

Figure 4.—Leveling, notes, and adjustments.

delicacy, cost, and a tendency for its pendulum to stick, the automatic level is a favorite for all kinds of leveling.

Tilting level

A tilting level's telescope is supported by a hinge at one end and a tilting screw at the other. An insensitive circular level is fastened to the frame. The instrument is leveled approximately with the circular level and then precisely with its tubular level. The ungraduated tubular level vial is viewed through prisms and mirrors that make split images of the bubble ends coincide when the line of sight is horizontal. The bubble ends are matched exactly by turning a knob, or micrometer dial, on the tilting screw. On some models the bubble ends are visible through the telescope eyepiece while the rod is being read, as illustrated in figure 6. Tilting levels are at least as accurate as automatic levels, are less costly and about as fast, and have no pendulums to stick.

Dumpy level

The dumpy level, a large, heavy, and obsolete instrument still in limited use, is time consuming to set up, to level, and to read. It is easily knocked out of adjustment, resulting in a collimation error, and is difficult to adjust. Its sensitive tubular bubble for precise leveling is attached to the telescope and is centered with a four-screw leveling head.

Level accessories

When a new level is ordered, the available features and options important to gaging-station leveling may

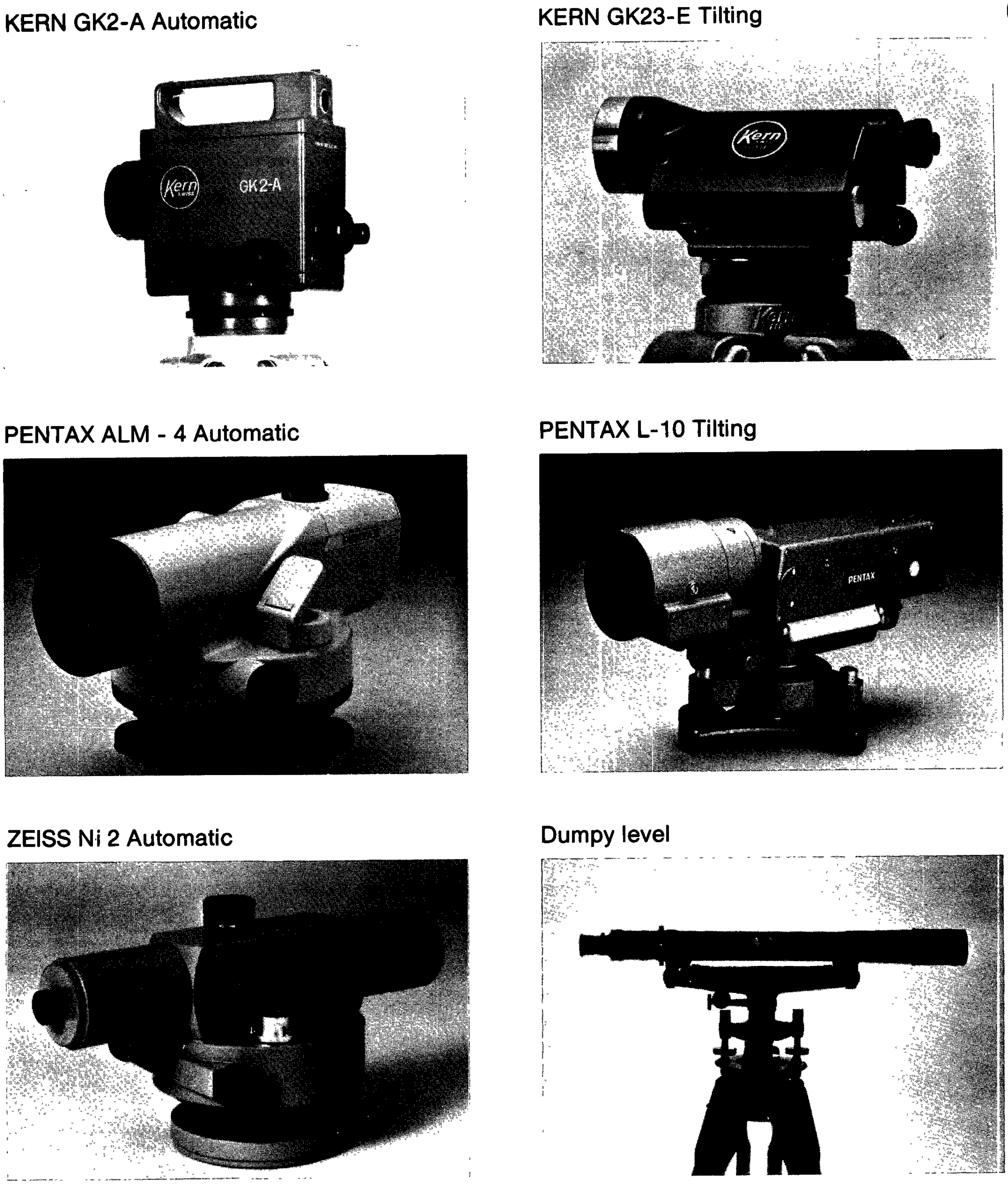


Figure 5.—Examples of engineer's levels.

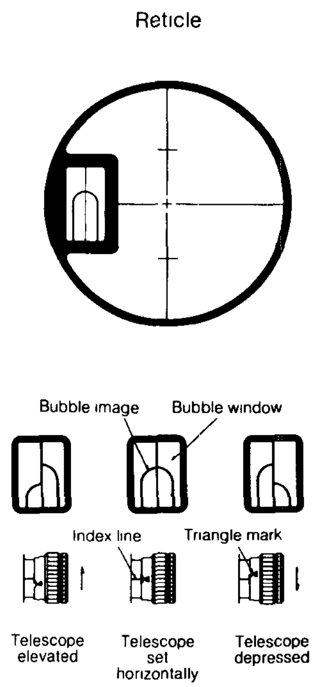


Figure 6.—Reticle and bubble windows as seen through a single-eyepiece tilting level.

warrant consideration, possibly with demonstrations in dealer's showrooms. The most important items to consider include:

Telescope.—Should provide magnification of 30 times or more with even resolution from center to edge. Should have a stadia ratio of 1:100 (avoid 1:30 or 1:60).

Collimation adjusting screw.—Must be easily accessible, and should be spring loaded so turning it will not shake the level.

Eyepiece.—Should be "erecting" so the leveling rod appears right side up. A single-eyepiece tilting level, with the rod and bubble ends visible simultaneously with the same eye, is much easier to use than a level having a separate eyepiece for the bubble.

Horizontal circle.—A horizontal graduated ring useful for reading horizontal angles.

Parallel-plate optical micrometer.—Allows the rod to be read directly to 0.001 foot and estimated to 0.0001 foot when used with a wedge reticle (standard on some levels) and a rod with fine-line graduations every 0.01 foot rather than with alternating wide stripes. The micrometer is a nonessential but sometimes desirable luxury.

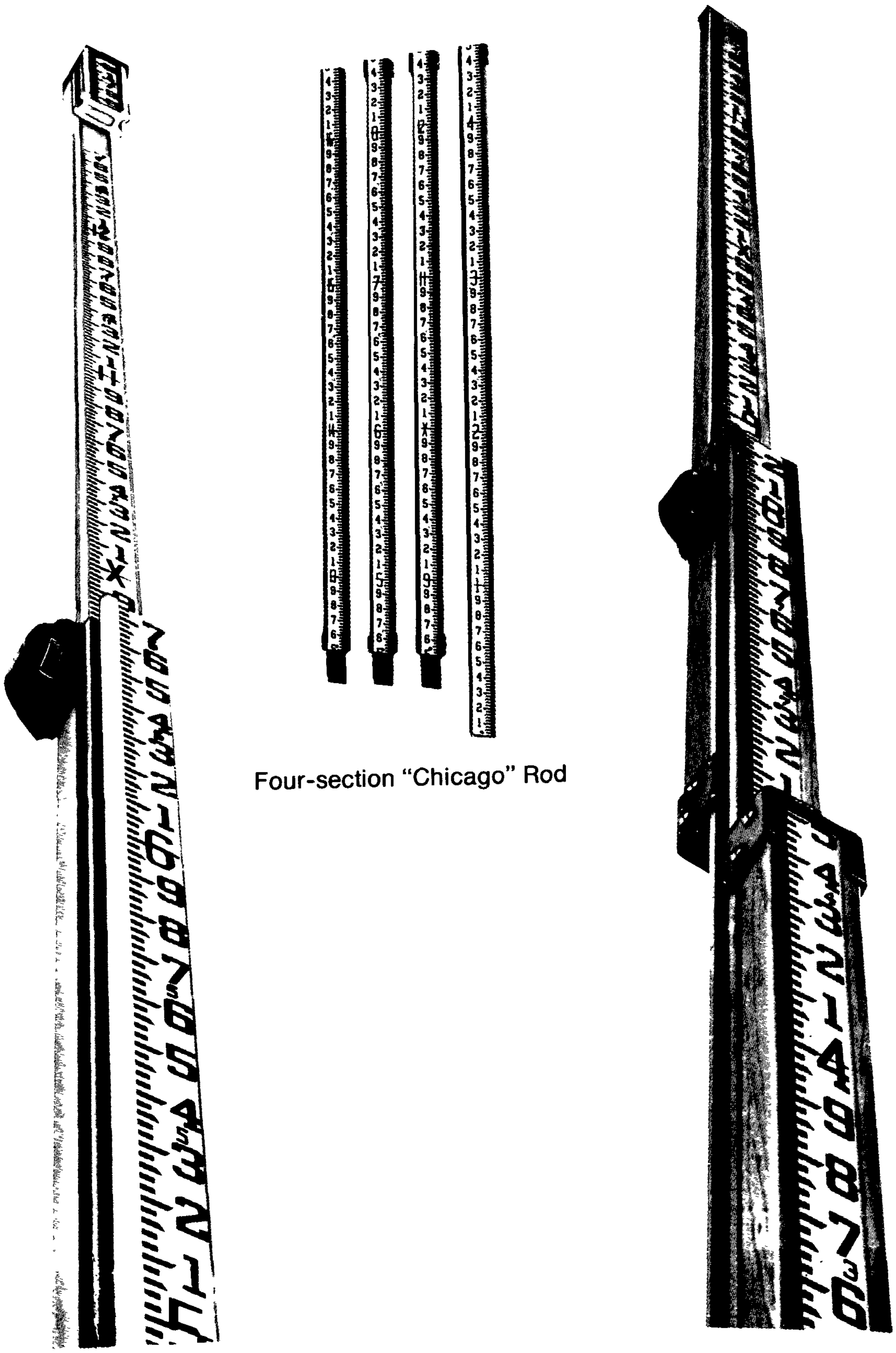
Automatic-level components.—Most magnetic-dampened compensators are preferable to most air-dampened models. Close-fitting Styrofoam cover attachments, available for some models, minimize the effect of the sun heating an otherwise bare instrument and offer some shock protection.

Leveling Rod

Leveling rods are made in a great variety of types and styles, each with some advantages for specific applications. The rods most often selected for gaging-station levels include "Philadelphia," "Frisco," and "Chicago" rods, all with self-reading scales and illustrated in figure 7. The two-section version of the "Philadelphia" rod is a very popular general-purpose model. It is primarily self-reading but also provides for an accessory target. The "Frisco" rod, preferably in two sections, is a targetless version of the "Philadelphia" that costs less because it has no parts to accommodate a target. A "Chicago" rod, in three or four wooden sections and with its graduations painted on the backing, is the easiest to use inside a gage well or instrument shelter. Its scales are adjustable to some extent, but only in a shop. The most practical rods for use at gaging stations have replaceable Invar or steel ribbon scales riding loosely in slots in their wood or fiberglass backings. Each scale section is held in place by a spring at the top of the section and a screw at the bottom, adjustable up or down in the field. The backing material has no effect on the calibration of this type of rod, but the scale material is important in cold or hot weather.

Thermal expansion or contraction of the material that makes up the rod scale affects rod readings by making the scale longer or shorter than when it was graduated. The resulting leveling error at a specific point depends on the material used for the scale, the difference between the temperature of the rod and the temperature at which it was calibrated, and the height of the mark being considered above or below the starting elevation. The leveling errors from expanded or contracted rod scales of various materials at a temperature 30 °F (17 °C) above or below the calibration temperature (usually 68 °F (20 °C)), for a point 50 feet higher or lower than the starting point, are as follows: Invar, 0.001 foot; wood, 0.005 foot; steel, 0.010 foot; and aluminum or magnesium, 0.02 foot.

Most rods having Invar scales are expensive, one-piece, metric models. "Philadelphia" rods having Invar scales, or replacement Invar ribbon scales to fit such rods, usually must be specially ordered. Steel-scale replacement ribbons are generally satisfactory standard items. Scales painted on, cut or molded into, or cemented to fiberglass, magnesium, or aluminum expand and contract too much for gaging-station leveling in most climates. Scales painted on wooden



Four-section "Chicago" Rod

Two-section "Philadelphia" Rod

Three-section "Frisco" Rod

Figure 7.—Examples of leveling rods.

backings, though unadjustable and short lived, are second only to Invar for stability at varying temperatures.

Rods should be stored carefully, preferably in a protective case, when being transported. The rods used for gaging-station leveling should be kept dry and never subjected to such rough use as construction work or cross sectioning. Walking with a fully extended rod over the shoulder, especially a "Chicago" rod, flexes and strains the joints severely and shortens the rod's useful life.

A 50-foot steel tape having a white face and black graduations, and a 6-foot wooden, folding engineer's rule, are excellent auxiliary measuring equipment useful in performing gaging-station leveling.

Checking the rod

The rod should be measured before use at each site. This can be done by matching the 2-foot graduation of a steel tape with the 1-foot graduation of the rod, then reading the tape at the bottom of the rod and at each foot mark. If all graduations are accurate within 0.002 foot, the rod is satisfactory. If the base of the rod is out of adjustment, the height-of-instrument values will be in error by the amount of the displacement. The errors ordinarily will cancel out without affecting the elevations. However, if such a rod is used for a backsight, but the foresight is made on a tape, a different rod, a gage-plate graduation, or the bottom of a gage weight, an appropriate correction may be necessary.

The scale plates and joints of some "Frisco" and "Philadelphia" rods can be adjusted in the field. A "Chicago" rod's calibration errors might be caused by dirt in the joints that can be cleaned off in the field. A worn joint or base plate can be shimmed in a workshop, but using a new rod may be a more satisfactory solution.

Holding the rod

The duties of the individual who holds the rod are fairly simple but very important. First and most importantly, the rod must be plumb while it is being read. A rod level, similar to the one sketched in figure 8, is essential for fast and accurate levels. On a calm day, the rod can be plumbed without a rod level by balancing it over the marks on which the rod is placed with only a little loss of accuracy. The level operator can tell by looking at the vertical crosshair if the rod is in the vertical plane passing through the instrument. If the rod holder slowly moves the top of the rod toward and away from the instrument (often referred to as "waving the rod") and the reading is well up on the rod, the lowest reading, which is the correct one, will occur when the rod is plumb. Moving a thick rod ("Philadelphia" or "Frisco") back and forth over a mark, such as a chiseled square in a flat concrete surface, causes the scale to rise when the back of the base rocks on the flat surface and could lead to serious errors in readings made low on the rod. This effect makes it advisable that the tops of all reference marks and reference points are high enough for the rod base to clear the surrounding surface.

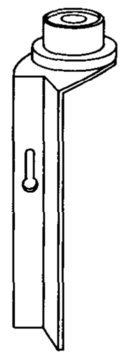


Figure 8.—Rod level.

Where a portable turning point (such as a hammer-driven steel stake or steel trivet plate) is used, the rod holder should set the rod on it gently. This prevents the turning point from being driven farther into the ground between sights by the impact of the rod being placed on it.

Operating the Engineer's Level

Transporting the level

Even the most rugged level can be jolted seriously out of adjustment or damaged, especially while being carried inside a field vehicle or being shipped. The instrument should be kept in its case, protected by heavy padding on all sides, while it is in a vehicle. When the level is mounted on its tripod, it should be carried under one arm with the instrument at the front in plain view. Particular care should be maintained while inside a building or moving through woods or brush. The level should be carried over the shoulder only along roads or in open fields, and it should not be left unattended while it is set up in the field.

Checking the tripod

The leg tension of a tripod should be checked daily when in use. This can be done by first setting the shoes about 3 feet apart and lifting the tripod by its head. The tension, adjustable by wing nuts on each leg or by special clamps under the tripod head, is satisfactory when each leg folds in slightly.

Setting up the level

The ideal setup location is on firm, level ground. If possible, the level should not be set up on tar, asphalt, ice, or frozen or marshy ground. These surfaces are likely to soften and allow the tripod to settle enough to disturb the level or even change its height of instrument between readings. The instrument can be set up on a satisfactory surface and the bubble almost centered before the leveling screws are touched by setting two of the legs and moving the third leg from side to side or in and out until the tripod head looks level. Then push each leg firmly into the ground and use the leveling screws to center the bubble. When this procedure is used with a domed leveling head, a device for rapid instrument leveling, an experienced surveyor can take a backsight within 30 seconds of the time the assembled level is placed on the ground.

Leveling the instrument

Leveling is done in two steps: the preliminary leveling, whose only effect on the setup is to level the horizontal crosshair, and the final leveling, which makes the line of sight horizontal while the rod is being read. Most levels have leveling screws or a lever for centering the bubble of a circular (or bull's-eye) level for the preliminary leveling and an automatic compensator or a tilting screw for the final leveling. For a dumpy level, the same level vial and leveling screws are used for both preliminary and final leveling.

Preliminary leveling of a three-screw leveling head is done as follows: Rotate the telescope until the circular level vial is over one of the three screws. Center the bubble by turning the other two screws. The bubble will move toward any screw being turned clockwise, and away from one being turned counterclockwise. If a leveling screw runs to the limit of its threads, back if off a few turns, rotate the telescope to place the vial over that screw, then level with the other two screws. Once the bubble has been centered, further trials at other telescope positions are unnecessary. Final leveling of an automatic level is done by its compensator, and of a tilting level by the operator turning the tilting screw until the bubble ends match.

Some instruments use a spherical or domed leveling head and are leveled by sliding the head around the spherical surface until the bubble is centered. The motion is controlled by a long lever that projects from the underside of the tripod and ends in a knob that is twisted tight to stop the movement. Most tripods can be equipped with a domed-head accessory that adapts any automatic or tilting level to this rapid-leveling method.

Preliminary leveling of the four-screw leveling head of a dumpy level is done as follows: Set up the level with one pair of opposing screws aligned in the general direction of the next backsight. Turn the telescope over one pair of screws and twist them in opposite directions to center the bubble. Finish each adjustment by turning only one screw to ensure that the screw is tight enough to prevent rocking on that pair of screws and loose enough to prevent stiffening of the other pair. When the bubble is centered, turn the telescope 90 degrees to place it over the other pair of screws and center the bubble with those screws. Repeat until each screw has been adjusted no more than three times. At this point the level is ready for final centering of the bubble using the pair of screws nearest the direction of the telescope, just before each rod reading.

The level, especially a dumpy, should not be touched with fingers, clothing, or dangling equipment or notebook while it is being read. Feet should be kept well clear of the tripod shoes of levels of all types, from the time of the first bubble centering until all readings are recorded.

Focusing the level's telescope

The knob on the top or side of the telescope controls the objective lens that brings the rod's graduations into focus at the plane of the crosshairs. The eyepiece is a small microscope that enlarges the images of the rod and crosshairs. Most eyepieces also rotate the images, which are upside down at the crosshairs, to make them appear upright to the operator. Focusing must be done before the instrument is leveled, and may be necessary again when a different level operator takes over or the operator's eyes tire. Focusing is done as follows: Point the telescope at the sky to eliminate all distracting background, then twist the eyepiece end until the crosshair image is sharpest. Before each reading, adjust the objective lens until it brings the rod into sharpest focus. Move your head up and down while sighting the rod. If the rod appears to move slightly in response to the eye movement, parallax is present, indicating that the rod is in focus either in front of or behind the crosshairs rather than at them. Parallax usually can be eliminated by adjusting the objective focus. If it persists, find some combination of eyepiece and objective focus adjustments that will keep the eyepiece setting constant from one reading to the next.

Establishing a reading routine

To ensure that all rod readings are made under proper conditions, a reading routine should be developed and used habitually. A good routine for reading all but automatic levels, after the instrument is leveled and in place with circular vial bubble centered, is as follows:

1. Focus the objective lens.
2. Check for parallax and, if present, eliminate it by refocusing.
3. Center the telescope bubble precisely.
4. Check the rod against the vertical hair. If out of plumb, direct the rod holder to adjust the rod until it is vertical.
5. Read the rod.
6. See that the telescope bubble is still centered. If not, return to step 3.
7. Read the rod and record the reading.

An automatic level, especially an air-dampened model, needs an occasional check of its compensator. When the instrument is first set up and leveled, test the compensator by looking through the telescope at the rod and turning the leveling screw nearest to the eyepiece slightly in one direction, then in the other. If the crosshair returns to the same reading smoothly from both directions, the compensator is working properly. If the readings differ, repeat the test, but tap the telescope lightly before each reading. If that makes the readings agree, the level can still be used as long as it is tapped before each reading. Compensator sticking is usually intermittent and is likely to go unnoticed for a long time unless the operator is alert. Tapping the telescope before each reading while looking for the telltale movement of the crosshair against the rod is an effective way to monitor the sticking. Some levels have a button-operated agitator. If the tapping or the agitator causes some movement, and additional agitation causes more movement, the level has a serious problem and must be repaired before it can be used.

Serious compensator sticking may be caused by a misadjusted circular level, dust particles in the compensator, or a stretched pendulum wire. The circular level can be adjusted in the field, but internal compensator problems must be corrected in a repair facility competent to clean, repair, or replace the mechanism.

A good routine for reading automatic levels that are in place with the circular vial bubble centered is as follows:

1. Focus the objective lens.
2. Check for parallax and, if present, eliminate it by refocusing.
3. Tap the telescope and look for movement of the crosshair against the rod.
4. Check the rod against the vertical crosshair. If it is out of plumb, direct the rod holder to adjust the rod until it is vertical.
5. Read the rod and record the reading.

Adjusting the Engineer's Level

A properly adjusted level can lose its adjustment during a single bumpy ride or from one incident of rough handling, or it may hold its adjustment through weeks of use. Misadjustment may show itself in the form of large circuit closure errors, or even as sticking of an automatic level's compensator. The level's collimation should be checked before the start of each week of use and again whenever there is reason to suspect its performance. The level should be adjusted when the collimation is in error by more than 0.003 foot per hundred feet.

A pair of fixed-vertical scales installed at a permanent site and set to a common datum enables one individual to check the collimation of any level in minutes and to adjust most models of automatic or tilting levels in a few additional minutes. A similar test and adjustment of the level in the field would take two individuals a great deal longer.

An automatic level's circular level and crosshairs are its only parts a surveyor can adjust. A tilting level's adjustable components are its circular level and a prism that moves one of the bubble-end images. A dumpy level's crosshairs and bubble vial can be adjusted to collimate the instrument by a lengthy trial-and-error procedure; that procedure is not described in this manual but is outlined in nearly all surveying texts and handbooks.

Adjustment of levels involves capstan-head nuts and screws, some of them very delicate with easily stripped threads. The adjuster must develop an instinct for the proper degree of tightness. Capstans left too tight lead to metal creeping and loss of adjustment in a short time. Capstans left too loose may allow the first light jolt to change the level's adjustment. Capstans should be turned only with adjusting pins of proper length and diameter. Loose-fitting pins will deform the holes in the soft metal capstans and make them unusable. Replacements for lost pins for most levels can be purchased from engineering-supply dealers.

Reticle

The reticle (crosshair ring) of a modern level is usually raised or lowered on rotation-preventing tracks by an adjusting device, often a spring-loaded capstan screw under a removable cover plate. A tilting level's reticle cannot be adjusted. A dumpy level's crosshairs can be rotated or moved up or down, somewhat awkwardly, by its capstan screws, but accidental rotation is a problem.

Circular level vial

A circular, or bull's-eye, level is used for the preliminary leveling of automatic and tilting levels. The adjustment of the circular level's vial could affect the operation of an automatic level's compensator. Testing and adjustment of a circular level vial is done as follows: Center the bubble by using the main leveling screws or the domed leveling head of instruments that have them. Then rotate the telescope slowly until the bubble's distance from the center is greatest. If the bubble does not move, but remains centered throughout the rotation, the vial needs no adjustment. If the bubble strays, bring it halfway back to the center with the main leveling head, and the rest of the way with the vial-adjusting screws. Repeat the process two or three times, if necessary, until the bubble stays centered through a complete revolution. This adjustment has no effect on the line of sight.

Some circular vials are held in place by three adjusting screws and a collar that compress an elastic washer between the vial and its seat. The screws may be visible, or may be hidden under a removable cover. Adjustments are made by turning one of the three screws clockwise; the bubble will move away from the screw being tightened. If the adjusting screw is turned to its limit and the bubble is still not centered, loosen all three screws, tighten each one until it moves the bubble slightly, and start adjusting again.

Other circular vials use four-screw adjusting rings. Opposing screws are turned in opposite directions simultaneously; the bubble usually moves toward the screw being turned clockwise.

Collimation

The inclination of a level's line of sight, when the telescope bubble is centered or the automatic compensator is operating, is its collimation error factor, "c," measured in feet per 100 feet of sight length; the error factor is positive when the line of sight points downward. The factor "c" is measured by setting the level near a point A and obtaining a backsight reading on a rod held at point B, then setting the instrument near B and obtaining a backsight reading on B and a foresight reading on A. The resulting error of closure is a measurement of the instrument's misadjustment. One of two collimation tests can be used—a fixed-scale test or a peg test. The fixed-scale test is fast and

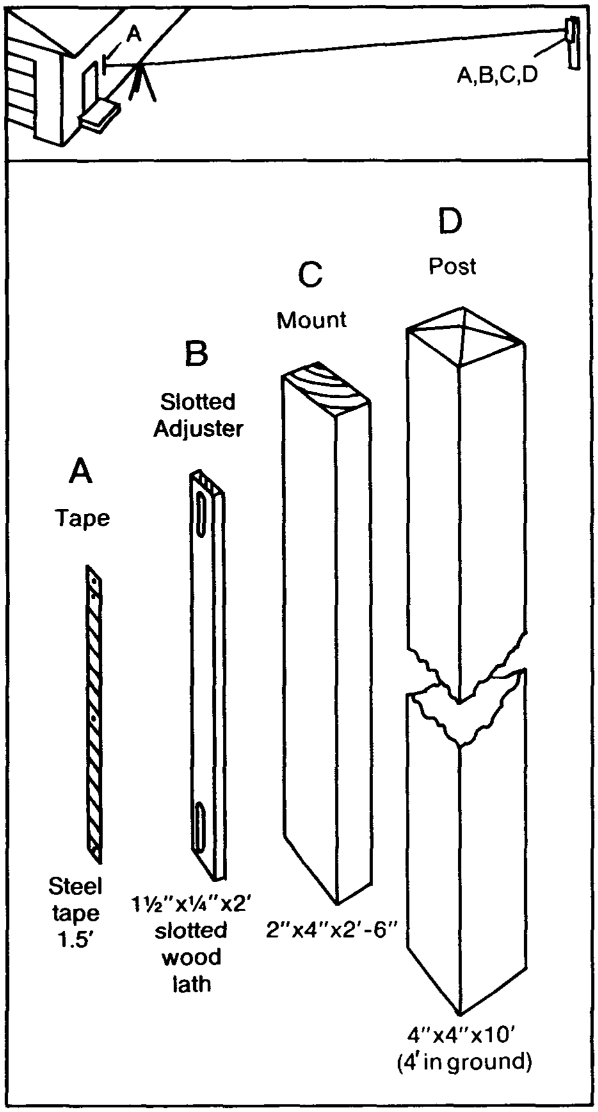


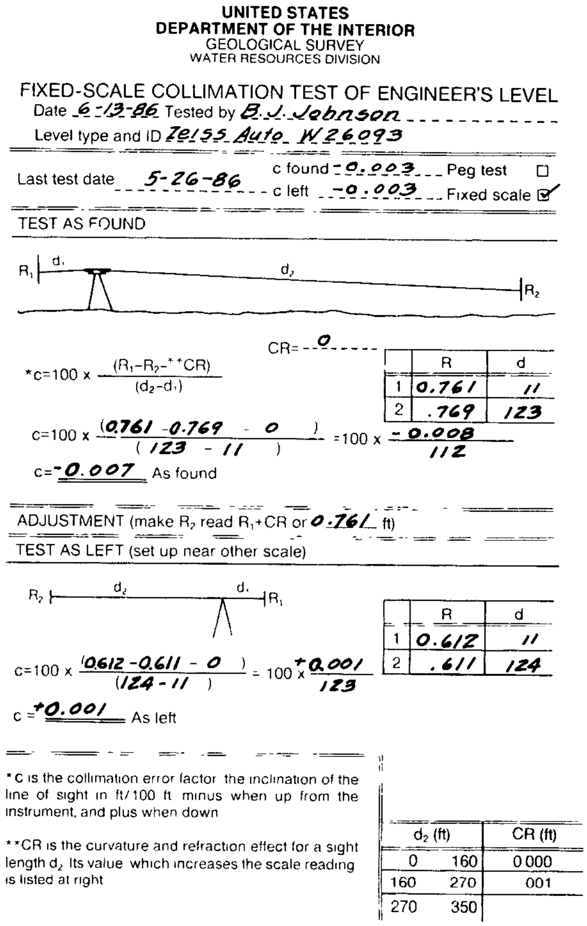
Figure 9.—Fixed-scale test apparatus and setup.

accurate but requires a specially prepared location. The peg test is nearly as accurate and can be made at any location but is more time consuming.

Fixed-scale test

A fixed-scale test can be set up outdoors between trees, deeply set posts, or buildings at a reasonably level location, or can be installed indoors, for example, between columns or doorframes in a long basement corridor of a large building. Before the test is conducted, two sections of vertical steel tape, each about 1.5 feet long and mounted about 120 feet apart, must be set to the same datum.

Typical mounting details are shown in figure 9. Set up a level equidistant from the two chosen points and screw one of the tape sections, "A" (the fixed tape), onto any flat vertical surface with the section's center



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

FIXED-SCALE COLLIMATION TEST OF ENGINEER'S LEVEL

Date 6-13-86 Tested by B. J. Johnson

Level type and ID Zeiss Auto W26093

Last test date 5-26-86 c found -0.003 Peg test ☐ c left -0.003 Fixed scale ☑

TEST AS FOUND

CR = 0

$*c = 100 \times \frac{(R_1 - R_2 - **CR)}{(d_2 - d_1)}$

	R	d
1	0.761	11
2	.769	123

$c = 100 \times \frac{(0.761 - 0.769 - 0)}{(123 - 11)} = 100 \times \frac{-0.008}{112}$

c = -0.007 As found

ADJUSTMENT (make R_2 read R_1+CR or 0.761 ft)

TEST AS LEFT (set up near other scale)

	R	d
1	0.612	11
2	.611	124

$c = 100 \times \frac{(0.612 - 0.611 - 0)}{(124 - 11)} = 100 \times \frac{+0.001}{123}$

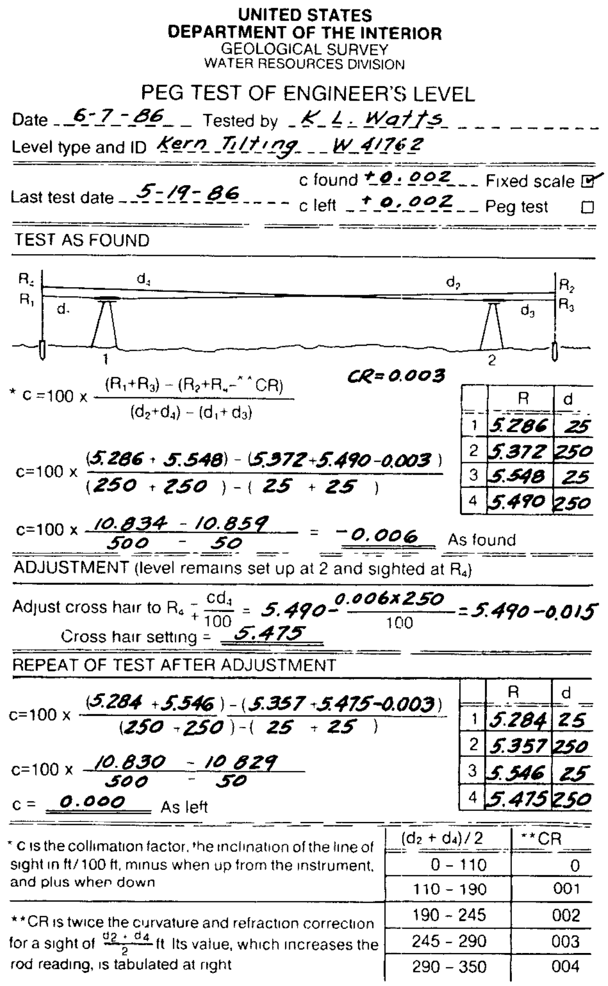
c = +0.001 As left

*c is the collimation error factor the inclination of the line of sight in ft/100 ft minus when up from the instrument, and plus when down

**CR is the curvature and refraction effect for a sight length d_2. Its value which increases the scale reading is listed at right

d_2 (ft)		CR (ft)
0	160	0.000
160	270	.001
270	350	

Figure 10.—Fixed-scale test notes and computations.



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

PEG TEST OF ENGINEER'S LEVEL

Date 6-7-86 Tested by K. L. Watts

Level type and ID Kern Tilting W 41762

Last test date 5-19-86 c found +0.002 Fixed scale ☑ c left +0.002 Peg test ☐

TEST AS FOUND

CR = 0.003

$* c = 100 \times \frac{(R_1+R_3) - (R_2+R_4 - **CR)}{(d_2+d_4) - (d_1+d_3)}$

	R	d
1	5.286	25
2	5.372	250
3	5.548	25
4	5.490	250

$c = 100 \times \frac{(5.286 + 5.548) - (5.372 + 5.490 - 0.003)}{(250 + 250) - (25 + 25)}$

$c = 100 \times \frac{10.834 - 10.859}{500 - 50} = -0.006$ As found

ADJUSTMENT (level remains set up at 2 and sighted at R_4)

Adjust cross hair to $R_4 \mp \frac{cd_4}{100} = 5.490 - \frac{0.006 \times 250}{100} = 5.490 - 0.015$

Cross hair setting = 5.475

REPEAT OF TEST AFTER ADJUSTMENT

$c = 100 \times \frac{(5.284 + 5.546) - (5.357 + 5.475 - 0.003)}{(250 + 250) - (25 + 25)}$

	R	d
1	5.284	25
2	5.357	250
3	5.546	25
4	5.475	250

$c = 100 \times \frac{10.830 - 10.829}{500 - 50}$

c = 0.000 As left

* c is the collimation factor, the inclination of the line of sight in ft/100 ft, minus when up from the instrument, and plus when down

**CR is twice the curvature and refraction correction for a sight of $\frac{d_2 + d_4}{2}$ ft. Its value, which increases the rod reading, is tabulated at right

$(d_2 + d_4)/2$	**CR
0 - 110	0
110 - 190	.001
190 - 245	.002
245 - 290	.003
290 - 350	.004

Figure 11.—Peg test notes and computations.

at the height of instrument. Screw the other tape section (the adjustable tape) onto the lath, "B," which is to be used as an "adjuster." Attach the lath to the mount, "C," and the mount to the post, "D," or other vertical surface at the opposite end of the test area so that the center of the tape section is approximately at the height of instrument (if the adjustable tape is attached to a tree, the tree can be shimmed to make it vertical). Read the fixed tape. Then slide the adjustable tape up or down until the height of instrument reading on it agrees with the fixed-tape reading, and secure its position. Repeat this procedure from time to time, moving the adjustable tape as necessary to keep the scales to the same datum, usually at the start of a leveling season and before changing the adjustment of any instrument.

To test a level's collimation, set it up as close to one scale as the minimum focus distance will allow, usually about 11 feet. Read the near scale, then the far one. Enter the readings (R) and distances (d) indicated by the stadia hairs on a form similar to that in figure 10. If the readings agree, the level is in perfect adjustment and "c" is zero. If they disagree, compute "c." If the absolute value of "c" is more than 0.003, the level must be adjusted. For an automatic level, raise or lower the crosshair until the reading on the far scale agrees with the reading on the near scale. For a tilting level, turn the tilting screw until the crosshair reading on the far scale agrees with the reading on the near scale, and then turn the collimation-adjusting device until the bubble ends match while the crosshair is at the correct reading.

Leave the completed test form in the instrument case in place of the form left there from the most recent test. Route the superseded form to a file of the instrument's service history.

Peg test

Several versions of the peg test, or two-peg test, are widely used. The test notes and computations shown in figure 11 were adapted from U.S. Geological Survey National Mapping Division instructions. To test and, if necessary, adjust a level, drive two stakes about 120 feet apart at a reasonably level site. Some surveyors prefer stakes as far apart as 300 feet in order to increase total closure error. However, rod readings are less precise at 300 feet than at 120 feet, and the curvature and refraction effect on the long sight is significant.

Set up the level as close to one stake as minimum-focus distance will permit. Take a backsight reading and a reading using the stadia hairs on the near stake, and a foresight reading and a reading using the stadia hairs on the far stake. Move the level close to the other stake and repeat the process. Enter the rod readings (R) and distances (d) in the first formula in figure 11, on a form similar to that in figure 11, and compute the collimation error factor, c. If the absolute value of c is greater than 0.003, the instrument must be adjusted. Solve the second formula to compute the corrected rod reading for the last long distance. For an automatic level, raise or lower the crosshair to that reading. For a tilting level, turn the tilting screw until the crosshair is at the corrected reading, and then turn the collimation adjustment device until the bubble ends match while the crosshair is at the corrected reading. A level should be tested at least twice before it is adjusted, and must always be tested again after adjustment.

Leave the completed test form in the instrument case, and route the form from the most recent test to a file of the level's service history.

Gaging-Station Datum Control

Determining frequency of levels

The individual gages at a site generally should be checked, by measuring vertical distances from reference points, when levels are run and also during routine station visits if there are unexplained discrepancies between gage readings. If the discrepancies cannot be resolved from reference point measurements, another set of levels, complete or partial, must be run.

Clearly, the frequency of checking a gage depends on the gage's location. A concrete gaging station, built with its foundation and reference marks set in rock, would be so unlikely to move that complete levels about every 10 years probably would be sufficient. A pipe well in an unprotected location on a bridge pier buffeted by debris during high water would need a complete set of levels every year and at least a partial set after every major water rise.

A leveling schedule should be prepared each year to provide for complete levels at each regular gaging station that fits in one of the following categories:

1. Has had fewer than three sets of levels since the gage was installed;
2. Has gone 3 or more years without complete levels;
3. Is movement prone and without complete levels during the past year; or
4. Has unresolved gage-reading differences.

Establishing gage datum

When a new gaging station is being started where no other station has been operated before, its datum should be set low enough to ensure that the lowest gage height ever likely to be recorded while the stream is flowing is at least 1 foot. This is done to avoid negative gage heights that would necessitate data adjustment. One way to accomplish this is to set the gage to read 1 foot more than the maximum depth of water over the stream control plus a reasonable allowance for future scour. The scour allowance may be zero if the control is a sound artificial weir or ledge rock extending across the entire stream. A scour allowance of 10 feet or more might be needed for a very unstable alluvial channel. If another gage was ever operated at a nearby equivalent site by a Federal, State, or municipal agency, the previous gage's datum, adjusted for channel slope between the sites, might be used for the new gage.

Installing reference marks

The objectives of gaging-station leveling are to define and maintain a datum, using reference marks installed in the most stable locations in the vicinity, and to adjust the gages as necessary to keep them in agreement with that datum. The most stable locations for reference marks are ledge rock outcroppings and substantial masonry structures. The ground below the frost line in sandy soils is stable in most places. Clay soils that expand and contract during seasonal variations in soil moisture should be avoided. If expansive clay soils cannot be avoided, the most stable sites (assuming there are no bridge piers nearby) are likely to be low and near the stream. At most such sites, the base of a reference mark can be placed in permanently saturated soil.

Some commonly used types of reference marks are illustrated in figure 12. The gravel-filled pipe used in types C and D provides visibility to the mark and protects people, mower blades, and tires from the projecting rod. It also prevents frozen soil from adhering to the rod and lifting it. The earth anchor used for type D is sold in a wide range of sizes by major building-supply dealers. The anchor can be screwed into rock-free soil by using a shovel handle or crowbar

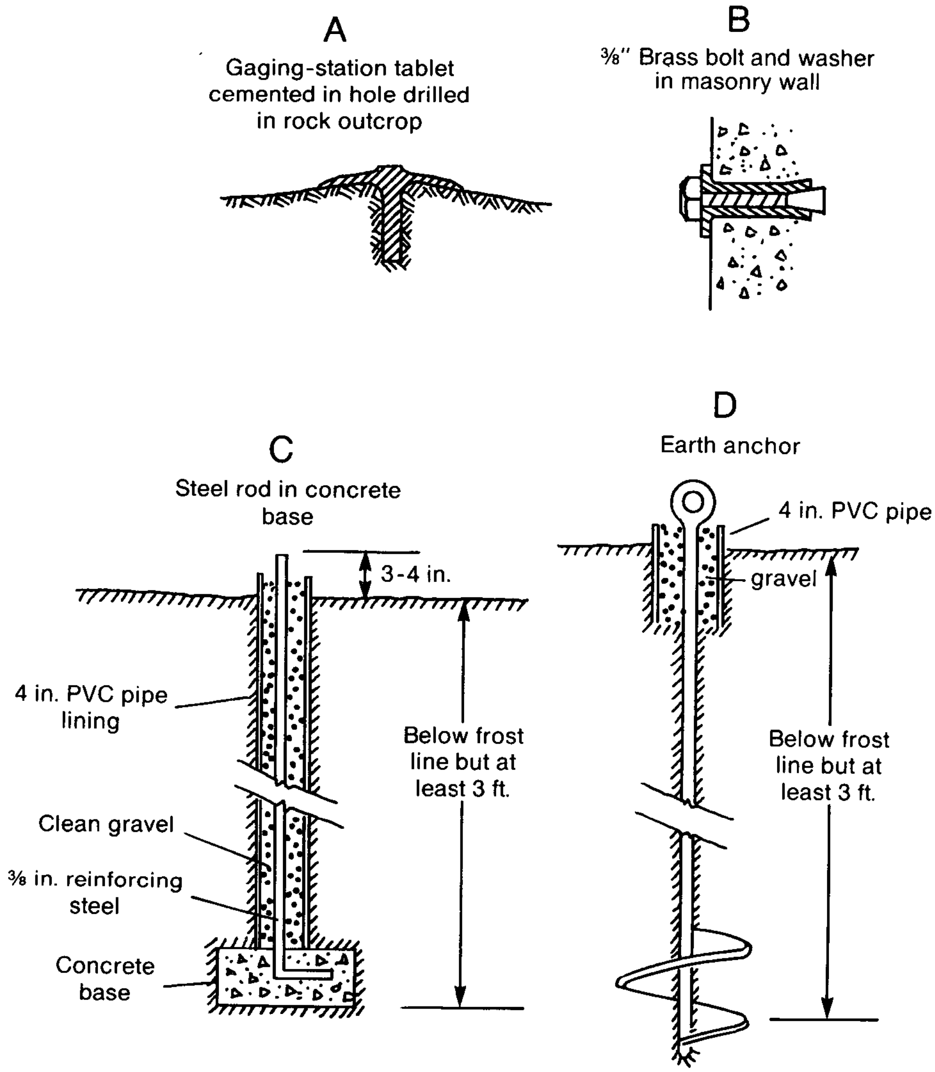


Figure 12.—Typical reference mark installations.

as a lever. The ring on the shaft can be left in place or, if it seems likely to tempt vandals to raise or lower the anchor, can be cut off and the shaft filed smooth. Large earth anchors have a separate auger, threaded so a length of pipe can be used as the shaft.

Each gaging station needs at least three reference marks: one, the most stable, as a starting point for levels, and the others to verify the elevation of the first mark. The reference marks should be independent in that only one should be on a single bridge pier or abutment; at least one of the marks should be above the highest potential stage and located to survive any future construction or major floods that might wash out or bury the other marks.

Installing reference points

One reference point, preferably a 0.25- ×1-inch lag screw and washer, should be installed, in the wooden gage-plate backing beside the plate for each set of enameled steel sections on a continuous backing. A similar reference point should be installed in a masonry anchor above water inside the gage well for taping down to the water surface. One of the flat faces of the bolt head should be kept horizontal in order to facilitate reading of a vertical steel tape held against it. Two reference points in a vertical line may be more convenient for transferring elevations from ground level up to a high bridge deck or gage shelter by taping, than leveling up and down the streambank. A reference point near the intake of a gage well, or the orifice or transducer of a pressure-type gage, is helpful when verifying low-flow stages. The wire-weight check bar and electric-tape index might also be considered as reference points.

Running Levels

Leveling should be scheduled for a low-water period when the weather is expected to be favorable, and should be postponed if inclement weather is likely to prevent reliable results. Check the level and rod for proper adjustment and calibration before starting, and use a rod level and a good reading routine. Keep notes and computations on standard forms to facilitate checking and review. (These forms can be reproduced from the blank forms in the appendix at the end of this manual.) Run the level circuit or series of circuits from the reference mark that appears to be most stable, turning on the other marks until the farthest one is reached. Then continue each circuit back to its starting point, turning on the same marks in reverse order. Read each foresight as soon as possible after the backsight is made, and balance their lengths as closely as possible. Try to make all lines of sight clear the ground by a foot or more.

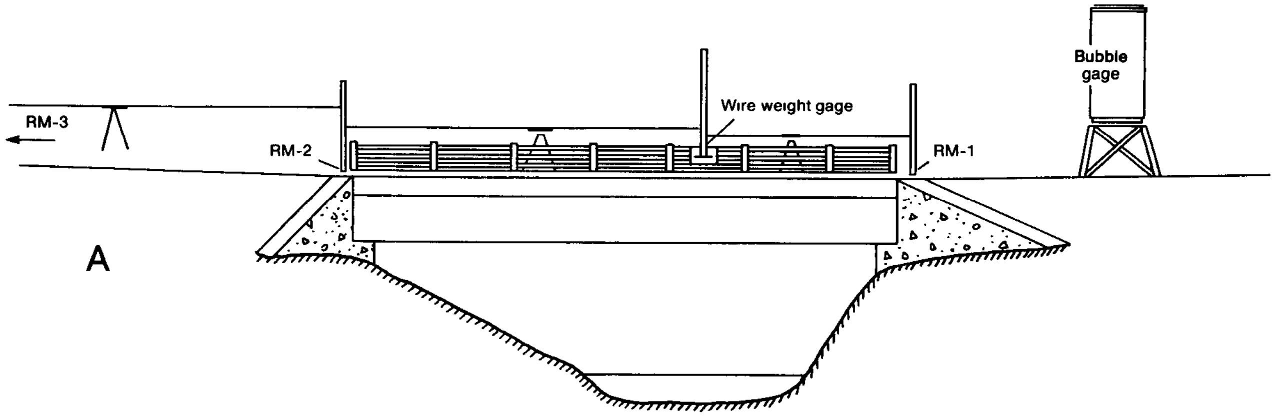
Side shots, that is, foresights from a single height of instrument to points that are not turned on, generally are avoided in high-quality leveling because the circuit has not been closed, they may have unbalanced sight lengths, and their errors may be much greater than the circuit's error of closure. If a side shot is used, it should be run twice, from different heights of instruments.

Check the levels for acceptable closure errors in the section labeled "Adjustment of elevations" on the level notes front sheet ("Summary and Adjustments of Gaging Stations Levels" in appendix). List the differences between the measured elevations of adjacent points in the first half of each circuit and those from the return half as each circuit is completed. If the first and second differences agree within 0.003 foot, indicating that the closure error is acceptable, enter the average difference in the appropriate column. Rerun any segments that have larger discrepancies.

When all the circuits have been run, compute a tentative adjusted elevation for each point on the level notes front sheet. Enter the starting elevation first, and then add or subtract the average difference to obtain the next point's elevation. Compare these elevations with those tabulated from previous levels run at the station to see how well they agree. For example, the current elevations might indicate either that all reference marks and points, except the starting point, rose by about 0.03 foot since the most recent levels, or that the starting mark settled by that amount. The latter assumption is more reasonable than the first and suggests that the current adjusted elevations should have been computed by starting from a different reference mark. This possibility can be tested by using the most logical of the other reference marks as a new starting point. Erase the originally computed adjusted elevations from the front sheet. Enter the elevation of the new starting point from the most recent levels in the appropriate space. Working up and down the sheet from the newly entered starting elevation, add or subtract differences to compute a new set of adjusted elevations. If the new set of elevations compares logically with the levels from prior years, abandon the unsatisfactory reference mark, replace it with a new one, and run levels to the new mark. Use the newly adjusted elevations of the reference points as final results and to check the gages.

The simplest type of gaging-station leveling is illustrated in figure 13. A bubble gage referenced to a wire-weight gage has three reference marks nearby, and all are at about the same elevation. The layout of the station, and the locations of the reference marks and logical instrument setup sites, are indicated in figure 13A. The level notes are shown in figure 13B, and the summary and adjustments are listed in figure 13C. The levels were started from reference mark 1 (RM-1) and continued to the wire-weight gage, reference mark 2, and reference mark 3, turning on every point. The line then returned over the same route to close the circuit on reference mark 1.

A more complex station is illustrated in figure 14. The levels covered a vertical range of 39 feet, and instrument setups on at least two locations were needed. The level notes front sheet (fig. 14C) indicates that the rod was checked and found essentially correct, so foresights could be made with either a leveling rod or a graduated tape. The electric-tape index elevation was measured by taping up from the height of instrument, using the tape on the station's electric-tape reel. The tape was read at the index and through the telescope at the height of instrument. The difference between the two readings, added to the height of instrument, was the elevation of the electric-tape index. A side shot was taken on reference point 1 and was checked by another side shot from a different height of instrument during the return circuit. Levels were carried up to the bridge deck by taping between reference mark 1 and reference point 2 vertically above it. The total circuit closure error (0.006 foot) was within the allowable limit ($0.003\sqrt{6}=0.007$ ft). The adjustment process disclosed a faulty rod reading



B

STATION	BS	HT INST	FS	ELEVATION	REMARKS
RM-1	4.938	20.938		16.000	
ch. bar	2.320	21.246	2.012	18.926	ch. bar reads 18.925
RM-2	4.873	20.904	5.215	16.031	Tape to W.S. 16.115
RM-3	2.761	22.777	.888	20.016	W.S. reads 2.82
RM-2	5.162	21.191	6.748	16.029	
ch. bar	2.563	21.486	2.268	18.923	
RM-1			5.490	15.996	

C

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta No 06927000

SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION Red Creek near Waddell, Mo.

DATE June 18, 1986 PARTY O.R. Shinn, B.J. Johnson

ADJUSTMENT OF ELEVATIONS

Object	1st Diff	2nd Diff	3rd Diff	4th Diff	Aver Diff	Elevation
RM-1						16.000
	2.926	2.927			+2.926	
ch. bar						18.926
	2.895	2.894			-2.894	
RM-2						16.032
	3.985	3.987			+3.986	
RM-3						20.018

WIRE WT.	Found	Left
Ch. Bar Rd.	18.925	18.925
Ch. Bar El.	18.926	18.926
Tape to W.S.	16.115	
W.S. El.	2.81	2.81
W. Wt. Rdg	2.82	2.82

BUBBLE GAGE	Found	Left
W. Wt. Rdg.	2.82	2.82
Bubb. Dial	2.82	2.82
Corr'n	0	0

DIGITAL RECORDER	Found	Left
Bubb. Dial ~~W.S. elev~~	2.82	2.82
Gage rdg	2.82	2.82
Corr'n	0	0

STAFF SECTIONS

Range	RP Ele	RP reading Found	RP reading Left	Gage corr'n

Level ID W 26093

Date of last check 6-10-86

Collimation error C −0.001

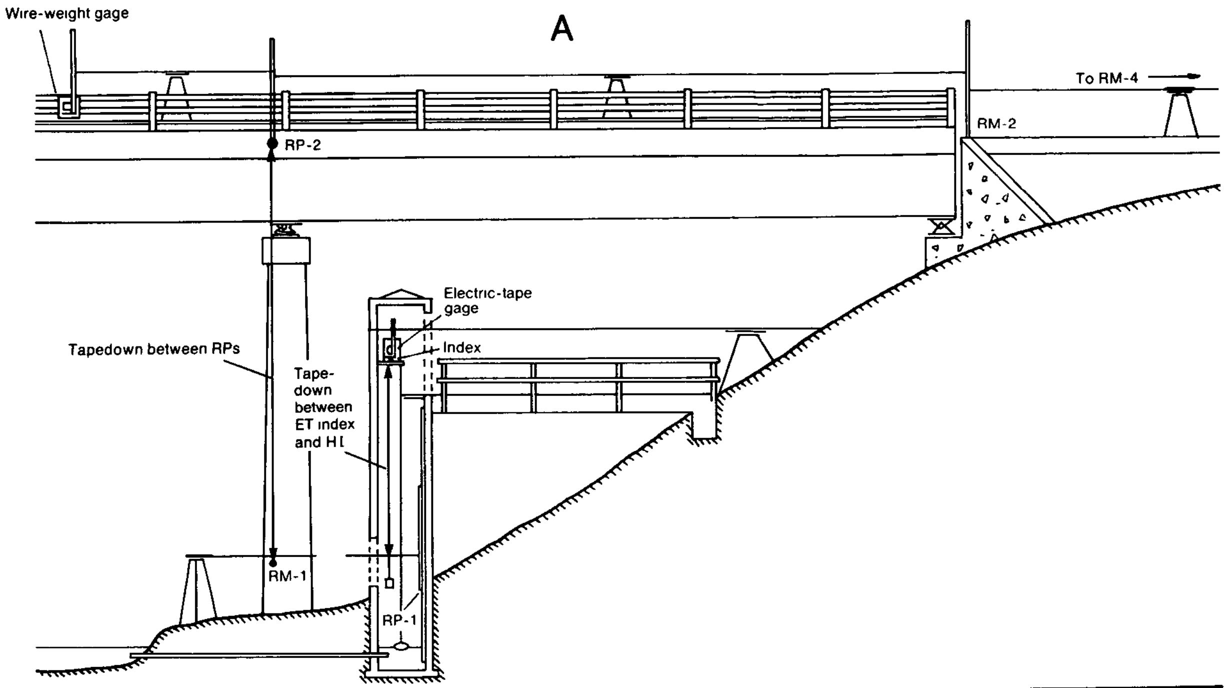
Tape reading on rod used

Base	1.000	Temp 78°F
1.000	2.000	Cloudy
5.0	6.002	Calm
10.0	11.000	

Sheet 1 of 2 Comp by ORS Chk by BJJ Date 6-18-86

Figure 13.—Instrument setup locations, field notes, and computations for simple gaging-station levels.

A



B

STATION	BS	HT INST	FS	ELEVATION	REMARKS
RM-1	2.103	9.209		7.106	
RP-1			3.005	6 204	Reads 6.201 on a tape matched with gage plates
On tape			0	9.209	
Tape up H I to Ind			—	+15.699*	= 21 712 (at H I) − 6 013 (at ET Ind.)
ET Ind			—	24.908	ET length 24 910; ET at W S 1 370, Dig rec 1 370
Tape down Ind. to H I			—	−17.103*	= 22 899 (at H I) − 5.796 (at ET Ind.)
On tape	0	7.805		7.805	
RP-1			1.602	6.203	
RM-1			.700	7.105	
Tape up RM-1 to RP-2			—	+35 720	
RP-2	5.037	47 862		42 825	
Wire-Wt. Ch. bar	2.918	47.656	3.124	44.738	
RP-2	4.994	47.822	4 828	42.828	
RM-2	3.874	46.672	5.024	42.798	Ch bar elev 44.738; Tape to WS 43 315
RM-4	1.821	46.726	1.767	44.905	W.S Elev 1 423; W.wt reads 1 32
RM-2	5.105	47.905	3.926	42.800	Corr'n −0.10; Ch bar reads 44.74
RP-2			5.086	42.819	Ch bar reset 44.84; W wt reads 1 42
Tape down RP2-RM-1			—	−35.719	
RM-1			—	7.100	
	Rerun RP-2 to RM-2				
RP-2	5.218	48 043		42.825	
RM-2			5.238	42 805	

* Difference between readings of the hanging unreeled tape of the ET gage at the H I and at the ET index mark

C

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta No 06963000

SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION Blue River at Elmont, Mo

DATE June 16, 1986 PARTY B.J.Johnson, O.R Shinn

ADJUSTMENT OF ELEVATIONS

Object	1st Diff	2nd Diff	3rd Diff	4th Diff	Aver Diff	Elevation
ET Ind.						24.908
	17.802	17.803			−17.802	
RM-1						7.106
	.902	.902			−.902	
RP-1						6.204
RM-1						7.106
	35.720	35.719			+35.720	
RP-2						42.826
	1.913	1.910			+1.912	
Ch. bar						44.738
RP-2						42.826
	~~.030~~	.019	.020		−.020	
RM-1						42.806
	2.107	2.105			+2.106	
RM-4						44.912

W. WEIGHT	Found	Left
C. bar rdg	44.74	44.84 (11 00 a)
C. bar elev.	44.738	44.738
Tape to W.S.	43.315	
W.S. elev	1.42	1.42
Gage Rdg.	1.32	1.42
EL. TAPE		
Index elev	24.908	
Tape length	24.910	
Corr'n	−.002	−.002

DIGITAL RECORDER

	Found	Left
W S elev	1.370	
Gage rdg	1.370	1.370
Corr'n	0	0

INSIDE STAFF SECTIONS

Range	R P Ele	R P reading Found	R P reading Left	Gage corr'n
0-21.0	6.204	6.201	6.201	+.003

Level ID W 26093
Date of last check 6-7-86
Collimation error C−0.001
Tape reading on rod used

Base	1.000	Temp 73°F
1 000	2.000	clear calm
5.000	6.001	
9.000	10.001	
12.500	13.499	

Sheet 1 of 2 Comp by BJJ Chk by ORS Date 6-16-86

Figure 14.—Instrument setup locations, field notes, and computations for complex gaging-station levels.

between reference mark 2 and reference point 2, so that portion was rerun.

This more complex station is also illustrated in figure 15. A weighted steel tape, temporarily suspended from the bridge, was used to transfer elevations from the ground near the stream up to the electric-tape index, and to the bridge deck. The side shot in the previous example was avoided by turning on reference point 1.

Checking gages

The first step at a float-operated station is to read all the inside gages and to check the floats and connectors. Shake each float to check it for leaks, and repair or replace it if necessary. Replace any kinked, twisted, or otherwise damaged tapes or cables. See that any surge protection devices (chains, float tunnels, and shafts) on digital-recorder floats are clean and working. Put the floats back in the water, and read them again to determine the effect of any problems that were found and corrected.

Use the reference gage, generally an electric tape or an independent float tape, to set the principal gage, which is usually the digital-recorder dial to which the recorder and discharge measurements are referred. The reference gage is ordinarily reset when found in error by more than 0.005 foot. The other gages are reset using criteria that depend on the type and use of the gage and the effort required to reset it.

Electric tape

The electric-tape gage reads the water-surface elevation correctly when the length of the tape (distance between the zero on the tape and the bottom of the weight) is the same as the value of the tape-index elevation. When the tape length is too long, the reading of the water-surface elevation is too high and the correction is a negative value. Measure the tape length from a foot mark near the weight to the bottom of the weight, and add that distance to the foot mark used. In areas where gaging stations are not ordinarily equipped with electric-tape gages, a portable electric-tape unit with a tape length of 50 or 100 feet is useful for running station levels. A flat plate or washer mounted beside a hole in the instrument shelf can be used as a reference point and as an index point for the portable electric tape. The portable unit also can be used to read the tapedown distance to the water surface inside a well visually or, with a ground connection and battery, electrically.

Float tape

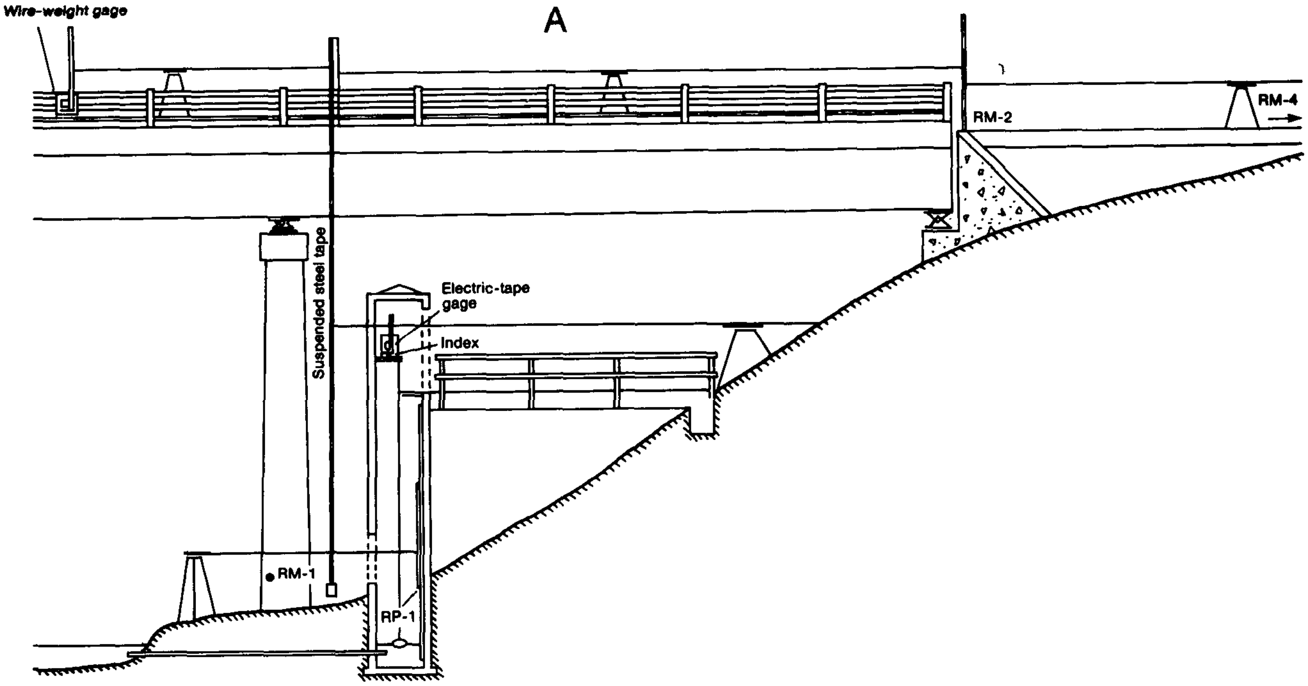
A float tape may be an independent gage or a driving tape for the recorder. If the station has an electric tape, it should be read after it has been checked by levels. That reading is the water-surface elevation in the well and should agree with the float tape. To read the electric tape to 0.001 foot, get an approximate reading, dry off the bottom of the weight, and, when the tape is 0.01 foot above the approximate reading, lower it in 0.001-foot increments until it contacts the water. If there is no electric tape, measure down from an appropriate reference point to the water surface and compare that elevation with the float tape reading. Reset the float tape if it is in error by more than 0.005 foot. The gage is best reset by loosening the connector screws near the float after noting the tape reading at the clamp. Slip the tape by the amount of the change, tighten the clamp, and note the tape reading after the change. A float tape also can be reset by moving its pointer. However, if it is later found that the gage has been reset in error and must be set again, the difference between the "found" and "left" readings cannot be checked.

The digital-recorder dial, the principal gage, may be driven by a beaded cable instead of a tape, but it can be checked in the same manner as a float tape gage. However, the interpolation between hundredths of a foot is less certain.

Wire weight

A wire-weight gage has several potential sources of error to be considered while checking it. For example, if the gage is mounted near the center of a long span of a modern slender bridge, the check-bar elevation may vary considerably. This occurs because bridges arch upward when their top surfaces are warmer than their bottom surfaces, and sag when the temperature differences are reversed. This effect is much greater for modern slim girder bridges than for deep trussed structures.

Variations in drum and cable diameter also result in wire-weight calibration errors, some as great as 0.10 foot per 60 feet of spooled-out cable. At the same check-bar setting (a check bar is a bar on the wire-weight gage used to check the length of the wire and its winding on the drum), replacement of an old cable (one stretched and made thinner by long use) with a new cable is likely to change the reading of a gage mounted high above the water by several hundredths of a foot. The weight spins rapidly when lowered a long distance. The reading is much different at the moment when the weight stops at the end of a spin in one direction than at the end of a spin in the other direction. These errors are usually negligible for gages mounted less than 15 feet above the water on short bridges. The errors may be tolerable for almost any wire-weight gage used at a station solely to ensure that the inside gages are operating properly.



B

STATION	BS	HT INST	F.S	ELEVATION	REMARKS
RM-1	2.328	9.434		7.106	
RP-1	3.065	9.268	3.231	6.203	Reads 6.201 on tape matched with plates
Tape 0	5.846	9.219	5.895	3.373	
RP-1	3.127	9.332	3.014	6.205	
RM-1			2.227	7.105	
Tape 0	22.409	25.782		3.373	
ET Ind.	1.083	25.992	.873	24.909	ET Length 24.910 ws 1.37 Dig. Rec. 1.37
Tape 0			22.618	3.374	
Tape 0	41.483	45.216		3.373	
WW Ch.b.	.638	45.378	.476	44.740	Ch. bar reads 44.74 w.s. reads 1.32
RM-2	3.332	46.138	2.572	42.806	
RM-4	1.489	46.403	1.224	44.914	Ch. bar elev 44.741 Tape to w.s 43.315
RM-2	3.207	46.013	3.597	42.806	w.s. elev. 1.426 wwt. reads 1.32
WW Ch.b.	1.084	45.827	1.270	44.743	Corr'n + 0.11 Ch. bar reads 44.74
Tape 0			42.452	3.375	Ch. bar reset 44.85 wwt. reads 1.43

C

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta No 06963000

SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION Blue River at Elmont, Mo.

DATE June 16, 1986 PARTY B.J. Johnson, O.R. Shinn

ADJUSTMENT OF ELEVATIONS

Object	1st Diff	2nd Diff	3rd Diff	4th Diff	Aver. Diff	Elevation
RM-1						7.106
RP-1	0.903	0.900			-0.902	6.204
Tape 0	2.830	2.832			-2.831	3.373
ET Ind	21.536	21.535			+21.536	24.909
Tape 0						3.373
W.W. Ch.b.	41.367	41.368			+41.368	44.741
RM-2	1.934	1.937			-1.936	42.805
RM-4	2.108	2.108			+2.108	44.913

WIRE-WT	Found	Left
Ch. bar rds.	44.74	44.85 (1100 hr)
Ch. bar elev.	44.741	44.741
Tape to w.s	43.315	
W.S. elev.	1.426	1.426
Gage rds.	1.32	1.43
EL. TAPE		
Index Elev.	24.909	24.909
Tape length	24.910	24.910
Corr'n	- 0.001	- 0.001

DIGITAL RECORDER

	Found	Left
WS elev	1.37	
Gage rdg	1.37	1.37
Corr'n	0	0

STAFF SECTIONS

Range	RP Ele.	RP reading Found	RP reading Left	Gage corr'n
0-21.0	6.204	6.201	6.201	+0.003

Level ID W26093

Date of last check 6-7-86

Collimation error C -0.001

Tape reading on rod used

Base	1.000	Temp 71°F
1.000	2.000	cloudy calm
5	6.001	
9	10.001	
12.5	13.499	

Sheet 1 of 2 Comp by BJJ Chk. by ORS Date 6-16-86

Figure 15.—Instrument setup locations, field notes, and computations illustrating use of a suspended steel tape.

Levels should be run at least to the check bar in its outer position. Further checking may be desirable in certain circumstances, described in the following paragraphs. Initial checking procedures for most wire weights are as follows: Let the weight down to the water, wait until the spinning stops, then wind the weight back up so the wire is spooled evenly on the drum. Read the check bar. If the reading differs from the check-bar elevation by more than 0.005 foot, or 0.01 foot for a normal outside gage at a float-operated station, reset the dial.

If the wire weight is seriously out of calibration and accuracy at low stages is very important, follow the procedure described above and then determine the water-surface elevation by taping down from the check bar. Compare the gage reading and the water-surface elevation. Adjust the check bar by the difference (if the wire weight reads 0.06 foot too low, adjust the gage until the check bar reads 0.06 foot higher than the elevation determined by levels). The gage should then be correct at low stages, though in error at high stages.

If, for some reason, maximum accuracy at all stages is necessary, follow the procedures described above but keep the check-bar reading at its correct elevation. Prepare a graph similar to that in figure 16, with zero correction plotted at the check-bar elevation and the difference between the water-surface elevation and the gage reading plotted at the stage of the reading. Leave copies of the graph in the appropriate folders and in the metal pocket of the gage, so each reading made can be corrected by the amount indicated by the graph.

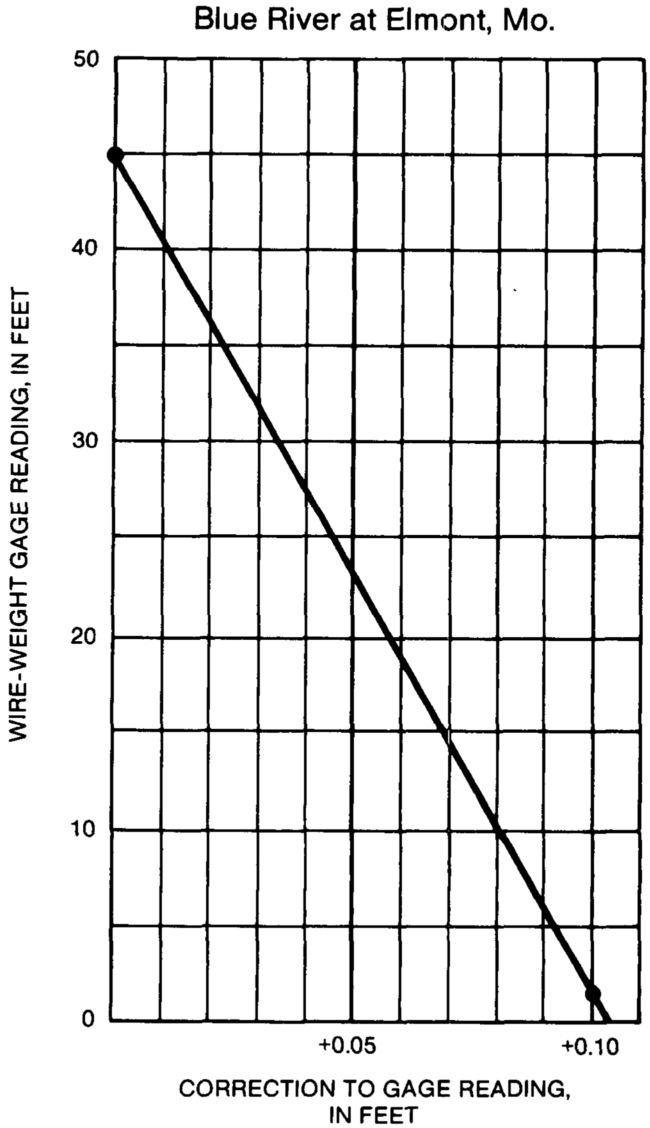


Figure 16.—Stage-related wire-weight gage corrections.

Vertical staff

When two or more enameled steel gage plates are set up at the same location, they are attached to a backing, usually a 2- ×6-inch board. A reference point on the backing should be included in the level circuit. This is done as follows: Stretch a steel tape along the entire range of all the gage plates on the backing, and adjust it up or down until the closest match between all gage-plate graduations on that series of plates and the tape graduations is made. Then read the reference point against the matched tape. The difference between the reference point reading on the tape and the reference point elevation determined by levels is the average error in that series of gage plates (RP Elev.−RP Reading=Correction).

Vertical staff gages are rarely reset for errors of less than 0.02 foot. The lowest section, if used as a reference gage for a very small well or a bubble gage, may be reset for errors as small as 0.01 foot, or even smaller if a reading aid (foot-long point gage) is used to improve the precision of readings.

Inclined staff

This type of gage is checked by leveling from a reference point on or near it whose adjusted elevation was included in the main level circuit. Use side shots to several foot marks throughout the gage's range, from one or more heights of instrument. Resetting of the scale markers on a long inclined staff is usually a major job, considered only when errors exceed 0.10 foot.

Bubble gage

A bubble gage is best set to agree with the reference gage, usually an outside staff or wire-weight gage, at low water and under optimum reading conditions, not necessarily at the time of levels. Reset it only under the same conditions.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta. No. 06963000

RESULTS OF GAGING STATION LEVELS

Station Blue River at Elmont, Missouri

Date of Levels	Party Chief	Elevations of reference marks and reference points									
		RM-1	RM-2	RM-3	RM-4	*L-50	RP-1	RP-2	ET index	Check bar	
9-21-72	Herndon		42.809			61.72				44.740	
9-26-72	Herndon	7.106	42.806	44.926			6.207	42.825	24.910	44.745	
9-06-73	Herndon	7.106	42.806	44.921			6.205	42.824	24.907	44.743	
7-26-75	Lopez	7.106	42.803	44.906	44.914		6.206	42.826	24.909	44.748	
9-15-78	Harrigan	7.106	42.802		44.911		6.203	42.827	24.909	44.745	
7-26-82	Lentz	7.106	42.807		44.909		6.207	42.828	24.906	44.742	
6-16-86	Johnson	7.106	42.806		44.912		6.204	42.826	24.908	44.738	

*NGS bench mark. Line 17 MO. Elev. 1259.299 NGVD of 1929.

Figure 17.—Sample level summary sheet for reference marks and points.

Other gages

A crest-stage gage is checked by leveling to its index. The index may be the top of the stick, or, more commonly, it may be the top of the lower fitting or stick-supporting bolt, which is usually built to be at the same elevation as the bottom of the stick.

An outside gage manometer (alcohol reservoir and transparent tubing) is checked by running levels to the reference points used with it.

Maintaining level summary sheets

The results of the current levels and all prior levels and gage checks that have a bearing on current operations should be tabulated on forms similar to those in figures 17 and 18. All of the necessary information can be recorded on one sheet if the station has no staff gages and few reference points. Add the results of the levels to the summary each time they are run, and include a copy of the latest summary with the material usually carried by the field person. Base the datum corrections used for the discharge record computations on these summary sheets.

National Geodetic Vertical Datum

The NGVD of 1929, spheroidal in shape, is a level surface that approximates mean sea level. It is based on records from approximately 30 tidal stations in the United States and Canada and nearly 100,000 miles of

UNITED STATES
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WATER RESOURCES DIVISION

Sta. No. 06963000

RESULTS OF GAGING STATION LEVELS

Station Blue River at Elmont, Missouri

Date of Levels	Party Chief	Electric tape			Wire-weight gage check bar				Inside staff		
		Index elev.	Tape length	Correction	Elev. found	Elev. left	Rdg. found	Rdg. left	R.P. Rdg.	Correction	
9-21-72	Herndon				--	44.740	--	44.74			
9-26-72	Herndon	24.910	24.910	0	44.745	--	44.74	44.74	6.199	+0.008	
9-06-73	Herndon	24.907	24.910	-.003	44.743	--	44.74	44.74	6.201	+.004	
7-26-75	Lopez	24.909	24.910	-.001	44.748	--	44.75	44.75	6.200	+.006	
9-15-78	Harrigan	24.909	24.910	-.001	44.745	--	44.75	44.75	6.200	+.003	
7-26-82	Lentz	24.906	24.910	-.004	44.742	--	44.74	44.74	6.201	+.006	
6-16-86	Johnson	24.908	24.910	-.002	44.738	--	44.74	*44.84	6.201	+.003	

*Adjusted to make low-water readings agree with water-surface elevations.

Figure 18.—Sample level summary sheet for gage corrections.

first-order leveling. Earlier national datums, starting in about 1878, were known as Sandy Hook Datum, adjustments of 1903, 1907, 1912, 1927, special adjustment of 1929, general adjustment of 1929, and from 1937 to 1973 Sea Level Datum of 1929. Some additional supplementary adjustments also have been used. Another general adjustment is planned for completion in 1990 or thereabouts.

Reference of every gage datum to the national datum is desirable, especially where flood profiles are likely to be needed. The tie-in ensures that the gage datum can be recovered in the future, even if the gaging station and its reference marks are destroyed. If a gaging station has not previously been tied into NGVD of 1929, those levels should be run as soon as it is feasible. In most areas this requires that there be a bench mark, or some other mark from a local network that is referenced to NGVD of 1929, within about 8 miles of the gaging station. Stations requiring longer or unusually difficult levels can wait until closer bench marks are installed or a pressing need for the data develops.

Some Federal, State, and municipal agency offices keep unpublished records of bench marks established to less than third-order accuracy for construction purposes. Some of these marks are near gaging stations, and in most cases their elevations are tied into former mean sea level datums that may be convertible to NGVD of 1929. Gage-datum elevations from such marks are usually credited to the organization that ran the levels and can be used until marks tied in to NGVD of 1929 are available.

Locations of most monumented (documented and fairly permanent) bench marks are indicated on recent U.S. Geological Survey topographic quadrangle maps. Descriptions and elevations of marks shown on the maps, as well as of other marks established after the maps were printed, are published in lists or booklets by the National Geodetic Survey (NGS) and the U.S. Geological Survey. NGS "Vertical Control Data" booklets are published separately by 30-minute quadrangles and can be ordered from

Director
National Geodetic Survey
NGS Information Center
Rockville, MD 20852

An index to U.S. Geological Survey "Vertical Control Lists" can be obtained from

U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, VA 22092

Once the 15-minute quadrangles of interest have been identified from the index, the lists can be obtained from the National Cartographic Information Center (NCIC) office serving the appropriate State:

Arizona, California, Hawaii, Idaho, Nevada, Oregon, and Washington

Western Mapping Center-NCIC
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Alaska, Colorado, Montana, New Mexico, Texas, Utah, and Wyoming

Rocky Mountain Mapping Center-NCIC
U.S. Geological Survey
Stop 504, Box 25046, Federal Center
Denver, CO 80225

All other States

Mid-Continent Mapping Center-NCIC
U.S. Geological Survey
1400 Independence Road
Rolla, MO 65401

Bench mark level tie

The following approach is suggested for surveying a long level line to a selected bench mark. The method requires only a two-person party and minimizes the distance between that party and its vehicle.

Start from a gaging-station reference mark and run all elevations to gage datum, which, unlike the national datum, will probably never be changed. Make sight lengths as long as possible up to 300 feet, and balance them by pacing. Read the rod to 0.01 foot. Select a route, preferably along roads, to the bench mark. Consider the time available for the work, and level toward the bench mark until half that time has been used. Set a temporary mark at the stopping point, and level back to the starting point and vehicle. If the closure errors are acceptable (less than $0.012\sqrt{n}$ or $.05\sqrt{M}$), drive to the previously set temporary mark, and repeat the process to and from another temporary mark. Continue until the NGVD of 1929 bench mark is tied in.

Mark and number approximately every third turning point with chalk, plastic or cloth flags, or lightly with spray paint so they can be found in the event of an unacceptable closure error; this will make it possible to rerun only the short segment between the turning points for which elevations are inconsistent. Use the same notekeeping format as for gaging-station levels. Figure 19 illustrates bench mark leveling notes and adjustments.

Checklist of Equipment for Gaging-Station Levels

Consider the following equipment, in addition to that ordinarily carried in a stream-gaging vehicle, when loading for a field trip involving levels:

- Level
- Tripod
- Rod; Old rod for use in stream
- Rod level
- 24-inch carpenter's level
- 50- or 100-foot tape with weight; Portable electric tape set
- 6-foot folding engineer's rule
- Gaging-station reference-mark tablets
- Posthole digger
- Earth anchors; 3- or 4-inch PVC pipe for reference-mark use
- Assorted brass or galvanized bolts; Masonry anchors for bolts
- 0.25- ×1-inch lag screws and washers; Masonry anchors for screws
- Hand drill and bit assortment
- Colored chalk
- Spray paint
- Star drill and hammer
- Small container of Portland cement
- Fresh sack of concrete mix
- Machete or brush hook
- Turning points:
  - Steel stakes
  - Wooden stakes
  - Trivets
  - Rubber hammer

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SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION Blue River at Elmont, Mo.

DATE Sept 21, 1972 PARTY G.K. Herndon, P.R. Crump

ADJUSTMENT OF ELEVATIONS

Object	1st Diff	2nd Diff.	3rd Diff	4th Diff	Aver Diff	Elevation
RM-4						44.91
TP-1	3.53	3.53			3.53	48.44
TP-2	2.73	2.70			2.72	51.16
TP-3	3.88	3.87			3.88	55.04
TP-4	3.15	3.17			3.16	58.20
TP-5	3.16	3.17			3.16	61.36
TP-6	1.85	1.85			1.85	63.21
BM L-50	1.49	1.49			1.49	61.72

DIGITAL RECORDER

	Found	Left
W.S. elev.		
Gage rdg		
Corr'n		

STAFF SECTIONS

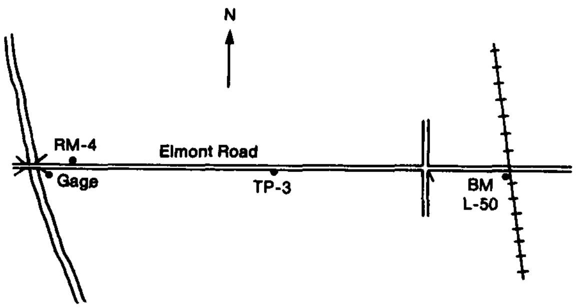
Range	R.P. Ele.	R.P. reading Found	R.P. reading Left	Gage corr'n

Level ID W 17618
Date of last check 9-14-72
Collimation error C -0.003
Tape reading on rod used

Base	1.000
1.000	2.000
5	6.001
9	10.001
12.5	13.499

Temp 78°F
cloudy
light breeze

Sheet 1 of 3 Comp by GKH Chk by PRC Date 9-21-72



STATION	BS	HT INST	F.S	ELEVATION	REMARKS
RM-4	5.06	49.97		44.91	
TP	5.13	51.16	3.94	46.03	
TP	5.08	52.36	3.88	47.28	
TP-1	4.91	53.35	3.92	48.44	℄ Road-painted
TP	5.00	54.25	4.10	49.25	
TP	4.97	55.21	4.01	50.24	
TP-2	5.12	56.29	4.04	51.17	N. Edge road-painted
TP	5.20	57.61	3.88	52.41	
TP	5.13	58.93	3.81	53.80	
TP-3	3.71	58.76	3.88	55.05	Flagged nail in oak root - S of road
TP	3.93	57.39	5.30	53.46	
TP	3.94	56.25	5.08	52.31	
TP-2	3.91	55.09	5.07	51.18	
TP	4.19	54.18	5.10	49.99	
TP	4.06	53.43	4.81	49.37	
TP-1	4.01	52.49	4.95	48.48	
TP	3.71	51.21	4.99	47.50	
TP	4.04	49.95	5.30	45.91	
RM-4			5.00	44.95	closure to .04 in 1.1 mi.
TP-3	5.03	60.07		55.04	
TP	4.97	61.07	3.97	56.10	
TP	5.01	62.17	3.91	57.16	
TP-4	5.05	63.24	3.98	58.19	S. edge road-painted
TP	5.06	64.36	3.94	59.30	
TP	4.91	65.32	3.95	60.41	
TP-5	4.01	65.36	3.97	61.35	℄ road-painted
TP	5.52	67.66	3.22	62.14	
TP	5.18	67.88	4.96	62.70	
TP-6	4.23	67.43	4.68	63.20	S. edge road-painted
TP	5.07	67.06	5.44	61.99	
TP	4.75	66.46	5.35	61.71	
BM L-50	4.99	66.70	4.75	61.71	
TP	5.13	67.36	4.47	62.23	
TP	5.31	68.12	4.55	62.81	
TP-6	5.14	68.34	4.92	63.20	
TP	4.66	67.19	5.81	62.53	
TP	5.04	66.90	5.33	61.86	
TP-5	5.35	66.70	5.55	61.35	
TP	4.21	64.77	6.14	60.56	
TP	4.61	64.04	5.34	59.43	
TP-4	3.95	62.13	5.86	58.18	
TP	3.96	61.03	5.06	57.07	
TP	4.01	59.99	5.05	55.98	
TP-3			4.98	55.01	closure -0.03 in 1.3 mi

Figure 19.—Sample bench mark leveling field notes, computations, and adjustments.

Note forms:
- Level notes and front sheets
- Summary sheets

Field station descriptions; Bench mark elevation and descriptions

Summary sheets of past levels

Selected References

Brinker, R.C., 1969, Elementary surveying (5th ed.): Scranton, Pa., International Textbook Co., 620 p.

Davis, R.E., Foote, F.S., and Kelly, J.W., 1966, Surveying theory and practice (5th ed.): New York, McGraw-Hill, 1,096 p.

Kissam, P., 1978, Surveying practice (3d ed.): New York, McGraw-Hill, 502 p.

McCormac, J.C., 1983, Surveying fundamentals: Englewood Cliffs, N.J., Prentice-Hall, 522 p.

Thomas, N.O., and Jackson, N.M., Jr., 1981, Manual for leveling at gaging stations in North Carolina: U.S. Geological Survey Open-File Report 81-1104, 37 p.

U.S. Geological Survey, 1966, Topographic instructions of the U.S. Geological Survey: Book 2, Part 2E—Leveling, 63 p.

Appendix: Master Copies for Duplicating Notekeeping and Level-Summary Forms

The notekeeping and level-summary forms used in this manual are printed on the last four sheets. They can be duplicated on an office copier if printed forms are unavailable.

1. Front sheet and level notes. This sheet can be folded to provide a front page (summary and adjustments) and one page of level notes, which is adequate for gaging stations for which an average number of reference marks and reference points has been used.
2. Level notes (two pages). This form can be printed on the reverse side of the front sheet and level notes to provide two additional pages of level notes for stations for which numerous reference marks and reference points have been used, or for long lines of cross-country levels.
3. Peg test and fixed-scale collimation test forms.
4. Results of gaging-station levels.

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SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION ______________________________

DATE ________ PARTY ______________________

ADJUSTMENT OF ELEVATIONS

Object	1st Diff.	2nd Diff.	3rd Diff.	4th Diff.	Aver. Diff.	Elevation

DIGITAL RECORDER

	Found	Left
W.S elev.		
Gage rdg.		
Corr'n		

STAFF SECTIONS

Range	R.P. Ele.	R.P. reading Found	R.P. reading Left	Gage corr'n

Level ID
Date of last check
Collimation error C
Tape reading on rod used
Base ____
1.000 ____

Sheet of Comp. by ____ Chk. by ____ Date ____

STATION	B.S.	HT. INST.	F.S.	ELEVA-TION	REMARKS

STATION	B.S.	HT. INST.	F.S.	ELEVATION	REMARKS

STATION	B.S.	HT. INST.	F.S.	ELEVATION	REMARKS

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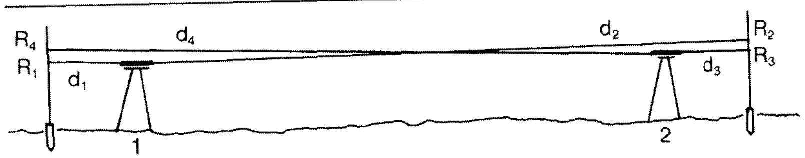
PEG TEST OF ENGINEER'S LEVEL

Date __________ Tested by ______________________

Level type and ID ____________________

Last test date ______________ c found __________ Fixed scale ☐
c left __________ Peg test ☐

TEST AS FOUND



$$* \; c = 100 \times \frac{(R_1+R_3) - (R_2+R_4-{**}CR)}{(d_2+d_4) - (d_1+d_3)}$$

	R	d
1		
2		
3		
4		

c=100 x (+) – (+ –) / (+) – (+)

c=100 x ____ – / – ____ = ______ As found

ADJUSTMENT (level remains set up at 2 and sighted at R_4)

Adjust cross hair to $R_4 \frac{-}{+} \frac{cd_4}{100}$ = ______ / 100 =

Cross hair setting = ______

REPEAT OF TEST AFTER ADJUSTMENT

	R	d
1		
2		
3		
4		

c=100 x (+) – (+ –) / (+) – (+)

c=100 x ____ – / – ____

c = ______ As left

* c is the collimation factor, the inclination of the line of sight in ft/100 ft, minus when up from the instrument, and plus when down.

**CR is twice the curvature and refraction correction for a sight of $\frac{d_2+d_4}{2}$ ft. Its value, which increases the rod reading is tabulated at right.

$(d_2 + d_4)/2$	**CR
0 - 110	0
110 - 190	.001
190 - 245	.002
245 - 290	.003
290 - 350	.004

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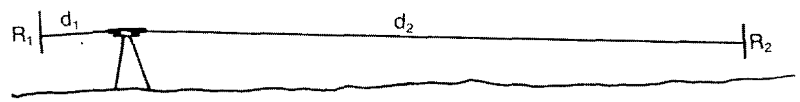
FIXED-SCALE COLLIMATION TEST OF ENGINEER'S LEVEL

Date ________ Tested by ______________________

Level type and ID ________________

Last test date ______________ c found __________ Peg test ☐
c left __________ Fixed scale ☐

TEST AS FOUND



CR= ________

	R	d
1		
2		

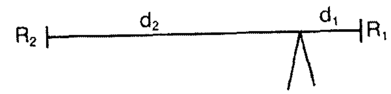
$$* c = 100 \times \frac{(R_1-R_2-{**}CR)}{(d_2-d_1)}$$

c=100 x (– –) / (–) =100 x ______

c= ______ As found

ADJUSTMENT (make R_2 read R_1+CR or ______ ft)

TEST AS LEFT (set up near other scale)



	R	d
1		
2		

c=100 x (– –) / ( ) = 100 x ______

c = ______ As left

* c is the collimation error factor, the inclination of the line of sight in ft/100 ft, minus when up from the instrument, and plus when down.

**CR is the curvature and refraction effect for a sight length d_2. Its value, which increases the scale reading. is listed at right.

d_2 (ft)		CR (ft)
0	160	0.000
160	270	.001
270	350	

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RESULTS OF GAGING STATION LEVELS

Station--

Date of Levels	Party Chief										