U. S. DEPARTMENT OF COMMERCE
SINCLAIR WEEKS, Secretary
COAST AND GEODETIC SURVEY
ROBERT F. A. STUDDS, Director

Special Publication No. 334

GEODETIC LEVELING INSTRUMENTS

By

D. L. Parkhurst

Chief, Instruments Division

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1955

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 15 cents (paper cover)

National Oceanic and Atmospheric Administration

ERRATA NOTICE

One or more conditions of the original document may affect the quality of the image, such as:

Discolored pages
Faded or light ink
Binding intrudes into the text

This has been a co-operative project between the NOAA Central Library and the Climate Database Modernization Program, National Climate Data Center (NCDC). To view the original document, please contact the NOAA Central Library in Silver Spring, MD at (301) 713-2607 x124 or www.reference@nodc.noaa.gov.

LASON
Imaging Contractor
12200 Kiln Court
Beltsville, MD 20704-1387
January 1, 2006

CONTENTS

ILLUSTRATIONS

PREFACE

The U. S. Coast and Geodetic Survey type Geodetic Level and its companion instrument, the Level Rod, originally designed by Mr. E. G. Fischer, have been used in what is essentially their present form, since about 1900. At that time, only a few instruments were required, and maintenance was not a serious problem; consequently their designs were basically functional.

In recent years, the expansion in geodetic leveling by the Coast and Geodetic Survey in this country, and the conduct of similar work outside continental United States by other organizations which have relied on this Bureau for servicing of the equipment, has necessitated redesign of these instruments from the production and maintenance viewpoint, more particularly the Rod.

As originally finished in painted or decalcomania-transfer surfaces, level rods usually required partial refinishing after 1 year's service, and complete refinishing after 2 years, at the most.

As a great deal of hand work was involved, the cost of a complete refinishing was a sizable percentage of the rod's first cost, and it became imperative that this work be speeded up and that expense be reduced. This has been effectively accomplished, and it is the purpose of this publication to explain the methods developed with the hope that the information will prove useful to others confronted with similar problems.

This publication has been prepared under the direction of Admiral R. F. A. Studds, Director of the Bureau, and grateful acknowledgement is made of the assistance and suggestions made by Dr. L. V. Judson, Chief, Length Section of the National Bureau of Standards, Mr. H. S. Rappleye, former Chief, Section of Leveling, Geodesy Division, U. S. Coast and Geodetic Survey, and Mr. William L. Goode, Instrument Maker, U. S. Coast and Geodetic Survey, whose assistance has been invaluable in working out of construction procedures.

GEODETIC LEVELING INSTRUMENTS

U. S. Coast and Geodetic Survey Design

INTRODUCTION

The two principal instruments used in geodetic leveling are the Level itself and its companion instrument, the Level Rod. Basically, these instruments are similar to those used in operations of less than geodetic accuracy, but the requirements for first-order leveling are such that various details of design, workmanship, and materials of construction of these instruments differ materially from those for work of a lower order. Among these are the effects of comparatively small changes in temperature, closeness of mechanical fit of parts, quality of optics, and accuracy of calibration. The Survey has used the same general type of instruments for many years, but recent changes in accuracy requirements, and a desire for greater ruggedness, and durability of finish on the rods, has led to their rather extensive redesign in numerous details.

The purpose of this publication is to furnish a description of the latest design and methods of construction of these instruments extant at the time of its preparation and, in considering them, it is of value to appreciate the quality of the work which they are called upon to perform. The Survey's lines of levels are extended to great distances, the requirements being that the probable accidental errors must not exceed ±1 mm. per km., regardless of the topographical characteristics of the country over which the operations are carried on.

GENERAL DESCRIPTION OF LEVEL

The elements which cause these levels, which are of the Dumpy type, to differ from the more customary instruments are:

1. The sensitivity of the bubble, which is from 1.6 to 2.0 sec. of arc per 2-mm. graduation.

2. The construction of certain of the telescopes of a material having a low temperature coefficient of expansion, to prevent or minimize uncorrected errors due to uneven heating of the parts of the instrument.

3. Reading of the bubble from the eyepiece end, so that observations upon the bubble and the rod will be made simultaneously.

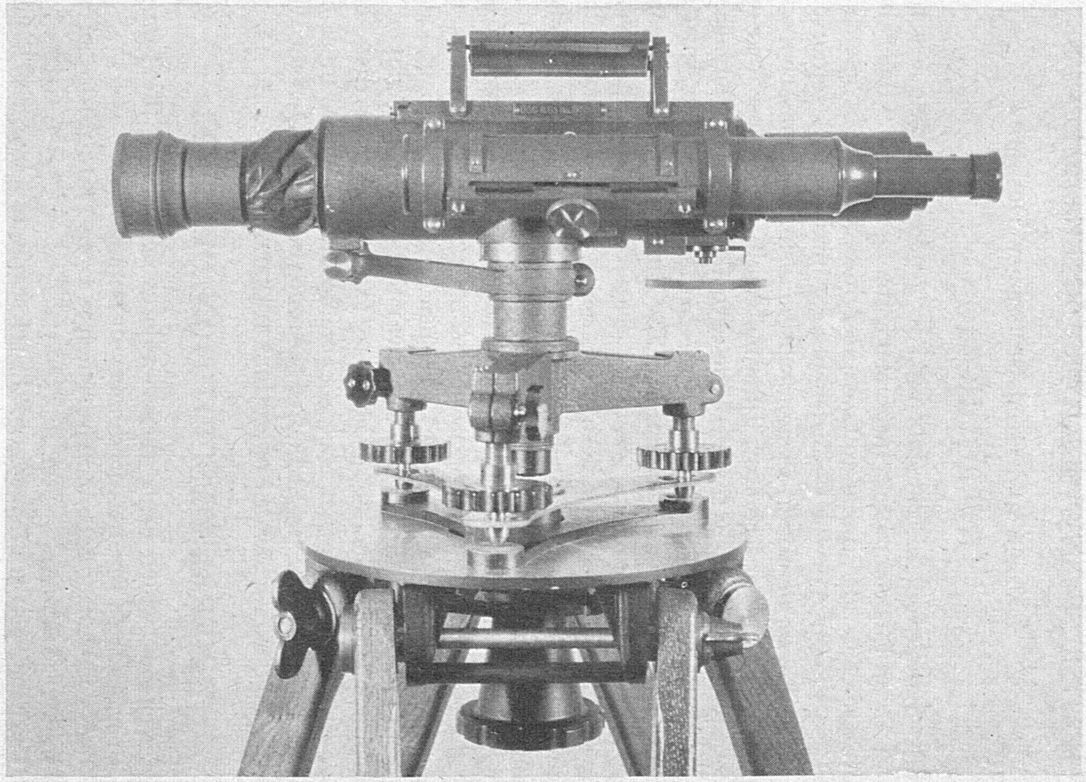

FIGURE 1.—Geodetic level. Left side view.

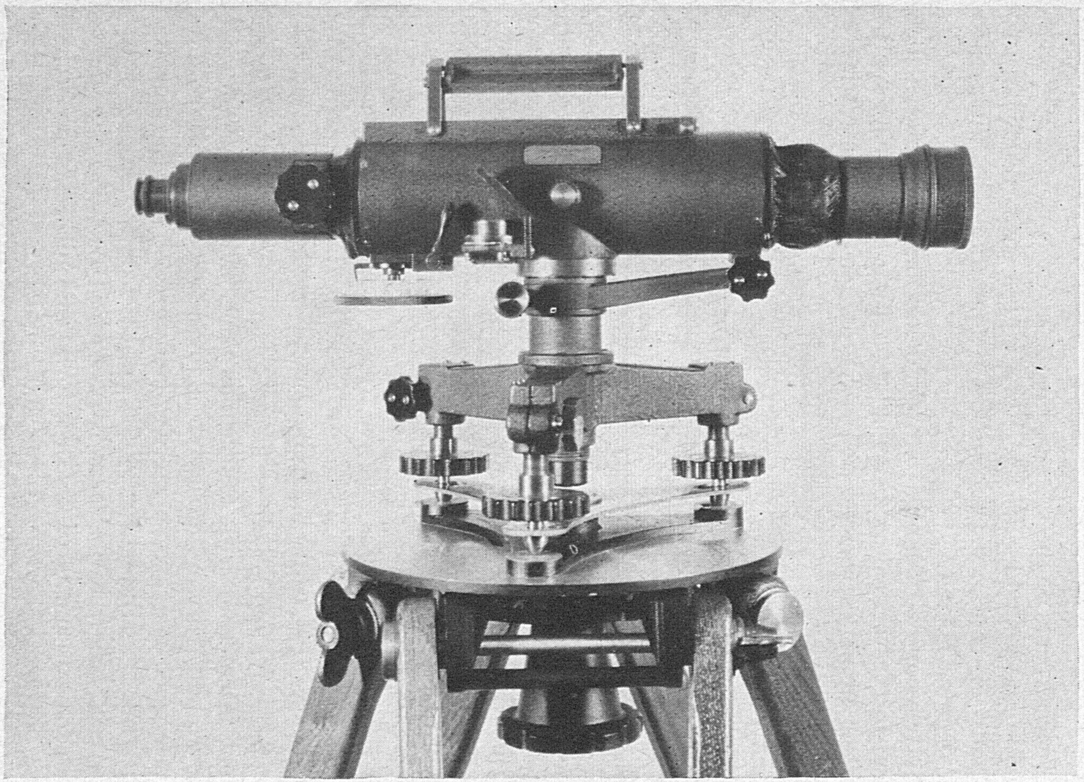

FIGURE 2.—Geodetic level. Right side view.

4. A powerful telescope with large-size objective, giving better field of view, high magnification, and sharpness of image, so that long sights may be made without sacrifice of accuracy.

THE TELESCOPE

All metal parts of the telescope with the exception of the eyepiece assembly and its holder are made of stainless steel. For instruments that must operate at extremely low temperatures, an alloy such as invar or lovar is used.

The telescope is mounted on cylindrical bearings, placed at and normal to the vertical axis so that the tilting of the telescope when adjusting by its micrometer screw will not change its elevation with respect to the earth.

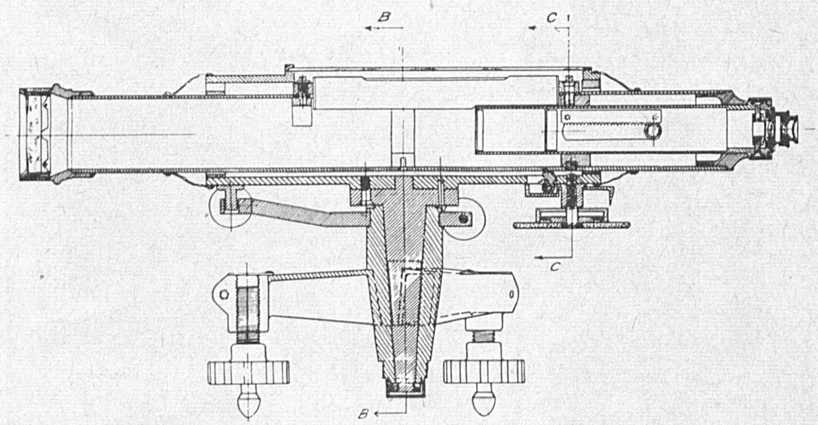

FIGURE 3.—Cross section through assembly of level.

The level-vial holder is mounted in an opening in the top of the telescope body, and placed as near to the optical axis as is possible without interfering with the vision. The body of the telescope is either ground truly cylindrical or is provided with two raised rings, one near each end, which are similarly ground for the purpose of facilitating the adjustment of the optical axis to coincide with the geometrical axis. Adjustment is performed with the telescope dismounted from the rest of the instrument and placed in the wyes of a testing fixture, observation being made upon a suitable collimator.

The objective lens has a clear aperture of 42 mm. and an outside overall diameter of 44 mm. $\frac{+0.0}{-0.2}$ mm. The focal length is 410 mm. ± 10 mm. The lens is of the achromatic type with its elements cemented together with stick balsam or optical cement, and its outer diameter ground true with its optical center. Two Steinheil eye-

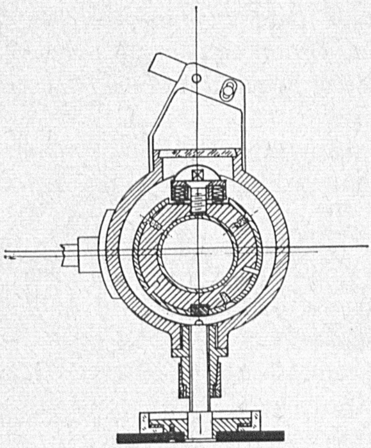

FIGURE 4.—Section of assembly at C–C (indicated in fig. 3) showing micrometer screw.

pieces of 9½ and 12½ mm. focal length are provided to give magnifications of 43 and 32 diameters, respectively. Hard coating of the optics is recommended.

The vial is of the chambered type to permit regulation of the length of the bubble, as temperature conditions may require. The graduation lines are 2 mm. apart, and each division represents an arc of from 1.6 to 2.0 sec. A short line ruled at the top of the vial and parallel to the longitudinal axis is placed at each end to facilitate calibration and mounting in proper position. The vial is mounted in a tube of the same material as the telescope, and is held in place by cork rings which are sufficiently resilient to permit such slight longitudinal expansion as may occur, without setting up strains which might cause a change in its curvature.

The holder is supported at one end by two pivot screws which permit the adjustment of the axis of the vial into parallelism with the line of collimation in the horizontal plane.

A square-headed, fine-pitched screw, also of the same material as the body of the telescope, passes through the other end of the holder with a shoulder which forces the holder down against two stiff helical springs, fitting in recesses in the holder, and bearing on the telescope body. This screw is for the purpose of adjusting the vial so that its axis is parallel to the line of collimation in the vertical plane.

THE BODY

The housing or main body of the instrument is a casting of any suitable material, such as cast iron, or preferably brass. This part carries the bearing on which the telescope is supported, the bearing for the micrometer leveling screw, and the bubble-reading device.

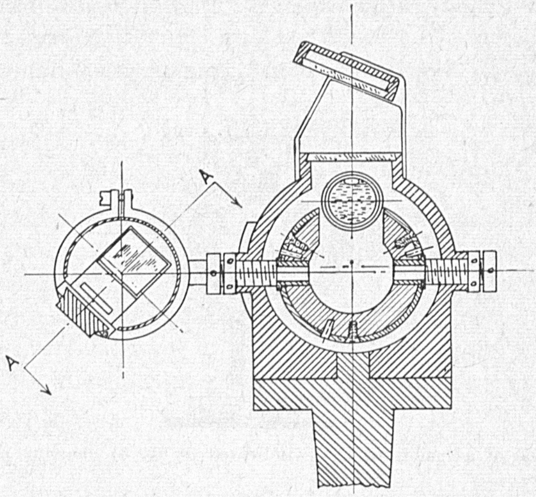

FIGURE 5.—Section of assembly at B–B (indicated in fig. 3) showing pivot-mounting of telescope.

A tapered steel vertical axis is attached to this housing, and rotates in a cast-iron socket cast integral with a 3-armed leveling head. It is essential that the vertical axis have a carefully ground shoulder at the top which shall bear upon the top of the socket in such manner as to take the thrust of the weight of the rotating elements, and at the same time the tapered part must correctly fit in its bearing to serve its purpose as a guide. No other thrust bearing is required, but a nut at the bottom prevents the telescope assembly from falling out in case the instrument is inverted. This nut in the normal position must not touch the leveling head in any way. A lug is attached to the lower front end of the body to furnish a bearing for the slow-motion tangent screw.

At the rear of the body is located a small eccentric, which, by means of an external lever, may tilt the telescope away from the micrometer screw to avoid damage to its point when the instrument is being transported. The eccentric bears against a plate of graphite-impregnated bakelite, set into the lower side of the telescope, and, when tilting the telescope, compresses a spring and plunger located near the front end of the housing. For the approximate leveling of the instrument, a small spherical level-bubble is attached to the side of the body with a 45° glass or metallic reflector, so that the bubble may be observed upon from the eyepiece end of the instrument. This bubble is mounted upon three adjusting screws.

The telescope and vial are protected from dust and dirt by means of thin flexible leather shrouds held to the telescope and housing by means of thin metallic clamping bands. This leather is of fine quality and is usually made of what is known as sheepskin skivers, such as are used in the manufacture of organ bellows or similar musical instruments.

The opening over the level vial, through which it is observed upon by the reading device, is enclosed by a tight-fitting glass plate to keep out dust and dirt.

THE LEVELING HEAD

The 3-armed head is of cast iron, with wide-spreading legs. The radial distance to the center of the leveling screws is 3½″, and the size of the leveling screw has been standardized at one-half-inch diameter, with a 32-pitch United States standard form thread. The ends of the legs are split with a narrow saw cut to permit clamping, and the threaded hole is covered with a light metal cap to keep out dust and dirt. This is attached to one side of the leg only, to avoid interference when clamping.

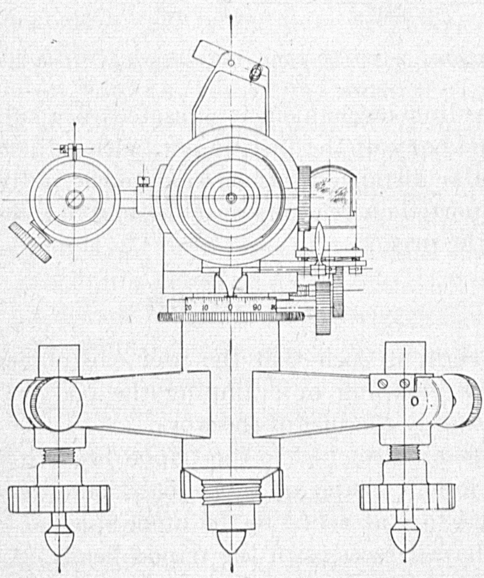

FIGURE 6.—Eyepiece view of level assembly.

The leveling screws are of stainless steel, and are fitted with 2″ diameter fluted hard-rubber thumb wheels which provide adequate leverage for turning, the flutes permitting a firm grip to be obtained without undue discomfort in cold weather.

THE LEVEL-READING DEVICE

It is important that the reading of the rod be made at the instant when the level bubble indicates horizontality of the line of sight. The bubble is viewed through a prismatic reading device, shown in figure 7, which is a modification of that used by Berthelemy. It consists of two 45° prisms mounted upon sliding brackets connected to a knob by a linkage in such a manner that the distance between them can be varied to compensate for variations in the length of the bubble due to temperature change.

The faces of the prisms directed toward the eye are ground to such curvatures as will bring the images of both ends of the bubble to a common focal plane. For the benefit of the observer who may need to wear glasses, the eye cap is arranged to hold a lens which will enable him to observe without them.

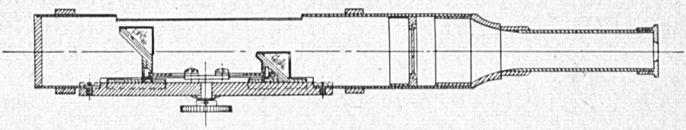

FIGURE 7.—Section of bubble-reading device at A–A, (indicated in fig. 5).

The entire reading mechanism is mounted in a tube and attached to the side of the body of the instrument, with adjustment for varying the interocular distance to accommodate the individual observer. A mirror is supported on brackets over the vial to reflect the image of the bubble into the prisms.

THE TRIPOD

The tripod height is such that the user can observe through the telescope without stooping or cramping the body. This is of importance in the speedy conduct of the work.

The tripod legs are attached to the tripod head through a form of ball-and-socket joint. Plates of fabric-base bakelite, having spherically shaped faces, are attached to the inner sides of the legs, and fit into similarly shaped recesses in the tripod head. A brass bolt and wing nut pull these elements together, but the rigidity of the tripod is not dependent upon the quality of the fit between the bolt and its hole, as is the usual case. Instead, the bolt is only a tension element to tighten the ball-and-socket joint, which, when clamped, is free from play.

Bakelite was chosen for the ball plate after accelerated tests indicated a probable life at least three times as great as for brass, the material originally used for this part.

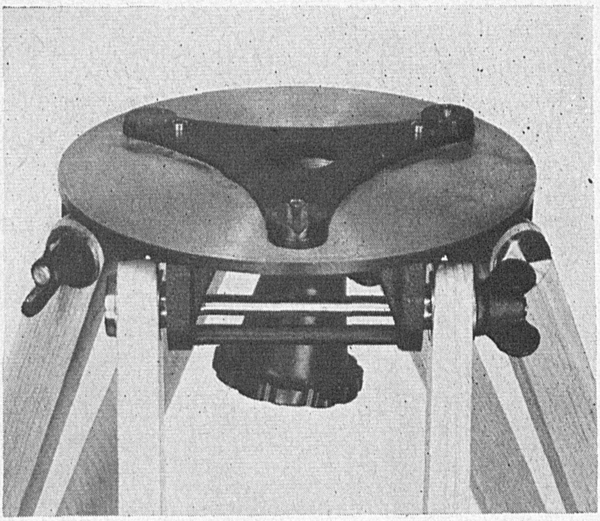

FIGURE 8.—The tripod.

The level is fastened to the tripod by a flat, 3-armed, steel spring, which, by means of elongated holes, slips over enlargements on the ends of the leveling screws. The screws must be removed from the level in order to attach this spring, and when in place the spring cannot be lost off. A large thumb nut in the tripod head is attached to a threaded hub at the center of the spring and applies the necessary tension to hold the instrument in place, the advantage of this design being that no stress is introduced into the leveling head, and consequently no possibility of deformation of the bearing surfaces.

When the instrument is mounted on the tripod, one of the leveling screws rests in a cup-shaped depression, a second in a radial V-shaped groove and the third on a plane surface, thus eliminating any possibility of improper seating of the instrument due to differences in position of the leveling screws in different instruments.

LEVEL RODS

In geodetic leveling, the rods are used in pairs, units of a pair being carefully selected so that calibration data are identical or similar within 0.1 mm.

It has been the usual practice to finish the rod with paint or enamel, with graduation identification in the form of decalcomania transfers. These materials have only a limited useful life as they wear rather quickly and white finishes have a tendency to turn yellow with age and exposure to sunlight.

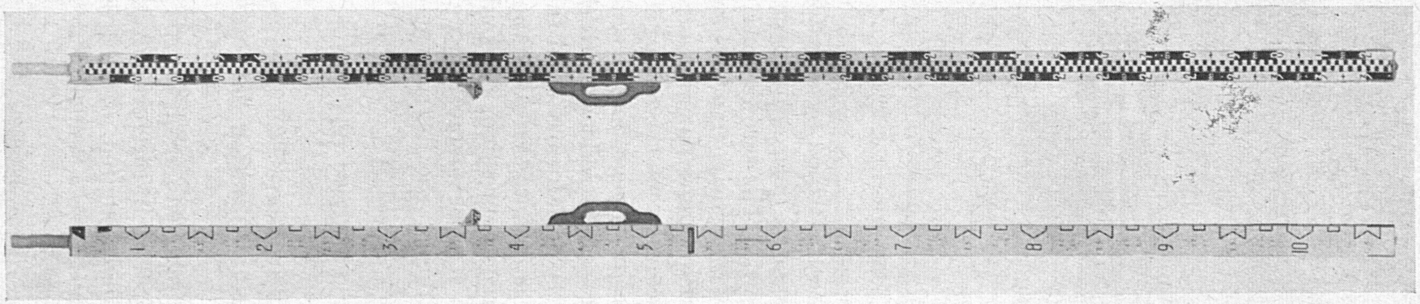

FIGURE 9.—Level rod, front and rear views.

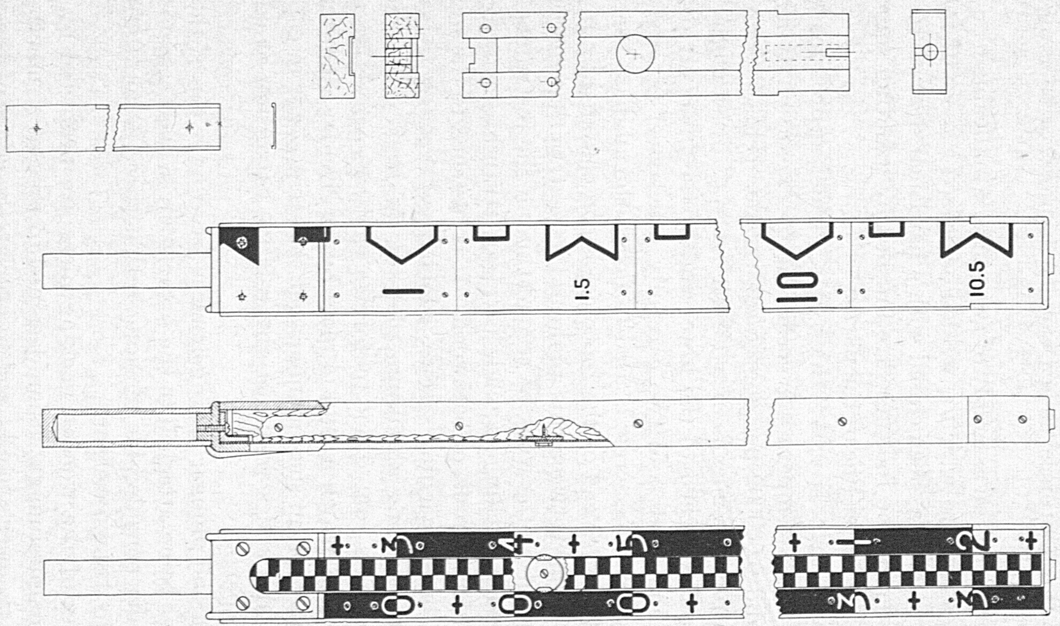

FIGURE 10.—Level rod, details of front, rear, and cross section.

The rods to be described have been designed with a view to longer life, elimination of objectionable color change, reduction in cost of reconditioning, and to strengthen certain structural weaknesses that have led to excessive breakage in the past.

The rod consists essentially of a metal footpiece, and an invar strip secured to this footpiece, as is a wooden support, or backing piece, for the invar strip.

The footpiece is an assembly of two parts, a malleable iron or bronze L-shaped casting, to which is welded or brazed a piece of steel tubing whose lower end has been closed with a hardened steel plug. The bottom and step of the footpiece are finished by grinding squarely with respect to the center line of the part.

The invar strip is 0.04″ thick x 1″ wide, approximately 10 ft. long and has a temperature coefficient of expansion lying between 0.000001 and 0.000002 per degree centigrade. This strip is attached to the footpiece by means of a 1″ x 1″ x 3/16″ brass angle, carefully squared, and attached to the lower end of the invar strip by means of a machine screw and two carefully fitted steel tapered pins. A large brass machine screw is used to fasten the angle to the footpiece. Wear at the lower end of the footpiece is compensated by introducing thin brass shims between this angle and its seat, so that rod calibration is not affected by the work of reconditioning the instrument.

The wooden backing is made of clear, straight-grained, well-seasoned, ponderosa pine, or basswood. It is fastened to the footpiece by four long brass machine screws, which pass through the wood and thread into a strong aluminum plate at the back. The face of the backing piece is routed out to form a shallow, protective recess for the invar strip, which is held in place by six circular aluminum guides set into the wood in such manner that the strip is not in contact with the wood, and slides freely in any relative expansion or contraction of the two parts.

A spring and plunger arrangement is set into the top of the backing, the plunger being attached to the invar strip in such a manner that it is held under considerable tension, so that there is no sagging of the strip due to its own weight.

The sides of the wooden backing piece are protected by strips of a special magnesium extrusion designed to present a smooth, rounded surface to the user's hands, and to overlap the edges of the segmental marking units of the front and back of the rod. The top of the rod is capped by a U-shaped precision aluminum casting.

FINISH

Invar Strip.—Invar is a material to which paints and lacquers do not ordinarily adhere well, as the metal has a "greasy" character which is not eliminated by use of the conventional cleaning agents. Treatment of the strip by a material known as "Metal-Prep," however, chemically cleans it and lightly etches its surface, so that priming coatings, and paints and lacquers adhere firmly. A white primer-surfacer is used, with as many as seven coats being applied, depending upon the condition of the strip, each coat being lightly rubbed down with wet or dry abrasive paper. The finished surface must be flat in order that when spraying, paint will not flow under the mask, and the edges of the markings will be straight and sharp.

Wooden Element.—The wooden element is finished with a lacquer type sealer, and waxed with auto body type wax.

Exposed metal parts of the rod and its accessories are finished in gray enamel, where such a finish is desired for decorative purposes.

GRADUATION

Invar Strip.—Graduation of this element must be considered in two parts, or steps, the first being the ruling of four reference lines on the basic invar strip, and the second the application, by painting of a checkerwork of alternate and staggered black and white rectangles of 1 cm. width.

Reference Lines.—Reference lines are necessary for calibration purposes and for registration of the markings. There is a reference line at positions 0.2, 1.2, 2.2 and 3.2 m. from the bottom of the footpiece. Lines are ruled with a diamond and are only a few thousandths of an inch wide and approximately ⅛″ long, cut into a small polished area at the center of the strip. When painting, a ¼″ diameter area is masked off over the line.

Special tools are used to lay off the initial, or 0.2 m. interval. The unit of footpiece and strip is held erect on a surface plate, and the line ruled with a scribing tool made up of an assembly of precision gage blocks, the top element being knife-edged. The height of the column of blocks is selected so that the middle of the scribed line is the line of reference. With this tool, no difficulty is experienced in laying off these intervals within the prescribed tolerance of $0.2000 \pm .0001$ m.

Using the above line as an initial, three similar lines are ruled on the invar strip, one meter apart, the work being performed in a special

346114°—55——3

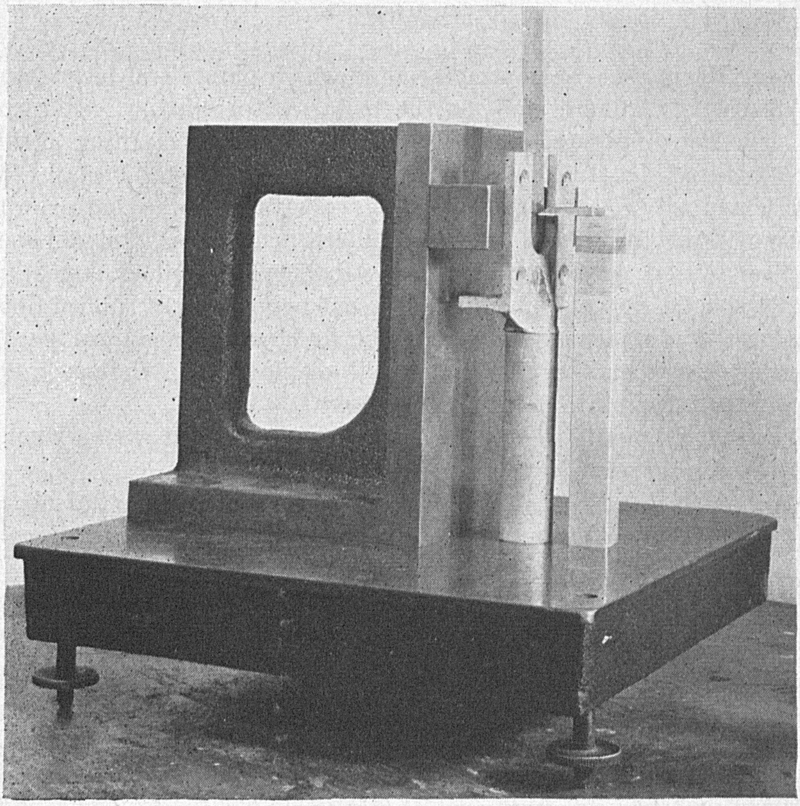

FIGURE 11.—Tools for scribing initial reference line.

comparator built for the purpose. Each meter interval must be correct in length within ±.0001 m., with the further requirement that each line must be correctly positioned with respect to the bottom of the rod within ±.0001 m. After calibration, the rods are mated in such manner that no reference line, even though it falls within the prescribed tolerance, shall differ in position from its similar line on the mating rod by more than .0001 m. Data relative to calibration and pairing are entered on a card and filed under the rod's serial number.

A micrometer microscope type height gage is used to check the .2000 m. interval against a set of gage blocks before submitting the rod to the National Bureau of Standards for calibration.

Checkerwork.—The "working" graduations on the invar strip are in the form of a black and white checkerwork, the blocks being .01± .0001 m. in width. These are applied by spraying black lacquer through a 100 opening mask, made of invar of the same category as the rod strip so that changes in temperature which may occur during the progress of the work, may be ignored.

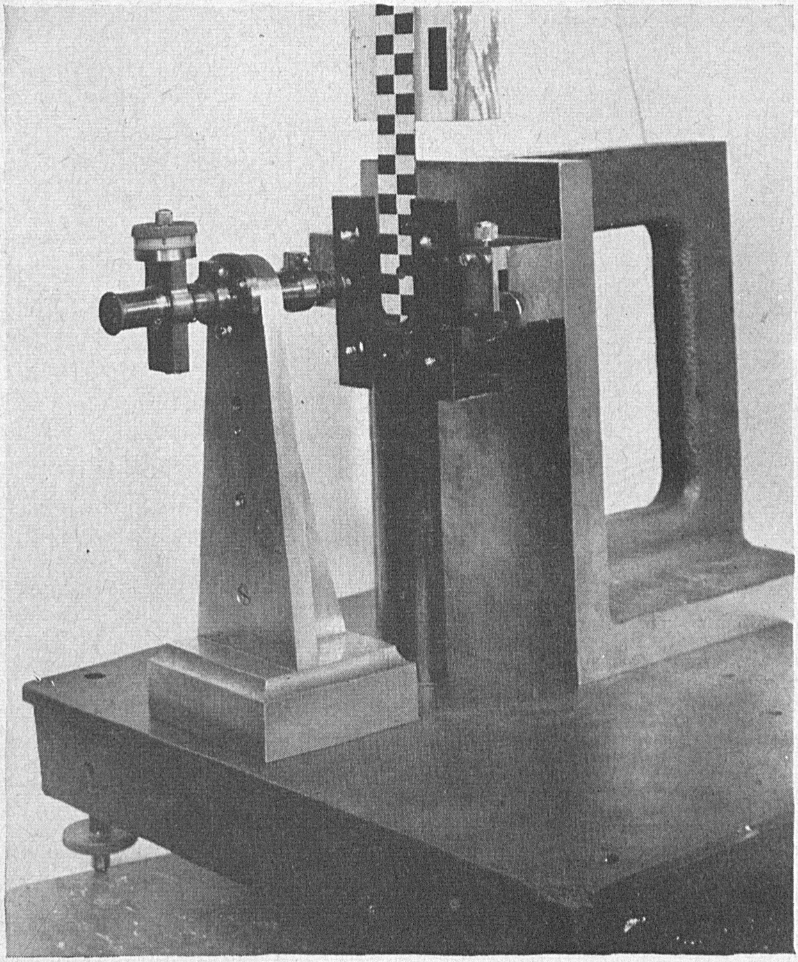

FIGURE 12.—Optical gage for checking initial reference line.

This mask is specially designed and constructed, using L-shaped blocks mounted in channels in a frame, the position of each block being checked with gage blocks during assembly to insure that the mask openings are correctly positioned within the prescribed tolerance.

The corners of the blocks located at 0 and 1 m. are clipped approximately 1/8″ to provide an opening for observing the reference lines on the invar. When preparing to paint, the mask is placed upon the invar strip and carefully registered by observing the reference lines and edges of the masking blocks through a small microscope to insure that they are in alinement.

The weight of the mask is sufficient to hold it in place, and the openings are sprayed with a quick drying dull black lacquer. The process

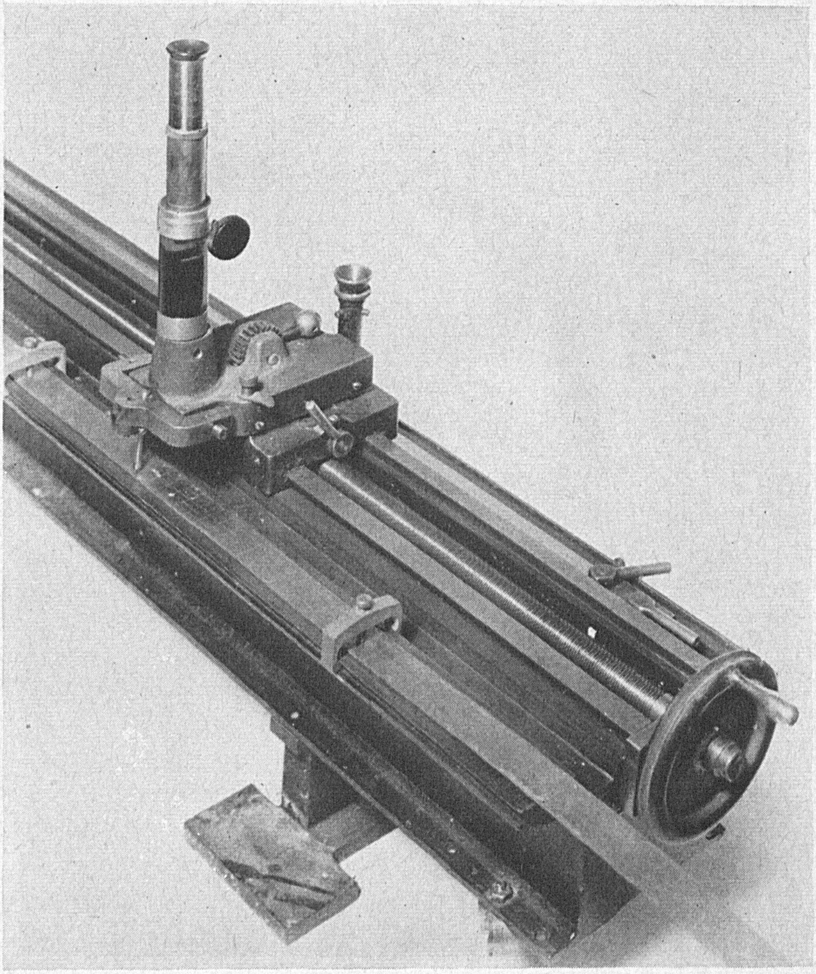

FIGURE 13.—Ruling machine.

is repeated until the entire rod is completed, after which the surface of the strip is given a light spray coating of clear pyroxylin base lacquer and, when thoroughly dry, a coating of auto body wax.

Backing graduations.—The rod is of the self-reading type and as there is insufficient space on the invar strip for numbering the intervals, an identification system is applied beside the strip, on the wood.

The system used on the face of the rod is to mark each decimeter by alternate and staggered black and white areas, each decimeter line being appropriately numbered, the number lying astride the line with the bottom of the footpiece being zero, with an intermediate number at the half-decimeter point.

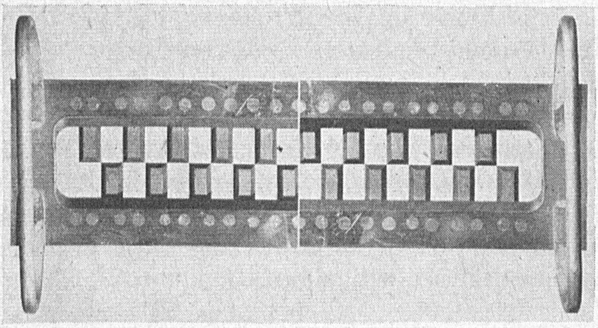

FIGURE 14.—Mask for painting checkerwork, top view.

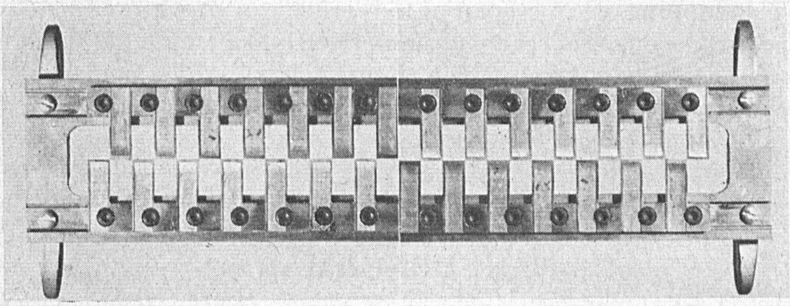

FIGURE 15.—Mask for painting checkerwork, bottom view.

The reverse side of the rod carries a coarse scale, in feet and tenths, which is observed upon during leveling operations, as a rough check against major errors in reading the face of the rod.

The material used in making the marking and scale elements is a laminated phenolic plastic, composed of an inner layer of black material, lying between two outer layers of white, and the reverse for alternate colored markings. The numbers and other markings are formed by routing in an engraving machine, which cuts through the outer layer to expose the inner material. Facing numbers are produced by placing alternate black and white blanks in the engraver, end to end, cutting the desired numbers across the junctions.

Units are assembled to the backing by means of wood screws, through holes carefully located in a jig so that a damaged element may easily be replaced.

ACCESSORIES

The rod has a small spherical level mounted at the side on an aluminum angle, or step, far enough down on the rod so that the observer may view the bubble with a minimum of parallax.

A thermometer is mounted in the back of the rod, with its bulb stem bent at 45°, the bend being of sufficient length for the bulb to extend through the wood and permit its tip to touch the underside of the invar strip. This thermometer has a range from −15° to +55° C., and reads to half degrees.

The hardwood handle mounted on one side is located to give the rod proper balance when carrying, with the forward end slightly raised.

The metal cap at the top of the rod is threaded to fit a small brass post, which has three rings attached to a collar. This post unit is for the purpose of permitting the attachment of guy wires when it is desired to support the rod without an attendant.

SHIPPING CASES

The shipping case for a pair of rods is made of 1″ white or ponderosa pine, with sponge rubber lined supporting and clamping blocks. The hinged cover has three special closure screws, which cannot be lost accidentally. The box is painted on the outside and has folding steel handles at each end for carrying. A similarly constructed case is provided for the level. For carrying, this case has a leather strap instead of metal handles.

THE BENCHMARK

While this publication deals primarily with the two instruments used in conducting leveling surveys, it would hardly be complete without mention of the tablet used to permanently mark the terrain surveyed.

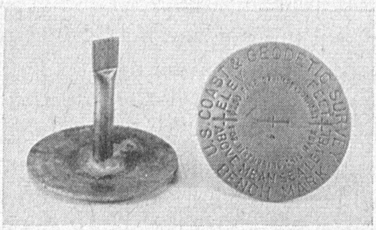

FIGURE 16.—Benchmark.

This takes the form of a brass or bronze tablet, or "benchmark" permanently set in a natural rock outcrop, if available, or in posts or blocks of concrete, if necessary.

For many years this tablet has been made as a casting in bronze, each weighing almost exactly one pound. In order to conserve critical materials, and to produce these units with the use of comparatively unskilled labor, the tablet was redesigned for mechanical fabrication, and is now made from sheet and tube stock, with the legend deeply impressed in the top surface by a suitable die, a press of approximately

200-tons capacity being required. After impression of the legend, the top piece is slightly cupped, legend uppermost.

The tubular stem is next hard soldered in place, and its lower end pressed flat to form a key, to hold the tablet in place when set in cement. The small hole which may be noted a little to one side of the center is for release of air trapped beneath when setting the mark in cement. This prevents the formation of voids which might later fill with water, with subsequent damage to the mark by freezing.

Markers produced by this method weigh only half as much as castings, and the legend is deeper and clearer. While this type of marker is somewhat easier to damage by a determined vandal, yet its removal from its setting is much more difficult, due to its yielding character.

O