NOAA Technical Report NOS 73 NGS 8

Control Leveling

Charles T. Whalen

National Geodetic Survey
Rockville, Md.
May 1978
Reprinted January 1979

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey

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NOAA geodetic publications

Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys. Federal Geodetic Control Committee, John O. Phillips (Chairman), Department of Commerce, NOAA, NOS, 1974 reprinted annually, 12 pp (PB265442). National specifications and tables show the closures required and tolerances permitted for first-, second-, and third-order geodetic control surveys.

Specifications To Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys. Federal Geodetic Control Committee, John O. Phillips (Chairman), Department of Commerce, NOAA, NOS, 1975, reprinted annually 30 pp (PB261037). This publication provides the rationale behind the original publication, "Classification, Standards of Accuracy, ..." cited above.

NOAA Technical Memorandums, NOS/NGS subseries

NOS NGS-1 Use of climatological and meteorological data in the planning and execution of National Geodetic Survey field operations. Robert J. Leffler, December 1975, 30 pp (PB249677). Availability, pertinence, uses, and procedures for using climatological and meteorological data are discussed as applicable to NGS field operations.

NOS NGS-2 Final report on responses to geodetic data questionnaire. John F. Spencer, Jr., March 1976, 39 pp (PB254641). Responses (20%) to a geodetic data questionnaire, mailed to 36,000 U.S. land surveyors, are analyzed for projecting future geodetic data needs.

NOS NGS-3 Adjustment of geodetic field data using a sequential method. Marvin C. Whiting and Allen J. Pope, March 1976, 11 pp (PB253967). A sequential adjustment is adopted for use by NGS field parties.

NOS NGS-4 Reducing the profile of sparse symmetric matrices. Richard A. Snay, June 1976, 24 pp (PB-258476). An algorithm for improving the profile of a sparse symmetric matrix is introduced and tested against the widely used reverse Cuthill-McKee algorithm.

NOS NGS-5 National Geodetic Survey data: availability, explanation, and application. Joseph F. Dracup, June 1976, 45 pp (PB258475). The summary gives data and services available from from NGS, accuracy of surveys, and uses of specific data.

(Continued at end of publication)

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Supersedes Coast and Geodetic Survey
Special Publication No. 226 (revised 1961)
Reprinted January 1979

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary
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Stock Number 003-017-00422-8

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CONTROL LEVELING

Charles T. Whalen
National Geodetic Survey
National Ocean Survey, NOAA
Rockville, Maryland

ABSTRACT Control leveling is used to determine precise elevations of bench marks (monumented points) above or below a reference surface called a datum. The National Geodetic Survey (NGS) of the National Ocean Survey (NOS), formerly the U. S. Coast and Geodetic Survey (USC&GS), now a component of the National Oceanic and Atmospheric Administration, determines elevations in meters above or below the National Geodetic Vertical Datum of 1929.

Bench marks are located at distances of about 1.6 km along railroads and highways in the United States to form level lines. These level lines form a net of closed loops. The present program for development of the fundamental vertical control net calls for first-order lines at approximately 160-km intervals with a subdivision of second-order lines spaced at 40 to 80 km. In certain areas of intense development, the net is again subdivided by second-order lines spaced at 8 to 16 km. The current net consists of 370,000 km of first- and second-order leveling.

INTRODUCTION

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

To define completely the location of any point on the Earth, it is necessary to determine not only its geographic coordinates but its elevation. Geographic coordinates are expressed in terms of latitude and longitude. Geographic latitudes are measured in degrees, minutes, and seconds north or south from the Equator, while geographic longitudes are measured in the same units east or west from the Greenwich meridian. The NGS measures elevation in meters above or below the National Geodetic Vertical Datum of 1929.

The horizontal control surveys of the NGS (triangulation and traverse) result in the establishment of numerous marked points throughout the country, and for each of these the latitude and longitude are known. The vertical control surveys (levelings) result in the establishment of numerous other marked points, and for each of these the elevation is known. Precise latitude, longitude, and elevation are seldom known for the same survey station because different methods are used in determining geographic positions and elevations. Triangulation and, to some extent, traverse stations are located on the highest and most commanding points so as to be visible from other similar points often located many kilometers away. The bench marks are usually adjacent to well-established transportation routes and are seldom located on summits, because the lines of levels that determine their elevations follow the easiest grades for reasons of economy and accessibility of marks.

To initiate a survey, the surveyor may connect with the nearest triangulation, or traverse stations, and the nearest bench marks.

Approximate differences of elevation may be determined by barometric observations. Vertical-angle or trigonometric leveling will be more accurate. The ordinary engineer's level and rod can achieve considerable precision in determining differences of elevation. On the other hand, the use of suggested geodetic equipment and methods in geodetic leveling will permit the determination of differences of elevation between widely separated points with the precision required for a geodetic control network.

For the guidance of Governmental agencies in classifying their work, the Federal Geodetic Control Committee (1974, 1975) adopted standard specifications for leveling of various grades of accuracy. These are the specifications used by NGS.

Until 1922, the control leveling run by the NGS was all first-order leveling. In 1923 and 1927, a small amount of second-order leveling was done. Since 1932, it has been standard practice to subdivide the loops of first-order leveling with leveling of second-order accuracy.

HISTORY OF THE LEVEL NET

Geodetic leveling was begun by the USC&GS in 1877 on the line of precise levels which was to follow the Transcontinental Arc of Triangulation. This arc extended across the United States from Chesapeake Bay to the Golden Gate approximately along the 39th parallel. The primary purpose of this line of levels was to provide accurate elevations for use in reducing horizontal network distances to the sea level surface. However, during the course of the leveling along the transcontinental line, marks were established at intervals of several kilometers and at most of the important towns along the route for the use of engineers and surveyors in initiating additional leveling on a sea level datum.

By 1899 the net had developed 25 circuits, either all spirit leveling or spirit leveling between sea-level connections at tide stations. Closing errors were becoming troublesome, so an adjustment of the net was decided upon. The adjustment was made in 1900, and the results were published in appendix 8, Precise leveling in the United States, **Report of the Superintendent of the Coast and Geodetic Survey showing the Progress of the Work from July 1, 1898, to June 30, 1899* (Hayford 1900). In addition to the details of the various studies and the adjustment, the report contained the descriptions and resulting metric elevations of all bench marks established along the lines in the net.

Fischer Level

In 1900, a new type of leveling instrument was designed and manufactured by E.G. Fischer, then Chief of the Instrument Division of the Coast and Geodetic Survey. This level, with slight changes, was used by this agency for geodetic leveling until about 1967.

Introduction of the new type of leveling instrument, which permitted levels of even greater accuracy to be run at much greater speed and consequently less cost, stimulated the leveling work. As the network of lines of levels extended, the engineering profession came to appreciate the value of a common datum for levels, readily accessible at many places throughout the country.

1903 Adjustment

By 1903 so much leveling had been added to the net that it became necessary to make a second adjustment to absorb the leveling added since 1899.

The details of the adjustment and the resulting metric elevations were published in appendix 3, Precise leveling in the United States, 1900-1903, with a readjustment of the level net and resulting elevations, **Report of the Superintendent of the Coast and Geodetic Survey showing the Progress of the Work from July 1, 1902, to June 30, 1903* (Hayford 1903). The descriptions of all bench marks added to the net since the publication of the results of the first adjustment were given in this publication. Reference was made to appendix 8 of the *Report of the Superintendent of the Coast and Geodetic Survey showing the Progress of the Work from July 1, 1898, to June 30, 1899* (Hayford 1900) for descriptions of the bench marks included in the net at the time of the first adjustment.

1907 Adjustment

Rapid progress in first-order leveling continued during 1903-07, when the first spirit-level connection was completed across the United States between the Atlantic and the Pacific coasts. By 1907 nine tide stations on the Atlantic and Gulf coasts had been connected to the level net. The one at Seattle, Wash., was the first on the Pacific coast to be connected by spirit leveling to the first-order level net.

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

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

The results of the 1907 adjustment were published in *Precise Leveling in the United States, 1903-1907, with a Readjustment of the Level Net and Resulting Elevations* (Hayford and Pike 1909). This contains the descriptions and elevations of all bench marks brought into the net after publication of the results of the 1903 adjustment. Elevations determined in 1903, but changed by the 1907 adjustment, were also included. For elevations not changed by the 1907 adjustment, it was necessary to refer to appendix 3 of the *Report of the Superintendent of the Coast and Geodetic Survey showing the Progress of the Work from July 1, 1902, to June 30, 1903* (Hayford 1903). The descriptions of the bench marks included in the adjustments of 1900 and 1903 are referenced in appendix 8 of the *Report of the Superintendent of the Coast and Geodetic Survey showing the Progress of the Work from July 1, 1898, to June 30, 1899* (Hayford 1900) and appendix 3 of the *Report of the Superintendent of the Coast and Geodetic Survey showing the Progress of the Work from July 1, 1902, to June 30, 1903* (Hayford 1903).

*This is an annual report for the Federal fiscal year indicated in the title.

1912 Adjustment

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

Like the one of 1907, the adjustment of 1912 was not strictly general because, after the rigid adjustment, marks that showed only slight changes from the results of the two previous adjustments were held fixed.

The results of the 1912 adjustment were published in *Special Publication* No. 18, Fourth general adjustment of the precise level net in the United States and the resulting standard elevations (Bowie and Avers 1914). This publication contains the elevations, in both meters and feet, for all bench marks in the net at the time of the adjustment. The descriptions for all bench marks brought into the net since the 1907 adjustment were also included. At that time it was necessary to refer to the three previous publications for the descriptions of the marks brought into the net up to 1907. An index by States in *Special Publication* No. 18 shows where all descriptions and elevations of bench marks in the net in 1912 are to be found.

Further Development of the Net

Additional leveling was added to the net at a fairly steady rate in the 15 years following the adjustment of 1912, but most of the new leveling fitted easily into the adjusted net, and it was not until 1927 that an additional adjustment was needed.

New Design for Leveling Rods

During this period the only marked change in instrumental equipment was the introduction in 1916 of an improved rod in which the fine graduations were placed on a strip of invar. This reduced the errors from temperature changes.

Orthometric Correction

Because the Earth is an oblate spheroid, level surfaces at different elevations are not parallel but tend to converge slightly toward the poles. This necessitates the application of an orthometric correction to the observed differences in elevation so that the resulting elevations of the bench marks may represent their true heights above mean sea level. This correction reaches a maximum on north-south lines run at high elevations, and it is zero on east-west lines. It is small on lines run in any direction at low elevations. For a more complete explanation of the orthometric correction, see *Special Publication* No. 240, Manual of leveling computation and adjustment, appendix C (Rappleye 1948).

The orthometric correction was not applied until 1910, and in the 1912 adjustment was applied only west of the Mississippi River. It is now applied to all first- and second-order leveling in the net.

1927 Special Adjustment

In 1927 a special study of the level net was undertaken. This resulted in the 1927 Special Adjustment (for theoretical studies). At that time only the closed circuits of spirit leveling, including water leveling in the Great Lakes region, were adjusted. After the net had been made consistent within itself, the elevation of the junction bench mark at Houston, Tex., was determined from mean sea level at Galveston. The elevations of all other junction points in the net were computed from the Houston junction bench mark elevation.

Elevations were computed for the mean-sea-level planes at the other tide stations using differences of elevation between the mean-sea-level planes at the various tide stations and the nearest junction points in the net. These elevations were independent of the local tide observations, but were based on the mean-sea-level surface at Galveston as carried to the other tide stations through the adjusted network.

The results implied that the mean-sea-level surface, as defined by the tide observations, slopes upward to the north along the coasts of the Atlantic and Pacific Oceans and upward to the west along the gulf coast. The mean-sea-level surface on the Pacific coast appears to stand appreciably higher than the similar surface on the Atlantic coast. The results of the study are in *Special Publication* No. 134, Geodetic operations in the United States, January 1, 1924, to December 31, 1926 (Bowie 1927).

1929 Special and General Adjustments

By 1929 the level net had been extended until it included 75,000 km of first-order leveling. Many additional tide stations had been connected to the net and a number of connections had been made to the leveling net of the Geodetic Survey of Canada. A general adjustment was needed to produce better elevations for all bench marks and to permit the adjustment of a large amount of leveling, added since 1912, without excessive rates of correction.

Greater strength and theoretically better results could be obtained if the first-order level net of the United States and that of the Geodetic Survey of Canada were combined and adjusted as a unit. Noel J. Ogilvie, then director of the Geodetic Survey of Canada, made available the results of the first-order leveling by that organization, and in 1929 an adjustment was made of the combined level nets of the United States and Canada.

To make a further test of the variation of mean sea level from a level surface, all closed land circuits in the combined nets and the water leveling in the Great Lakes region were adjusted without holding any sea-level connections. Then, as in the 1927 Special Adjustment, elevations based on Galveston, Tex., were computed for the mean-sea-level planes at the other tide stations. This was called the 1929 Special Adjustment.

The equations for all circuits involving connections to tide stations were then added, resulting in the 1929 General Adjustment, in which sea level was held fixed as observed at 26 tide stations—5 in Canada and 21 in the United States.

About 107,000 km of leveling lines were used in the adjustment—75,000 km in the United States and 32,000 km in Canada.

The results of the 1929 Special Adjustment verified and extended the findings of the 1927 Special Adjustment and were published in *Special Publication* No. 166, Geodetic operations in the United States, January 1, 1927 to December 31, 1929 (Bowie 1930).

The results of the 1929 General Adjustment were not published in a single publication. Descriptions of bench marks with their elevations based on the 1929 General Adjustment have been published as "Standard elevations based on the 1929 General Adjustment" by lines on lithographed lists. The present policy is to publish all level data by 30-minute quadrangles.

Rapid Expansion of the Net

During 1934 and 1935 rapid progress was made because emergency funds were used to relieve unemployment. This permitted prompt completion of field work which normally would have taken many years.

As a result of the rapid expansion of the net and the resulting mass of new leveling which had to be fitted to the net, many supplementary adjustments became necessary. Also, releveling disclosed some areas where marks had been moved by earthquakes, by the removal of underground water, oil and gas, or by other factors. These conditions made further local adjustments necessary. Confusion was caused by calling the elevations resulting from the supplementary adjustments "Standard elevations based on the 1929 General Adjustment through the medium of the ______ ______ Supplementary Adjustment." Accordingly, a policy was established for readjustment of the net:

> That adjustment be held fixed with the possible exceptions outlined below, and that the datum be officially designated as the "National Geodetic Vertical Datum of 1929."
>
> 1. Where new leveling discloses blunders in the old work, a readjustment of a limited portion of the net is required.
> 2. Earthquakes or other Earth movements may necessitate readjustment of limited portions of the net.
> 3. Introduction of new tidal stations and connections into the net should be handled by fitting the new work to the net in the usual manner, but not necessarily holding the tidal datum planes in determining the geodetic elevations.

The present program for the development of the fundamental vertical-control net calls for (1) first-order lines at approximately 160-km intervals; (2) subdivision (by the use of second-order levels) of these areas bounded by first-order lines, with lines spaced at 40 and 80 km intervals; and (3) in certain sections, second-order levels to subdivide the smaller areas with lines from 8 to 16 km apart. Figure 1 shows the current net.

INSTRUMENTATION AND METHODS

The principal instrument used by the NGS for first- and second-order leveling is the Jenoptik NI 002 reversible compensator level with micrometer, shown in figure 2. The Zeiss NI 1 compensator level, figure 3, and the MOM NI A 31 compensator level, figure 4, are also used. The Kern 0.5-cm invar rod with low and high numbered scales, figures 5 and 6, is the principal rod used by the NGS. Figure 6 also shows the turning pin with driving cap which is used as a rod support when surface conditions permit. A triangular turning plate is used on hard surfaces where the pin cannot be driven.

The instrument is set up and rough-leveled with a circular vial midway between the two rods, which are placed on turning pins and also leveled with a circular vial. Horizontality of the instrument line-of-sight is achieved with the compensator. The observing sequence is: backsight low scale; backsight stadia; foresight low scale; foresight stadia; reposition the compensator by reversing the compensator on the NI 002 or by turning the footscrews on the NI 1 or NI A 31; foresight high scale and backsight high scale.

Leveling observations are keyed into a programmable Monroe 326 calculator (fig. 7) which checks stadia distances, stadia distance imbalance, and low vs. high rod scale elevation difference for each setup against tolerance limits (see table 1). If checks are within the tolerance limits, the calculator sums the stadia and elevation differences, stores the data on a Monroe 392 cassette recording unit, and displays the accumulative stadia distance imbalance so corrective action can be taken, if needed, on the next setup. By repeating the operation at successive instrument stations, the elevation difference between bench marks (widely separated points) may be determined.

The first- and second-order levelings of the National Geodetic Survey are almost always run along highways. Safety regulations have made it almost impossible to level along railroads, and lines surveyed along railroads in the past are being moved to roads. A truck is used to transport the observing unit between setups when leveling along a highway. The crew walks where the truck cannot be used.

Bench marks are spaced at about 1.6 km on first- and second-order level lines. The spacing is decreased on steep hills so that the number of setups between bench marks will not be excessive. Temporary bench marks are used when leveling must be stopped before reaching a

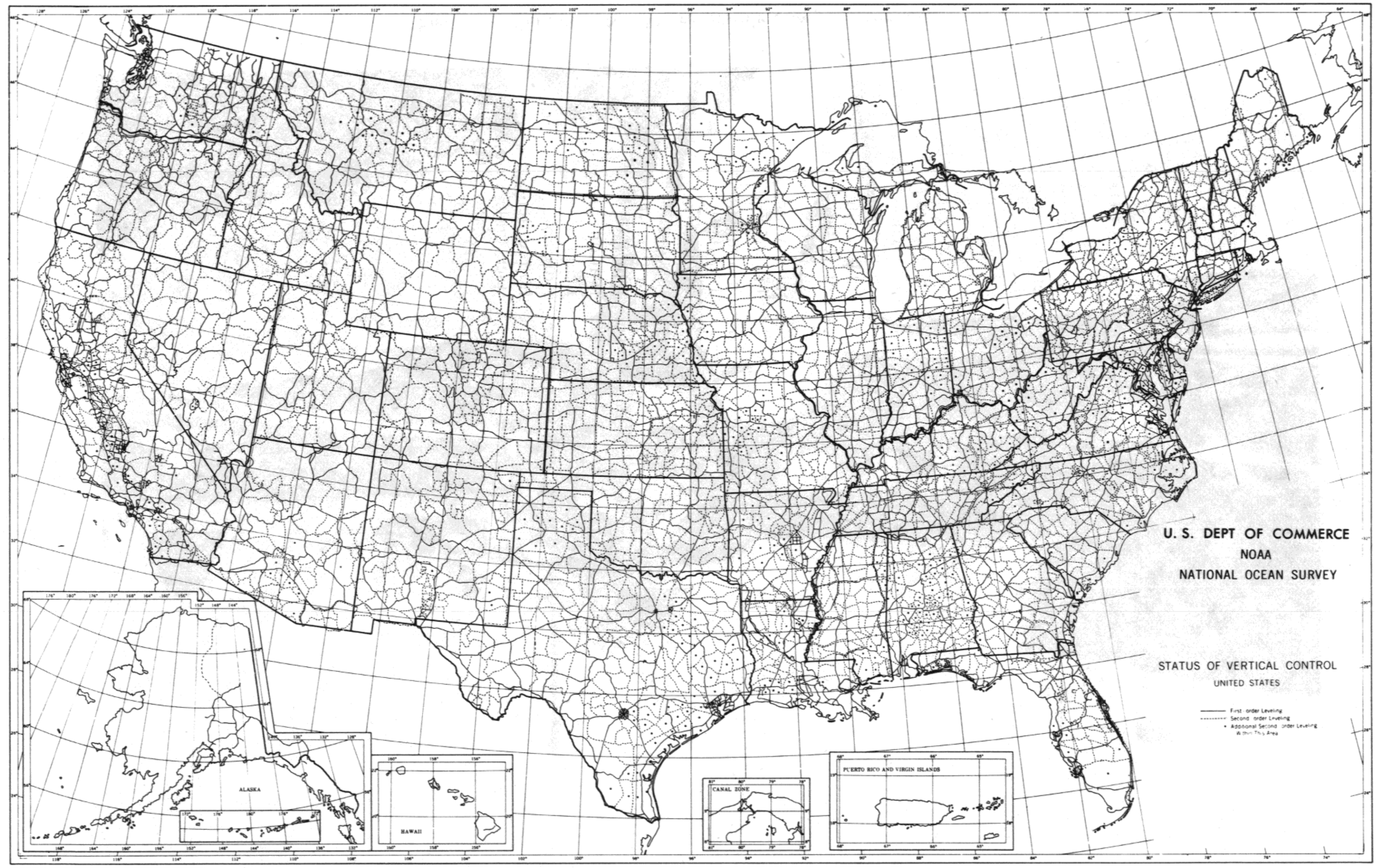


Figure 1.—The United States geodetic vertical control net.

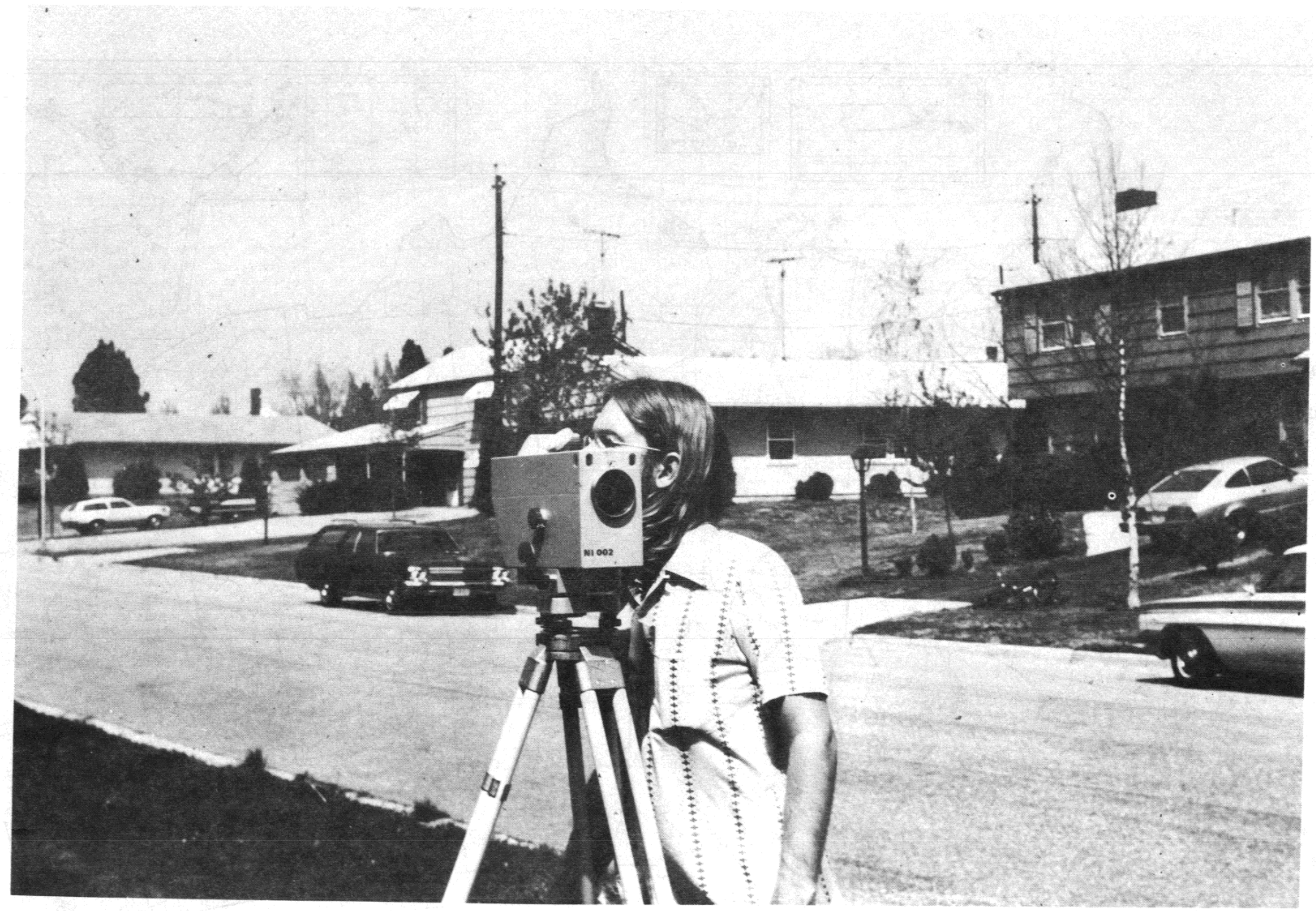


Figure 2.—Jenoptik NI 002 reversible compensator level.

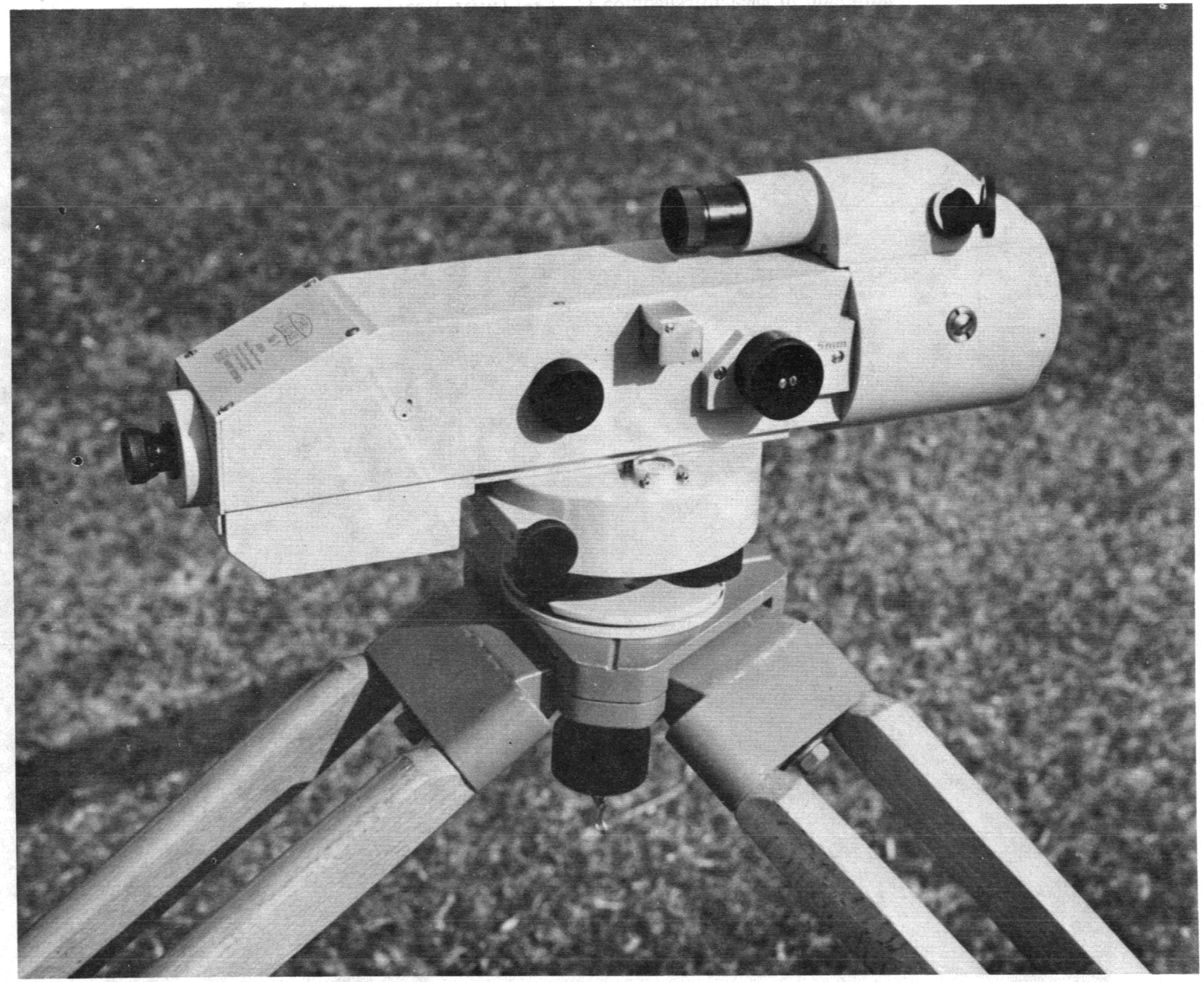


Figure 3.—Carl Zeiss NI 1 compensator level.

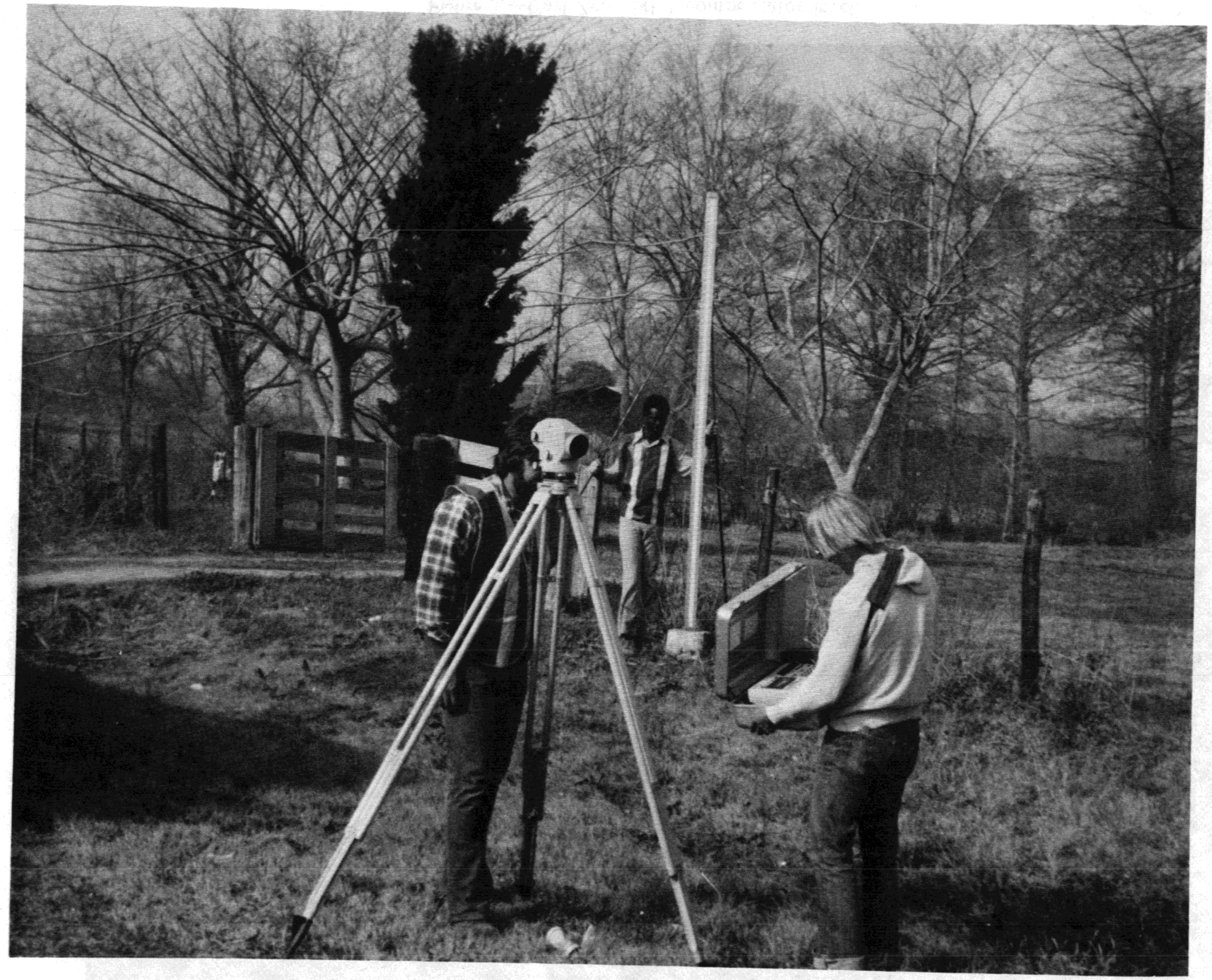


Figure 4.—Magyar Optikai Muvek (MOM) NI A 31 compensator level in operation.

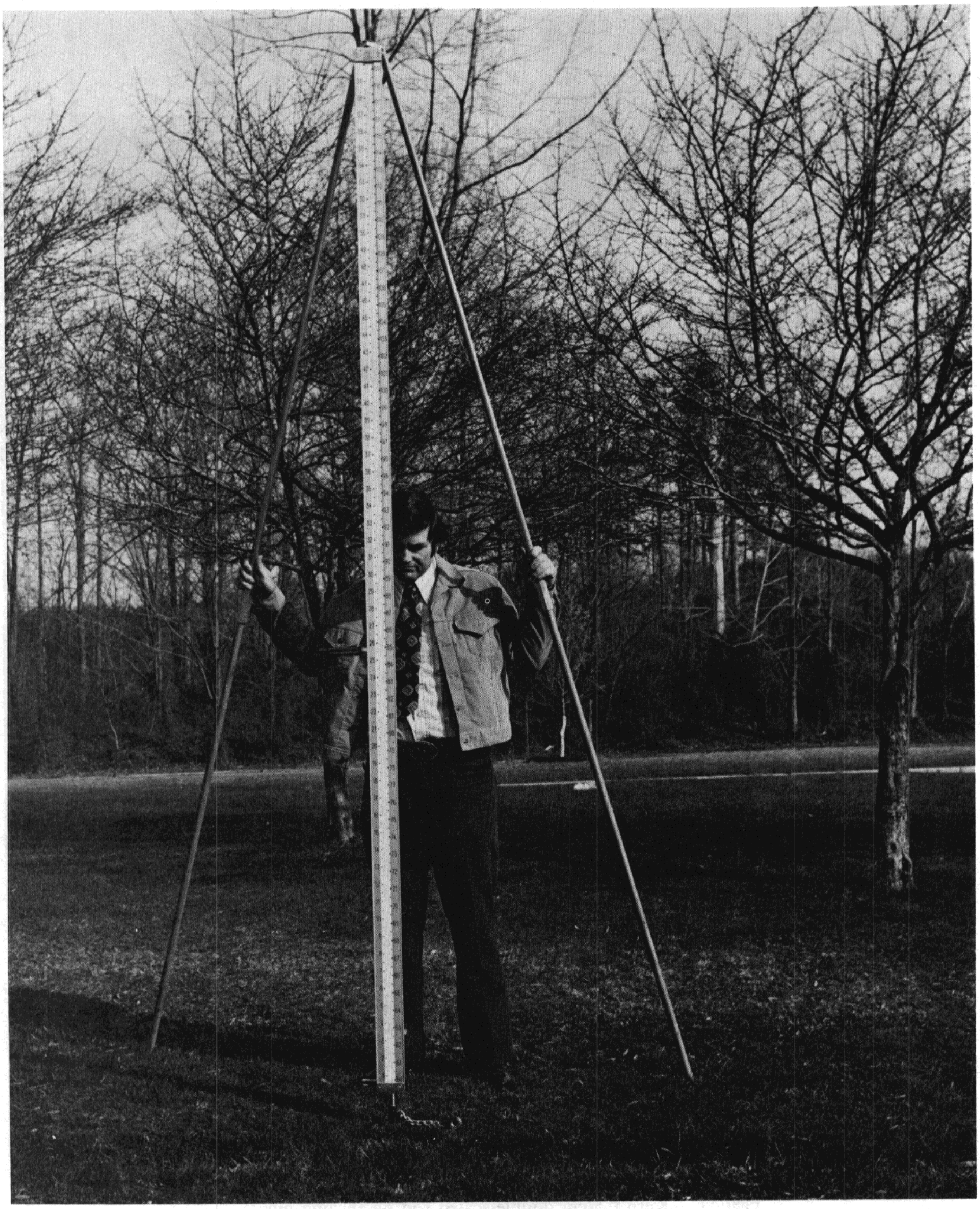


Figure 5.—Kern 0.5-cm double-scaled rod with braces.

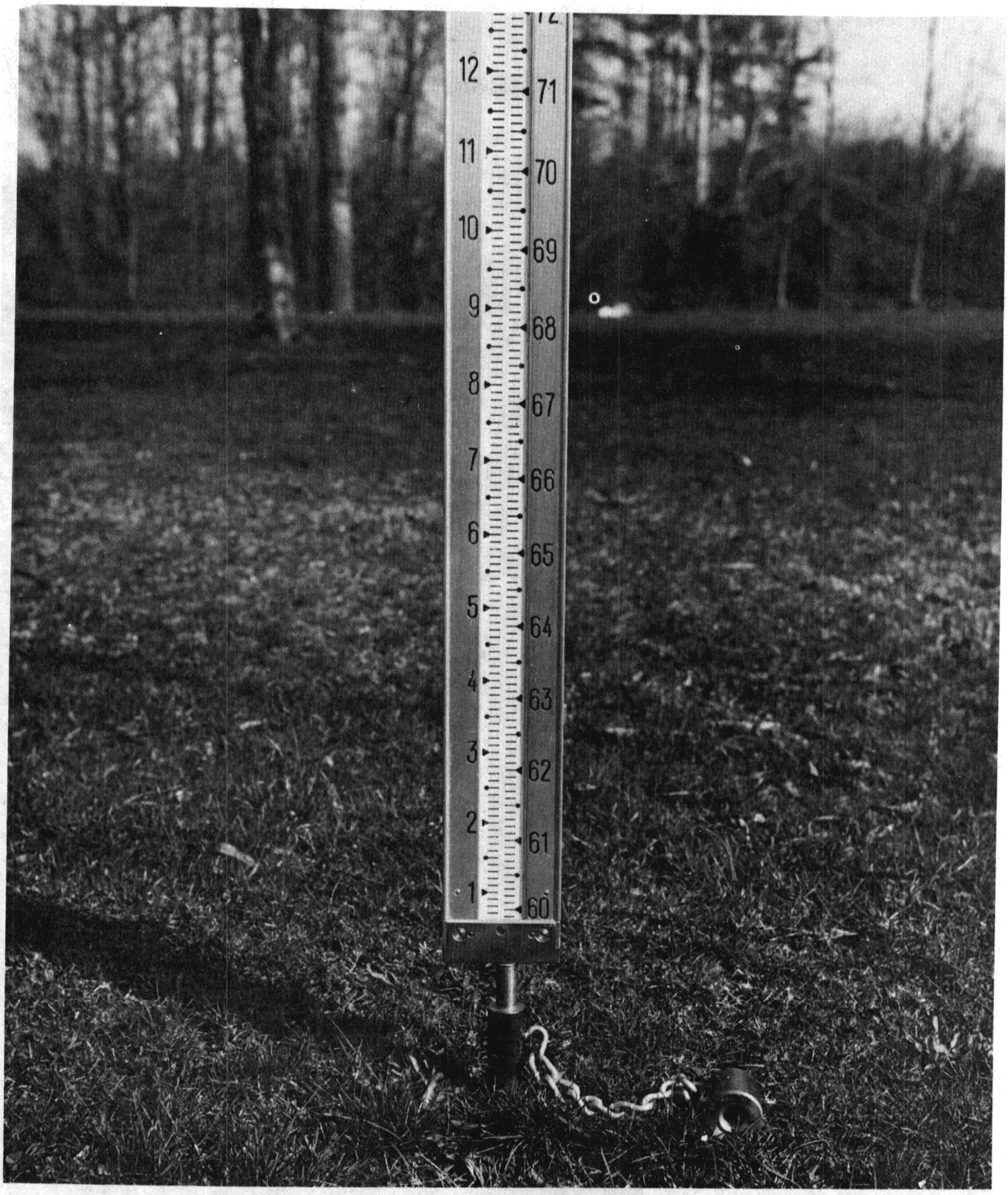


Figure 6.—Kern 0.5-cm double-scaled rod on turning pin.

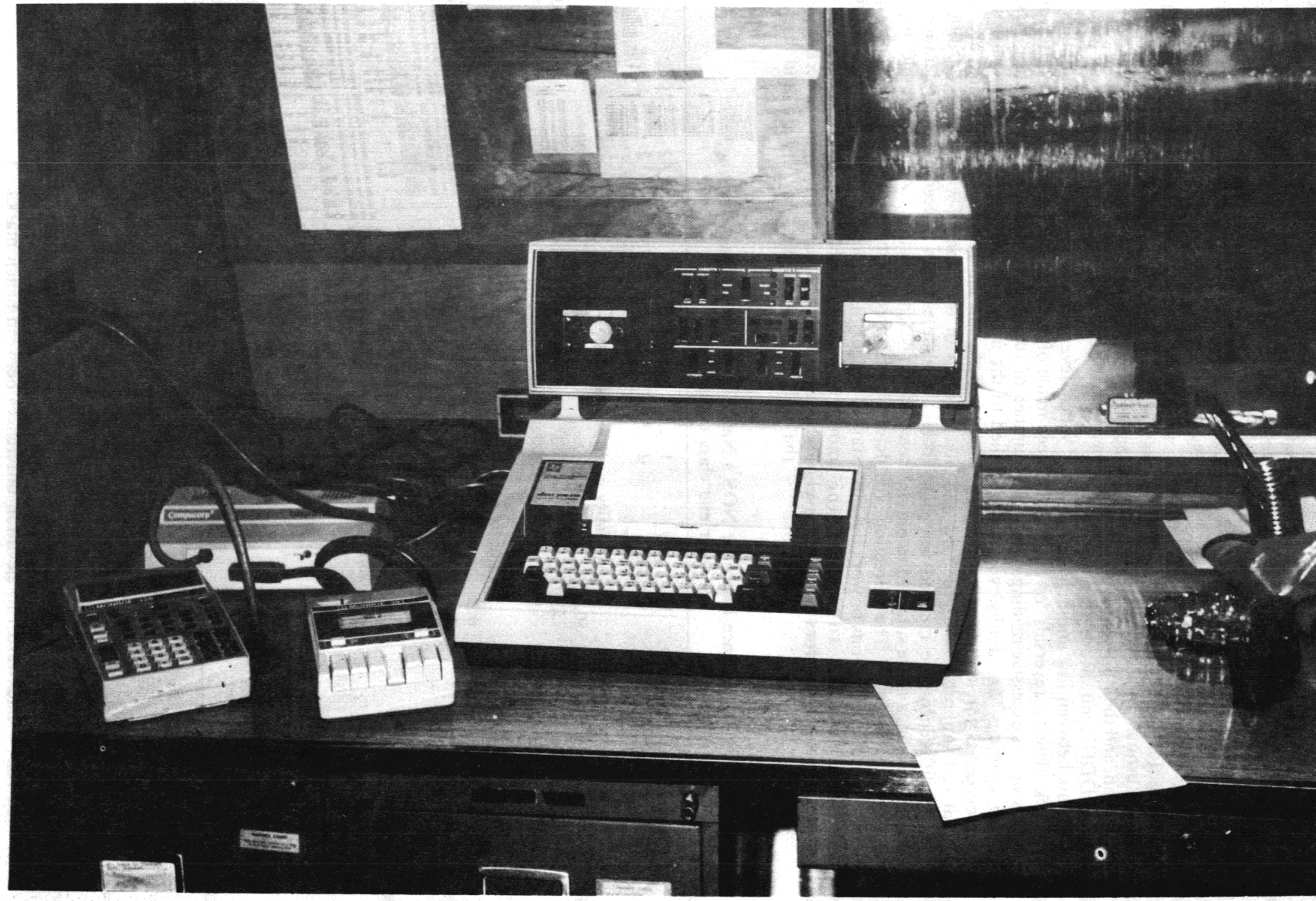


Figure 7.—Monroe 326 calculator and 392 recorder, Compucorp 396 interface unit, and Texas Instruments programmable terminal.

permanent bench mark because of rain or other problems. In forward and backward leveling, sections between bench marks are run in forward and backward directions until two runnings in opposite directions agree within tolerance limits given in table 1. This table also shows tolerance limits from the simple mean when three or more runnings are made of a section. In double-simultaneous leveling low and high scale elevation differences between turning points are determined at each instrument station, and their difference is evaluated against the table 1 DDH limit. Rods of a pair have different rod constants between low and high scales, so the difference check detects reversals of back and foresight readings as well as excessive reading errors and blunders. All rod readings are reobserved if the tolerance limit is exceeded for any reason before the instrument and rear rod support are moved. Low and high scale elevation differences are meaned for each instrument station and the means are summed to obtain the section elevation difference. The direction of running is reversed on alternate sections or work days in double-simultaneous leveling to reduce the accumulation of small systematic errors along the level line.

The millimeter factors given in the table for loop or section misclosures must be multiplied by the square root of the distance (k) in kilometers to obtain the tolerance limits. If k is less than 0.1 km, use 0.1 km or square root k = 0.316 in computing tolerance limits for sections.

When sections are forward and backward run, the f+b tolerance limit is applied to the absolute value of the algebraic sum of a forward and a backward run of each section.

When several forward and backward runnings have been made of a section, the tolerance limit, based on the number of runnings and the section length, is first applied to the absolute value of the differences from the simple mean of all runnings. Rejections are made iteratively with the running with the largest difference from the simple mean exceeding the tolerance limit rejected on each iteration. A new simple mean is determined from the remaining section differences at the start of the next iteration. The process continues until no more runnings are rejected or until only one forward and one backward running remain to be checked against the f+b tolerance limits. In forward and backward

Table 1.—Tolerance limits for NOS's National Geodetic Survey leveling, by order and class of surveys

Order	1	1	2	2	3
Class	1	2	1	2	—
		(Limits given in meters)			
SBS or SFS	50.00	60.00	60.00	70.00	90.00
DS	2.00	5.00	5.00	10.00	10.00
SDS	4.00	10.00	10.00	10.00	10.00
		(Limits given in millimeters)			
DDH	0.25	0.30	0.60	0.70	1.30
Loop misclosure	4.00	5.00	6.00	8.00	12.00
Section, f+b	3.00	4.00	6.00	8.00	12.00
No. runnings					
		Section, limits from the simple mean (millimeters)			
3	2.10	2.81	4.21	5.63	8.44
4	2.33	3.10	4.66	6.23	9.34
5	2.48	3.31	4.96	6.64	9.95
6	2.59	3.46	5.19	6.94	10.4
7	2.68	3.58	5.36	7.18	10.7
8	2.75	3.67	5.51	7.37	11.0

SBS = Stadia distance for Backsight.
SFS = Stadia distance for Foresight.
DS = Delta Stadia = SBS - SFS at any setup.
SDS = Sum of Delta Stadia along a section.
DDH = Delta Delta Height = low scale elevation difference - high scale elevation difference between turning points.
f+b = Forward run + Backward run elevation differences between bench marks.

leveling at least one forward and one backward running must remain after rejections.

First- and second-order levelings of the National Geodetic Survey satisfy specifications given in *Classification, Standards of Accuracy and General Specifications of Geodetic Control Surveys* (Federal Geodetic Control Committee 1974).

COMPUTATIONS AND ADJUSTMENTS

The Monroe 326 calculator is used in the field office to recall the leveling observations from the 392 cassette recorder (fig. 7) and transfer them through an interface unit to a Texas Instruments 742 programmable computer terminal, where they are listed and stored on another cassette. The TI 742 terminal is then used to transmit the data by telephone lines to a large computer in the Washington, D.C., area where they are stored on computer files and processed through a program for editing and conversion to a standard data base format. Descriptions of bench marks are keyed into the TI 742 terminal, stored on cassettes, transferred to files on the same computer in the Washington, D.C., area, and processed through an editing program. The terminal is also used to operate a program at the large computer which selects data from observation and description files and prepares field abstracts. The results of the above program runs may be listed on the TI 742 in the field office, on a terminal at the main office, or on a line printer at the computer facility.

The field parties plot the locations of bench marks on standard topographic maps and scale the latitudes and longitudes for use in subsequent office computations and adjustments.

Office abstracts are prepared on the computer by applying office corrections for rod length, temperature, instrument collimation, refraction, nonparallelism of level surfaces, astronomic influences, and gravity, and then computing unadjusted elevations for bench marks. The abstract information is saved in computer files for adjustments and for publications. Least-squares adjustments are used to fit new leveling to the primary net, and to determine surface velocities for crustal motion studies. New elevations from the adjustments are stored on computer files for publication.

Adjusted elevations and descriptions are merged in the computer, sorted by quads, and used to generate graphics and quad publications.

BENCH MARKS

In the early days of control leveling, the bench marks established along the lines of levels were of several types. Many were chiseled squares and chiseled crosses, often flanked by lettering cut in the masonry. These marks were established at infrequent intervals. After the lapse of years they became inconspicuous and frequently were destroyed by construction operations. When these widely spaced marks on a line of levels were destroyed, the spacing sometimes became so wide as to cause great difficulty in securing a checked start for new leveling.

At one time, bronze caps fastened to the top of iron pipes set in the ground were used as marks. However, these were soon discontinued because of rusting at the ground surface.

Before 1905 small copper or bronze bolts were often leaded or cemented into masonry structures to serve as bench marks. Although the bolts were more conspicuous than the chiseled squares or crosses, there was nothing on the marks to indicate their use. Consequently many were destroyed in construction projects.

Around 1905, metal disks were introduced as bench marks. The first bench-mark disks or tablets similar to those now in use were cast of bronze. They were about 83 mm in diameter and had a round shank centered in the back, 22 mm in diameter and 76 mm long. This shank was split, and a wedge was inserted to spread it, thus giving greater holding power. The disk had a depression in the center, about 64 mm in diameter by 13 mm deep. Around the rim of the depressed portion were the raised letters "U.S.C.&G.S." Within the ring of letters was a smooth, flat, circular, raised portion, 38 mm in diameter, on which the rod was held, representing the portion of the disk to which the elevation of the mark referred. These marks were not used very long because they filled up with dirt, were hard to recover, and required a thorough cleaning before reuse.

Since then bench-mark tablets have been gradually improved. The present bench-mark disk for first- and second-order leveling is shown in figure 8, no. 3. This tablet has a 92-mm diameter, and a 76-mm shank. The surface of the disk is raised in the center, to which the elevation refers. When these marks are set vertically (shank horizontal) in walls, the elevation refers to the horizontal line in the center of the disk.

During 1933-35, separate State organizations were developed to carry on geodetic surveys of second- and third-order accuracy. Funds were allocated by the Civil Works Administration and later by the Works Progress Administration, under the technical supervision of the Coast and Geodetic Survey, through State-appointed representatives. The points established by these State organizations were usually marked by bronze tablets similar in style to the standard bench-mark disk, but bearing the legend shown in figure 9, no. 11. These disks were only 73 mm in diameter and had 64-mm shanks. Some of the State organizations used special disks of the same type but different in appearance and size. The legend cast in them differed considerably from that cast in the standard "State Survey" disks. Another type of mark sometimes used by State organizations was a commercial, round-headed, monel metal rivet, 10 mm by 51 mm, set with only the round head exposed.

In the years immediately before, during, and shortly after the expanded leveling program, a cooperative effort existed in which the engineering organizations of

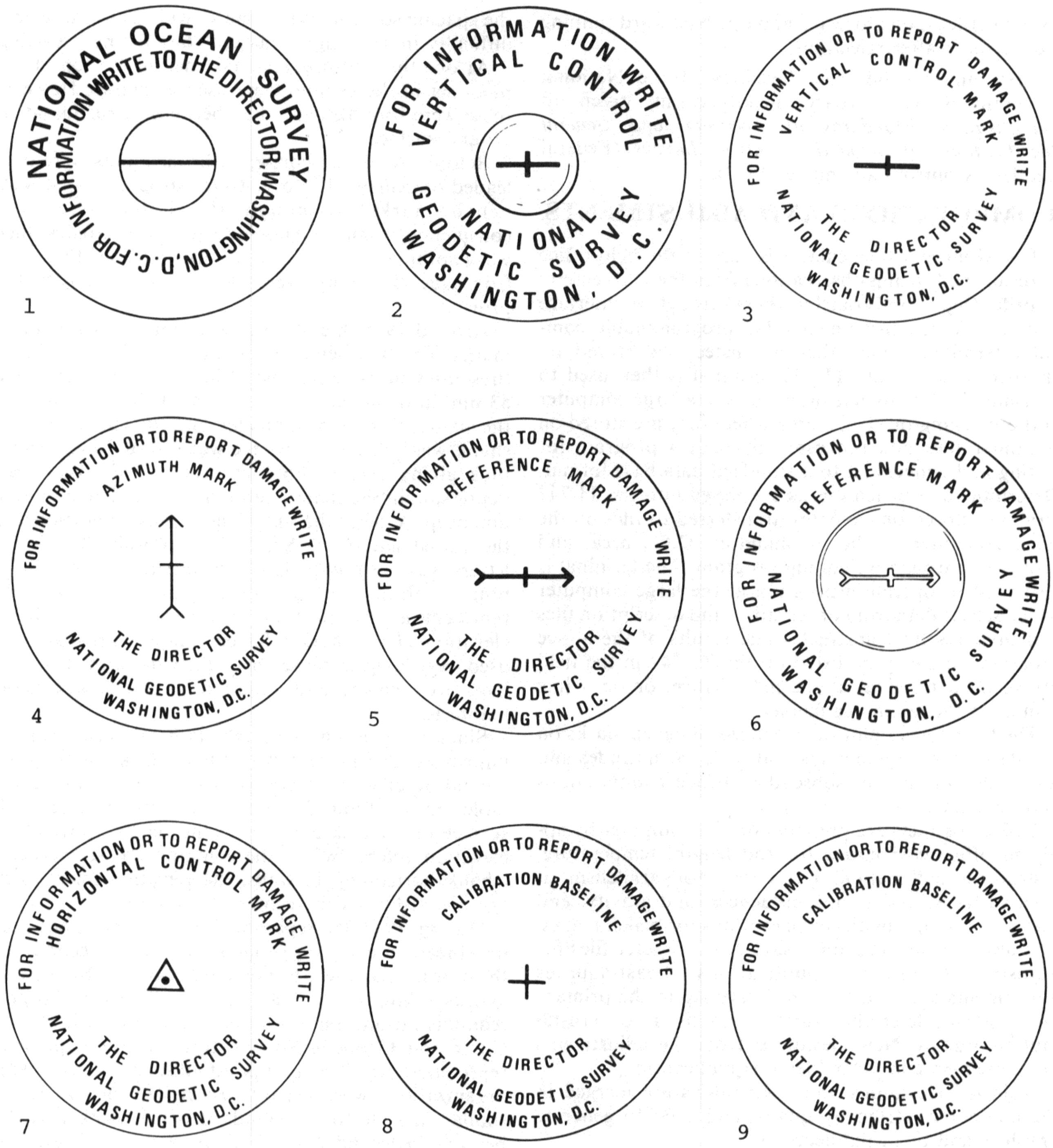
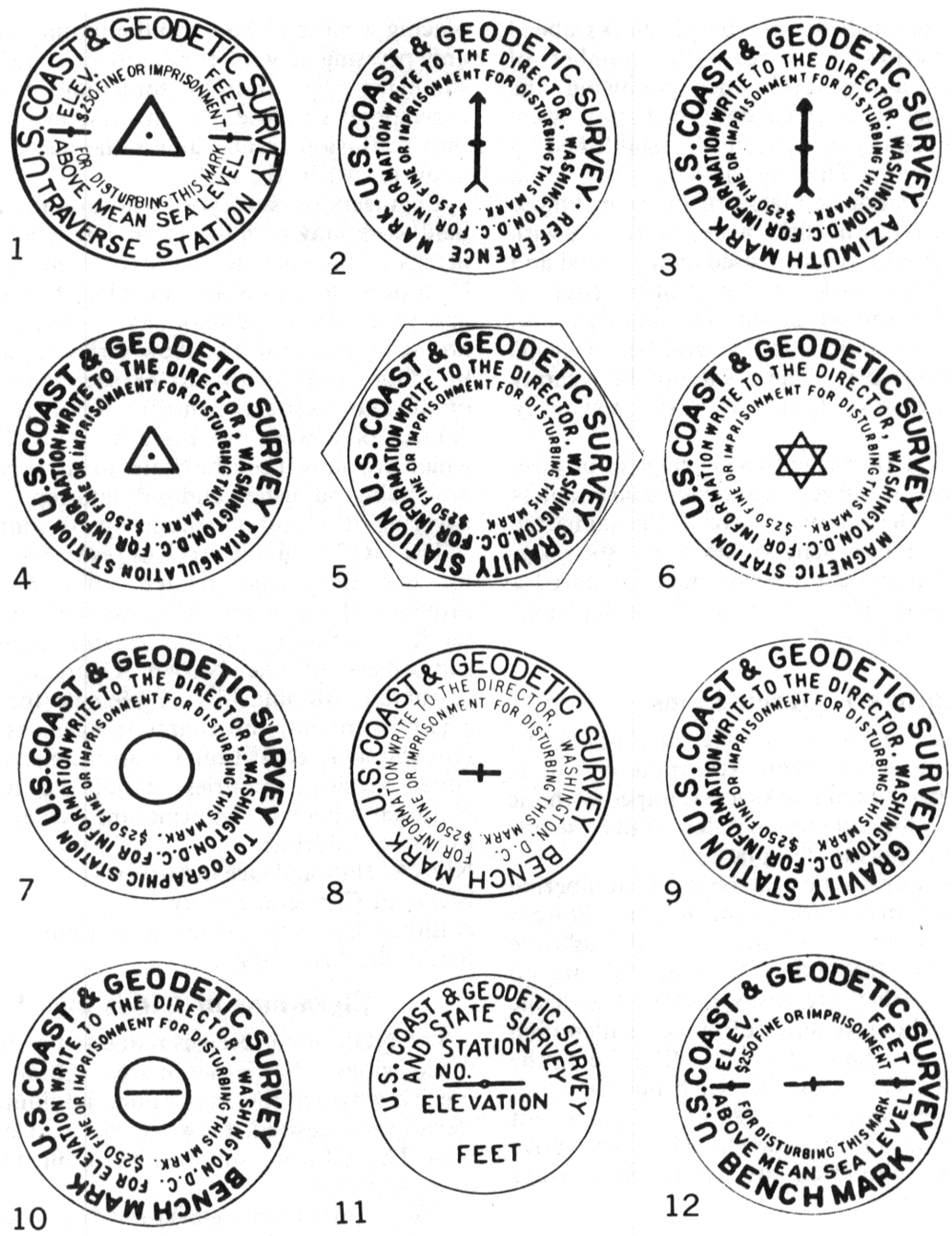


Figure 8.—Standard bronze marks of the National Ocean Survey/National Geodetic Survey.



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

Figure 9.—Standard marks of the Coast and Geodetic Survey.

various railroads established extra bench marks ahead of our leveling parties to increase the number of permanent marks along level lines following the railroads. The monel metal rivets described above were used on this work. Many marks already established by the railroads were tied in. These marks vary widely from chiseled squares to elaborate marks of different kinds.

Several different types of disks which were cast with slightly varying legends have been used by the Coast and Geodetic Survey since early in this century (fig. 9). However, most of them are about the same size and shape as the present standard tablet, and bear legends that are self-explanatory. They should be readily recognized by persons familiar with surveying operations.

During World War II, owing to a shortage of bronze, the Coast and Geodetic Survey used bench-mark tablets made of cast iron. These tablets were of the same size and shape as the standard bench-mark tablet shown in figure 8, no. 3, but manufacturing problems required a more simplified legend. The lettering is 18 mm high and reads simply "USC&GS BM."

Bench Mark Designations

Metal disk-type bench marks are identifiable by designations that have been stamped by dies. Theoretically, no two bench marks are stamped with the same designation in any one State. A few States use one or more series of duplicate designations.

The system generally used by the NGS for numbering bench marks is: The first mark established in a State is designated "A," the next "B," and so on through the alphabet, except that the letters "I" and "O" are no longer used because they are easily confused with the numbers 1 and 0. The next series of marks is identified as "A 1," "B 1," etc., the next "A 2," "B 2," etc., the number being increased by one for each new set.

The State survey disks (fig. 9, no. 11) are not ordinarily numbered in accordance with the above system, but are identified by individual State designations.

REQUESTS FOR VERTICAL CONTROL DATA

Any request for bench mark elevations must be accompanied with specific information on the character, designation, and exact location of the mark in question. To avoid delay and confusion, requests for elevations of bench marks should give the letter, number, and year that are stamped on each disk; the State in which each disk is located; and the distance and direction from the nearest town. The requester should also provide brief information on the character or location of the mark.

It is well to include rubbings or imprints of the marks with the request. A rubbing may be made by placing a piece of light- or medium-weight paper over the disk and rubbing over the paper with a hard pencil to bring out the legend on the disk. An imprint may also be made by placing a piece of household aluminum foil on the disk and pressing it with the hand or a soft eraser. Other surveying organizations sometimes use systems that correspond so closely to the system used by the NGS that confusion results unless the name of the organization is cast in the disk.

Engineers or surveyors who are about to undertake field work may wish to obtain data concerning all bench marks in the specific territory. Control diagrams have been published by States showing the routes of leveling and publication line numbers. These State diagrams are being replaced by a new series covering 1° latitude by 2° longitude on a 1:250,000 scale showing both horizontal and vertical control. Until recently, vertical control data were published by lines (the numbers of which are shown on the State diagrams). New data are now being published and old data republished by areas covering 30 minutes latitude by 30 minutes longitude.

The NGS annually receives several thousand requests for elevations and related information which are provided through the NGS geodetic data user-charge service. Vertical control information is also provided to subscribers of the NOAA Geodetic Control Data Automatic Mailing List Agreement for a nominal fee. There is presently no charge to agencies of the Federal Government, educational institutions, or libraries for either service. Inquiries should be directed to the National Geodetic Information Center (NGIC) at the following address:

NOAA, National Ocean Survey
National Geodetic Survey
National Geodetic Information Center, C18
Rockville, MD. 20852

Elevations of Cities and Towns

The NGS often receives requests for the elevations of towns, cities, or other large areas. Often requests fail to specify whether the maximum, minimum, or average elevation is desired, or what use is to be made of the data. This information must be supplied if the request is to be satisfied.

Often approximate elevations are required for use in deciding which of several places is best suited to some sort of recreation, to the search for health, etc. Sometimes accurate elevations are described at particular locations in a city for the purpose of adjusting aneroid barometers. In many cases, elevations of bench marks can be given with great accuracy. From these, other elevations can be determined locally.

COOPERATION IN PRESERVING BENCH MARKS

Reports on Condition of Marks

The final results of all the field and office work related to control leveling are represented by the marks themselves and the lists of the descriptions and their elevations. A bench mark is useful only as long as it is recoverable. When changes occur in the surrounding natural and cultural features, it becomes increasingly difficult to find the mark by means of the published description. People who visit Government bench marks can do a public service by reporting the condition of the marks and making suggestions for changes in the descriptions. Such reports are solicited and are very much appreciated.

NOAA Form 76-91, Report on Condition of Survey Mark (see fig. 10), is a 127 x 203-mm card used to report the condition of marks. Copies will be furnished by the NGIC to anyone who searches for or recovers NGS (C&GS) bench marks and is willing to report their condition. The cards are self-addressed and require no postage. Sample blank forms are provided at the end of this publication.

Stamping Elevations on Bench Marks

Elevations are no longer stamped on bench-mark disks, since many factors contribute to vertical change. Some of these are: frost action; varying moisture content of soil; removal of underground water, oil, and gas; fault lines; and earthquakes. A releveling will often indicate that a mark should have a new elevation or requires a readjustment of lines.

Relocation of Bench Marks

Frequently, new construction, or repairs to existing structures, necessitates the destruction of bench marks, despite efforts to place them permanently. If these marks are to be preserved, we must depend on the co-operation of engineers and surveyors throughout the country. It is in the best interest of everyone that bench marks be relocated rather than destroyed.

Whenever a mark must be moved, a letter should be sent to the Director, National Geodetic Survey, National Ocean Survey, NOAA, Rockville, MD 20852, stating the necessity for moving the mark, the approximate time limitation, and the mark designation. The designation consists of the letters and numbers stamped with dies on the disk. It is also desirable to furnish a rubbing of the disk (as explained previously). Upon receipt of this information, the NGS will usually send a representative to replace the mark.

When a mark maintenance representative is not available to move the mark within the time required, private engineers or those from other Governmental agencies are requested to do the work as a public service. This office has no funds to pay for relocation work, but will furnish a new disk stamped to show that it is a replacement.

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

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

After the new mark has been established and leveling to it accomplished, the old disk should be removed and returned in a franked mailing sack supplied by NOAA, NOS, National Geodetic Survey, Code C172, Rockville, MD 20852. A complete report ((fig. 11) should also be forwarded to NGS, C172, giving a description of the location of the new mark and a copy of the field notes involved in the transfer of elevation. A franked envelope will be furnished by this office. The cooperation extended by individuals and organizations to this organization in preserving bench marks is a public service, not only to NGS and other Government surveying organizations, but to all who may have occasion to use the marks in the future.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SURVEY
ROCKVILLE, MD. 20852
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U.S.MAIL

NATIONAL OCEAN SURVEY
NATIONAL GEODETIC SURVEY INFORMATION CENTER, C-18
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ROCKVILLE, MD. 20852

(front side)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1974-665-074/1047 Region 6

REPORT ON CONDITION OF SURVEY MARK

Form Approved
Budget Bureau No. 41-R1923

Name or Designation: U 150 Year Established: 1941

State: PA County: Huntingdon Organization Established by: C&GS

Distance and direction from nearest town: about 4.6 miles north along PA RR from station at Huntingdon

Description published in: *(Line, book, or quadrangle number)* Quad 400781

Mark searched for or recovered by: Name - Roger C. Poe

Organization - Michael Baker, Jr., Inc.

Date of report June 17, 1975 Address - P. O. Box 280, Beaver, PA 15009

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

Mark stamped:	Condition:
U 150 1941	Good

Marks accessible? [X] Yes [ ] No Property owner contacted? [ ] Yes [X] No

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

Witness Post? Yes ___ No X
Witness Post set ___ feet ___ of ___ mark.
Witness Post set ___ feet ___ of ___ mark.

If additional forms are needed, indicate number required. ________

NOAA FORM 76-91 (11-72) U.S. DEPARTMENT OF COMMERCE - NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION - NATIONAL OCEAN SURVEY

(reverse side)

Figure 10.—Example of a properly executed NOAA Form 76-91, Report on condition of survey mark.

NOAA FORM 76-60 (6-71) U. S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

REPORT ON RELOCATION OF BENCH MARK

(See instructions on reverse side)

DESIGNATION OF MARK: K 133

STATE: New Mexico | COUNTY: Luna

A. DESCRIPTION OF ORIGINAL MARK

2.9 miles north along State Highway 11 from the Southern Pacific Company Railroad station at Columbus, Luna County, 64 feet west of a row of poles. 38 feet east of the center line of the highway, and 1.1 feet east of a white wooden witness post. A standard disk, stamped "K 133 1934" and set in the top of a concrete post projection 1 foot above ground.

PUBLISHED ON ________ STAMPING K 133 1934

B. WAS ORIGINAL BENCH MARK DESTROYED? [X] YES [ ] NO HORIZONTAL CONTROL POINT? [ ] YES [ ] NO

REMARKS

DATE OF LEVELING 23 March 1977

(Feet ~~or Meters~~)*

POINT	B.S.	H.I.	F.S.	ELEVATION	REMARKS
#1	3.791	4,182.759		4,178.968 ft.	weather: clear, warm, calm
			5.191	4,177.568	
					An apparent attempt had
#2	3.767	4,182.735		4,178.968	been made to remove old disk without success. BM
			5.167		did not appear to have been moved.
#3	3.444	4,182.412		4,178.968	4,178.968 ft. old
			4.844	4,177.568	-1.400 ft. difference
					4,177.568 ft. reset

C. DESCRIPTION OF NEW MARK

STAMPING ON NEW MARK K-133 Reset 1977

2.9 miles north along State Highway 11, from the Old Southern Pacific Company Railroad station at Columbus, Luna County, in line with a row of power poles, 99 feet east of center line of highway, and 1.0 foot west of highway right-of-way fence, at mile post 6.13. A standard disk, stamped "K-133 Reset 1977" and set in the top of a concrete post projecting 1 foot above ground.

*Strike out unit NOT used.

SIGNED ________

AGENCY ________

Figure 11.—Example of a properly executed NOAA Form 76-60, Report on relocation of bench mark.

REFERENCES

All Coast and Geodetic Survey publications that are listed as being out of print are a part of the permanent record of the National Geodetic Survey and may be viewed by the public. These documents are also available for reference in all National Depository Libraries and may be requested for viewing through your local public library.

Bowie, William, 1927: Geodetic operations in the United States, January 1, 1924, to December 31, 1926. *Special Publication* No. 134, U.S. Coast and Geodetic Survey, U.S. Government Printing Office, Washington, 34 pp. (out of print).

Bowie, William, 1930: Geodetic operations in the United States, January 1, 1927, to December 31, 1929. *Special Publication* No. 166, Coast and Geodetic Survey, U.S. Government Printing Office, Washington, 38 pp. (out of print).

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Federal Geodetic Control Committee, 1975, reprinted 1977: *Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys.* U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, Rockville, Md., 30 pp. (Single copies are available upon request from the National Geodetic Information Center, NOS, Rockville, MD 20852. Additional copies may be purchased from the National Technical Information Service, Springfield, VA. Please refer to document accession no. PB261037.)

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Rappleye, Howard S., 1948: Appendix C, Orthometric and dynamic corrections. Manual of leveling computation and adjustment, *Special Publication* No. 240, Coast and Geodetic Survey, U.S. Government Printing Office, Washington, pp. 155-160. (Copies may be purchased from the National Technical Information Service, Springfield, VA. Please refer to document accession no. COM-72-50181.)

REPORT ON CONDITION OF SURVEY MARK

Form Approved
Budget Bureau No. 41-R1923

Name or Designation: ______ Year Established: ______

State: ______ County: ______ Organization Established by: ______

Distance and direction from nearest town: ______

Description published in: *(Line, book, or quadrangle number)* ______

Mark searched for or recovered by: Name - ______

Organization - ______

Date of report ______ Address - ______

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

Mark stamped:	Condition:

Marks accessible? ☐ Yes ☐ No Property owner contacted? ☐ Yes ☐ No

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

Witness Post? Yes ____ No____
Witness Post set ___ feet ___ of ______ mark.
Witness Post set ___ feet ___ of ______ mark.

If additional forms are needed, indicate number required. ______

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REPORT ON CONDITION OF SURVEY MARK

Form Approved
Budget Bureau No. 41-R1923

Name or Designation: ______ Year Established: ______

State: ______ County: ______ Organization Established by: ______

Distance and direction from nearest town: ______

Description published in: *(Line, book, or quadrangle number)* ______

Mark searched for or recovered by: Name - ______

Organization - ______

Date of report ______ Address - ______

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

Mark stamped:	Condition:

Marks accessible? ☐ Yes ☐ No Property owner contacted? ☐ Yes ☐ No

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

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Witness Post set ___ feet ___ of ______ mark.

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(Continued from inside front cover)

NOS NGS-6 Determination of North American Datum 1983 coordinates of map corners. T. Vincenty, October 1976, 8 pp (PB262442). Predictions of changes in coordinates of map corners are detailed.

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NOS NGS-8 Establishment of calibration base lines. Joseph F. Dracup, Charles J. Fronczek, and Raymond W. Tomlinson, August 1977, 22 pp (PB277130). Specifications are given for establishing calibration base lines.

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NOS NGS-11 Applicability of array algebra. Richard A. Snay, February 1978, 22 pp (PB281196). Conditions required for the transformation from matrix equations into computationally more efficient array equations are considered.

NOS NGS-12 The TRAV-10 horizontal network adjustment program. Charles R. Schwarz, April 1978, 52 pp (PB283087). The design, objectives, and specifications of the horizontal control adjustment program are presented.

NOS NGS-13 Application of three-dimensional geodesy to adjustments of horizontal networks. T. Vincenty and B. R. Bowring, June 1978, 7 pp (PB286672). A method is given for adjusting measurements in three-dimensional space without reducing them to any computational surface.

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NOS 68 NGS 4 Test results of first-order class III leveling. Charles T. Whalen and Emery Balazs, November 1976, 30 pp (GPO# 003-017-00393-1) (PB265421). Specifications for releveling the National vertical control net were tested and the results published.

NOS 70 NGS 5 Selenocentric geodetic reference system. Frederick J. Doyle, Atef A. Elassal, and James R. Lucas, February 1977, 53 pp (PB266046). Reference system was established by simultaneous adjustment of 1,233 metric-camera photographs of the lunar surface from which 2,662 terrain points were positioned.

NOS 71 NGS 6 Application of digital filtering to satellite geodesy. C. C. Goad, May 1977, 73 pp (PB-270192). Variations in the orbit of GEOS-3 were analyzed for M_2 tidal harmonic coefficient values which perturb the orbits of artificial satellites and the Moon.

(Continued on inside back cover)

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