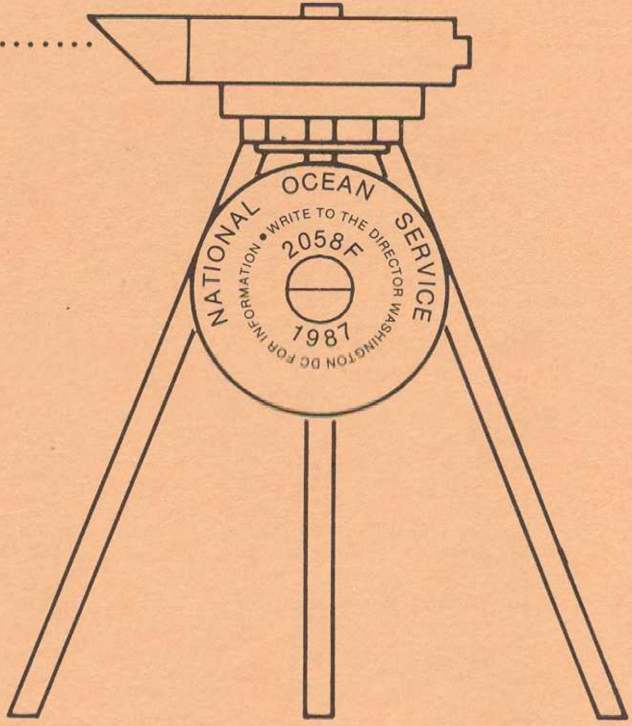
User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Level Stations



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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Oceanography and Marine Assessment
Rockville, Maryland 20852

User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Levels

by
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Physical Oceanography Division
Office of Oceanography and Marine Assessment

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Based on the original publication of A. Nicholas Bodnar, Jr.

PREFACE

The primary purpose of this User's Guide is to provide a convenient field reference for Sea and Lake Levels Branch, ship, and contract personnel engaged in installing bench marks at water level stations of the Great Lakes and along the marine coasts of the United States. Equally important are the procedures it conveys for the required initial and periodic relevelings at these stations. In planning, the User's Guide enumerates the necessary information for cost estimates and logistic preparation. Finally, it serves as a documentation of the general quality of the subject installation and leveling methods.

This User's Guide is the consumation of four progressive manuscripts prepared and used by the Sea and Lake Levels Branch. The first, by A. Nicholas Bodnar, Jr., was drafted in 1975 under the title, User's Guide for the Establishment of Tidal Bench Marks and Leveling Requirements for Tide Stations. The second, revised and edited by A. Nicholas Bodnar, was printed in 1977 under the same title. With additional material by Harry A. Lippincott on procedures used in the Great Lakes, the title was changed to User's Guide for the Establishment of Tidal/Water Level Bench Marks and Leveling Requirements for Tidal/Water Level Stations. This version was further edited by Richard A. Hess and drafted in 1979. The last, prepared in 1981, was also edited by Mr. Hess using the latter title.

ACKNOWLEDGMENTS

The original authorship of A. Nicholas Bodnar, Jr. is acknowledged.

Major portions of the publications of Ralph M. Berry, John D. Bossler, Richard P. Floyd, and Christine M. Schomaker have been included with appreciation. These portions are both direct or adapted, and cited or inferred. Complete references to these publications are listed at the end of this document.

The authors are particularly grateful to Josephine E. Bergner and Pauly H. Plunkett for typing the manuscript with its many revisions. In addition, the authors are indebted to Mark W. Allen for designing and constructing all of the diagrams and to Jill R. Meldon for writing the section on third-order leveling.

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USER'S GUIDE FOR THE INSTALLATION OF BENCH MARKS AND LEVELING REQUIREMENTS FOR WATER LEVEL STATIONS

1. INTRODUCTION

A water level* gage, measuring water surface elevation against time, requires a power source, reference point, and water level bench marks. In addition, a water level station may also include a stilling or protective well, water level staff or electric tape gage (ETG), digitizing mechanism (if an analog gage), data storage facility, encoder, modem for transmission via direct distance dial telephone lines, transmitter for line of sight radio, GOES satellite transmitter, and shelter (for instrument protection). Ancillary equipment for water temperature and density, tsunami, meteorological, and geodetic measurements may also be located at the station. This Guide, however, is only concerned with the water level bench marks and their relationship to the water level staff or ETG. Hereafter, the adjectives, water level, will be omitted for convenience in most instances.

A network of bench marks is an integral part of the station. These bench marks are established in the most stable and permanent material available (bedrock, if possible) in the general vicinity of the gage. The bench marks are leveled between each other and to the staff or ETG. The staff is permanently attached to a stable structure adjacent to the gage and is mathematically related to it by simultaneous readings of the gage and staff. Thus, the gage measurements are all related to the bench marks, of which one is designated the primary bench

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* The term "water level," as used in this document, replaces the terms "tide" and "tidal" for coastal regions and "lake level" for the Great Lakes.

mark (PBM). It follows that the overall quality of datums is partially dependent on both the quality of the bench mark installation and the quality of leveling between these marks and the staff (or other vertical water reference).

2. BENCH MARKS

2.1 Definitions - Bench mark is the all-inclusive term for the fixed physical object, point, or line used as reference for a vertical or horizontal datum. The bench marks discussed in this publication are located in the vicinity of a water level station and in this application are used to reference vertical datums only. They are the bench marks to which the staff and datums are referred. Monumentation is the specific type of integral unit which, when set, contains the referenced elevation by a surface, line, or point. A monument, per se, is the structure in which the mark itself is affixed. A bench mark is considered permanent unless designated a temporary bench mark. Recovering a bench mark means physically finding and identifying a previously described (historic) bench mark. Recovery usually involves providing suggested additions, deletions, and changes to the existing bench mark description (or noting that the mark was recovered as described) by the field party for subsequent updating.

2.2 Types of Bench Marks - The most common type of monumentation is a survey disk. The standard bench mark of the National Ocean Service (NOS) is an installed brass disk about 3 5/8 in. in diameter with a shank about 3 in. long. The disk contains the inscription NATIONAL OCEAN SURVEY or NATIONAL OCEAN SERVICE together with other individual identifying information. Numerous bench marks of predecessor organizations to NOS, or parts of other organizations absorbed into NOS, still bear the inscriptions, U.S. COAST & GEODETIC SURVEY, U.S. LAKE SURVEY, CORPS OF ENGINEERS, and U.S. ENGINEER OFFICE.

Monumentation of temporary bench marks might be spikes driven into the base of telephone poles, projecting bolts, or any stable recognizable object or point.

2.3 Number and Type of Bench Mark Monumentation at Particular Water Level Stations

2.3.1 Short Period Station - A short period station is one at which continuous observations have been made over a period of less than 30 days. At least three bench marks shall be installed at this type of station; however, they may be temporary bench marks of suitable monumentation.

2.3.2 Tertiary Station - A tertiary station is one at which continuous observations have been made over a minimum period of 30 days but less than 1 year. At least five bench marks shall be installed at this type of station. Preference should be given to disks set in bedrock, in large man-made structures, and on deep driven rods.

2.3.3 Secondary Control Station - A secondary control station is one at which continuous observations have been made over a minimum period of 1 year but less than 19 years. At least five permanent bench marks shall be installed at this type of station. Three of the five shall be disks set in bedrock and/or on deep driven rods. The remaining two shall be installed on the most suitable structures for the locality. Preference should be given to disks set in bedrock, in large man-made structures, and on deep driven rods. Bench mark requirements for the seasonal datum monitoring program in the Great Lakes network are to meet these specifications.

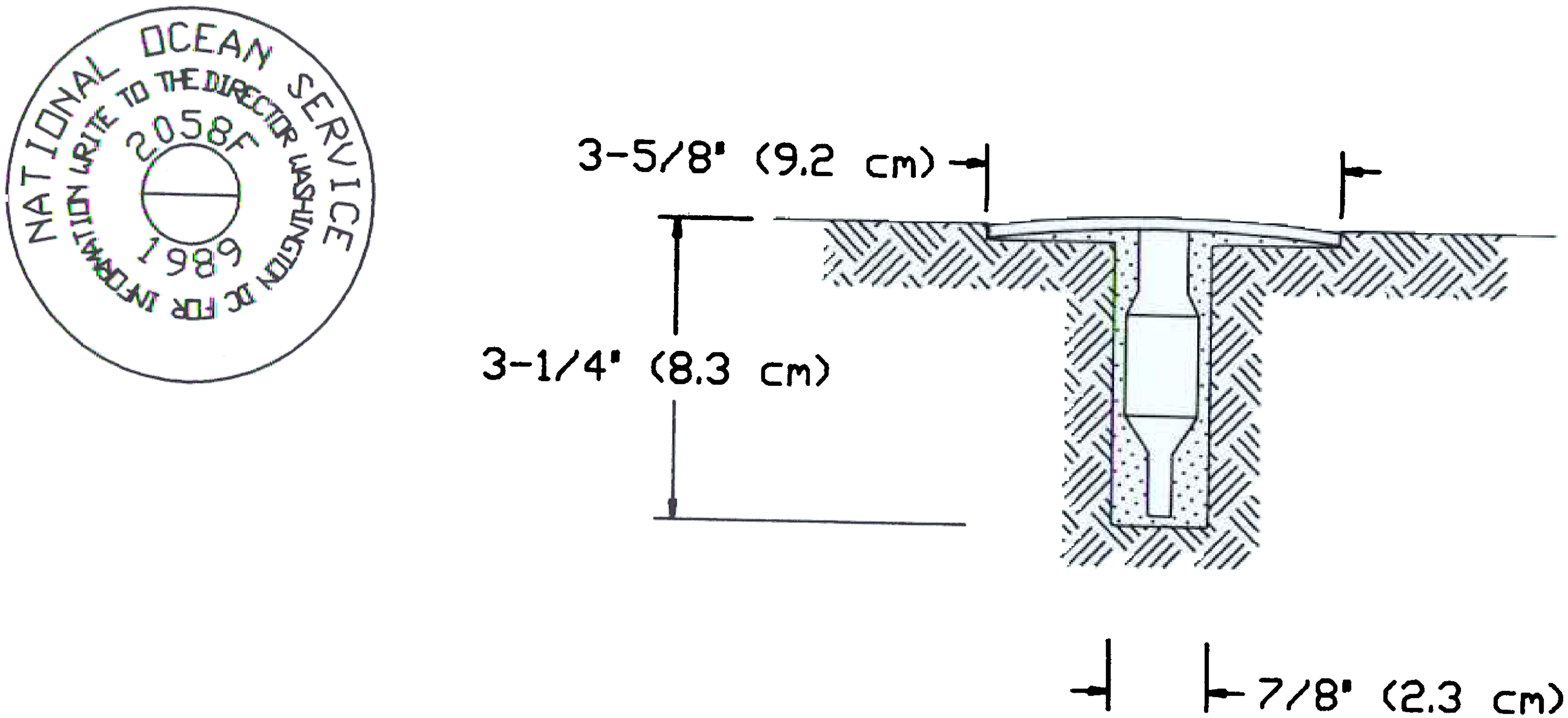
2.3.4 Primary Control Station - A primary control station is one at which continuous observations have been made over a minimum period of 19 years. Five bench marks shall be installed during the first year of operation at a station which is intended to become a primary control station. Additional bench marks shall be installed in following years until a total of ten have been installed by the sixth year. At least three of the ten shall be disks set in bedrock and/or on deep driven rods. The remaining seven shall be installed on the most suitable structures for the locality. Preference should be given to disks set in bedrock, in large man-made structures, and on deep driven rods. Bench mark requirements for the permanent stations in the Great Lakes network are to meet these specifications. When installed by the National Geodetic Survey Division, the class A rod mark (connected to the National Geodetic Vertical Network by first-order leveling) should be considered part of the bench mark network. Existing bench marks of other agencies may be used, provided the marks meet the specifications for the type of station.

2.4 Primary Bench Mark (PBM) - One bench mark at each station is designated the PBM by the Sea and Lake Measurement Section (N/OMA121), Sea and Lake Levels Branch, Physical Oceanography Division, Office of Oceanography and Marine Assessment. The PBM is selected for stability (or expected stability). Convenience of location and use are secondary considerations. Leveling between the PBM and staff zero or ETG reading mark enables effective monitoring of the vertical stability of the staff or ETG relative to the PBM. The very localized relative vertical stability of the PBM is monitored, in turn, by repeated leveling to the other bench marks at the station. The PBM must be included in the run each time the station is leveled. See Section 3.3.

2.5 Spacing of Bench Marks - Bench marks should be distributed in the area around a station such that any expected event which might disturb a mark will not damage or destroy more than one mark. This means, for example, that no more than one mark should be set in a building foundation, on one owner's property, or on the same side of a street where road expansion could occur Marks should be spaced at least 60 m (200 ft.) from each other, but no further than 1 km (0.6 mi.) apart. Overall, all bench marks should be within a radius of about 1.6 km (1 mi.) from the gage in order to keep leveling time to a minimum.

2.6 Bench Mark Disk - Identification is greatly enhanced by using standard NOS bench mark disks for bench marks. Those currently being set are inscribed with NATIONAL OCEAN SURVEY or NATIONAL OCEAN SURVEY BENCH MARK. In the future, the disks will be inscribed, NATIONAL OCEAN SERVICE. In the center of the disk is a circle with a line through its center (Figure 1a). Some disks have a tick mark bisecting the line.

2.7 Numbering Bench Marks - To help avoid confusion and ensure positive identification, new bench marks will be stamped and designated with the last four digits of the station number, a letter, and the current year. For example, five new bench marks set at station 905-2058 would be stamped 2058A, 2058B, 2058C, 2058D, and 2058E, along with the current year (Figure 1a). Note that the first three numbers (state/lake identifiers) are not stamped on the mark. Also, the letters I and O are not used since they could be confused with the numbers 1 and 0. Duplication of letters must be avoided; a number previously assigned to a bench mark shall not be used for a new mark. A mark replacing a destroyed mark shall be stamped with a new letter. For example, if bench marks 2058A, 2058C, 2058D, and 2058E are recovered and bench mark 2058B has been destroyed, the bench mark disk set to replace bench mark 2058B will be stamped 2058F with the current year. Station numbers are assigned by N/OMA121. All stations are assigned a number regardless of length of operation. Existing bench marks that have not been stamped according to the current numbering system retain the designation stamped on the mark. Temporary bench marks are not stamped, but are referred to as TBM 1, TBM 2, TBM 3, etc.



1a Bench Mark Disk
with Typical Casting
and Stamping

1b Bench Mark Disk
Set in Bedrock

Figure 1 Bench Mark Disk and Bedrock Setting

2.8 <u>Location of Bench Marks</u> - The choice of location is critical to prolonging the life and usefulness of the bench mark. The choice should be made carefully, considering the likelihood of the mark being destroyed. Permission must always be obtained from the landowner. It is desirable to set the face of the bench mark disk horizontally for convenience in holding the level rod, and there should be sufficient vertical clearance above the mark for rods used in first-order leveling which are about 3 m (10 ft.) long. Depending on the area, greater permanency may be assured by placing the bench mark disk vertically in the wall of a structure or bedrock. In this position, the line through the center of the disk becomes the reference elevation. Care must be taken to ensure that this line is set horizontally. The disk should be about 1 m (3 ft.) above the ground for convenience in holding a tape or special short rod/scale used in leveling to the reference point.

Public squares and parks are preferable places for bench marks. Public structures are generally preferable to private, since they have a longer life expectancy.

When setting marks along a highway, locate them near the edge of the right of way, away from intersections, and on alternating sides of the road in order to minimize the chances of all marks being destroyed by road repair or construction. Since highway curves are flattened more often than sharpened, the outside of the curve is usually safer. Avoid setting a majority of the marks along any one road or in any one structure.

High ground is preferable to low lying areas. The water table is usually closer to the surface in low areas, thereby increasing the chance of frost heave. Also, fluctuations in water content are greater in low areas, thereby increasing the chance of swelling and shrinkage if expansive soils are present. Slopes are potentially unstable and should be avoided.

2.9 Monumentation - The installation of the more common types of monuments are discussed in Sections 2.9.1 through 2.9.7, in order of preference. It should be remembered that good craftmanship will increase life expectancy, increase stability, enhance appearance, and be a credit to NOS.

2.9.1 Bench Mark Disks Set in Bedrock - Bench mark disks in outcrops of bedrock (not boulders) are the most stable and easiest to set (Figure 1b). A 7/8-in. diameter hole, 3 1/4 in. deep, is drilled into the rock to accommodate the shank of the disk. This is done with a powered rock drill or by hand using a star drill and hammer. Next, a counter-sunk solid level base is chiseled for the disk. The rock is then wetted to prevent absorption of water from the cement paste. Cement paste is placed in the hole and on the underside of the disk to prevent air from becoming trapped in the concave portion. The cement paste should have a stiff consistency, but still be workable. The prestamped disk is then tapped into the drill hole and leveled using a small line level. Finally, the excess paste is removed and the mark cleaned by rubbing dry cement powder over the finished mark. In hot weather, a wet cloth placed on top of the disk will help prevent the cement paste from drying too fast and cracking.

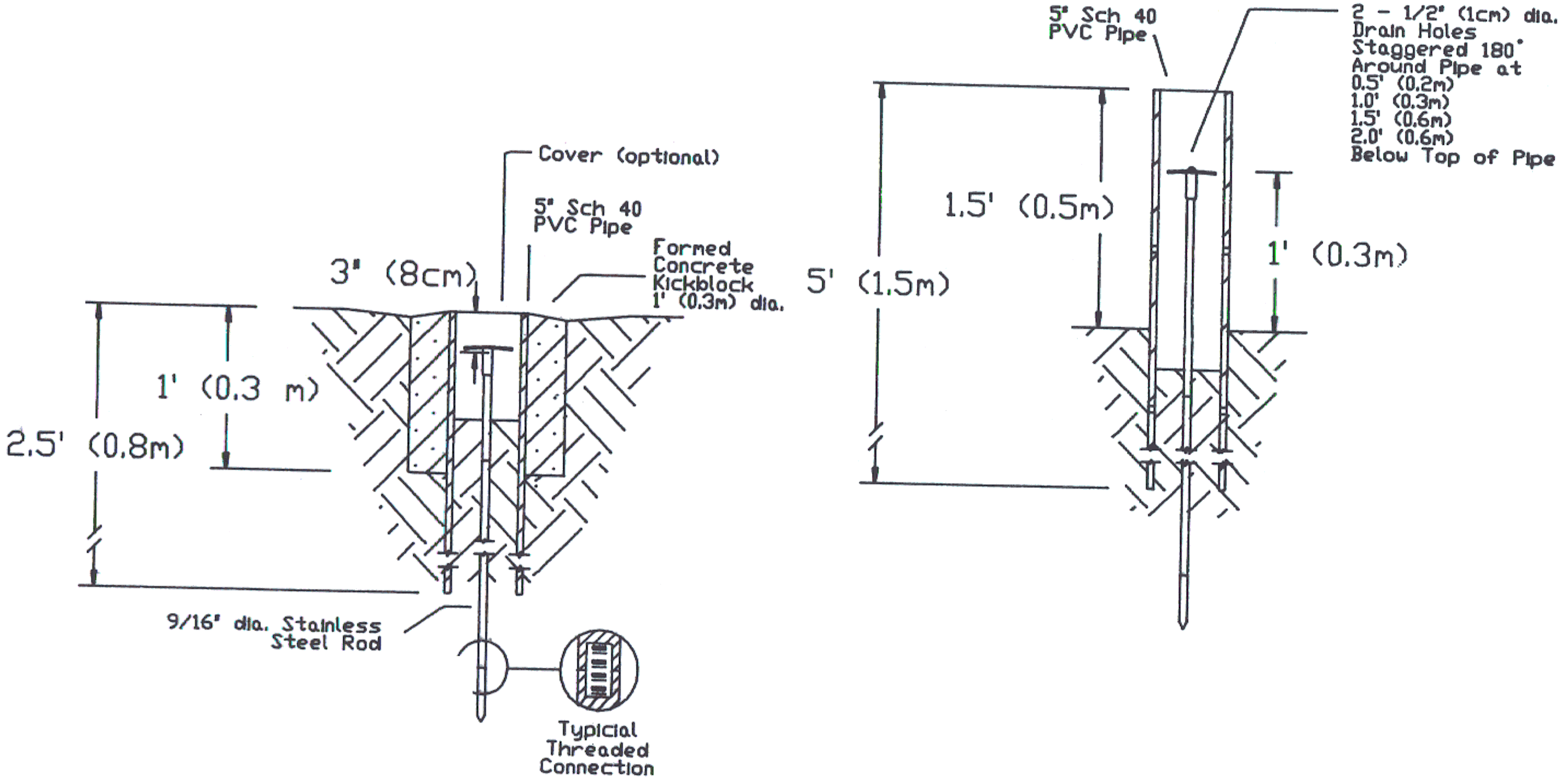
2.9.2 Class A Rod Type Bench Marks - These marks are not generally set by the Sea and Lake Levels Branch because of the heavy support equipment needed for installation. The National Geodetic Survey Division plans to set one of this type at each primary control station. They are probably the most stable (next to bedrock) and shall be included in the station levelings where available. The class A rod mark consists of an outer pipe inserted in an augered hole and an inner rod driven to refusal in a stable soil layer with a truck mounted rig (Floyd, 1978, pp.14-25).

2.9.3 Class B Rod Type Bench Marks - This mark, commonly called a deep rod mark, consists of a 9/16-in. diameter stainless steel rod driven vertically into the ground. A specially adapted prestamped disk is crimped to the top of the rod. The mark is protected by a 5-in. PVC pipe and surrounded by a concrete kickblock (Figure 2a). This type of mark tends to be more stable than all other types of bench marks except for those set in bedrock and class A rod marks. The rods are in 4- or 5-ft. sections, joined tightly with internal threaded couplers and pipe compound, and are driven with a 56-lb. gasoline hammer or a 30-lb. manual drop hammer having a minimum drop of 2 ft. A short section of rod (securely threaded on top) is used as a driving head. A clockwise torque of 1/2 turn every 5 ft. is applied, by pipe wrench, during the driving in order to prevent loosening of the threaded couplers. A pointed end section of rod facilitates driving. The procedure for setting a class B rod mark is given in Floyd (1978, pp.25-26).

Soilcrete may be used for the kickblock instead of concrete when the latter is not available. Soilcrete is made by adding one part cement with six parts native soil and only enough water (use only fresh water) to make the mixture slightly damp. The mixture is then thoroughly compacted.

In remote unpopulated areas where periodic flooding or continual submergence of low lying terrain would result in the deposition of sediments around or over the upper portion of the deep rod mark, the following procedures should be followed. The bench mark disk is attached to the rod 1.0 ft. (0.3 m) above the natural grade. A 5-ft. section of schedule 40, 5-in. PVC pipe with drainage holes drilled in the upper portion is set around the disk and rod and driven into the ground (Figure 2b).

2.9.4 <u>Bench Mark Disks in Large Man-Made Structures</u> - All structures resting on bedrock or having deep foundations are excellent for bench marks. In general, buildings over three stories high, towers, and bridge abutments are suitable. These



2a. Standard Installation

2b Marsh Installation

Figure 2 Class B Rod Mark

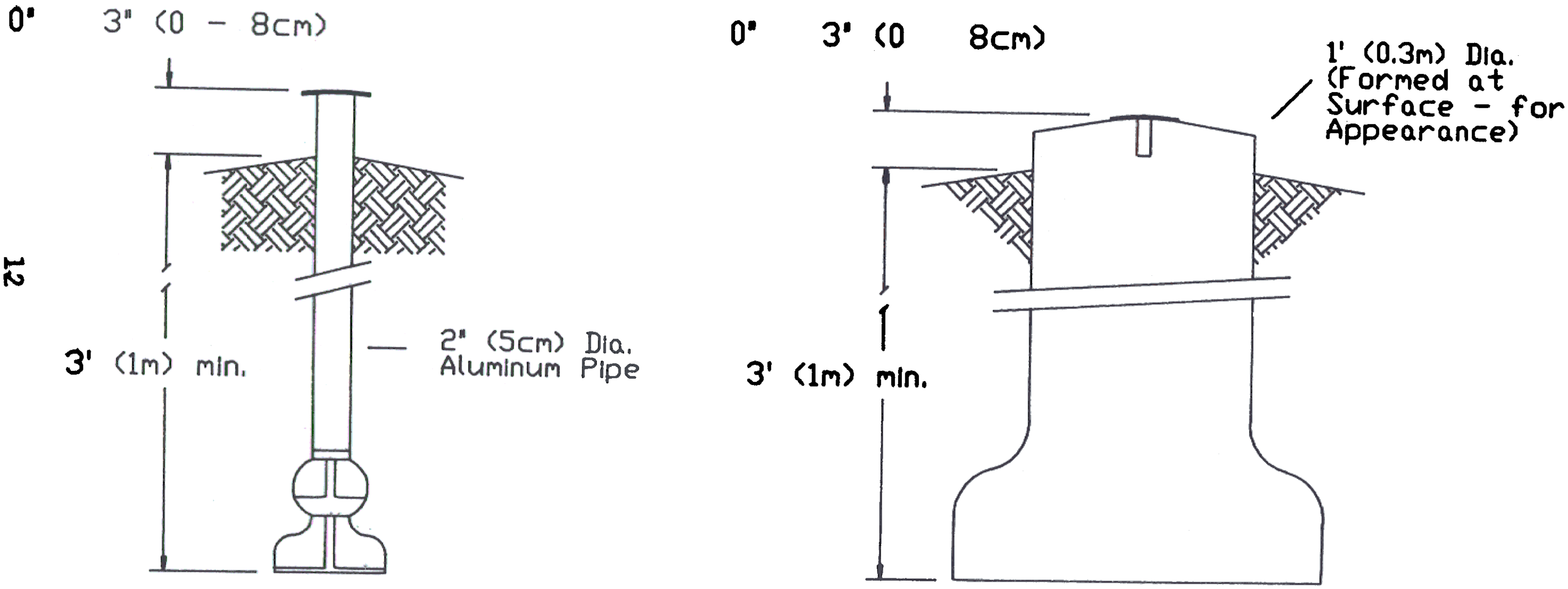
structures, as a group, tend to be the next most stable locations for bench marks.

Most buildings, however, settle; the rate of settlement decreases with time. Most of the settlement occurs in the first few years; therefore, marks are never to be set in structures less than 5 years old. Curbs, sidewalks, pavements, porches, and small seawalls are not to be used. These structures move due to soil, moisture, and frost action, and generally have a relatively short life expectancy. In areas with expansive soils, most surface structures (even large buildings with shallow foundations) are subject to heaving and settling.

Permission will usually be granted for the installation of a bench mark disk when its use is explained to the owner or appropriate authority. Marks must be set neatly so as not to deface the structure. The technique for setting a disk in large man-made structures is identical with that described for bedrock in Section 2.9.1.

2.9.5 Bench Mark Disks on Pipes - This type of mark is made from prefabricated pipe or a section of 9/16-in. diameter metal rod with a disk on top and a base plate on the bottom (Figure 3a). The pipe is set in a hole backfilled with compacted earth. It can be installed easily at almost any location, but may be subject to movement in an unstable area.

A hole is dug with a 6-in. auger or post-hole digger to a depth that will allow the bench mark to extend about 3 in. (0.08 m) above grade. The pipe is then set in the hole to ensure full bearing value of the base plate. The hole is then backfilled with slightly damp soil and thoroughly compacted in 0.5-ft. (0.2-m) lifts. If the soil will not compact satisfactorily, dry soilcrete may be used in the first few lifts. Percolating rainwater will provide the required moisture for hydration.



3a Bench Mark on Prefabricated Pipe

3b Bench Mark Set in Concrete Monument

Figure 3 Bench Mark on Prefabricated Pipe and Bench Mark Set in Concrete Monument

2.9.6 Bench Mark Disks in Concrete Monuments - Concrete monuments have been the most frequently used supporting monument in the past. Since they are subject to movement, however, they are seldom used today. The monuments, if used, must be at least 1 week old before leveling in order to allow time for initial settlement.

Concrete is placed in a 1-ft. (0.3-m) diameter hole about 3 ft. (1 m) deep, unless frost action requires a deeper foundation. A bell-shape is dug at the base of the hole in order to reduce the possiblity of heaving or settling. The monument should be formed at the top and free from projections which could assist in lifting the mark (Figure 3b).

To produce the needed durability and strength of the concrete, a 1:3:2 mix (one part cement, three parts sand, and two parts gravel) shall be used. The mix should be stiff and rodded in place. The sand and gravel must be clean and sound. Ready mix concrete sold in bags generally has a poor aggregate gradation and low cement content. If ready mix is used, however, extra sand and cement shall be added as needed.

Concrete mixing water should be potable water. Seawater can be used, but it will cause a reduction in strength of about 20 percent. The reduction in strength can be offset to some degree by either increasing the cement content and/or reducing the seawater content. Strength of concrete is increased by decreasing the water content as much as workability allows. Full hydration and maximum strength is obtained at water/cement ratios much too dry for workability.

Before placing the prestamped disk in the fresh concrete, cement paste is placed on the underside of the disk to prevent air from becoming trapped in the concave part of the disk.

2.9.7 Bench Mark Disks in Boulders - This type of mark is only acceptable in remote areas when, due to logistic problems, other types of monuments are not feasible. The boulder must be large and embedded deep enough to go well below the frostline.

2.9.8 Maximum Depth of Frost Penetration - To guard against frost heave, both a pipe mark or a disk set in a concrete monument (or boulder) must go at least 0.3 m (1.0 ft.) below the frostline. The extreme depth of frost penetration varies but, in general, it is less than 0.6 m (2.0 ft.) deep along the west coast of the contiguous United States and south of New Jersey on the east coast. The extreme depth varies from 1 m (3 ft.) in northern New Jersey to about 2 m (7 ft.) in northern Maine. The extreme depth and a table to determine frost penetration is given in Floyd (1978, p.34).

2.10 Staff - A staff is a graduated board secured to a pile, etc., near the gage. The rod stop is a convenient point on the staff used to reference an elevation above staff zero. A 1 1/2-in. by 1 1/2-in. by 3/8-in. brass or galvanized angle with a round head bolt (as a definite high point) of the same material is the reference elevation. The height of the reference above staff zero is measured with a steel tape, graduated in 0.01-ft. intervals, and estimated to the nearest 0.001 ft. The rod stop on a portable staff is the staff stop on the support board.

2.11 Electric Tape Gage (ETG) - At coastal stations the ETG is often used in lieu of a staff, where conditions make staff measurements impractical. At all permanent stations in the Great Lakes network, the ETG is used as the reference for daily checks of the principal and backup recording gages.

In leveling to the reading mark of the ETG, a steel tape or specially designed short level rod is used. The position of the weighted end of the ETG shall be verified to ±0.001 ft. and noted in the leveling record and station report. The weight should be pinned to the tape so that it cannot move in its sleeve.

2.12 Bench Mark Descriptions, Recovery Notes, and To Reach Statement - Descriptions of bench marks are of great importance, for only with these descriptions can the marks be recovered and used. Descriptions must be accurate, clear, concise, and complete. They are forwarded through appropriate channels with the leveling record and other station documentation.

The following paragraphs provide detailed instructions on preparing descriptions (NOAA Forms 76-75 and 76-89) for bench marks located at stations in marine areas. For stations located in the Great Lakes network, the descriptions (NOAA Form 76-186) are prepared following the guidelines in Pfeifer and Morrison (1980).

A complete description for all new bench marks and a To Reach Statement shall be written in the field and neatly printed or typed on DESCRIPTION OF BENCH MARK (NOAA Form 76-75). Previously described bench marks shall be reported on RECOVERY NOTE, BENCH MARK (NOAA Form 76-89). If the existing description is adequate for recovery, the statement, "Recovered as described in ... (source and date)", may be entered in the Detailed Report section on the form. All entries above the Detailed Report section must be completed. The condition of the mark should always be reported If a source other than NOS is used, a copy of its complete text shall be included with the RECOVERY NOTE, BENCH MARK. If the existing descriptions are inadequate (street names changed, reference point object moved or destroyed, etc.), resulting in abnormal time-consuming recovery efforts, a completely revised description shall be written and reported on the RECOVERY NOTE, BENCH MARK form. Particular attention should be paid to documenting the actual stamping on the bench mark during every recovery.

The text of the To Reach Statement provides information needed to locate the bench marks, station, and staff. Directions should be given to the general vicinity and then to the exact spot. They should start from a highway intersection or prominent landmark in the nearest city or town. The staff or ETG shall be referenced to at least two permanent objects.

The Detailed Description section of the DESCRIPTION OF BENCH MARK shall first reference the bench mark, by distance and direction, from the furthest of at least three permanent prominent objects. Descriptions should be from the furthest to the closest permanent object until all are tied to the bench mark, preferably at right angles. Descriptions of the setting and monumentation shall be included. The number of significant digits shall reflect the accuracy of the distance measurement. The metric equivalent of all distances shall be included in parentheses after the English unit. The directions shall be at least to the nearest 16 compass points; i.e., north (N), north-northeast (NNE), northeast (NE), east-northeast (ENE), east (E), etc. Vertical references, if required, should also be provided at the end of the description.

In areas where three permanent objects are not available or to facilitate recovery, one or two witness posts are set near the mark for reference. A prefabricated witness post or an 8-ft., 4 in. by 4 in. treated wooden post projecting 4 ft. above the ground is used. Prefabricated witness posts are less expensive and easier to install than the wooden ones, but private land owners and park directors usually prefer the wooden posts because they blend into the natural scenery.

2.13 Bench Mark Sketch - A sketch showing the gage, staff or ETG, and all bench marks is submitted with the leveling record. This sketch should be on a separate sheet of 8 1/2-in. by 11-in. paper, at appropriate scale. A new sketch is not required at previously established stations if the existing sketch is correct and complete. The sketch must have a scale, north arrow, and title block (NOAA Form 76-199) containing the name of the preparer, date, station name, and number.

3. LEVELING

Quality of leveling is a function of the procedures used, the sensitivity of the leveling instruments, the precision and accuracy of the rods, the attention given by surveyors, and the refinement of the computations.

3.1 Standards and Specifications - The leveling used at stations shall generally follow the Standards and Specifications for Geodetic Control Networks (Bossler, 1984).

Second-order, class I levels shall be used in connections at all primary and secondary control stations. Although third-order levels may be used at all other stations, the on-site, self-checking capability inherent in second-order levels warrants its use if at all feasible.

The following tolerances shall be observed in levelings at all stations:

a. maximum length of sight, 60 m (197 ft.) for 2nd-order, class I and 90 m (295 ft.) for 3rd-order;
b. maximum difference in length of forward and backward sights,
    1) 5 m (16 ft.) per setup (2nd-order, class I) and 10 m (33 ft.) per setup (3rd-order),
    2) 10 m (33 ft.) cumulative per section;
c. maximum closure between forward and backward runnings, 6 mm$\sqrt{K}$ (0.025 ft.$\sqrt{M}$) per section and line (2nd-order, class I) and 12 mm$\sqrt{K}$ (0.050 ft. $\sqrt{M}$) per section and line (3rd-order) - where K

and M are the one-way distances in kilometers and miles, respectively;

d. minimum ground clearance of line of sight, 0.5 m (1.6 ft.) for 2nd- and 3rd-order; and

e. determination of temperature gradient for vertical range of line of sight at each setup, for 2nd-order only.

3.2 Vertical Movement Precautions - Although the purpose of releveling is to detect movement (or lack thereof) between the staff or ETG and the marks, certain departures require careful attention. When the change of height exceeds 6 mm (0.02 ft.) at primary and secondary control, and 13 mm (0.04 ft.) at tertiary stations, a special check should be made for the possibility of a loose staff or a disturbed bench mark, etc. Stability of the mark should be determined by leveling to other station marks to check previously determined height relationships. Any findings or conclusions should be noted in the Remarks section of the leveling record.

3.3 Frequency of Leveling - Leveling between bench marks and the staff or ETG shall be conducted at all stations unless otherwise directed:

a. at establishment (all bench marks),

b. 6 months after establishment (PBM plus four other bench marks) - project instructions or contract documents may modify this requirement,

c. before and after any modification affecting the elevation of the staff or ETG (PBM plus two other bench marks),

d. upon discontinuation of data collection (all bench marks),

e. annually (all bench marks),

f. as often as necessary to ensure minimum data loss at stations exposed to extreme environmental conditions (PBM plus two other bench marks), and

g. after installation of new bench marks (PBM plus two other old bench marks and new bench mark).

The Project Instructions or contract document will list the PBM and designate the other bench marks to be connected, as required.

3.4 Connection with National Geodetic Vertical Datum (NGVD) - If NGVD is within a one mile leveling distance of the station, a level connection shall be made, as detailed below, during one of the required levelings. Stations established solely for hydrography are exempt from this requirement, except when otherwise directed. If NGVD is in the immediate vicinity, the mark(s) can be used for the station if the provisions of Section 2.3 are satisfied.

For the connection to be meaningful, the observed difference between two marks of the network must agree with the published value within the allowable closure tolerance: 6 mm$\sqrt{K}$ (0.025 ft $\sqrt{M}$) for second-order, class I levels, and 12 mm$\sqrt{K}$ (0.050 ft. $\sqrt{M}$) for third-order levels - where K and M are the one-way distances in kilometers and miles, respectively.

As an example, assume the following using second-order leveling:

Bench Marks	Distance	Published Difference	Observed Difference	Pub.-Obs.
A - B	1.00 km	+0.100 m	+0.110 m	-0.010 m
B - C	1.00 km	+0.200 m	+0.185 m	+0.015 m
A - C	2.00 km	+0.300 m	+0.295 m	+0.005 m

The observed difference between A and B did not agree with the published difference within the allowable closure tolerance (6 mm $\sqrt{1.0\text{ km}}$ = ±0.006 m <0.010 m), therefore, leveling was extended to C. The difference between B and C did not agree either

$(\pm 0.006 \text{ m} < 0.015 \text{ m})$. However, the difference between A and C does check $[6 \text{ mm}\sqrt{2.0 \text{ km}} = \pm 0.008 \text{ m} > (-0.010 \text{ m} + 0.015 \text{ m} = 0.005 \text{ m})]$, and the connection is adequate. In this example, B appears to have moved (become unstable).

3.5 Instruments

3.5.1 Level - Compensator or spirit leveling instruments are acceptable. The following are examples:

COMPENSATOR INSTRUMENTS		SPIRIT-LEVEL INSTRUMENTS	
Jena	NI 002	Breithaupt	NABON
Jena	NI 007	Jenoptik	Ni 004
Lietz	B1	Kern	GK2-A
MOM	NiA31	Pentax	L20
Wild	NA2	Wild	N3
Zeiss	Ni1		
Zeiss	Ni2		

If other than listed, approval may be granted after instrument specifications (optic power, repeatability, etc.) are reviewed by appropriate authority.

Several instruments listed above can be equipped with a device called an optical micrometer. This device eliminates the need to estimate the intercept of the middle wire of the reticle as it appears against the image of the rod scale. Micrometer leveling is the most precise procedure for geodetic leveling. While primarily used only in first-order leveling, it may also be used in second-order.

3.5.2 Level Rod - In differential leveling, vertical differences in elevation between bench marks are measured with a rod. The accuracy of leveling, therefore, depends on both the quality of the rod and the instrument itself (in addition to procedures and technique). All too often, a very high quality observing instrument is used with little attention given to the equivalent quality of the rod.

The rod used in second-order leveling is composed of a single continuous (not collapsible or folding) Invar metal scale supported on a staff of wood or light metal. The scale is permanently attached to the foot of the staff, and is freely supported under tension by a spring-loaded clamp at the top.

Thus, the staff is free to change length in response to changes in humidity and/or temperature without affecting the length of the graduated scale. A circular level bubble is used to keep the rod plumb.

Line-type graduation patterns (double offset scale) are to be used with levels equipped with optical micrometers. Block-type graduation patterns are to be used with all others. Rod graduation intervals (rod units) may be in 0.01 foot, 0.01 yard, 1 centimeter, or 0.5 centimeter intervals. The actual rod reading with the 3-wire method is estimated to 0.001 foot, 0.001 yard, 0.1 centimeter, or 0.05 centimeter (tenths of rod units), respectively. When using a level equipped with an optical micrometer, the rod graduations and the micrometer graduations must be in compatible units of measure, and the actual readings are in hundredths of rod units.

All second-order Invar rods are to be calibrated, with both index and length errors determined. This requirement may be accomplished at the time of purchase by receipt of a calibration certification from the manufacturer or by calibration and certification by an approved laboratory.

For third-order leveling, rods with continuous metal scales on a wooden or fiberglass staff (calibrated in metric or English units in a block graduation pattern) are acceptable. A hand-held level bubble is used to keep the rod plumb.

When using two rods, they must be a matched pair (rods with the same rod units, graduation pattern, index error, etc.). In addition, two-rod leveling procedures require an even number of instrument setups per section in order to cancel out any mismatch error. When using one rod, or if the rods are calibrated to each division (detailed calibration), an odd number of setups may be used. The rod type, rod unit, graduation pattern, and serial number must be referenced in all field notes.

3.5.3 Turning Points - Two important characteristics of any turning point, which should always be considered when selecting the type and position, are: (a) its stability while being used (supporting the running elevation), and (b) the precision of the rod resting point. The following table lists the most common types of turning points, together with the various surfaces upon which they are used.

TURNING POINT	SURFACE TYPE	REMARKS
Steel pins with driving cap	Firm ground, dirt roads.	Pin is driven vertically into the ground and removed when the rodman moves to the next point. Remove cap to expose high point.
Portable turning plate (turtle) weighing at least 7 kg (15 lb.)	Concrete pavement, hard packed gravel.	Turtle is firmly planted and removed when rodman moves to next point. Use with great caution!
Double headed nail in wooden stake	Soft ground, marsh, sandy shoreline.	Stake is driven to firm bearing. Nail is driven into stake to the first bead for precise point. Elevation can be checked for a short time after run.
Ball bearing or marble*	Concrete pavement.	Ball is firmly placed in niche of pavement to prevent movement. Use with great caution!
PK nail*	Asphalt road.	Nail is driven into roadway. Head of nail is left exposed for point. Elevation can be checked for short time after run.

---

*Not recommended for geodetic leveling

When levels are run across extremely unstable ground (marsh, swamp, shallow water bodies, etc.), conventional points may be useless and special equipment may have to be fabricated for the turning points (Figure 4).

3.6 Some Sources of Leveling Error - Two sources of leveling errors, curvature and refraction, are described. Corrections can be applied to observed leveling data to minimize the effects of these known systematic errors. The errors are best minimized, however, by use of appropriate field observation procedures.

3.6.1 Curvature - The line of sight of a level instrument intersects the rod on a level plane. Since the surface of the earth is a curve, a small amount of curvature error, proportional to the square of the sighting distance, is introduced into each observation (Figure 5). Corrections for the curvature error are always negative (i.e., to be subtracted from the observed rod readings).

3.6.2 Refraction - Variations in atmospheric density, primarily a function of temperature, cause the line of sight to refract (bend toward the air of greater density). Scintillation, the short period boiling of the air, is also caused by differences in air densities. The effect of refraction is proportional to the square of the sighting distance and is greatest:

a. on sunny windless days,
b. during unbalanced sights,
c. when observing near the top of one rod and the bottom of the other (line of sight going through layers of significantly different air densities),
d. when the line of sight approaches the ground at any intermediate point along the backsight or foresight line of sight,

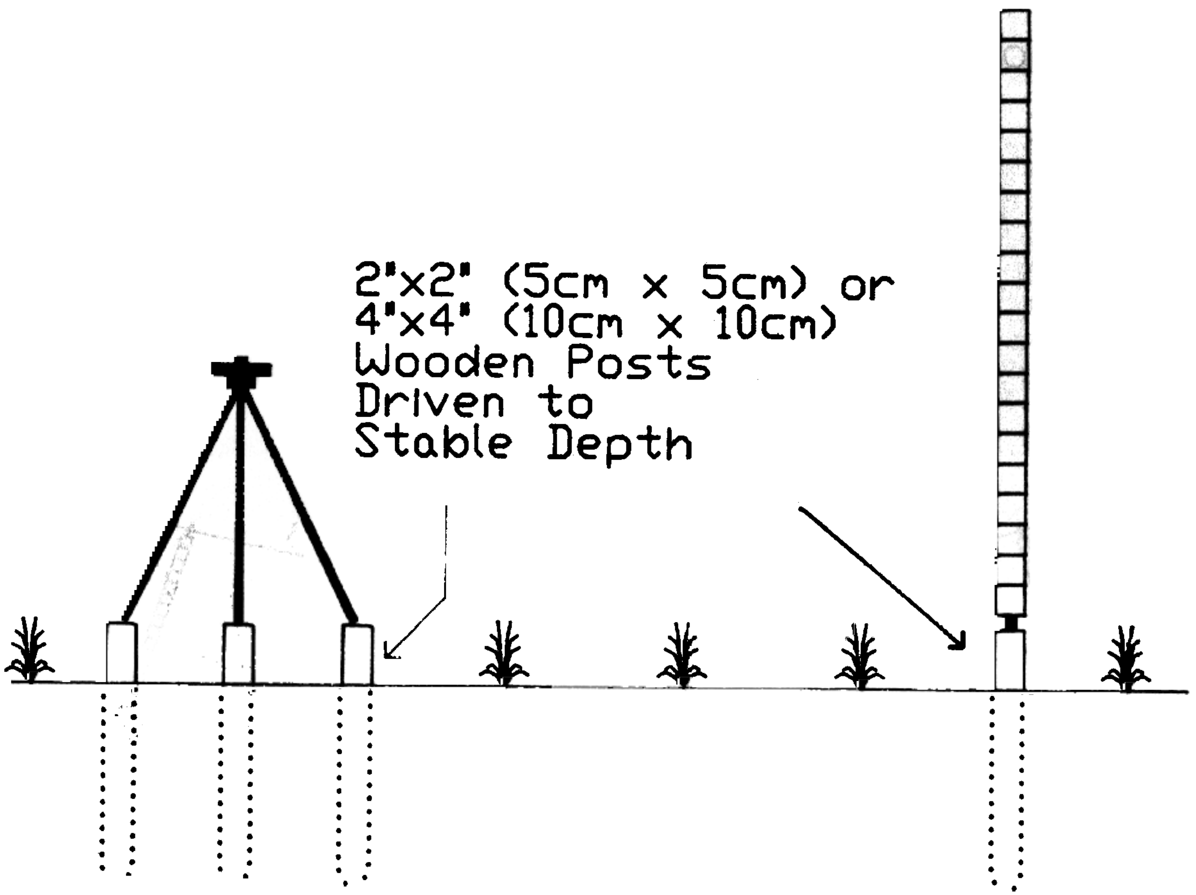
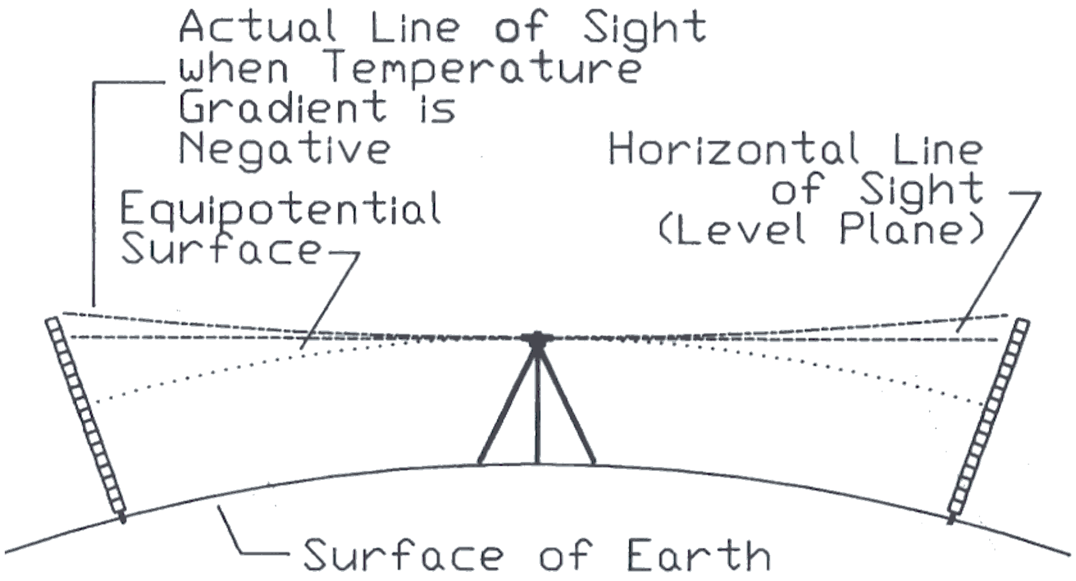


Fig. 4 Stability Precautions for Leveling in Wetlands & Marshes

Not to Scale



Not to Scale

Figure 5 Effects of Curvature and Refraction

e. when conditions are not the same along both lines of sight (as in an onshore backsight and offshore foresight) in non-reciprocal or unbalanced observations,

f. at night (during calm windless conditions) when the temperature gradient is positive (i.e., when the air near the ground is cooler than the air above), and

g. when the line of sight passes over a surface with a high refractive index (e.g., paved roads, sand, etc.

Previously, simple refraction tables were developed that described average leveling conditions but, due to the nature of most coastal leveling, departures from these average conditions are generally great and thus result in improper corrections. Refraction error (and the resulting corrections) may be positive as well as negative, depending on the temperature gradient at the time of observation. The best way to reduce refraction error is to avoid the causes of refraction in the first place and therefore minimize the errors. This may be accomplished by:

a. increasing the height of the instrument,

b. reducing the sight distance and avoiding unbalanced sights,

c. taking advantage of cloudy and breezy days to run levels,

d. keeping the line of sight at least 0.5 m (1.6 ft.) above the ground (or any intervening object) at all points (required),

e. avoiding positive temperature gradient conditions (usually at night), and

f. conducting observations during the time interval from 2.5 hours after sunrise to 0.5 hours before sunset.

Additional information on corrections which can be applied to observed leveling data, including formulas, is given in Balazs and Young (1982).

3.6.3 Leveling Collimation Error (adapted directly from Schomaker and Berry, 1981, pp. 3-29 through 3-36) - No instrument is perfectly aligned. The level collimation error is the angle from which the line of sight departs from the actual level surface when the instrument is leveled.

3.6.3.1 Collimation Check - In the field, the collimation error of a leveling instrument is measured by obtaining a set of observations called the collimation check (Peg-test). Collimation error must be reduced by adjusting the instrument to within a standard accuracy. Because the necessary adjustment can change easily under field conditions (thus changing the collimation error), the collimation check should be made daily with most instruments. In addition, the check should be made any time an instrument sustains a severe shock or seems to function abnormally.

The collimation check has two purposes: to determine, against a standard of accuracy, whether the instrument is properly adjusted; and to compute a factor to correct data obtained from imbalanced setups and sections.

The error, CR, must be removed from each rod reading. It may be obtained in either one of two ways. The first is to look it up as a function of the sighting distance in Table 1. The second, more precise way, is to compute it as a function of both sighting distance and a formula for temperature differential (Jordan, et al., 1956).

Table 1 is the result of computations using the temperature differential formula and assuming average temperature gradients at a height of 1.5 m (5 ft.) under daytime conditions. Distances given are for sight lengths permitted by either Kukkamaki or 10-40 methods for collimation check.

Table 1 Curvature and refraction corrections for single sights

DISTANCE (D)		CORRECTION TO ROD READING (CR)	
METERS	FEET	MILLIMETERS	FEET
10	33	-0.02	-0.0001
20	66	-0.07	-0.0002
30	98	-0.15	-0.0005
40	131	-0.27	-0.0009
50	164	-0.42	-0.0014
60	197	-0.60	-0.0020
70	230	-0.81	-0.0027
80	262	-1.06	-0.0035
90	295	-1.34	-0.0044

3.6.3.2 <u>Standard of accuracy for collimation error</u> - In a properly adjusted instrument, the collimation error should be no more than ±10.0 arc-seconds ($C \leq \pm 0.05$ mm/m). If an instrument exceeds this tolerance, it must be adjusted and another check made. Two methods of observation are included in the procedure for the collimation check.

3.6.3.3 <u>Collimation error</u> - During the collimation check, the angular value of the collimation error is determined. The tangent of the angular value is computed in mm/m.

If the first setup is balanced and the second unbalanced (as for the Kukkamaki method given in 3.6.3.5), then:

$$C = \frac{\Delta h_1 - (\Delta h_2 - CR)}{\Delta s_2} = \frac{\Delta h_1 - \Delta h_2 + CR}{\Delta s_2}$$

where Δh_1 = difference in elevation, setup 1

Δh_2 = difference in elevation, setup 2

Δs_2 = unbalanced distance, setup 2

CR = sum of curvature and refraction error $(-CR_b + CR_f)$, the error being opposite in sign of correction in Table 1.

If both setups are unbalanced by the same amount, and they are leveled in opposite directions, then the corrected elevation differences are opposite in sign, and:

$$C = \frac{(\Delta h_1 - CR_1) + (\Delta h_2 - CR_2)}{\Delta s_1 + \Delta s_2}$$

Since $\Delta s_1 = \Delta s_2$ and $CR_1 \cong CR_2$, the formula can be simplified to:

$$C = \frac{(\Delta h_1 + \Delta h_2) - 2CR}{2\,\Delta s}$$

The elevation differences, the curvature and refraction errors, and the imbalances should be measured in the same units; the resulting collimation error is a nondimensional value. For convenience, however, it is often expressed in millimeters per meter. If the collimation error is not within the tolerance for the survey, the instrument must be adjusted. When adjustment can be made in the field, the amount of error to be removed is computed from the following formula. It is referenced to the rod at the farthest sighting distance, s_F, and computed in rod units:

$$\text{error}_F = s_F \times C_{mm/m} \times \text{conversion factor}_{\text{rod unit/mm}}$$

The error is subtracted from the last reading made on the far rod. The instrument is then adjusted in such a way that the corrected reading is observed. After performing the adjustment, the entire procedure should be repeated in order to compute and check the new collimation factor.

Note that the quantity C, commonly used to correct data from three-wire leveling, is not the collimation error. In the past, C has been defined as the product of the stadia factor and the tangent of the collimation error. This was done so that the imbalances, expressed in units of stadia interval, could be converted to units of distance at the same time that a correction for collimation error was applied to the leveling data. Modern instruments, rods, and computers make this practice unnecessary.

3.6.3.4 <u>General instruction for the collimation check</u> - Two methods, sufficiently precise to satisfy the purpose of the collimation check, are presented here. However, the accuracy of the result, with either of these methods, depends on the assumption that the error observed is entirely a function of collimation error. Other effects that alter the line of sight, such as refraction, must be controlled. To achieve this:

a. make the collimation check on uniformly flat ground, the slope of which should be less than 2%,

b. make the check only when the temperature gradient is negative (temperature decreases with height). If thermistors are not available, make the check at least 3 hours after sunrise on sunny days, or at least 5 hours after sunrise on cloudy days (this instruction may be disregarded if a damaged instrument check is conducted immediately following an accident; in this case, another check should be made as soon as the negative gradient conditions can be met),

c. allow the instrument and leveling rods to acclimatize for at least 5 minutes after removal from their cases,

d. make sure that the circular bubble levels on the instrument and rods are properly adjusted, and

e. correct for curvature and refraction.

3.6.3.5 Kukkamaki method - The Kukkamaki method for making a collimation check was developed by T. J. Kukkamaki of the Finnish Geodetic Institute. The method is especially suitable for an instrument whose collimation error changes when refocused. This change may be unacceptable with the more imbalanced setups of other methods (such as the 10-40 method).

The following instructions apply to any instrument-rod combination. Record data on a standard recording form.

a. On the flattest possible ground, lay out a setup with precisely 20 m (66 ft.) between the turning points (using a tape to measure this and all other distances). Position the instrument on a line between and precisely 10 m (33 ft.) from each turning point (Figure 6).

b. In the Remarks column of the recording form (NOAA Form 75-29), enter the instrument type and serial number, rod type and serial numbers, and the names of the observer, recorder, and rodman. Check all serial numbers against the equipment actually used. Label the recording form Kukkamaki Collimation Check (Figure 7).

c. First setup. Level the instrument. Check that the circular levels on the instrument and the rods are properly adjusted. Observe and record a set of readings by either the micrometer or three-wire procedure. Use Rod 1 as the backsight. Check that the imbalance is no more than 0.4 m (1.3 ft.).

d. Second setup. Position the instrument in line with the turning point 20 m (66 ft.) from Rod 1. With Rod 1 as the backsight, observe and record another set of readings. Check that the distances are between 19.6 and 20.4 m (64.3 and 66.9 ft.). Remain in position until the collimation error has been checked.

e. Convert the elevation differences, Δh_1 and Δh_2, from rod units to millimeters. Look up the values for CR at the

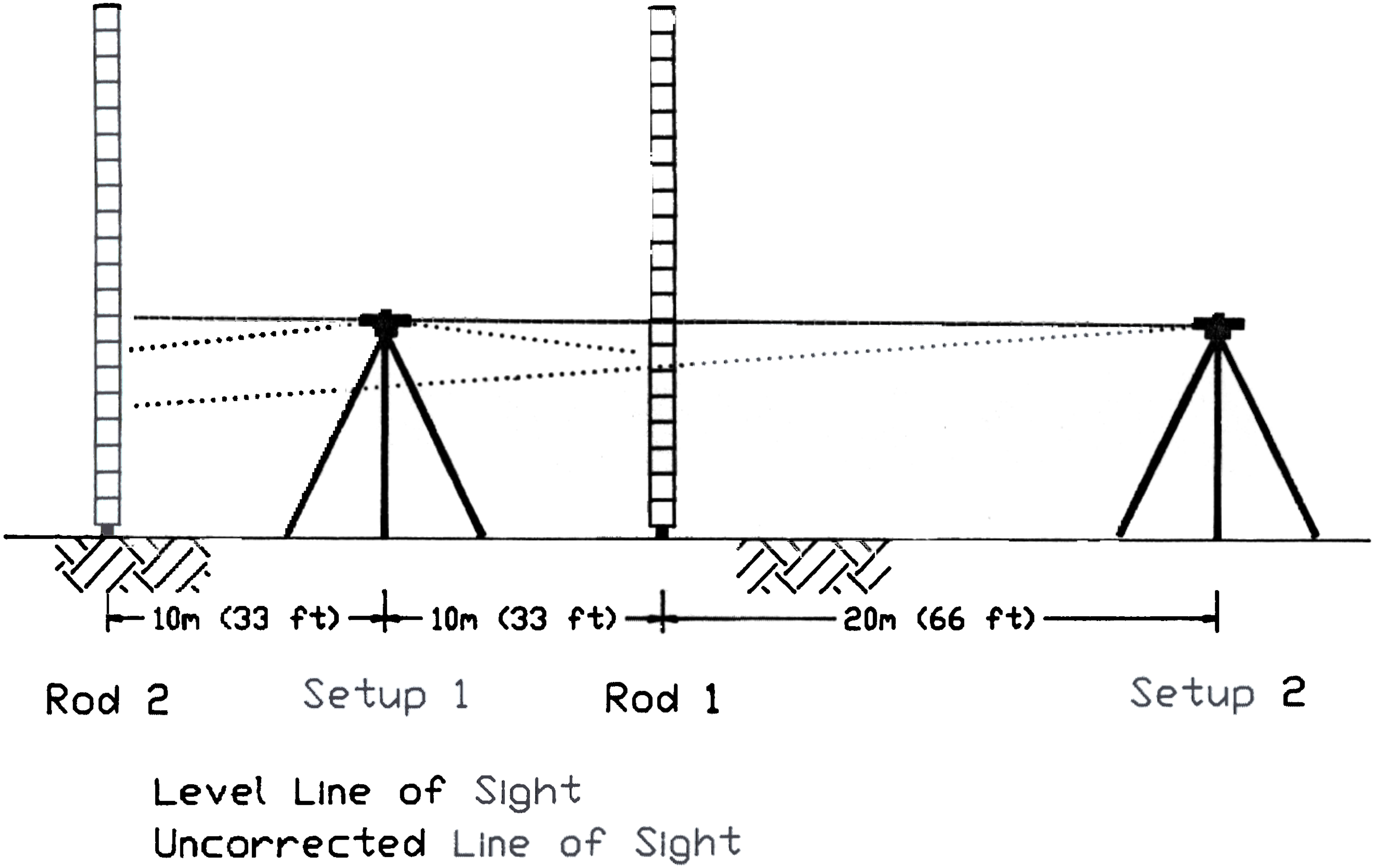
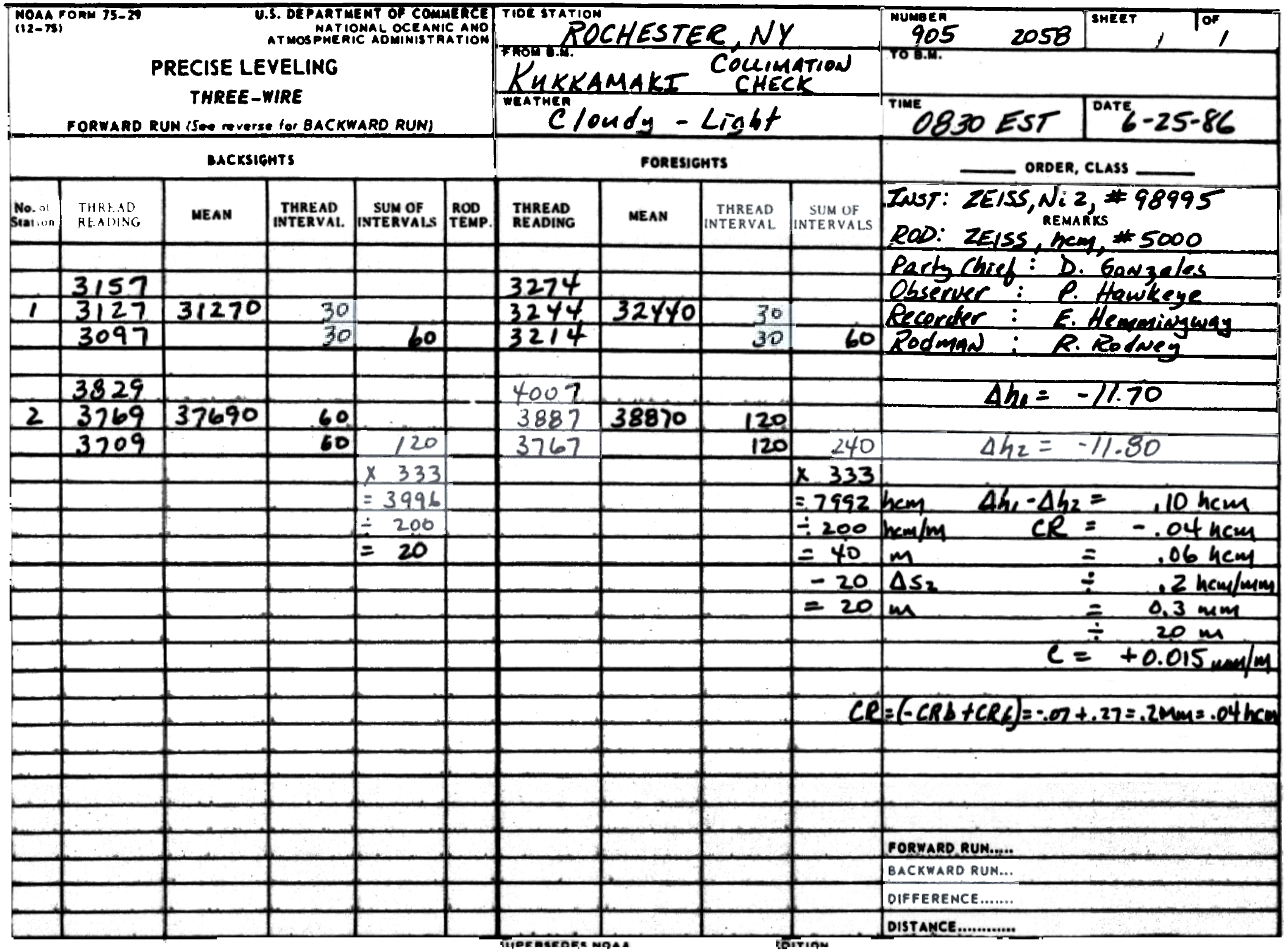


Figure 6 Kukkamaki Collimation Check Setup



NOAA FORM 75-29
(12-75)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

PRECISE LEVELING
THREE-WIRE
FORWARD RUN (See reverse for BACKWARD RUN)

TIDE STATION ROCHESTER, NY
FROM B.M. KUKKAMAKI COLLIMATION CHECK
WEATHER Cloudy - Light

NUMBER 905 2058
SHEET 1 OF 1
TO B.M.
TIME 0830 EST
DATE 6-25-86

ORDER, CLASS

INST: ZEISS, Ni 2, # 98995
ROD: ZEISS, hcm, # 5000

BACKSIGHTS						FORESIGHTS				
No. of Station	THREAD READING	MEAN	THREAD INTERVAL	SUM OF INTERVALS	ROD TEMP.	THREAD READING	MEAN	THREAD INTERVAL	SUM OF INTERVALS	REMARKS
										Party Chief : D. Gonzales
	3157					3274				Observer : P. Hawkeye
1	3127	31270	30			3244	32440	30		Recorder : E. Hemmingway
	3097		30	60		3214		30	60	Rodman : R. Rodney
	3829					4007				$\Delta h_1 = -11.70$
2	3769	37690	60			3887	38870	120		
	3709		60	120		3767		120	240	$\Delta h_2 = -11.80$
				x 333					x 333	
				= 3996					= 7992	hcm $\Delta h_1 - \Delta h_2 =$ .10 hcm
				÷ 200					÷ 200	hcm/m CR = -.04 hcm
				= 20					= 40	m = .06 hcm
									- 20	ΔS_2 ÷ .2 hcm/mm
									= 20	m = 0.3 mm
										÷ 20 m
										C = +0.015 mm/m
									CR	=(-CRb+CRf)=-.07+.27=.2mm=.04hcm
										FORWARD RUN.....
										BACKWARD RUN...
										DIFFERENCE.......
										DISTANCE............

SUPERSEDES NOAA EDITION

Figure 7 Example of Kukkamaki Collimation Check Calculations two sighting distances, 20 and 40 m (66 and 131 ft.), in Table 1. Compute the collimation error by:

$$C = \frac{(\Delta h_1 - \Delta h_2) - (CR_{20} - CR_{40})}{\Delta s_2}$$

f. Check C against the standard using:

$$C \leq \pm 0.05 \text{ mm/m}$$

If the standard is exceeded, adjust the instrument as follows

g. Compute the error, in rod units, resulting from collimation error in the reading made at 40 m (131 ft.) with:

$$\text{error}_{\text{rod units}} = 40 \times C_{\text{mm/m}} \times \text{conversion factor}_{\text{rod units/mm}}$$

For half-centimeter rods, the correction to the foresight readings is 8C. For centimeter rods, it is 4C. Subtract this value from the foresight reading, obtained on Rod 2 during the second setup. The result is the reading that should be obtained after adjusting the instruments. The instrument must not be moved until the adjustment is completed. Refer to the instrument manual for the mechanics of adjusting the instrument.

h. While still in position for the second setup, point toward Rod 2 and adjust the instrument until the line of sight intercepts the corrected reading.

i. Repeat the second setup (step d) and compute and check the new collimation error. Δh_1 remains unchanged.

3.6.3.6 <u>10-40 method</u> - The 10-40 method for making a collimation check is so called because each setup is unbalanced, with one rod 10 m (33 ft.) and the other 40 m (131 ft.) from the instrument.

The following instructions apply to any instrument-rod combination.

a. On the flattest possible ground, lay out a setup with precisely 50 m (164 ft.) between the turning points (using a tape for measurement). Position the instrument in line between the turning points, precisely 10 m (33 ft.) from Rod 1 (Figure 8).

b. In the Remarks column of the recording form (NOAA Form 75-29), enter the instrument type and serial number, rod type and serial numbers, and the name of the observer, recorder, and rodman. Check all serial numbers against the equipment actually used. Label the form 10-40 Collimation Check (Figure

c. First setup. Level the instrument. Check that the circular levels on the instrument and the rods are properly adjusted. Observe and record a set of readings by either the micrometer or three-wire procedure. Use Rod 1 as the backsight.

d. Second setup. Position the instrument in line between the turning points, precisely 10 m (33 ft.) from Rod 2. Observe and record another set of readings as in step c, using Rod 2 as the backsight.

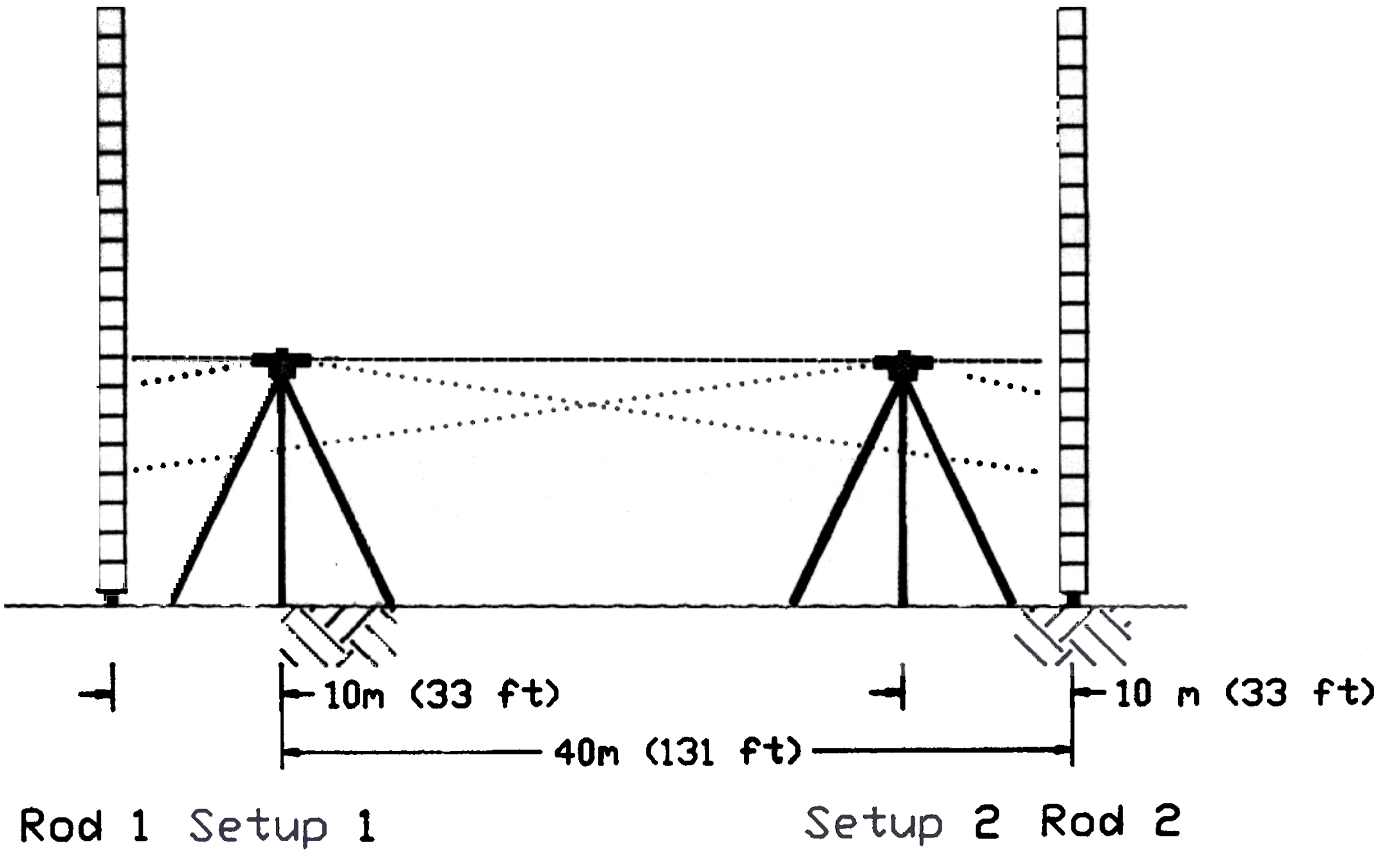
e. Convert the elevation differences, Δh_1 and Δh_2, from rod units to millimeters. Look up the values for CR at the two sighting distances, 10 and 40 m (33 and 131 ft.), in Table 1.

Compute the collimation error, in millimeters per meter, by the following formula:

$$C = \frac{(\Delta h_1 + \Delta h_2) - 2(CR_{10} - CR_{40})}{\Delta s_1 + \Delta s_2}$$

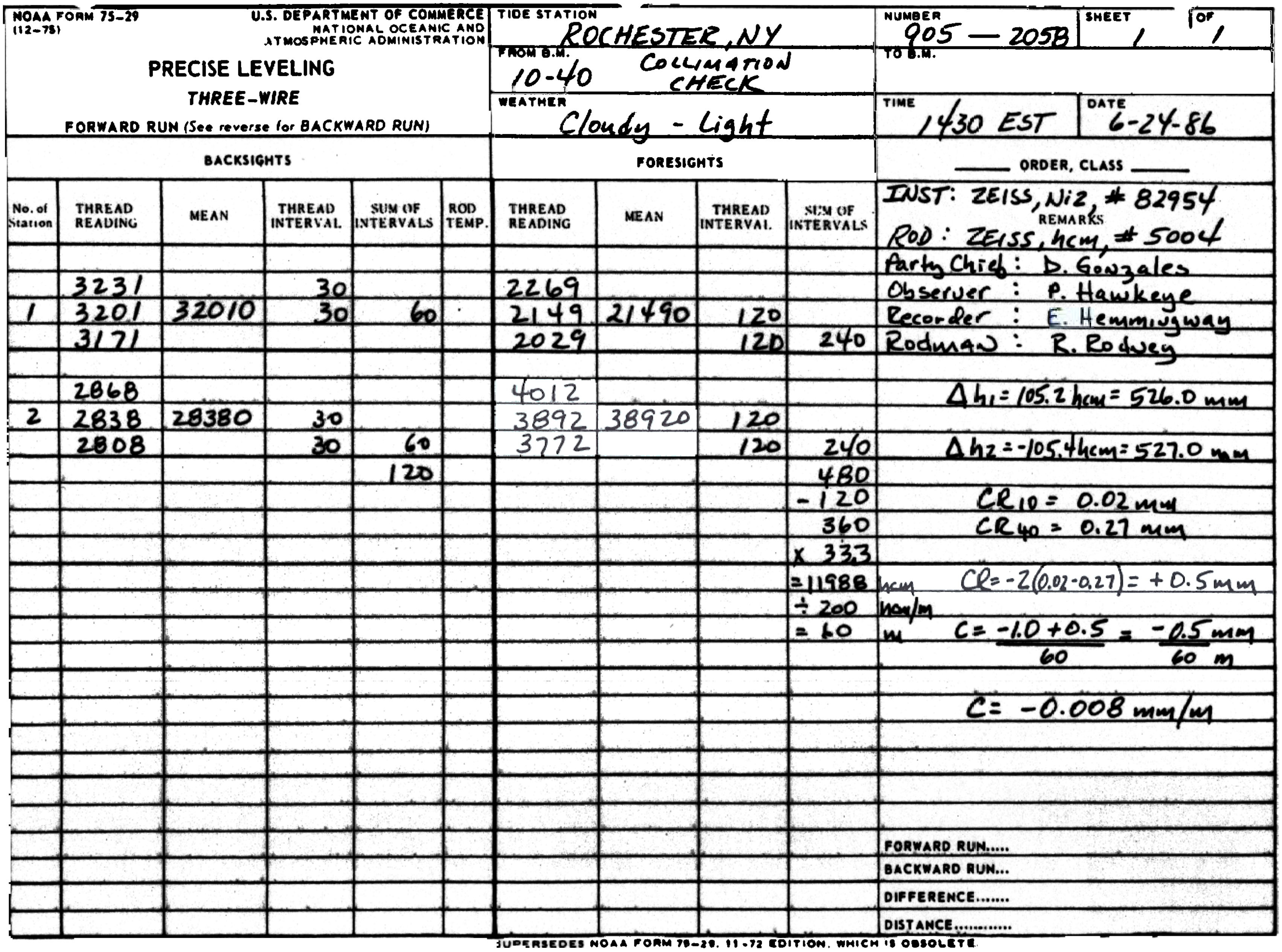
f. Check the collimation factor against the tolerance:

$C \leq \pm 0.05$ mm/m



Not to Scale

Figure 8 10-40 Collimation Check Setup



NOAA FORM 75-29
(12-75)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

PRECISE LEVELING

THREE-WIRE

FORWARD RUN (See reverse for BACKWARD RUN)

TIDE STATION: ROCHESTER, NY
NUMBER: 905 — 205B
SHEET: 1 OF 1
FROM B.M.: 10-40 COLLIMATION CHECK
TO B.M.:
WEATHER: Cloudy - Light
TIME: 1430 EST
DATE: 6-24-86

	BACKSIGHTS					FORESIGHTS				ORDER, CLASS
No. of Station	THREAD READING	MEAN	THREAD INTERVAL	SUM OF INTERVALS	ROD TEMP.	THREAD READING	MEAN	THREAD INTERVAL	SUM OF INTERVALS	INST: ZEISS, Ni2, # 82954 REMARKS ROD : ZEISS, hcm, # 5004
										Party Chief : D. Gonzales
	3231		30			2269				Observer : P. Hawkeye
1	3201	32010	30	60	·	2149	21490	120		Recorder : E. Hemmingway
	3171					2029		120	240	Rodman : R. Rodwey
	2868					4012				$\Delta h_1 = 105.2$ hcm $= 526.0$ mm
2	2838	28380	30			3892	38920	120		
	2808		30	60		3772		120	240	$\Delta h_2 = -105.4$ hcm $= 527.0$ mm
				120					480	
									- 120	$CR_{10} = 0.02$ mm
									360	$CR_{40} = 0.27$ mm
									x 333	
									= 11988	hcm $CR = -2(0.02 - 0.27) = +0.5$ mm
									÷ 200	hcm/m
									= 60	m $C = \frac{-1.0 + 0.5}{60} = \frac{-0.5 \text{ mm}}{60 \text{ m}}$
										$C = -0.008$ mm/m
										FORWARD RUN.....
										BACKWARD RUN...
										DIFFERENCE.......
										DISTANCE...........

SUPERSEDES NOAA FORM 75-29, 11-72 EDITION, WHICH IS OBSOLETE.

Figure 9 Example of 10-40 Collimation Check Calculations

If the tolerance is exceeded, adjust the instrument as described in steps g-i of the Kukkamaki method. Repeat the first setup.

3.6.3.7 <u>Compensation check</u> - When an automatic leveling instrument is approximately leveled, the compensator should be freely suspended, unaffected by its suspension and dampening mechanisms. The range of arc in which the compensator is expected to suspend freely should be somewhat greater than the arc described by a 2-mm movement of the bubble in the circular level. Thus, when the circular level is properly adjusted, the compensator should provide a line of sight having the same collimation error, within ±2 arc-seconds (±0.0097 mm/m), no matter which direction the instrument is pointed.

A compensator, however, may hang or stick in such a way that releveling or repositioning may not remove all the error introduced. The observer should lightly tap the side of the instrument on each pointing to make sure the image oscillates

3.7 <u>General Observing Routine</u> - Rodman A holds the rod plumb on the starting mark (usually the staff stop or ETG reading mark). The observer sets up a maximum of 60 m (200 ft.) away for second-order leveling or 90 m (300 ft.) for third-order. Rodman B paces the distance from A to the instrument, walks the same distance past the instrument toward the next mark, sets a turning point, and holds Rod B plumb (both rodmen must keep the bottom of the rods clean). The observer takes a backsight on Rod A [keeping the line of sight at least 0.5 m (1.6 ft.) above the ground], then a foresight on Rod B. Rodman A and the observer move to the next setup, A pacing the distance as B had done on the previous setup. The observer then takes a backsight on Rod B and a foresight on Rod A. This procedure is repeated throughout the forward and backward funs of the level circuit. When a single rod is used, the time between backsight and foresight should be kept to a minimum.

The instrument shall be off-leveled (physically moving the tripod) and releveled after the last foresight on the forward run, even though the instrument location does not change. This ensures that the backward and forward readings on the last mark are independent.

3.7.1 Parallax - The cross hairs in the level must lie in the common focal plane of the objective and eyepiece lenses. This is done by focusing the instrument on a distant light-colored object (sand, sky) and then focusing the cross hairs with the eyepiece. When in focus, the observer can move his eye up and down and the cross hairs will not move with respect to the level rod.

3.7.2 Balanced Sights - Forward and backward sights must be nearly equal in length in order to minimize the errors due to curvature of the earth and the collimation error of the instrument. The maximum allowable difference between forward and backward sights per setup is 5 m (16 ft.) for second-order leveling and 10 m (33 ft.) for third-order. The maximum cumulative difference between forward and backward sights between marks is 10 m (33 ft.) for both second- and third-order leveling. These lengths are determined by stadia readings for second-order and pacing for third-order. The instrument normally should not be refocused between backsights and foresights.

3.7.3 Sight Length - The maximum length of sight is 60 m (197 ft.) for second- and 90 m (295 ft.) for third-order. Normally, the sights should be shorter due to scintillation, wind, or haze. In any instance, the sight must be short enough to eliminate uncertainty in the reading.

The sighting distance (S) between the instrument and a leveling rod is observed and computed by the stadia method:

S = [I x Stadia Factor] + Stadia Constant

where;

I is the Stadia Interval = upper rod reading - lower rod reading in rod units,

Stadia Factor is a dimensionless number, usually a function of the spacing of the upper and lower stadia lines in the reticle (in most instruments it is 100:1 or 333:1), and

Stadia Constant is the distance from the instrument to the point from which the stadia factor is used to determine sighting distance (in most instruments with internal focusing telescopes, as in the Zeiss Ni2, the stadia constant is equal to zero).

The use of the above formula will result in distances in rod units. These units are to be converted to meters or feet and ultimately to kilometers or miles.

3.7.4 Atmospheric Conditions - During precise leveling, atmospheric conditions must be determined. The purpose is two-fold; to correct for the effects of atmospheric refraction on the line of sight and to correct for effects of thermal expansion of rod scales. The three measurements to be recorded in the proper locations on the recording sheets for each section of leveling are air temperature, solar radiation intensity, and wind speed (see also Balazs and Young, 1982). Air temperature is measured to the nearest degree and recorded in the appropriate measurement unit at the beginning and ending of every section.

Solar radiation should be recorded as: Overcast - fewer than 25 percent of setups performed under sunny conditions, Cloudy - 25 to 75 percent of setups performed under sunny conditions, and Clear - more than 75 percent of setups performed under sunny conditions. Wind speed should be estimated and recorded as: Light - wind speed averaged less than 10 km (6 mi.) per hour, Moderate - wind speed averaged 10 to 25 km (6 to 15 mi.) per hour, and Strong - wind speed averaged greater than 25 km (15 mi.) per hour.

3.7.5 Closure Tolerance - The maximum closure tolerance between the forward and backward running of a section is $6\ \text{mm}\sqrt{K}$ ($0.025\ \text{ft.}\sqrt{M}$) for second-order leveling and $12\ \text{mm}\sqrt{K}$ ($0.050\ \text{ft.}\sqrt{M}$) for third-order, where K and M are the length of the section measured in kilometers and miles, respectively. Closure tolerances for one setup sections, two runnings of sections less than 0.10 km, and all other sections from 0.10 to 1.60 km in length are listed in Table 2. Tolerances in English units are also given in Table 2. If the closure tolerance is greater than allowed, the section shall be rerun until independent forward and backward runs agree within the allowable limits.

Random and systematic errors usually cause some differences in closing. The allowable closure tolerance is used to eliminate blunders and systematic errors too large for the required accuracy. The prescribed procedures minimize systematic errors. Sections with excessive misclosures must be rerun until a satisfactory closure is obtained.

3.7.6 Cumulative Closure - It is possible to have individual sections that by themselves have acceptable closure tolerances but, when combined, exceed the maximum allowable closure tolerance. The summation of the divergences must never exceed the closure tolerance for the corresponding summation of distance. This may at times require a rerun of the section or sections which individually close but, when combined, do not. For example, two 0.5-km sections, each with differences between forward and backward runs of 0.0040 m, would individually close (maximum allowable 0.0042 m) but, when combined, become a 1.0-km run with a closure of 0.0080 m. This exceeds the maximum allowable limit of 0.0060 m. A cumulative closure tolerance is exceeded typically when several consecutively run sections are very close to the individual closure tolerances and the divergences all have the same sign. This is particularly apt to occur when one or more very short section (typically the staff to the first bench mark) barely closes under the one setup closure tolerance as the distance is minimized and the divergence maximized.

A cumulative closure tolerance may also be exceeded by an instrument that is out of calibration. An example of one such condition is where level sections are being run on a fairly steep incline. Refraction is greatest when the top of one rod is read and then the bottom of the other. This error is magnified due to the many setups it may take to run a steep section, even though the actual distance may not be great.

Table 2 Maximum closure tolerance

METRIC UNITS

DISTANCE (KILOMETER)	SECOND-ORDER (6 mm $\sqrt{K}$)	THIRD-ORDER (12 mm $\sqrt{K}$)
One setup section	0.0010 METER	0.0020 METER
Two runnings of a section less than 0.10 km in length	0.0019	0.0038
0.10	0.0019	0.0038
0.11	0.0020	0.0040
0.12	0.0021	0.0042
0.13	0.0022	0.0043
0.14	0.0022	0.0045
0.15	0.0023	0.0046
0.16	0.0024	0.0048
0.17	0.0025	0.0049
0.18	0.0025	0.0051
0.19	0.0026	0.0052
0.20	0.0027	0.0054
0.21	0.0027	0.0055
0.22	0.0028	0.0056
0.23	0.0029	0.0058
0.24	0.0029	0.0059
0.25	0.0030	0.0060
0.26	0.0031	0.0061
0.27	0.0031	0.0062
0.28	0.0032	0.0063

Table 2 (Continued)

DISTANCE (KILOMETER)	SECOND-ORDER (6 mm $\sqrt{K}$)	THIRD-ORDER (12 mm $\sqrt{K}$)
0.29	0.0032	0.0065
0.30	0.0033	0.0066
0.31	0.0033	0.0067
0.32	0.0034	0.0068
0.33	0.0034	0.0069
0.34	0.0035	0.0070
0.35	0.0035	0.0071
0.36	0.0036	0.0072
0.37	0.0036	0.0073
0.38	0.0037	0.0074
0.39	0.0037	0.0075
0.40	0.0038	0.0076
0.45	0.0040	0.0080
0.50	0.0042	0.0085
0.55	0.0044	0.0089
0.60	0.0046	0.0093
0.65	0.0048	0.0097
0.70	0.0050	0.0100
0.75	0.0052	0.0104
0.80	0.0054	0.0107
0.85	0.0055	0.0111
0.90	0.0057	0.0114
1.00	0.0060	0.0120
1.05	0.0061	0.0123
1.10	0.0063	0.0126
1.15	0.0064	0.0129
1.20	0.0066	0.0131
1.25	0.0067	0.0134
1.30	0.0068	0.0137
1.35	0.0070	0.0139

Table 2 (Continued)

DISTANCE (KILOMETER)	SECOND-ORDER ($6\ \text{mm}\sqrt{K}$)	THIRD-ORDER ($12\ \text{mm}\sqrt{K}$)
1.40	0.0071	0.0142
1.45	0.0072	0.0144
1.50	0.0073	0.0147
1.55	0.0075	0.0149
1.60	0.0076	0.0152

K=DISTANCE OF RUN (ONE WAY) IN KILOMETERS

Table 2 (Continued)

ENGLISH UNITS

DISTANCE (MILES)	SECOND-ORDER (.025 ft. $\sqrt{M}$)	THIRD-ORDER (.050 ft. $\sqrt{M}$)
One setup section	0.003 FEET	0.007 FEET
Two runnings of a section less than 0.06 mi. in length	0.006	0.012
0.06	0.006	0.012
0.07	0.007	0.013
0.08	0.007	0.014
0.09	0.008	0.015
0.10	0.008	0.016
0.11	0.008	0.017
0.12	0.009	0.017
0.13	0.009	0.018
0.14	0.009	0.019
0.15	0.010	0.019
0.16	0.010	0.020
0.17	0.010	0.021
0.18	0.011	0.021
0.19	0.011	0.022
0.20	0.011	0.022
0.21	0.012	0.023
0.22	0.012	0.024
0.23	0.012	0.024
0.24	0.012	0.025
0.25	0.013	0.025
0.26	0.013	0.026
0.27	0.013	0.026

Table 2 (Continued)

DISTANCE (MILES)	SECOND-ORDER (.025 ft. $\sqrt{M}$)	THIRD-ORDER (.050 ft. $\sqrt{M}$)
0.28	0.013	0.027
0.29	0.014	0.027
0.30	0.014	0.027
0.31	0.014	0.028
0.32	0.014	0.028
0.33	0.014	0.029
0.34	0.015	0.029
0.35	0.015	0.030
0.36	0.015	0.030
0.37	0.015	0.030
0.38	0.015	0.031
0.39	0.016	0.031
0.40	0.016	0.032
0.45	0.017	0.034
0.50	0.018	0.035
0.55	0.019	0.037
0.60	0.019	0.039
0.65	0.020	0.040
0.70	0.021	0.042
0.75	0.022	0.043
0.80	0.022	0.045
0.85	0.023	0.046
0.90	0.024	0.047
0.95	0.024	0.049
1.00	0.025	0.050

M=DISTANCE OF RUN (ONE WAY) IN MILES

3.7.7 Leveling Procedures to the Reading Mark (RM) of the Electric Tape Gage (ETG) - When leveling to the zero of the ETG, a section of calibrated steel tape or a specially designed short rod is held at the center of the RM line. Care must be taken to ensure that the tape is held plumb and that the zero on the tape is held stationary. The tape is read in the same way as a rod. A note is made in the record indicating which of the readings were made on tape, the type of tape, and the graduation units of tape

It is preferable that the graduation interval on the tape be the same as on the rod used in the rest of the section. When the same interval is not available, all graduation conversions are t be recorded and completed on the level record form. This same procedure may be followed when leveling to vertically set marks.

In those cases when a tape is read below the reading mark (or vertical mark), the observations are to be entered in proper order (top wire, middle wire, bottom wire), and entered in the proper Backsight or Foresight columns (but with a negative sign to reflect the down shot). The observation is then computed algebraically with the other observations. Note in Remarks on the level record form that the observation was a tape shot observed below the bench mark, i.e., "Tape down".

3.8 Field Records and Computations - The field notes are the only reliable record of the measurements and other pertinent information obtained. The reliability of these records are always under suspicion unless the records have been entered in the field book at the time and place of observation. If, for clarity, an original record is copied, the original and copy are to be appropriately labeled and submitted together.

The record shall always be made in ink and be as neat and clear as possible. No erasures shall be made and no correction fluid used. If an entry is found to be in error, it is crossed out neatly with a single line to retain legibility and the correction entered immediately above. All corrections are initialed by the corrector. All computations shall be checked before leaving the station.

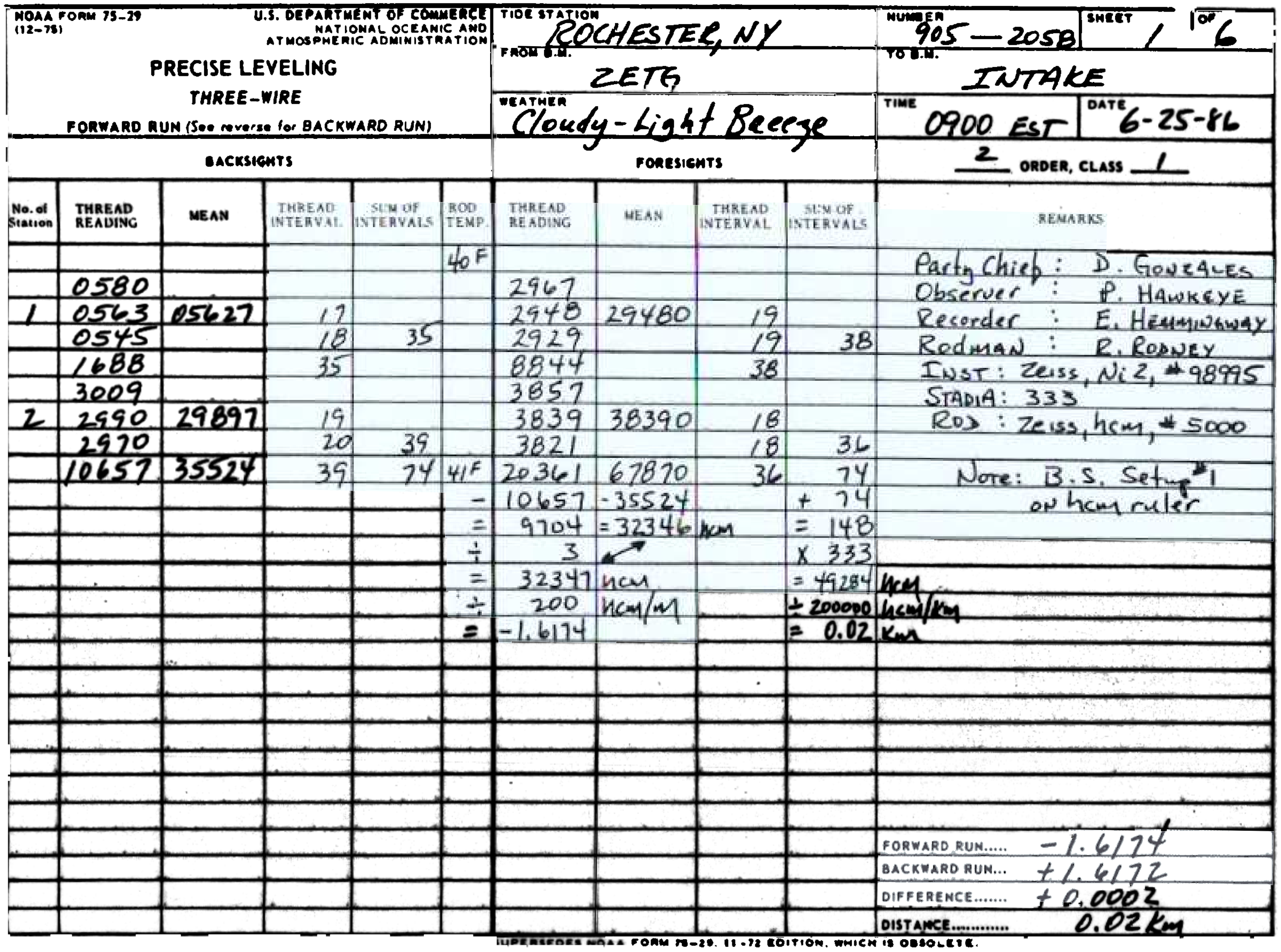
3.8.1 Tabulation and Computation of Second-Order Levels -

The following discussion on recording three-wire leveling will serve to illustrate the method of recording and also explain some details on the method of observations.

3.8.1.1 Three-wire procedures -

NOAA Form 75-29, PRECISE LEVELING THREE-WIRE, is a loose-leaf recording form. The forward run is recorded on the front side (Figure 10) and the backward run on the reverse (Figure 11). The first sheet contains information on the personnel, rod (type and graduations), and instrument (type, manufacturer, stadia factor, and serial number). Each section is reduced in the lower right hand corner; the recorder must check to see that each section closes along with the cumulative run. The loose-leaf sheets for each station are to be attached together with the abstract sheet, NOAA Form 76-183. Computations are checked before forwarding to the appropriate office.

In defining the difference in elevations for each station leveled the difference in elevations is to be computed from the computations in the columns subtitled Thread Reading on NOAA Form 75-29, at the entries titled Backsights and Foresights. This method is more precise than using calculations from the values in the columns subtitled Mean. The calculations obtained from the columns subtitled Mean are an additional check on the difference in elevations for the section run, and must be computed and shown on the level sheet. Only the quantities computed from the columns Thread Reading shall be entered at the entries titled Forward Run and Backward Run. The entries shall be transferred to the abstract sheet.



NOAA FORM 75-29
(12-75)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

PRECISE LEVELING
THREE-WIRE
FORWARD RUN (See reverse for BACKWARD RUN)

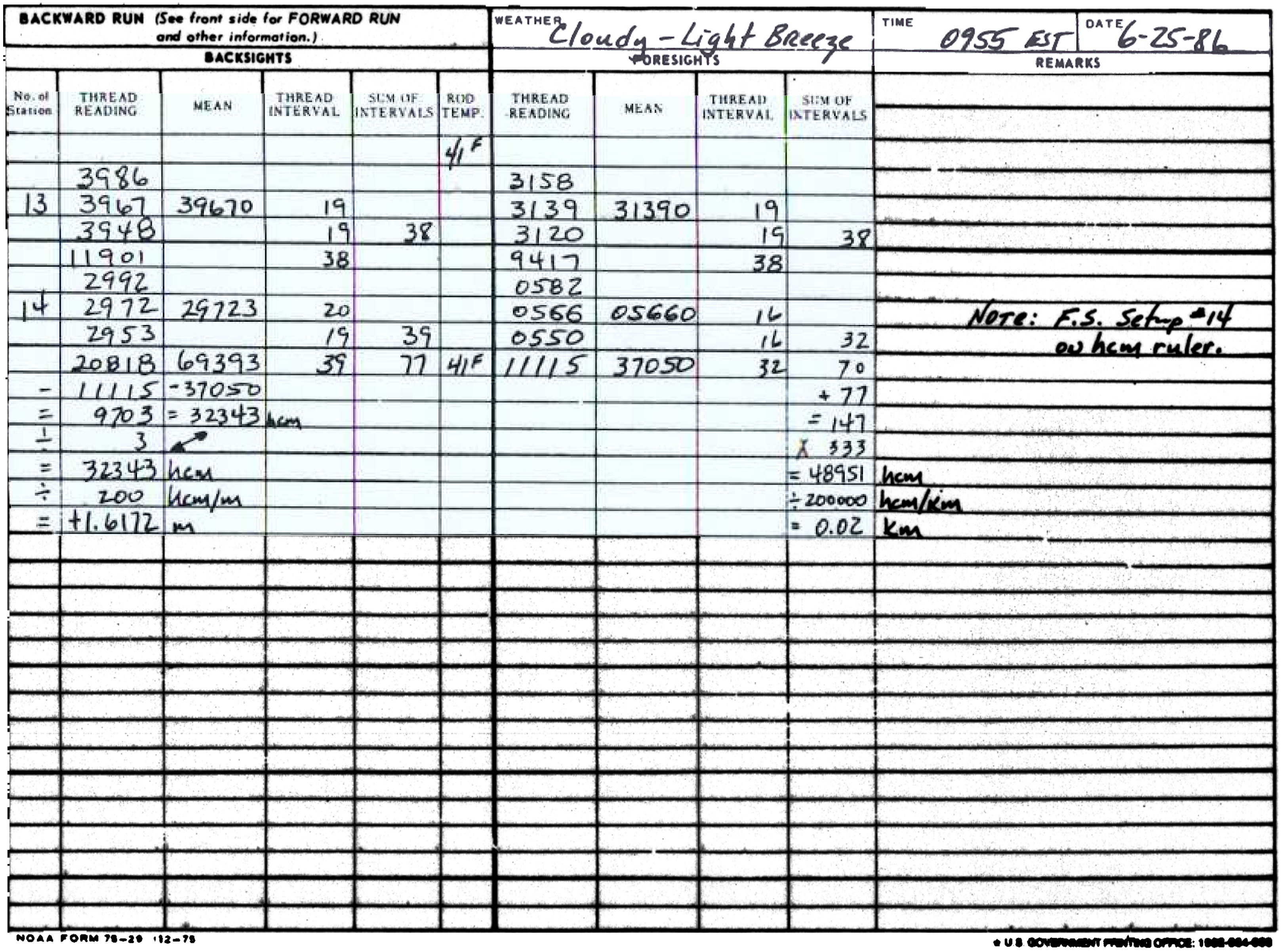
TIDE STATION ROCHESTER, NY
NUMBER 905 — 205B
SHEET 1 OF 6
FROM B.M. ZETG
TO B.M. INTAKE
WEATHER Cloudy-Light Breeze
TIME 0900 EST
DATE 6-25-86
2 ORDER, CLASS 1

	BACKSIGHTS					FORESIGHTS				
No. of Station	THREAD READING	MEAN	THREAD INTERVAL	SUM OF INTERVALS	ROD TEMP.	THREAD READING	MEAN	THREAD INTERVAL	SUM OF INTERVALS	REMARKS
					40F					Party Chief : D. Gonzales
	0580					2967				Observer : P. Hawkeye
1	0563	05627	17			2948	29480	19		Recorder : E. Hemmingway
	0545		18	35		2929		19	38	Rodman : R. Rodney
	1688		35			8844		38		Inst : Zeiss, Ni 2, #98995
	3009					3857				Stadia : 333
2	2990	29897	19			3839	38390	18		Rod : Zeiss, hcm, #5000
	2970		20	39		3821		18	36	
	10657	35524	39	74	41F	20361	67870	36	74	Note: B.S. Setup #1
					−	10657	-35524		+ 74	on hcm ruler
					=	9704	=32346 hcm		= 148	
					÷	3			X 333	
					=	32347 hcm			= 49284	hcm
					÷	200	hcm/m		÷ 200000	hcm/km
					=	-1.6174			= 0.02	km

FORWARD RUN..... −1.6174
BACKWARD RUN... +1.6172
DIFFERENCE....... +0.0002
DISTANCE........... 0.02 km

SUPERSEDES NOAA FORM 75-29, 11-72 EDITION, WHICH IS OBSOLETE.

Figure 10 Procedures for Recording Three-wire Leveling, Including Computation of Section Elevation Difference and Length (Forward Run)



BACKWARD RUN *(See front side for FORWARD RUN and other information.)*

WEATHER Cloudy - Light Breeze | TIME 0955 EST | DATE 6-25-86

BACKSIGHTS						FORESIGHTS				REMARKS
No. of Station	THREAD READING	MEAN	THREAD INTERVAL	SUM OF INTERVALS	ROD TEMP.	THREAD READING	MEAN	THREAD INTERVAL	SUM OF INTERVALS	
					41F					
	3986					3158				
13	3967	39670	19			3139	31390	19		
	3948		19	38		3120		19	38	
	11901		38			9417		38		
	2992					0582				
14	2972	29723	20			0566	05660	16		Note: F.S. Setup #14
	2953		19	39		0550		16	32	on hcm ruler.
	20818	69393	39	77	41F	11115	37050	32	70	
-	11115	-37050							+ 77	
=	9703	= 32343 hcm							= 147	
÷	3								X 333	
=	32343	hcm							= 48951	hcm
÷	200	hcm/m							÷ 200000	hcm/km
=	+1.6172	m							= 0.02	km

NOAA FORM 76-29 (12-75)

★ U.S. GOVERNMENT PRINTING OFFICE: 1982-

Figure 11 Procedures for Recording Three-wire Leveling, Including Computation of Section Elevation Difference and Length (Backward Run)

The instrument stations (not the turning points) are numbered consecutively as shown in the column headed No. of Station, through the entire level run. The last digits (in rod units) in the columns headed Thread Reading, Thread Interval, and Sum of Intervals correspond directly to the rod graduation pattern and are estimated to tenths of the rod unit (e.g., half millimeters for rods graduated in half centimeter units, or millimeters for rods in full centimeter units). The entries in the columns headed Mean are carried one place further than the readings themselves.

The column headed Thread Interval shows the interval between the upper and middle thread readings and the middle and lower readings. The comparison of the upper and lower thread intervals (half intervals) serves two functions. The first, an indication of the presence of observational blunders, is exhibited by the difference between the two intervals. The difference must agree within three units (of the last estimated digit) for readings on a 0.5-centimeter (graduated) rod, two units for readings on a 0.01-meter rod, two units for readings on a 0.01-yard rod, and five units for readings on a 0.01-foot rod. If the agreement is not met on the first attempt, all three threads should be reread.

If agreement is still not obtained, the instrument should be off-leveled and releveled in place, and the setup reobserved. The thread interval should not be forced. Nonzero agreement (within the allowable tolerance) is not to be confused with inaccurate readings. It is a function of the resolution of the rod, instrument, and the distance between the two.

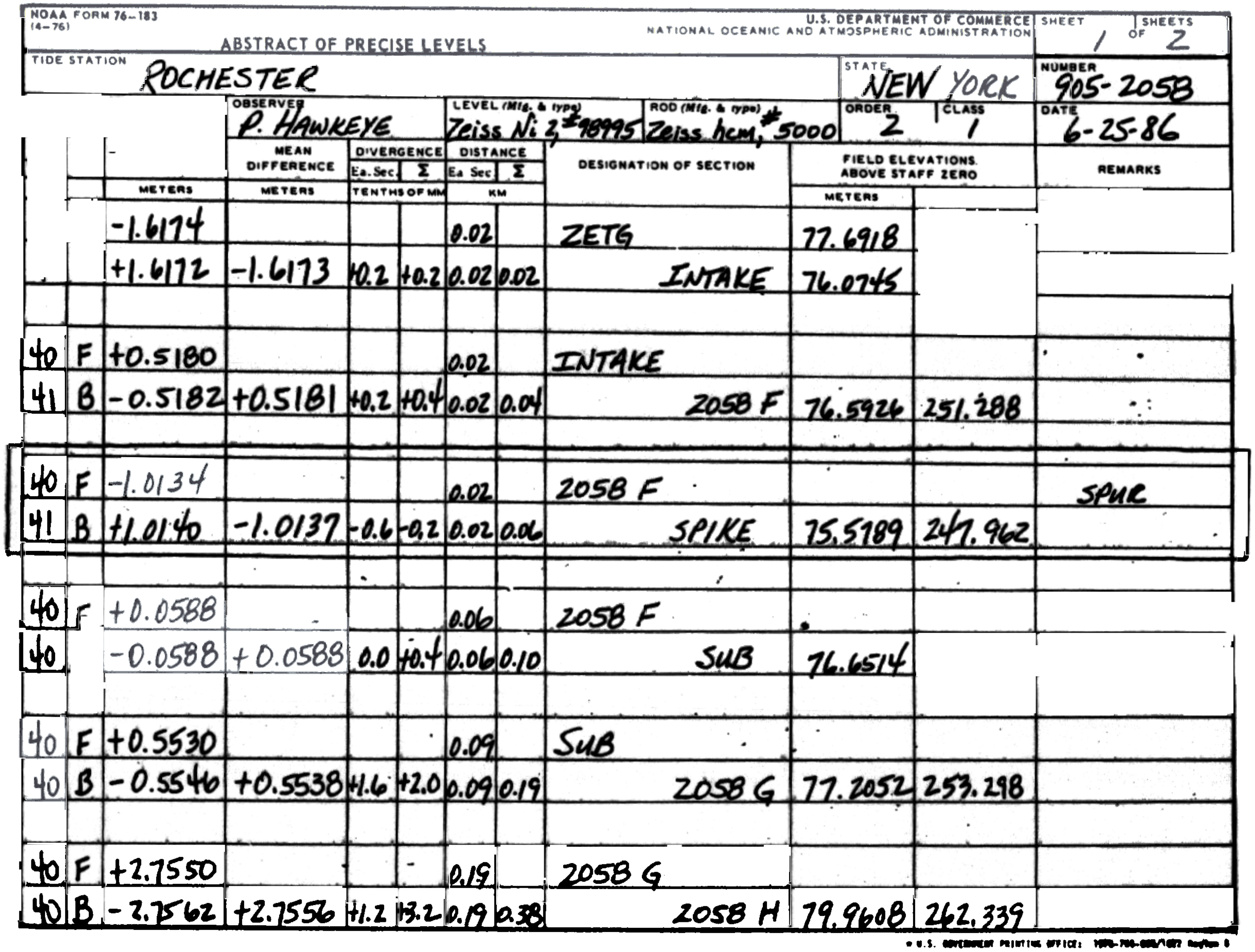
The second function of the comparison of half intervals is to offer a short method for meaning the three thread readings. It allows the recorder to use the fact that the difference of the upper and lower half intervals, when divided by three, is the correction to be applied (with proper sign) to the middle thread reading in order to give the mean of the three. It is then noted in the Mean column.

The length of a section is computed by converting the total Sum of Intervals for the forward run (backsights and foresights) to rod units, multiplying by the instrument stadia factor (normally 100 or 333), and then converting to kilometers or miles and noting the result in the Distance block on NOAA Form 75-29. Example procedures for recording three-wire leveling, including the computation of section elevation difference and length, are shown in Figures 10 and 11.

3.8.1.2 Abstract of precise leveling - NOAA Form 76-183 (Figures 12 and 13) shall be completed and submitted for each second-order, class I level run. The headings on the form are self-explanatory. Each abstract sheet shall show the separate results of each running over each section (including rejected sections), the mean difference, the divergence, the length of th section, the designation of each section, the cumulative divergence and distance of each bench mark from the staff or ETG, and the total distance (all spurs) of levels run. Rejected runs are designated by an R placed beside the rejected number.

The field elevations of each bench mark are computed above the zero of the staff or the reference relative to the RM of the ETG, except at Great Lakes network stations where the field elevations are computed from the published elevation of the PBM. To convert the starting elevation of the staff rod step or PBM from feet to meters, multiply feet by 0.3048, exactly, to obtain meters.

Sections of leveling at each station are arranged in order along the line from the staff or ETG toward the last bench mark to be leveled. A majority of the bench marks to be leveled shall constitute the main line of leveling. Spur leveling shall be



NOAA FORM 76-183
(4-76)

ABSTRACT OF PRECISE LEVELS

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

SHEET 1 OF 2 SHEETS

TIDE STATION ROCHESTER

STATE NEW YORK

NUMBER 905-2058

OBSERVER P. HAWKEYE

LEVEL (Mfg. & type) Zeiss Ni 2 #98995

ROD (Mfg. & type) Zeiss hcm, #5000

ORDER 2

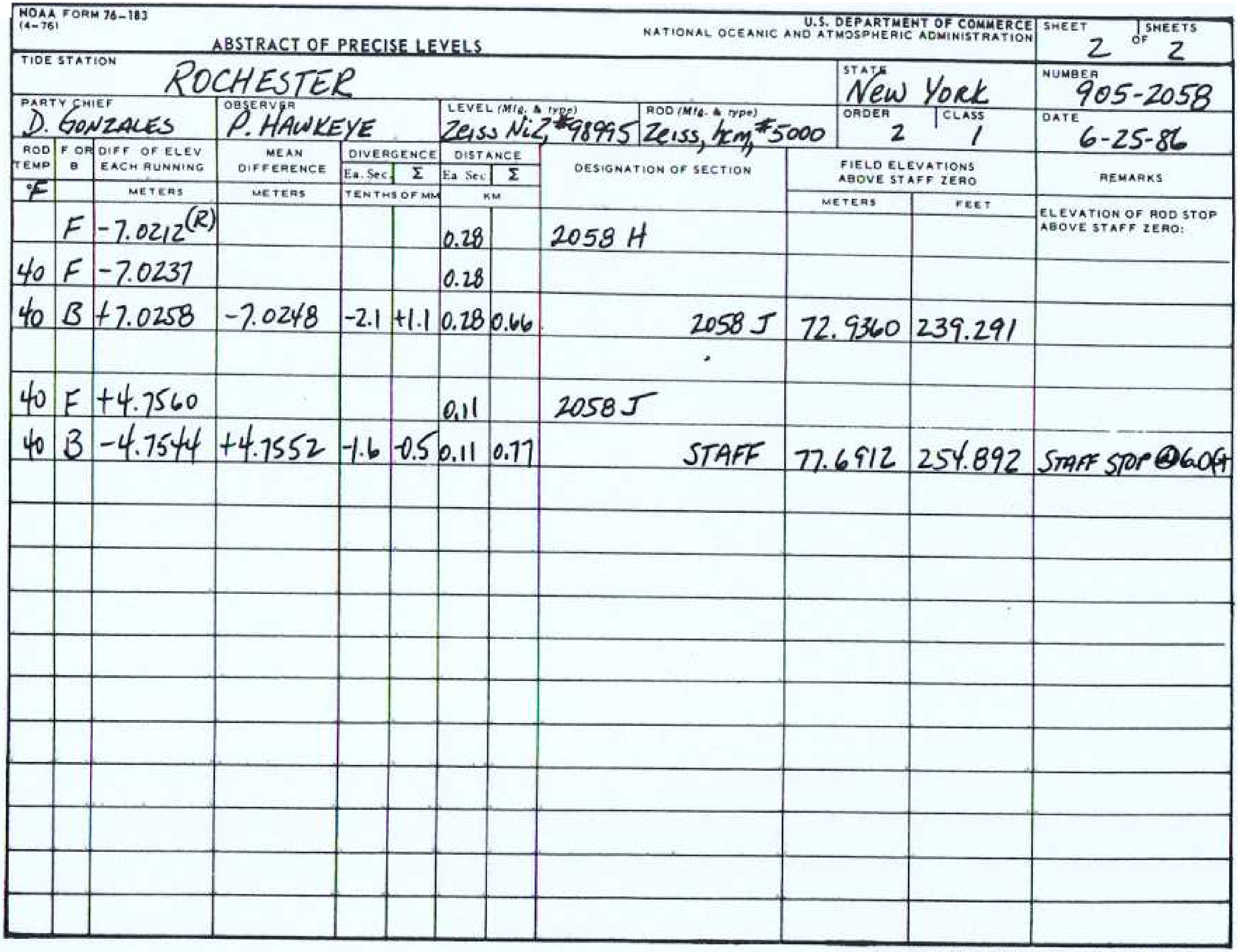
CLASS 1

DATE 6-25-86

			MEAN DIFFERENCE	DIVERGENCE		DISTANCE		DESIGNATION OF SECTION		FIELD ELEVATIONS ABOVE STAFF ZERO		REMARKS
				Ea. Sec.	Σ	Ea. Sec	Σ					
		METERS	METERS	TENTHS OF MM		KM				METERS		
		-1.6174				0.02		ZETG		77.6918		
		+1.6172	-1.6173	+0.2	+0.2	0.02	0.02		INTAKE	76.0745		
40	F	+0.5180				0.02		INTAKE				
41	B	-0.5182	+0.5181	+0.2	+0.4	0.02	0.04		2058 F	76.5926	251.288	
40	F	-1.0134				0.02		2058 F				SPUR
41	B	+1.0140	-1.0137	-0.6	-0.2	0.02	0.06		SPIKE	75.5189	247.962	
40	F	+0.0588				0.06		2058 F				
40		-0.0588	+0.0588	0.0	+0.4	0.06	0.10		SUB	76.6514		
40	F	+0.5530				0.09		SUB				
40	B	-0.5546	+0.5538	+1.6	+2.0	0.09	0.19		2058 G	77.2052	253.298	
40	F	+2.7550				0.19		2058 G				
40	B	-2.7562	+2.7556	+1.2	+3.2	0.19	0.38		2058 H	79.9608	262.339	

* U.S. GOVERNMENT PRINTING OFFICE:

Figure 12 Example of Abstract of Precise Levels - (computations in this example are referenced to the published elevation of a primary bench mark)



NOAA FORM 76-183
(4-76)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

ABSTRACT OF PRECISE LEVELS

SHEET 2 OF 2 SHEETS

TIDE STATION ROCHESTER				STATE New York	NUMBER 905-2058
PARTY CHIEF D. GONZALES	OBSERVER P. HAWKEYE	LEVEL (Mfg. & type) Zeiss NiZ, #98995	ROD (Mfg. & type) Zeiss, hcm, #5000	ORDER 2 CLASS 1	DATE 6-25-86

ROD TEMP °F	F OR B	DIFF OF ELEV EACH RUNNING METERS	MEAN DIFFERENCE METERS	DIVERGENCE Ea. Sec.	DIVERGENCE Σ	DISTANCE Ea Sec	DISTANCE Σ	DESIGNATION OF SECTION	FIELD ELEVATIONS ABOVE STAFF ZERO METERS	FIELD ELEVATIONS ABOVE STAFF ZERO FEET	REMARKS
				TENTHS OF MM		KM					ELEVATION OF ROD STOP ABOVE STAFF ZERO:
	F	-7.0212(R)				0.28		2058 H			
40	F	-7.0237				0.28					
40	B	+7.0258	-7.0248	-2.1	+1.1	0.28	0.66	2058 J	72.9360	239.291	
40	F	+4.7560				0.11		2058 J			
40	B	-4.7544	+4.7552	-1.6	-0.5	0.11	0.77	STAFF	77.6912	254.892	STAFF STOP @6.0ft

* U.S. GOVERNMENT PRINTING OFFICE: 1976-785-005/1022 Region 6

Figure 13 Example of Abstract of Precise Levels (continued) listed following the bench mark on the main line from which the spur departs. Proper notation indicating the spur leveling shall be made in the Remarks column.

The computation of a line of levels is a progressive calculation and to have all the sections in their proper order will not only facilitate the computation, but will make errors in the computed elevations much less likely to occur. All entries on the abstract pertaining to spur lines shall be boxed in on the form with the notation Spur made in the Remarks column.

If staff or ETG reading mark movement in excess of 0.020 ft. (relative to the PBM) is indicated by comparing current levels with the preceding levels, another level run shall be performed. It shall be performed immediately from the staff or ETG reading mark to a minimum of three marks (including the PBM) in order to verify the movement.

3.8.2 Tabulation and Computation of Third-Order Levels - The equipment and procedures are less precise than for second-order leveling. Only the middle (center) wire is observed and recorded, the length of the sights are balanced by pacing, the closure tolerance of 12 mm$\sqrt{K}$ (0.050 ft.$\sqrt{M}$), and non-Invar rods (metal) may be used.

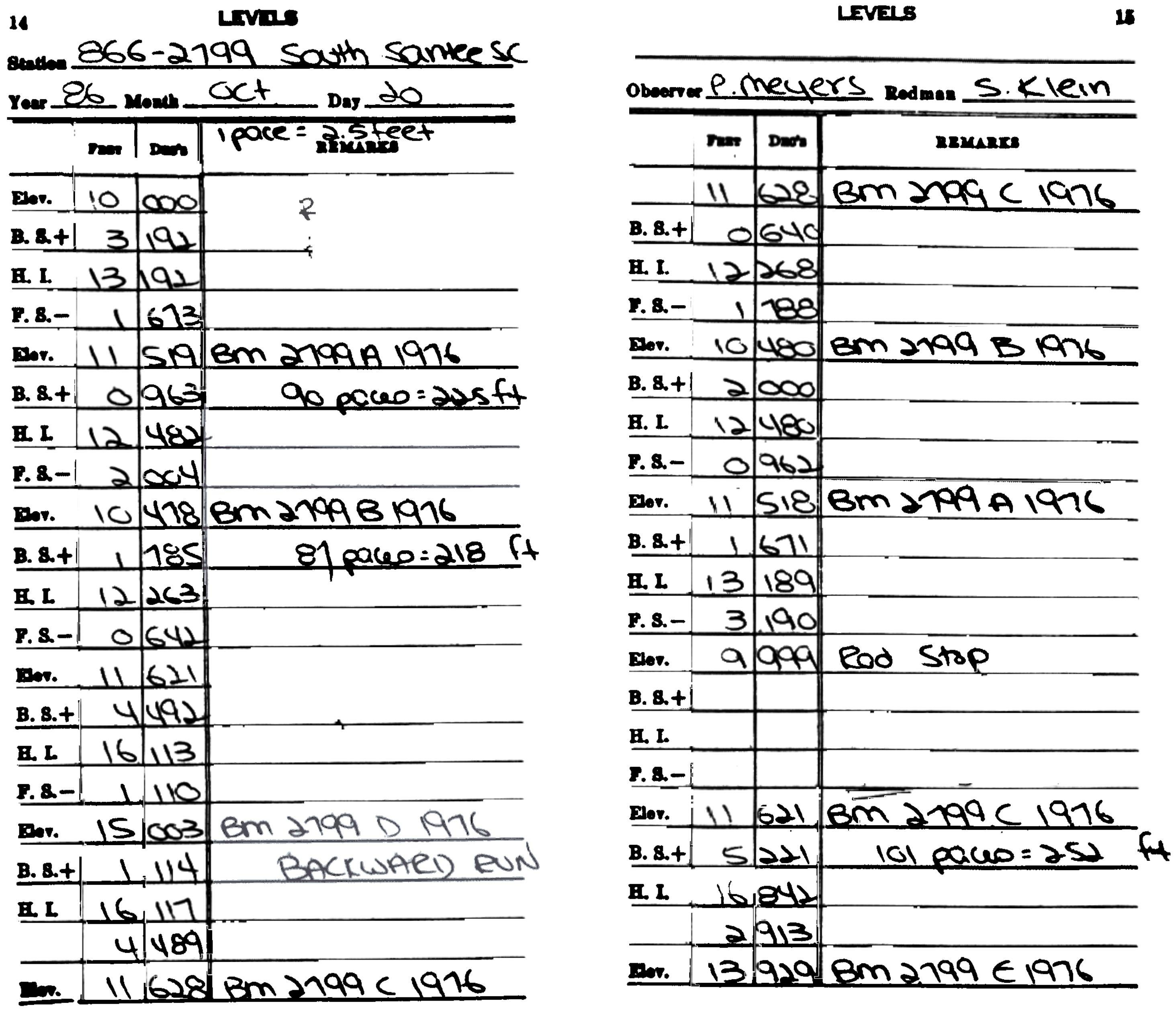
LEVELING RECORD-TIDE STATION (NOAA Form 76-77) is used to record all field data obtained at the station where third-order leveling is performed. The station information required on the front of the recording book must be completed and should include: station name, station number, chief of party, observer, rodman, and the instrument and rod(s) (with type, manufacturer, serial number(s) and rod unit graduation). Page three, Description of Tide Staff, must be completed for each level run. New bench mark descriptions or recovery notes need to be recorded on pages 6-13, Description of Bench Mark, or submitted on the appropriate NOAA forms as detailed in Section 2.12.

The levels are run from the staff to each bench mark in line and then back along the same route (if field conditions warrant, a double-run spur line is acceptable). Running loops or observing more than one backsight and one foresight from each individual setup is unacceptable.

It is necessary to determine the distance of the level run to ensure closure. The length of sections can be calculated by taping, stadia, or pacing. Paces are converted to a foot or meter distance. This information should be recorded on page 5 Remarks, or on the inner margins of the level record pages, in the Remarks column.

The leveling results are abstracted on the last two pages of the recording book. Instructions for filling out this abstract are printed in the book. It is important to convert final meter elevations to feet (multiply meters by 3.2808399 to obtain feet). Note the elevation above zero of the staff. Measure the distance from the zero mark to the staff stop. Under no circumstances shall the average of the starting elevation and ending elevation be used. At Great Lakes network stations, the abstract should be completed with the bench mark and ETG elevations referred to the published elevation of the PBM. The following examples (Figures 14-18) illustrate the proper recording and abstracting procedures for leveling with a metric or foot rod.

The use of three-wire leveling procedures for third-order leveling is encouraged. The procedures are identical to those discussed in Section 3.8.1.1 for second-order, however, the equipment and the tolerances conform to third-order standards. Also, NOAA Form 75-29, PRECISE LEVELING THREE-WIRE, is used for recording and NOAA Form 76-183, ABSTRACT OF PRECISE LEVELS, is used for the abstract. The three-wire observation method is considered superior to the single wire for several reasons: the setup imbalance, maximum sight length, and distances are known;



14 LEVELS

Station 866-2799 South Santee SC

Year 86 Month Oct Day 20

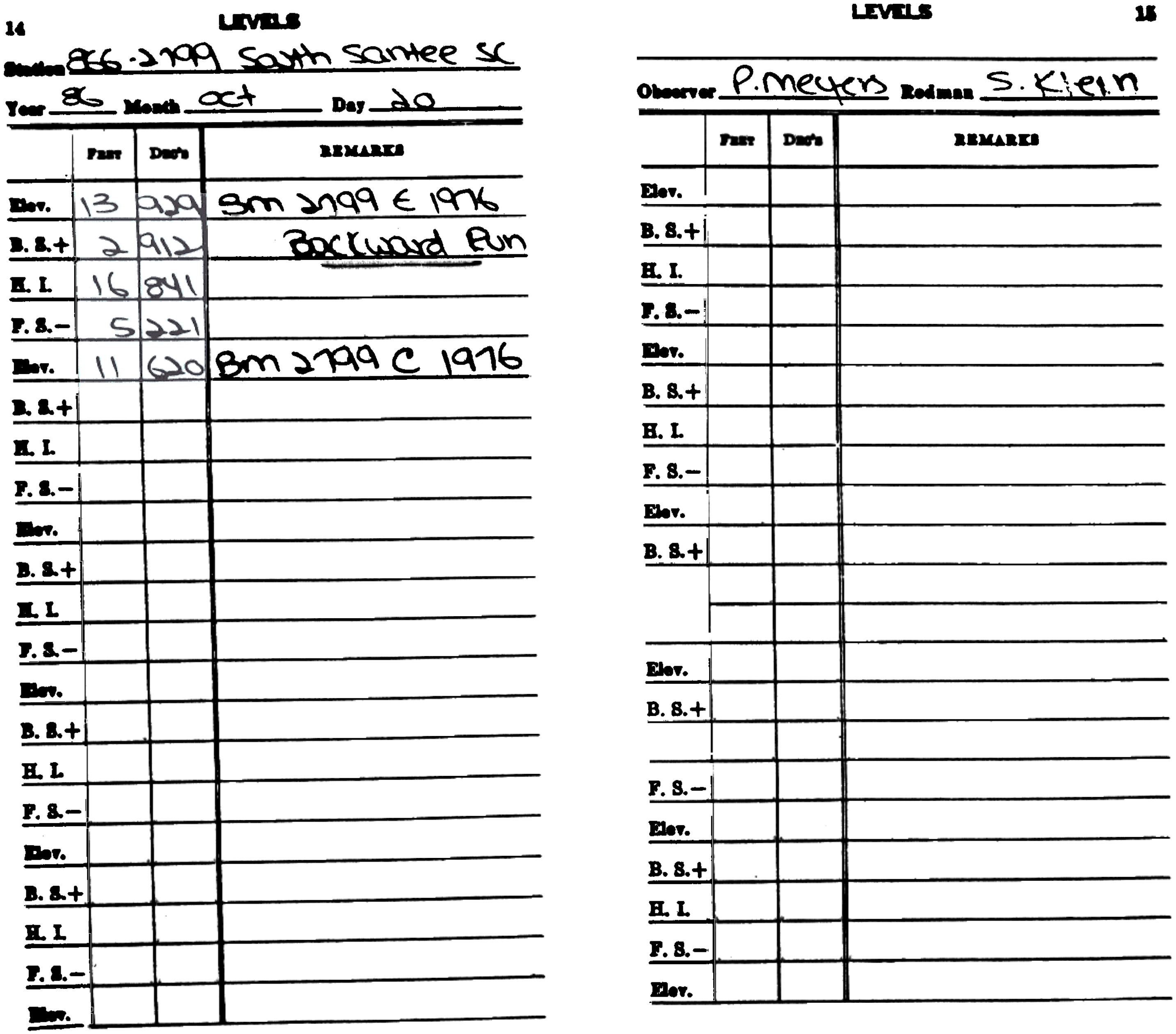
	Feet	Dec's	1 pace = 2.5 feet REMARKS
Elev.	10	000	
B. S.+	3	192	
H. I.	13	192	
F. S.–	1	673	
Elev.	11	519	Bm 2799 A 1976
B. S.+	0	963	90 pace = 225 ft
H. I.	12	482	
F. S.–	2	004	
Elev.	10	478	Bm 2799 B 1976
B. S.+	1	785	81 pace = 218 ft
H. I.	12	263	
F. S.–	0	642	
Elev.	11	621	
B. S.+	4	492	
H. I.	16	113	
F. S.–	1	110	
Elev.	15	003	Bm 2799 D 1976
B. S.+	1	114	BACKWARD RUN
H. I.	16	117	
	4	489	
Elev.	11	628	Bm 2799 C 1976

LEVELS 15

Observer P. Meyers Rodman S. Klein

	Feet	Dec's	REMARKS
	11	628	Bm 2799 C 1976
B. S.+	0	640	
H. I.	12	268	
F. S.–	1	788	
Elev.	10	480	Bm 2799 B 1976
B. S.+	2	000	
H. I.	12	480	
F. S.–	0	962	
Elev.	11	518	Bm 2799 A 1976
B. S.+	1	671	
H. I.	13	189	
F. S.–	3	190	
Elev.	9	999	Rod Stop
B. S.+			
H. I.			
F. S.–			
Elev.	11	621	Bm 2799 C 1976
B. S.+	5	221	101 pace = 252 ft
H. I.	16	842	
	2	913	
Elev.	13	929	Bm 2799 E 1976

Figure 14 Third-order Level Run With Foot Rod and Spur Line



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LEVELS

Station 866-2799 South Santee SC

Year 86 **Month** oct **Day** 20

	Feet	Dec's	REMARKS
Elev.	13	929	Bm 2799 E 1976
B. S.+	2	912	Backward Run
H. I.	16	841	
F. S.–	5	221	
Elev.	11	620	Bm 2799 C 1976
B. S.+			
H. I.			
F. S.–			
Elev.			
B. S.+			
H. I.			
F. S.–			
Elev.			
B. S.+			
H. I.			
F. S.–			
Elev.			
B. S.+			
H. I.			
F. S.–			
Elev.			

LEVELS

15

Observer P. Meyers **Rodman** S. Klein

	Feet	Dec's	REMARKS
Elev.			
B. S.+			
H. I.			
F. S.–			
Elev.			
B. S.+			
H. I.			
F. S.–			
Elev.			
B. S.+			
Elev.			
B. S.+			
F. S.–			
Elev.			
B. S.+			
H. I.			
F. S.–			
Elev.			

Figure 15 Third-order Level Run With Foot Rod and Spur Line (continued)

LEVELS

Station 866-2799 South Santee SC

Year 86 **Month** oct **Day** 20

ABSTRACT OF LEVELING

The symbol B. M. (a) is used here to designate the staff stop on the support used with the portable tide staff, or the graduation of the scale corresponding to the point at which the level rod was held.

For convenience, copy the direct elevations for each bench mark, as given by the forward and backward runnings of levels into the form below. List the bench marks in the order of their connection to the staff on the forward run.

ELEVATION

B. M. Nos.	Forward Run	Backward Run
	Feet	Feet
assumed elev (a)	10.000	9.999
Bm A	11.519	11.518
Bm B	10.478	10.480
Bm C	11.621	11.628
Bm D	15.003	15.003
Spur: Bm C	11.621	11.620
Bm E	13.929	13.929

LEVELS

DIFFERENCE OF ELEVATION

Designation of Section	Forward Run	Backward Run	Mean
	Feet	Feet	Feet
Elevation of (a) above zero of tide staff=			12.000
a → A	+1.519	-1.519	+1.519
A → B	-1.041	+1.038	-1.040
B → C	+1.143	-1.148	+1.146
C → D	+3.382	-3.375	+3.378
C → E	+2.308	-2.309	+2.308

Indicate sections as "Staff to 1," etc., with the sign of the forward run for the mean.

The algebraic sum of the successive mean differences gives the elevations above zero of tide staff.

ELEVATIONS ABOVE ZERO OF TIDE STAFF

B. M. A 13.519 feet.	B. M. E 15.933 feet.
B. M. B 12.479 feet.	B. M. ________ feet.
B. M. C 13.625 feet.	B. M. ________ feet.
B. M. D 17.003 feet.	B. M. ________ feet.

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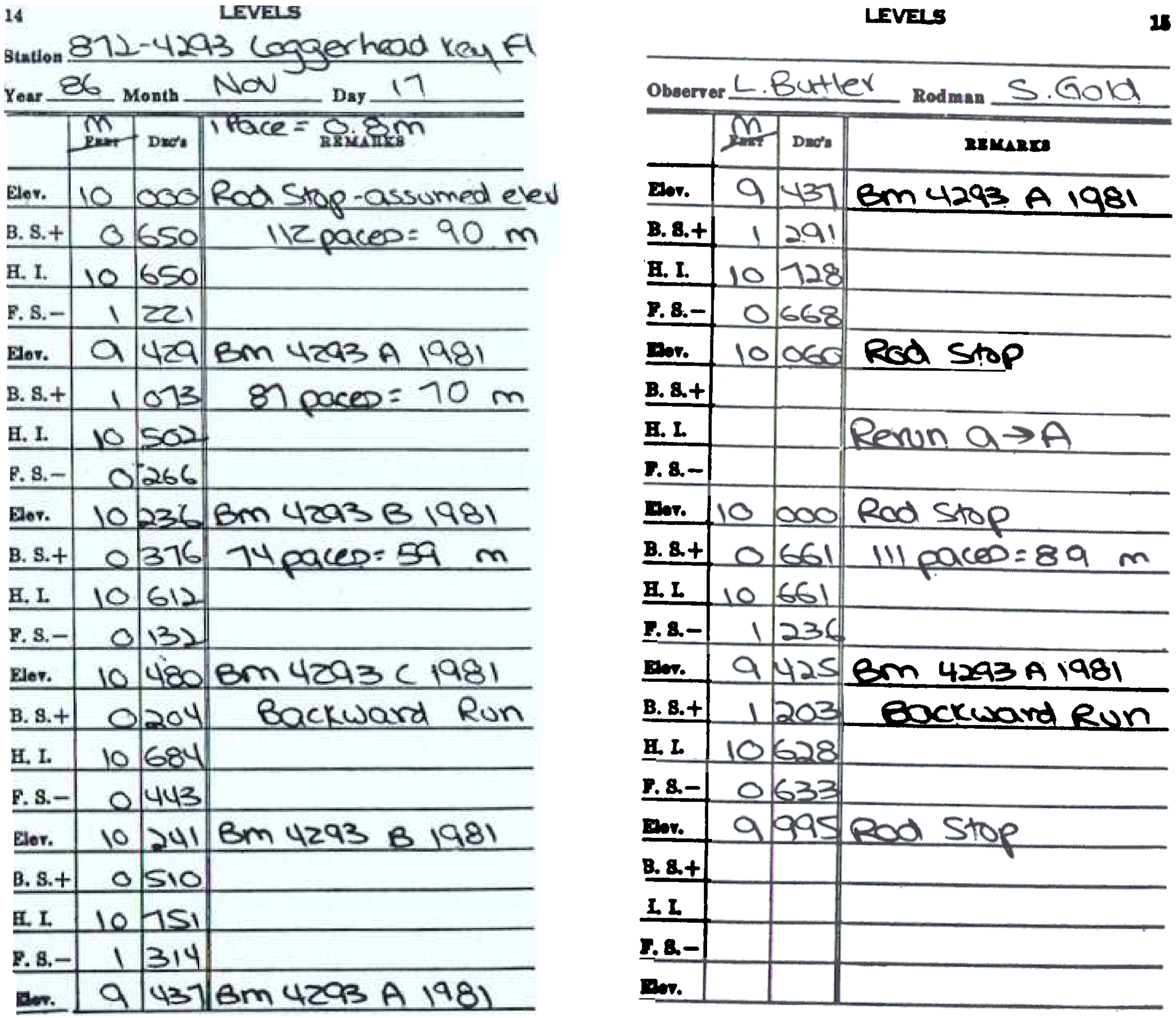


14 LEVELS

Station 872-4293 Loggerhead Key Fl
Year 86 Month Nov Day 17

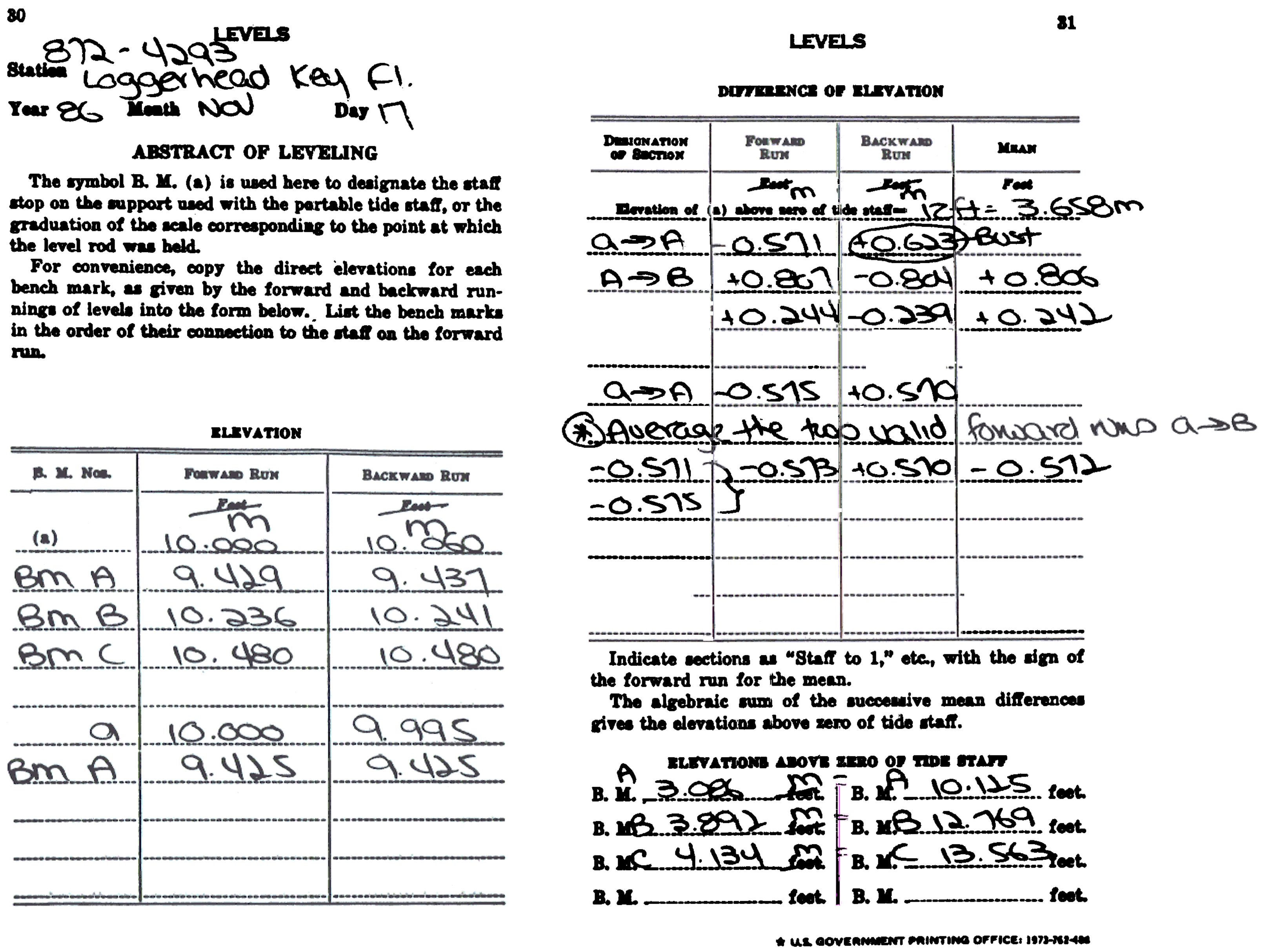
	~~Feet~~ m	Dec's	REMARKS 1 Pace = 0.8m
Elev.	10	000	Rod Stop-assumed elev
B. S.+	0	650	112 paces= 90 m
H. I.	10	650	
F. S.–	1	221	
Elev.	9	429	Bm 4293 A 1981
B. S.+	1	073	87 paces= 70 m
H. I.	10	502	
F. S.–	0	266	
Elev.	10	236	Bm 4293 B 1981
B. S.+	0	376	74 paces= 59 m
H. I.	10	612	
F. S.–	0	132	
Elev.	10	480	Bm 4293 C 1981
B. S.+	0	204	Backward Run
H. I.	10	684	
F. S.–	0	443	
Elev.	10	241	Bm 4293 B 1981
B. S.+	0	510	
H. I.	10	751	
F. S.–	1	314	
Elev.	9	437	Bm 4293 A 1981

LEVELS 15

Observer L. Butler Rodman S. Gold

	~~Feet~~ m	Dec's	REMARKS
Elev.	9	437	Bm 4293 A 1981
B. S.+	1	291	
H. I.	10	728	
F. S.–	0	668	
Elev.	10	060	Rod Stop
B. S.+			
H. I.			Rerun 9→A
F. S.–			
Elev.	10	000	Rod Stop
B. S.+	0	661	111 paces=89 m
H. I.	10	661	
F. S.–	1	236	
Elev.	9	425	Bm 4293 A 1981
B. S.+	1	203	Backward Run
H. I.	10	628	
F. S.–	0	633	
Elev.	9	995	Rod Stop
B. S.+			
H. I.			
F. S.–			
Elev.			

Figure 17 Third-order Level Run With Metric Rod and a Rerun Section Due to a Bust



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LEVELS

Station 872-4293 Loggerhead Key Fl.

Year 86 Month NOV Day 17

ABSTRACT OF LEVELING

The symbol B. M. (a) is used here to designate the staff stop on the support used with the portable tide staff, or the graduation of the scale corresponding to the point at which the level rod was held.

For convenience, copy the direct elevations for each bench mark, as given by the forward and backward runnings of levels into the form below. List the bench marks in the order of their connection to the staff on the forward run.

ELEVATION

B. M. Nos.	Forward Run	Backward Run
	~~Feet~~ m	~~Feet~~ m
(a)	10.000	10.060
Bm A	9.429	9.437
Bm B	10.236	10.241
Bm C	10.480	10.480
a	10.000	9.995
Bm A	9.425	9.425

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LEVELS

DIFFERENCE OF ELEVATION

Designation of Section	Forward Run	Backward Run	Mean
	~~Feet~~ m	~~Feet~~ m	Feet
Elevation of (a) above zero of tide staff= 12 ft = 3.658m			
a→A	-0.571	+0.623	Bust
A→B	+0.807	-0.804	+0.806
	+0.244	-0.239	+0.242
a→A	-0.575	+0.570	
⊛ Average the two valid forward runs a→B			
-0.571 }	-0.573	+0.570	-0.572
-0.575 }			

Indicate sections as "Staff to 1," etc., with the sign of the forward run for the mean.

The algebraic sum of the successive mean differences gives the elevations above zero of tide staff.

ELEVATIONS ABOVE ZERO OF TIDE STAFF

B. M. A 3.086 ~~feet~~ m = B. M. A 10.125 feet.
B. M. B 3.892 ~~feet~~ m = B. M. B 12.769 feet.
B. M. C 4.134 ~~feet~~ m = B. M. C 13.563 feet.
B. M. ______ feet. B. M. ______ feet.

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Figure 18 Abstract of a Third-order Level Run Converted from Meters to Feet the three wire reading provides a check whereby blunders can be quickly corrected; and closure can be accurately determined.

3.8.3 Closure Tolerance (2nd- and 3rd-order) - If all leveling errors could be eliminated, section runnings would always agree. However, since this is not possible, tolerances have been set to ensure that accepted runnings disagree by no more than an amount consistent with the precision of the prescribed leveling method. When multiple runs of a section disagree by more than the tolerance, blunders or excessive systematic errors may have occured, and the section shall be rerun.

3.8.3.1 Closure procedure - Whenever a section is double-run, check that the difference between the two levelings agree within the tolerance for the order and class of the survey.

a. Compute the difference between the two levelings. Because they are opposite in sign, this is the backward run plus the forward run. As a matter of convenience, the divergence is opposite in sign from the difference.

b. Compute the tolerance for the distance leveled, K. It is $T \times \sqrt{K}$, in millimeters, where T is the factor for the order and class of the survey (6 $\mathrm{mm}\sqrt{K}$ for second-order, class I, and 12 $\mathrm{mm}\sqrt{K}$ for third-order), and K is the one-way distance (shortest if more than one) in kilometers. For example, if the distance leveled is 1.6 km, and the survey is second-order, class I, then:

$$\text{Double-run Tolerance} = 6 \text{ mm} \times \sqrt{1.6} = \pm 7.6 \text{ mm}$$

c. If the divergence from step a is within the tolerance from step b, the section is closed; additional runs are not required unless staff/bench mark movement is determined. If the divergence exceeds the tolerance, relevel and recheck the section to satisfy two criteria: (1) that all runs likely to contain blunders or systematic errors are rejected, and (2) that at least one forward and one backward run are acceptable. Use the rejection procedure, given below, to determine statistically unreliable runs.

d. When releveling to close the section, alternate the direction of leveling to maintain an equal number of forward and backward runs. If systematic error persists in the leveling, the mean of all the elevation differences may be biased in favor of the majority direction. Equalizing the number of runs in each direction prevents this bias.

3.8.3.2 Field check of third-order leveling - The following procedures are to be utilized in the field check of third-order levels. They need not be submitted unless verifying a blunder or systematic errors in the level run. Computations shall be documented on any of the blank pages in the level book or on a separate piece of paper forwarded with the level book.

Example: Checking the closure of a leveling section using a rod.

BM 2799C to BM 2799D Distance = 258 ft. (from Figure 14)

258 ft. x 1 mi./5280 ft. = 0.05 mi

Using Table 2 for third-order, the closure tolerance for a one setup section is ±0.007 ft.

Compute the difference between the two elevation differences:

Forward run BM 2799C to BM 2799D	+3.382 ft.	(from Figure 16)
Backward run BM 2799D to BM 2799C	-3.375 ft.	(" " ")
	+0.007 ft.	

The difference, +0.007 ft. (or divergence, -0.007 ft.), is within the one setup section tolerance obtained from Table 2 (±0.007 ft.).

Example: Checking the closure of a leveling section using a metric rod.

Staff to BM 4293A	Distance = 90 m (from Figure 17)

90 m x 1 km/1000 m = 0.09 km

Using Table 2 for third-order, the closure tolerance for a one setup section is ±0.0020 m.

Compute the difference between the two elevation differences:

Forward run Staff to BM 4293A	-0.571 m	(from Figure 18)
Backward run BM 4293A to Staff	+0.623 m	(" " ")
	+0.052 m	

The difference, +0.052 m (or divergence, -0.052 m), exceeds the one setup section tolerance obtained from Table 2 (±0.0020 m); therefore, the run is rejected and requires a rerun of the section to obtain forward and backward runs which agree within the allowable limits.

3.8.3.3 <u>Rejection procedure</u> - After three or more runs of a section, check for agreement as follows:

a. Compute the mean of all runs, disregarding their signs. Do not include runs with obvious blunders.

b. Compute the difference between this mean and each run.

c. Compute the allowable difference from the mean of more than two runs. It is based on the order and class of the survey, the number of runs which were meaned, and the distance leveled. The formula is T x $\sqrt{K}$, where T is the approximate factor from the following table and K is the section length in kilometers. For a section less than 0.10 km in length, K is 0.10 km.

Table 3 Tolerance T factors for closing multiple runs

Number of Runs	Second-Order Class I (mm)	Third-Order (mm)
3	4.21	8.44
4	4.66	9.34
5	4.96	9.95
6	5.19	10.40
7	5.36	10.70
8	5.51	11.00

d. Reject any run outside the allowable difference from the mean.

e. Check the remaining runs to see if there is at least one forward and one backward. If there is, and none were rejected in step d, the section is closed. If one was rejected, compute a new mean with the remaining runs and return to step b. If only runs in one direction remain, relevel the section in the opposite direction and begin again at step a.

Notice that certain runs, rejected when the number of runs were three or four, may now be accepted when the total number increases. This is because the accuracy of the mean improves with a larger sample of data; i.e., it becomes easier to recognize when a run is different enough to be considered a blunder.

Example: Assume the following second-order, class I differences in elevation for a section 1.6 km in distance.

F	+1.4473 m
B	-1.4420 m
F	+1.4523 m
B	-1.4430 m
F	+1.4441 m
Mean	1.44574 m

Allowable (from the table) = ±4.96 mm $\sqrt{1.6}$
= ±6.27 mm

Allowable range = 1.44574 m ± 0.00627 m
= 1.43947 m → 1.45201 m

Therefore, reject the 1.4523 run

New mean and range =

$$\frac{(1.4473 + 1.4420 + 1.4430 + 1.4441)}{4} = 1.44410 \text{ m}$$

Allowable (from the table) = ±4.66 mm $\sqrt{1.6}$
= ±5.89 mm

Allowable range = 1.44410 m ± 0.00589 m
= 1.43821 m → 1.44999 m

No rejections

If, for any reason, a run is rejected for any cause other than excessive divergence from the indiscriminate mean of all the runs for that section, the reason for rejection shall be clearly stated in the remarks.

3.9 Special Cases: Water Crossings, Precise Reciprocal Leveling, and Unbalanced Sights - Terrain and leveling conditions often force leveling parties to use other than standard procedures to accomplish their mission. Three methods for overcoming certain obstacles are outlined in the order of quality of their results (and the magnitude of the obstacle they overcome).

3.9.1 Water Crossings - Special methods requiring reciprocal observations and special equipment have been developed for determining elevation differences for offshore station platforms and/or to extended level lines across spans where the distance exceeds the maximum tolerable sight length for standard leveling procedures. These methods are used to increase accuracy by minimizing the error in the collimation of the instrument and refraction of the atmosphere, and by eliminating the effect of the curvature of the earth.

The method, which is detailed in Berry (1969) and Schomaker & Berry (1981), requires:

a. two observation stations,
b. four level instruments (Zeiss Ni2) mounted on two specially designed tribrachs,
c. four rotating optical wedges, and
d. two specially designed Invar rods and targets.

This system has proven itself on projects involving sights of more than 4 km (2.5 mi.) with first-order results.

3.9.2 Precise Reciprocal Leveling - Simultaneous reciprocal observations are made at each of two points. The success of this method, like all reciprocal leveling, depends on the equality of the refraction over the line in opposite directions. To secure this equality, the lines of sight at both ends should be about equal, the instrument (at both ends) should be at approximately the same height, and the lines of sight should have the highest practical clearance over land and water. For water crossings up to 600 m (about 2,000 ft.), this method is designed to obtain second-order accuracy.

Two instruments (equipment with optical micrometers) with known acceptable collimation errors and two level rods (each equipped with a target) are set up as shown in Figure 19. The graduation units of the plate micrometers are to be compatible with the rod unit graduations.

Each observer directs the far rodman by radio (or suitable visual means). The target is positioned in line with the center cross hair of the instrument and within the range of the micrometer such that the optical micrometer is at about one-half its vertical rotation range. The target heights are then recorded. Each observer reads the close rod (be sure to check minimum focus) and records that reading. Simultaneous readings on the far rod, using the micrometer only, are conducted every 30 seconds until ten readings have been obtained. The micrometer readings and the beginning and ending time of the readings are recorded. This completes half the observations in the set (run 1). The mean of the differences observed from each side is one observed difference between the bench marks.

The observers then change places, taking their instruments with them, but leaving the tripods and rods in place. The reading sequence is repeated in order to obtain another 10 readings (run 2). This completes one set of reciprocal observations. The final rod readings are the target heights plus the average micrometer readings. Individual differences in elevation vary considerably. This is because the readings have not been corrected for instrument error, earth's curvature, or variations of refraction. The observing program and computation procedures are so arranged, however, that these effects are minimized in the mean of the runs.

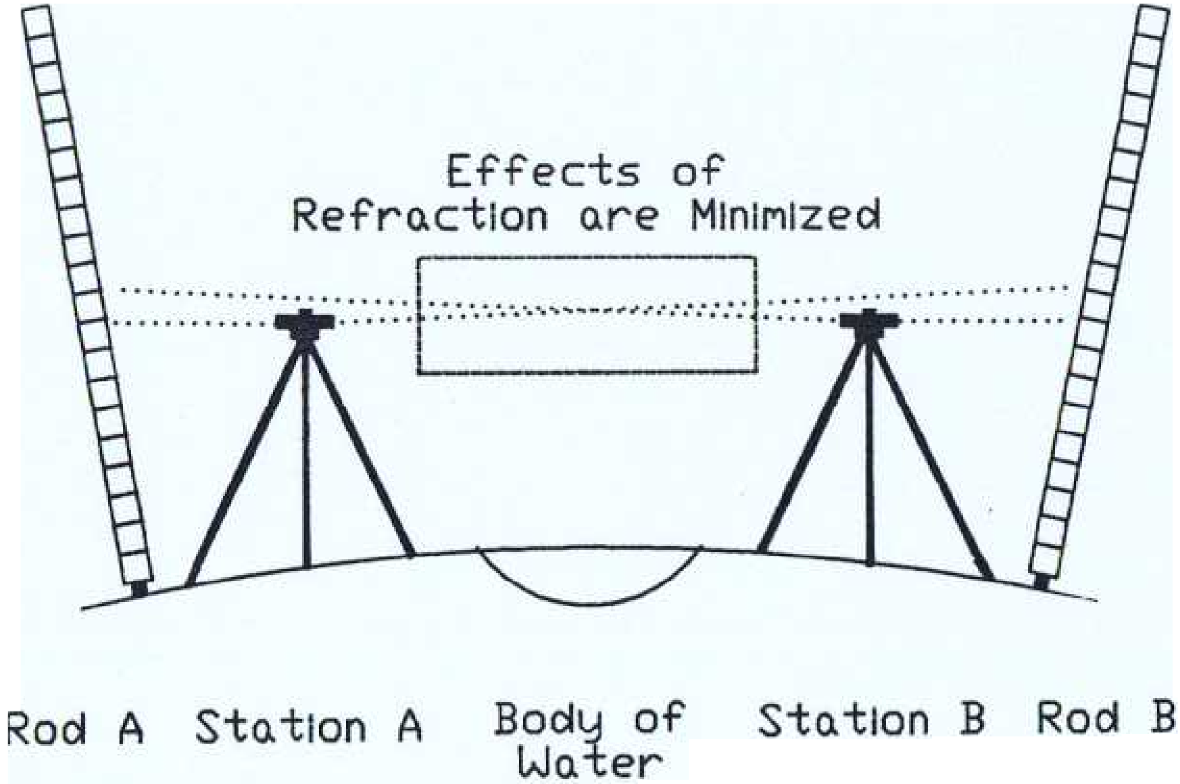

Figure 19 Precise Reciprocal Leveling

Not to Scale

The final elevation difference for a set of observations is the mean of the two runs. The mean of a run is determined as in standard leveling procedures. The distance is determined by reading the three cross hairs directly on the far rod from one of the setups (visibility conditions may require use of the target to make these readings), or by scaling from a map. At stations where more than one set of reciprocal observations are required, the final elevation difference will be the mean of paired sets of observations retained after rejections required by the closure tolerance. Specific observation requirements will be specified in Project Instructions or contract documents.

3.9.3 Unbalanced Sights - For staffs positioned up to 150 m or about 500 ft. offshore, unbalanced sights may be used. Since curvature errors do not cancel in a non-simultaneous, non-reciprocal leveling observation, the total correction to the offshore rod reading is the algebraic sum of the collimation and curvature corrections.

The collimation error in the instrument is determined by running a collimation check just before the unbalanced setup. The collimation check must be submitted with the leveling data. The correction to the offshore rod reading would be the value times the imbalance (offshore distance minus land distance). The curvature corrections are computed from the imbalance, Δs, and the mean radius of the earth, r: $-(\Delta s^2/2r)$, where $r = 6,378,000$ m. Three wires shall always be recorded (even for third-order levels with excessive sight lengths). All attempts will be made to follow the precautions to minimize refraction. Specific observation requirements also will be specified in Project Instructions or contract documents for unbalanced sights.

REFERENCES

Balazs, Emory I. and Gary M. Young. Corrections applied to the National Geodetic Survey to precise leveling observations. NOAA Technical Memorandum NOS NGS 34. National Ocean Survey, National Oceanic and Atmospheric Administration, Rockville, MD, June 1982, 12 pp.

Berry, Ralph M. The Zeiss apparatus for crossing water spans in precise leveling. Miscellaneous Paper 69-6. U.S. Lake Survey, Detroit, MI, October 1969, 53 pp.

Bossler, John D. Standards and specifications for geodetic control networks. Federal Geodetic Control Committee. Rockville, MD, September 1984, 29 pp.

Floyd, Richard P. Geodetic bench marks. NOAA Manual NOS NGS 1. National Geodetic Survey, National Ocean Survey, National Oceanic and Atmospheric Administration, Rockville, MD, September 1978, 52 pp.

Jordan, William, Eggert, and Max Kneissl. Handbuch der Vermessungskunde, Vol. III. J.B. Metzlersche Verlagsbuchhandlung, Stuttgart, 1956.

Pfeifer, Ludvik and Nancy L. Morrison. Input formats and specifications of the National Geodetic Survey data base. Volume II. Vertical control data, Federal Geodetic Control Committee, NOAA Manual NOS NGS 2, National Geodetic Survey, National Ocean Survey, National Oceanic and Atmospheric Administration, Rockville, MD, 1980 (reprinted 1982).

Schomaker, M. Christine and Ralph M. Berry. Geodetic leveling. NOAA Manual NOS NGS 3. National Geodetic Survey, National Ocean Survey, National Oceanic and Atmospheric Administration, Rockville, MD, August 1981.