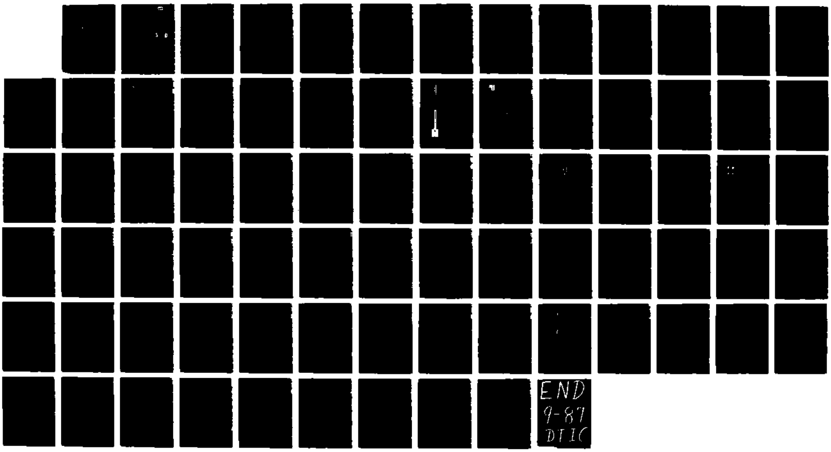
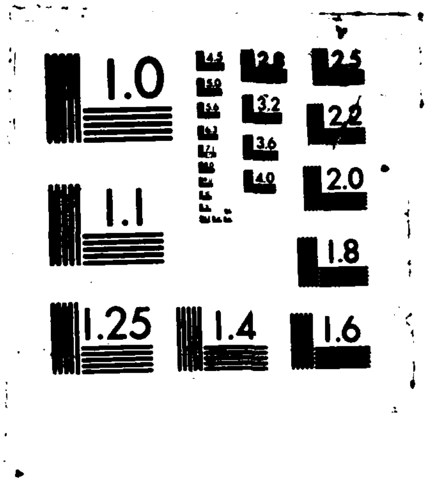
AD-A183 925 BENCHMARK DESIGN AND INSTALLATION: A SYNTHESIS OF EXISTING INFORMATION(U) COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH L W GATTO JUL 87 1/1

UNCLASSIFIED CRREL-SR-87-10 F/G 8/10 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(12)

Special Report 87-10

July 1987

DTIC FILE COPY

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Benchmark design and installation
A synthesis of existing information

Lawrence W. Gatto

AD-A183 925

DTIC
S ELECTE D
AUG 3 1 1987
D

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

Approved for public release; distribution is unlimited.

87 8 28 299

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

AD-A183 925

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188
Exp. Date Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Special Report 87-10	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Cold Regions Research and Engineering Laboratory 6b. OFFICE SYMBOL (If applicable) CECRL	7a. NAME OF MONITORING ORGANIZATION Office of the Chief of Engineers
6c. ADDRESS (City, State, and ZIP Code) Hanover, New Hampshire 03755-1290	7b. ADDRESS (City, State, and ZIP Code) Washington, D.C. 20314-1000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER CWIS 32246
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO / WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)
BENCHMARK DESIGN AND INSTALLATION: A Synthesis of Existing Information

12. PERSONAL AUTHOR(S)
Lawrence W. Gatto

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
	FROM ______ TO ______	July 1987	79

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Benchmarks; Frost heave; Stable benchmarks; Subsidence; Surveying; Survey monuments

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Techniques used for topographic, hydrographic, construction, boundary, geodetic and structural movement surveys are only as accurate as the benchmarks used as reference. In northern areas, frost action can cause substantial vertical movement of benchmarks. Benchmarks may also subside or shift in wetlands and coastal areas. Various benchmark designs and installation procedures reduce or eliminate movement, but information on the designs and procedures is widely scattered and not available to Corps of Engineers Districts in one report. This report is a synthesis of information compiled from surveys of Corps of Engineers Districts and Divisions, U.S. and Canadian government agencies, private industry and a literature review. Matrices for selecting and installing benchmarks that meet third-order accuracy requirements or better and that are appropriate for various climatic and soil conditions were prepared from the synthesized information. Procedures to be followed while installing various types of benchmarks are included.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Lawrence W. Gatto	22b. TELEPHONE (Include Area Code) 603-646-4273 / 22c. OFFICE SYMBOL CECRL-RE

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

PREFACE

This report was prepared by Lawrence W. Gatto, Geologist, of the Geological Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded by the Directorate of Civil Works, Office of the Chief of Engineers, under the Surveying and Mapping Program CWIS 32246, Vertically Stable Benchmarks.

The author thanks all the people in the Districts and Divisions who took the time to respond to the questionnaire and to review the matrix (see p. iii). Their input made it possible for this report to be prepared. Special thanks go to the following individuals who reviewed this report: Robert Applegate (Huntington District), John Coode (Nashville District), Stephen DeLoach (ETL), Jack Erlandson (Seattle District), Charles Malphrus (Savannah District), Boyd McClellan (Louisville District), Lawrence Parente (New England Division), Richard Rauch (Philadelphia District), Harold Smith (Memphis District) and Dennis Hoar (National Geodetic Survey). Also thanked are Robert Eaton and Frederick Crory (CRREL), Scott Kool (Omaha District) and M.K. Miles (OCE), for reviewing earlier versions of this report. All the reviewers provided many constructive criticisms and useful suggestions. The author gives special thanks to Mark Hardenberg. His many editorial changes made this report more orderly and easier to read.

Some of the figures in this report are not high quality reproductions; the author used the illustrations as provided to him to minimize redrafting. Only when absolutely necessary was an illustration redrawn.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

PERSONS THAT PROVIDED INFORMATION OR REVIEWED THE MANUSCRIPT

Organization*	
NED	J. Clyde, J.F. O'Leary, L. Parente
NAO	S. Deloach (now with ETL)
NAP	R. Rauch
NAB	E. Moore
SAM	J. Reaves
SAC	W. Huxford
SAS	D. Bell, C. Malphrus
SAW	G. Boone, G. Nyhus
NCB	J. LaFountain
NCC	T. Verges
NCE	C. Lamphere
NCS	G. Dasovic
NCR	W. Rieke
ORP	F. Schmidt, T. Taylor
ORH	K. Ash, R. Applegate
ORL	B. McClellan
ORN	J. Coode
LMK	E. Howe
LMM	H. Smith
LMS	C. Myers, B. Strauser
LMN	D. Eames
MRK	D. Vanhaverbeke
MRO	S. Kool, M. Taylor, D. Slobodnik
SWG	L. Gana
SWF	N. Bennett, B. Griswold
SWL	J. Long
NPP	L. Alford, E. Lazar
NPS	J. Erlandson
SPN	K. Kuhn
SPK	K. Lally
SPL	H. Anderson
USGS - Reston	W. Chapman
NOAA - NGS	D. Hoar, E. Balazs
Canadian National Research Council	G. Johnston
Canadian Geodetic Survey	C. Colwell, R. Gareau
Alaska Dept. of Transportation	D. Esch
LHD Associates	J. Davis.
Geo Tec Services, Inc.	M. Metz
CRREL	F. Crory, R. Eaton, R. Berg, J. Brown, G. Aitken
OCE	M.K. Miles

Accesion For
NTIS CRA&I
DTIC TAB
Unannounced
Justification
By
Distribution /
Availability Codes
Dist Avail and/or Special
A-1
QUALITY INSPECTED 2

* See Table 1 for definitions.

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To obtain
inch	25.4	millimeter
foot	0.3048	meter
gallon	0.003785412	$meter^3$

BENCHMARK DESIGN AND INSTALLATION:
A SYNTHESIS OF EXISTING INFORMATION

Lawrence W. Gatto

INTRODUCTION

Techniques used for monitoring crustal deformations (Wyatt et al. 1979), or for conducting hydrographic surveys, topographic surveys, surveys of the movement of structures (Gupta et al. 1973), or any other vertical control survey, are only as accurate as the benchmarks used for reference. In the northern contiguous states and Alaska, frost action can cause benchmarks to be substantially uplifted. In temperate regions, benchmarks can be uplifted, can subside, or can shift in wetland and coastal areas or in expandable and unstable soils.

Data on benchmark designs and installation procedures in general and in areas where benchmark stability is a special problem are available, but are widely scattered. Many Corps Districts have their own survey manuals and guidelines that present such data. This report synthesizes these data and provides Districts with information on benchmark designs and installations that has been used by other government agencies, private industry and other Districts (Table 1). Since few Districts have tested their benchmarks, it is generally not known how stable their benchmarks are. However, NOAA-National Geodetic Survey and Geodetic Survey of Canada benchmarks have been tested and successfully meet accuracy requirements. This report also consolidates the scattered information and data with enough detail for someone to select and install an appropriate benchmark. A matrix that can be used in selecting benchmarks appropriate for different climatic and soil conditions is included.

Slater and Slater (1979) and Floyd (1978) point out that benchmark designs and installation procedures have remained virtually unchanged for the last 20 years, yet survey instrument precision has substantially improved. Some of the information on benchmark designs and installation techniques in this report has not been improved as required to ensure

Table 1. Organizations that provided information on benchmarks.

Corps Districts and Divisions*		Other government agencies	Private industry
Nashville (ORN)	Vicksburg (LMK)	U.S. Geological Survey	LHD Associates
New England (NED)	Memphis (LMM)	NOAA-National Geodetic Survey	Geo Tec Services, Inc.
Philadelphia (NAP)	St. Louis (LMS)	Canadian National Research Council	
Norfolk (NAO)	New Orleans (LMN)	Geodetic Survey of Canada	
Baltimore (NAB)	Kansas City (MRK)	USACRREL	
Mobile (SAM)	Omaha (MRO)	Alaska Department of Transportation	
Charleston (SAC)	Galveston (SWG)		
Savannah (SAS)	Ft. Worth (SWF)		
Wilmington (SAW)	Little Rock (SWL)		
Buffalo (NCB)	Portland (NPP)		
Chicago (NCC)	Seattle (NPS)		
Detroit (NCE)	San Francisco (SPN)		
St. Paul (NCS)	Sacramento (SPK)		
Rock Island (NCR)	Los Angeles (SPL)		
Pittsburgh (ORP)			
Huntington (ORH)			
Louisville (ORL)			

* A questionnaire and a matrix were sent to 36 Districts, NED and POD; 24 questionnaires were filled out and returned; 5 responses were received via phone and letter regarding data on the questionnaire; 15 matrices were returned (2 had new information, 13 had no additions).

appropriate accuracy of surveys made with these improved instruments. Consequently, many of the old designs and techniques may be inadequate.

The Corps of Engineers is a member of the Federal Geodetic Control Committee (FGCC). One of the goals of the Corps as a FGCC member is to densify the national control networks to make them more useful to the

Corps. This densification involves a limited amount of second-order vertical control surveying, and extensive third-order control surveying tied to benchmarks of the National Geodetic Survey (NGS). In the past, the Corps control densification surveys have generally not been incorporated into the NGS's National Geodetic Data Base. Instead, separate data files of these surveys are maintained at various Corps Districts, primarily for Corps use, but also to be provided to other agencies and the private sector if requested. As a result of recent decisions by FGCC and the Office of the Chief of Engineers, the Corps will now provide more of its control densification survey data to NGS to be included in the national data base.

To be incorporated into the data base, vertical control surveys must be done in accordance with third-order or higher NGS elevation difference accuracy standards and be tied to the National Geodetic Vertical Network (FGCC 1980, 1984).* These standards are defined in Table 2. As part of the standards, the NGS points out that control points must be permanent, vertically stable and have a vertical location defined as a point. The FGCC (1980 and 1984), Floyd (1978) and Hoar (1983) provide additional standards, specifications and requirements for monuments and reporting.

The Office of the Chief of Engineers wants all District surveyors to follow the requirements in the FGCC references to ensure that benchmarks in their Districts meet NGS standards. This is not a move toward standardiz-

Table 2. National Geodetic Survey accuracy standards (FGCC 1984).

Classification	Maximum elevation difference accuracy* ($mm/\sqrt{km}$)
First-order, class I	0.5
First-order, class II	0.7
Second-order, class I	1.0
Second-order, class II	1.3
Third-order	2.0

* Elevation difference accuracy = $S/\sqrt{d}$, where d = approximate horizontal distance in kilometres between control point positions traced along existing level routes, and S = propagated standard deviation of the elevation difference in millimetres between survey control points obtained from the least squares adjustment.

* Personal communication with D. Hoar, Operations Branch, National Geodetic Survey, Rockville, Maryland, 1985.

ing benchmark designs throughout the Corps, but a move toward trying to ensure that permanent benchmarks installed by the Corps meet NGS standards and can become part of the national data base. The benchmarks can be of various designs and materials as long as they meet the standards. This report can be used as a guide for meeting these standards. Official Corps requirements and specifications will be available in the Corps Surveying and Mapping Manual being prepared by the Office of the Chief of Engineers and a field user group.

APPROACH

Information on general types of survey benchmarks and on special methods for eliminating or reducing vertical movement in benchmarks was compiled from the Corps of Engineers, other government agencies, private industry and the open literature. Input from the Corps was obtained via a questionnaire and phone conversations (Table 1). The questionnaire (Appendix A) covered the purposes for which benchmarks are required, types of benchmarks used for each purpose, lateral and vertical stability requirements, special conditions that affect benchmark stability within each District or Division, preinstallation site characterization, steps for installation, and costs.

Data from other agencies and private industry were obtained through personal conversations, from letter reports, and published and unpublished reports. Four literature data bases (Georef, Compendex, NTIS, Engineering Index) were also searched and all open literature available up to May 1985 was reviewed.

CAUSES OF BENCHMARK INSTABILITY

There are many types of benchmarks used for vertical reference, and many of them may not meet the accuracy requirements of the NGS. A permanent, very stable benchmark must not be affected by natural or human disturbances (Bozozuk et al. 1963). Some surveys requiring third-order or better accuracies are being conducted using benchmarks that can give only fourth-order or lower surveys. Some benchmarks are as simple as fire hydrants, manholes, nails in trees or fenceposts, and pins in stone or concrete steps, house foundations or platforms. Usually, these are unsatis-

Table 3. Problem conditions that affect benchmark stability.

Frost heave	Deterioration of monuments
Weak bedrock	Temperature changes
Unstable Soils	Slope movements
- Expansive clays	Seismic activity
- Wetland or marsh conditions	
- Soil compaction	Human-induced problems
- Groundwater fluctuations	
- Rock or soil shrinkage and swelling	Soil erosion
Subsidence	
- Regional	
- Local	
- Near structures	

factory as precise references for repetitive, long-term surveys. More stable benchmarks include disks in bedrock, in large concrete foundations resting on stable soil, and in piles driven to bedrock or refusal.

Some of the causes of instability (Table 3) are environmental, including frost heave, shrinking and swelling of soil and rock because of moisture changes, soil expansion and contraction because of soil temperature changes, slope instability, soil consolidation (settlement), and soil erosion (Floyd 1978).* Human activities can cause vertical changes in benchmarks anywhere, and the NGS suggests ways of reducing their likelihood (Floyd 1978, Hoar 1983).

Floyd (1978) lists additional subsurface (greater than 50 ft deep) causes of benchmark instability, i.e., crustal motion, subsidence near mines or caves, or subsidence caused by oil or water pumping, and suggests that their effects usually cannot be economically prevented. He recommends that areas where these instabilities occur be avoided.

Soil consolidation and settlement can happen naturally or be man-induced near railroads, highways (Karcz et al. 1975) or large structures (Floyd 1978).** Regional subsidence attributable to consolidation of

---

* Personal communication with R. Gareau, Chief, Primary Vertical Control Section, Surveys and Mapping Branch, Geodetic Survey of Canada, Ottawa, 1983.

** Personal communication with D. Slobodnik and S. Kool, Surveys and Mapping Section, U.S. Army Engineer District, Omaha, Nebraska, 1983.

Pleistocene sediments occurs naturally in the New Orleans District.* To account for this subsidence, deep-set casement-type benchmarks have been placed to depths of 80-135 ft in stable areas to determine benchmark changes in subsiding locations. Eames* suggests that perhaps the best way to improve the vertical stability of benchmarks is by using all available geological data when selecting sites.

Instability is also caused by unstable soils in marshy areas.* In some southern coastal areas there is a "crust" 3 to 30 ft thick overlying an unstable soil zone that is above firm sands. Benchmarks must penetrate to the lower firm sand zone. Benchmarks in some southern river bottom areas have also moved 0.1 ft vertically because of water table fluctuations.**

Benchmark elevations can be changed by frost heave where soil freezes and thaws annually (Jarman 1955, Johnston 1962). This problem is most severe where annual frost penetration is deep. Significant subsurface movement of soil in permafrost areas can occur to depths of up to 30 ft (Black 1957), and conventional benchmarks can be moved several inches a winter by frost heave and thaw settlement (Black 1957, Linell and Lobacz 1980). Frequently used benchmarks designed to be vertically stable in frost areas will be discussed later.

Soil expansion and contraction induced by temperature changes cause benchmark movement and are active and variable in frozen soils because soil temperature varies with depth. Benchmarks in bedrock that freezes and thaws can also be moved (Linell and Lobacz 1980). Temperature fluctuations can also change the size of benchmark materials and affect their stability (Floyd 1978).

Soil and bedrock moisture changes can cause vertical displacements in benchmarks, especially where expansive montmorillonite clays are common (Johnston 1962). Wetting and drying of clay-rich soils and nonuniform wetting of such soils can make certain sites unsuitable for benchmarks required for high-precision surveys (Currer 1962, Kryukov and Garevski 1973, Slater and Slater 1979). Slope instability caused by soil creep,

---

* Personal communication with D. Eames, Chief, Precise Survey Section, U.S. Army Engineer District, New Orleans, Louisiana, 1983.

** Personal communication with J. Reaves, Chief, Survey Section, U.S. Army Engineer District, Mobile, Alabama, 1983.

slides or soil erosion can also change benchmark position (Linell and Lobacz 1980).

RESULTS

The bulk of this section is drawn from Corps input, with additional information from the other sources. Each subsection addresses a topic covered in the questionnaire (Appendix A).

Purposes for and types of benchmarks

The types of surveys for which benchmarks are required in the Corps are topographic, construction, hydrographic, boundary (cadastral), geodetic, structural movement and layout of aerial photograph control points. Most Corps Districts indicated they did construction surveys; fewer Districts performed topographic, hydrographic and structural movement surveys (Table 4). The types of benchmarks Districts use for their surveys are variable (Appendix B) and have been adapted for the needs of the respective Districts. The Philadelphia District provided some general suggestions (Table B1) for setting some of the more common benchmarks.

Specific project requirements dictate the type of benchmark required. Karcz et al. (1975, 1976) report that all benchmarks move some, but project needs will determine if the likely amount of movement is acceptable. Of the commonly used benchmarks, they found those anchored in bedrock, walls and buildings to be the most stable. Those in bridges, culverts and concrete posts, bases and platforms are less stable. Of course, the type of foundations of the walls and buildings (i.e., pile foundations, spread footings, etc.) should be investigated before assuming they are adequately stable to meet project and NGS accuracy requirements.

Floyd (1978) points out that it is not feasible, and too expensive, to counteract vertical instability because of deep-seated processes, so NGS specifications have been developed to resist near-surface movements (less than 50 ft deep). Generally, sound bedrock with a low moisture content and with joints more than 3 ft apart is acceptable. In unstable soils, permanent benchmarks should be anchored in a stable zone below the zone of soil movement and a protective sleeve should extend to the maximum depth of soil movement (Fig. 1a). Bozozuk et al. (1963) also found deep benchmarks useful in unstable areas (Fig. 1b).

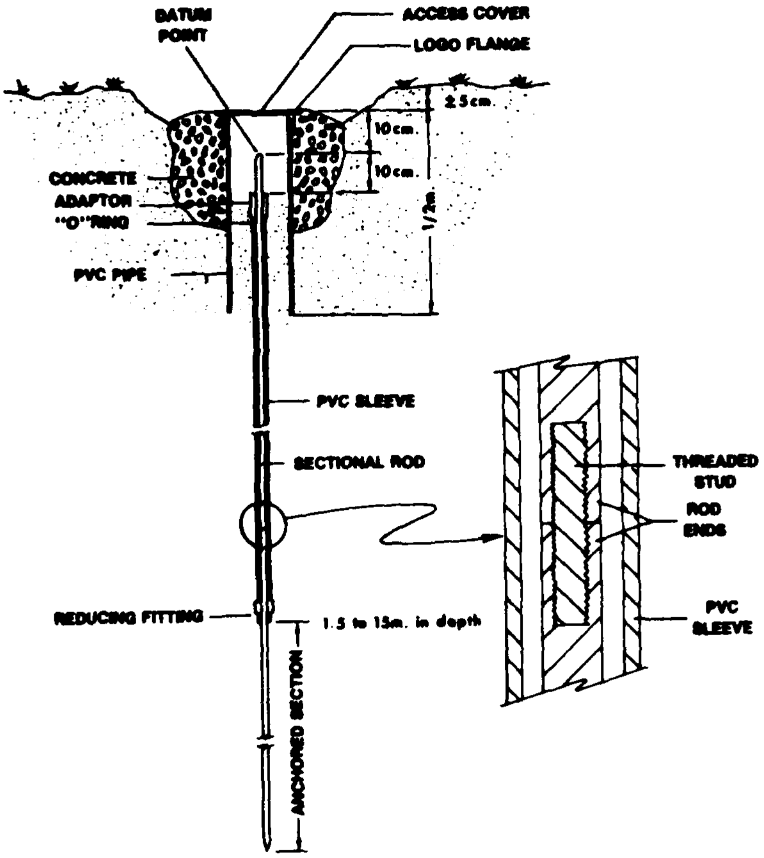
Table 4. Purposes for and types of benchmarks (from Corps responses to the questionnaire.

	Purposes*							
	TS	CS	HS	BS	GS	SM	APCP	Types of benchmarks used*
NED†	X	X	X	-	-	X	-	NA.
NAP	-	-	-	-	-	-	-	Fig. B1, Table B1.
NAO	-	X	X	-	-	X	-	Fig. B2; will often grout disk into foundations or concrete headwalls, if available.
NAB	X	-	-	-	-	X	-	TS - iron pipes with caps.
SAM	-	-	-	-	-	-	-	Standard Berntsen aluminum rods; conventional BMs not always usable due to unstable soils.
SAC	-	X	X	-	-	X	-	Galvanized pipe driven to refusal, concrete placed around, pipes capped.
SAS	-	-	-	-	-	X	-	Fig. B3; use permanent BMs; reinforced square concrete monuments with brass disk; aluminum rod with aluminum foot and Corps disk.
SAW	-	X	X	-	X	-	-	HS = 4-ft concrete monument in sandy coastal areas.
NCB	X	X	X	-	-	-	-	Temporary BMs; use existing USGS and NOAA BMs.
NCC	X	X	X	-	-	-	X	BMs near coast set in concrete foundations of CG light towers; BM on concrete cylinders.
NCE	X	X	X	-	-	-	-	Brass disks in concert, driven pipes or disks on existing stable structures.
NCS	X	X	X	-	-	X	X	Fig. B4.
NCR	X	X	-	-	-	X	-	Table B5.
ORP	X	X	-	-	X	X	-	Berntsen aluminum monuments or standard brass disks set in rock or concrete structures for PBM; railroad spike in tree or reber in ground for TBM.
ORH	X	X	X	X	X	X	X	Table B2.
ORL	X	X	X	X	X	X	X	Fig. B5, Table B3.
LMK	X	X	X	-	X	X	-	TS, CS, HS, GS=1-1/2 in. iron pipe or 4-ft concrete post with brass cap; SM = deep encased BM or driven to refusal.
LMM	X	X	X	-	-	X	-	Concrete post or iron pipe with brass cap; pipe and slab-type BM.
LMS	-	X	X	-	X	X	-	Chiseled squares on concrete foundation, boat spikes in trees and top of hydrant for vertical BM; pipe driven in ground to 1-3 ft for horizontal BM.
LMN	-	-	-	-	-	-	-	PBM = deep set casement type.
MRK	-	-	-	-	-	-	-	NA.
MRO	-	X	-	-	-	X	-	Reber; aluminum pipe; pre-cast BM; movement pedestals; Fig. B6.
SWG	X	X	X	-	X	-	-	CS=spikes in trees (TBM); GS=brass disk on reber (PBM); TS and HS=same as for GS but with monel cap on T-iron (TBM); Fig. B7.
SWF	X	X	-	-	-	X	-	TS/CS=TBM, spike in tree, mark on a culvert, concrete marker; SM=PBM, deep set and backfilled with grease (Fig. B8).
NPP	X	X	X	-	X	X	-	Fig. B9.
NPS	X	X	X	-	-	X	-	Brass caps in bedrock; 1-ft-square, 5-ft-long concrete monuments installed with reber.
SPN	X	X	X	X	-	-	-	NA.
SPK	-	-	-	-	-	-	-	Fig. B10.
SPL	X	X	X	-	-	X	-	Located on bedrock wherever possible.

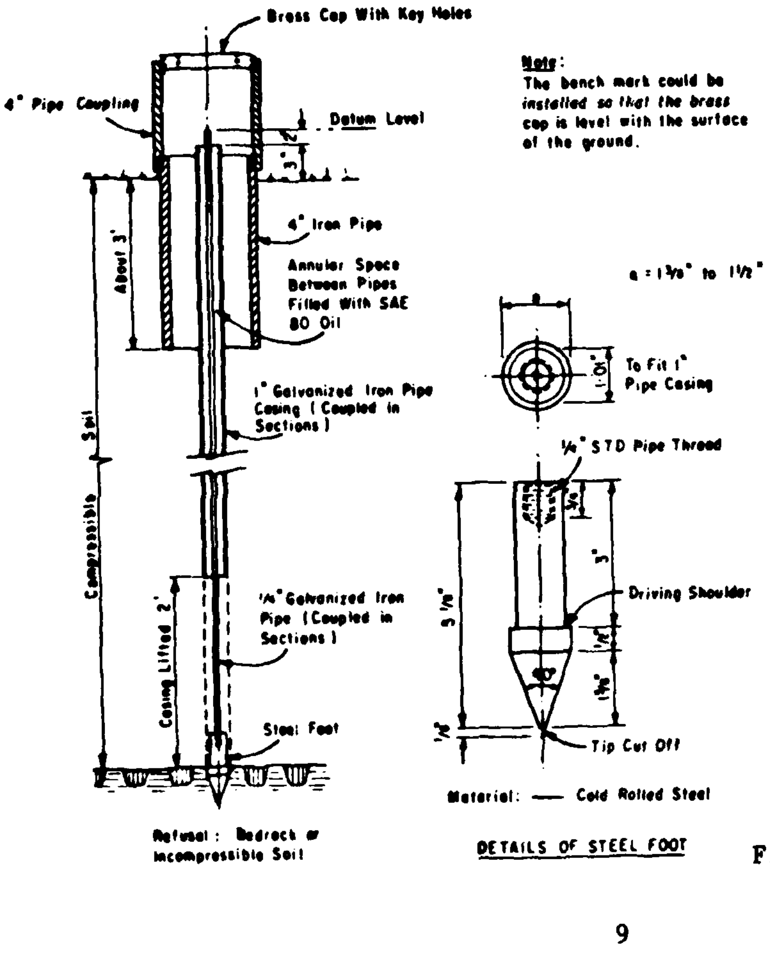
* Dash = no response from District or Division.
TS = Topographic surveys.
BS = Boundary or cadastral surveys.
SM = Structural movement (precise) surveys.
APCP = Aerial photo control point surveys.
NA = Not answered; no input from District or Division.
CS = Construction surveys.
GS = Geodetic or control surveys.
HS = Hydrographic surveys.
BM = Benchmark.
TBM = Temporary benchmark.

† See Table 1 for definitions.

Where either sound bedrock does not exist or sleeved benchmarks cannot be installed, the NGS suggests a sleeveless class B benchmark driven to an appropriate depth based on local soil and weather conditions (Floyd 1978). These class B benchmarks are not as stable as those in class A but both classes are being used in establishing the new North American Vertical Datum of 1988 (NAVD88) (Hoar 1983). It is possible that benchmarks con-

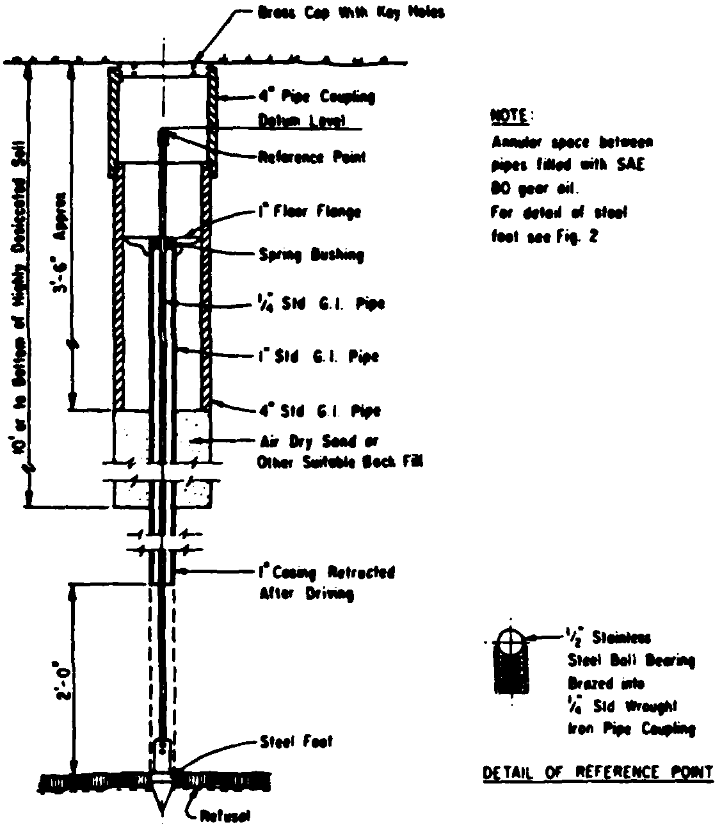


a. NGS class A benchmark (from Floyd 1978).



b. Deep benchmark in sensitive clay, similar to NGS class A benchmark; see Appendix D for installation details (from Bozozuk et al. 1963; copyright ASTM, reprinted with permission).

Figure 1. Sample benchmarks.



c. Deep benchmark in lacustrine clay, similar to NGS Class A ; details in Appendix D (from Bozozuk et al. 1963; copyright ASTM, reprinted with permission).

Figure 1 (cont'd). Sample benchmarks.

structed to be vertically stable may also be horizontally stable. Surveyors should check the horizontal minimum distance accuracy as prescribed by the FGCC (1984), however, before using the benchmarks for third-order, or better, horizontal control.

There is no way to recommend which benchmark option is best for a particular project. It is obvious that many have been tried throughout the Corps and elsewhere with varying degrees of success. As a general guide, the less elaborate, less expensive and more commercially available options have been used by Districts in the past. Project and NGS requirements should dictate the benchmark to be used.

Stability requirements and benchmark selection factors

Corps surveys generally require second- or third-order vertical accuracy, with structural movement surveys requiring the most stable benchmarks (Table 5). In the past, project scope and accuracy requirements influenced the type of benchmark used for a specific job. Project funds available (economics) for a survey project were also very important in the selection of the type of benchmark used. Other factors are listed at the bottom of Table 5. The need to meet NGS requirements will play a major role in selecting benchmarks for Corps use in the future.

Since terrain and ground conditions also determine the benchmarks most appropriate for a particular project, one of the most effective ways to improve the likelihood of a stable benchmark is to select a good location for installation. Many of the causes of benchmark instability can be avoided or minimized by wise site selection based on a complete analysis of site conditions.

Problem conditions and precautions

Eleven Districts listed subsidence or frost heaving, or both, as special problems in their areas, while inundation, vandalism, expansive clays, unstable soils, tectonics, incompetent bedrock, slope instability, soil erosion, and corrosion or deterioration of benchmark materials were also named (Table 6).

The precautions (Table 6) taken to counteract these problems include wise site selection (using geotechnical data), special benchmark designs with proper installation (i.e., frost-free benchmarks), use of special materials for benchmarks, deep-set benchmarks, and periodic verification and readjustment of data for benchmarks.

Many benchmark designs (Fig. 2) have been used to prevent frost heaving forces from acting on benchmarks (ACFEL 1957, Johnston 1962, Gupta et al. 1973, Floyd 1978, Johnston 1981, Mackay 1984).* One of the most frequently used designs is described by Linell and Lobacz (1980). They detail some of the procedures to use and precautions to take when installing this type of "frost-free" benchmark. Following their general design and the details of installation, adaptations of their recommended benchmark have been tried at Sukakpak Mountain and Buckland, Alaska.

* Personal communications with F. Crory, CRREL, 1981; J. Davis, LHD Associates, Construction Surveyors, Anchorage, Alaska, 1981; D. Esch, Alaska Department of Transportation, Fairbanks, Alaska, 1983; M. Metz, Geo Tec Services Inc., Golden, Colorado, 1984.

Table 5. Stability requirements and benchmark selection factors (from Corps responses to the questionnaire).

	Stability requirements*	Benchmark selection factors*
NED†	Bedrock usually used.	NA
NAP	2nd and 3rd order leveling; no need for 1st order BM.	TGC, location appropriate for uses.
NAO	Tidal surveys = 2nd order, 1st class surveys; SM = vertical movement of 0.001 ft (99% confidence); CS = 3rd order.	PS, PAS, P, E.
NAB	Horizontal or vertical control.	PS
SAM	NA	NA
SAC	Depends on project requirements, i.e. more stable for SM than for HS; installed to minimize movement and assume BM does not move.	NA
SAS	Monitoring structural movement requires a more elaborate BM.	TGC
SAW	No requirements established.	PS, PAS
NCB	No criteria established.	NA
NCC	Vertical, 0.01 ft; horizontal, usually 0.01 ft, but depends on project accuracy requirements.	TGC, P, A, AD
NCE	± 0.03 ft for most work (unless geodetic control is required).	TGC, PS, availability of massive stable structure nearby.
NCS	SM = 1st order, ± 0.001 ft (hor. and vert.); TS, CS, HS, APCP = 3rd order, ± 0.05 ft (vert.).	PAS, AEB, A, AD
NCR	TS = no hor., ± 0.1 ft vert.; SM = ± 0.02 ft hor., ± 0.005 ft vert.; CS = no hor., ± 0.05 ft vert.	E, A, PAS
ORP	± 0.005 ft.	PAS; availability of structures at site to set BM.
ORH	2nd order, ± 0.005 ft; 3rd order, ± 0.01 ft.	PS, E, TGC, A, AEB, availability of concrete structure and NGS BMs.
ORL	Table B3.	PAS, E, P, AD
LMK	CS = 0.05 hor., 0.10 ft vert.; HS = 0.20 ft hor., 0.10 ft vert.; SM = 0.03 ft hor., 0.02 ft -0.03 ft vert.; GS = 0.06 ft hor., 0.06 ft vert.; TS = 0.03 ft hor., 0.03 ft vert.	PAS, P
LMM	3rd order hor. control from NGS BM; <1 in 5000 error 3rd order vert. control from ≥ 3rd order BM; 0.05 ft$\sqrt{d(mi)}$.	P, PAS, TGC, A
LMS	≤ 3rd order.	NA
LMN	NA	NA
MRK	NA	NA
MRO	NA	TGC, PAS
SWG	TBM = ≤ 3rd order, 0.10 ft vert. and hor.; PBM = 3rd order, <0.05 ft movement.	PAS, TGC
SWF	BM is usually one magnitude more accurate than accuracy requirement of point being surveyed.	P, E, TGC
NPP	Determined by the order of the survey developed by NOAA.	PS, P, AD
NPS	Usually ± 0.01 ft.	PAS
SPN	TS, CS = 2nd or 3rd order; HS = 3rd order; BS = 2nd order.	P, PS, TGC, AD
SPK	NA	NA
SPL	SM = little or no movement; CS = minor movement tolerable.	P, E, TGC, PAS, A

*

NA = Not answered; no input from District or Division.
BM = Benchmark.
TGC = Terrain/ground conditions.
SM = Structural movement surveys.
CS = Construction surveys.
PS = Project scope.
PAS = Project accuracy specifications.
P = Permanency.
E = Economics.
HS = Hydrographic surveys.
A = Accessibility.
AD = Away from disturbances.
AEB = Accuracy (order) and availability of existing BMs.
TS = Topographic surveys.
APCP = Aerial photo control point surveys.
GS = Geodetic or control surveys.
TBM = Temporary benchmarks.
PBM = Permanent benchmarks.
BS = Boundary or cadastral surveys.

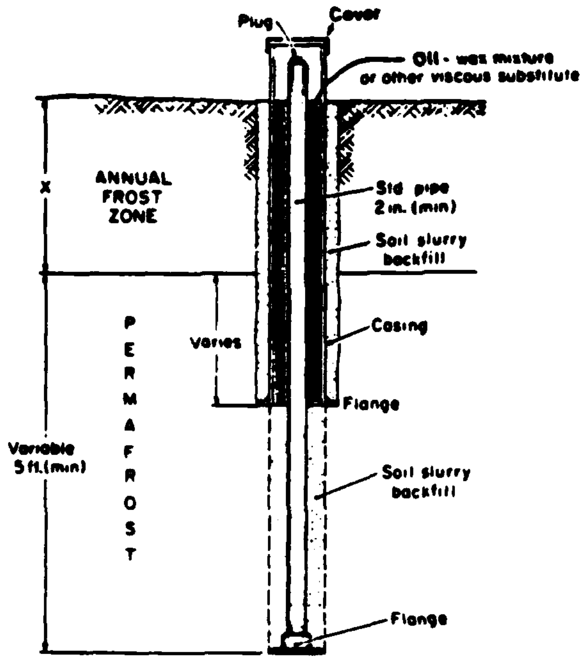
† See Table 1 for definitions.

Table 6. Problem conditions and precautions (from Corps responses to the questionnaire).

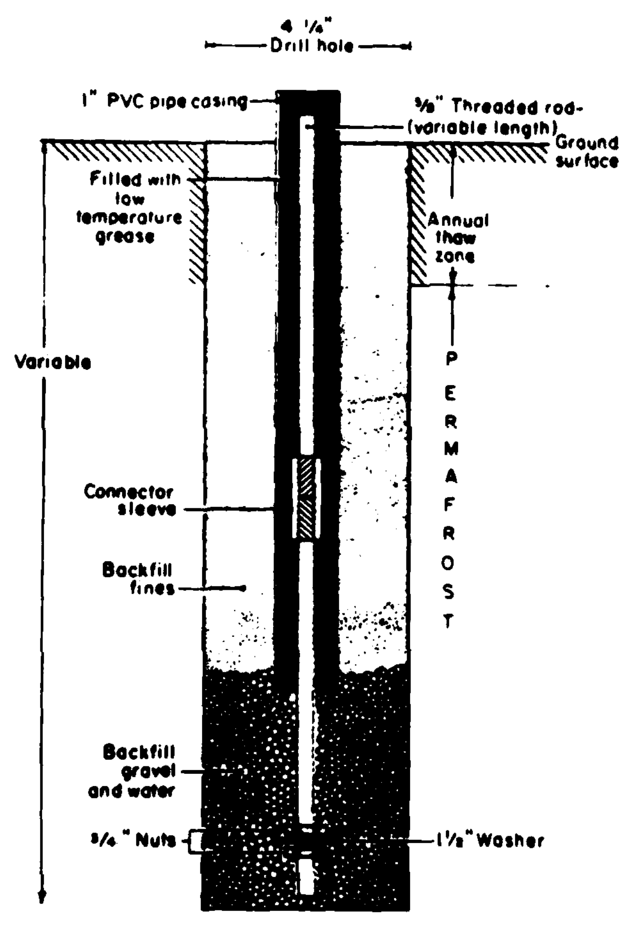
	Problem conditions*	Precautions*
NEDt	None	None
NAP	Conditions variable	Often must anchor BM in concrete mass.
NAO	I, FH, V, erosion	NA
NAB	FH	BM set below frost line or in stationary structure or bedrock.
SAM	I, S-SC, S-GWF, US	Deep encased rods 16-45 ft long in N. Miss and Ala. driven through soil crusts to deeper stable sands; 80-120 ft long in coastal areas.
SAC	I, S, US	Broad-based monument.
SAS	None	None
SAW	Tidal range, line of sight, boat and vehicle access, visibility between BMs.	NA
NCB	FH	Loop all level runs between 2 or more BMs.
NCC	I, beach erosion, sand covering a BM.	BM in concrete cylinder deep enough not to be undermined or high enough not to be covered.
NCE	FH, I (limits full use of BM).	Set below frost line; where inundation occurs, at least 20 ft long and approx. 2 in. diameter.
NCS	C/D, S-SC	Testing new monument materials, i.e., aluminum and Fiberglas; accessible to existing monuments; natural ties.
NCR	FH	Poured-in-place concrete monument with frost-free configuration.
ORP	FH, S	NA
ORH	FH, landslides	Consider all aspects of regional problems.
ORL	FH, S-SC	Set below frost line; set in undisturbed or well-compacted soil.
LMK	None	None
LMM	Possibly horizontal or vertical tectonic movement.	NA
LMS	FH, slope stability, underground mines.	None
LMN	S	Deep-set, casement BM.
MRK	FH	Set below frost line.
MRO	S-GWF, FH, EC, S (near structure), slope movement.	Deep-set, below frost line, clear of structures.
SWG	S, I	Deep-set BM or installed on structure.
SWF	EC	Deep-set in bedrock, isolated from clays; cone-tipped BM backfilled with grease to reduce infiltration; none (BM based on local conditions).
NPS	None	None
SPN	Tectonics, weak bedrock, S-GWF.	Periodic verification and readjustment of data for monuments.
SPK	NA	NA
SPL	G-GWF, S-SC	BM in bedrock if possible.

* BM = Benchmark.
I = Inundation.
FH = Frost heave.
V = Vandalism.
NA = Not answered; no input from District or Division.
S-SC = Subsidence due to soil compaction and consolidations.
S-GWF = Subsidence due to groundwater fluctuations.
US = Unstable soils.
S = Subsidence.
C/D = Corrosion and deterioration of monuments.

† See Table 1 for definitions.

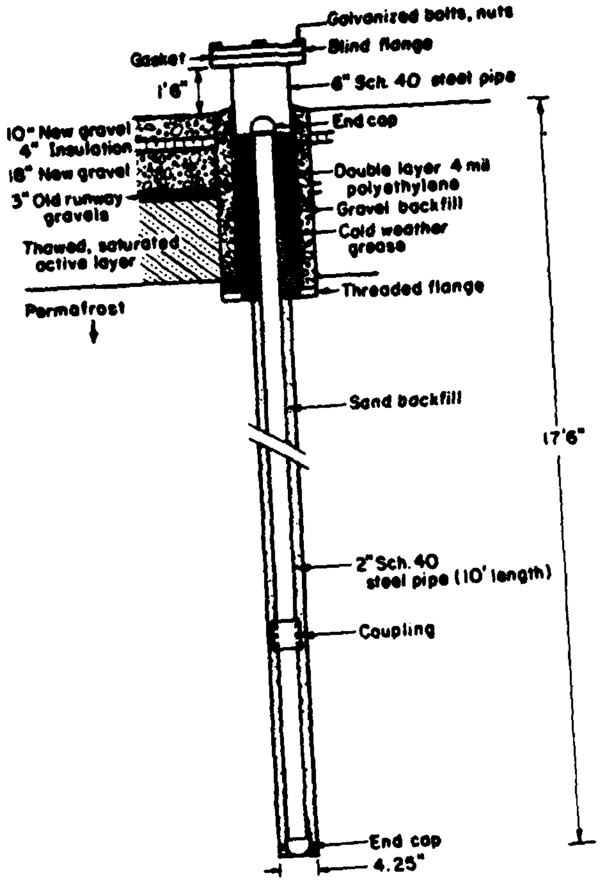


a. From Linell and Lobacz (1980).

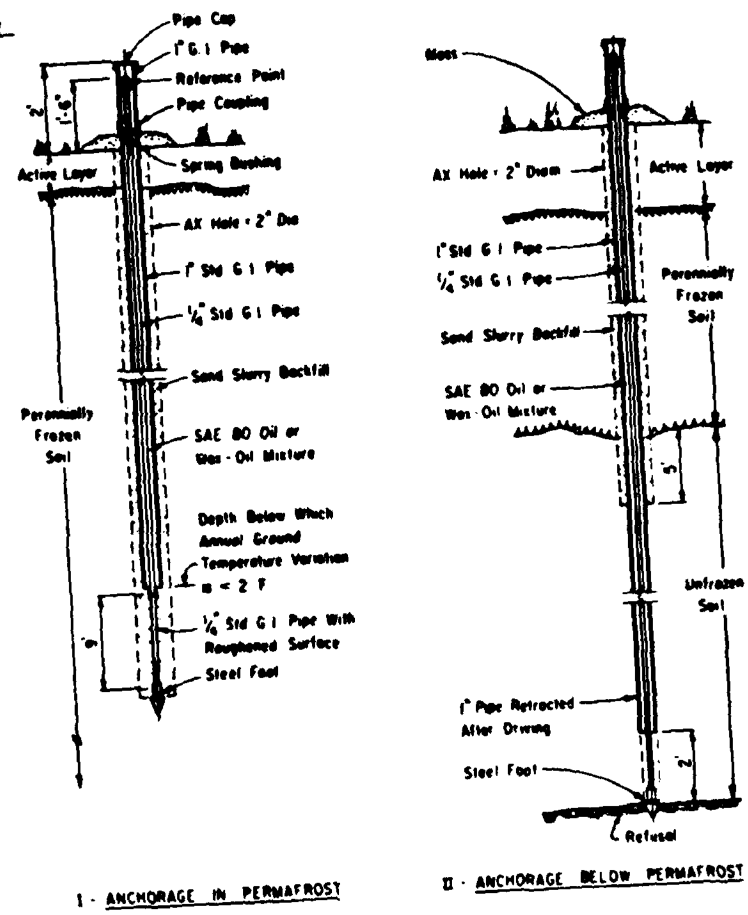


b. Adaptation used at Sukakpak Mountain, Alaska (drawing courtesy of B. Brockett, CRREL).

Figure 2. Frost-free benchmarks.

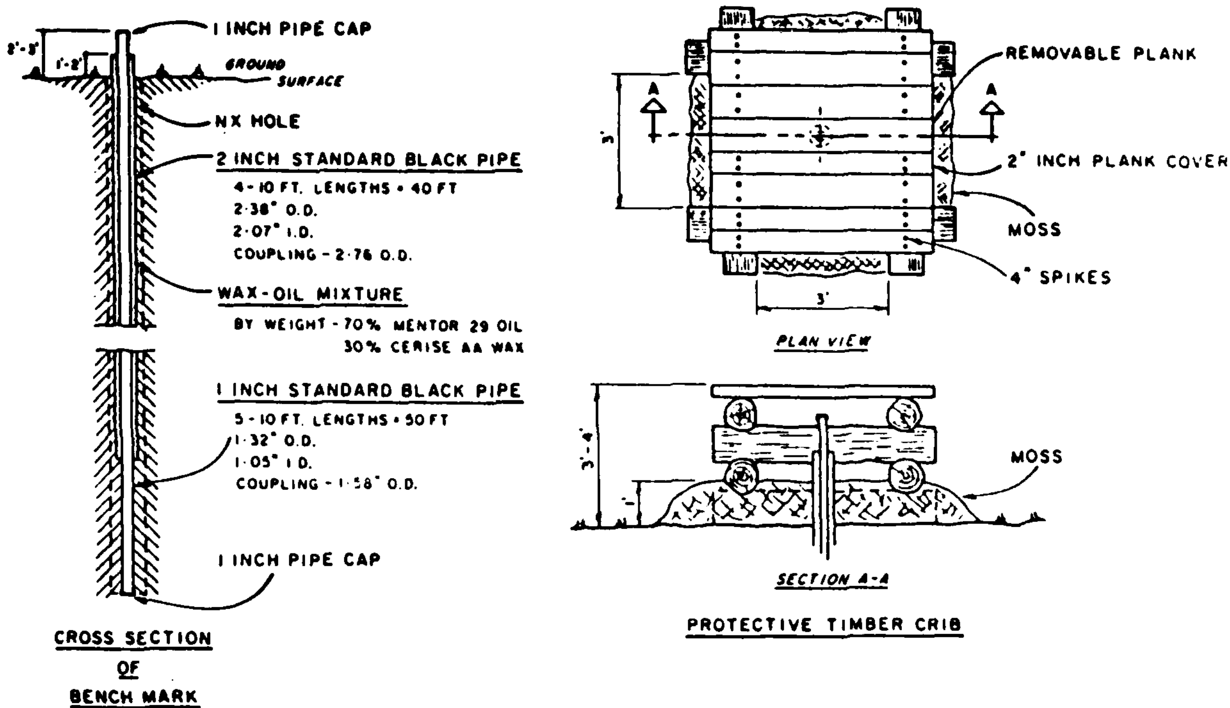


c. Adaptation used at Buckland, Alaska (drawing courtesy of B. Brockett, CRREL).



d. From Bozozuk et al. (1963; copyright ASTM, reprinted with permission); details in Appendix D.

Figure 2 (cont'd).



e. Inuvik primary benchmark installation (from Metz 1984).

Figure 2 (cont'd). Frost-free benchmarks.

Resurveys have not been done to check the vertical stability of some of these adaptations.

Metz* reports that three designs for "frost-free" benchmarks are in use in Canada (Fig. 2d,e) for continuous and discontinuous permafrost zones. The Inuvik design (Fig. 2e) includes a platform that reduces or eliminates surface disturbances near the benchmark caused by surveyors using the monument. The disturbances destroy the organic mat around the benchmark, which leads to deepening of the active layer and possible instability. He recommends that in permafrost areas benchmarks be installed where the ground is frozen, that plywood be used in the work area to minimize construction effects and to facilitate cleanup, and that all unused excavated material be removed.

Thorough site selection procedures constituted one of the most frequently cited and important precautions to be taken. By understanding project requirements in relation to the conditions at the site where bench-

* Personal communication with M. Metz, Geo Tec Services Inc., Golden, Colorado, 1984.

marks are required, the most useful benchmark can be chosen. The matrix (Fig. 3) can be used in deciding on acceptable methods (down the left side) to counter particular problem conditions (across the top). In conjunction with Tables 8 and 9 and other information, the matrix is useful in final selection of the appropriate benchmarks for a given project.

Preinstallation data

Districts usually locate the nearest state, Geological Survey or NGS benchmarks for bringing the datum to a project site (Table 7). Some Districts do probing tests to characterize soils at a site, check for evidence of subsidence, sloughing or previous cut and fill, drill for groundwater conditions and do a general geologic reconnaissance to determine terrain conditions. No special site selection considerations and observations were mentioned by the Districts.

Floyd (1978) describes five site selection considerations. The first is security, which implies that the benchmark would be free from vandalism. The second is utility, meaning that the benchmark must be accessible and usable later. Third is stability. This requires knowledge of the effects of sediment grain size, vegetation, slope position, the types and ages of nearby man-made structures, and lakes on local soil stability. Other geologic considerations -- especially regarding bedrock condition, location and type -- are also very important. The fourth consideration is the existence of corrosive conditions in the local area being considered for a benchmark. The last is safety, which addresses the knowledge of buried power lines or other potentially hazardous features.

Installation steps

Table 7 provides some general steps followed by most Districts when setting commonly used benchmarks. Some special precautions beyond those listed in Table 6 that should be taken when particular benchmarks are being installed are provided in Table B4. Most of the installation steps for benchmarks of a particular type would be the same in all parts of the country, although depth requirements and sizes and quantities of materials may vary depending on the severity of local problems.

Whenever benchmarks are installed in soils, drilling, driving or digging is required. In remote areas getting a drill rig on site may be a problem. Several portable drill rigs are available and CRREL has been very

COUNTERMEASURES	UNDESIRABLE CONDITIONS: Damage/destruction	Frost heave	Expansive soils/rock	Compression of soils	Slope instability	Subsidence from pumping	Caverns/underground mines	Depression of permafrost	Settling of structures	Concealment	Corrosion	Erosion
Use disk set in bedrock	X	X	X	X	X	X	X					X
Seek coarse-grained soils		X	X									
Seek well-drained soils		X									X	
Seek well-aerated soils											X	
Set on crests of nills		X			X							
Seek soils with high resistivity											X	
Natural/readymade protection[a]	X											
Anticipate future construction[b]	X											
Set near edge of right-of-way	X										X	
Bench mark design	X	X	X	X							X	
Anchor sleeved rod below level of disturbance		X	X	X								
Set disk in massive, deep structure		X	X	X	X							
Historically significant structure	X											
Modern buildings	X											
Remain distant from thawing effects[c]								X				
Ensure good referencing										X		
Avoid heavy vegetation			X							X		
Avoid river banks												X
Avoid flood plains										X		X
Avoid shoreline scarps												X
Avoid salt water shorelines											X	X
Avoid areas as determined by geological data[d]			X		X	X	X					
Avoid expansive bedrock			X									
Avoid new structures (less than 5 years old)									X			
Establish BM on oil or water well casing						X						

[a]Includes fence lines, utility poles, structures, and private and public grounds.

[b]Includes highways, parking lots, buildings, pipelines, and waterways.

[c]Includes lakes, rivers, buildings, and pipelines.

[d]Overviews of karsts, slope instability, shale outcrops, oil and gas bearing formations, etc., from the U.S. Geological Survey, States' Geological Surveys, States' Departments of Natural Resources, and public utilities commissions.

Figure 3. Measures taken to set high-quality benchmarks (after Floyd 1978, p. 11).

Table 7. Preinstallation data, installation steps and costs (from Corps responses to the questionnaire).

	Preinstallation data*	Installation steps*	Costs*
NED†	Locate nearest state/GS BM and bring in datum.	Find bedrock and mark permanently with disk or chiseled mark.	< $100
NAP	Geodetic control.	Concrete monuments on stable soils; Table B1.	NA
NAO	No special data collection; site selected by Party Chief.	BM set according to NOS or NGS specs.	$500-$1000/BM
NAB	Predetermined by project officer.	Start survey with NGS datum.	SM = $1800; TS = $125
SAM	NA	Rods driven by Cobra Hammer through 6-8 in. PVC pipes that provide horizontal stability and protect againsts elements and man.	NA
SAC	Locate nearest NGVD or MLW BM.	Table B6.	$10,000/yr for updating, maintaining and expanding vertical network.
SAS	NA	Set concrete monument 3-4 ft deep; aluminum monument, 2-1/2 ft deep.	Minimum costs since no problem conditions.
SAW	None specific.	Concrete monuments typically set flush with or near ground.	Survey party = $500/day; each monument = $50; to set control = $500-$2000/day.
NCB	Do not install PBM only TBM.	None special.	NA
NCC	BM near project site; permanent easement to BM.	Control to BM by 1st order leveling from GS/NGS BM.	Depends on line length to bring in control; no BM installed recently - no costs available.
NCE	Probing tests.	Have necessary tools on site, alum. sectional rods with base to be flared, alum. piston monument.	Variable with grade level of party; generally $50 to 200$.
NCS	Existing NOAA control used; previous Corps data.	NA	1st order = $170/hr; 2nd order = $135/hr; 3rd order = $75/hr.
NCR	Site checked for subsidence, sloughing, previous cut and fill.	Table B5.	Boat spike = $10; Cap in rock/structure = $25; Frost-free = $300.
ORP	Geotechnical Branch provides data for site selection or suggests location on dam structure.	Normal procedures.	Disk in rock/structure = $15; Spike/rebar = $<5; Alum. monu. = $45.

Table 7 (cont'd). Preinstallation data, installation steps and costs (from Corps responses to the questionnaire).

ORH	Normal consideration of regional and local conditions.	Planning, scheduling, recon., site location, coordinate equipment; Table B2.	Variable, from TBM spikes, (35 cents) to steel casing pedestal ($1200).
ORL	Field observations.	Monument - preselected site; TBM - site selected by field people.	Table B3
LMK	None.	Conventional steps only.	Iron pipe = $40; concrete post = $100; encased = $2000; driven to refusal = $275.
LMM	General observations for siting BM.	Normal procedures.	PBM = concrete post = $250; labor = $200 to run control to new BM; TBM = spike = $250.
LMS	Locate nearest control BM.	NA	Minimal = spikes, alum. pipes and labor.
LMN	Subsurface geological data.	NA	NA
MRK	NA	Set below frost line.	NA
MRO	NA	NA	NA
SWG	On-site visit to determine terrain conditions.	Site selection for solid natural or man-made structure; install PBM if nothing available.	TBM = $5; PBM = $70.
SWF	Usually make borings and get data on groundwater fluctuations.	Table B4.	Deep PBM = $3250; cone-tip deep PBM = $1000; conc. BM = $300; Free-standing deep PBM = $2200.
NPP	General knowledge of area, specific site investigations.	Standard procedures.	$100-$130/hr for material and labor.
NPS	Select stable area near project based on Corps knowledge and data.	Standard procedures.	Establish project datum is $5000-$20,000, with average $10,000.
SPN	Geologic reconnaissance.	Check existing BM for error, install new BM based on condition of old one.	2nd order = $1500; 3rd order = $1000.
SPK	NA	NA	NA
SPL	None.	Consider permanence, access and suitability for surveying.	$700 for concrete monument, disks in bedrock, iron pipes.

* BM = Benchmark.
NA = Not answered; no input from District or Division.
SM = Structural movement surveys.
TS = Topographic surveys.
PBM = Permanent benchmark.
TBM = Temporary benchmark.
MLW = Mean low water.

† See Table 1 for definitions.

successful in using a small rig at several locations in Alaska. Additional details on this small rig are available from Brockett et al. (1984) and Brockett and Lawson (1985). Also, installation of deep-driven rod benchmarks requires special tools and equipment. Information on this may be obtained from the Districts that use this type of benchmark (Table 4).

Costs

District costs (Table 7) varied, depending on labor and materials charges and on the complexity of the benchmark. Note that some of the cost estimates may be several years old and may not reflect current prices. The amount of project funds available and project accuracy requirements determine the type of benchmark that can be used, although meeting the NGS requirements for third-order or better vertical accuracy in benchmarks is equally important.

CONCLUSIONS AND RECOMMENDATIONS

Corps Districts have developed and tried a large variety of benchmarks. Each District eventually comes to use those benchmarks that they believe provide the accuracy required in the terrain and climatic conditions of their region at a reasonable cost. Information on these benchmarks was compiled and synthesized for this report so that District surveyors would have data on benchmark designs, installation procedures and costs from many sources in a single report.

This report in no way suggests that there are standard benchmark designs that are being used or standard ways of installing them. The variety of installations shown here suggests that Corps surveyors have used their ingenuity to develop many options. Standardization of benchmarks within the Corps might lead to inappropriate installations being made if the surveyors did not exercise good judgment in selecting the best one for a given project. However, as part of the Corps participation in the Federal Geodetic Control Committee, there is a strong desire at the Office of the Chief of Engineers that Corps Districts use state of the art benchmark designs and installation procedures so benchmarks would be appropriate for site conditions, and would meet project accuracy requirements and those of the NGS. Then the benchmarks could be included in the National Geodetic Data Base.

Table 8. National Geodetic Survey benchmark quality classes (adapted from FGCC 1980).

Quality class A: most reliable; expected to hold their elevations very well.

1. Bronze disks cemented into rock outcrop, ledge or cut, bedrock, massive structures with deep foundations, large structures with foundations on bedrock.*

2. Sleeved, deep-set (≥ 10 ft deep) -- galvanized steel pipe or rod, stainless steel rod, aluminum alloy rod.**

Quality class B: will probably hold their elevation well.

1. Unsleeved, deep-set (≥ 10 ft deep) -- copper-clad steel rod, galvanized steel pipe or rod, stainless steel rod, aluminum alloy rod.

2. Sleeved, deep-set (≥ 10 ft deep) -- copper-clad steel rod, unspecified rod or pipe.

3. Structures -- massive retaining walls, abutments and piers of large bridges, tunnels, massive structures other than those listed above.

4. Rock -- unspecified as to type, condition, etc.

Quality class C: may hold their elevation but are commonly subject to surface ground movements.

1. Shallow-set (< 10 ft deep) -- metal rod with base plate, concrete post.

2. Boulders.

3. Structures -- retaining walls, culverts, small bridges, footings or foundation walls of small to medium structures, mat foundations including landings, platforms, steps, etc.

Quality class D: questionable or unknown reliability.

1. Shallow-set (< 10 ft deep) -- pipe, metal rod without base plate.

2. Structures -- piles, poles, spike in utility pole, pavement, streets, sidewalks, curbs, aprons, light structures other than those listed above.

* First choice
** Second choice; see Floyd (1978) and Hoar (1983) for details.

The NGS has classified the most frequently used benchmarks into four groups based on reliability (Table 8). Only classes A and B meet the first-order vertical accuracy requirement for establishing the NAVD88. Consequently, the NGS uses only class A and B benchmarks in their first order survey lines.* In running second-order lines, the NGS uses class A

* Personal communication with E. Balazs, National Geodetic Survey, Rockville, Maryland, 1985.

and B marks but also some class C marks, and the line is tied to a line of equal or higher order vertical accuracy. The requirement for vertical accuracy is for the survey; benchmarks do not have orders of accuracy. As long as the accuracy of a survey line meets or exceeds second-order specifications, the survey is accepted as a second-order line. In a third-order line, there could be more class B and C marks plus some class D marks and it must be tied to an equal or higher ordered line. Again the accuracy requirements are on the survey, not benchmarks.

To assist Corps surveyors in selecting benchmarks that would most likely allow them to achieve third-order or better vertical accuracy in their surveys in different site conditions, I assigned each of the various Corps benchmarks shown in this report to a NGS class (Table 9). This assignment was based on the information in Table 8 and FGCC (1984), and from conversations with NGS personnel.* The assignments have not been verified by the NGS.

Based on the large amount of information available from the Corps, I make the following recommendations to aid surveyors in selecting appropriate benchmarks for their future survey needs. The recommendations are not in any particular order of importance; I feel that they are equally important.

1. Every District should use the NOAA Manual NOS NGS 1, Geodetic Benchmarks (Floyd 1978). All benchmarks except those for temporary use should be installed to meet the standards described in this manual. When these standards are met, the Corps' benchmarks can be made part of the national data base.

2. Good judgment in site selection is the prime factor in ensuring benchmark stability. Many problems will be avoided if all available information (i.e., geologic data, experience, borings, etc.) is used in site selection. Extra time spent in reviewing all available information during site selection can reduce benchmark installation costs and increase the likelihood that the benchmark will be adequate.

3. Permanent benchmarks should be installed based on project and NGS accuracy requirements, on project site conditions and on available funds. Elaborate, costly and very stable benchmarks may not be required for every

* Personal communications with D.A. Hoar and E. Balazs, National Geodetic Survey, Rockville, Maryland, 1985.

Table 9. Assigned NGS classes for some benchmarks used by Corps Districts and site conditions in which benchmarks can be used; refer to Figure 3 and Floyd (1978).

Benchmark	Reference in this report	NGS†† class	Site conditions
Disks	Fig. B1,B9,C1,C2,C3,C9; Tables B1,B2	A	Sound bedrock, large to massive structures.
Encased (sleeved)*	Fig. 1,2,C8; Table B4	A,B	Granular soils (sand & gravel); cohesive soils; frost heave; construction fill; marsh; subsiding, consolidating, or compacting areas; shrinking and swelling soils.
- various depths	Fig. B8	NA	
- with base plates	Fig. B8,C7; Table B4	A	
- various types of reference rods, piles, etc.**		A,B	
- various types of casements		NA	
- driven or drilled		NA	
Pipes, rods, posts, rebar		†	Stable, granular or cohesive soils.
- with caps, disks	Fig. B1,B9, Table B3	NA	
- without caps, disks	Fig. C12	NA	
- prefabricated	Fig. B9,C4	†	
- various materials**: alum, wood, Fiberglas, galv., steel, brass	Table B2	B-D	
- driven or drilled	Fig. C6; Tables B2,B6	NA	
- variable lengths and diameters		B-D	
- concreted at top, bottom, throughout	Fig. B2,B4,B6,B7,B9; Tables B1 B2,B3,B6	NA	
- with baseplate, foot, flarable base or pins in base	Fig. B6,C5,C10,C11	B,C	
Poured concrete	Fig. B1; Table B1	†	Stable soils.
- various shapes and lengths	Fig. B8; Table B4	B-D	
- reinforced	Fig. B3,B5	NA	
- anchored by pipe, posts, rebar, etc.	Fig. B1	C	
- broad-based	Fig. B2,B5; Table B5	C	
- anchored in rock	Fig. B10	B	
- with disks	Fig. B2,B3	NA	
Precast concrete	Fig. B1	†	Stable soils.
- various lengths, sizes, shapes		B-D	
- with disks		NA	
Chiseled shapes	Table B3	U	
- in bedrock	Table B5		
- in structures	Table B5		
Spikes, nails	Tables B2,B3	TBM	
- in trees, posts, poles	Fig. B9	D	
- in roads, pavements	Fig. B9, Table B3	D	

* More than 10 ft deep, may be as deep as 100 ft.
** Materials that show little or no size change with temperature are better.
† Less than 10 ft deep, class C or D; more than 10 ft deep, class B or C.
†† NA No effect, does not improve class.
U Unacceptable as a permanent BM; must use disk.
BM Benchmark.
TBM Temporary BM.

project, but all permanent benchmarks should meet or exceed the requirements for third-order accuracy. Sometimes simplicity of design is preferred.

4. Installations can be modified to meet site-specific conditions and project needs as long as the basic design of a particular benchmark is not changed so radically that it reduces the likelihood of its stability. As Floyd (1978, p. ii) points out, there is no optimal monument for every case; he suggests "judicious modification of design when the occasion arises."

5. If permanent, NGS-type benchmarks (Floyd 1978) are used, their construction and installation instructions should be closely followed. These benchmarks have been tested and shown to be stable. Any alteration to the tested design has not been evaluated and may cause a benchmark to be unstable (Floyd 1978).

6. Some benchmarks used by the Corps Districts provide stable references (Table 9) if they are installed properly with care and attention to design. Improper, careless installation will result in an unstable benchmark, which equates to wasted time and money and useless surveys.

7. Benchmarks must be anchored below the depths where instability processes occur; a massive monument alone does not ensure stability.

8. Special surveys such as instrumentation type surveys need particular consideration because they require a stable instrument pedestal and deep-driven rods for benchmarks when soil conditions permit.

9. All permanent benchmarks should include as a minimum a Corps Survey benchmark data disk with identification stamped on it. A circle, square, triangle, or cross chiseled in bedrock is insufficient as a permanent benchmark.

10. Temporary benchmarks should not be used except for truly temporary work sites.

LITERATURE CITED

Arctic Construction and Frost Effects Laboratory (1957) Permanent benchmarks in permafrozen fine-grained soils. USA Cold Regions Research and Engineering Laboratory, Miscellaneous Paper 17.

Black, R.F. (1957) Some problems in engineering geology caused by permafrost in the Arctic Coastal Plain, northern Alaska. Arctic, 10(4): 230-240.

Bozozuk, M., G.H. Johnston and J.J. Hamilton (1963) Deep benchmarks in clay and permafrost areas. In Field Testing of Soils. American Society of Testing and Materials Special Technical Publication 332. Philadelphia: ASTM, pp. 265-275.

Brockett, B.E., J.A. Farmwald and F. Sayles (1984) Benchmark and thermistor installation and shallow core sampling of permafrost at Buckland, Alaska, August 1984. USA Cold Regions Research and Engineering Laboratory, Technical Note (Unpublished).

Brockett, B.E., and D.E. Lawson (1985) Prototype drill for core sampling fine-grained perennially frozen ground. USA Cold Regions Research and Engineering Laboratory, CRREL Report 85-1.

Currer, E.W.H. (1962) An investigation into the movement of shallow benchmarks. The Surveyor, 121:781-783.

*Federal Geodetic Control Committee (1980) Input formats and specifications of the National Geodetic Survey Data Base, Vol. 2. Vertical control data (L. Pfeifer and N.L. Morrison, Ed.). National Oceanic and Atmospheric Administration Manual NOS NGS 2. Rockville, Maryland: National Ocean Service.

*Federal Geodetic Control Committee (1984) Standards and specifications for geodetic control networks. Rockville, Maryland: National Geodetic Information Branch, National Geodetic Survey, National Oceanic and Atmospheric Administration.

*Floyd, R.P. (1978) Geodetic benchmarks. National Oceanic and Atmospheric Administration Manual NOS NGS 1. Rockville, Maryland: National Geodetic Survey.

Geodetic Survey of Canada (1983) Bench mark recommendations for precise leveling. Ottawa, Canada: Surveys and Mapping Branch, Energy, Mines and Resources Canada, pp. B1-B20.

Gupta, R.C., R.G. Marshall and D. Badke (1973) Instrumentation for dykes on permafrost, Kettle Generating Station. Canadian Geotechnical Journal, 10(3):410-427.

*Hoar, D.A. (1983) The new adjustment of the North American Vertical Datum. ACSM Bulletin, December, p. 21-22.

Jarman, J.T. (1955) Movement of triangulation marks set in permafrost. Journal of the Coast and Geodetic Survey, 6:11-22.

Johnston, G.H. (1962) Benchmarks in permafrost areas. The Canadian Surveyor, 16(1):32-41.

Johnston, G.H. (1981) Operation, maintenance and performance of structures. In Permafrost Engineering Design and Construction (G.H. Johnston, Ed.). New York: John Wiley and Sons, pp. 473-481.

* These references should be used by all District surveyors in designing, installing and reporting benchmarks for vertical control.

Karcz, I., J. Morreale and F. Porebski (1975) Vertical crustal movements in New York and Pennsylvania -- neotectonics or benchmark-instability? Geological Society of America Abstracts Program, 7(7):1138-1139.

Karcz, I., J. Morreale and F. Porebski (1976) Assessment of benchmark credibility in the study of recent vertical crustal movements. Tectonophysics, 33:T1-T6.

Kryukov, Y.A., and V.V. Garevski (1973) Dependence of benchmark stability on geological and geomorphological conditions. Geodesy, Mapping and Photogrammetry, 15(1):187-189.

Linell, K.A., and E.F. Lobacz (1980) Survey datum points. In Design and construction of foundations in areas of deep seasonal frost and permafrost. USA Cold Regions Research and Engineering Laboratory, Special Report 80-34, pp. 255-258.

Mackay, J.R. (1984) Lake bottom heave in permafrost; Illisarvik drained lake site, Richards Island, Northwest Territories. Geological Survey of Canada Paper 84-1B, Part B, pp. 173-177.

Slater, R.E., and L.E. Slater (1979) A note on natural and man-made causes of benchmark instabilities (abstract). EOS, 60(18):234.

Wyatt, F., J. Berger and K. Beckstrom (1979) Precision measurements of surface benchmarks (abstract). EOS, 60(46):811.

BIBLIOGRAPHY

Long, G.H. (1981) Retracement surveys in Pacific Northwest Coast Range. Journal of Surveying and Mapping Division, American Society of Civil Engineers, 107(SU1):45-58.

Maltby, C.S. (1970) Metal-rod benchmark supports. Reston, Virginia: U.S. Geological Survey.

Maltby, C.S., and E. Doskins (1966) Benchmark monumentation. Reston, Virginia: U.S. Geological Survey.

Snedeker, R.B. (1979) Land surveying research needs: the next decade. Journal of Surveying and Mapping Division, American Society of Civil Engineers, 105(SU1):85-91.

U.S. Geological Survey (1966) Topographic instructions of the U.S. Geological Survey. In Leveling. Book 2. Chapters 2E1-2E5.

APPENDIX A: INFORMATION SENT TO CORPS DISTRICTS, NED and POD.

Questionnaire

Your Name ____________
District ____________
Date ____________

Information on Survey Benchmarks in the Districts

1. List of the purposes for which benchmarks are required in your District (i.e., monitoring during construction, monitoring structural deformations, geodetic surveys, etc.). Show the types of benchmarks the District used for each purpose in the past. Diagrams of the benchmark installations would be very helpful if available (just attach to these sheets).

2. For each purpose listed above, how stable must the listed benchmarks be? What are the lateral and vertical limits of movement that you must have?

3. What factors determine the type of benchmark used?

4. What special problem conditions (i.e. expandable clays, subsidence, groundwater fluctuations, frost heave, etc.) exist within the District that must be considered in setting a benchmark? What precautions are taken to reduce the effects of these conditions?

5. What pre-installation data collection is done for characterizing a site and for selecting a benchmark?

6. What are the steps for installing each type of benchmark?

7. How much does each benchmark listed in No. 1 cost? Include materials and labor. Estimates are fine.

8. Can I cite you by name as a contributor to the report? Yes No
(Circle one)

Please return your responses and any attachments to:

Lawrence Gatto
USACRREL
72 Lyme Road
Hanover, NH 03750

Thank you very much for your help. I'll send a draft copy of the report so you can comment and suggest changes if you want to.

Matrix

VERTICALLY STABLE BENCHMARKS

Instructions

Add to and change as appropriate, i.e. add undesirable or problem conditions in your District that are not mentioned here; include countermeasures you've used for conditions listed or those you add. If the table already covers all items of importance to your District, please indicate and return this sheet.

Please return this sheet before the end of March (1985) to:

Lawrence W. Gatto
USACRREL
72 Lyme Road
Hanover, NH 03755-1290
FTS: 836-4273
Comm: (603) 646-4273

(If you haven't filled out a questionnaire and are willing to, let me know and I'll send you a copy.)

Table 1.—Summary of measures taken to set high-quality bench marks (from Floyd, 1978, p.11)

COUNTERMEASURES \ UNDESIRABLE CONDITIONS	Damage/destruction	Frost heave	Expansive soils/rock	Compression of soils	Slope instability	Subsidence from pumping	Caverns/underground mines	Degradation of permafrost	Settling of structures	Concealment	Corrosion	Erosion
Use disk set in bedrock	x	x	x	x	x	x	x					x
Seek coarse-grained soils		x	x									
Seek well-drained soils		x									x	
Seek well-aerated soils											x	
Set on crests of hills		x			x							
Seek soils with high resistivity											x	
Natural/readymade protection[a]	x											
Anticipate future construction[b]	x											
Set near edge of right-of-way	x										x	
Bench mark design	x	x	x	x							x	
Anchor sleeved rod below level of disturbance		x	x	x								
Set disk in massive, deep structure		x	x	x	x							
Historically significant structure	x											
Modern buildings	x											
Remain distant from thawing effects[c]								x				
Ensure good referencing										x		
Avoid heavy vegetation			x							x		
Avoid river banks												x
Avoid flood plains										x		x
Avoid shoreline scarps												x
Avoid salt water shorelines											x	
Avoid areas as determined by geological data[d]			x		x	x	x					
Avoid expansive bedrock			x									
Avoid new structures (less than 5 years old)									x			

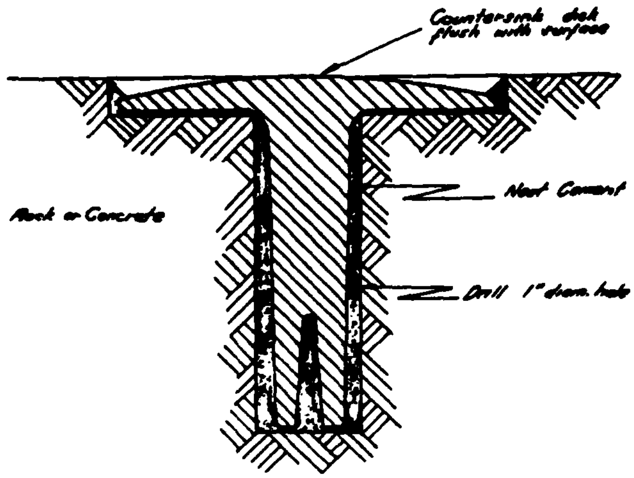
[a] Includes fence lines, utility poles, structures, and private and public grounds.

[b] Includes highways, parking lots, buildings, pipelines, and waterways.

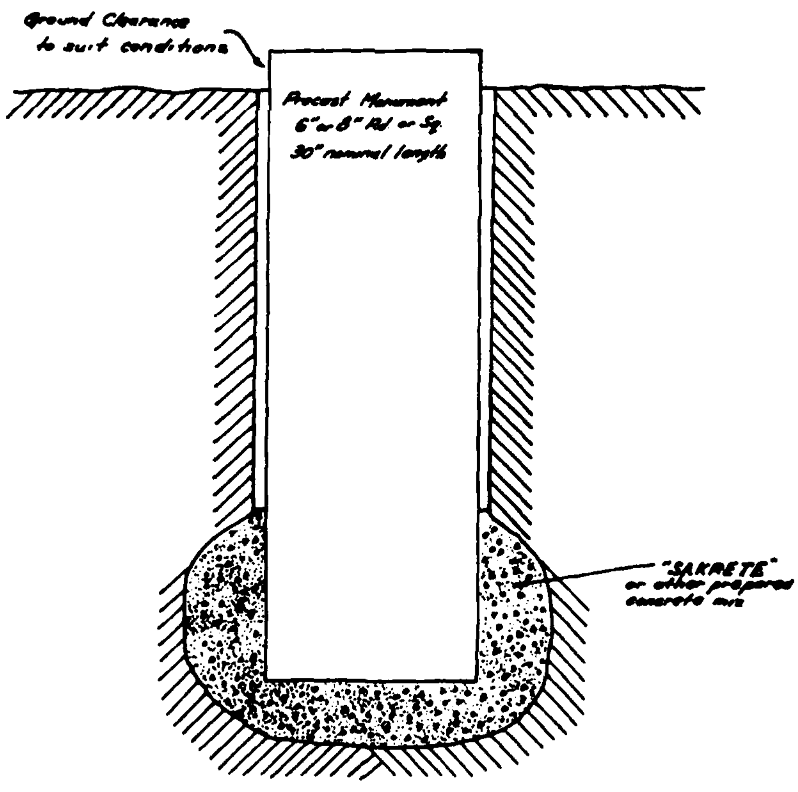
[c] Includes lakes, rivers, buildings, and pipelines.

[d] Locations of faults, slope instability, shale outcrops, oil and gas bearing formations, etc., from the U.S. Geological Survey, States' Geological Surveys, States' Departments of Natural Resources, and public utilities commissions.

APPENDIX B: BENCHMARKS USED BY THE DISTRICTS

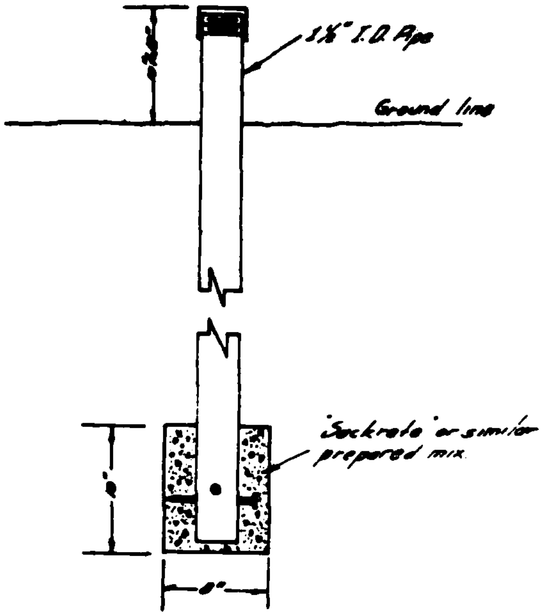


a. Standard disk in rock or concrete.

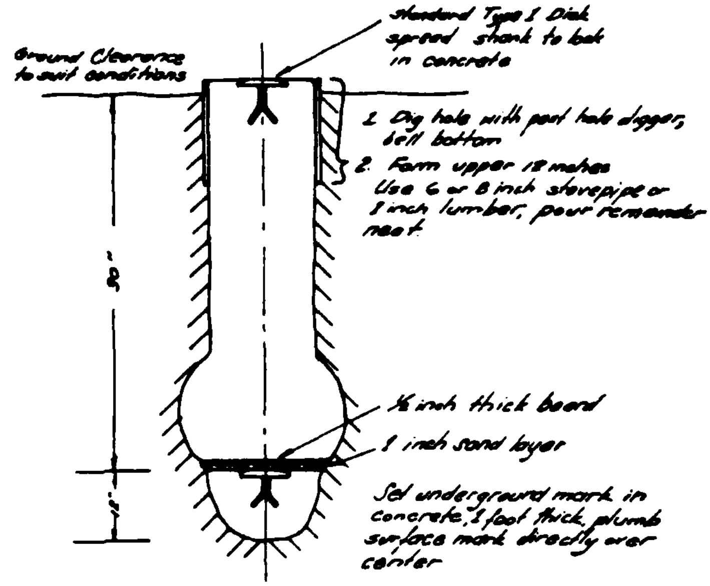


b. Precast concrete monument.

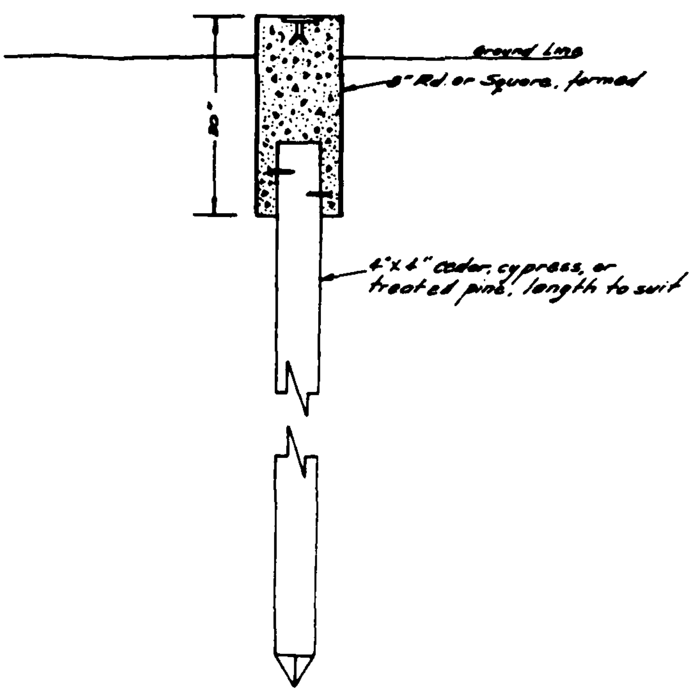
Figure B1. Benchmarks used by the Philadelphia District.



c. Capped pipe.

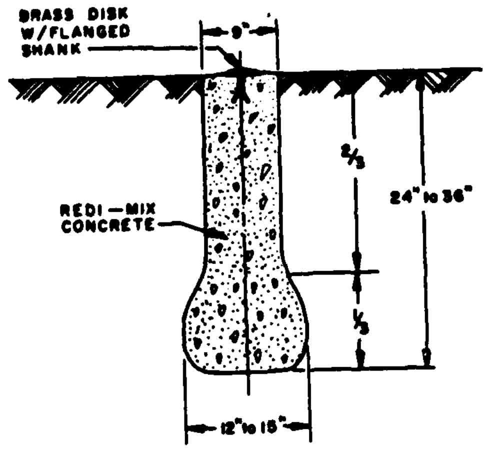


d. Poured in place monument.

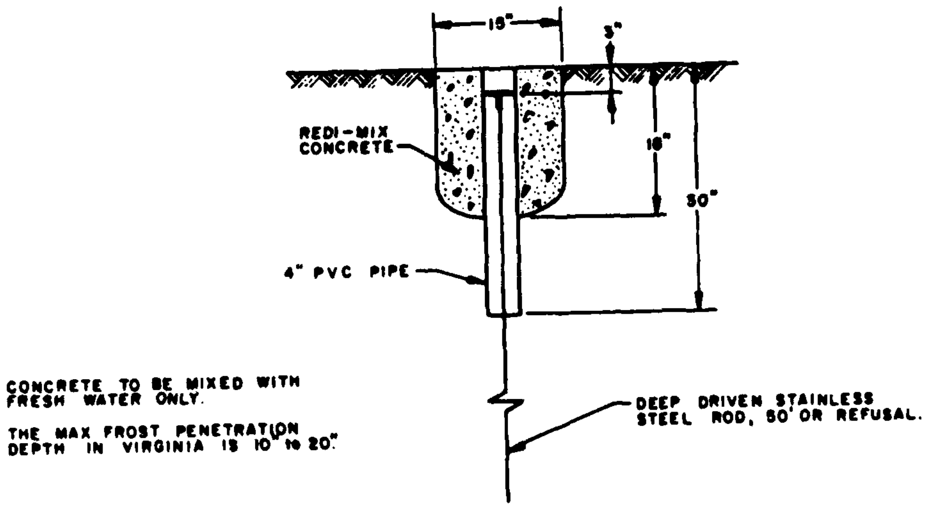


e. Poured in place monument on unstable ground.

Figure B1 (cont'd). Benchmarks used by the Philadelphia District.

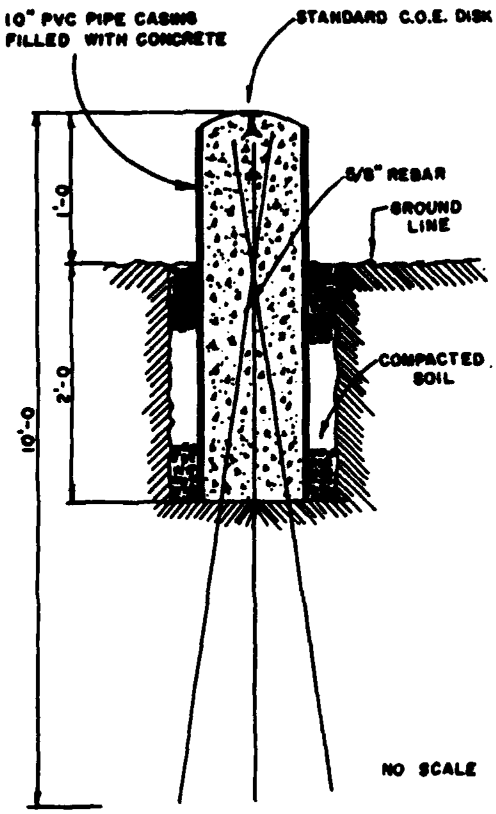


a. Generic benchmark.

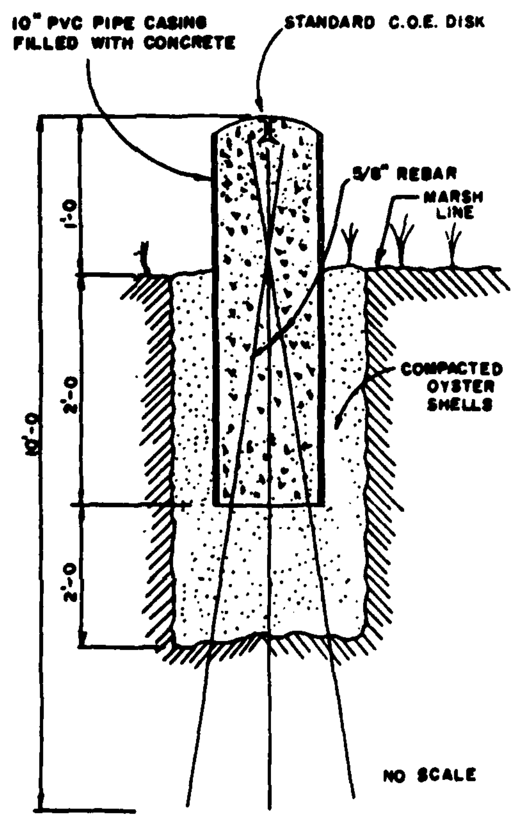


b. Tidal benchmark.

Figure B2. Benchmarks used by the Norfolk District.

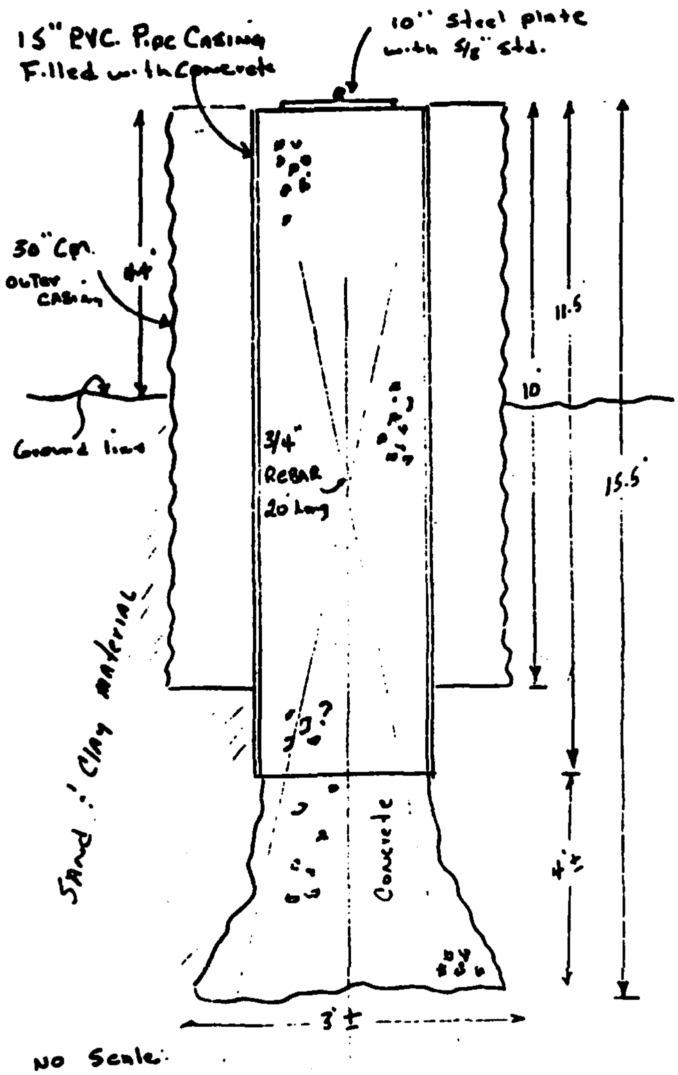


a. Type A (for good soil conditions, Kings Bay project).

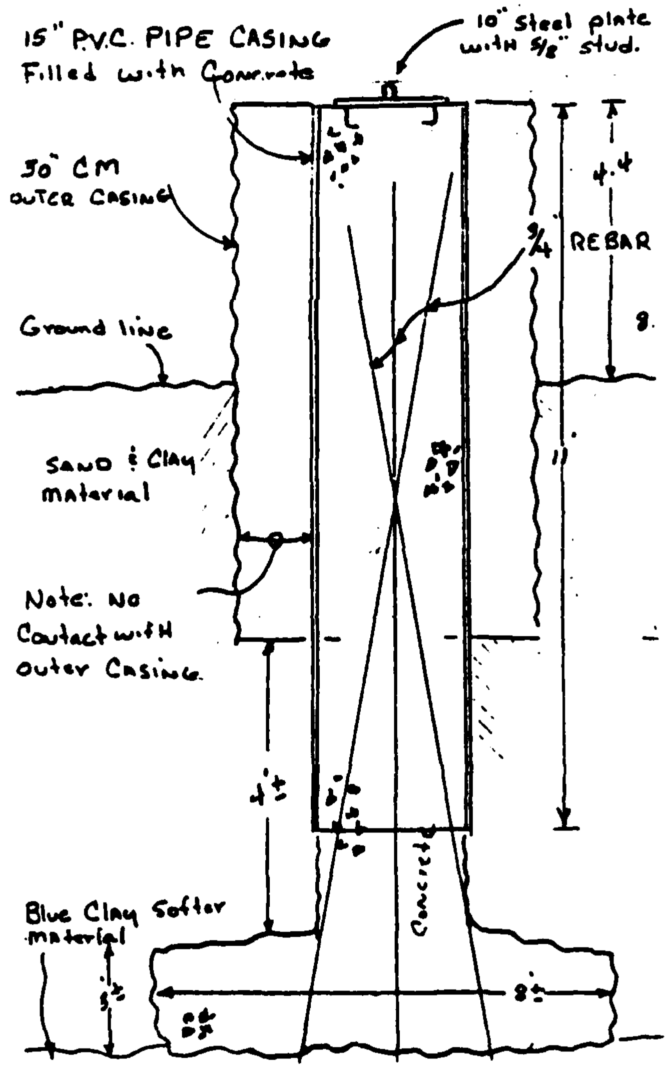


b. Type B (for marsh conditions, Kings Bay project).

Figure B3. Benchmarks used by the Savannah District.



1. South Carolina pedestal.



2. Georgia pedestal.

c. Instrument pedestals for the New Savannah Bluff lock and dam.

Figure B3 (cont'd).

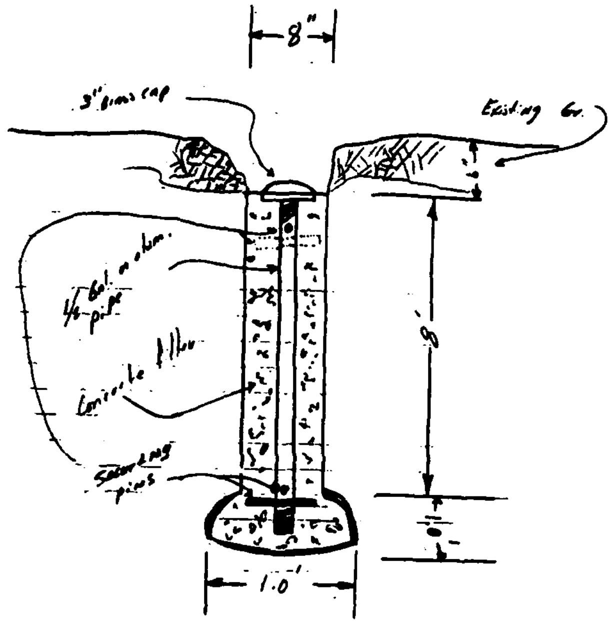
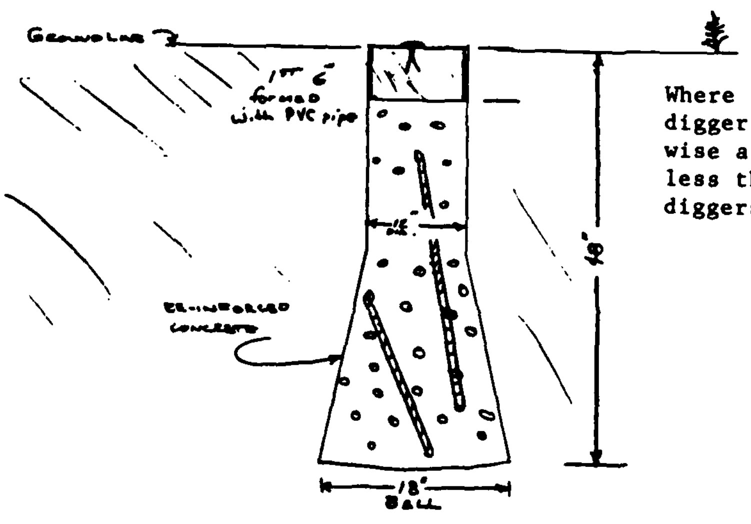


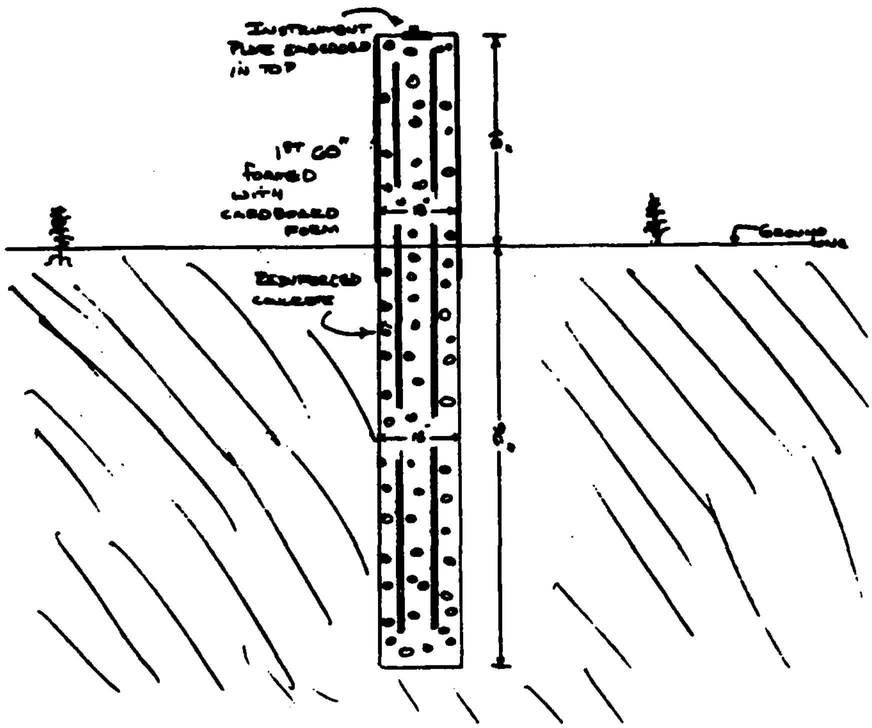
Figure B4. First-order or second-order benchmarks used by the St. Paul district.



Where possible, post-hole diggers can be used, otherwise a gas auger. For depths less than 36", post-hole diggers will suffice.

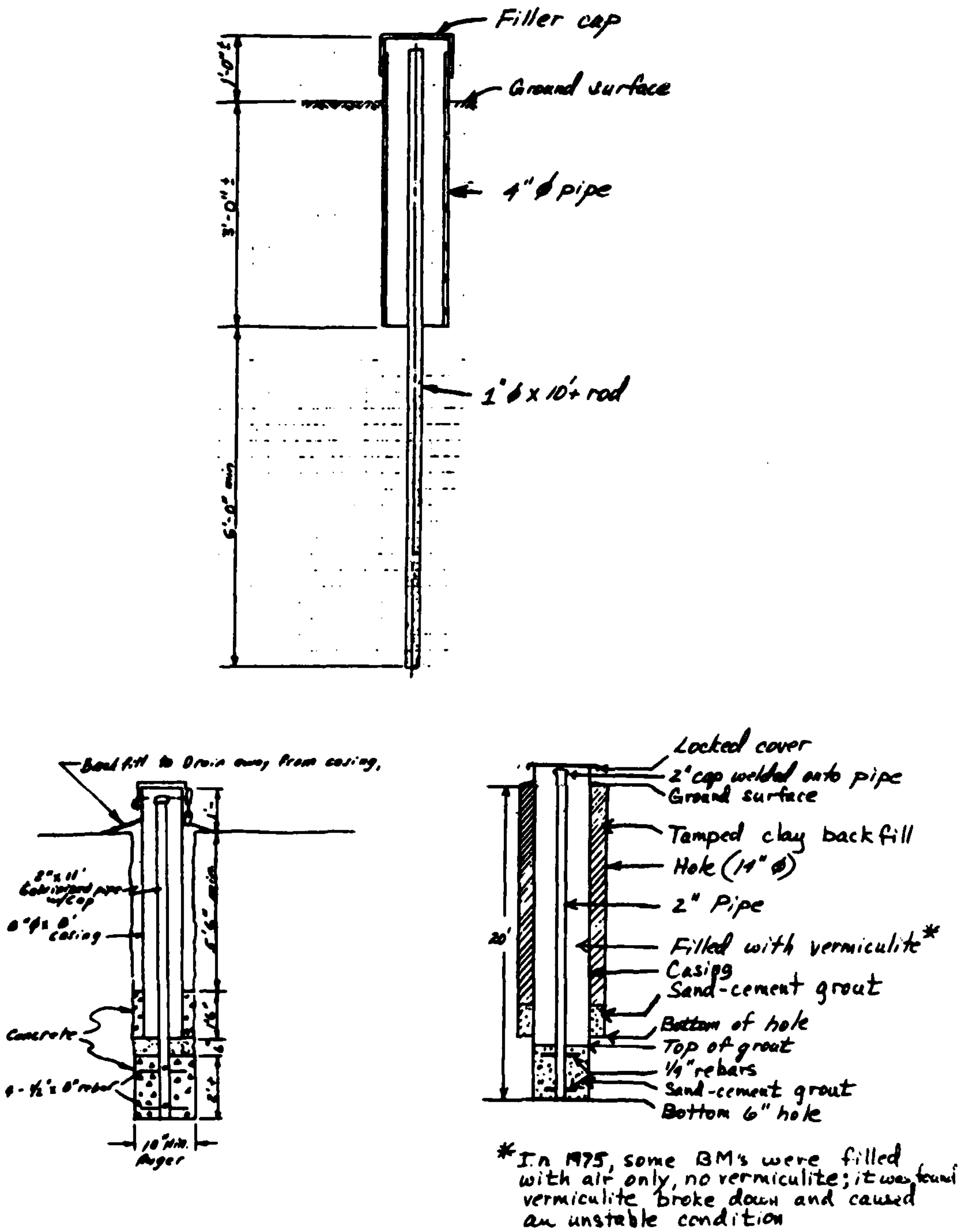
a. Geodetic survey benchmark.

Figure B5. Benchmark and pedestal from the Louisville District.



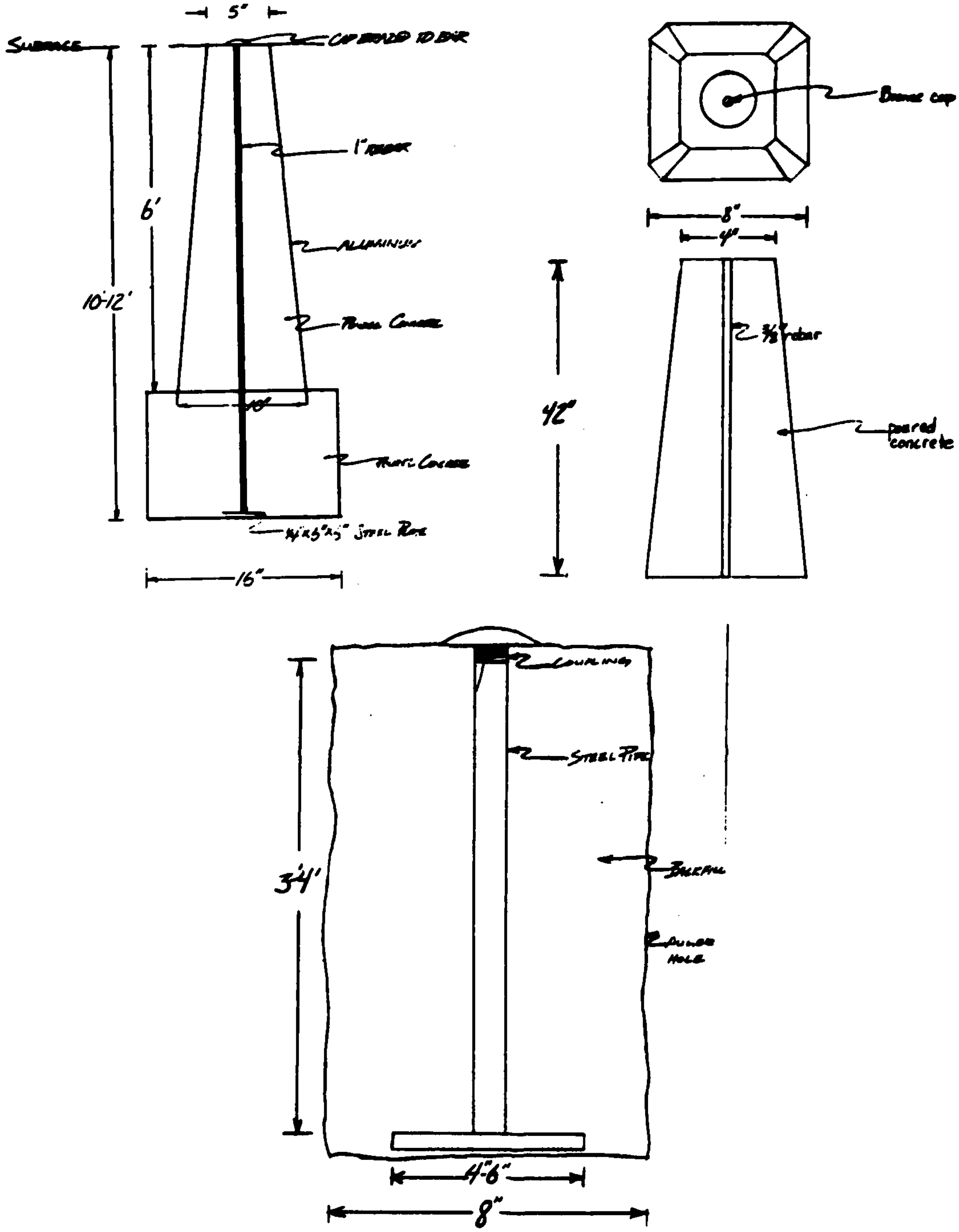
b. Instrument pedestal for a movement study.

Figure B5 (cont'd).



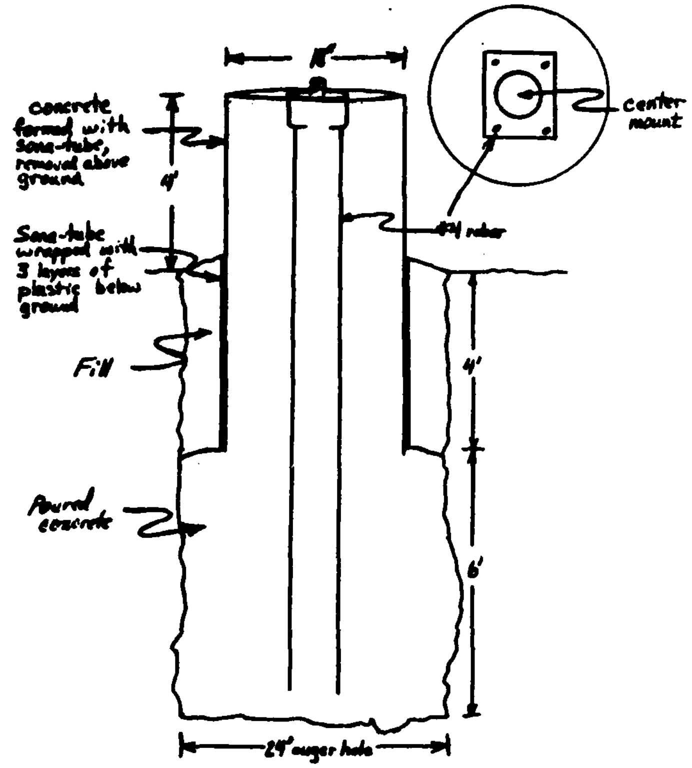
a. Various benchmarks.

Figure B6. Benchmarks and pedestals from the Omaha District.

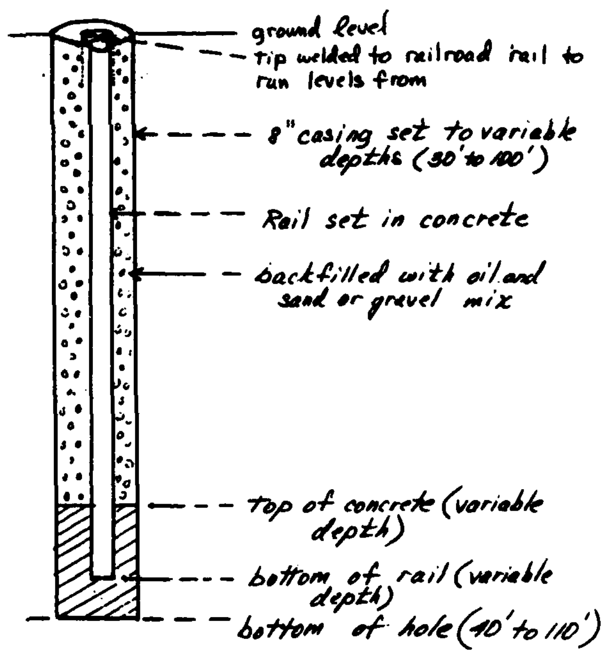


a. (cont'd).

Figure B6 (cont'd).



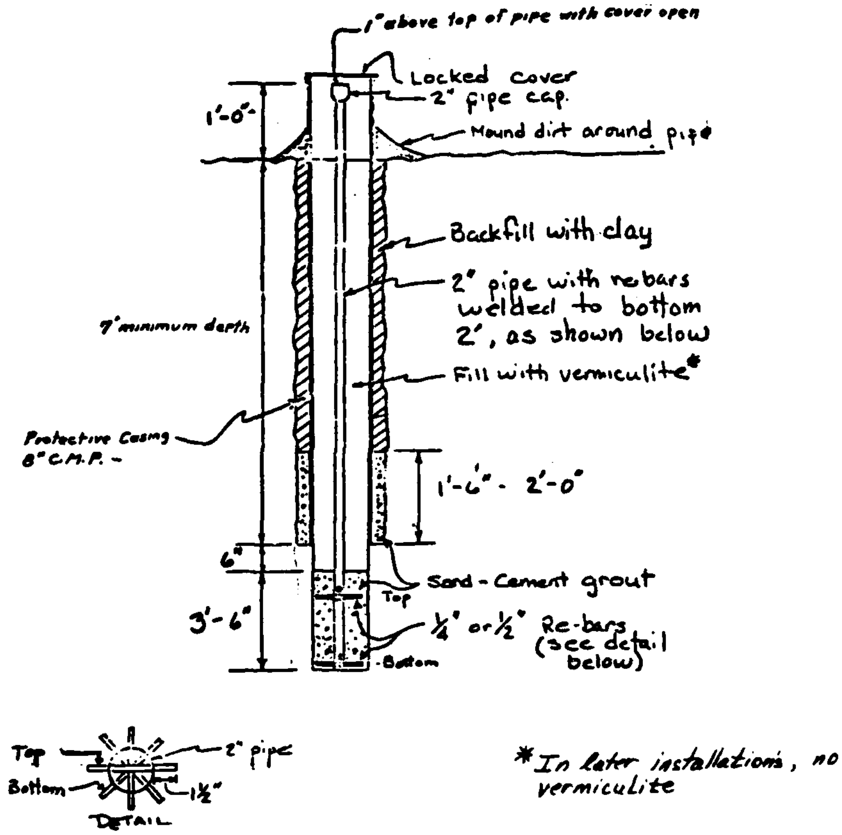
b. Instrument pedestal.



General procedure: pour 2'-8' of concrete into hole for rail to set on; let set for 72 hrs; set rail on set concrete; pour additional concrete (8'-10'); let set; pour in mixture of oil and sand or gravel up to ground surface

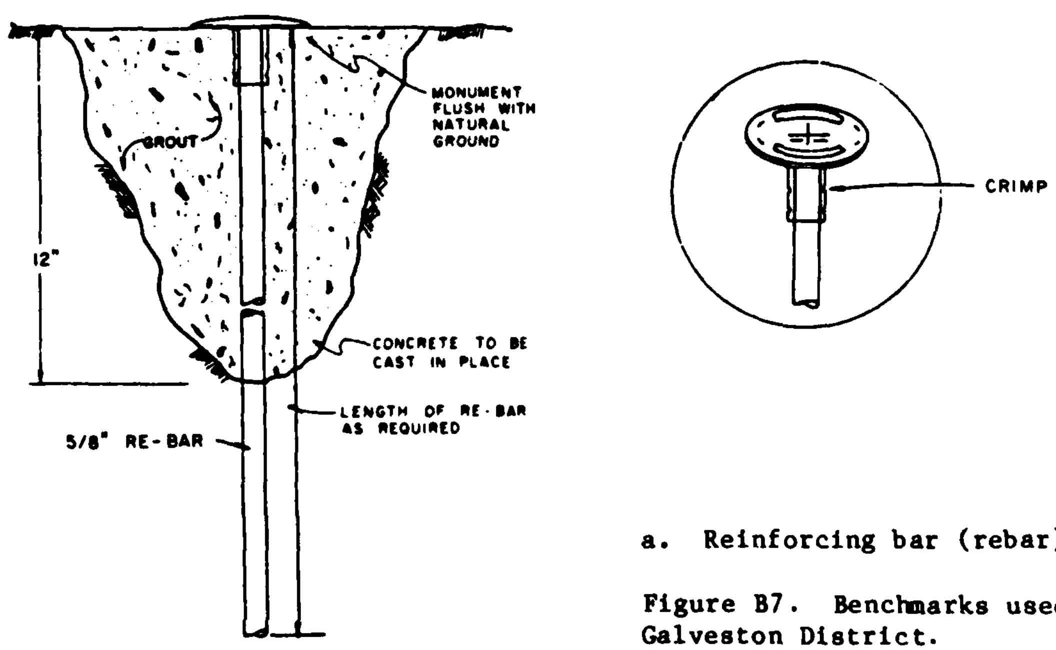
c. Permanent benchmark.

Figure B6 (cont'd). Benchmarks and pedestals from the Omaha District.



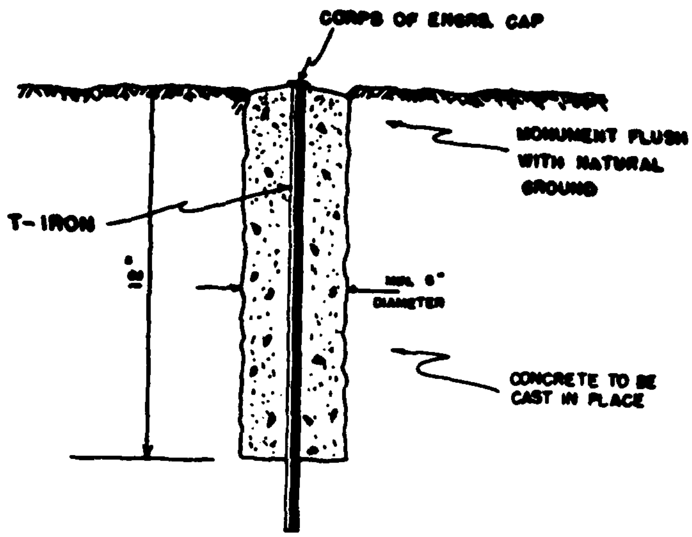
d. Frost-free benchmark.

Figure B6 (cont'd).



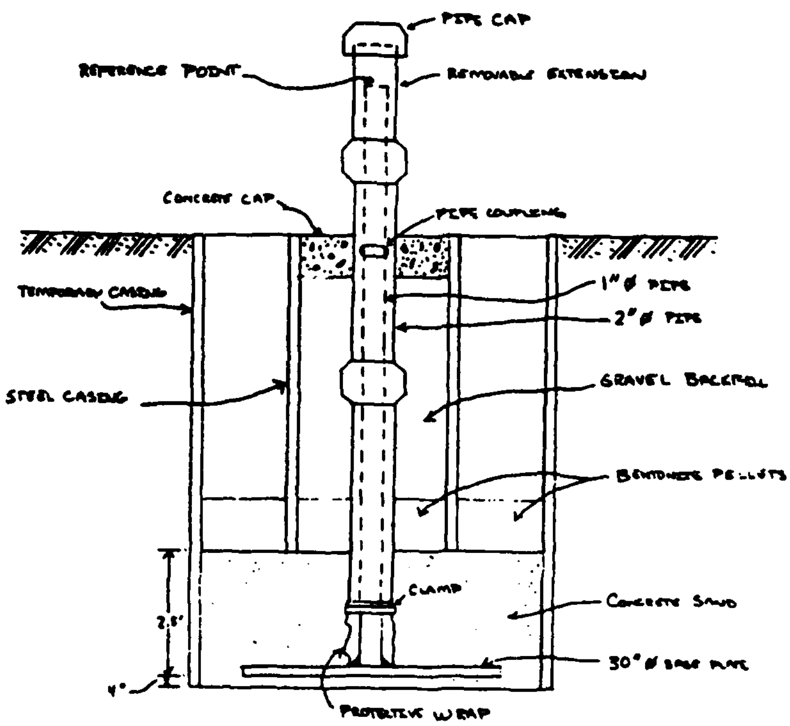
a. Reinforcing bar (rebar) benchmark.

Figure B7. Benchmarks used by the Galveston District.



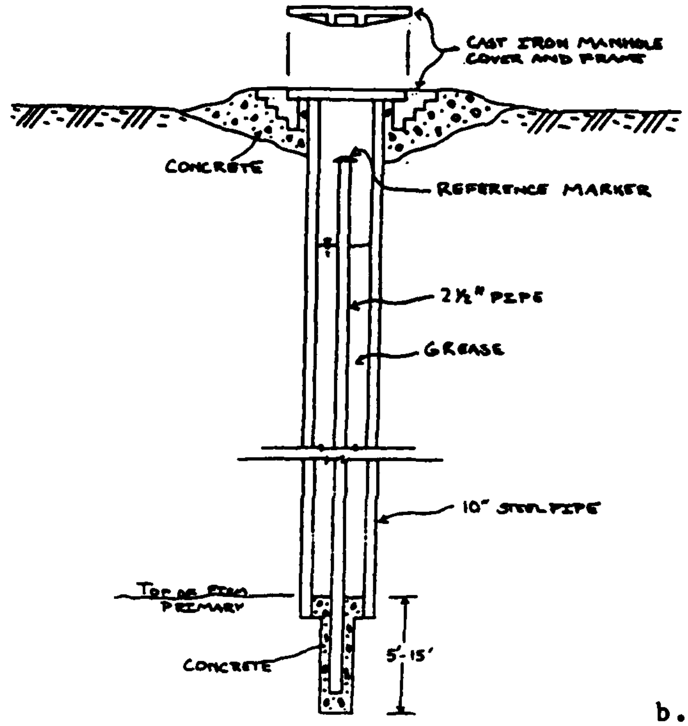
b. T-iron benchmark.

Figure B7 (cont'd). Benchmarks used by the Galveston District.

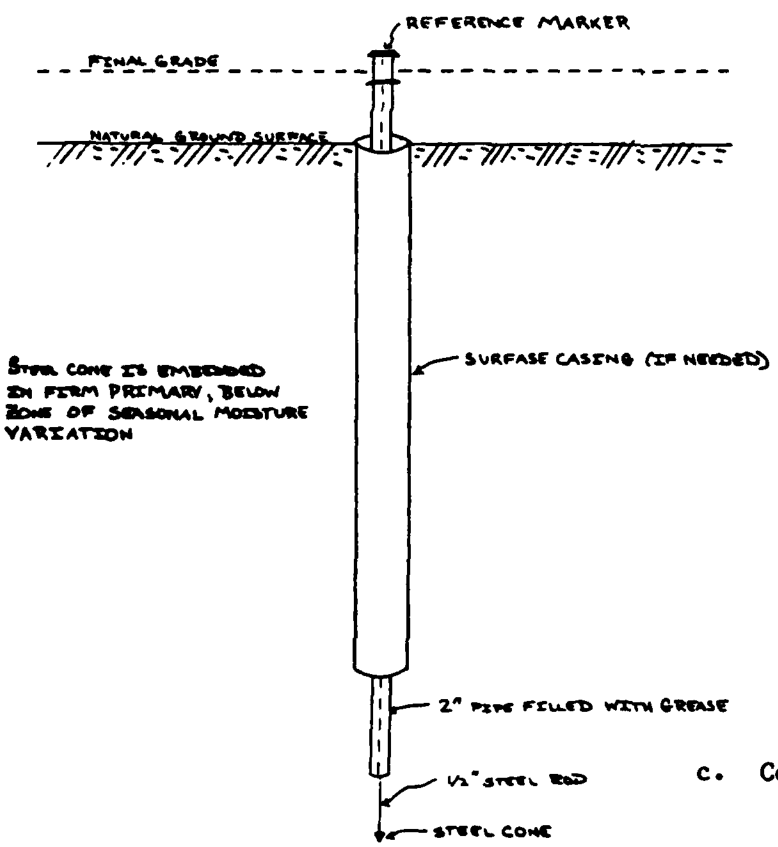


a. Deep benchmark and settlement plate.

Figure B8. Benchmarks used by the Ft. Worth District (not to scale).

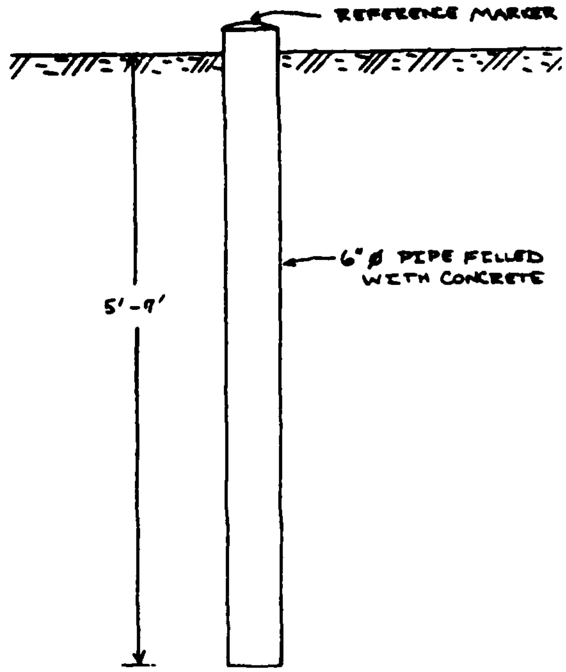


b. Free-standing, deep benchmark.



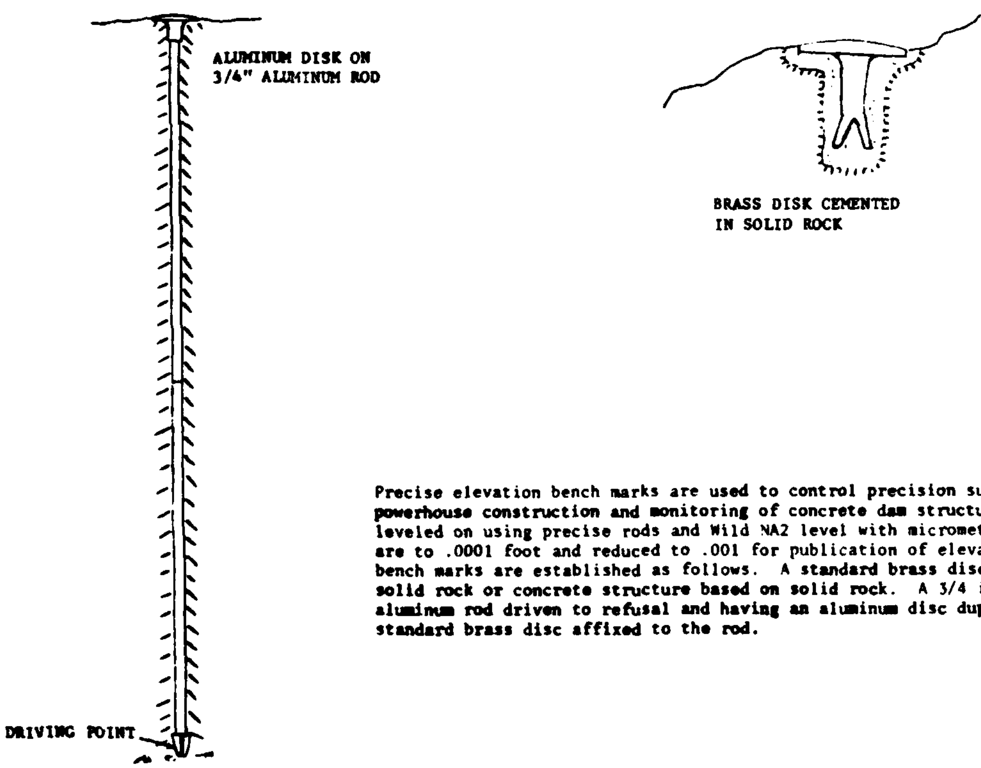
c. Cone-tipped, deep benchmark.

Figure B8 (cont'd).



d. Concrete benchmark.

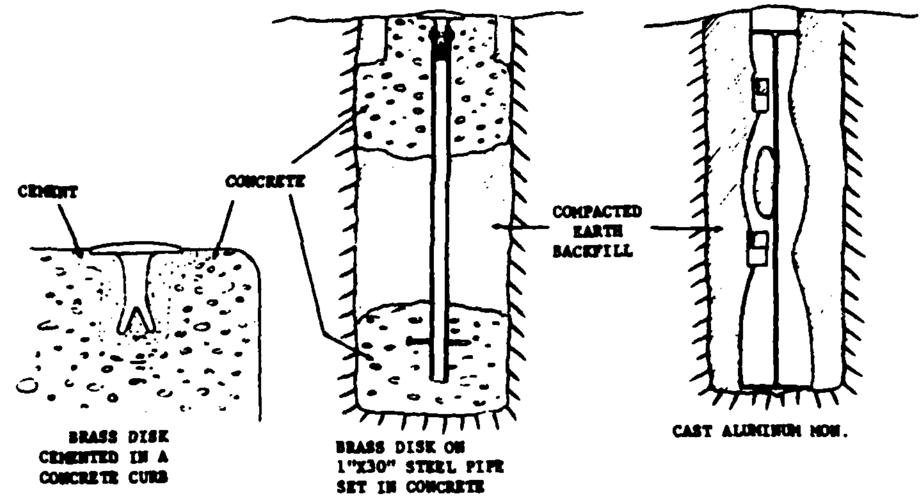
Figure B8 (cont'd). Benchmarks used by the Ft. Worth District (not to scale).



Precise elevation bench marks are used to control precision surveys such as powerhouse construction and monitoring of concrete dam structures. They are leveled on using precise rods and Wild NA2 level with micrometer. Readings are to .0001 foot and reduced to .001 for publication of elevations. These bench marks are established as follows. A standard brass disc cemented in solid rock or concrete structure based on solid rock. A 3/4 inch diameter aluminum rod driven to refusal and having an aluminum disc duplicate of a standard brass disc affixed to the rod.

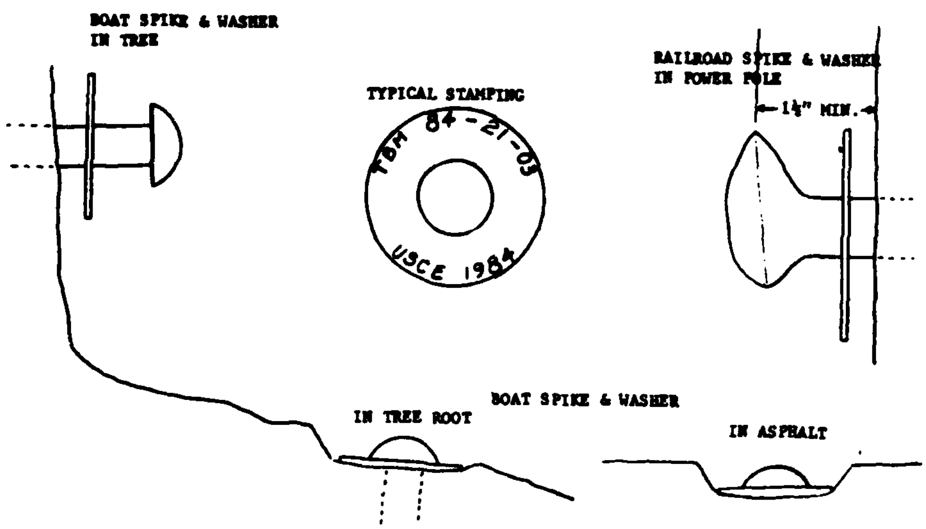
a. Primary benchmarks.

Figure B9. Benchmarks and instrument pedestals used by the Portland District.



Secondary bench marks for establishing precise elevations to control TBM's and most construction projects. These bench marks are generally constructed in the following manners. A standard brass disc riveted to a 1"x30" steel pipe and set in a concrete monument near flush with ground surface. A standard brass disc cemented into a concrete sidewalk or other relatively solid base. A pre-cast aluminum monument set flush with ground surface with backfill compacted.

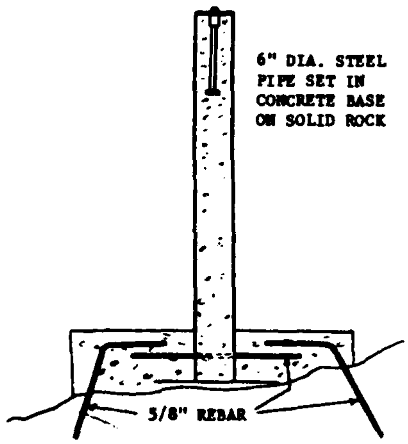
b. Secondary benchmarks.



For maintaining vertical control between precise vertical control points during preliminary surveys, construction and post construction surveys of highway, road, railroad, some building construction and river bank protection projects. The Portland District Survey Section uses the following systems, the following being general descriptions. In each case an aluminum washer is used and the designation of point, agency and year set, are stamped around the outer edge. In wood structures, solid posts, power and telephone poles a 8" or 10" wire nail, boat spike or railroad spike is driven to a depth where the leveling rod can be placed and swiveled upon the top of the head. The spike or nail is driven through the appropriately marked washer with small enough hole that the washer cannot be removed without removing the spike or nail. The information stamped on the washer gives anyone access to recorded information in the District Office.

c. Temporary benchmarks.

Figure B9 (cont'd).



For dam monitor control monuments a 4'x4' square concrete base is laid on solid rock with either a pyramidal concrete monument with 12" square aluminum plate and projecting 5/8 inch stainless steel stud or a 6" or 8" steel pipe set in the concrete base with an aluminum cap and stainless stud on top. The primary use of these pillar type monuments is as instrument mounts but due to the solid construction they may be used as precise elevation benches.

d. Instrument pedestal.

Figure B9 (cont'd). Benchmarks and instrument pedestals used by the Portland District.

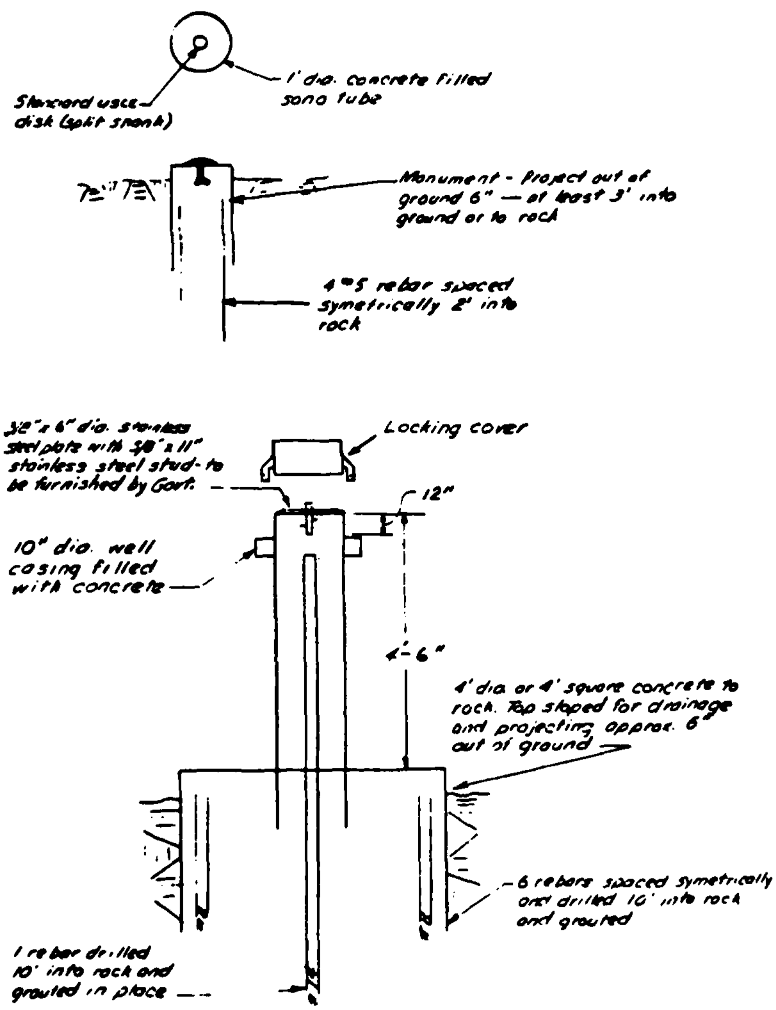


Figure B10. Benchmark and instrument pedestal used by the Sacramento District.

Table B1. Suggestions for benchmarks, Philadelphia District (see Figure B1).

Standard disks

Not set in curbs or sidewalks (too movable).

Set in drilled holes deep enough to hold entire shank.

Countersink below surface of rock or concrete.

Fill drilled hole with full-strength cement, push disk in, allow cement to ooze out and around disk to seal disk edge.

Concrete monuments

Stable soils — whenever possible, set underground marks in case surface mark is disturbed; precast or poured in place.

Unstable soils (marsh-swamp) — center on wood post long enough to assure stability.

Capped pipes

Set in concrete, not driven.

Put spikes (20d nails) through pipe 4 in. from bottom (prevents withdrawal of pipe).

Table B2. Benchmarks, Huntington District.

Pedestals — 10 in. casings (15 ft deep) drilled to rock and filled with concrete.

Disks — 1. Set on vertically stable structures (e.g., dam monoliths).
2. Set in rock outside of limits of subsidence.
3. Set in walks, bridges, etc.

Steel posts — 6 ft, driven flush with ground and concreted in place.

Monuments — 36-in. (4- x 4-in.) concrete monuments set flush or below ground.

Mine spikes — set in trees, pavements, base of wood structures or products.

Iron pins — 36-in., driven flush with ground.

Brass rods — set in concrete 3 ft or more underground.

Pipe — driven to variable depths.

Rods -- aluminum or Fiberglas, driven below frost line.

Table B3. Benchmarks, Louisville District.

Type of survey	Type of monument	Limits of movement (ft) Horizontal	Vertical	Approx. cost**
Normal structural deformation (earthen and concrete structures)	Brass plug in drill hole in reinforced concrete (Fig. B5)	--	--	$20 (plugs)
Sedimentation surveys	Five-foot-long rod with disk, surrounded with a concrete ring 12 in. in diameter to below frost depths	± 0.1	0.1	$30
Military and civil E&D for construction	Chiseled square or spikes in trees (temporary benchmarks)	--	0.10	$5-10
Planning studies (reconnaissance and detailed)	Temporary benchmarks and 24-in.	--	0.10	$5-10
	rebar no. 4 with plastic caps	0.10	0.10	$15
Military master planning	Temporary benchmarks in reinforced concrete	--	0.10	$5-10
Flood insurance studies and FPIS	Temporary benchmarks	--	0.10	$5-10
Real estate monumentation	Reinforced concrete, 8 in. x 30 in. (Fig. B5)	0.05	0.05	$40
Photo control	Temporary benchmarks	--	0.10	$10
	P.k. nails in road	0.10	0.10	$5
Digital data base maps	Reinforced concrete (Fig. B5)	--	--	--
Geodetic surveys	Same as digital data base maps monumentation	--	--	See detail below

** No overhead

Table B3 (cont'd).

Instrument pedestal costs

Two-man survey team, 8 hr (salary, no overhead)	$ 101.00	
Concrete (ready-mix truck, 3 yd)	120.00	
Rebar	25.00	
Cardboard form	5.00	
Auger rental	50.00	
Anodized instrument plate	120.00	
	± $ 421.00	(does not include overhead, truck, tools, etc.) Rates as of April 1984.

Geodetic survey marker costs

Two-man survey team, 2 hr (salary, no overhead)	$25.20	
Cement (5 bags)	15.00	
Rebar (no. 4 or 5)	3.00	
PVC	1.00	
Auger rental	14.00	
	$60.00	(does not include overhead, truck, tools, etc.) Rates as of April 1984.

Table B4. Installation and costs for benchmarks used by the Ft. Worth District (see Fig. B8).

a. Installation of deep settlement-plate benchmark

1. A 36-in.-wide hole is drilled to the desired depth.

2. After placing approximately 4 in. of sand on the bottom of the hole, the plate and pipe are lowered and centered.

3. About 4 ft of sand is added, followed by 1 ft of bentonite pellets.

4. A 6-in. casing is placed and filled with gravel to approximately 1 ft from the surface.

5. The empty space around the casing is filled with cuttings from the hole and the top 1 ft is then filled with concrete.

6. After letting the marker stabilize after installation stresses abate, it is surveyed.

Estimated cost

$3,250 materials and labor for 50-ft hole (January 1984).

Precautions

The deep settlement-plate benchmarks have proven to be stable. However, they are expensive to fabricate and install. The size of the hole (36 in.) requires special equipment, and placing the casing and centering the plate require careful attention. Other problems are cuttings left on the bottom of the hole, which could cause settlement, and the time required for installation.

b. Installation of free-standing deep benchmark

1. A 12-in. hole is drilled followed by an 8-in. hole to the required depth (casing is placed).

2. The inner pipe is then lowered and positioned inside the smaller hole and cemented.

3. Grease is added to the desired depth.

4. After letting the marker stabilize after installation stresses abate, it is surveyed.

Table B4 (cont'd).

Estimated cost

$2,200 materials and labor (for 50-ft hole)

Precautions

Free-standing deep benchmarks have the advantage of supplying horizontal as well as vertical control. The main disadvantages are the cost of installation and the need for close vertical alignment tolerances during construction to ensure that the inner pipe does not touch the outer pipe. This type of benchmark has been tried using PVC casing. Difficulties were encountered because of curvature of the PVC casing. Although PVC proved to be inadequate, steel casing should work, but has not been tried. Some of the other problems encountered were: centering the 8-in. bore inside the 12-in. hole, voids that can occur in the concrete, keeping the pipe in place while the concrete sets, and material sloughing in the bottom of the hole.

c. Installation of cone-tipped deep benchmark

1. A hole is bored of the required depth and diameter.
2. A 0.5-in. cone-tipped rod and 2-in. pipe are lowered into the hole.
3. The cone tip is then hydraulically pushed by the 2-in. pipe until refusal.
4. The 2-in. pipe is then raised about 1 ft and grease is pumped down the 2-in. pipe. The grease is allowed to flow until it fills the annular space between the borehole and the 2-in. pipe to within a few feet of the ground surface.
5. The remaining space at the top of the borehole is then cemented.
6. After letting the marker stabilize after installation stresses abate, it is surveyed.

Estimated cost

$1,000 materials and labor (for 50-ft hole).

Precautions

Cone-tipped deep benchmarks, if installed correctly, are quite stable. The simplicity of the design is a significant advantage, leading to fewer

Table B4 (cont'd). Installation and costs for benchmarks used by the Ft. Worth District (see Fig. B8).

problems than with the other types. The small hole and the small amount of material needed normally make this a more economical benchmark. One potential problem is buckling of the inner and outer pipe when pushing the tip into the foundation medium.

d. Installation of concrete benchmark

1. After a hole is drilled to the desired depth, a 6-in.-diameter pipe is placed into position.
2. The inside of the pipe is filled with concrete that is allowed to harden with a brass marker placed on the top.
3. Let the marker stabilize after installation stresses abate, it is surveyed.

Estimated Cost

$300 materials and labor.

Precautions

Concrete benchmarks are the easiest to install and the lowest in cost. The major problem is that they can only be used as shallow markers in firm material, i.e., well consolidated sandstone. If the surface material is unstable then a deep benchmark is required.

Table B5. Benchmarks, Rock Island District.

Construction or topographic surveys

1. Boat spike driven through short sleeve and washer.

2. Spike driven horizontally into a tree or pole.

Structural movement survey

1. Rock outcrops (first choice) -- chiseled square on high point.

2. Massive concrete structure (second choice) -- cut square on particular point on a structure (preferably founded on bedrock), i.e., dams, spillways, bridge piers or abutments.

3. Concrete structure (third choice) -- cut square on well-aged (not decrepit) structure, i.e., large culvert, clear of area influenced by structure to be monitored.

4. Poured-in-place concrete monument (fourth choice):
   - Dig or drill 6-7 in. hole to below frost line (about 6 ft).
   - Enlarge bottom to bell shape so major mass is below frost line.
   - Place two no. 5 rebars.
   - Fill with concrete.
   - Place standard Type I brass cap on top of concrete.

Table B6. Installation steps used by Charleston District.

1. Excavate hole about 18 in. deep.

2. Drive 1-in. galvanized pipe into hole to refusal, cut and thread.

3. Cap pipe.

4. Place 8-in. clay flue liner around pipe and cap.

5. Place concrete in hole and liner.

APPENDIX C: ADDITIONAL DETAILS ON INSTALLING BENCHMARKS

Provided by the Geodetic Survey of Canada,
Primary Vertical Control Section (1983)

Divide	By	To obtain
millimetre	25.4	inch
centimetre	2.54	inch
metre	0.3048	foot

Bronze tablet (type 1)

This tablet (Fig. C1) is circular, 79 mm in diameter with a 70-mm shank. The top is rounded to provide a definite datum point when the tablet is set with shank vertical. There is a slot cut in which the surveyor can hold a chisel for a datum point when the tablet is set with the shank horizontal.

Tablet benchmarks are driven into drilled holes in rock, masonry, or concrete. The shank of the tablet is always set in grout to assure firmness and to prevent water intrusion.

A nail or wire staple or wedge should be fitted into the split shank of the tablet prior to it being driven into the prepared hole. This will help to hold the tablet more securely.

When the hole has been drilled for the shank, the area around should be countersunk so that only the face of the tablet will be exposed. This presents a neat appearance and helps to resist removal.

Steps to follow in setting a tablet (Fig. C2)

1. Drill a 2-cm-diameter hole about 8 cm deep.

2. Countersink the tablet head so that only the face of the tablet will be exposed. It is desirable to countersink all tablets; however, if a tablet is to be installed in smooth-dressed stonework, it is permissible to have the tablet head resting tightly against the smooth surface.

3. Clean out the drilled hole with air and water.

4. Number the tablet. Cover the tablet with masking tape to keep it clean of grout. The tape can be easily removed after installation.

5. Put grout in the hole and countersunk area.

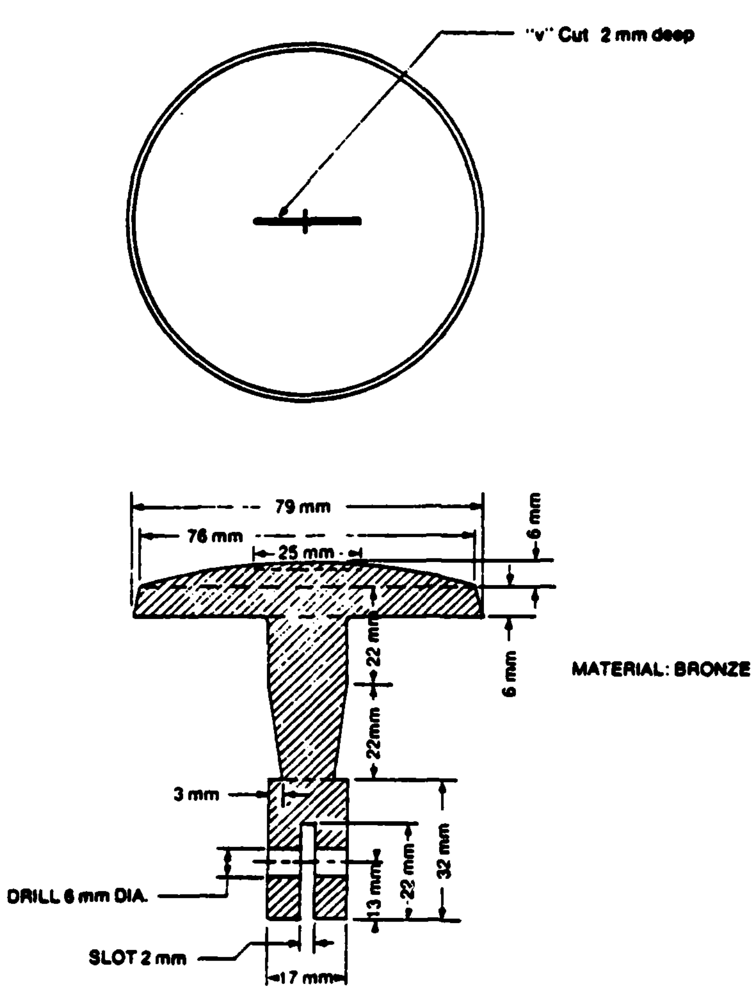


Figure C1. Survey tablet marker (type 1).

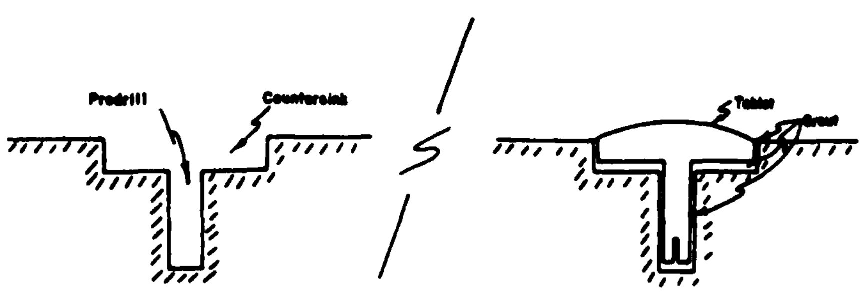


Figure C2. Setting the tablet.

6. Insert a nail, wire staple or fox wedge into slot in the end of tablet shank, and drive tablet into position. Place a piece of wood on the tablet when it is being driven; this protects the tablet face.

7. If the tablet is being set so that the slot is to be used as the datum point, care must be taken to ensure that the slot is horizontal. Fine adjustment may be made using a chisel and a hammer on the outer edge of the tablet. Use a carpenter's level to check that the slot is horizontal.

8. Carefully finish around the tablet face and clean off all excess grout from the tablet face and lettering.*

Referencing a tablet benchmark

1. When tablets are set in structures such as buildings, bridges and culverts, the structures are not to be marked in any way.

2. Tablets in rock outcrops, especially in remote areas, should be referenced as follows:

a. If the tablet has been set with the shank horizontal, paint a neat ring 25 mm wide around the tablet (if local ordinance permits) (Fig. C3).

b. If the tablet has been set with the shank vertical, an angle iron or a pipe with BM sign is to be set securely with grout in a drill-hole about 25 cm behind the tablet (Fig. C3).

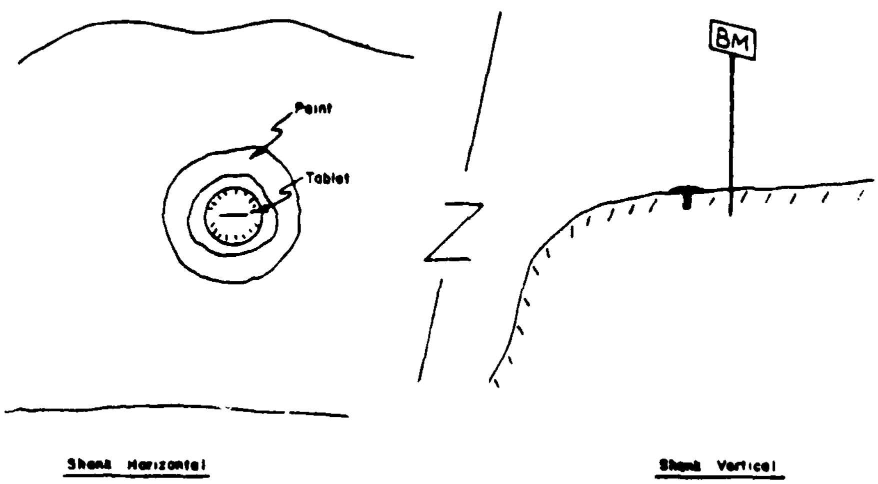


Figure C3. Referencing the set tablet.

* Grout also reduces the likelihood of frost action destroying the mark (author's note).

Bronze bolt (type 2)

This marker is circular in cross section and about 90 mm long; the top surface is convex (Fig. C4). It may be used in many instances as an alternative to type 1 (Table C1). It is installed in a similar manner to type 1, the top being allowed to protrude slightly above the surrounding surface material. The bolt is secured by grout with a wedge or a pin through the shank.

Iron pipe with bronze cap (type 3)

The benchmark consists of a galvanized iron pipe with cast iron base threaded onto it, and a rounded brass cap screwed and pinned to the top to act as the datum point (Fig. C5). See Figure C13 for an alternate design.

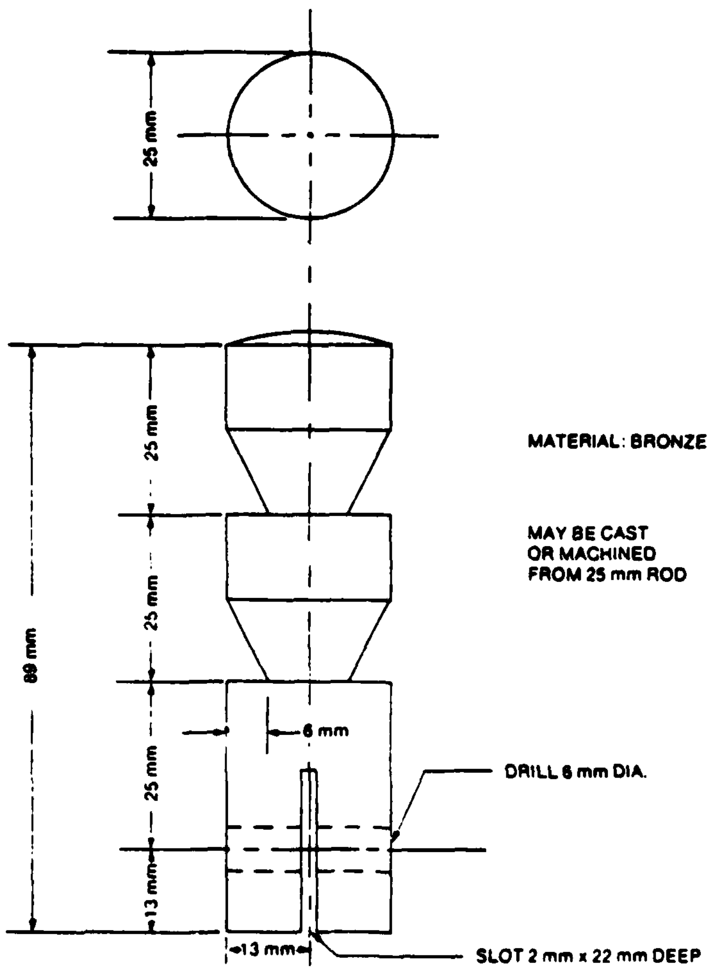


Figure C4. Survey bolt marker (type 2).

Table C1. Recommended benchmarks.

Type of condition or terrain	Type of marker†
Bedrock, rock outcrops, large boulders, concrete structures	1 or 2
Granular soils (sand and gravel)	3, 5*
Till (glaciated cohesive soils)	3, 5*
Fine-grained soils (silts and clays of low plasticity)	6, 4
Low-bearing-strength soils (very fine silts and clays of medium to high plasticity)	6, 4
Construction fill	6
Permafrost	6

* The sleeve type survey marker (type 5) is designed for use on municipal control surveys where one marker would be suitable for both vertical and horizontal control. Because material and installation costs are high for this type of marker, consideration should be given to two separate markers. By doing this, better locations can be selected for the vertical control markers, which don't have to be intervisible.

† Listed in order of preference from left to right.

This type of benchmark was designed so that a permanent benchmark could be left at any desired point, regardless of the lack of a suitable structure or rock outcrop to contain a tablet.

The excavation for the pipe should be deep enough so that only the brass cap projects above ground level.

The earth used for back-filling must be tamped firmly. The back-filling around the base plate must be especially well tamped to anchor the pipe into the ground securely.

Pile-driven pipe (type 4)

This marker is a galvanized pipe, pile-driven to required depth with a type 1 or type 2 marker secured in the top. The benchmark datum point is installed below the ground surface, surrounded by a cast iron rim and a cover set flush with the ground surface (Fig. C6).

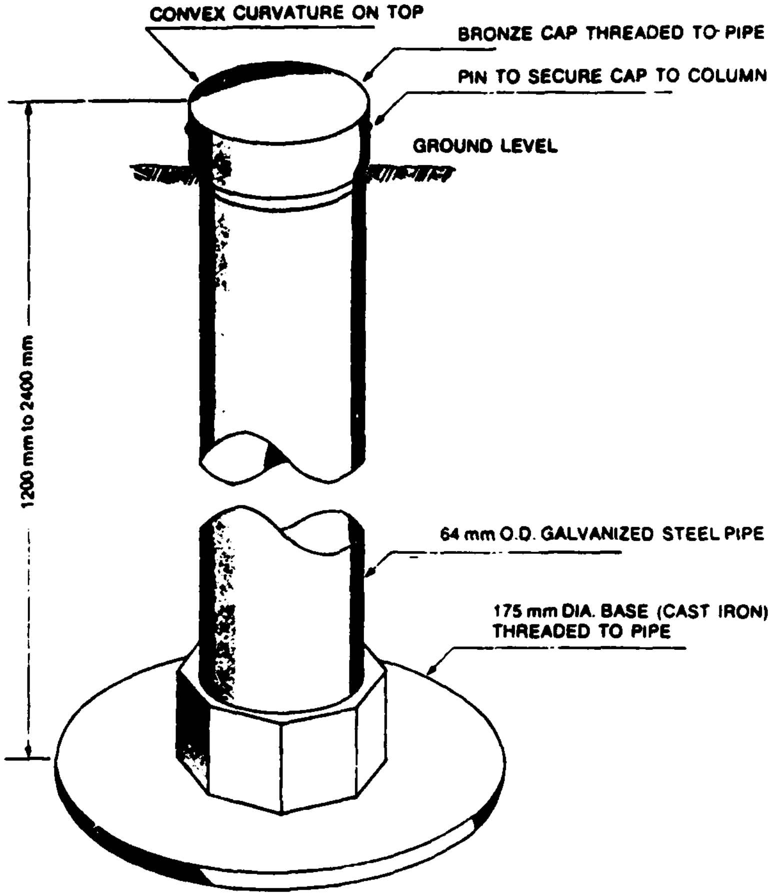


Figure C5. Iron pipe with cap (type 3).

Sleeve-type marker (type 5)

This is a double pipe style marker. The space between the pipes is grease-filled. This permits movement of the outer pipe without disturbing the inner. The inner pipe is attached to a base plate for vertical stability. A type 1 or 2 marker is the reference point and is fastened to the top of the inner pipe (Fig. C7).

Deep benchmark (type 6)

This type of benchmark used by the Geodetic Survey was designed and developed by the Division of Building Research of the National Research Council [of Canada]. The benchmark consists of a pointed steel foot pushed to refusal and connected to the surface by a galvanized steel pipe. For protection the annular space between the pipes is filled with heavy oil. At the surface the pipes are covered by a manhole-type of cast iron cover.

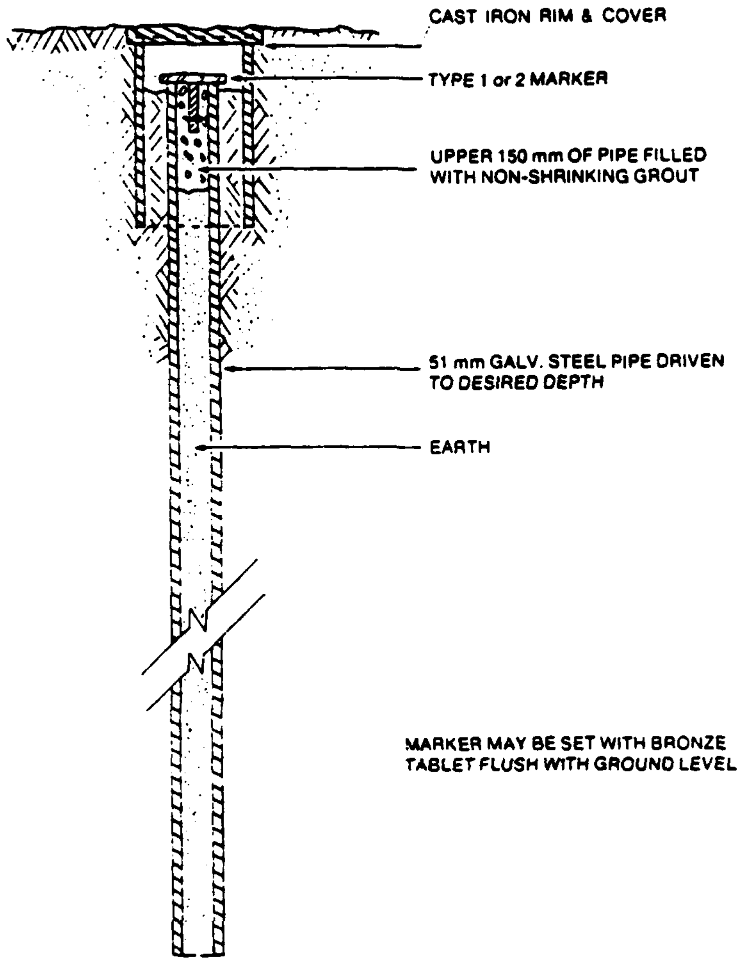


Figure C6. Pile-driven survey pipe marker (type 4).

The reference point is a stainless steel ball welded to the top of the inner pipe (Fig. C8).

The Geodetic Survey uses a mobile drill mounted on a truck to install the NRC-type deep benchmarks. The drill is hydraulically operated and produces a downward thrust with rotations.

The procedure for installation in areas of sensitive clays is as follows:

1. Position and level the drill rig.

2. Do predrilling with a 10-cm auger to determine the depth of the bedrock. The minimum depth for a deep benchmark should be 5 m. In areas of sensitive clays, 5 to 7 m may be a sufficient depth. In areas of hardened clays or other materials, up to 9 m (30 ft) of drilling may be

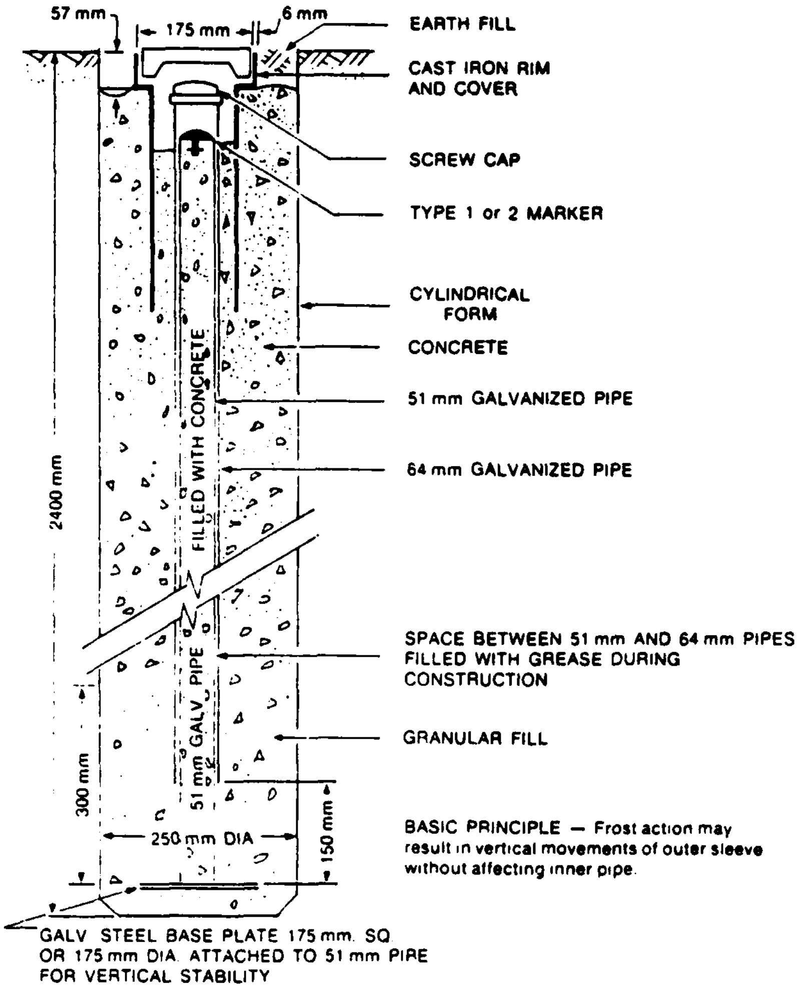


Figure C7. Sleeve-type survey marker (type 5). This is similar to the NGS class A benchmark.

required to achieve a better depth. A carbide-tipped rock drill may be required to drill through harder strata.

3. Use a 40-cm auger to drill the hole (75 cm deep) for installation of the steel culvert that supports the manhole cover.

4. Assemble a 1- and 3-m length of 10-mm-diameter pipe to the steel foot. Over this assembly, slip a 3-m length of 25-mm-diameter pipe, making sure it is seated on the shoulder of the steel foot.

5. Lower this assembly directly through the chuck of the drill, slowly push and rotate the pipes into the ground, adding 3-m lengths of both pipes until refusal is reached.

6. Withdraw the outer casing 60 cm, making sure that the steel foot and inner pipe do not move.

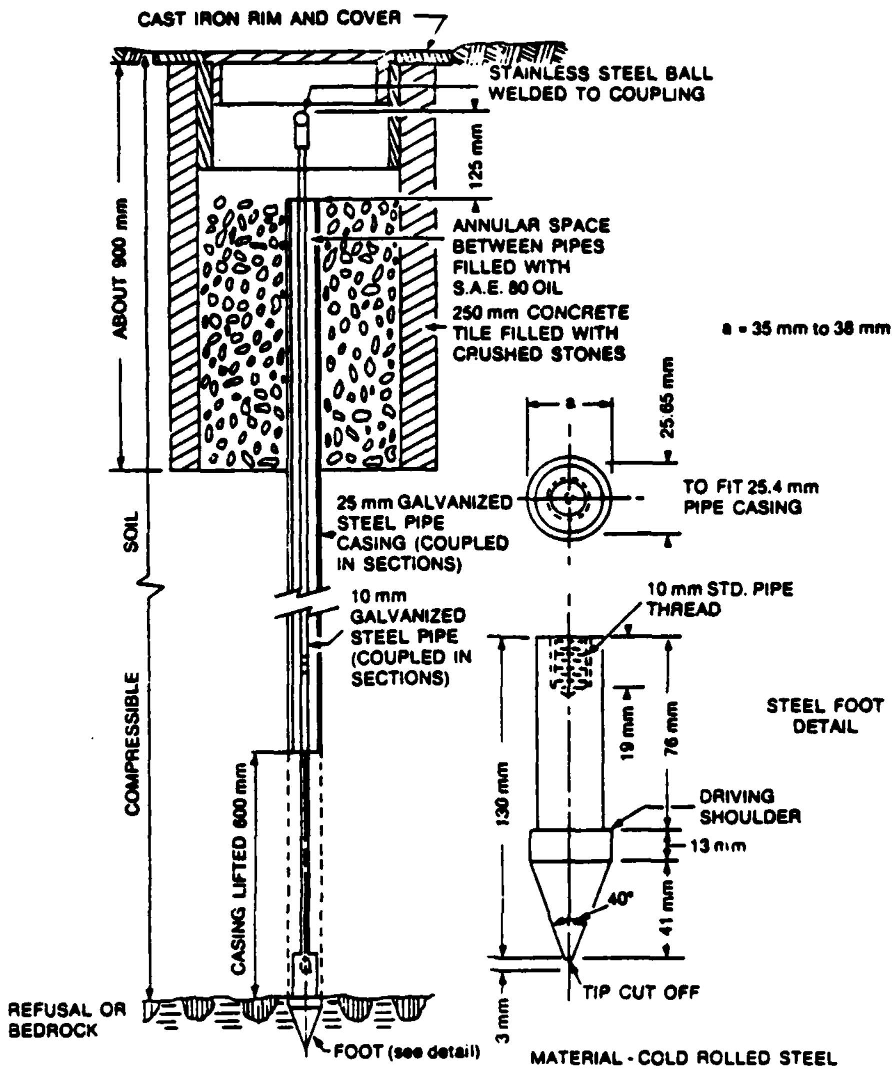


Figure C8. National Research Council deep benchmark (type 6).

7. Cut the inner pipe about 15 cm below cast iron cover level and cut the outer pipe about 10 cm below that.

8. Pump No. 80 or 90 oil down the inner pipe where it will find its way through the predrilled holes in the 1-m length of pipe and up through the sleeve until it appears at the surface between the two pipes.

9. Install a stainless steel ball as the datum point on the inner pipe.

10. Install the galvanized steel culvert and painted manhole cover to complete the benchmark.

11. Stamp the benchmark number on the lid of the culvert.

12. Where conditions permit, and particularly in more remote areas, install a benchmark sign post by driving the post into the ground beside the manhole casing.

13. Clean up the surrounding site.

Item 6 is the critical operation in the installation of this type of benchmark. By withdrawing the outer pipe 60 cm after refusal is reached, the steel foot and inner 10-mm pipe are completely free from the outer casing. The soil will press around the steel foot and hold it secure. The end result is a steel foot anchored at refusal and connected to the surface by the 10-mm pipe. Any ground movement caused by frost action, varying water content of the soil or natural phenomena is absorbed by the outer casing.

It must be stressed again that neatness is of prime importance in establishing benchmarks. This is especially so in the case of deep benchmarks, which are frequently installed in parks, ornamental grounds and public places.

Alternative benchmark types

There will be instances when one of the standard type benchmarks (type 1-6) cannot be installed. In such instances one of the following hybrid types may be selected.

Deep tablet (type 7)

When bedrock is completely buried by shallow overburden, excavate to the rock surface, install a regular brass tablet, and a 30-cm-diameter steel culvert as a retaining wall around the excavation; top with a manhole cover (Fig. C9).

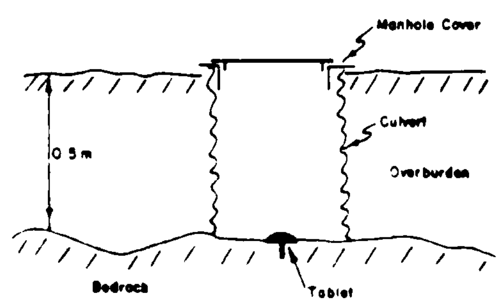


Figure C9. Deep tablet (type 7).

Short pipe or short ground rod (type 8)

When bedrock is buried by more than 0.7 m of overburden, but not enough so that a regular pipe benchmark can be installed, either a short pipe or short ground rod should be used. These two types of benchmark are essentially the same and the available materials at hand will determine the type of use.

Short pipe. Excavate to bedrock; cut bottom off pipe to fit depth of excavation; have base welded to bottom of pipe (if welding facilities not available, splay end of pipe); concrete the base to bedrock; backfill and reference as for type 3 (Fig. C10).

Short rod. Excavate to bedrock; drill hole in bedrock; drive copper-weld rod with coupler into hole; grout around hole; backfill and reference (Fig. C11).

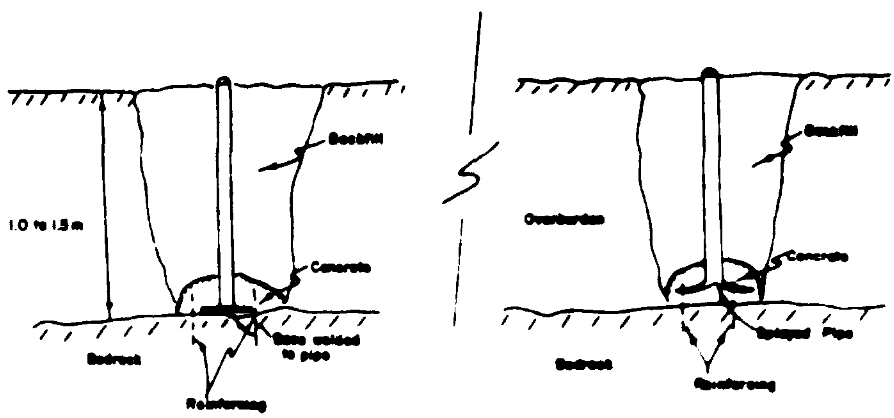


Figure C10. Short pipe (type 8a).

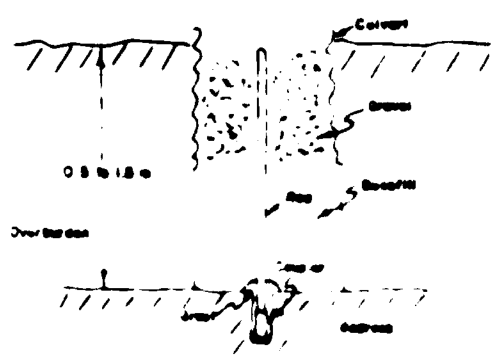


Figure C11. Short rod (type 8b).

Ground rod (type 9)

The ground rod is generally used in regions that are unsuitable for iron pipe benchmarks (e.g., marshy soil, muskeg, permafrost).

This benchmark consists of successive lengths of 1.5-cm-diameter copperweld rod that are coupled together and driven into the ground to refusal. A gas operated jackhammer, suspended from a tripod or held with the use of a stepladder, is used for driving the rod. The top of the rod, cut at ground level and slightly rounded serves as the datum point. The top 50 cm of the rod is surrounded with a 30-cm-diameter metal culvert (Fig. C12). This type of benchmark is referenced with a metal benchmark sign, the same as for a pipe benchmark. The benchmark number is stamped along the length of the rod just below the datum point.*

Sites for permanent benchmarks

Judgment and caution must be exercised in selecting benchmark sites. The first consideration is to select benchmark sites where no movement will take place. The second consideration is to place benchmarks where the danger of their being disturbed or rendered inaccessible is minimal.

On roads or railways, benchmarks should be placed as close to the edge of the right-of-way as possible; in buildings, main wall foundations are to be used.

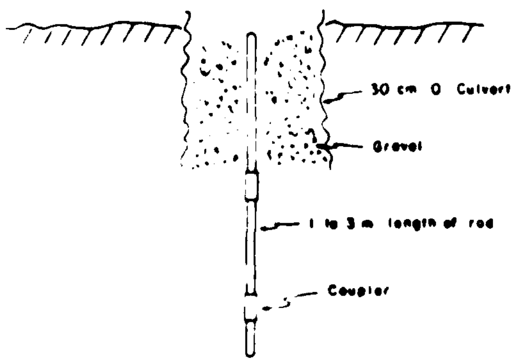


Figure C12. Ground rod (type 9). This is similar to the NGS class B, deep-driven rods, which are very stable in salt marshes (author's note).

* The rod should be driven to approximately a 50-ft depth or to refusal and a disk crimped on top of the rod (author's note).

The benchmark locations should be chosen on alternate sides of the leveled route, when possible, to minimize loss due to future construction.

Bronze tablet (type 1)

Rock outcrops provide the best base for tablet type benchmarks. It is preferable to avoid rock cuts and to use the undisturbed rock around the ends of the cut.

Bridges and substantial culverts are good locations for tablets. It must be emphasized that only substantial culverts are useful for benchmark placement; very small culverts are to be avoided. Benchmarks in bridges should be placed in the abutment, bridge seat or columns. In the case of long bridges or bridges over major rivers, place one benchmark at either end of the bridge, on opposite sides of the roadway.

Boulders may be used for tablets if they are exceptionally massive and deeply imbedded.

Concrete foundations for buildings are suitable benchmark locations if the foundations extend below the frost line. It is preferable to use public or semi-public buildings, such as post offices, city halls, churches and schools. The foundation under a main wall should be chosen in preference to that of a vestibule or porch. *When using a building, care should* be taken to select a position for the benchmark so that it will not be liable to destruction by additions or alterations; front walls or walls facing a street are preferred locations.

Iron pipe with brass cap (type 3)

Pipes should be located near the boundaries of the right-of-way of the highway or railway being followed. They should be located at safe distances from intersections in anticipation of future road improvements.

Pipes should be placed in the highest ground in the immediate vicinity, where the drainage should be best.

Light, sandy soil or gravel is preferred to clay type soil; marshy type soil is to be avoided.

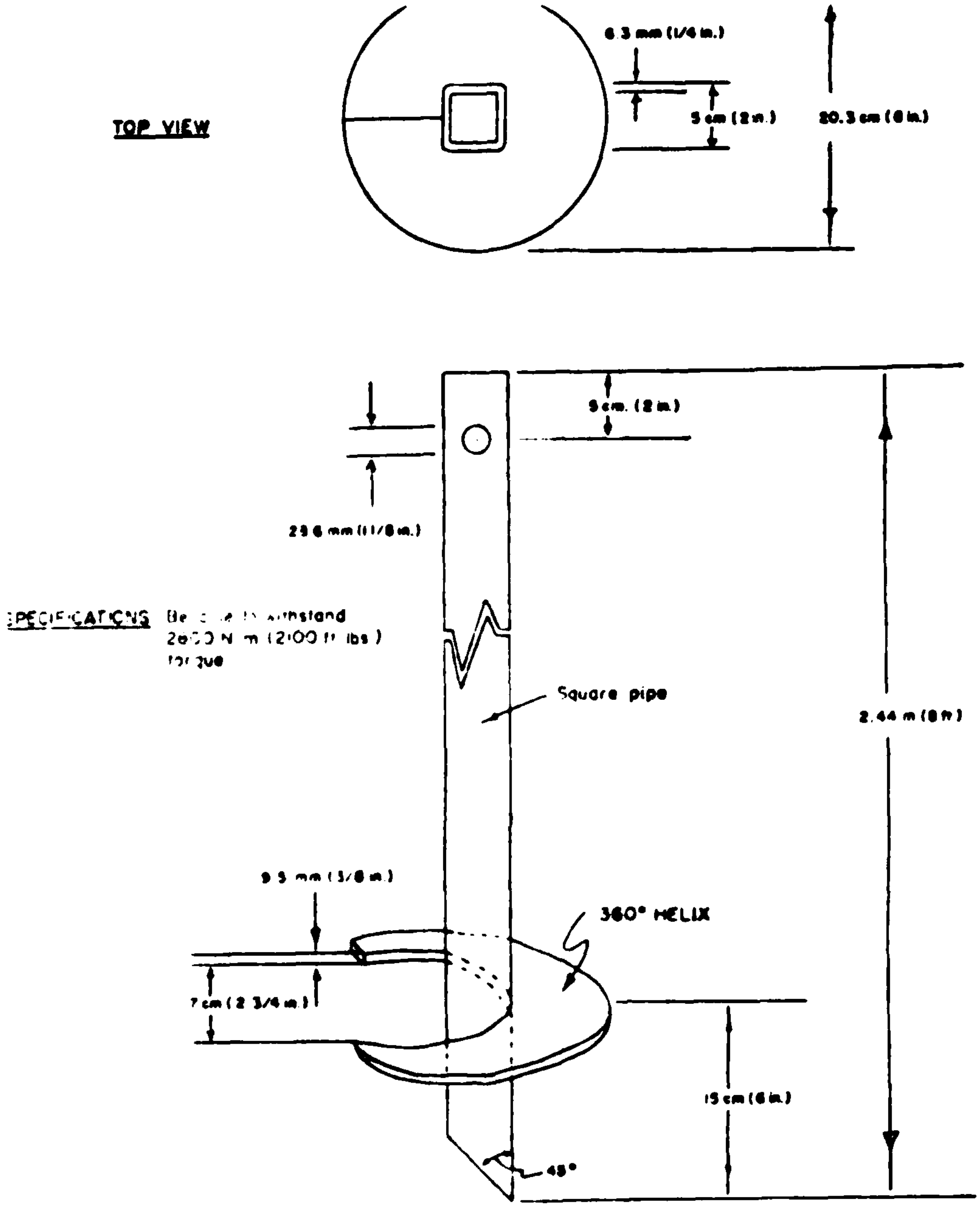


Figure C13. Helix pipe, 1983 replacement for iron pipe with cap (type 3). This marker is driven into the ground with the use of an articulated hydraulic power driver installed at the end of a 20-ft boom section. The top of a rounded benchmark serves as datum point.

APPENDIX D: DETAILS FOR INSTALLING DEEP BENCHMARKS IN SENSITIVE CLAY, LACUSTRINE CLAY AND PERMAFROST AREAS (from Bozozuk et al. 1963; copyright ASTM, reprinted with permission).

Installation of a deep benchmark in sensitive clay (see Fig. 1b)

1. At the desired location, bore a hole large enough for a 4-in. pipe casing to a depth of 3 to 4 ft. Center the base frame over the hole and clamp it firmly to the ground by means of two earth anchors. The turning of the spiral earth anchors into the ground can be eased if two pilot holes are augered in advance. At the center of the large hole, auger a 1-1/2-in. pilot hole vertically through the fissured crust to a depth of 15 ft or more. Check the auger frequently with the carpenter's level to ensure that the hole is vertical.

2. Assemble the steel foot, the 3-ft and 10-ft lengths of 1/4-in. galvanized iron pipe. String a 10-ft length of 1-in. galvanized iron pipe casing over the 1/4-in. pipe so that it is seated firmly on the shoulder of the steel foot. To prevent relative movements between component parts, clamp the inner pipe firmly with vise grips at the top of the casing. The 3-ft length of 1/4-in. pipe projecting above the casing permits easier coupling of successive pipes and casings. It also ensures that the first 1/4-in. pipe coupling above the steel foot will be located inside the 1-in. pipe casing after the installation is completed.

3. Lower the unit into the hole, and jack it into the ground to refusal as quickly as possible with the jacking device, adding successive lengths of pipe as required. (Usually a 50-ft benchmark can be jacked into the ground within 2 hr.) This operation should be completed in one working period since any delays will permit the casing to "seize" in the soil, at which time it becomes very difficult to move even with much heavier jacking equipment.

4. To ensure that the steel foot is firmly seated, check the refusal of the benchmark to penetration by percussion driving. This may be done by threading an additional length of 1-in. pipe, adding a jar plate, then driving with a hammer or drive weight. Take care not to overdrive the pipe casing. When satisfactory seating of the steel foot has been achieved, the elevation of the top of the 1/4-in. datum pipe should be established precisely with an engineer's level.

5. Jack the casing up 2 ft to separate it from the steel foot. Check the elevation of the datum pipe to ensure that it has not been lifted with the casing.

6. Cut off the casing about 3 in. above ground, or as required, and the inner pipe 2 in. above the casing. The top of this pipe serves as the reference datum.

7. Fill the 1-in. pipe with heavy oil. Install the 4-in. pipe casing, together with the coupling and brass cap, as shown in Figure 1b, allowing 5- to 6-in. clearance between the datum pipe and the brass cap.

Note -- If desired this installation can be improved with the addition of a stainless steel ball datum point, a "spring" bushing to center the inner pipe within the 1-in. casing and with the addition of a floor flange to provide lateral stability for the 1-in. casing within the 4-in. diameter pipe.

<u>Installation of a deep benchmark in lacustrine clay (see Fig. 1c)</u>

1. Position and level the drill rig over the point selected and remove the sod. Bore a 4-in. hole to the bottom of the highly desiccated soil strata (10 ft or more), using continuous flight augers. In these cohesive, self-supporting clays, a casing is not required to keep the hole open. It may be necessary to auger or wash bore a small-diameter pilot hole before setting the benchmark pipe in very stiff clays or clay shales.

2. Pour 2 to 3 gal. of automotive crank case oil into the augered hole. In clayey soils near saturation, there will be very little loss of oil into the soil, and a 4-in. hole will be filled to a depth of about 4 ft.

3. Assemble the materials, following step 2 (for installation in sensitive clay). Center the pipes through the "A" chuck of the drill rig and lower them into the hole. It is most important at this stage that the pipe is vertical and that it is well centered in the chuck of the drill rig.

4. Push and rotate the pipes into the ground to refusal, adding successive lengths as required. By using a slow speed of rotation and a steady push with the drill feed, penetration resistance is reduced and the chances of obtaining a straight and vertical installation are greatly increased. This operation should be continuous and completed within a

working period. Although the oil lubrication and the oversized hole made by the 1-1/2-in.-diameter steel foot tend to reduce skin friction, the casing may "set up" quite firmly in the soil if it is allowed to stand for a period of time.

5. Usually penetration refusal is easily detected by the reaction of the drill rig and by rotation of the pipe casing relative to the inside pipe. After loosening the drill chuck, refusal of the benchmark to penetration by percussion driving can be checked, as outlined in step 4 for installation in sensitive clay.

6. With the drill rig, retract the 1-in. casing 2 ft and check the elevation of the inner pipe to ensure that it has not been lifted with the casing.

7. Cut off and thread the 1-in. pipe 6 in. below the desired final elevation of the benchmark datum point, and the 1/4-in. pipe about 5 in. above the 1-in. casing. If the datum elevation is at or below existing grade, a shallow pit must be dug around the pipe to allow the use of the pipe cutter and threader.

8. Fill the 1-in. pipe with gear oil. This time-consuming operation can be speeded considerably if two or three 1/8-in. holes have been drilled in a staggered pattern in the first 3-ft section of 1/4-in. iron pipe to allow trapped air to escape from the bottom of the casing. Install the spring bushing (coiled strap of 30-gage sheet galvanized iron) at the top of the 1-in. casing, thus centering the inner pipe. Finally, screw on the special steel ball datum point.

9. Fill the 4-in. auger hole with air-dry sand or gravel (maximum particle size 1-1/2 in.) or with dry concrete mix to within 3 ft of the ground surface. Push the 4-in. pipe into the hole, making sure that it is well centered and that a clearance of at least 6 in. is provided between the datum point and the brass cap. Screw the floor flange onto the 1-in. pipe by means of a small rod inserted in one of the bolt holes. Finally, backfill the hole around the 4-in. casing with suitable fill or cast a concrete marker pad around it.

Installation of deep benchmarks in permafrost areas (see Fig. 2d)

Benchmark anchored in permafrost

1. Carefully position the drill rig so that disturbance of the moss cover will be kept to a minimum. Place a suitable length of NX casing

through the active layer into the perennially frozen ground to prevent thawed material and surface water from entering the hole. Drill a hole to a depth of 39 ft with AX size drill equipment, using an AX core barrel if samples are desired; otherwise use an AX non-coring bit. If caving occurs, AX drill casing should be placed to the bottom of the hole. When the hole is completed, bail out all the water.

2. Connect the steel foot to the 9-ft length of 1/4-in. pipe having a roughened surface and lower it into the hole to a depth of 8 ft. String a 10-ft length of 1-in. pipe over the 11-ft length of 1/4-in. pipe. With the vice grips clamped securely to the top of the inner pipe to prevent it from sliding out of the 1-in. casing, raise the two pipes vertically above the hole and connect the 1/4-in. pipes together. Retaining a hold on the outside pipe, lower the assembly into the hole, adding successive 10-ft lengths of 1/4-in. and 1-in. pipe until the steel foot rests on the bottom. Secure the 1-in. pipe so that it projects about 6 in. above the ground. The inner pipe should then protrude about 1 ft above this casing.

3. Holding the pipes in this position, carefully backfill the hole with a not-too-wet sand-slurry mixed so that it just pours easily. If drill casing has been used, withdraw it carefully so that the relative positions of the benchmark pipes are maintained as the hole caves in around them. To ensure that the lower portion of the datum pipe is adequately surrounded by soil it may be necessary to fill the lower part of the hole with the slurry before removing the drill casing. If such is the case, even greater care is required to maintain the relative positions of the benchmark pipes as the drill casing is removed.

4. Remove the NX casing from the active layer and backfill the hole to the ground surface, carefully replacing the moss cover around the pipes.

5. Fill the annular space between the inner and outer pipes with an SAE 80 gear oil or a special wax-oil mixture. This mixture can be made up of 70% oil (such as Mentor 29) and 30% wax (such as Socony Mobil Cerise AA) by weight, mixed after heating to about 200°F. The mixture is poured into the assembled 10-ft lengths of pipe and allowed to congeal before they are placed in the drill hole.

6. Install the "spring bushing" inside the top of the 1-in. pipe casing and mount the stainless steel ball datum point on the top of the 1/4-in. pipe.

7. Connect the 1-1/2-ft length of 1-in. pipe and pipe cap to the top of the 1-in. casing protruding above the ground surface.

8. If desired, a suitable length of 4-in. pipe with pipe cap may be driven into the ground over the benchmark assembly to provide additional protection.

Benchmark anchored below permafrost

1. Following the same procedures given above, drill an AX hole to a depth 5 ft below the perennially frozen layer.

2. If the unfrozen soil underlying the permafrost is relatively soft, complete the installation following the procedures given for a benchmark in lacustrine clay.

3. If the unfrozen soil is stony or very stiff it may be necessary to extend the borehole to bedrock or other resistant material. The installation can then be completed following the procedures used for anchoring benchmarks in permafrost.

MATERIALS AND EQUIPMENT FOR INSTALLING DEEP BENCH MARKS

Sensitive Marine Clays	*Lacustrine Clays*	*Permafrost Areas*
	EQUIPMENT	
1. Jacking equipment consisting of a 5-ton jack, ball cone clamp, base frame, and two earth anchors 2. 1½-in. earth auger and extensions 3. Auxiliary tools, such as pipe cutters, vice grips, shovels, pipe wrenches, measuring tapes, spirit level, funnel, hammer, etc.	1. Drill rig with hydraulic head, "A" rod chuck and accessory equipment to auger 4-in. holes to depths of refusal 2. Pipe cutters and dies for ¾-in. and 1-in. pipe 3. Auxiliary tools, consisting of pipe wrenches, vice grips, funnel, shovel, tape, spirit level, etc.	1. Standard diamond drill with hydraulic head and "A" rod chuck 2. Accessory drilling tools and equipment including AX and NX casing 3. Pipe cutters and dies for ¾-in. and 1-in. pipe 4. Pipe wrenches, vice grips, tape, shovel, etc.
	MATERIALS*	
1. 1⅝-in. diam steel foot 2. ¾-in. pipe, 3 ft long 3. ¾-in. and 1-in. pipes in 10-ft lengths to complete installation 4. SAE 80 gear oil 5. 4-in. standard iron pipe casing 3 ft long with coupling and brass cap cover 6. ¾-in. and 1-in. wrought iron couplings	1. 1½-in. diam steel foot 2. Stainless steel ball datum point 3. 1-in. wide spring bushing (coiled strap of 30-gage galvanized iron) 4. ¾-in. pipe, 3 ft long 5. ¾-in. and 1-in. pipe in 10-ft lengths to complete the installation 6. 4-in. standard iron pipe 3 ft long with coupling and brass cap cover 7. SAE 80 gear oil, and used crankcase oil 8. Backfill, such as sand, gravel, or dry concrete mix 9. ¾-in. and 1-in. wrought iron pipe couplings	1. 1½-in. diam steel foot 2. Stainless steel ball datum point 3. Spring bushing 1-in. wide (coiled strap of 30-gage galvanized iron) 4. ¾-in. pipe, 9 ft long with spot weld roughening 5. ¾-in. pipe, 11 ft long 6. ¾-in. and 1-in. pipe in 10-ft lengths to complete the installation 7. 1-in. pipe, 1½ ft long with cap 8. SAE 80 gear oil or wax-oil mixture 9. Fine to medium sand for slurry backfill 10. ¾-in. and 1-in. wrought iron pipe couplings

* All pipes and couplings are galvanized iron

*U.S. GOVERNMENT PRINTING OFFICE: 1982-737-053/62721

END
9-87
DTIC