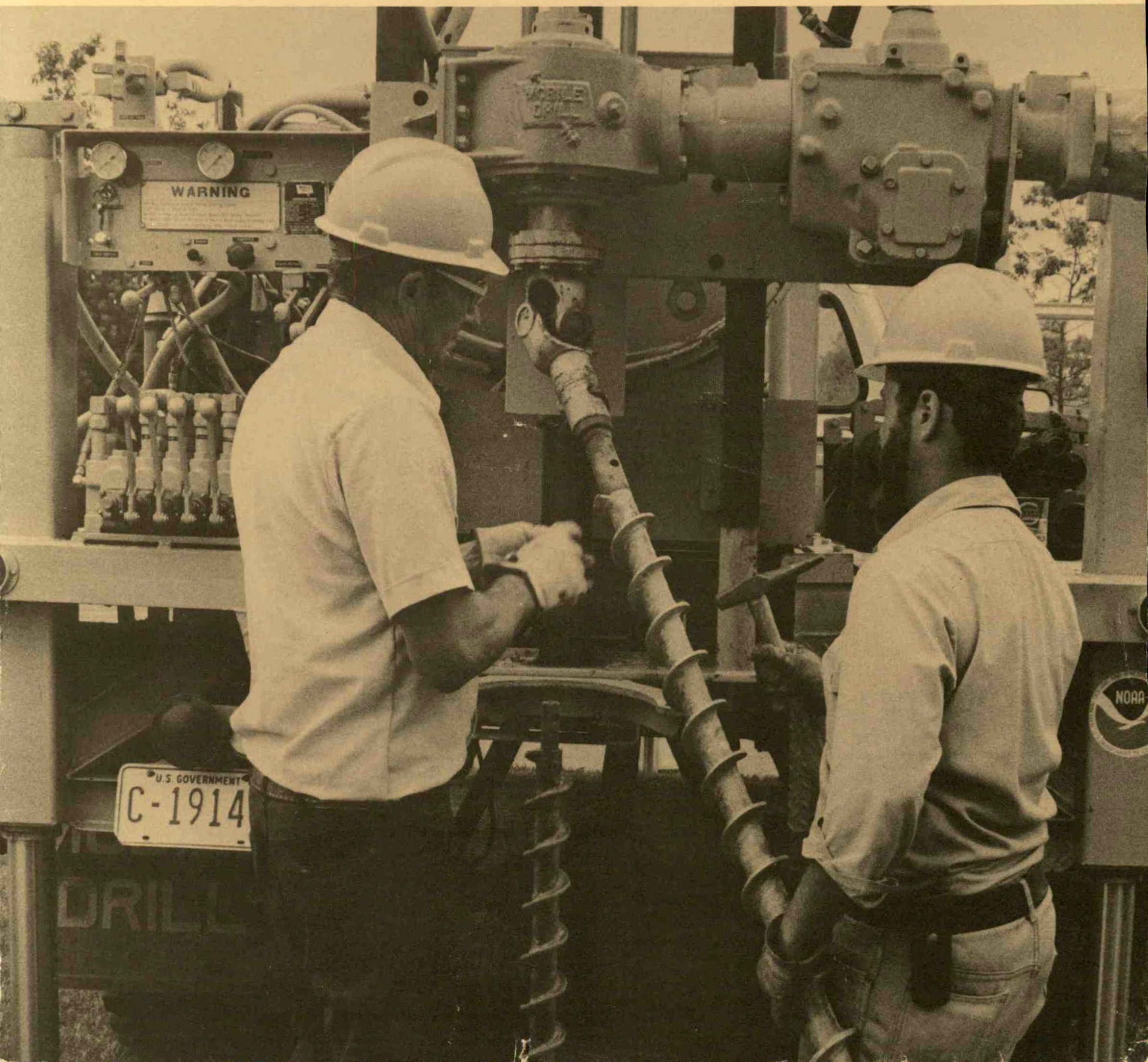
A Manual NOS NGS 1

odetic Bench Marks

DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey, Rockville, Md.

September 1978

Lt. Richard P. Floyd



NOAA Manual NOS NGS 1

Geodetic Bench Marks

Lt. Richard P. Floyd
NOAA Corps
National Geodetic Survey
Rockville, Md.
September 1978

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator

National Ocean Survey
Allen L. Powell, Director

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 003-017-00442-2

FOREWORD

Bench marks are long lasting points for which elevations have been determined, used to control other surveys and to monitor movement of and within the Earth's crust. They constitute the visual evidence of vertical control established by the National Geodetic Survey (NGS), an office of the National Ocean Survey, National Oceanic and Atmospheric Administration. Bench mark design and setting procedures are important to the leveling program. In the past, however, availability of materials and ease of setting were often the primary considerations rather than soil mechanics, geology, properties of materials, and the like.

Advancing technology brought both the ability to determine elevations more precisely and a greater need for bench marks to hold these elevations. The releveling program for the new adjustment of the National Vertical Control Network provided an ideal opportunity to upgrade the quality of NGS bench marks to meet future geodetic requirements.

This manual was written for two main groups of users. One includes managers and field personnel, both publicly and privately employed, who are involved with setting bench marks that will meet NGS specifications. The guidance given here must be adhered to strictly to obtain the quality required by the National Geodetic Survey. The other group consists of the users of NGS vertical control data. Supplementing other vertical control data, the information in this manual makes it possible to judge the reliability of an NGS bench mark elevation.

Because of a limited number of bench mark types, it is not possible to set the optimal monument in every case. For some installations, geologists or other specialists might be consulted. The manual includes enough detail to enable judicious modification in design when the occasion arises.

Dimensions have been given only in metric units wherever feasible. Commercial products are normally specified in English units, and consequently, English units are given in parenthesis when applicable. A conversion table from metric to English units is given in appendix A.

CONTENTS

TABLES

FIGURES

GEODETIC BENCH MARKS

Lt. Richard P. Floyd
National Geodetic Survey
National Ocean Survey, NOAA
Rockville, Md. 20852

ABSTRACT.—Geodetic survey control points must be remarkably stable due to the very intent of establishing geodetic control. All monuments are subject to the effects of geologic and soil activity. Vertical control points are particularly vulnerable because this activity results in vertical movements much more so than horizontal motion. In addition to natural disturbances, damage inflicted by mankind is a critical problem in monumentation. This manual explains how and where to set bench marks for maximum stability and calls attention to the factors that affect vertical instability.

1. INTRODUCTION

To function as good references for elevations, bench marks must be relatively stable points. Accordingly, it is necessary to define what is meant by stability before an understanding of high quality monumentation can be gained. "Stability" refers to the ability to maintain a fixed position. It is characterized by its degree and duration.

To the local surveyor running a topographic survey on a small construction site, a stable point could be defined as the top of a prominent boulder or a spike driven into a gravel road surface. These objects are subject to movements of a few centimeters to a decimeter or more in a year's time, but they are adequate for the surveyor's needs. It would be uneconomical to spend the time and money necessary to set higher quality bench marks.

Another surveyor might be concerned with laying out a major highway that could take years to complete. Therefore, the control must be more stable in its position and longer lasting. To this surveyor, a stable point could be represented by a concrete post extending to a depth of a meter or so, or a spike in the side of a large utility pole. These bench marks might hold their elevations within a few centimeters while the project is being carried out. It follows that the bench mark stability required depends on the precision of the survey being carried out and the duration of the project for which the elevations are needed.

The National Geodetic Survey (NGS) of the National Ocean Survey is responsible for establishing and maintaining the National Networks of Geodetic Control. The survey markers comprising these networks serve as basic reference points for numerous surveying, engineering, mapping, land use planning, and scientific projects. If the networks are to adequately serve these purposes, they must be established to a high degree of accuracy and monumented in a manner that best preserves their original geodetic positions.

Stability requirements for the National Vertical Network control points have increased significantly in recent years due to continually advancing technology. Both the ability to determine elevations more precisely and the need to know elevations more accurately have resulted from this technological boom. Uses have increased from basic control for boundary surveys and mapping to large scale planning and construction of transportation systems such as interstate highways and transcontinental pipelines. More recently, increased emphasis on crustal motion studies and control for missiles, satellites, and spacecraft has brought about a need for more accurately known positions and, consequently, more stable control points.

Elevations are referenced to a level surface, or geoid, which is approximately equivalent to mean sea level.[1] Not even the Earth's crust, which averages 35 kilometers in thickness, is stable relative to the geoid. Young mountains are uplifting while areas of the ocean floor subside. Ideally, a bench mark used strictly for control should remain motionless with respect to the geoid. Since the geoid is intangible, the only basis we have for appraising bench mark stability is the Earth's crust, even though it is in constant motion. A monument can be considered as stable as possible if it is motionless with respect to the crust.

To clarify this, a distinction must be made between crustal motion and motion within the crust. Crustal motion is movement of the crust as a whole. It is caused by phenomena such as isostasy (the concept of the crust floating on the mantle) and tectonic plate movement. Motion within the crust originates above the base of the crust.

It is motion originating above the base of the crust that we would usually like to prevent from being transmitted to our bench marks. Prevention being impossible, the next best thing is to reduce the motion's effects. This can be done by (1) minimizing surface effects and (2) with the aid of geological information, avoiding or accounting for movements of deeper origins.

The following chapters deal with identification of the various factors that can cause changes in bench mark elevations, and steps that must be taken to set high-quality bench marks. These marks include disks set in bedrock or structures, sleeved rod type bench marks, rod marks with disks, and some miscellaneous types.

2. SOURCES OF VERTICAL INSTABILITY

The subject of bench mark instability can be more easily understood if it is separated into two categories characterized by the depths at which movement originates. Those with their roots within about 15 meters of the surface will be called "near-surface sources of instability," while those that originate below about 15 meters will be called "subsurface sources of instability." If the effects of near-surface sources of instability cannot be avoided by prudent selection of the bench mark site, they can be counteracted so that they are not reflected in the bench mark elevation. Subsurface effects usually cannot be economically counteracted by a suitable bench mark design so they must be avoided or accounted for.

Bench mark movement can be likened to that of a float bobbing up and down on the surface of the ocean. The total vertical movement of the float is the result of accumulated movements caused by sea (locally generated choppy waves), swell (long, rolling waves from a distant origin), and tide. At times, these individual effects act together, amplifying the total movement. For example, the float might be lifted by a sea which is on the crest of a swell at high tide. Other times, one effect will tend to cancel another, as when the float is on the crest of a wave which is in the trough of a swell. At any rate, the float is in motion with respect to a reference surface, which in this case is the ocean floor.

To correlate this to bench mark movements, the respective counterparts of sea, swell, tide, and the ocean floor are near-surface movements, movements within the crust, motion of the entire crust, and the geoid.[2] It would be ideal if we could fix the bench mark to the geoid as we can anchor a piling to the ocean floor to eliminate tidal motion. However, there is no analogous way to counteract the effect of crustal motion on a bench mark.

In the ocean, the effect of swell could be avoided in some areas by making use of an existing breakwater, harbor, or bay. Similarly, with proper bench mark site selection, many movements within the crust can be avoided, but choice of a location is not as obvious. Considerable geological information is needed to determine which areas exhibit no subsurface instability.

Finally, the effects of sea in many situations can be avoided. Where this is not possible, they can be economically counteracted by building a small floating barrier. Essentially, this is what can be done for vertical control points. The sleeved class A rod mark (see fig. 4, page 16) consists of a steel rod that is isolated from near-surface motion by the sleeve.

Origins in the Subsurface

Crustal Motion

First among the subsurface causes of vertical movement is crustal motion. Even if it were possible to prevent this movement, it would be undesirable in many cases. Crustal motion studies are an important application of leveling data. The movement of one area of the crust in relation to another serves as the basis for these studies. To determine this, knowledge of crustal motion with respect to the geoid is not essential. What *is* necessary is to know which bench marks reflect *only* crustal motion. Referring to the parallel drawn with the sea surface, if a float is to be used to monitor tides, it must be known that the effects of seas and swell have been eliminated.

[1] A concise, easily understood description of the geoid is given in appendix B.

[2] The gravitational effects of the sun and moon exert an influence on land masses just as they do on the oceans, causing a phenomenon known as "Earth tides." No analogy for Earth tides is made in this parallel.

Caverns and Mines

Caverns and underground excavations contribute to vertical movements on the surface of the Earth. Sometimes the motion is abrupt as is the case with sink holes, and other times their effects result only in gradual subsidence. When crustal uplift is occurring simultaneously with subsidence caused by a gradual caving in of an underground mine, the wrong conclusion can be drawn about the stability of an area. In general, the National Geodetic Survey is not concerned with monitoring subsidence caused by underground excavations and caverns. Since it is too costly to anchor bench marks below the depth of disturbance and isolate monuments against such movement, these areas must be avoided wherever possible.

Pumping

Subsidence is also caused by pumping of oil or water. When fluid is removed from the ground, the resulting decrease in pressure allows gravity to pull down the overlying soils. Associated with this is piping, or the removal of fines from a soil stratum, which aggravates the situation. Again, in carrying out its basic mission of developing and maintaining a network of geodetic control, NGS is not primarily concerned with monitoring this type of motion. Except where subsidence is the subject of special study, such as in the Houston, Tex., area and Santa Clara Valley, Calif., these areas too should be avoided wherever possible.

On or Near-Surface Origins

Impact

The reliability of a bench mark elevation is largely dependent upon its exposure to impact. The results of impact can range from an infinitesimal change in elevation as a result of being stepped on to total destruction caused by earth-moving equipment, which is perhaps the most common cause of bench mark loss. NGS bench marks have been designed to minimize the chances of vandalism, tampering by souvenir hunters, and impact which is relatively small in magnitude.

For class A rod marks, this is accomplished by three precautionary measures: first, the datum point is set slightly below ground level; second, a protective pipe is placed around the datum point; and third, the bench mark component which is imprinted with the NGS logo, and might be considered a worthy souvenir, is not an integral part of the datum point.

By their inherent nature, other types of NGS bench marks are not vulnerable to relatively slight impact. Heavy impact, such as that caused by construction equipment, cannot be counteracted by economical design so it must be avoided by judicious placement.

Frost Heave

Besides disturbances caused by human intervention, there are a great many resulting from natural phenomena. Of these, frost heave is one of the most severe. The occurrence of frost action depends on three factors: freezing temperatures; available water; and certain soil characteristics, most notably soil particle size. The absence of any one of the essential conditions precludes the occurrence of frost heave.

For example, it is the influx of additional water into a soil's freezing zone after the freezing has already begun that results in excessive frost heave. The freezing of water initially present does not cause a significant problem. When the water table is near the surface, additional water is available to be drawn up into the freezing zone causing the frost heave problem. A water table within 2 meters of the ground surface indicates a potential hazard and it is normally further from the surface on hills than in low-lying areas. Consequently, less severe frost heave can be expected to be found on hills.

Even though water is available, significant frost heave will not occur unless the soil can draw it up and hold it in the freezing zone. Soils which are capable of this are called "frost susceptible." The main factor in determining frost susceptibility of a soil is particle size distribution. Coarse-grained soils contain spaces that are too large to draw up and hold water. At the other extremity, many clays are impervious to water. (Clays, however, are detrimental for reasons other than frost heave as explained in other sections of the manual.) The soils most susceptible to frost action, and therefore to be avoided where freezing occurs, are silts and silty sands with soil particle sizes less than 0.02 millimeter (U.S. Army Corps of Engineers 1967).

Shrinking and Swelling of Soil and Rock

Another phenomenon that can cause bench mark instability is shrinking and swelling of soil due to changes in moisture content. The magnitude of soil volume change depends upon two factors. One is the character of the soil, including particle size and distribution, degree of cementation, and, most importantly, mineralogy (Patrick and Snethen 1976). Fine-grained soils containing certain clay minerals, particularly montmorillonite,[3] are highly expansive.

The other factor governing the shrinking or swelling of a soil is the measure of its variation in moisture content. Seasonal climate variability provides a good indication of the degree and depth

[3] **Montmorillonite is a clay mineral made up of layered, plate-like particles separated by water. The addition of more water causes the particles to separate even more until they finally disperse.**

to which volume change will occur.[4] An expansive soil subject to either a consistently moist or dry climate year around will not exhibit a change in volume, but if the climate is wet during one season and dry during another, a volume change will occur. Figure 12 (page 33) separates the United States into areas of differing climate variability. The higher the value of the climate factor, the more variable the moisture content of the soil.

This expansive character is not limited to soils. Sedimentary rocks are those which were formed by the consolidation of sediments. If the parent materials were of an expansive nature, the rock itself will likely have this characteristic to a surprisingly high degree. Substantial pavement damage has occurred on some highways founded on sedimentary bedrock when the water content has been altered.

Soil Expansion and Contraction

The terms "expansion" and "contraction" indicate changes in volume resulting from a change in temperature rather than a change in moisture content. Like other materials, soil expands when its temperature rises and contracts when its temperature is lowered. It differs from most other materials in that the range of temperature variation is not constant throughout its depth. At the surface, the temperature variation is near that of the air. At some depth, the temperature is nearly constant throughout the year. In unfrozen soils, expansion and contraction due to temperature change is negligible, but in frozen soils they are factors to consider. In permafrost, temperature change can have a significant effect on a bench mark down to a depth of about 10 meters (Bozozuk *et al.* 1962).

Slope Instability

Slope instability covers a wide range of movements ranging from rockslides and mudflows to the nearly imperceptible movement known as creep. Rockslides and mudflows are obvious and would probably result in the total destruction of a bench mark. Creep presents a greater problem to monumentation because it could result in only a slight change in the bench mark elevation which could lead to erroneous conclusions. Evidence of creep can sometimes be witnessed in leaning utility poles where the upper layer of soil slides in relation to that beneath it.

Gravity is the main force that produces creep, but gravity can be aided by a number of other factors, among which the presence of moisture is probably the most dominant. In some instances, a small amount of water can increase cohesion and retard the flow of soil downhill. More often, water decreases friction between soil particles, allowing them to flow more rapidly. When moisture is confined to the upper layers of a slope by an impermeable substratum, the likelihood for creep is quite high.

Sometimes a slope can be stable until a cut is taken from it which upsets the equilibrium and starts a slide. If the cut was taken from an area providing substantial support to a slope, the slide will occur rapidly. When the slope is less steep or provides more of its own support through cohesion of the soil, a cut will have no effect or result only in creep. Highways are notorious for producing slides in some parts of the country.

Soil Consolidation

When a soil mass is subject to loading, the soil particle orientation undergoes a change resulting in a condition of closer packing and smaller voids. The longer the load remains, the more stable the particle reorientation becomes, until a condition of equilibrium is finally reached. If a load is removed, rebound occurs.

Many kinds of loads can cause a soil mass to consolidate significantly. Large structures can cause soil consolidation resulting in settlement of the structure. They are often constructed in such a manner that they do not exceed a specified settlement, or at least a certain settlement rate. The total allowable settlement is usually a few centimeters. The rate occurs rapidly at first and decreases with time. Some structures continue settling for many years after construction has been completed. Besides compressing the soil directly beneath it, a new building causes the surrounding soil to be drawn down.

Water reservoirs exert tremendous stresses on soil deposits. As a reservoir is filled or drained, the soil mass below it compresses and rebounds accordingly. As with structures, the surrounding soil is also affected by the loading and unloading. Large rivers also exhibit this trait to some extent with the seasonal change in water level.

A special case of consolidation due to loading can be seen in manmade deposits or fill. Not only do these deposits exert a pressure onto what may be a compressible soil below, but they themselves are subject to consolidation. When the purpose of fill is other than to improve the subgrade of a construction site, it is usually deposited loosely, and will compact under its own weight. Fills are usually deposited in small or narrow areas. Examples include levees, landscape improvements, and disposal sites for undesirable materials such as trash, overburden, and dredge deposits. However, sometimes the areas can be very extensive, as in the case of reclaimed strip mines.

[4] Soil mechanics being a complex science, the maximum depth at which soil is affected by this phenomenon is not universally agreed upon. Here, it is assumed to be 15 meters.

Erosion

Impairment of some bench marks can be attributed to erosion. Soils in or on which a monument is set are subject to removal by the action of wind and water. This can result in the monument being obviously displaced, or only a subtle disturbance rendering it unsuspectingly unfit for use as a geodetic control point. Undercutting can occur along the outsides of curves in rivers and embankments near large bodies of water where storms are likely to occur. It is conceivable that wind erosion could also present a problem in some locations, but it would probably result in the loss by burying a bench mark rather than changing its elevation.

Motion Intrinsic to the Monument

Choice of materials for a bench mark monument is critical for two important reasons. First, ultimate deterioration of materials results in the loss of a bench mark's reliability. The outmoded copper clad rod mark (page 44) has been known to corrode to such an extent that sections of the rod have separated entirely. Failure of a bench mark from this cause would not be abrupt. In fact, it could be difficult to detect. For this reason, when a monument is recovered for releveling, it should be tested to ascertain its condition. For rod type bench marks this can be accomplished by grasping the rod and pulling it to make sure its integrity has been retained.

Secondly, a bench mark's elevation can change with the expansion and contraction of the monument due to temperature change. Theoretically, this can amount to changes on the order of a millimeter or more between hot and cold seasons. In choosing bench mark materials, the thermal coefficient of linear expansion must be considered. If modifications involving changes in materials are made to the prescribed designs for rod marks, materials having a direct bearing on the bench mark elevation should be limited to those having a coefficient less than 20×10^{-6} cm/cm per °C.

Intended Stability of NGS Bench Marks

From the information in this chapter, it is evident that the causes of instability vary widely in both depth of origin and geographical extent. To counteract deep subsurface activity would be economically unfeasible, so bench mark specifications for the National Vertical Control Network have been developed to resist movements at or near the surface. Among such movements are those caused by impact, frost heave, shrinking and swelling of soils, soil expansion and contraction, and in some cases where the effect is not too deep, consolidation. Except for consolidation, bench marks set as described herein can always be expected to resist movements from these causes.

To accomplish this objective, most bench marks must be anchored *below* the depths at which these movements originate. Mere massiveness does not insure stability. This point is extremely important to bear in mind. Even a very large building is subject to vertical displacements beyond those tolerable if it rests on a shallow foundation in expansive clay.

3. CONSIDERATIONS IN SELECTING A SITE

The most effective precaution that can be taken to assure a bench mark's stability and survival is to choose a good location for setting it. Because there is such a wide variety of situations that can be encountered when setting the monuments, it is impossible to cover them all in a manual. The ultimate selection of a site is necessarily left to the discretion of the mark setter and it is imperative that good judgment be exercised. There are many things to consider. Table 1 (page 11) will help keep them in perspective.

Security

Foremost on the list of considerations is the bench mark's susceptibility to damage or destruction, which is probably the major cause of bench mark disturbance. In view of the great expense of leveling, foresight spent to preserve a monument is well worthwhile. Anticipate construction that might occur at the location. Is the site in the path of a future highway, waterway, ditch, or pipeline? Will an adjacent shopping center or parking lot be expanded in the foreseeable future? Is the prospective bench mark site near a potentially active mine or quarry? Highway maintenance often involves the widening of its surface and the straightening of curves. Setting the marks near the edge of the right-of-way and on the outsides of curves increases their chances for survival.

Conversely, the outside of a bend in a river should be avoided because erosion eventually undercuts the bank. Undercutting can also occur on shoreline scarps where stormy waters slowly but surely wear away the embankment. Do not set bench marks at these locations. Flood plains should be avoided when otherwise comparable sites can be used because marks may be buried in sediment or washed out.

Often, sites can be located which provide natural protection for the monuments. Locations near the edge of the right-of-way, well away from a highway surface, provides protection from mowers and other maintenance vehicles. Property fence lines and utility poles usually remain in place for years and afford good protection for marks. Structures which are of themselves not suitable for bench mark settings prevent vehicles and equipment from damaging monuments that are set adjacent to them. And finally, private property and public areas such as parks and cemeteries provide excellent sites from a standpoint of survival.

Utility

Availability to users is another important consideration in choosing a bench mark site. The major use of NGS bench marks is to provide vertical control for other surveys. If the bench mark cannot be found or conveniently leveled to, its worth is questionable. Many users first inadvertently find a survey mark, then request information about it. Others use vertical descriptive information to locate control points near a proposed engineering project; so locate bench marks where they can be accurately described.

Again, foresight must be used when selecting the exact location. A bench mark set flush with the ground is easily concealed with debris. Are there nearby objects that can be used to reference the monument? Are these objects fairly permanent? Will the measurements define a precise point where the hidden bench mark can be found?

To enable the mark setter to situate a monument where its position can be accurately described, a familiarity with referencing techniques is required. Bench marks are usually located in the following manner: First, directions are given to the general area in which the bench mark is located. Normally, this puts the individual within 100 meters or so of the monument. Then the bench mark is found by following distances and directions from prominent reference objects. These distances and directions establish lines-of-position (LOPs). The prominent objects are referred to here as "origins."

For example, a bench mark can be referenced by stating a distance and direction from the corner of a house as follows: "The monument is 35.8 meters northeast of the east corner of the house." (See fig. 1a.) In this case, there is one origin and two LOPs. The origin is the east corner of the house. One LOP is referred to as "35.8 meters [from]. . . the east corner of the house." It defines a circle with a radius of 35.8 meters and its center at the east corner of the house. The other LOP is given as "northeast of the east corner of the house." It defines a line beginning at the east corner of the house running at an azimuth of 45° east of north.

At least two LOPs are required to define a point. If the description read only "35.8 meters from the east corner of the house," the bench mark could be anywhere on the circle with a radius of 35.8 meters and a center at the east corner of the house. Or, if the description read only "northeast of the east corner of the house," the mark could be anywhere on the line beginning at the east corner of the house and running at an azimuth of 45° east of north. In either case, it would be difficult to find.

Sometimes more than two LOPs are required to define a point. "The bench mark is located 26.7 meters south of the centerline of the highway and 10.2 meters from a 40-centimeter oak tree." Two LOPs are given by this statement, but they define more than one point as can be seen in figure 1b. An additional LOP, such as a direction from the water tank or tree, is required for the unique point to be located.

The important concept to be concluded is that the more nearly perpendicular the angle at which lines-of-position intersect, the more accurately a position can be determined and the easier it will be to locate. (See figs. 2a and 2b.) To apply this concept to bench mark setting, consideration should be given to the ease with which future recovery can be made from the reference measurements. Other considerations in bench mark placement rarely restrict the site to such a limited area that this cannot be done. Leeway of just a few meters is usually enough to make the difference between a mark that can be accurately referenced and one that cannot.

Stability

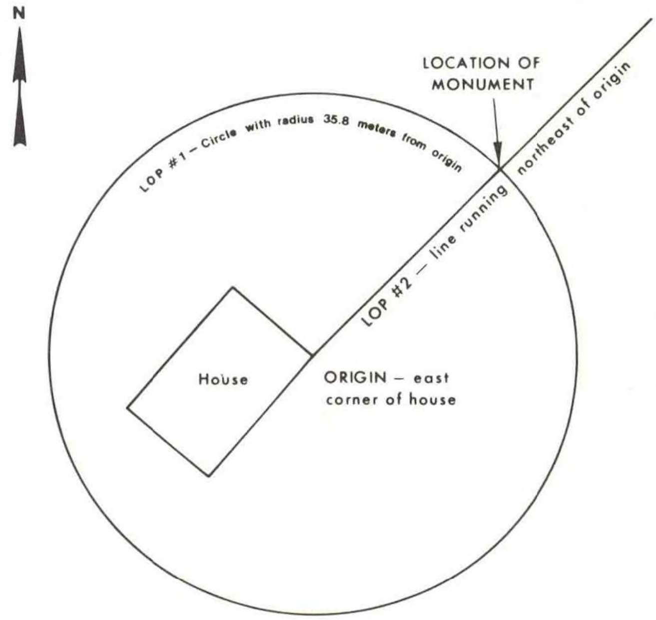
Advantageous Topographic Features

Crests of hills are good places to set bench marks for three reasons. First, the problem of slope instability is eliminated. Even though the neighboring hillside might be sliding, the summit will remain stable. Second, frost heave is less likely with the increased separation from the water table. And third, the consistency of the soil will tend to be more firm.

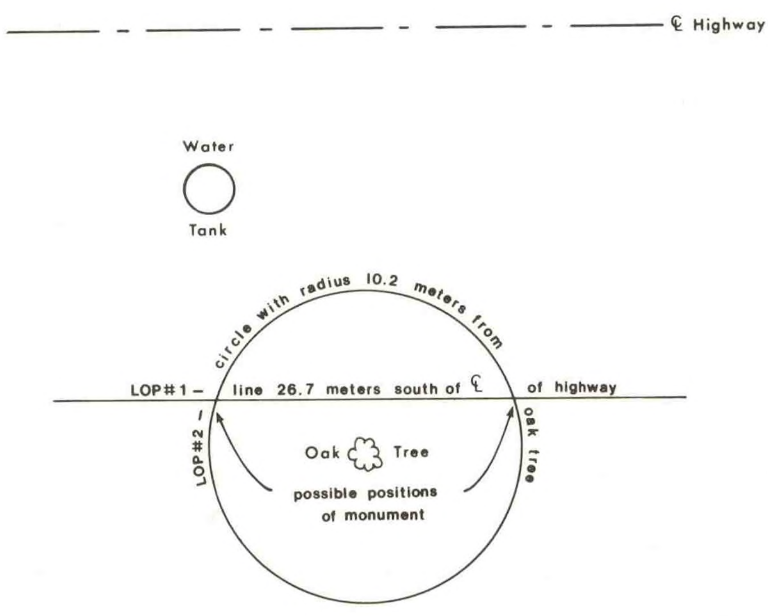
Effect of Soil Grain Size

Whenever soil types can be ascertained, it is preferable to choose a site with coarse-grained soils over one with fine-grained soils. Most of the problems associated with soil movements are attributable to the fine particles it contains. The fraction of grain sizes less than 0.02 millimeter governs whether or not a soil is frost susceptible. Soils susceptible to high volume change due to variation in moisture content are normally clays, which are fine-grained. Also, poorly drained clays provide environments conducive to corrosion. Avoid sites with fine-grained soils whenever an alternative is available.

One way to determine the type of soil in the locality is to examine that which has been exposed by digging, especially where a bank has been left

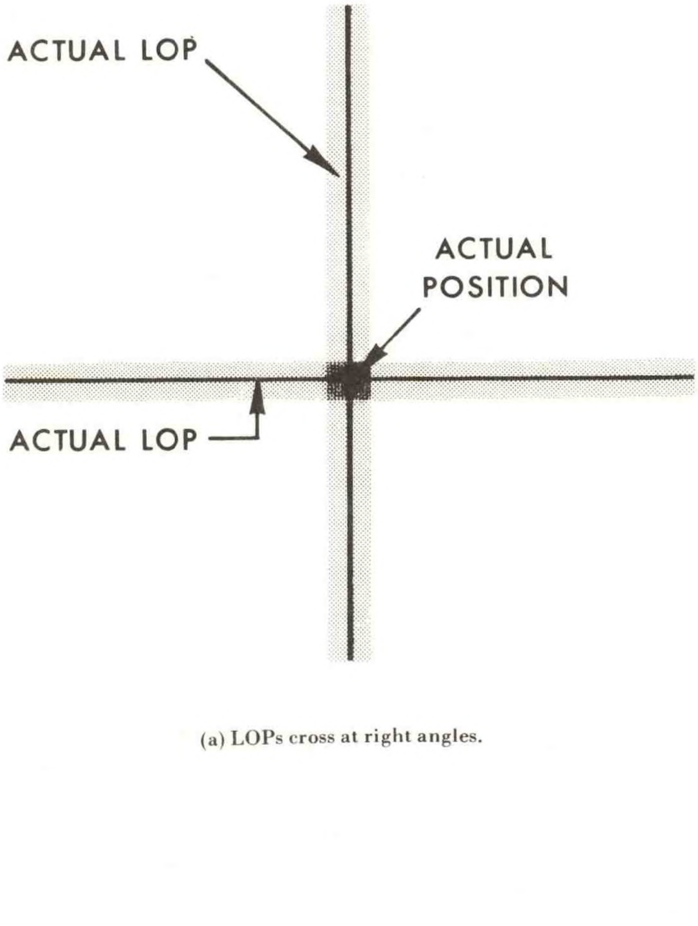


(a) Bench mark referenced to house corner.

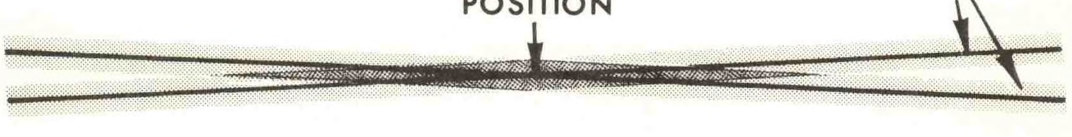


(b) Bench mark referenced to tree and road centerline.

Figure 1.—Referencing of bench marks.



(a) LOPs cross at right angles.



(b) LOPs cross at shallow angle.

Figure 2.—Intersection of lines-of-position. Light shade indicates range of measurement errors. Dark shade indicates area in which monument could be found.

exposed. Look at soil grain size in nearby highway cuts and excavations. Good drainage is usually inherent in coarse-grained soils and therefore can also be used as an indication. It can be recognized by uniform coloration with depth.

Effects of Vegetation

The presence of vegetation, particularly trees, has marked influence on the stability of the upper layers of a soil mass. Trees, underbrush, grass, and moss act as insulation, reducing the depth of the active frost zone and thus reducing frost heave. However, the problem of expansive soils is aggravated by vegetation. In seasons of abundant rainfall, vegetation exerts very little influence on soil volume change. When the weather is dry and only a little free water is available in the soil, trees and other plants draw even more out than normally is lost through evaporation and lowering of the water table. This results in even greater shrinkage. With trees, this effect occurs within a distance from the trees roughly equal to their heights (Bozozuk and Burn 1960).

Areas covered with thick vegetation should be avoided even where expansive soils do not exist because vegetation will conceal a bench mark, making it of much less value than one that is open to view. Do not place bench marks near lone trees because this will subject them to disturbances from growing roots.

Geological Considerations

It will not be feasible to determine the nature and extent of subsurface geological activity in many instances. Nevertheless, it is an important consideration that should never be overlooked when the means are available. A generally stable area may have pockets of unstable ground within it, and detailed geological data are required to determine this. Caverns and underground mines, and water and oil bearing strata subject to pumping are especially prone to cause significant subsidence. Bench marks established strictly for geodetic control should not be set in these areas.

Geological information is available through Federal, State, and even private organizations. General overviews of karsts (subterranean cavities), slope instability, and the like are available from the U.S. Geological Survey. For more specific information on larger scale maps, the individual State Geological Surveys, State Departments of Natural Resources, universities, and public utilities commissions must be contacted. These agencies can provide pertinent geological data including maps of underground mines, cavernous areas, slope movements, and areas subject to subsidence from the pumping of oil, gas, or water. Liaison with these organizations is a necessity.

Whenever possible, sound bedrock should be used for a bench mark setting. However, it is often difficult to determine whether or not an outcrop is indeed sound bedrock, the decision being based mainly on visual evidence of only the exposed portion of the formation. Where a large portion of the outcrop is exposed, try to ensure that the part in which the disk will be set is essentially intact with the rest of the outcrop. Large outcrops with widely spaced fractures and crevices can be considered bedrock for mark setting purposes. Where only a small portion of the outcrop is visible, use a pry bar to make certain the intended setting is not a separate boulder.

Examine the surface of the bedrock. Make sure it is solid, and not in a state of deterioration. The margin of weathered rock can be surprisingly thick. If its surface has begun to crumble or has deep fissures in close proximity, the outcrop is unsound and should not be used. Another type of bench mark will be more stable.

Some sedimentary rock contains detrimental clay minerals, such as montmorillonite, but it is difficult to determine this. When geological maps or expert advice indicates that sedimentary outcrops are expansive, they shall not be used for bench mark settings. A site must be located in a structure or another rock outcrop, or a rod type mark must be used. Expansive bedrock will not be a problem is if lies beneath sufficient overburden because it will not be subject to variations in moisture content.

Structural considerations

Structures are subject to movements from any of the sources pointed out in chapter 2. Fixing a bench mark disk on a structure by no means assures that it will be a good geodetic control point. Before setting the disk, determine whether or not the structure will be at least as stable as a class A rod mark (page 14). If not, use the class A or B rod mark instead.

Relating the stability of a large structure to that of a class A rod mark can be accomplished by (1) comparing the depth of the structure's foundation to the required depth for the sleeve (table 2, page 27), and (2) assuring that the structure is a multistory concrete, masonry, or steel unit. The class A rod mark sleeve is set to a depth below that affected by expansive soils and frost heave. For comparable stability, a massive structure's foundation need not be as deep as the sleeve because the weight of the structure can resist some of the force exerted by the ground which tends to move it. Also, the structure itself will have a shielding effect on the soil below, making conditions such as temperature and moisture content less variable. If its foundation is at least a quarter as deep as a class A rod mark's specified sleeve depth, a massive structure will be considered stable. Small structures, such as semaphores, concrete culverts, platforms, retaining walls, bridges, etc., must never be used. Very large bridges can be used only if it is positively determined that the structural member in which the disk will be placed rests directly on bedrock.

Since most structures are expected to settle both during and some time after construction, those less than 5 years old must not be used as settings for bench marks unless the foundations are on bedrock. Choose a structure that has a long life expectancy. Modern buildings will probably remain undisturbed a long time, but make sure that they have not been too newly constructed. Older buildings may last a long time if they have historical significance.

Caution must be taken to assure that the disk is placed in a spot that is an integral part of the structure's foundation or fixed rigidly to it. Placing a disk on an appendage, such as steps entering a building, is unacceptable unless the appendage has its own foundation of sufficient depth. Avoid places which might be damaged or covered during construction of an addition to the structure. Building entrances are especially susceptible to reconstruction.

Miscellaneous Areas To Avoid

As explained in the chapter on sources of instability, sites near water reservoirs and large rivers, where the water level is variable, can rise and fall due to rebound and compression of the soil. This movement might be thought by the layman to be minor, but in terms of precise geodetic measurements, it is not. Where possible, bench marks should be established a few hundred meters from the confines of these sources of ground activity.

Permafrost has a stabilizing effect on bench marks anchored to a sufficient depth within it, but significant expansion and contraction of frozen ground due to temperature variation can occur to a depth of about 10 meters. A bench mark anchored below this depth can be expected to be quite stable. In regions where permafrost normally exists near the surface, thawing influences can keep the ground in an unfrozen condition to a depth greater than that which is prevalent. Any body of water, such as a pond, lake, or river, will have this effect. Other influential effects include buildings, roads, pipelines, and, in short, any mark of civilization.

Corrosive Environment

The rate at which a material will corrode or deteriorate is affected by its environment. Two conditions are required before corrosion can occur. (1) The metal being corroded *must* be in contact with an electrolyte, or liquid capable of conducting electric current. This makes it possible for certain chemical reactions to occur. Electrolytes vary widely, ranging from a minute amount of nearly pure water formed by condensation, to sea water. (2) There must be a dissimilarity in two areas of the surface being corroded. This could result from the presence of strains or inclusions in an alloy, the contact of dissimilar metals, or a multitude of possibilities between these extremes.

Environmental factors governing the corrosive character of a soil are principally the degree of aeration and the presence of water-soluble salts. Aeration is important because many metals need oxygen to form a dense, tough layer of metallic oxide on their surfaces, which prevents further corrosion by isolating the remaining metal from the electrolyte. Aluminum and steel protect themselves in this manner. In addition, when one area of a metal is in an environment with a good supply of oxygen while another area lacks oxygen, a condition of dissimilarity is set up in which corrosion is accelerated. An example of this can be seen in a partially submerged piece of iron. That portion above water is supplied with more oxygen than the portion below water. At the waterline these dissimilarities are close to one another, resulting in intensified corrosion.

Water-soluble salts have an effect on corrosion in two ways. First, the ions that form when salts dissolve improve the capability of the electrolyte to carry current. The greater the ability of the electrolyte to carry current, the faster corrosion will occur. In both atmospheric and underground corrosion, water is normally the electrolytic medium. Water with dissolved salts is a better electrolyte than pure water. The salts most often found in highly corrosive soils are sodium chloride ($NaCl$), commonly known as table salt, sodium sulfate (Na_2SO_4), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium sulfate (K_2SO_4), and calcium bicarbonate ($Ca(HCO_3)_2$) (Romanoff 1957).

The second effect of water-soluble salts is the influence they have on the formation of the dense, tough protective layer which forms on the surface of certain metals. Sometimes this layer cannot form in the presence of various ions. For example, aluminum is normally quite noncorrosive because aluminum oxide quickly forms on its surface. However, in the presence of dissolved salts, the oxide layer does not form densely enough to prevent infiltration of the electrolyte, so corrosion continues at a high rate.

Of the types of monuments which may be used in the National Vertical Control Network, only the

Table 1.–Summary of measures taken to set high-quality bench marks

COUNTERMEASURES (Discussed on page no. shown in parentheses)	UNDESIRABLE CONDITIONS: Damage/destruction (3)	Frost heave (3)	Expansive soils/rock (3)	Compression of soils (4)	Slope instability (4)	Subsidence from pumping (3)	Caverns/underground mines (2)	Depression of permafrost (10)	Settling of structures (10)	Concealment (6)	Corrosion (10)	Erosion (5)
Use disk set in bedrock (13)	X	X	X	X	X	X	X					X
Seek coarse-grained soils (6)		X	X									
Seek well-drained soils (9)		X									X	
Seek well-aerated soils (10)											X	
Set on crests of hills (6)		X			X							
Seek soils with high resistivity (12)											X	
Natural/readymade protection[a] (5)	X											
Anticipate future construction[b] (5)	X											
Set near edge of right-of-way (5,12)	X										X	
Bench mark design (3,12,14)	X	X	X	X							X	
Anchor sleeved rod below level of disturbance (14)		X	X	X								
Set disk in massive, deep structure (9)		X	X	X	X							
Historically significant structure (10)	X											
Modern buildings (10)	X											
Remain distant from thawing effects[c] (10)								X				
Ensure good referencing (6)										X		
Avoid heavy vegetation (9)			X							X		
Avoid river banks (5)												X
Avoid flood plains (5)										X		X
Avoid shoreline scarps (5)												X
Avoid salt water shorelines (12)											X	
Avoid areas as determined by geological data[d] (9)			X		X	X	X					
Avoid expansive bedrock (9)			X									
Avoid new structures (less than 5 years old) (10)									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.

class A and B rod marks (pages 14 and 25) are particularly vulnerable to corrosion. The rods for these marks will unavoidably be placed in corrosive soils. As a protective measure, the rod is made of type 316 stainless steel, which is more resistant to corrosion in nearly all environments than other affordable alloys. Even so, steps can be taken to increase its life. It is most susceptible to corrosion in poorly aerated environments and those in which there are chlorides.

Iron compounds are commonly contained in soils. Well-aerated soils are generally recognized by their red, yellow, or brown colors resulting from the oxidation of these compounds. Sites with these soils should be sought for bench mark setting. Poorly aerated soils are usually gray in color due to the lack of sufficient oxygen to oxidize the iron compounds. They may also be identified by their poor drainage characteristics.

Avoid areas where there is a high concentration of chlorides. When setting marks along highways, keep them at least 10 meters from the road surface where heavy salting might be done in winter; setting along the edge of the right-of-way is generally a good practice. Although it will sometimes be impossible due to project requirements, try to avoid salt water shore lines. When the purpose of a project is to provide shore line control, stay off the beach if project instructions will allow.

Finally, if the means are available to measure soil resistivity, a good indication of the corrosive character of a soil can be obtained. The more resistant a soil, the poorer the electrolyte, and consequently, the less corrosive it will be.

Safety

If a monument extends below ground level, there is a chance of encountering underground cables or pipes when installing it. This is especially true when drilling a hole for the sleeved class A rod mark (page 18), and the situation is more critical in urban areas than in rural areas. Evidence of underground utility lines often can be observed at the surface. Waterlines are marked by valve boxes at most street intersections. Avoiding the line between valve boxes will decrease the chances of hitting a pipe. Also, fire hydrants indicate where a water main lies. Hydrants usually are placed within a meter of the line and to the side away from the street centerline. Most water and sewer lines lie under the road surface, but some are placed adjacent to it. Avoid the area between the street and sidewalk.

Telephone and electrical cables are normally laid from 1/2 to 1 meter below the surface. Housing developments built in the 1960's and later are much more apt to have underground cables than those built before that time. The absence of telephone and power poles is conclusive evidence that there are underground cables in the area, but the presence of poles does not necessarily dictate otherwise. Buried telephone lines usually run directly between junction box pedestals or between telephone poles. Electrical cables may be run adjacent to telephone lines. Where an electric appliance such as an air conditioning unit or flood light is located apart from other structures, an underground cable to it would probably run directly from a metering device. Stay clear of that path.

Gas lines are harder to detect. Meters and valves are helpful if they are not too far apart. As with telephone cable pedestals, do not drill on a direct line between them.

If circumstances permit, the best way to avoid problems is to contact the local metropolitan utilities commissions. Underground pipe and cable information can often be had by calling one centralized office which maintains liaison with all the various utility companies. When it is possible to do reconnaissance a few days in advance of the actual mark setting, this alternative will be efficient. If this is not possible, it is advisable to use a pipe and cable locator for detecting conductive materials underground. However, these devices are not infallible. Plastic, unreinforced concrete, and clay tile pipe will not register on them. Get into the habit of looking for "Buried Cable" signs. And finally, set marks near utility poles, but not on line between them when other considerations in site selection will allow. Utility poles cannot be set over water and sewage pipes.

4. INSTALLATION

Maintaining Good Public Relations

The purpose of the Federal Government is to serve the public. Pertaining to the establishment and maintenance of geodetic control, this principle has at least two applications. One is to gain the understanding and good will of the public. Another is to project the credibility of the National Ocean Survey/National Geodetic Survey through the visible evidence of its mission—survey control markers.

These objectives can be accomplished with only a little extra effort. Always obtain permission from the landowner when setting bench marks on private property. Responsible officials must be consulted when a prospective site is located on public or corporate land. If approached in a polite and tactful manner, a hesitant individual often can be persuaded to permit installation at the desired site. Most citizens can be convinced to take personal interest in having a bench mark carrying NGS's distinction on their property. Appeal to the individual's public spirit. Explain what bench marks are used for, the need for their stability and durability, and the expense involved with replacing them. The setting of bench marks provides an excellent opportunity to make the public aware of NOS/NGS activities. Under no circumstances shall a bench mark be installed on an unwilling property owner's land, thereby provoking hostility toward the Federal Government.

The importance of a clean, neat installation cannot be overemphasized. Not only does it help maintain friendly relations with the local citizens, but it also upholds the esteem of the Federal Government. Sloppy bench mark installations by a few mark setters could understandably lead users to believe that the whole leveling program is run in a haphazard manner. Do not allow this to happen.

Special Considerations at Line Intersections

Level line intersections are of prime importance when it comes to mathematical adjustment of a vertical control network or portion of it. Junction points are used for the initial adjustment of the system. Intermediate elevations are not taken into account until after this initial phase of the adjustment. As a result, no elevations can be better than those at the junctions; therefore, only the highest quality bench marks should be used there.

Sound bedrock should be used for these points if at all possible. Relocating the point of intersection as much as 10 kilometers to take advantage of an outcrop would not be unreasonable. When outcrops of sound bedrock are not available, choose the next best location following the guidelines enumerated in chapter 3. Other than bedrock marks, only disks in structures and class A rod marks as explained in succeeding sections are permissible for first-order junction bench marks.

Once the location is found, steps must be taken to preserve the junction by placing supplemental monuments nearby which can also serve as junction points. In the event the primary monument is destroyed, the integrity of the network will remain. At intersections of two first-order lines, a minimum of three monuments shall be placed not less than 0.5 kilometer apart. At intersections of first- and second- or two second-order lines, a minimum of two monuments shall be placed not less than 0.5 kilometer apart. Junctions with third-order lines need no special considerations. In all cases, try to select sites that will not all be destroyed by one common cause such as the widening of a highway.

Disk Set in Bedrock or Structure

Sound bedrock is the most desirable setting for a bench mark. Besides the ease with which a disk can be installed in bedrock, it provides the most stable setting that can be used in terms of both underground activity and disturbances inflicted by people. Always use bedrock when a suitable outcrop exists. As a rule of thumb, the bedrock is good if the distance between joints and fissures is greater than 1 meter.

The National Geodetic Survey bench mark disk (see fig. 3) is made of brass or bronze. It is about 9 centimeters in diameter and has a spherical surface to support the foot of the leveling rod. Information is imprinted on this surface to identify the monument and to aid the user in obtaining data on it. This logo is recessed so that it does not interfere with placement of the leveling rod. A deformed shank, about 7-1/2 centimeters long, is silver-soldered to the bottom surface of the disk to help prevent the disk from being dislodged. Disks with tubular shanks can also be used.

The step-by-step procedure for setting the disk in bedrock is as follows:

1. Stamp the designation and year on the top surface using 4.75-millimeter (3/16-inch) steel dies.
2. Pick a fairly level and accessible spot on the outcrop that is intact with the bulk of the rock.
3. Drill a 2-1/2-centimeter hole about 10 centimeters into the bedrock and recess the area around the top of the hole to a diameter slightly larger than that of the disk. When the installation is completed, the top surface of the disk should set level and flush with the surrounding rock. *Caution*: Safety goggles should be worn when drilling into bedrock or masonry.
4. Remove the rock powder from the hole and recessed area and fill the hole with *clean* water; then pour cement into it. Mixing of the ingredients is done right in the hole. By adding more water and cement, make enough mortar so that an extra amount is available to place on the underside of the disk and, if applicable, inside the shank. When the mortar is completely mixed, it should be thick but still workable.
5. Fill the depression on the underside of the disk with mortar. For disks having tubular shanks, also fill the shank with mortar. This is very important because it will prevent the existence of highly undesirable voids under the disk once it is in place.
6. Place the shank of the disk into the drilled hole and press the mark firmly into place. Work the excess mortar around the outer edge of the disk, making sure that it is smooth and flush with the top surface. An exposed edge of the disk would provide an area which could be used by someone to dislodge it. Fresh mortar

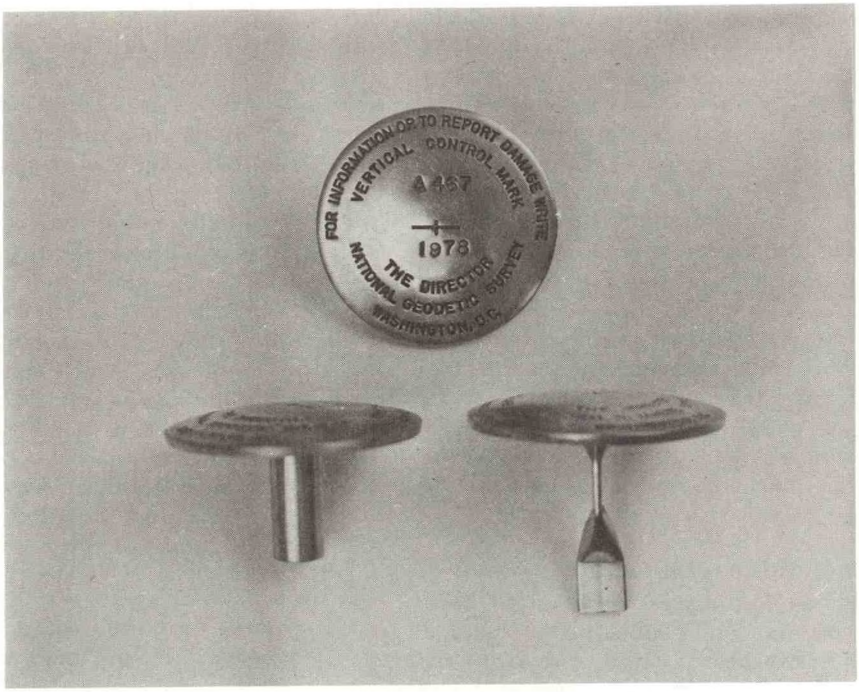


Figure 3.—NGS bench mark disk stamped with designation and year.

on the upper surface of the disk can easily be cleaned off.

7. Sprinkle some dry cement on the exposed surface of the disk; then rub it with a clean rag using circular strokes. This will clean the disk very nicely, removing all excess mortar from its surface and recessed letters. Rubbing the wet mortar around the edge of the disk in the same manner will do no harm. On the contrary, this is often done intentionally to finish its surface and prevent cracking. Brush away loose cement and make sure that the finished product has a very neat appearance.
8. If there is a nearby crevice or spot of ground in which a witness post can be conveniently set, this should be done.
9. While the mortar is still wet, it must be covered to prevent heavy rains from ruining its surface and to conceal the disk from people who might tamper with it. A piece of wood, cardboard, heavy paper, or similar biodegradable item will suffice.
10. The installation is not complete until all accumulated trash has been picked up. Leave the place in good order.

In setting a disk in a massive concrete or masonry structure, first make sure the structure is stable. Its foundation must extend to a depth that equals or exceeds 25 percent of the specified depth of the sleeve for the class A rod mark, as indicated in table 2 (page 27). Furthermore, the foundation must be at least as deep as the maximum depth of frost penetration indicated on the map in figure 13 (page 34).

The disk can be mounted vertically in the wall of a structure, but should always be set horizontally if possible. The procedure for setting a disk horizontally in a structure is identical to that for setting one in bedrock. Make sure safety goggles are worn when drilling into masonry or concrete. Since for a vertical setting the hole for the disk's shank must be drilled horizontally, the mortar must be mixed separately. When drilling into brick or other soft material, a hammer and star drill should be used, rather than heavy power equipment, to prevent extensive damage to the exterior. The hole should be wetted before mortar is put into it. After placing the shank of the disk into the mortar filled hole, work it to the bottom edge of the hole so that it will not settle askew while the mortar is curing.

Class A Rod Mark

The class A rod mark is to be used whenever possible where sound bedrock and substantially stable structures are not available. The top of a steel rod serves as the datum point. The rod itself anchors the datum point to a stable stratum of soil. In most areas a sleeve is required to isolate the rod from soil movements occurring above the stable stratum.[5] (See fig. 4.) This sleeve is omitted where no soil movements are expected. At the surface an encasement around the datum point provides protection from impact and information to the user. (See fig. 5.)

The rod is assembled from sections of 1.43-centimeter (9/16-inch) type 316 stainless steel[6] coupled with threaded studs of the same material. The sleeve is made from 2.54-centimeter (1-inch) schedule 40 polyvinyl chloride (PVC) pipe with fittings to couple the sections. The annular space between the rod and sleeve must be filled to prevent water from infiltrating it. If water is allowed to seep into this space, two problems will arise: corrosion will occur; and when the water freezes, stresses between the sleeve and soil will be transmitted to the rod. The substance used as the filler should be a grease or grease-like product with a consistency that will remain soft at cold temperatures. It must be insoluble in water, noncorrosive to the rod and sleeve, and must have an extremely long life expectancy.

The casement consists of a 12.7-centimeter (5-inch) PVC pipe, 1/2-meter long, fitted with an aluminum flange around its top edge. The flange is imprinted with the standard information that accompanies all bench mark monuments and is stamped with the station's designation and year. Its inside edge is recessed to accommodate a hinged aluminum cover. This arrangement is placed around the top of the rod, slightly below ground level. Approximately 20 liters (2/3 cubic foot) of concrete is then poured around it to hold it firmly in place and to aid in recovery of the monument if it becomes buried.

This type of monument has been designed to prevent near-surface soil movements from changing the bench mark elevation. The two major kinds of movements it can counteract are frost heave, and shrinking and swelling of expansive soils. Averting these movements is accomplished by extending the sleeve to the maximum depth to which these soil movements are expected to occur. Then the rod assembly, after being placed inside the sleeve, is driven or pressed into the soil so that it is anchored below the sleeve, and consequently, below the layer of disturbance.

When frost heave can occur, the sleeve is placed to a depth three times as great as the maximum frost penetration indicated in figure 13 (page 34). When any type of upright, such as a post, pile, or pipe, is subject to frost action, the upward motion caused by frost heave is normally greater than the subsequent settlement after the ground has thawed. Unless there is an opposing force, the object will eventually be ejected from the ground. A sleeve placed to three times the depth of frost will have, in nearly all instances, enough friction between it and the soil below the frozen layer to resist the upward force of frost heave. In any case, the jacking effect of frost action will be retarded.

Consolidation of a soil mass can be counteracted with this bench mark when it is placed to a sufficient depth. As long as the sleeve isolates the rod from the soil where consolidation (or rebound) can have an effect, movement from this cause will not change the bench mark's elevation. To be used effectively in this manner, a geologist or soils expert must determine where these movements occur.

It is suggested that one of two methods be used to place the 2.54-centimeter (1-inch) PVC sleeve, though other methods might also prove effective. (1) Where the soil is self-supporting, the cleanest and quickest method is to use a small diameter, conventional flight auger. Briefly, a hole is drilled to the specified depth of the sleeve, the string of augers used in drilling the hole is retracted, and the sleeve is lowered into the hole. (2) Where the soil is subject to caving, as in a loose dry sand, or in working below the water table, a hollow-stem auger can be used. The auger is drilled to the specified depth, the bench mark sleeve is lowered into place through the auger, and the auger is retracted, leaving the sleeve in place.

When it is unknown whether or not a hole will support itself, use the conventional flight auger. If the hole caves before the bench mark sleeve can be lowered into it, start over using a hollow stem auger. Once some experience is gained in a particular region, the mark setter will intuitively know whether a conventional auger will likely suffice or if efficiency would be lost in this trial-and-error method.

A suggested routine using the conventional flight auger is given next. Some of the steps need not necessarily be taken in the prescribed order. Experience will dictate the most efficient manner for a particular crew. One crew's method is pictorially illustrated in figure 6 (pages 20-24).

WARNING: Precautions must be taken before drilling into the ground. Underground pipes and cables can be damaged and can also cause damage to drilling equipment. Conceivably, injury or death could result from drilling into an electrical cable or gas line. (See "Safety," page 12.)

[5] **Although it is somewhat detrimental from a corrosion standpoint, the sleeve is normally essential for stability.**

[6] **This alloy has the optimum combination of iron, nickel, and chromium to combat corrosion in both weight loss and pit depth, and yet remains economical.**

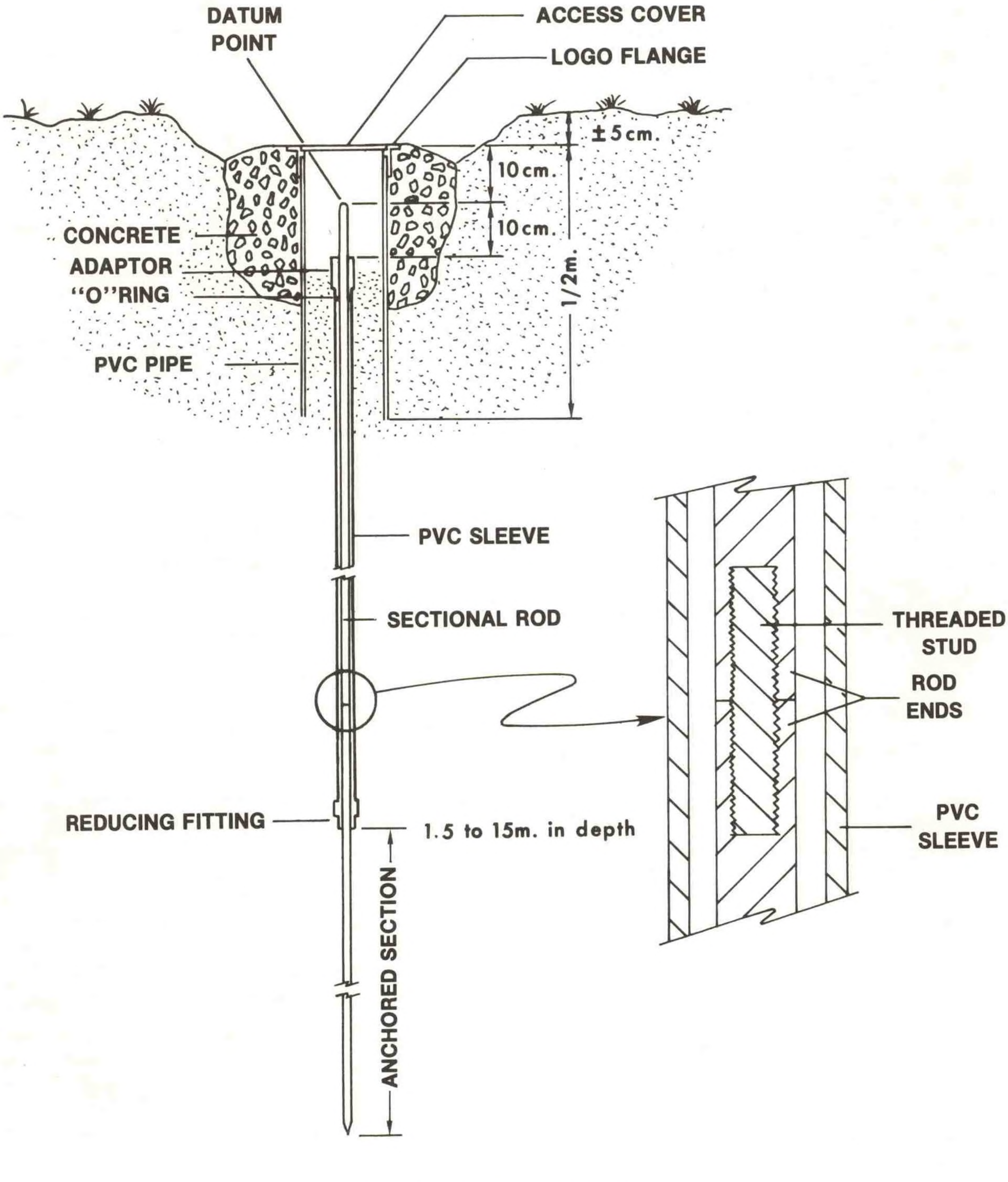


Figure 4.—Sleeved class A rod mark.

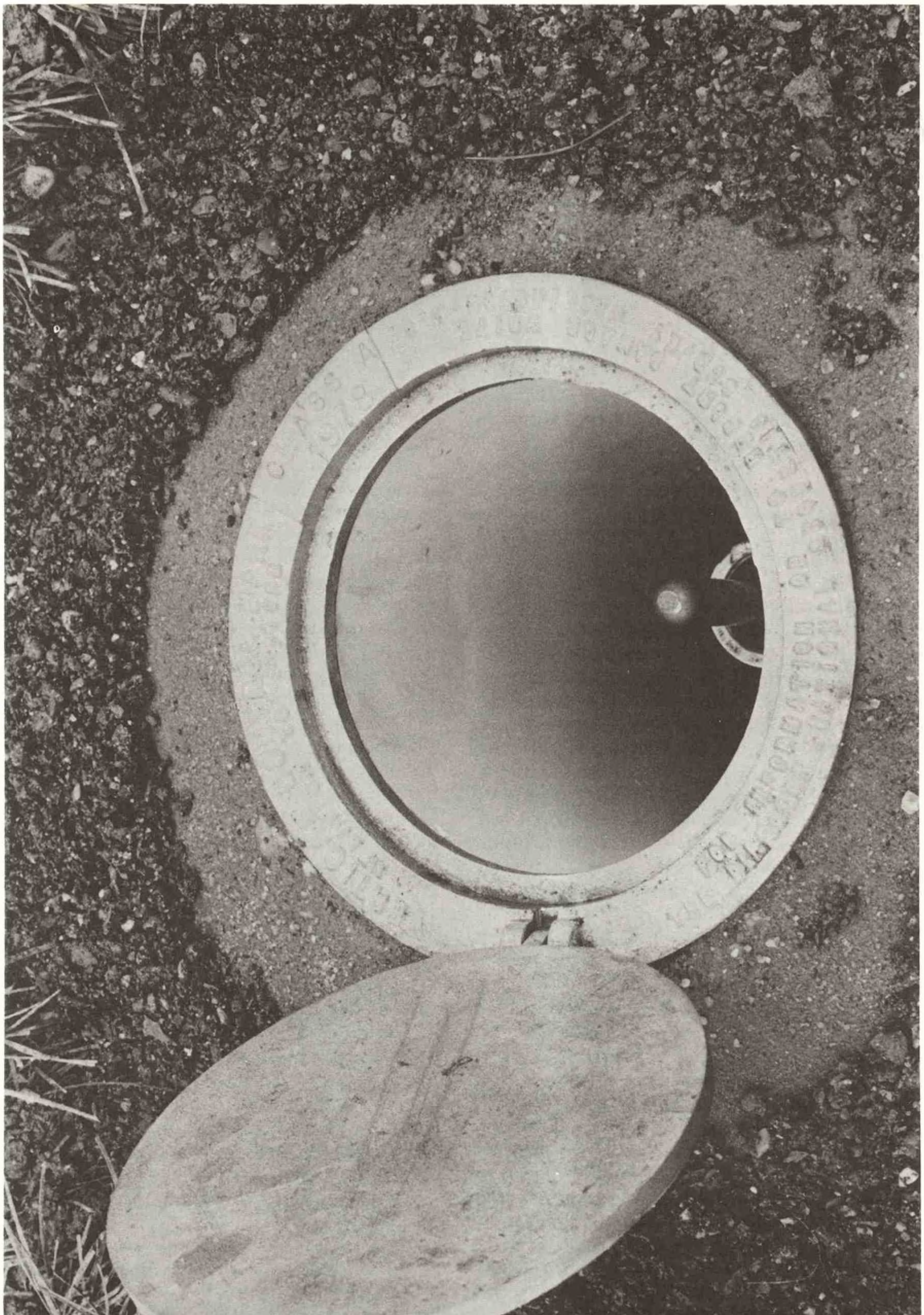


Figure 5.—Class A rod mark showing logo flange and hinged access cover.

1. Maneuver the drill into position with the rotary head situated over the spot where the monument is to be placed. When the site is on an incline, the vehicle should be facing uphill.
2. Level the vehicle with the stabilizing jacks. A carpenter's level can be placed vertically against the drill head mast to make sure it is plumb both transversely and longitudinally.
3. Where neat landscaping must be preserved, place a 2-meter square tarpaulin on the ground and drill through a 1/2-meter hole cut in its center.
4. Bore a hole 30 centimeters in diameter to a depth slightly more than 1/2 meter for the protective flanged encasement. This hole will be filled with soil during subsequent operations, but the objective is to loosen the soil in preparation for setting the encasement.
5. Connect an appropriate bit to the first section of a small diameter conventional flight auger and begin drilling a hole to the required sleeve depth. Depths for sleeves set within the continental United States are specified in table 2 (page 27). Use figures 7 through 13 in conjunction with this table to determine the depth. Use the deepest depth indicated when a variety of conditions exists. In regions outside the conterminous States, the sleeve shall be placed to a depth of 10 meters. Examples for determining the depths are given in appendix E.
6. When the required depth is reached, pull the augers straight up with no rotation to keep the hole clean. Before removing the last section of auger, clean the loose soil out and away from the hole bored in step 4. After all the flights have been retrieved, move the rotary drill head off the axis of the hole to provide clearance for the next steps.
7. Attach appropriate fittings to one end of a 2.54-centimeter (1-inch) PVC pipe to reduce the inside diameter to 1.59 or 1.90 centimeters (5/8 or 3/4 inch). Lower the pipe into the hole with the reduced end down, then connect and lower more sections of pipe as required. The last section to be assembled must be cut to length so that when the bottom of the hole is reached, the top of the sleeve will be about 25 centimeters below the surface of the ground. Finally, glue a female slip-to-thread adaptor to the top of the sleeve. This will be used to make connections to a grease pump for filling the annular space with lubricant.
8. Assemble the 1.43-centimeter (9/16-inch) stainless steel rod and lower it into the sleeve. If a long, unwieldy length is required, the rod may be coupled while it is being lowered into the sleeve. To obtain tight joints, finger tighten them and then apply one-quarter turn more.
9. When the rod assembly rests in the bottom of the hole, it must be pressed or driven into the soil beneath the sleeve. Alternately couple and drive more sections of rod until it resists a downward static force of 250 kilograms,[7] but make sure at least 1 meter of rod extends below the sleeve. In clay, driving may be terminated if the 250 kilograms of resistance are not met after 10 meters of rod have been driven.

   Care must be taken not to deform the end of the rod being driven, or coupling of the next section will be difficult. In the event refusal is met before the minimum of 1 meter is driven, the rod and sleeve must be pulled up, and the hole must be drilled to the depth at which the rod will ultimately be placed (1 meter below the sleeve). New soil, soil mixed with cement, or concrete must then be compacted in the bottom of the hole to provide a good anchoring material for the rod. In cases where soil mixed with cement or concrete is used, extreme care must be taken to prevent the sleeve from becoming embedded in the anchoring material, or movement of the sleeve will be transmitted to the rod. One way to do this would be to dump a layer of the original soil over the anchoring material to provide a buffer between it and the bottom of the sleeve. If a large obstruction makes it impossible to drill to the required depth, the anchoring material must be compacted in the bottom of the hole to a depth 1 meter above the obstruction. Adjust the sleeve length accordingly and take precautions to isolate it from the anchoring material.
10. Provide the top of the rod with a suitable high point on which a leveling rod can be supported. This may be done in one of three ways. (1) When the depth to which the rod will be driven is known in advance, use a prerounded top section for the last length of rod to be coupled. (2) Cut off the rod when the proper depth is reached and round the top with a file. Or (3) crimp a type 316 stainless steel cap with a hemispherical end onto the top of it.
11. Pump the filler into the annular space between the rod and sleeve, making sure no voids are

---

[7] The 250-kilogram resistive force can be determined indirectly by relating dynamic resistance to driving rate. Ignoring energy losses, the work done in driving the rod equals the energy output of the driving equipment. For a drop hammer, the *R*esistance offered by the soil times the *s*et (penetration per blow) equals the *W*eight of the hammer times the *H*eight from which it was dropped (Rs = WH). For a gasoline powered impact hammer, the *R*esistance times the *s*et equals the effective *E*nergy output of the impact hammer (Rs = E). Since the ultimate bearing capacity under static load is usually many times the driving resistance, this relationship will yield conservative results if R is set to 250 kilograms.

left. Approximately 1/3 liter (0.1 gallon) of filler is needed for each meter of sleeve. During this operation, the sleeve may have to be lifted slightly to allow air to escape from its bottom. When the entire space is filled, place a 1.43-centimeter (9/16-inch) ID (inside diameter) × 2.54-centimeter (1 inch) OD (outside diameter) "O" ring or rubber bushing around the rod inside the top of the sleeve just below the adaptor. This will serve to steady the rod for the process of differential leveling. It will also stabilize the rod horizontally in the event the mark is someday used also for horizontal control.

12. Backfill the hole around the bench mark sleeve with soil. Much of the soil brought to the surface during the drilling of the hole can be disposed of in this manner. Make sure the sleeve gets firmly impacted in the hole in case the monument is eventually used also for horizontal control. In areas subject to frost heave, it is desirable to use a clean sand in the upper end of the hole to the depth of maximum frost penetration.
13. Clean the soil out of the 30-centimeter hole around the bench mark sleeve to a depth of about 30 centimeters. Place a 1/2-meter length of 12.7-centimeter (5-inch) PVC pipe around the rod and sleeve so that they are centrally located within it. Press or drive the pipe down until its top edge is about 5 centimeters below the surface of the ground and 10 centimeters above the top of the rod. Fill the protective pipe around the sleeve with soil until about 2 to 4 centimeters of the sleeve and 10 centimeters of the rod are exposed.
14. Stamp the bench mark designation and year in the area provided on the aluminum flange supplied for the top of the protective PVC pipe. Then fit the flange and cover over the pipe.
15. Mix about 20 liters of concrete, the approximate amount produced by the commercially available 36-kilogram (80-pound) bag of premixed concrete. Pour the concrete around the pipe and flange and tamp it into place. Finish the surface of the concrete so that it is flush with the top surface of the flange and it slopes gently away from it. This is important because no exposed edges will be left to facilitate removal of the flange, and water will drain away from the access cover rather than into it. Remove excess concrete from the flange and be sure the imprinted information is not defiled with concrete.
16. Set a witness post when appropriate.
17. Before leaving the area, clean it up. Scatter or otherwise dispose of any leftover soil from the drilled holes. Pick up trash which has accumulated during the installation. Finally, set a temporary covering over the wet concrete to shelter it until it cures.

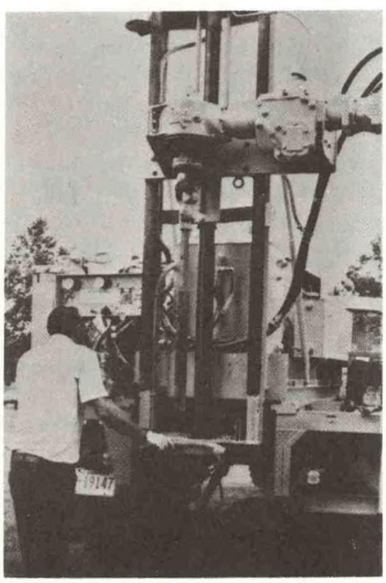
The procedure for placing a sleeved bench mark using hollow-stem augers is nearly the same, with the following exceptions:

1. After boring the 30-centimeter hole for the encasement, attach an appropriate cutterhead to the first section of a small diameter, hollow-stem auger. At the time of this writing, the smallest known available size has a 5.7-centimeter (2-1/4-inch) ID and a 12.7-centimeter (5-inch) OD. Fit the cutterhead with a disposable knockout plug. Plastic is preferred to a wood plug which could swell when used in a wet environment, making its removal difficult. Never use a metal plug unless it is type 316 stainless steel. Contact of dissimilar metals in the completed installation must be avoided.
2. Drill to the required sleeve depth in such a manner as to bring as little soil to the surface as possible. This is accomplished by combining proper speeds of rotation and feed to obtain a screwing effect rather than a boring effect, and by halting rotation immediately after the drill head has reached the bottom of the feed stroke.
3. Retract the string of augers about 1/4 meter and secure them with an auger fork. Disconnect the augers from the rotary drill head and move the head off the axis of the hole to provide clearance for lowering the sleeve.
4. Assemble and lower the 2.54-centimeter (1-inch) PVC sleeve into the hollow stem of the auger string. To knock out the disposable plug in the cutterhead, lift the assembled sleeve about 2 or 3 meters and let it drop. When working below the water table, cohesionless soils at the bottom of the hole can sometimes be washed up inside the hollow stem by pressure of water outside the augers. To prevent this, fill the inside of the auger with water to at least the height of the water table before the plug is knocked out.
5. Retract the string of augers by reversing the rotation of the drill head and lifting it with the pullout mechanism. With the appropriate combination of rotation and pullout speeds, excess soil that was brought to the surface can sometimes be returned and compacted around the bench mark sleeve.
6. Assemble and lower the stainless steel rod as before and complete the remaining steps as listed in the procedure for using the conventional flight auger.

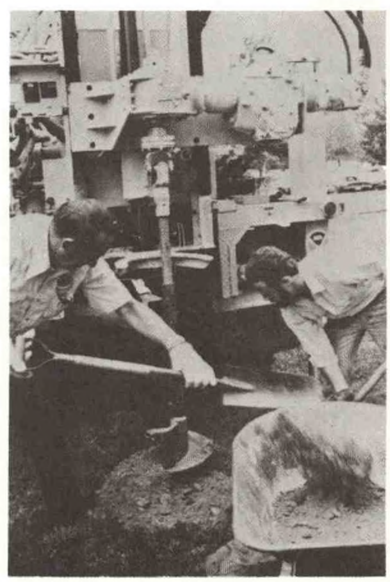
In some situations, unexposed bedrock will be encountered before the required bench mark sleeve

(1) Drill rig maneuvered into position and leveled.

(2) Digging through the sod.

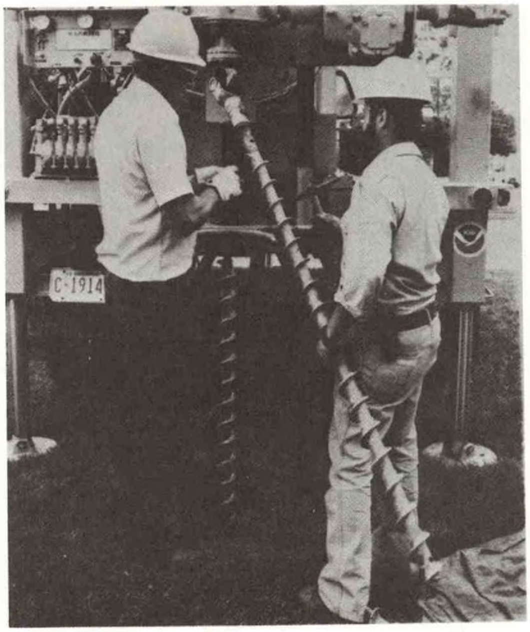


(3) Preparing to attach a large auger.



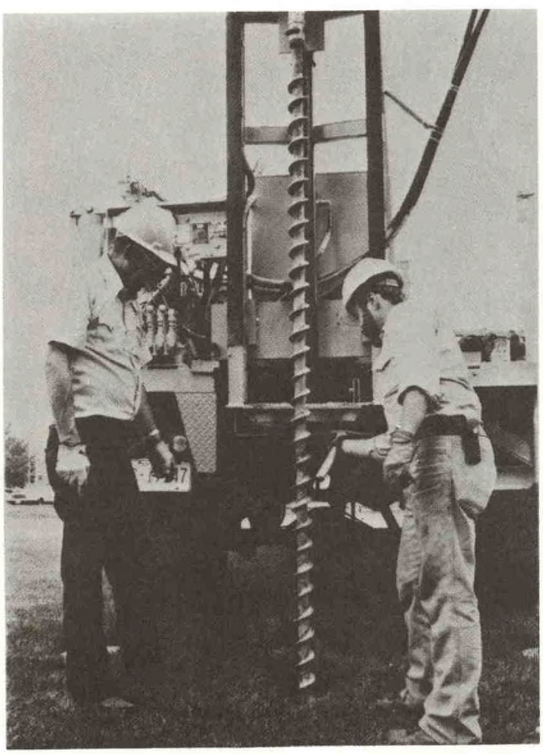
(4) Boring a hole for the protective casement.

Figure 6.—Setting a sleeved class A rod mark.

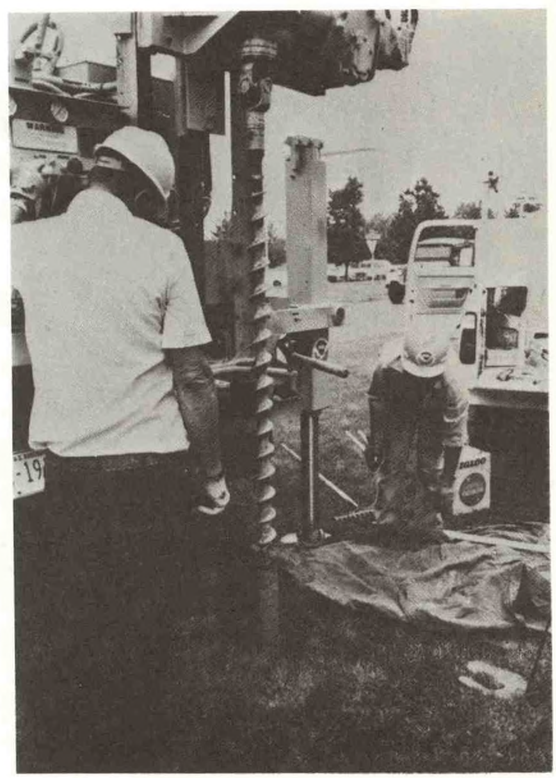


5 **Attaching a length of conventional flight auger.**

6 **Drilling a hole for the sleeve.**



7 **Retracting the flight augers.**

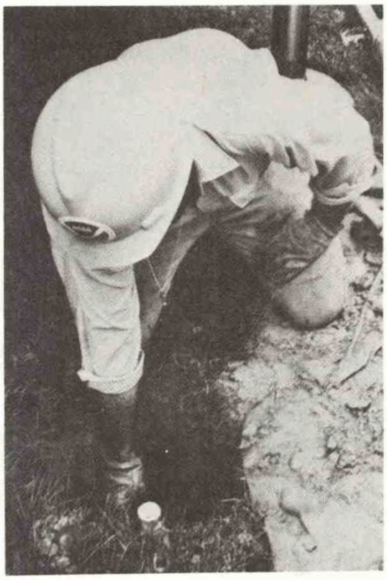


8 **Retracting the lower sections of flight auger.**

Figure 6.—Continued.

9

Pumping filler into the sleeve.



10

Sleeve lowered into the hole.

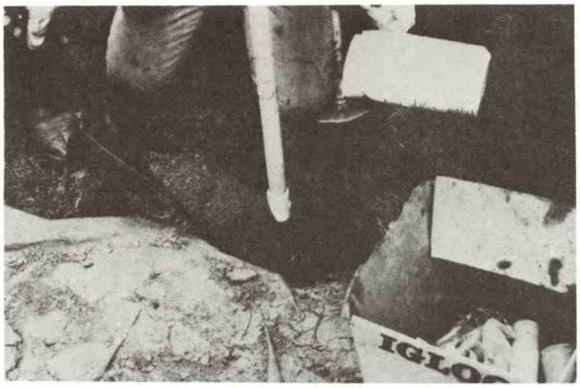
11

Lowering the rod into the sleeve.

12

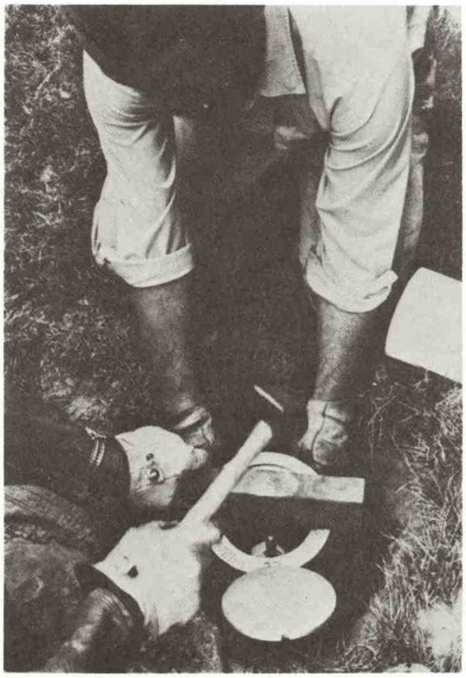
Driving the rod into soil beneath the sleeve.

Figure 6.—Continued.



(13) Filling soil in hole around the sleeve. (Sleeve temporarily extended to keep dirt out.)

(14) Sleeve and rod in place.



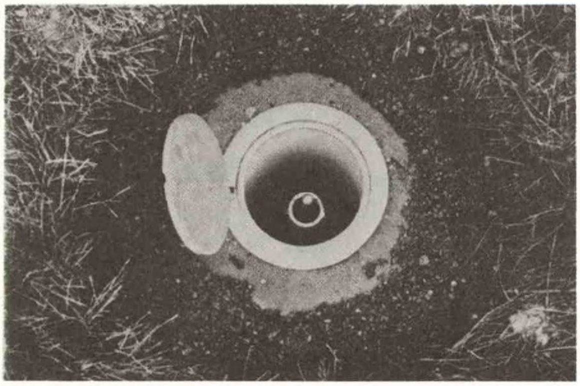
(15) Driving the protective pipe into place.

(16) Filling soil inside the protective pipe.

Figure 6.—Continued.

(17) Preparing the hole for concrete.

(18) Working concrete around the protective pipe and logo flange.



(19) The completed bench mark.

(20) Writing the description.

Figure 6.—Continued.

depth is reached. If drilling is halted by an underground obstruction, note the depth of the obstacle, move the equipment a few meters, and try drilling again with a conventional flight auger. If the obstruction is once again encountered at roughly the same depth, it is likely to be bedrock. The class A rod mark can be set to a depth less than normally required if one of the holes is 4 meters or more in depth. If both holes are less than 4 meters, another try must be made or another site located.

Once it has been established that there is probable bedrock at a depth of 4 meters or more, a rod type bench mark can be set. Where the soil is self-supporting and the desired hole stays open, backfill it with concrete or soil for 1 meter above the bedrock. If the hole has caved, redrill it with a hollow-stem auger to a depth 1 meter above the bedrock. Place the sleeve into the hole as usual making sure it does not become fixed to the concrete in the bottom, if used. Before placing the rod, cut its bottom section off so that when pressed or driven to the bedrock, its upper end will be about 15 centimeters below ground level. The remaining steps are identical to those for placing the usual sleeved rod mark. (See pages 18-19.)

To anchor the rod into the underground bedrock would be desirable but not absolutely necessary. Total vertical motion at any particular depth results from the accumulation of incremental changes below it. Accumulation begins at the level where movement is nonexistent and the surface of bedrock delineates the level where no soil movement occurs. Since the rod will be exposed to the soil for only 1 meter above that depth, only the activity accumulated over a 1-meter depth starting from zero movement will be transmitted to the rod. This amount is negligible.

Where the soil is nonexpansive and the maximum depth of frost penetration is less than 1/2 meter as determined in figures 7 through 13, no sleeve is required for the class A rod mark. The setting procedure is simple.

1. Maneuver the drill rig into position and level it.
2. Bore a hole 30 centimeters in diameter to a depth slightly greater than 1/2 meter to accommodate the protective flanged encasement.
3. Press or drive the rod to its required 4-meter depth. In areas where this is made difficult due to the existence of hard clay, scattered stones or cobbles, or frost, a hole can be drilled to a depth of 3 meters, *maximum*. The rod can be placed in the hole and pressed or driven another meter so its top is about 15 centimeters below ground level. Then the hole is backfilled.
4. Fabricate the protective encasement, set a witness post, and clean up as with installing the sleeved class A bench mark.

This mark can also be set with an ordinary post hole digger and gasoline powered hammer. First, the 30-centimeter hole is dug. Then the sectional rod is driven and connected, one length at a time. And finally, the protective casement is constructed and the remaining steps taken as indicated.

Class B Rod Mark

To perpetuate the National Vertical Control Network with monuments of only the most stable nature would be ideal, but other factors make this impossible. Situations will be encountered where bedrock or other stable settings are not at hand, and where the soil is unstable but the equipment required to set the sleeved rod mark is unavailable. Among others, mark maintenance personnel, who relocate monuments which are destined for destruction, and those who set tidal bench marks for the Office of Marine Surveys and Maps, National Ocean Survey, need an alternative to the sleeved class A rod mark.

The class B mark consists of a stainless steel rod assembly driven to a depth based on soil and weather conditions, and capped with the standard bench mark disk. It has no sleeve. A casement at the surface protects the monument from damage by impact. This casement differs from the flanged encasement for the class A rod mark in that a PVC clean-out plug is used in place of the logo flange and access cover. The bench mark disk carries the logo and designation. Except where soil movements are nonexistent, these marks cannot be expected to hold their elevations as well as the class A rod marks. The procedure for setting a class B rod mark is as follows:

1. Dig a 30-centimeter hole to a depth slightly greater than 1/2-meter for the protective casement.
2. Taking care not to deform its end, drive the first section of 1.43-centimeter (9/16-inch) stainless steel rod down to just above ground level. Make sure it remains plumb while driving. Couple another section of rod tightly to the first and drive the assembly down as before. To obtain tight joints, finger tighten them and then apply one-quarter turn more. Repeat this procedure until the required depth is reached as indicated in table 3 (page 27). When a variety of conditions occur, use the deepest depth specified. In clay, however, the depth may be limited to 10 meters. Drive the last section down to about 10 centimeters below ground level. Every effort must be made to reach the minimum depth specified. If firm resistance is met before the required rod depth is nearly approached, discontinue driving before the rod becomes tightly embedded in the resistant layer. Using a pipe wrench to rotate the rod

clockwise while simultaneously pulling up on it, try to pull it out so the installation can be attempted in another spot. When firm resistance is met at nearly the required rod depth, continued driving will probably result in reaching that depth. Drive with determination; as long as the rod keeps going down, no matter how slowly, keep at it. If the required depth is not reached after exhaustive efforts, cut the rod off about 10 centimeters below ground level and use as is.

3. Stamp the designation and year on the bench mark disk and crimp the hollow shank on the disk onto the top of the rod.
4. Place a 10.2- or 12.7-centimeter (4- or 5-inch) PVC pipe 1/2 meter in length around the disk and rod. Press or drive the pipe down until its top edge is about 5 centimeters below ground and 5 centimeters above the disk. Fit the top of the pipe with the proper size slip plug or threaded plug with appropriate female adaptor.
5. Mix about 20 liters of concrete to place around the top of the protective pipe. Twenty liters is the approximate amount produced by the commercially available 36-kilogram (80-pound) bag of premixed concrete. Pour concrete around the pipe and tamp it into place. Finish the top surface of the concrete so that it slopes gently downward and away from the top of the pipe. This is important because it will help drain water away from the protective pipe rather than into it.
6. Set a witness post when appropriate.
7. Before leaving the area, clean up any trash that accumulated during the installation. Finally, set a temporary covering over the whole arrangement to protect it until the concrete cures.

Miscellaneous Marks

Occasionally, a natural or readymade bench mark setting will exist that would be more stable than a rod mark but which cannot accommodate a brass disk. An example is a deep well casing. It would resist not only near-surface movements, but also, to a degree, movements originating in the subsurface such as subsidence from pumping. A good illustration of this can be seen in Santa Clara Valley, Calif., where well casings project prominently because of ground subsidence. These settings should not be passed by simply because disks cannot be mounted on them. They can furnish excellent references for elevations, *provided* they extend at least three times as deep as the required sleeve depth for a class A rod mark in that area.

It is important to select a good point of reference for the elevation of this type of bench mark. A prominent protrusion can be used if it is definite and has a good high point on which to rest the leveling rod. Alternatively, a cross can be etched with deep fine lines on a spot accessible to a leveling rod or tape. If possible, stamp or etch the bench mark designation and year nearby.

Table 2.—Sleeve depth for class A rod mark set within the continental United States

Condition	Extent of occurrence	Depth
Soil volume change[a]	nonexpansive	no sleeve required[b]
	low expansive character	6 meters × CF[c]
	medium or high expansive character	10 meters × CF[c]
Active frost penetration[d]	maximum 0.5 meter or less	no sleeve required[b]
	maximum greater than 0.5 meter	3 × max frost penetration
Permafrost[e]	any extent	10 meters

[a] Categories of expansiveness are shown on the maps in figures 7 through 11. Inability to accurately delineate category boundaries necessitates assumption of the greater expansive character when working near a boundary. A consolidated map of these figures, at a larger scale, in color, is available by writing to the USAE Waterways Experiment Station, P.O. Box 631, Attn: GEO, Vicksburg, MS 39180. It is entitled Occurrence and Distribution of Potentially Expansive Materials in the United States.

[b] Where no sleeve is required, the rod assembly shall be set to the depth at which a static load of 250 kilograms causes no movement (see footnote 7, page 18) but at least 4 meters.

[c] The Climate Factor (CF) is indicated on the map in figure 12. Use the larger value when there is doubt as to what value applies to a particular site.

[d] Depth of maximum frost penetration is indicated on the map in figure 13. Use the upper limit for each area delineated.

[e] For an excellent overview of permafrost areas, consult Ferrains (1965).

Table 3.—Minimum depth for class B rod mark[a]

Condition	Depth
Nonexpansive soils	4 meters
Soils of low expansive character	5 meters × CF
Medium or highly expansive soils	6 meters × CF
Low penetration resistance[b]	To substantial resistance[c]
Seasonal frost penetration	4 × maximum frost penetration[d]
Permafrost	2.5 × maximum depth of active frost layer

[a] Footnotes a, c, d, and e from table 2 also apply here.

[b] A static load of 250 kilograms will move the rod.

[c] Substantial resistance is indicated when a static load of 250 kilograms will not move the rod (see footnote 7, page 18).

[d] The minimum depth shall be 4 meters.

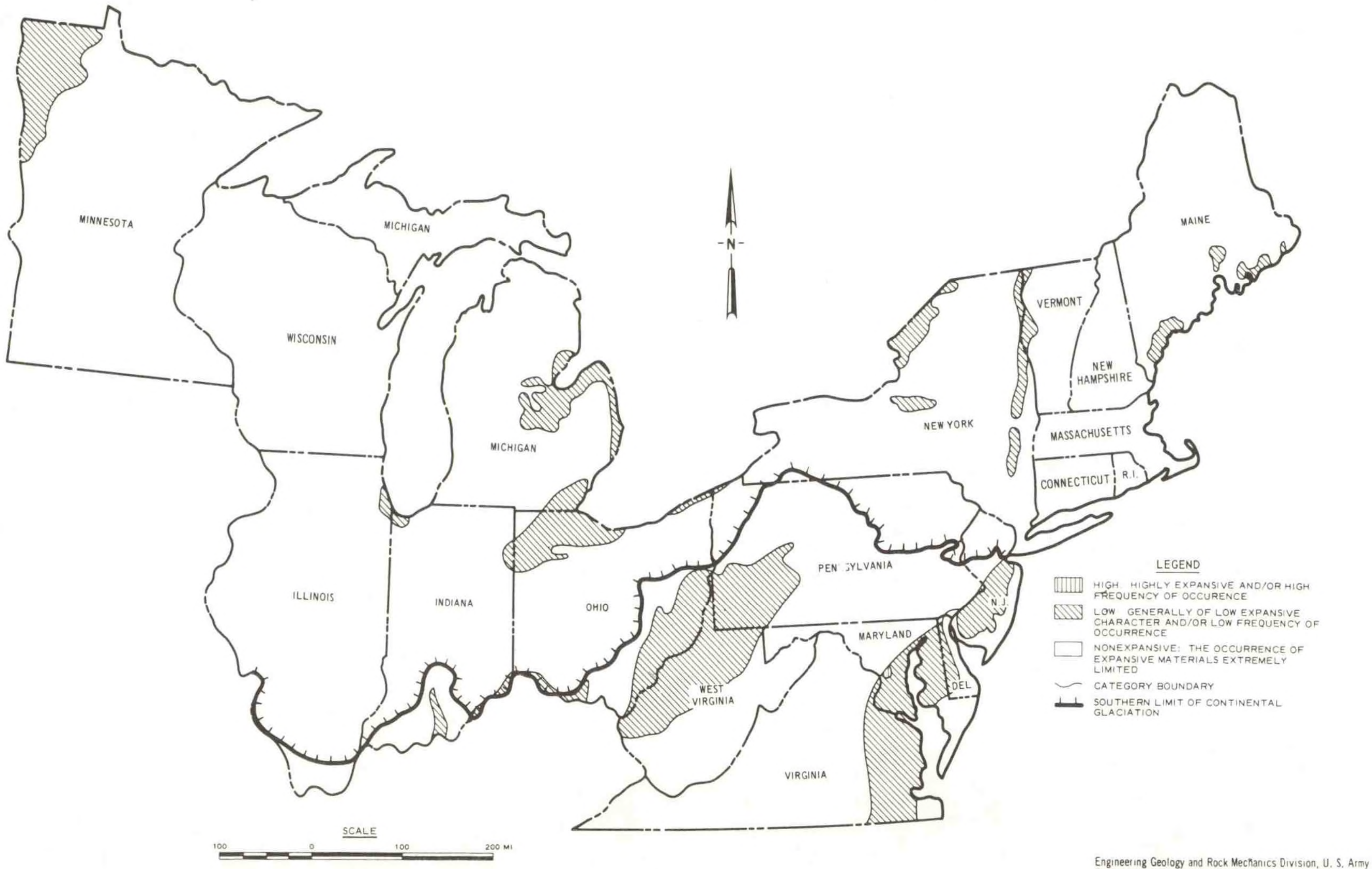


Figure 7.—Distribution of potentially expansive materials, Northeastern States.

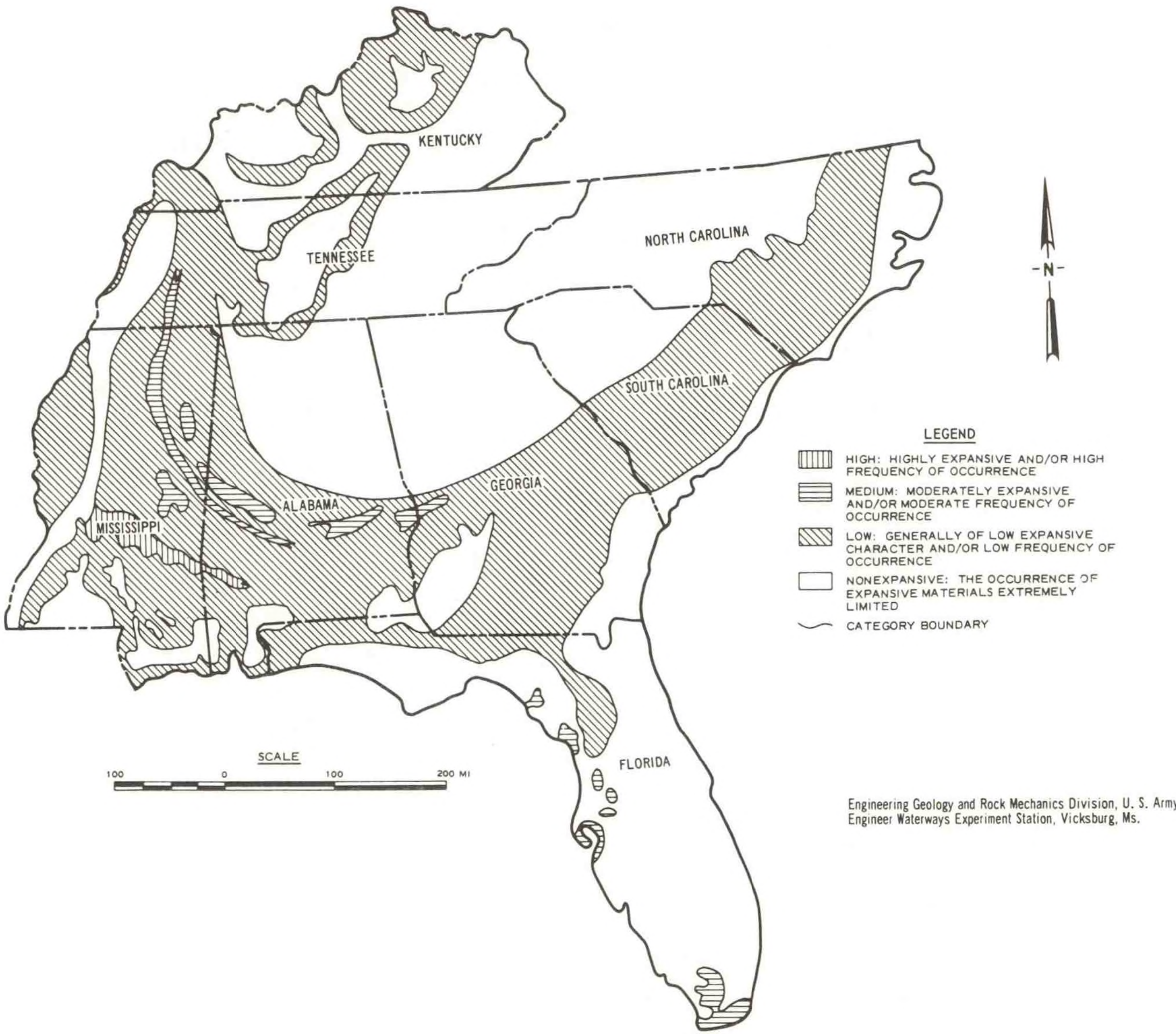


Figure 8.—Distribution of potentially expansive materials, Southeastern States.

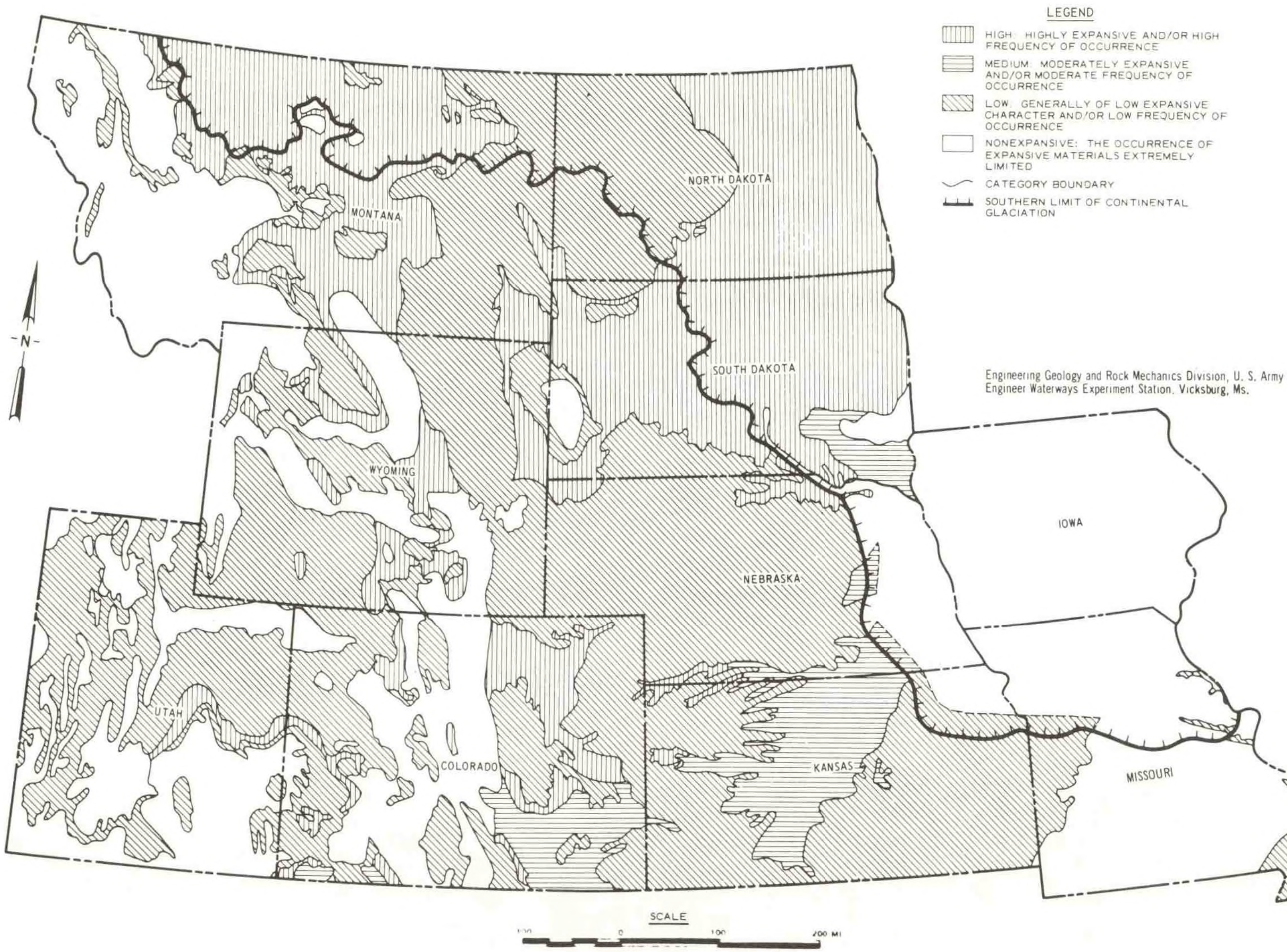


Figure 9.—Distribution of potentially expansive materials, North-Central States.

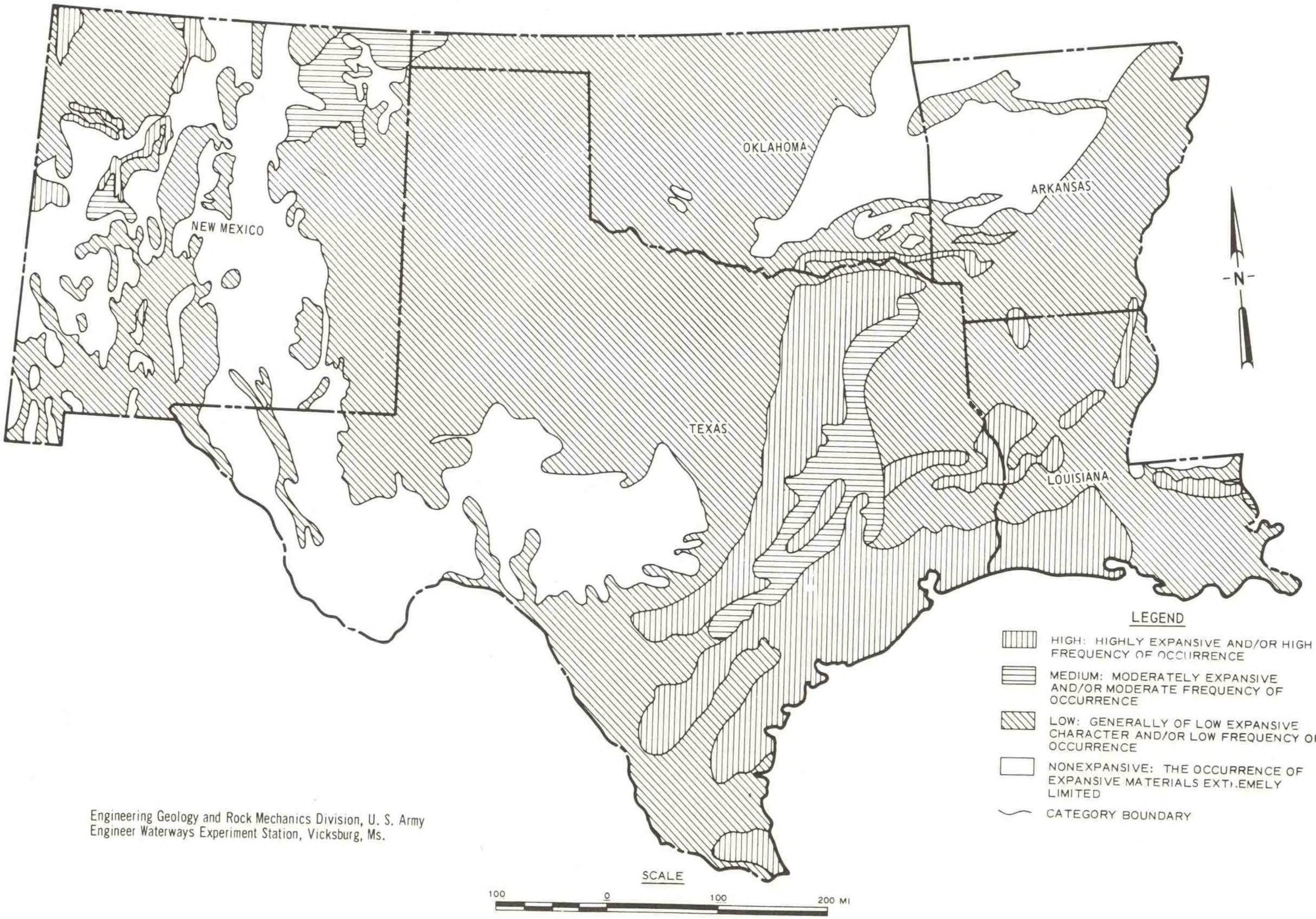
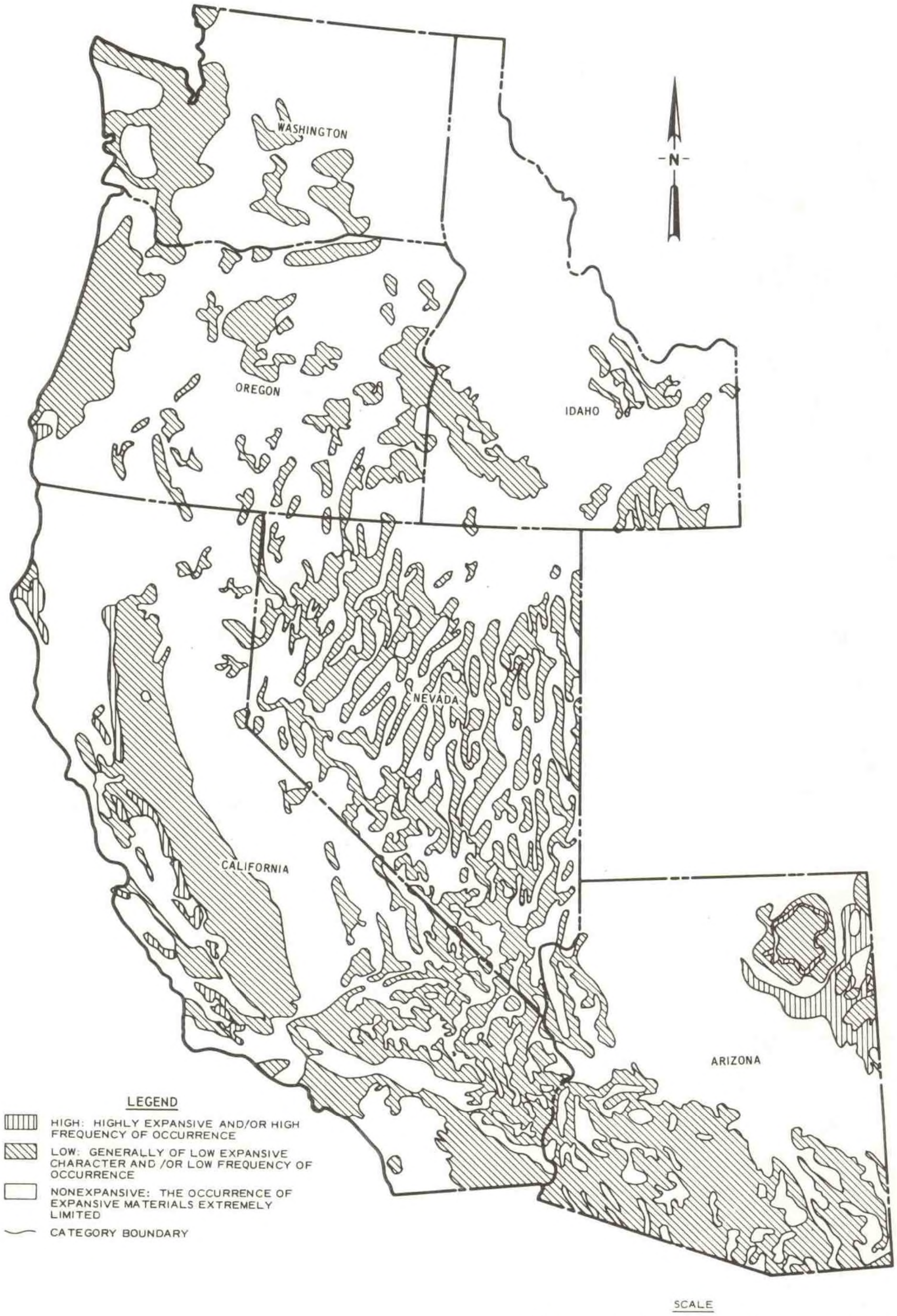


Figure 10.—Distribution of potentially expansive materials, South-Central States.



Engineering Geology and Rock Mechanics Division, U. S. Army
Engineer Waterways Experiment Station, Vicksburg, Ms.

Figure 11.—Distribution of potentially expansive materials, Western States.

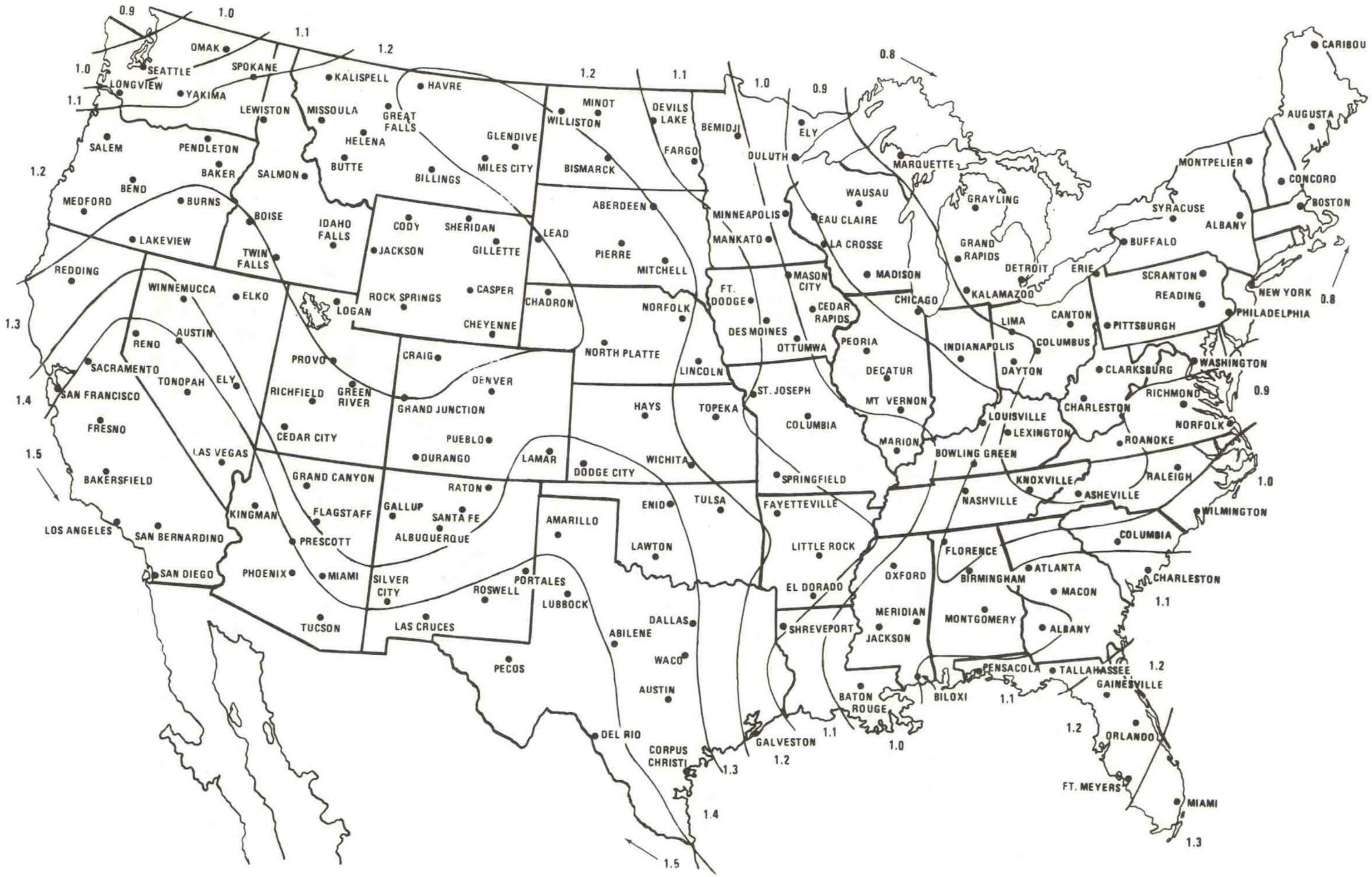


Figure 12.—Climate Factor (CF), adapted from Building Research Advisory Board (National Academy of Sciences 1968).

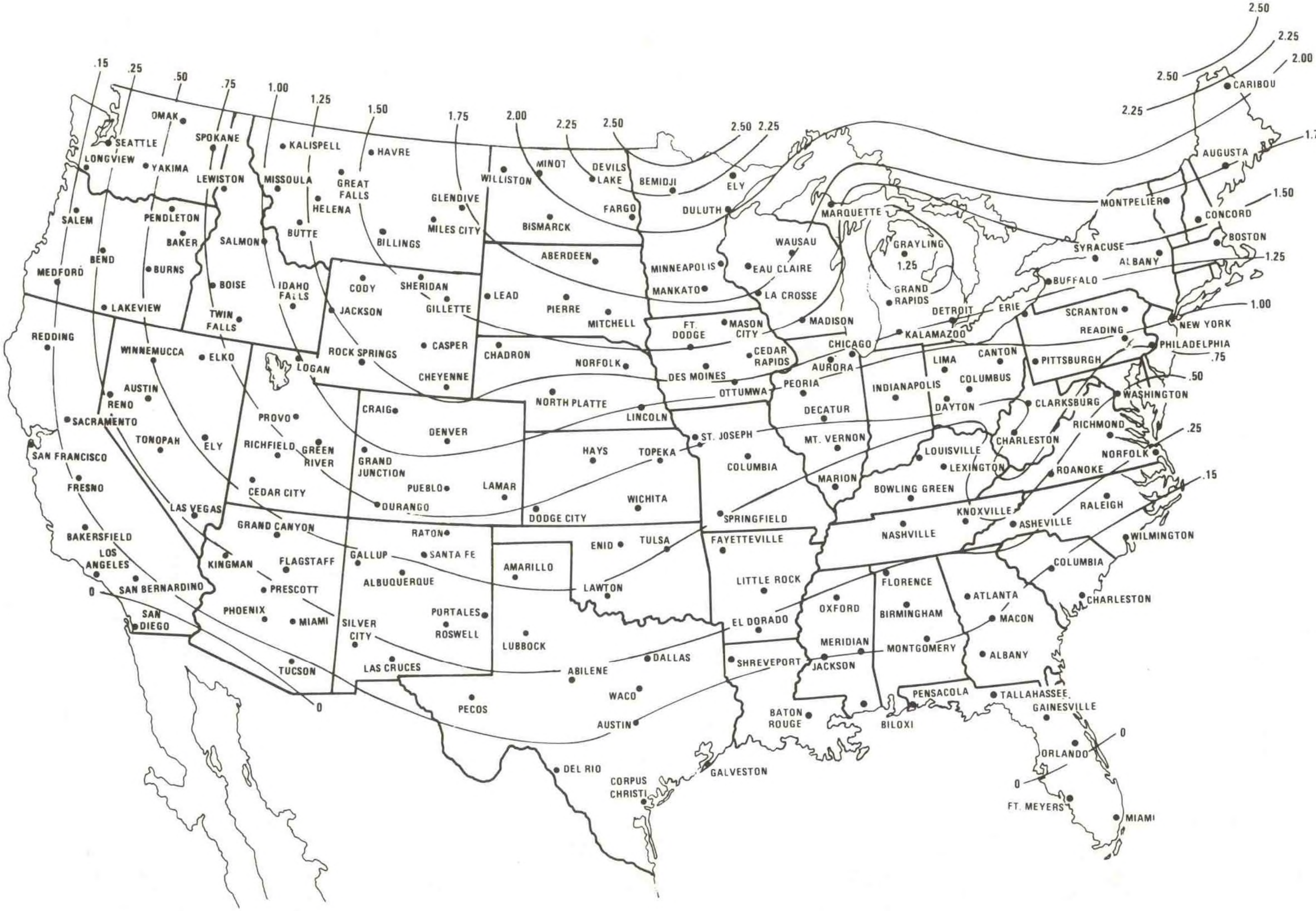


Figure 13.—Extreme depth of frost penetration (in meters).

5. DESCRIPTIONS

Descriptions are an important product of geodetic leveling because the utility of the vertical control network depends largely on how effectively they facilitate bench mark recovery. Consult the *NOAA Manual*, Geodetic leveling (Berry 1978), in preparation at the time of this writing, for detailed instructions on how to write descriptions. If this is not available, *Special Publication* No. 239, Manual of geodetic leveling (Rappleye 1948), also contains some valid information. General guidance for describing a monument is given here. In NGS, geodetic data, including descriptions, are stored, manipulated, retrieved, and sometimes disseminated by computer. Consequently, descriptions must be submitted in proper computer-readable form for inclusion with NGS vertical control data. Consult chapter 7 of *Input Formats and Specifications for the NGS Data Base* (NOAA 1977) for acceptable format.

The text of the description provides information needed to locate a bench mark. It must be clear and concise, first leading the reader to the general vicinity of the monument, then to the exact spot. Directions should start from a highway intersection or prominent landmark in the nearest city shown on an official state highway map.

Unless the bench mark is very near the starting point, distances are first given to the nearest tenth of a mile (or kilometer). The nearer the monument is approached, the more refined the measurements become, going from miles and tenths, to tenths of a mile, to feet and tenths (or kilometers and tenths, to tenths of a kilometer, to meters and tenths). As a rule, give distances in order of decreasing magnitude, but the final reference measurements should be made in the order which lends most conveniently to recovery. For example, if a monument is located 2.6 meters from the corner of a building and 5.4 meters from a fence, it should be stated in that order because the building would be spotted first. Distances must usually be accompanied by directions to 8 points of the compass (i.e., north, northeast, east. . .). Where confusion could result with only 8 points, 16 points of the compass may be used (i.e., east, east-southeast, southeast. . .).

Do not record numeric data with more significant digits than those with which they were obtained. The number 2.90 does not imply the same meaning as the number 2.9. The former refers to a value between 2.895 and 2.905, which is accurate to the nearest hundredth of a unit. The latter refers to a value between 2.85 and 2.95, accurate only to the nearest tenth.

All bench marks to be included in the national network must be referenced with consistent techniques, or misinterpretation of some descriptions will result. Distances between reference objects and monuments should nearly always be measured horizontally or mathematically reduced to a horizontal distance. In special circumstances where great convenience results, a sloped distance may be recorded in the description, but it *must* be labeled as such. Distances not labeled as "sloped" are always assumed to be horizontal. For an angle of 30°, the difference between a horizontal distance of 10 meters and its sloped counterpart is more than a meter. A discrepancy of this magnitude can result in considerable loss of time when searching for a buried monument, expecially if the lines-of-position intersect at a shallow angle as shown in figure 2 (page 8). Furthermore, a distance measured from a line, such as a fenceline or centerline, should always be measured perpendicularly to that line.

The origins of measurements must be clearly defined in all cases except the following two, where by convention they are inferred. (1) At the junction of two or more roads, the origin will be assumed to be the intersection of the centers of the roads unless specifically defined otherwise. "The intersection of U.S. Highway 29 and State Road 120" means the intersection of their centers. (2) Measurements are assumed to be from the center of objects such as utility poles. Where another position is desired for the starting point, it should be noted (e.g., "4.5 meters southeast of the southeast edge of telephone pole number 258").

Good descriptions are very important. Some bench marks are not recovered and used for many years after they are set. During this time heavy vegetation can grow up around the monument, making recovery difficult and time consuming. Objects used as reference points can be moved or destroyed. Good judgment and foresight are needed in referencing the mark and writing the description.

APPENDIX A.—APPROXIMATE CONVERSION TABLE: METRIC TO ENGLISH UNITS

1 millimeter	=	0.039 inch
1 centimeter	=	0.39 inch
1 decimeter	=	3.9 inches
1 meter	=	3.3 feet
1 kilometer	=	0.62 mile
1 liter	=	0.26 gallon
1 liter	=	0.035 cubic foot

APPENDIX B.—EXCERPT FROM U.S. LAKE SURVEY *MISCELLANEOUS PAPER* 68-6, THE USE OF GEOPOTENTIAL HEIGHTS FOR GREAT LAKES VERTICAL DATUM, BY CARL B. FELDSCHER AND RALPH MOORE BERRY, LAKE SURVEY DISTRICT, DEPARTMENT OF THE ARMY, U.S. CORPS OF ENGINEERS[8]

This discussion deals in general with a subject that the average civil engineer, without any geodetic orientation, would think of as "levels." This average engineer, having been exposed to the subject through a course in "basic surveying," is inescapably inclined to think of "levels" as the process of determining "elevations," in the context of a summation of vertical "height differences" above some arbitrary "horizontal" plane assumed as a datum.

If the purpose of "levels" is merely to provide reference for setting of pavement forms, or any other type of construction of moderately limited extent, this first intuitive concept is adequate; witness the fact that the average sewer undeniably manages to flow "down hill." But if the purpose of "levels" is to provide vertical control over a relatively large area, or of higher accuracy than that required in ordinary construction, additional considerations must be introduced.

The first additional consideration to be introduced is the well-known fact that the earth is not, in fact, a plane surface. Even the engineer with only a basic course in surveying is willing to concede this point. However, the nature of this surface involves some moderately subtle concepts that are not immediately apparent.

For example, many people are willing to accept a sphere as being a suitable geometrical figure of the earth. This, however, can lead to some patent absurdities if carelessly applied to the principles of levels. There is the case of the flow of the Mississippi River. Considering the 1535 kilometer section from the mouth of the Ohio River (Cairo, Illinois) to Head of Passes, Louisiana, engineer's levels indicate that the mid-stage elevation of the water surface drops approximately 91 meters. (See fig. 14, this manual.) This agrees with common sense but, to the unwary, is a bit difficult to reconcile with the fact that Head of Passes is 2643 meters farther from the *center of the earth* than the Mississippi River is at Cairo, Illinois. This could lead to the conclusion that the river is running *uphill* at a rate of 1.7 meters per kilometer, instead of downhill at a rate of 6 centimeters per kilometer. (The explanation of this absurdity lies in the fact that the meridional section of the earth is approximately elliptical.)

This can, of course, be countered by the engineer with the statement that he never meant for his levels to define the distance of a point from the center of the earth. When pressed for another definition, he will mutter something about height above "Mean Sea Level." This can, however, be an elusive concept unless carefully defined. There is not much difficulty with the definition at any single point on an unobstructed ocean shoreline. Here, we are told, mean sea level will be revealed as the average height of the water over the 19-year period that is required for the earth and moon to go through their entire cycle of combinations that produce the tides. This concept is simple in principle even though a bit difficult to implement. Even the generalization that Mean Sea Level must be the surface defined by a number of such points is not difficult until faced with the theoretical proposition of just what is meant by Mean Sea Level when it is used as a reference to define the "elevation" of a point far inland and high above the level of the ocean. (See fig. 15, this manual.) The usual explanation for this is that Mean Sea Level is the surface that would be generated if all the continents were criss-crossed with a number of narrow canals extending from ocean to ocean, admitting ocean water without causing any currents and without diminishing the quantity of water in the oceans.

Accepting this concept, the question immediately arises as to just what is the actual shape of this Mean Sea Level surface, and this leads back to the questions originally brought out. Isaac Newton in his *Principia*, first published in 1687, made substantial contributions to the theory of the attraction of gravity and concluded that the figure of the earth is that of an ellipsoid of revolution.

---

[8] **Presented at Army Science Conference, U.S. Military Academy, West Point, New York, June 1968. The U.S. Lake Survey was abolished in 1976. Some functions were transferred to the National Ocean Survey, NOAA.**

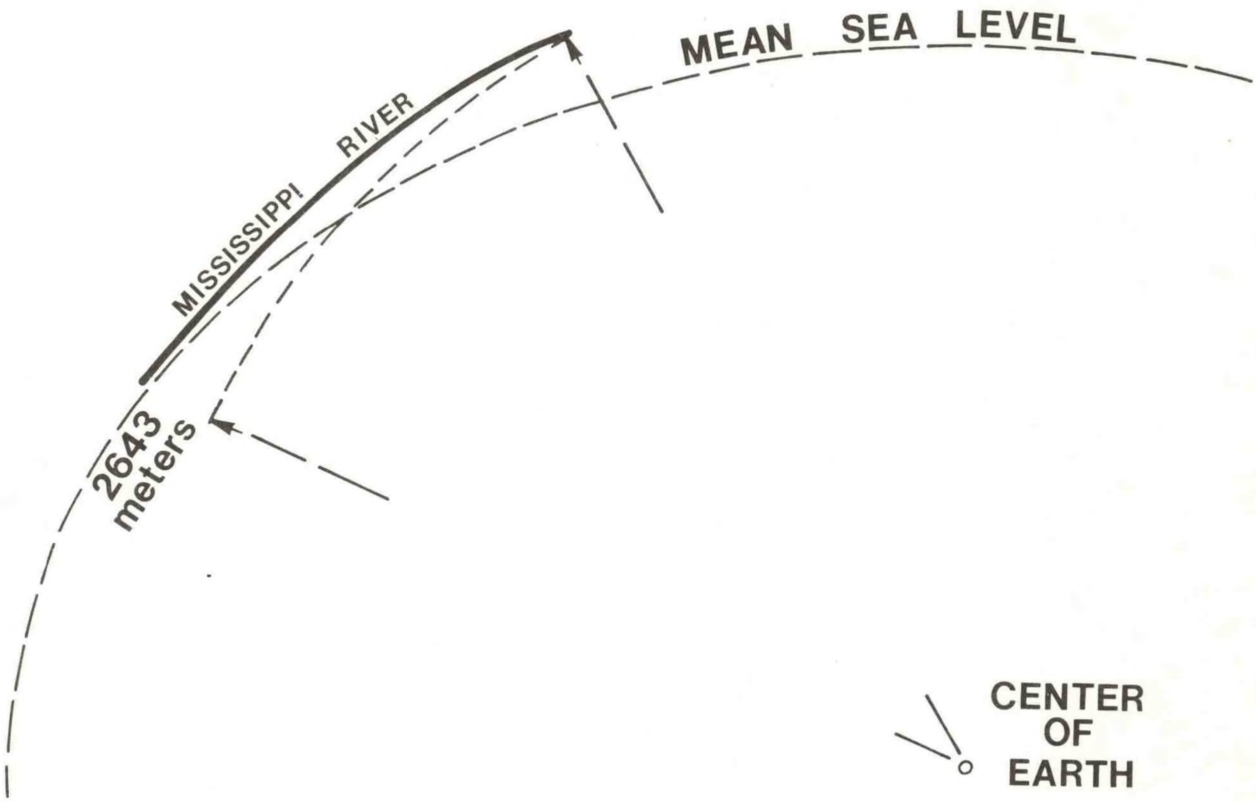


Figure 14.—Mississippi River flows uphill.

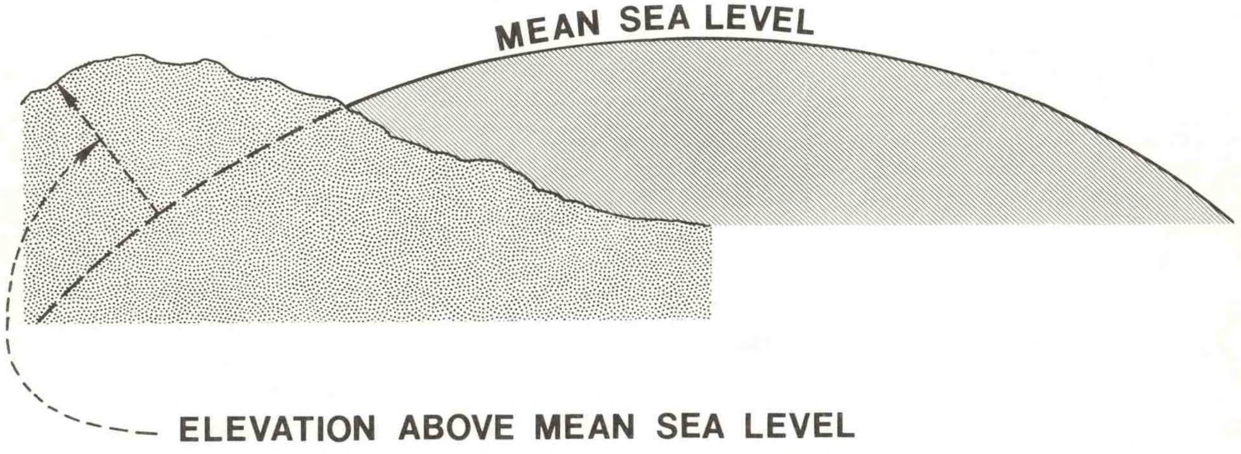


Figure 15.—Elevation.

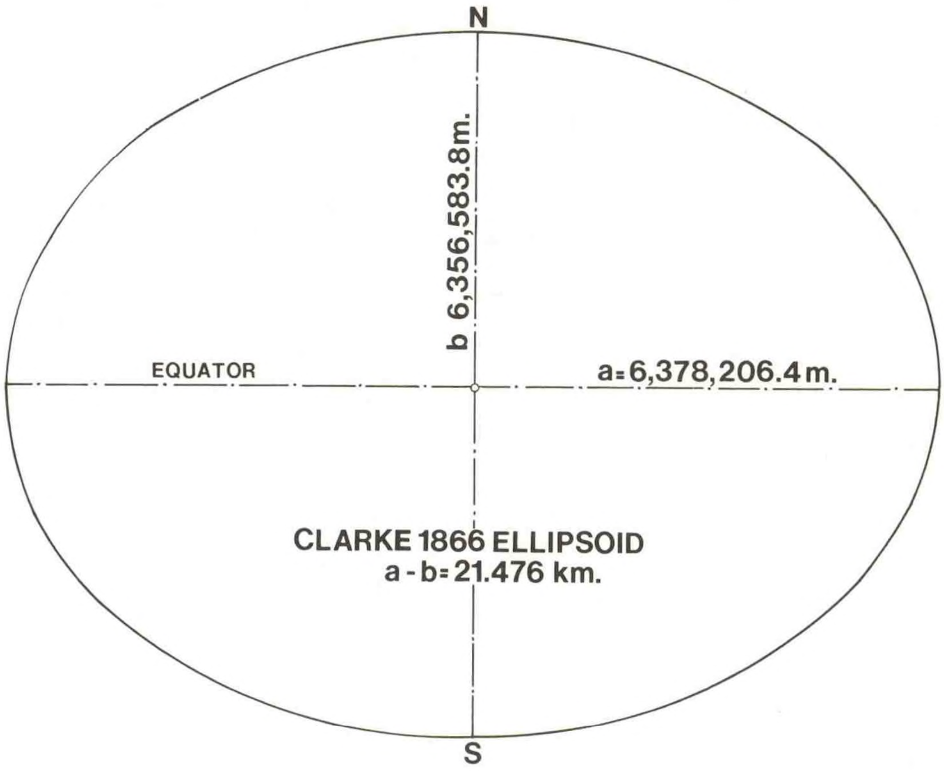


Figure 16.—Geodetic reference ellipsoid.

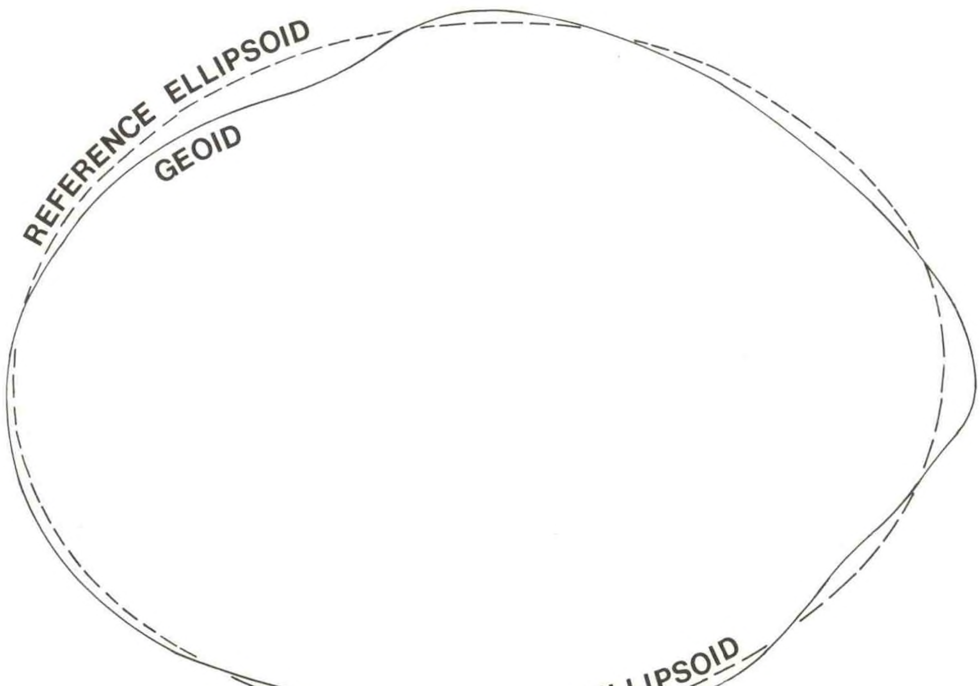


Figure 17.—The geoid.

This was based strictly on a mathematical derivation, with certain assumptions made about homogeneity. This was subsequently substantiated by the measurements made by the French mathematicians Picard, Clairaut, Bouguer, Maupertuis, Cassini *et al.* (Todhunter 1873) considered to be the beginning of modern metrical geodesy, in the interval 1669-1735-1743.

The figure generated by rotating an ellipse about its minor axis is generally adopted by geodesists today as an acceptable approximation to the shape of the sea-level surface but it must be understood that this is actually only a mathematical model on which the calculations of geodetic positions can be carried out with sufficient accuracy for most work. The adoption of this geometrical shape is actually a compromise with expediency, because of the use of other more complicated shapes would enormously increase the complexity of calculations. The dimensions of the reference ellipsoid in actual use vary throughout the world, with, as might be expected, different figures being used in North America, Europe, Russia, etc. (See fig. 16, this manual.)

The actual shape of the Mean Sea Level surface, however, is not readily amenable to description by a simple mathematical expression. If the waves, tides, currents, etc., be "averaged out" and the sea level surface considered to be the quiet, undisturbed, smooth surface of the sea, a liquid in equilibrium, it will be immediately obvious that this surface will be everywhere normal to the direction of gravity. This is indeed the definition of the Mean Sea Level surface even when it is extended underneath the surface of the continents. Further consideration will reveal that this is an *equipotential* surface. Whatever its shape, the technical name assigned to the particular equipotential surface that is defined by mean sea level (where available) is the *geoid*. If the earth were a homogeneous body, or if density varied systematically with distance from the center of the earth, the geoid would be a smooth surface of revolution, closely approaching an ellipsoid. Since, as is well known, the mass distribution within the earth is not systematic, the surface of the geoid does approach an ellipsoid as the simplest "best fit" figure, but it is actually an undulating surface, sometimes above and sometimes below the mathematical figure. (See fig. 17, this manual.) Since the level bubble in a surveying instrument indicates a perpendicular to the local direction of gravity, the surface of reference in leveling is actually the geoid and not the geodetic ellipsoid.

APPENDIX C.—SOILS

Elementary knowledge of soil classifications and terms is necessary to understand the information presented in this manual. Terms used by the layman and expert alike carry many connotations and can cause considerable confusion. Technical classifications can even be confusing in that a variety of classification systems have been devised, each for a different use. A synopsis of soil classification and explanation of some of the more common soils terms are set forth below.

To the engineer the term *soil* generally refers to an unconsolidated mixture of discrete particles interspersed with gasses and liquids, which lies above bedrock. No fine line can be drawn between *soil* and *bedrock* without arbitrarily defining bedrock in terms of physical properties such as compressive strength or degree of consolidation. There are an infinite number of phases between the hardest rock and the loosest soil. For the purpose of this manual, it will suffice to call bedrock any extensive, hard, earthen material which cannot be penetrated without a diamond or tungsten carbide tipped drill bit. Soil includes the materials formed by mechanical disintegration and chemical decomposition of bedrock.

Soils are divided into two groups called *organic* and *inorganic*. Organic soils are those which contain an appreciable amount of decayed plant or animal matter. They can be identified by their dark color and distinctive odor resulting from the decomposition of the organic matter. Large deposits of these soils form peat bogs, muskeg, and swamps, but they also overlie other soils in an often thin layer of humus. The main disadvantage of organic soils from an engineering standpoint is their high compressibility. A load placed on this type of soil is subject to excessive settling.

Inorganic soils are distinguished from one another by a number of criteria, the most important being texture. Texture is mainly a reflection of grain size, but it is also influenced by particle shape. Soils may be grouped on this basis into four classes—*clay*, *silt*, *sand* and *gravel*. The size limits for these particles are as follows: [9]

[9] Some systems use 0.002 and 0.074 mm to distinguish between clay and silt, and silt and sand respectively.

clay . . . . less than 0.005 mm
silt. 0.005 to 0.05 mm
sand . . . . 0.05 to 2.0 mm
gravel. . . . . greater than 2.0 mm

Sands and gravels are often referred to as *coarse-grained* or *granular* soils. They are *cohesionless* and the individual particles can be distinguished with the unaided eye. Accordingly, visual inspection of a soil sample to determine whether or not it is coarse-grained is the first step in field identification. For the purpose of mark setting, it is not necessary to distinguish between sand and gravel. Both are very good soils in which to set monuments.

Clays and silts are *fine-grained* materials. Their individual particles cannot be differentiated with the unaided eye. Normally, particles of this size are flat and plate-like rather than rounded, and due to this the soils are usually *cohesive*. The degree of this characteristic gives an indication of grain size and can therefore be used to determine whether a soil contains mostly clay or mostly silt.

By varying its water content, a clay can be made into a consistency where it can be deformed rapidly without cracking or crumbling, exhibiting a property called *plasticity*. A clay can be rolled into long thin threads without breaking, and upon air drying it will have considerable strength. Silts can also be rolled into threads but when held by its end, a silt thread which is more than about 10 centimeters long will break. Unlike clay, a small amount of air-dried silt can easily be crushed with the fingers. If enough water is added to a pat of silt to make its consistency like that of a thick paste, and this pat is shaken in the palm of the hand, it will appear wet and shiny. If the pat is then squeezed, the surface moisture will disappear and the pat will eventually crack. Clay, on the other hand, will remain unchanged when handled in such a manner.

A soil mass consisting mainly of a limited range of particle sizes is said to be *uniform*. More often, soils contain appreciable amounts of many different particle sizes, frequently including all four of the major classes (i.e., clay, silt, sand, and gravel). These are called *mixed* soils. They are described by naming the two most predominant constituents, the one of lesser abundance qualifying the greater. For example, a silty sand might contain 60 percent sand-sized particles and 30 percent silt-sized particles. The remainder would be clay or gravel or both.

Another way to qualitatively describe a coarse-grained soil is with the term *clean*. A clean sand or gravel does not contain an appreciable amount of fines (particles less than about 0.1 millimeter). Locations with these types of soils provide excellent sites for setting bench marks.

A description of soil is not complete until some indication is given as to its natural condition. Granular soils may be *loose* or *dense*. Fine-grained soils are described by their *consistency*, which can be *soft*, *medium*, *firm*, *stiff*, or *hard*. A simple test can be employed to determine the consistency by pressing the fist, thumb, or fingernail into the soil and gauging the resulting penetration. In addition, one of the most significant conditions of a soil mass is described by its drainage characteristics. Good drainage is indicated with a sloping topography to facilitate the removal of surface water, granular soil particles which allow water to percolate through, and a water table not too near the surface. It is desirable to locate bench marks in soils with good drainage.

APPENDIX D.—EXISTING MONUMENTATION IN THE VERTICAL NETWORK

Since the beginnings of precise geodetic leveling in the United States in 1877, and the subsequent formation of the Coast and Geodetic Survey in 1878, a variety of different types of bench marks have been established in our National Vertical Control Network. For the most part, they were appropriate for their times, but according to today's high standards, they have various shortcomings and are no longer to be set. Many of the monuments, to be sure, were set in such a manner as to have maintained their positions very well. In any event, they do comprise the major portion of the network.

The first bench marks were placed at intervals of from 5 to 15 kilometers. They were established on structural members of buildings, dams, aqueducts, bridges, locks, piers, culverts, arches, and pedestals; on granite, marble, or cedar posts; and in bedrock and boulders. Some of them had no physical markings for the exact elevation reference point, but were defined descriptively by phrases such as "centre of the sill," "top of a post," and "northwest corner of the top surface." Others were marked with chiseled square or circular cavities, centers of triangles, crosses, lines, bolts, and rectangular metal plates.

Early in this century, precast concrete posts, 1 to 2 meters in length and, in a few instances, 1-meter lengths of pipe began supplementing the stone posts. Along with this development, bronze tablets came into use. The disks were a major improvement over the chiseled squares and other markings in that they provided a more definite high point to support the leveling rod and were more clearly visible to a person searching for the bench mark.

Cast in place concrete monuments were introduced in the latter half of the 1930's. The procedure for setting them started with digging a hole about 30 to 35 centimeters in diameter to a depth of about 1 meter or below the frost line. The better monuments were cast in tapered holes with a smaller diameter at the top. The bottom of the hole was then extended and enlarged to provide greater resistance to heaving and settling. A form was set in place for the top of the mark and sometimes for the entire length of it to make its sides smooth, thereby lessening the effect of frost heave. Casting posts in place eliminated the work required to manhandle the heavy precast posts, which consequently were phased out completely in the 1940s.

In 1954, the Coast and Geodetic Survey began experimenting with the copperclad steel rod mark. Until this time, bench mark settings had been limited to two basic types: structures and posts (or pipes). Bench marks in structures have generally held their elevations well. When foundations are investigated to the extent directed in this manual, they will be even more reliable. Concrete or stone posts, however, are excessively vulnerable to the forces of nature. Frost heave jacks them up, expansive soils cause them to "float," and their own weight makes them settle. If they are located in well-drained, coarse-grained soils, they make very good bench marks, but anything resistant to impact and corrosion will suffice in these areas.

Disks have had relatively few changes through the years. Most of them have been made of brass or bronze. The tops have been about 8 to 10 centimeters in diameter and spherically shaped. Irregularly shaped shanks have served as anchors to secure the tablets in drill holes. The earlier tablets were cast in one solid piece. Later the shank was fabricated separately and silver soldered to a disk which was cut and pressed from sheet stock. Legends have varied little. They indicated the organization which established the mark (i.e., Coast and Geodetic Survey, National Ocean Survey, or National Geodetic Survey), the type of mark (i.e., bench mark, tidal bench mark, or vertical control mark), whom to write for information (i.e., The Director and organization, Washington, D.C.) and a phrase warning against vandalism.

Changes occurred to the disks during the following time periods: (1) From 1934 until 1956, the adjusted elevation was stamped on the disk as a matter of standard procedure. This was a very poor practice because both movements of the monument and readjustments of the network caused many of the stamped elevations to be erroneous. (2) For a short time during and immediately after World War II, cast iron was used because brass and bronze were in short supply. A considerable number of these disks corroded to such an extent that the precise datum point was worn down and the logo became illegible. Brass or bronze disks make good bench marks when set in substantial structures of concrete or masonry. An improvement could be made, however, by providing the upper surface with a protuberance to define a more precise datum point. Flat disks should never be used for bench marks.

In 1955, the Coast and Geodetic Survey began installing rod type bench marks. They consisted of 5/8-inch copper-clad steel rods in 5-, 8-, and 10-foot sections driven to refusal or some maximum depth. The required rod depth was attained by joining threaded ends of rod sections with brass couplings. Some of these marks have been driven to depths well in excess of 30 meters. A brass bench mark disk with a tubular stem was either crimped or soldered over the top of the rod.

The major problem encountered with this mark was one of corrosion. Copper and steel are quite incompatible in many environments. A galvanic cell is set up where the copper coat is protected at the expense of the corroding steel core. This situation is aggravated at the rod ends because the area of exposed steel is small in relation to the area of exposed copper. Rod marks have been known to fail completely at the first joint below the surface, the results of which are obvious.

Another problem with this type of bench mark stems from the fact that even though it may be driven deeply into the soil, the stable substratum in some cases does not grip the rod as tightly as the unstable soil near the surface. Consequently, it will move with disturbances in the upper layers. Reaching refusal at shallow depth makes this an even more serious problem.

In the early 1970s, a modofication to the rod mark was made by attaching a base plate to a 4-foot section of rod. Use of the rod mark continued, but at a less frequent interval. The purpose of the modified rod with base plate, sometimes called the "pre-fab," was to replace the cast-in-place concrete post which was subsequently phased out. The advantages of the prefab over the concrete post were that it was easier to install and, because it was quite lightweight, it was not prone to settlement. The disadvantages of vulnerability to frost heave and expansive soils remained.

The problem of galvanic corrosion in the copper clad rod mark and prefab mark was identified in 1976. Galvanized steel was temporarily substituted for copper-clad steel until the entire bench mark program could be studied in detail and revamped. This manual is a result of that study.

Bench marks established in bedrock have been recognized for many years as a most desirable elevation reference and have been used throughout our leveling history. The only drawbacks in using a bedrock reference (which are minor in comparison to the shortcomings of some of the other marks) are (1) it is sometimes difficult to distinguish between bedrock and large boulders, and (2) bedrock can sometimes exhibit volume change with variation of moisture content. The guidelines in this manual will reduce these problems.

APPENDIX E.—EXAMPLES FOR DETERMINING BENCH MARK DEPTHS

The following examples illustrate how to compute class A and B rod mark depths for four different geographical areas. Part A of each example gives four basic steps for determining the sleeve depth of a class A rod mark. Determining the rod depth for this mark is usually straightforward, as explained in steps 8 and 9 (page 18) of the routine for setting the mark. Part B of each example shows how to determine the rod depth for a class B rod mark. In addition to the four steps needed for class A rod marks, one extra step is required.

Step 1

A depth is determined to prevent expansive soils from changing the elevation of the mark.

Step 2

A depth is determined to prevent frost heave from affecting the mark.

Step 3

A determination is made as to whether or not permafrost is present.

Step 4

In regions without permafrost, the deeper depth determined in steps 1 and 2 is taken as the depth for the sleeve or minimum depth for the rod (class A or B, as appropriate). In regions where permafrost occurs, the depth specified for permafrost regions is used.

Step 5

Rod depth is further determined by the resistance of the ground at the time the rod is driven into position. The penetration rate indicates whether or not the rod must be driven to a greater depth than that determined above. With the "Cobra" used by NGS mark setters, the rate must not exceed 4 centimeters per second. (It must take at least 25 seconds to drive 1 meter of rod.)

Example 1

Location: Battle Mountain, Nevada

Part A. Sleeve depth for class A rod mark.

Step 1

a. Find Battle Mountain on a road atlas and estimate its location in figure 11. At this particular location it is difficult to determine whether the soil is nonexpansive or of low expansive character. Therefore, consider the worse condition—a soil of low expansive character.

b. Using figure 12, determine the climate factor. Battle Mountain is located on or very near the line delineating 1.3 from 1.4. Again, use the worse case—1.4.

c. From table 2, determine the sleeve depth reouired to prevent changes in soil volume from altering the elevation of the rod. In this instance, it is 6 meters $\times$ 1.4, or 8.4 meters.

Step 2

a. Check figure 13 to determine the extreme depth of frost penetration. For Battle Mtn, frost depth is between 0.50 and 0.75 meter.

b. Return to table 2. Footnote d states, "Use the upper limit for each area delineated." So use 0.75 meter. The sleeve depth required to counteract the effect of frost heave is 3 $\times$ 0.75 meter, or 2.25 meters.

Step 3

Permafrost is not a consideration here. The only locations where permafrost occurs in the conterminous United States are Mount Washington in New Hampshire and the Front Range of the Colorado Rocky Mountains.

Step 4

In this illustration, eliminating the effect of expansive soils would require an 8.4-meter sleeve, while eliminating frost heave would require only a 2.25-meter sleeve. The greater of the two, an 8.4-meter sleeve, must be set.

Part B. Rod depth for class B rod mark.

Part A must be studied to understand how the expansive character of the soil, climate factor, and extreme depth of frost penetration were determined. The particulars are not repeated here.

Step 1

a. The soil is of low expansive character.

b. Climate factor is 1.4.

c. From table 3, compute the minimum rod depth for expansiveness of soil—5 meters $\times$ 1.4, or 7.0 meters.

Step 2

a. Extreme depth of frost penetration is between 0.50 and 0.75 meter. Use 0.75 meter.

b. From table 3, the minimum rod depth required to counteract the effect of frost heave is 4 $\times$ 0.75 meter, or 3.0 meters.

Step 3

As in part A, permafrost is not a consideration.

Step 4

Expansive soil requires a 7.0-meter rod, and frost heave requires a 3.0-meter rod. Minimum rod depth is the greater of the two—7.0 meters.

Step 5

When a depth of 7.0 meters is reached, if the rod can be driven faster than the allowable rate, continue driving the rod until the rate decreases to the maximum rate allowed.

Example 2

Location: Thief River Falls, Minnesota

Part A. Sleeve depth for class A rod mark.

Step 1

a. From figure 7, the soil is of low expansive character.

b. From figure 12, the climate factor is 1.1.

c. From table 2, the sleeve depth required to prevent changes in soil volume from changing the elevation of the rod is 6 meters × 1.1, or 6.6 meters.

Step 2

a. From figure 13, the extreme depth of frost penetration is between 2.25 and 2.50 meters. Use 2.50 meters.

b. From table 2, the sleeve depth required to counteract the effect of frost heave is 3 × 2.50 meters, or 7.5 meters.

Step 3

Permafrost is not a consideration here.

Step 4

In this case, elimination of the effect of expansive soils requires a 6.6-meter sleeve, while elimination of frost heave requires a 7.5-meter sleeve. The greater of the two, a 7.5-meter sleeve, must be set.

Part B. Rod depth for class B rod mark.

Step 1

a. The soil is of low expansive character.

b. The climate factor is 1.1.

c. From table 3, the minimum rod depth when considering expansiveness of soils is 5 meters × 1.1, or 5.5 meters.

Step 2

a. The extreme depth of frost penetration is between 2.25 and 2.50 meters. Use 2.50 meters.

b. From table 2, the minimum rod depth required to counteract frost heave is 4 × 2.50 meters, or 10.0 meters.

Step 3

Permafrost is not a consideration here.

Step 4

Expansive soils require a 5.5-meter rod, and frost heave requires a 10.0-meter rod. The minimum rod depth is the greater of the two—10.0 meters.

Step 5

When a depth of 10.0 meters is reached, if the rod can be driven faster than the allowable rate, continue driving until the rate decreases to the maximum rate allowed.

Example 3

Location: Alpine, Texas

Part A. Sleeve depth for class A rod mark.

Step 1

a. From figure 10, the soil is nonexpansive.

b. From table 2, no sleeve is required to prevent changes in soil volume from changing the elevation of the rod.

Step 2

a. From figure 13, the extreme depth of frost penetration is less than 0.5 meter.

b. From table 2, no sleeve is required to prevent frost heave from changing the elevation of the rod.

Step 3

Permafrost is not a consideration here.

Step 4

No sleeve is required to eliminate the effects of either expansive soil or frost heave. This is an example of a class A rod mark with no sleeve. According to note b in table 2, the rod is driven to 4 meters or until its driving rate decreases to the maximum rate allowed, whichever is the greater depth.

Part B. Rod depth for class B rod mark.

Rod depths for class B rod marks in areas of nonexpansive soils, extreme depth of frost penetration less than 0.5 meter, and no permafrost (all three conditions satisfied) are the same as rod depths for class A rod marks. The only difference between the marks in these areas is that the class A mark has no disk, but an aluminum logo cap is built into the surface casement. The class B mark is topped with a disk and has a PVC plug in the surface casement. Since the type of surface casement can be used to distinguish visually between class A rod marks (which are more reliable) and class B rod marks (less reliable), all rod marks in these areas set to specifications should be provided with an aluminum logo cap, but no disk. Where no sleeve is required for the class A rod mark, class B rod marks are not easier to set and, therefore, should not be used.

Example 4

Location: Sourdough, Alaska
(Between Paxton and Gulkana)

Part A. Sleeve depth for class A rod mark.

Step 1

The presence of permafrost overrides this step.

Step 2

The presence of permafrost overrides this step.

Step 3

Consult Map I-445, Permafrost Map of Alaska (Ferrains 1965). The area around Sourdough is generally underlain by thick to thin permafrost. Local knowledge of conditions, available from utilities companies and local citizens, should also be considered.

Step 4

From table 2, the sleeve depth is 10 meters.

Part B. Rod depth for class B rod mark.

Steps 1 and 2

The presence of permafrost overrides these steps.

Step 3

From Map I-445, the area is generally underlain by permafrost.

Step 4

a. From local knowledge, the ground has never been known to thaw below 1.2 meters.
b. From table 3, the minimum rod depth is 2.5 $\times$ 1.2 meters, or 3.0 meters.

Step 5

If the driving rate is not exceedingly slow, the site is not underlain by permafrost and a new rod depth will have to be determined accordingly.

Note: In areas of Alaska that are not underlain by permafrost, information on expansiveness of soils (such as that found in figures 7 through 11 of this manual) must be obtained locally if possible. When no information is available, step 1 is omitted. Extreme depth of frost penetration, used in step 2, must also be obtained locally.

BIBLIOGRAPHY

Ballantine, William, 1976: Choosing corrosion-resistant fasteners for marine application. *Sea Technology*. Compass Publications, Inc., Arlington, Va., February, pp. 8-10.

Baracos, A. and Bozozuk, M., 1957: Seasonal movements in some Canadian clays. *Proceedings of the Fourth International Conference on Soil Mechanics and Foundation Engineering*, London, England, August 12-24. Butterworths Scientific Publications, London, pp. 264-268.

Berry, Ralph Moore, 1978: NOAA Manual, Geodetic leveling (in preparation).

Bozozuk, M. and Burn, K. N. 1960: Vertical ground movements near elm trees. *Geotechnique* 10(1), pp. 19-32.

Bozozuk, M., Johnston, G. H., and Hamilton, J. J., 1962: Deep bench marks in clay and permafrost areas. *Special Technical Publication* No. 322, Symposium on Field Testing of Soils, American Society for Testing and Materials, 266 pp.

Construction Research Center, University of Texas, 1976: Interim report of experimental foundation designs on expansive clay soils. Department of Housing and Urban Development, Washington, D.C., May, 67 pp.

Feldscher, Carl B. and Berry, Ralph Moore, 1968: The use of geopotential heights for Great Lakes Vertical Datum, *Miscellaneous Paper* 68-6, Lake Survey District, Corps of Engineers, Detroit, Mich., August, 20 pp.

Ferrains, Jr., Oscar J., 1965: Permafrost map of Alaska. Map I-445, U.S. Geological Survey, Washington, D.C.

International Nickel Company, Inc., 1970: *Corrosion in Action.* International Nickel Co., New York, N.Y., June, 47 pp.

Kjellman, W., Kallstenius, T., and Liljedahl, Y., 1955: Accurate measurements of settlements. *Royal Swedish Geotechnical Institute Proceedings*, No. 10, Stockholm, Sweden, pp. 7-33.

Leonards, G. A. (editor), 1962: *Foundation Engineering.* Civil Engineering Series, McGraw Hill, New York, N.Y., 1136 pp.

Maltby, Calvin S. and Doskins, Eriks, 1968: Bench mark monumentation. *Surveying and Mapping* XXVIII (1), 45-51.

National Academy of Sciences, 1968: Criteria for selection and design of residential slabs-on-ground. *Publication 1571*, Building Research Advisory Board, National Academy of Sciences, Washington, D.C., p. 38.

National Oceanic and Atmospheric Administration, 1977: Input Formats and Specifications for the NGS Data Base. Available in preprint form from NGS, Code Clx4, National Ocean Survey, NOAA, Rockville, MD 20852.

Patrick, D. M. and Snethen, D. R., 1976: An occurrence and distribution survey of expansive materials in the United States by physiographic areas. Interim Report under Federal Highway Administration contract, Rept. No. FHWA-RD-76-82. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. Available from National Technical Information Service, Springfield, VA 22161 (NTIS document no. PB 265230).

Rappleye, Howard S., 1948: Manual of geodetic leveling, *Special Publication* No. 239, Coast and Geodetic Survey (now National Ocean Survey) 94 pp. Available from National Technical Information Service, Springfield, VA 22161. (NTIS document no. COM-72-50049.)

Romanoff, Melvin, 1957: Underground Corrosion. National Bureau of Standards *Circular* 579, U.S. Government Printing Office, Washington, D.C., 227 pp.

Snethen, Donald R. and Johnson, Lawrence D., 1977: Characterization of expansive soil subgrades using soil suction data. Presented at conference on Moisture Influence on Pavement Materials, 56th Annual Meeting of Transportation Research Board, Washington, D.C., January 24-28, 32 pp.

Todhunter, I., 1873: *A History of the Mathematical Theories of Attraction and the Figure of the Earth.* Vol. I, Macmillan, London. Reprinted by Dover Publications, 1962: New York, N.Y., vols. 1 and 2 in one book.

U.S. Army Corps of Engineers, 1967: Frost and permafrost problems with soil and rock. Cold Regions Research and Engineering Laboratory, Hanover, N.H., December 2-3.

U.S. Department of Agriculture, 1941: *Yearbook of Agriculture.* U.S. Government Printing Office, Washington, D.C., pp. 270-274.

U.S. Geological Survey, 1966: *Topographic Instructions of the United States Geological Survey, Book 2.* U.S. Government Printing Office, Washington, D.C., pp. 37-45.

INDEX

NOTES

NOTES

☆ U.S. GOVERNMENT PRINTING OFFICE : 1979 O—273-588

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey
National Geodetic Survey, C13x4
Rockville, Maryland 20852

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE
COM-210
THIRD CLASS MAIL

NOAA--S/T 78-391