International Hydrographic Review, Monaco, LVII (1), January 1980.

STABLE AND ENDURING MONUMENTS FOR VERTICAL CONTROL NETWORKS

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ABSTRACT

Bench marks, or survey control points of known elevation, are used by geophysicists for many purposes, but problems inherent with bench marks have long hindered the scientist. These problems include instability, deterioration, damage, and destruction of the monument. They can be overcome by prudent selection of level line routes and bench mark sites, and by use of a suitable monument. Disks set in sound bedrock are always best. If unavailable, a suitable structure, or specially designed monument can be used. The class A rod mark, developed by the National Geodetic Survey, National Ocean Survey, NOAA, is one such monument.

INTRODUCTION

The objective of any survey is to yield two distinct but interdependent products—monuments and positions. Without one the other is of no value. Therefore the quality of the monuments should be comparable to the quality of the positions. Stability and life expectancy of the monument should reflect the precision and the resources expended in determining its position respectively.

This paper explores the problems encountered in setting up a stable and long-lasting bench mark, and offers solutions to these problems. It also details suitable monuments to use, including a new bench mark developed by the author for use by the National Geodetic Survey. For more comprehensive information on bench marks used for precise surveys, consult NOAA Manual NOS NGS-1, *Geodetic Bench Marks* (FLOYD, 1978).

PROBLEMS AND THEIR SOLUTIONS

To set a stable permanent bench mark is often no easy task. First, it must be decided whether the purpose of the bench mark is to *provide control* for a project, or to *reflect vertical movement* which can be measured relative to the control provided. (The second type might be set in a subsiding area to monitor the magnitude or rate of subsidence.) A foundation must be chosen to serve as a datum to which stability of the monument can be related. For *control* bench marks this datum would be the geoid. For others it might be a particular tectonic plate, geologic formation, or stratum of soil. Once this choice is made, steps must be taken to ensure that the monument will remain intact and stable relative to the foundation chosen.

Damage and destruction

Bench marks, like all survey monuments, are chronically in danger of damage and destruction by construction equipment. Highway maintenance equipment also presents a serious threat to the many bench marks set along roadways. Further, damage and destruction is sometimes inflicted by souvenir hunters, scavengers, and vandals.

There are several ways to decrease the probability of damage or destruction of a survey monument. The most effective way is to use good judgement and forethought when selecting a site. Consideration must be given to the probability of widening roads, vulnerability to off-highway traffic, possible expansion of commercial facilities, and erosion. The locality should be scanned for any natural protection in the area which can be utilized.

Another way to prevent damage or destruction of the monument is through its design. A protective housing surrounding a vulnerable bench mark would take a blow without disturbing the actual point of reference.

Sometimes drawing attention to the monument will help preserve it if it is prone to accidental disturbance, for construction engineers are apt to respect the marks. Witness posts can be used to alert the public. On the other hand, if the monument is prone to wilful disturbance, drawing attention to it may have the opposite effect.

Deterioration

Bench marks are constructed from a variety of materials, most commonly concrete and/or metal. These materials are subject to deterioration, for concrete breaks down and metals, even the most corrosion resistant, are eaten away. While some materials are more durable than others in most environments, few are superior in all cases.

Corrosion is an electrochemical process created by a difference in electrical potential between two areas of the metal's surface. One area, the anode, is electrically more negative than the other area, the cathode. Electrons are given up by the metal at the anode and flow to the cathode in an attempt to equalize the electrical potential. For corrosion to occur, there must be an anode and cathode in electrical contact with each other in the presence of an electrolyte.

In some metals in certain environments, however, the corrosive products precipitate on the parent material's surface in a dense and tough layer. Known as passivation, this process prevents the electrolyte from coming into contact with the remaining parent material and thus halts further corrosion.

By understanding the causes of corrosion and the concept of passivation, steps can be taken to minimise deterioration.

1. Do not combine dissimilar metals in the bench mark design for to do so establishes an anode and a cathode. The greater the potential difference between the two metals, the greater the rate of corrosion. If it is absolutely necessary to connect dissimilar metals, those with nearly equal potentials should be chosen. A galvanic series chart can be used to determine this. The closer together metals lie in the galvanic series, the less potential difference they will have.
2. Use a noble metal. Unfortunately, the most noble metals are also the most valuable. Examples include gold, platinum, silver, and titanium. Obviously, less optimal choices must be made. The nobility of pure metals is indicated by the electromotive series. The nobility of alloys can be approximated by the galvanic series. Those which are more cathodic are more noble.
3. Use a metal or alloy that passivates itself, e.g. aluminum alloys and stainless steels. Precautions must be observed when using these alloys because an alloy passive in one environment is not necessarily passive in another. The tough passivating film that normally forms on the surface of aluminum, for example, forms too loosely in the presence of dissolved salts, and corrosion proceeds at a high rate.
4. Use metals with protective coatings only as a last resort. During installation, the protective coating may be scratched or peeled off exposing the vulnerable material beneath. Ensure that the coating is either nonreactive or anodic to the base material, e.g. galvanized steel, in which the Zinc is anodic to steel. Try to use a base material which will afford satisfactory protection on its own if the coating is scraped off. The plain carbon steel core of galvanized steel is only fair in this respect.
5. Whenever possible, select bench mark sites that are not conducive to corrosion. Many variables can be considered, but each must be viewed in light of the alloy chosen for the monument. Drainage

characteristics and electrical resistivity of the soil are the best indicators for most alloys, as the better the drainage or the greater the resistivity, the less corrosive the soil. If an alloy is used that protects itself through passivation, avoid environments that break down the passive film. Aluminum should not be used near salt water shorelines or highways that are salted when laden with snow.

Instability

The problem of instability, as defined in this paper, refers simply to movement. It has already been mentioned that the geoid provides the basis against which movement of a *control* bench mark is to be measured (*). Therefore, vertical instability is a change in elevation relative to the geoid.

Vertical motion at the surface of the earth, where bench marks are installed, is the result of a conglomeration of movements occurring below it. Some movements act in the same direction, amplifying the surface effect. Others act in opposite directions and counteract one another. Starting with movements having the deepest origins, there is isostasy, tectonic motion, subsidence from the pumping of oil and water, rebound from previous glaciation, subsidence from underground mines or karst areas, consolidation of sediments and fill, shrinking and swelling of expansive clay and rock, slope movement, and finally frost heave. Generally, the rates of the individual movements increase as the surface is approached.

To counteract all the various kinds of vertical movements in the bench mark design is clearly not possible. Monuments are installed near the ground surface, normally to less than a small fraction of the depth where motion can originate. However, since the rates of various movements increase as their sources approach the surface, steps taken to eliminate movement originating near the surface will minimize the total effect of all movements. In particular, movements that should be eliminated by proper bench mark design are shrinking and swelling of expansive clays, and frost heave. Slope movement, though quite shallow in origin, can only be avoided by setting bench marks on the crests of hills.

As the depth of its origin increases, elimination of motion by a suitable bench mark design is increasingly restricted by economics. Instead, it can be circumvented by prudent site selection. Areas of fill such as dredge deposits, sanitary landfill, and strip mine reclamation areas should be avoided, as should areas overlying karsts and underground mines. In the United States, detailed maps of these areas might be obtained from States' geological surveys, departments of natural resources, departments of transportation, and the like, or from educational institutions.

Motion originating at deeper depths affects large regions of the surface and cannot be avoided by measures taken in the field alone. Action must

(*) The geoid itself is not even rigid when one considers the effect of changing mass distribution over eons of time.

be taken at the planning stage of a survey. Level loops established strictly to provide *control* should be routed where crustal motion is least likely to occur, after allowing for other considerations. Reciprocative information from the geodynamics community can be used to mutual benefit.

TYPES OF RELIABLE MONUMENTS

Disks in existing settings

Sound bedrock

Sound bedrock provides the best bench mark support possible in terms of stability, permanence, and economy. The only drawback however is that it may be difficult, if not impossible, to distinguish that which is sound, or even that which is, in fact, bedrock. The surface of the outcrop must be solid. Surfaces with deep cracks in close proximity are constantly being nudged about and eroded by the forces of nature. In addition, some bedrock exhibits volume change with a change in moisture content just as expansive clays do. Except by sophisticated testing or prior knowledge, this may be impossible to determine.

The standard bench mark disk is used to mark the exact point of known elevation. It is made of brass or bronze, because of their anticorrosive qualities with respect to air and the mortar in which the mark is set.

Massive structures

In absence of sound bedrock, a disk can be set in a massive structure, defined as one of both great size and weight. Substantial size is needed to shield the soil beneath it, thereby reducing the influence of weather on soil conditions. Ponderous weight is needed to counter the force exerted by the soil (e.g. pressure for swelling) when it does undergo a change in condition (e.g. increased moisture content). Multi-story concrete, masonry, or steel buildings are usually satisfactory choices, and are excellent choices when founded on bedrock. Because heavy structures are prone to settlement, new structures (less than 5 years old) should not be used. Small structures such as concrete culverts, platforms, retaining walls, headwalls, bases of semaphores, etc., should never be used.

The class A rod mark

The class A rod mark was developed to overcome many of the problems common to vertical control monuments as discussed.

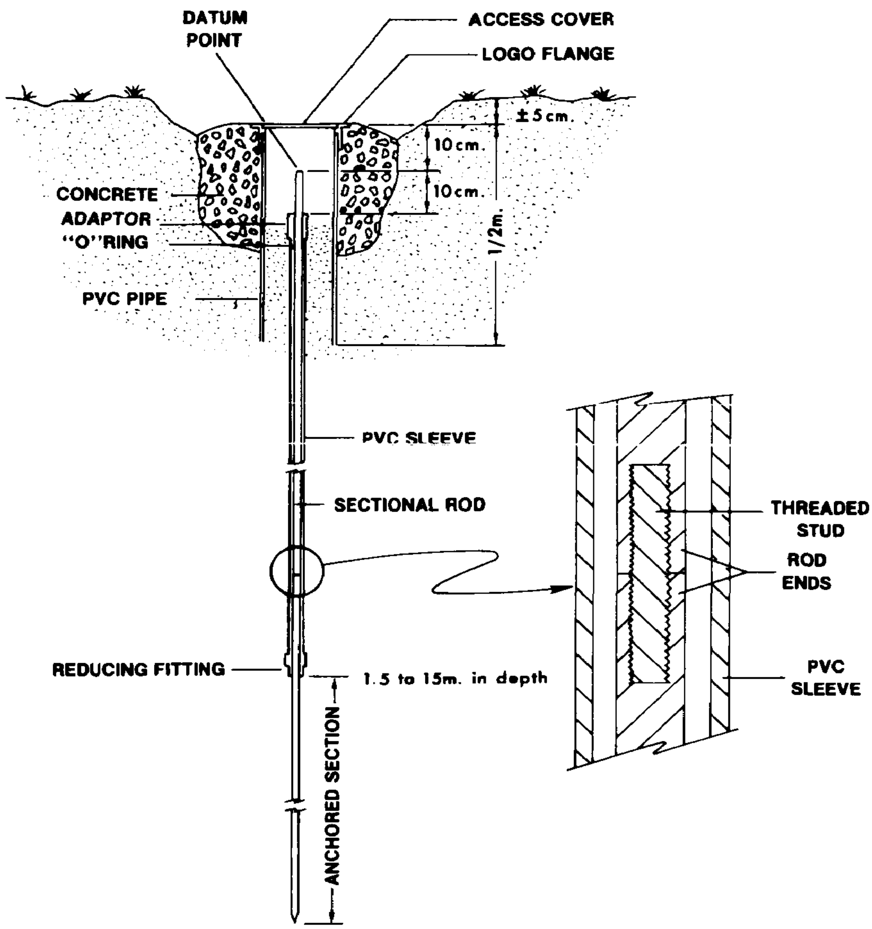

FIG. 1. — Sleeved class A rod mark.

Configuration

This bench mark consists of a rod assembly, usually encased in a sleeve, and a protective surface casement (see fig. 1). The rod provides the support that bridges the point of known elevation to a "stable" stratum of soil (i.e. one that is not intrinsically a source of movement). The top of the rod is the point for which the elevation is determined. It is hemispherical to allow for accurate placement of the leveling rod. (See figs. 2 and 3.)

Bench mark rods are made of type 316 stainless steel, which is highly resistant to corrosion in a wide variety of soil environments. It is cut to convenient lengths for ease in installation. The rod ends are female threaded so that lengths can be coupled to obtain the required depth. Coupling is achieved by use of a threaded stud made of the same material as the rod, thereby avoiding contact of dissimilar metals in the finished mark (*).

(*) The threaded stud should be made of cold drawn stainless steel for extra strength.

A sleeve is normally required to isolate the rod from soil movements. It is used in about 90 % of the area of the conterminous United States. Without a sleeve, the length of rod embedded in the stable stratum of soil might not provide enough friction to prevent the active layer of soil from moving it. It would seem that if the rod were set more than twice as deep

FIG. 2. — Class A rod mark, top open.

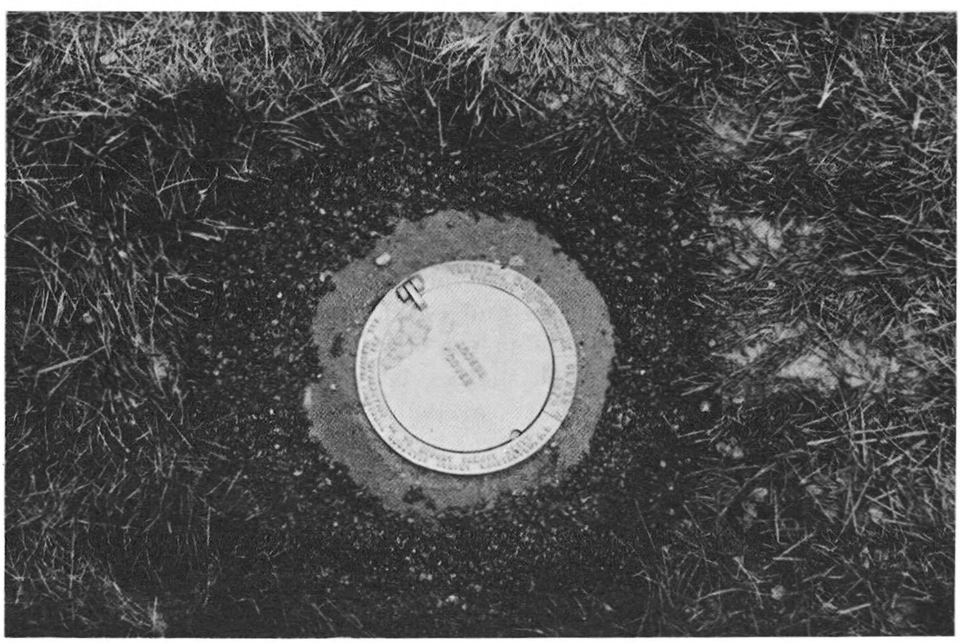

FIG. 3. — Class A rod mark, top closed.

as the active layer, the length of rod anchored in the stable stratum would provide enough friction to overcome the frictional force exerted by the active layer. Soil masses are far from homogeneous with depth, and friction between rod and soil varies considerably with the type of soil. In addition, the time and effort involved in reaching a depth greater than twice the thickness of the active layer would often be prohibitive.

Water must be prevented from infiltrating the annular space between the rod and sleeve. This is required as a further precaution against corrosion and to prevent the formation of ice there in cold weather. Ice could unite the rod to the sleeve, defeating the purpose of the sleeve. To keep water out, the space is filled with grease. It is important that the grease used resist degradation, retain a soft consistency in cold weather, and contain no additives that would accelerate rod corrosion even at the slightest rate.

The surface casement is built around the top of the rod to protect it from impact. The protective surface casement also thwarts attempts to tamper with the rod. It consists of a one-half-meter length of 13-cm PVC pipe set in concrete, topped with an aluminum logo cap and access cover. The whole arrangement is constructed flush with, or slightly below, ground level. An additional function of the surface casement is to aid in locating the monument at a later date. It is common practice to probe around with a rod when searching for a concealed bench mark. The upper surface of the protective casement facilitates recovery by this method.

Depth of the monument

Depths for class A rod marks are based on the presence or absence of permafrost, the depth of maximum seasonal frost penetration, and the depth to which expansive soils shrink and swell. Where permafrost is nonexistent, frost penetration is less than one-half metre, and the soil is nonexpansive, no sleeve is required. The rod is driven to a depth of about 4 metres. Where these criteria are not met, the rod is placed in the sleeve and driven to some nominal depth below the sleeve to anchor it in place.

The presence of permafrost near the surface overrides all other considerations for sleeve depth. Within 1 or 2 metres of the surface, the zone of seasonal frost penetration is very active. Below that, to a depth of 10 metres, permafrost can expand and contract significantly with seasonal changes in temperature just like many other substances (BOZOZUK 1972). Permafrost below a depth of 10 metres is quite stable innately (though still subject to deep crustal activity) as long as it is not thawed as a result of human intervention. For these reasons, in permafrost areas the sleeve is placed to a depth of 10 metres.

For the purpose of mark setting, all seasonal frost penetration is considered to cause frost heave. Frost heave can have a systematic lifting effect on partially buried objects. This occurs when the object does not settle, after the ground thaws, to the extent that it heaved when the ground froze. Over a period of years, an object can be entirely removed from the ground.

This effect must be counteracted or the bench mark sleeve will be jacked up over the top of the rod, and have to be cut off before the bench mark can be used. The sleeve must be placed to such a depth that friction with the soil beneath the layer that heaves exceeds the adfreeze bond with the heaving layer. A depth of 3 times the maximum frost penetration is assumed to be sufficient.

Swelling and shrinking of soil due to varying moisture content is governed by two factors: soil characteristics and moisture content fluctuations.

The deepest depth to which swelling and shrinking of soils occurs is about 15 metres. Therefore, this is the maximum sleeve depth required to isolate the bench mark rod from its effect. This depth is reduced as susceptibility of the soil and/or variability of soil moisture content decreases.

Installation procedure

A procedure for setting the class A rod mark, including illustrations for determining depths, is detailed in *NOAA Manual* NOS NGS-1 (FLOYD, 1978).

Before the mark is set, it must be determined whether or not a sleeve is required and, if so, to what depth. If no sleeve is required, the stainless steel rod is driven with a pneumatic or gasoline powered reciprocating hammer. Sections of the rod are alternately coupled and driven until a depth of 4 metres is reached. Driving continues beyond this depth if a dynamic resistance of 250 kilograms is not met. After the rod is driven, the protective surface casement is built.

If a sleeve is required, a hole must be drilled to the depth to which the sleeve must be set. This requires a drilling rig. The sleeve is filled with grease and lowered into the hole. Next, sections of rod are coupled and lowered into the sleeve until the rod assembly rests in the bottom of the hole. At this point, the rod is driven into the soil beneath the sleeve for a depth of at least 1 metre. Again, it must oppose a minimum resistance before driving can stop. Finally, the surface casement is built.

SUMMARY

The setting of a stable and enduring bench mark involves three measures: knowledgeable routeing of level lines to take advantage of stable regions, prudent site selection to avoid localized problems, and the use of a suitable bench mark to counterbalance near surface movements and inhibit deterioration of materials. The ideal vertical control network would contain monuments of only the most reliable nature. But as always, idealizations must be tempered with practicality and economy. Monuments of a highly reliable nature, as discussed in this paper, can be used where they are most needed, and interspersed with those that are a little less reliable but more economical. At the very minimum, only the most reliable bench marks should be used in the following places:

— Junctions of first-order lines with first- or second-order lines.
— Intersections of first-order lines and international boundaries.
— Bases of spurs from the first-order net to primary tide stations.
— At primary tide stations (at least one).

Additional highly reliable monuments should be set along first-order lines as regularly as manpower and funding permit.

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