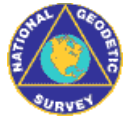




NATIONAL GEODETIC SURVEY



PROCESS ACTION TEAM 20

NATIONAL CONTINUOUSLY OPERATING REFERENCE STATION (NATIONAL CORS) SITE MONUMENTATION

FINAL REPORT

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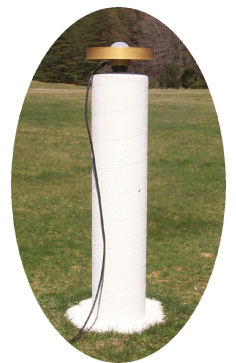


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Executive Summary

Process Action Team 20 (PAT 20) was established by the National Geodetic Survey (NGS) Executive Steering Committee (ESC) to develop design recommendations for a site monumentation system for future National Continuously Operating Reference Station (National CORS) operations. The Team's charter was issued on March 24, 1999 (with a revised charter issued on June 23, 1999). It defines PAT 20's ultimate goals as the development of recommendations for a monument design for future National CORS operations and the deployment of a monument.

Modernization of the National Spatial Reference System (NSRS) is partially dependent on successful implementation of (CORS) technology. CORS site monumentation is an important aspect of the technology. A properly designed CORS monument provides a benign GPS signal environment and a high degree of positional stability.

The process of developing CORS monumentation design recommendations involved the investigation of various issues including: existing monumentation types, properties of potential monumentation materials, GPS signal reception factors, and CORS site environment. PAT 20 examined a wide range of existing monumentation scenarios that are in use throughout the world.

PAT 20 recommends the following monument design for most future National CORS installations: a step-tiered cylindrical concrete pier that is a minimum depth of 10 ft. (3.0 m) by a minimum diameter of 1.5 ft. (0.46 m) below ground level, 5 ft. (1.5 m) tall by 1 ft. (0.3 m) diameter above ground, with an antenna mount consisting of a traditional tribrach adapter attached to a non-metallic base that is integrated into the concrete pier. The Team believes that this design is suitable for a wide range of site conditions and that it has an excellent chance for long term endurance. This type of monument provides the high level of horizontal and vertical stability required for CORS applications. The monument's shape and materials have a negligible impact on the quality of the GPS signals. The materials are readily available and affordable. The preparation of materials and the installation procedures are relatively straightforward and require only a limited amount of specialized equipment and technique. The antenna can be locked in a true north orientation and will be force-centered to a repeatable position whenever it is removed and replaced.

On November 23-24, 1999, PAT 20 installed a prototype monument at the NGS facility in Corbin, Virginia. This prototype is based on the design recommendations developed by the Team. The total cost for the services and materials involved in this installation was \$688.30, excluding about 24 staff-hours of time from NGS employees.

PAT 20 was instructed also to address the issue of National CORS reference marks. The team recommends that NGS continue its current policy and procedures regarding National CORS reference marks.

Introduction

Continuously Operating Reference Stations (CORS) play a fundamental and essential role in the establishment, definition, and utility of the National Spatial Reference System (NSRS). The future of the nation's positioning-related activities is dependent on proper implementation of CORS technology. The National Geodetic Survey (NGS) must therefore perform the functions required to assure that the National CORS system is robust and viable and that it is capable of supporting the broad spectrum of the geospatial user community. Site monumentation is an extremely important aspect of CORS technology. CORS monumentation must provide both a high degree of positional stability and an environment that has a minimal impact on the GPS signals. Implementation of the National CORS network requires the involvement of many cooperating organizations. The monumentation materials, therefore, should be readily accessible, the installation procedure should be straightforward, and the overall cost should be affordable.

Process Action Team 20 (PAT 20) was established to address the important issue of CORS site monumentation. This report will discuss the process by which PAT 20 investigated the various technical issues pertaining to CORS monumentation. It will present a summary of some representative existing monumentation systems that were researched. This will be followed by a discussion of the pertinent issues and constraints that impact the specification of a design. Finally, a set of CORS site monumentation design recommendations, as well as information about the resultant prototype monument installation, will be presented. A variety of related background and research materials pertaining to the Team's efforts is included with this report (Book 2).

Team's Purpose and Approach

The NGS Executive Steering Committee (ESC) established PAT 20 by issuing the Team's charter on March 24, 1999. Partway into its process, the Team requested clarification of some elements of the charter. In response, the ESC issued a revised charter on June 23, 1999. As outlined in the charter, PAT 20's ultimate goals were to recommend a site monumentation system for future National CORS operations and to deploy such a system. The charter defines the term "site monumentation" as referring to "mounting a GPS antenna, establishing nearby ground markers, and determining relative position between the antenna reference point and those nearby ground markers." The Team was instructed to make the appropriate contacts necessary to gather information on existing CORS-like monumentation configurations and to evaluate these options with a consideration of stability, permanence, and cost. Evaluation criteria were to include thermal expansion and multipath effects, other electrical characteristics, and any other issues deemed appropriate by the Team. The Team would then develop monumentation design recommendations and use these as the blueprint for a prototype deployment. This report provides the pertinent information for the publication of a NGS Technical Memorandum.

The first Team meeting was held on May 5, 1999. Meetings thereafter were held weekly, with only a few hiatuses caused by Team members' conflicting commitments. The Team held a total of 44 meetings. The Team's final meeting was held on April 06, 2000. The NGS individuals that comprised PAT 20 are listed on the cover of this report. All meetings were held in the Silver Spring Metro Center - Building 3. Three PAT 20 members attended the meetings by way of telephone conference call due to their remote duty stations. Dennis Hoar was elected Team Leader and Roy Anderson was elected Alternate Team Leader. Sid Safford helped facilitate the first meeting. Joyce Turpin then took over the role of Facilitator. Dennis Milbert attended the first meeting to provide an ESC perspective to the Team. Early Team activities included the establishment of Team operating procedures and rules of conduct. Team members took turns serving as note-taker and recorder. The Team Charter, Operating Procedures, Rules of Conduct, and Minutes from all Team meetings are in Book 1.

The Team's approach included the compilation and discussion of information about existing CORS monumentation. Team members made personal contact with many individuals outside of NGS to gather pertinent information. The Team asked three NGS employees to speak about various aspects of CORS technology. Neil Weston shared his knowledge of some of the monumentation configurations that comprise the current National CORS network. He focused his discussion on monumentation stability issues, using positional time-series plots from three National CORS sites (Columbia, Lake Houston, and New Jersey IT) as illustration. David Crump discussed several specific National CORS monument designs, with an emphasis on details about their construction procedures. He also brought a sample University NAVSTAR Consortium (UNAVCO) antenna leveling mount for Team members to assess. Gerald Mader presented his recommendations about monumentation design. He emphasized signal-environment issues including multipath, signal resonance, and radiometric problems caused by the presence of metal. The Team's discussions of the information gathered from various sources led to the compilation of a list of factors that should be considered in the design of a monumentation system. Members were asked to describe their

individual visions of a National CORS monument design. These ideas led to an iterative process that ultimately resulted in a set of monumentation recommendations. This set of recommendations was then used as the basis for the deployment of a prototype monument, as prescribed by the Team's charter.

Existing Monumentation Designs

This section summarizes information about some examples of the wide range of existing CORS monumentation designs that was compiled during the process of developing recommendations. This information is based on research performed by Team members, presentations made to the Team, and through discussions with resources outside of NGS. Photographs, diagrams, and other documents about existing monumentation designs that were examined are in Book 2. PAT 20 identified two components, the monument structure and the antenna mount, that together comprise a CORS monument. Research and recommendations pertaining to these two monumentation elements are addressed separately.

Monument Structure

The monument structure provides the foundation of a CORS monument. It comprises the bulk of any configuration and is the element whose design is most dependent on the specific site conditions. Most existing CORS monumentation designs can be classified into one of the following general categories: pier, mast, metal rod/pipe, or building. Several examples of each of these four types of monument structures follow.

Pier

A pier (sometimes referred to as a pedestal or pillar) monument is usually constructed of a continuous mass of concrete, although a single massive piece of metal is sometimes used. Pier monuments are found to be in use throughout the world. The designs range greatly in their dimensions and complexity. Examples of existing pier monumentation are:

The joint UNAVCO/NGS National CORS in Platteville, Colorado, consists of a rebar-reinforced, poured in place concrete pier that is 11 ft. (3.4 m) deep by 3 ft. (0.91 m) in diameter underground and 5.5 ft. (1.7 m) tall by 14 in. (0.36 m) diameter above ground. Foam insulation and PVC pipe encase the above-ground portion of the monument (Figure 1).

The Canadian Geodetic Survey Division's GPS Validation Network piers consist of rebar-reinforced concrete that is anchored to bedrock, when present. The specifications call for a monument with a diameter of 1.6 ft. (0.5 m) and a height above ground level of 3.3 to 4.9 ft. (1 to 1.5 m) and below ground of 0 to 6.6 ft. (2 m), depending on the depth to bedrock (Figure 2).

The New Mexico State Highway and Transportation Department's pier monument utilizes a 50-ft. (15.2 m) section of steel H-beam (1 ft. (0.3 m) wide) that is pile-driven 45 ft. (13.7 m) into the ground. The above-ground portion of the monument is encased in PVC and foam insulation (Figure 3).

The Nelson Pier monument, developed by Bendix Field Engineering Corporation (BFEC) for the National Aeronautics and Space Administration (NASA), consists

of a rebar-reinforced concrete cylindrical structure that protrudes 6 ft. (1.8 m) above ground level and is 1 ft. (0.3 m) in diameter. The dimensions and design of the sub-surface portion of the monument are dependent on the presence of bedrock. If bedrock is present within a meter below the surface, the monument is anchored to the bedrock with re-bar and epoxy in drill holes. When shallow bedrock is absent, the monument's sub-surface portion extends 4 ft. (1.2 m) below grade, with the same diameter as above (Figure 4).

The Australian Regional GPS Network consists of several pier monuments of varying designs. The prevalent design is a 1.97-ft.-diameter (0.6 m) reinforced concrete pillar that is set into the ground to a depth of 8.2 ft. (2.5 m) and projects 1.6 ft. (0.5 m) above the surface of the ground (Figure 5).

Mast

Mast monuments generally extend several meters above ground level and may be constructed of a variety of materials, but generally are made of metal. Examples of existing mast monumentation are:

U.S. Coast Guard (USCG) Nationwide Differential GPS (NDGPS) installations utilize a Rohn tower constructed of braced steel piping and anchored to a concrete pad. The heights of the Rohn towers vary from site to site, and can be as tall as 65 ft. (20 m), depending on the local visibility conditions. The taller towers are stabilized with guy wires (Figure 6).

The Texas Department of Transportation (TXDOT) operates a Regional Reference Point (RRP) network. Monumentation at RRP is of two varieties: four of the stations use 16.4-ft.-tall (5.0 m) steel towers and six stations use 5-ft.-tall (1.5 m) stands mounted on roof tops. In both cases, GPS antennas are plumbed over a station disk that is located either at ground level or on the roof beneath the antenna (Figure 7).

The Geographical Survey Institute of Japan monitors crustal deformation with an extensive network of reference stations. Most stations consist of a 16.4-ft.-tall (5.0 m) stainless steel pillar. The GPS receiver and related hardware are stored inside the pillar, and the antenna sits on top (Figure 8).

NOAA's Forecast Systems Laboratory (FSL) uses a chain link fence post at each of their wind profiler sites for a CORS monument. The 4-in.-diameter (0.1 m) fence posts are set in concrete and are stabilized by the attachment of the fencing cross members. The GPS antenna is attached to the top of the post. Antenna heights vary between about 10 ft. (3 m) and 16.5 ft. (5 m) above ground level (Figure 9).

Metal Rod/Pipe

Metal rod or pipe monuments are often anchored into bedrock or utilize bracing to provide stability. Depending on the design, the antenna height can vary from just above ground level to several meters above ground level. Examples of existing metal rod monumentation are:

The Southern California Integrated GPS Network (SCIGN) rock pin monument consists of a 5/8- to 1-in.-diameter (1.6 to 2.5 cm) length of stainless steel rod that is cemented into a drill hole in solid bedrock. The GPS antenna is attached to the upper end of the pin. The resultant antenna height above ground level will depend on the length of the pin that is used, but is usually less than 1.6 ft. (0.5 m) (Figure 10).

The Basin and Range Geodetic Network (BARGN) utilizes a drilled, braced monument that consists of five lengths of 1.25-in.-diameter (3.2 cm) metal pipes that are anchored into drill holes to a minimum of 39.5 ft. (12 m) depth (four pipes are inclined at 35 degrees from vertical and the center pipe is vertical). The top ends of the pipes converge and are welded together, forming a stable antenna attachment point about 6.6 ft. (2 m) above ground level. This monument is based on an original design from the 1980s by Frank Wyatt of the Scripps Institution of Oceanography (Figure 11).

The National CORS monument in Eastport, Maine, consists of a 6.6-ft. (2 m) long invar rod that is cemented into bedrock. The rod is encased in a grease-filled PVC pipe which is surrounded by a rebar reinforced concrete column. The concrete column protects the invar, and the grease-filled PVC isolates the invar from any motions of the column. The antenna is attached to the top end of the invar which is about 4.6 ft. (1.4 m) above ground level (Figure 12).

Building

Buildings are sometimes utilized as a monument or as the foundation for a monument. Examples of the use of buildings for monumentation are:

TXDOT's RRP's use rooftop installations for most of their monuments. The monuments consist of stands that are 3.3 ft. (1 m) to 4.9 ft. (1.5 m) tall. These are constructed on top of concrete pads that are integrated into the roof. The GPS antenna must be plumbed over a station disk that is set into the concrete pad (Figure 13).

NGS established a National CORS in Bar Harbor, Maine, that uses a chimney stack atop three-story building for its monument foundation. A stainless steel bolt that is epoxied into a drill hole in the chimney attaches the antenna mount to the chimney (Figure 14).

SATLOC, a private differential GPS service company, operates a network of permanent reference stations. Most of these stations are monumented with a braced steel bracket that is attached directly to the roof or to the top of an exterior wall (Figure 15).

Antenna Mount

A CORS monument must include an antenna mount that connects the GPS antenna to the monument structure. Team members found a variety of antenna mounts, ranging greatly in their design complexity. Several examples of antenna mounts follow.

UNAVCO personnel developed an antenna mount ("leveling mount") that is used at many permanent reference stations operated by several organizations. The leveling mount is constructed of stainless steel and is designed to be attached to a threaded rod or bolt. The mount provides forced-centering and leveling of the antenna (Figure 16).

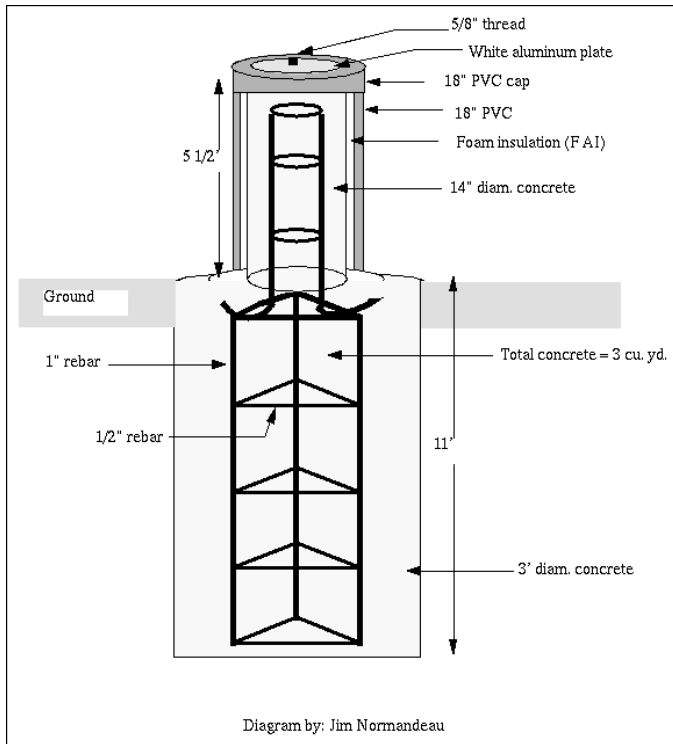
The SCIGN reference station network uses an antenna mount ("D3 GPS Antenna Adaptor") that was designed and fabricated specifically for the SCIGN project. This mount was designed to allow for 0.1 mm (0.004 in.) repeatability in both horizontal and vertical position when the antenna is removed and replaced. It allows the antenna to be leveled and was designed to be resistant to vandalism (Figure 17).

NOAA/FSL wind profiler site reference station antennas are attached to the top of chain link fence posts. Project personnel designed an aluminum antenna mount that consists of a cap that fits over the end of the fence post and a circular plate that sits above the cap. The plate is supported by bolts that connect to the cap and allow the plate to be leveled. The antenna is attached to the plate by means of a mounting bolt that penetrates through a hole in the center of the plate (Figure 18).

Many installations use a threaded bolt that protrudes above the top surface of the monument structure. The antenna is simply attached directly to the bolt and secured by tightening the antenna down so that it sits on the top surface of the structure (Figure 19).

Figure 1

Concrete Pier

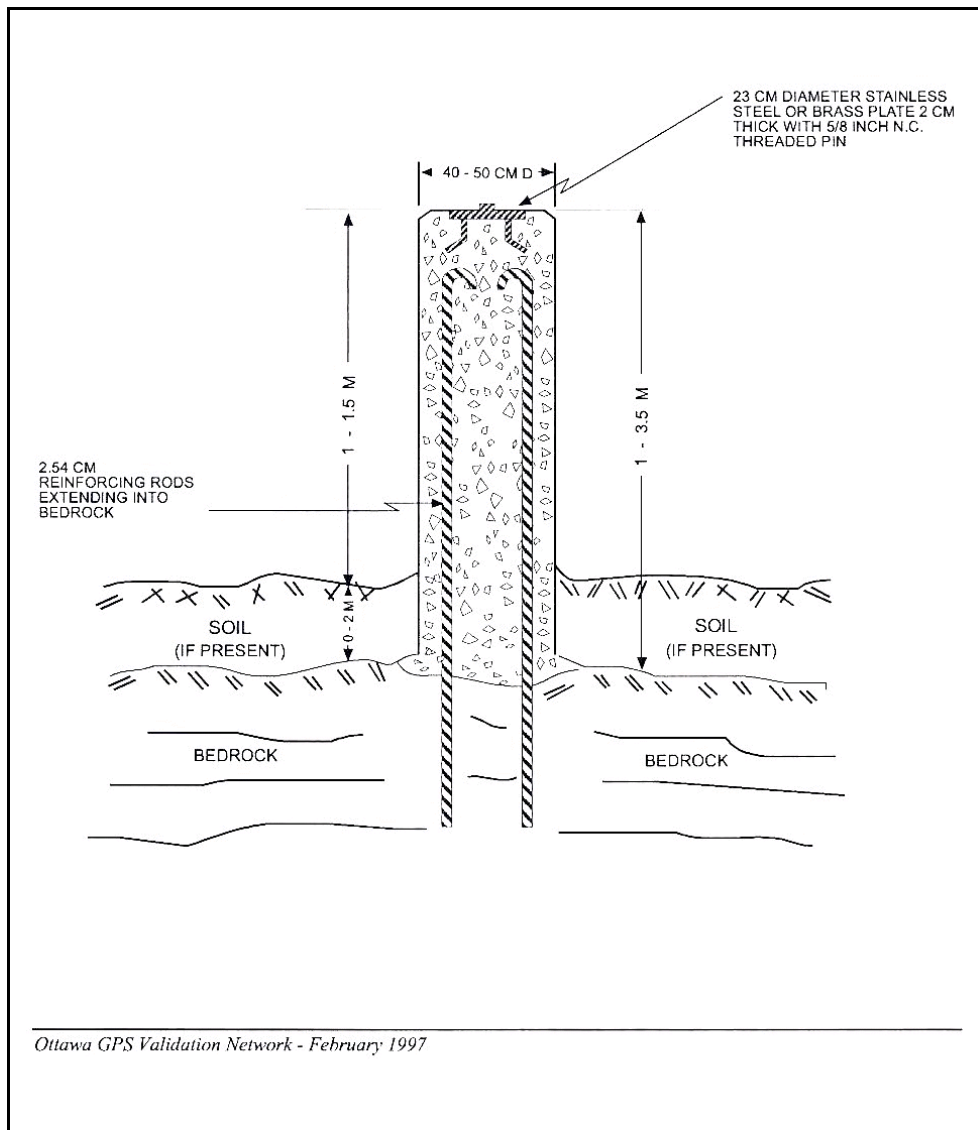


UNAVCO/NGS

Platteville, Colorado

Figure 2

Concrete Pier



**Canada Centre For Surveying
Geodetic Survey Division**

**Ottawa GPS Validation Network
Forced Centering Pillars**

Figure 3

H-Beam Pier

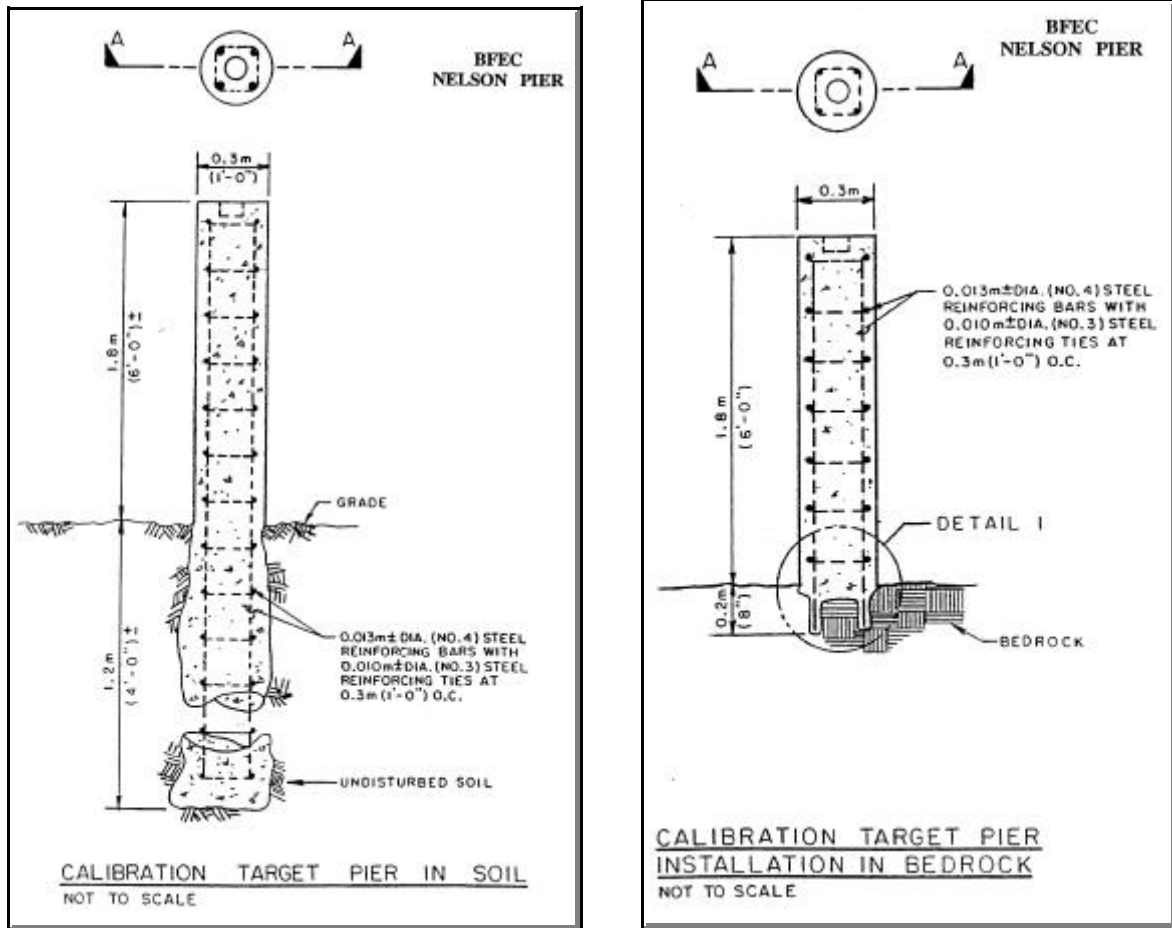


**New Mexico State Highway
and
Transportation Department

Albuquerque, New Mexico**

Figure 4

Concrete Pier



**Bendix Field Engineering Corporation (BFEC)
"Nelson Pier"**

**Developed for the National Aeronautics and Space Administration
(NASA)**

Figure 5

Concrete Pier

Alice Springs



Macquarie-1



Casey-2



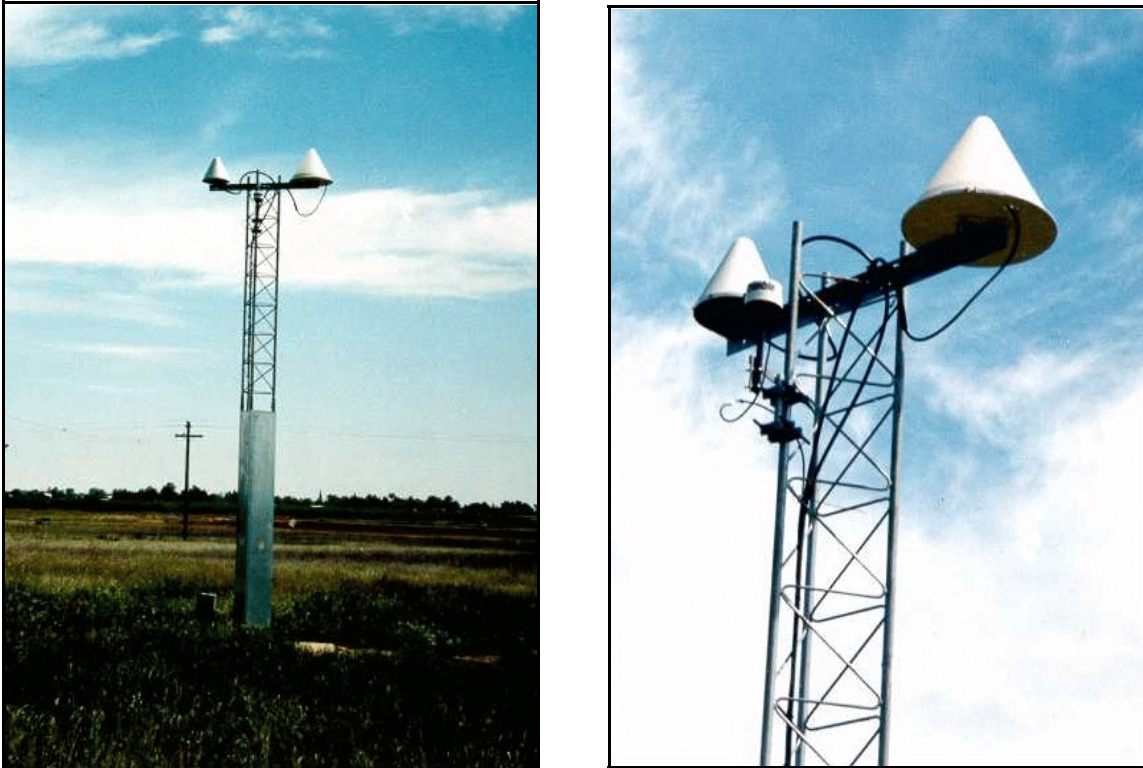
Tidbinbilla



Australian Regional GPS Network

Figure 6

Rohn Tower 55G Reference Mast



U.S. Coast Guard NDGPS Station

Chico, California

Figure 7

Steel Mast



Texas Department of Transportation (RRP)

Austin, Texas

Figure 8

Stainless Steel Mast



**GEONET Station
of the
Geographical Survey Institute of Japan**

Figure 9

Mast (Chain Link Fence Corner Post)



NOAA Forecast Systems Laboratory (FSL)

Tucumcari, New Mexico

Figure 10

Metal Rod (Stainless Steel)



Southern California Integrated GPS Network (SCIGN)

Lake Mathews, California

Figure 11

Metal Pipe



Basin and Range Geodetic Network (BARGN)

Egan, Nevada

Figure 12

Invar Rod Encased in Concrete



**BAYONET Station
(GPS Network to Monitor Subsidence Along the East Coast)**

Eastport, Maine

Figure 13

Building (Roof Mounted)



Typical Texas Department of Transportation RRP

Figure 14

Building (Chimney)



**BAYONET Station
(GPS Network to Monitor Subsidence Along the East Coast)**

Bar Harbor, Maine

Figure 15

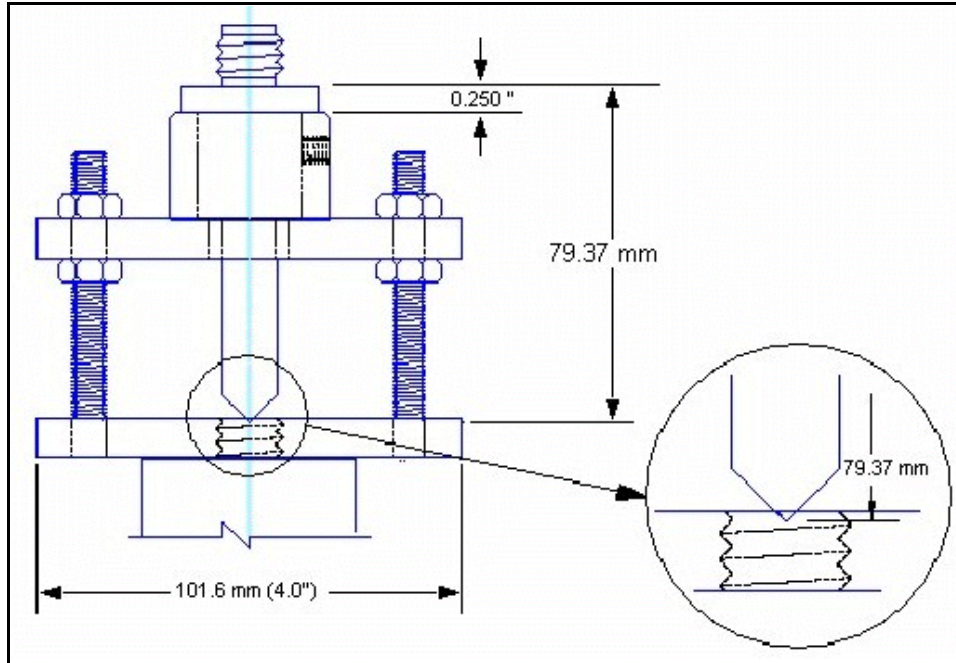
Building (Roof Mounted)



Representative SATLOC Sites

Figure 16

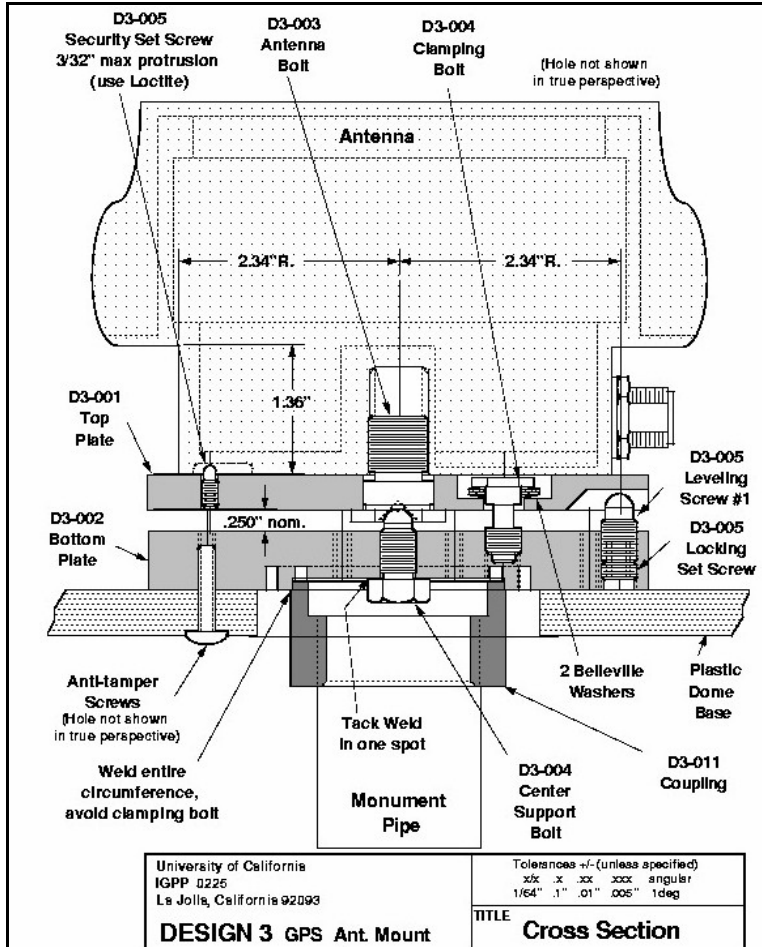
Antenna Mount



UNAVCO

Figure 17

Antenna Mount



SCIGN

Figure 18

Antenna Mount

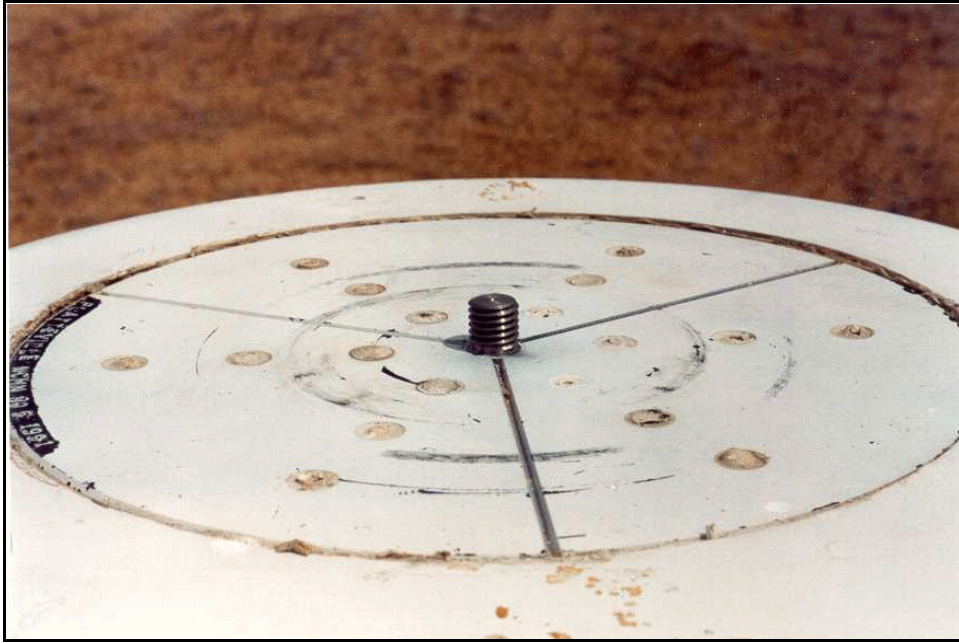


NOAA/FSL

Tucumcari, NM

Figure 19

Antenna Mount



UNAVCO/NGS

Platteville, Colorado

Monumentation Design Issues

As the Team examined existing monumentation scenarios and worked towards developing a set of design recommendations, several pertinent issues were identified, researched, and discussed. These issues are: GPS signal-related effects, physical site conditions, monument construction materials, antenna mounting requirements, and other miscellaneous issues. This section summarizes these issues and their impact on the Team's recommendations.

GPS Signal Issues

A CORS monumentation system must be capable of providing a stable platform for a GPS antenna and a benign GPS signal environment. The main GPS signal-related issues impacting monumentation design are multipath, resonance cavities, and the presence of metal in close proximity to the antenna. One of the Team's guest speakers, Gerald Mader, addressed these issues. For detailed information, see his paper titled "GPS Antenna Calibration at the National Geodetic Survey" (Book 2). A few highlights of this information are presented in this section.

The most crucial aspects of a CORS monument design, from a multipath mitigation standpoint, are the above-ground width and the antenna's height above ground level. By restricting the width of the monument near the antenna to less than the diameter of the antenna ground plane utilized, signal reflections from the top of the monument will be minimized. If the monument width exceeds that of the antenna ground plane, signal radiation can pass off the top of the monument and impinge on the edge of the antenna, thereby resulting in multipath. Signals from high-elevation satellites are particularly prone to this problematic phenomenon.

A resonance cavity, in which GPS signals become trapped and reflected around, can be created if there is too much empty space between the top of the monument and the antenna. This process results in multipath signals being received at the antenna. Any void beneath the antenna should therefore be minimized.

The height of the monument/antenna can also impact the quality of the received GPS signals. The frequency of multipath (caused by signal reflection from the ground) variations is directly correlated with the antenna height above ground level. For very high (greater than about 10 ft. (3 m)) antenna setups, the measured multipath signal can change very quickly. At lower heights, the slow variation of multipath may not average out over short time intervals therefore causing systematic effects in position determination. An antenna height of about 5 ft. (1.5 m) offers the optimal compromise between the extreme antenna height situations and their accompanying problems.

The presence of metal in close proximity to the antenna is a potential source of signal degradation. Although the process is not completely understood, evidence exists that the presence of metal beneath the antenna can alter the radiometric characteristics of

the antenna. The amount of metal used in a monument should be kept at a minimum to avoid this potential problem.

Site Issues

For any CORS installation, the most appropriate type of monumentation will be partially dictated by the physical site conditions. These conditions include the soil type, presence of bedrock, water table level, frost penetration depth, nearby obstructions, and climate. Since these conditions can vary greatly from site to site, it is impossible to design a CORS monument that is optimal for all sites. Most concerns about the subsurface character of the site can be adequately addressed by designing a monument that is of sufficient breadth and depth that it provides the required stability. Proper depth of a monument will anchor it to a level that is unaffected by frost action and that is free of near-surface soil motion and instability. The depth of the water table can impact the choice of design but is not an overriding factor in most areas. Whenever a monument can be attached to solid bedrock, an extremely stable monument foundation will result. The use of bedrock probably provides the ultimate in monument stability potential.

The presence of nearby obstructions will dictate the monument height required to provide adequate sky visibility to incoming satellite signals. In cases where a very tall monument is required in order to avoid obstructions, some CORS performance characteristics, such as multipath-mitigation and positional stability, might be compromised. Tradeoffs such as these are sometimes unavoidable.

The local climate can also be a factor that impacts the monument's design. In heavy snowfall areas, the monument must be tall enough so that the antenna is not buried beneath accumulated snow. In areas with large temperature fluctuations, the thermal expansion of materials might be of such a magnitude that it must be considered when selecting the proper monument design.

Construction Material Issues

In developing a set of monumentation recommendations, various aspects of the construction materials and installation procedure must be considered. Although positional stability and a benign signal environment are of prime importance, a CORS monument should also be affordable and relatively easy to install. The construction materials should be easy to procure, and any components should be available off-the-shelf whenever possible. The design and materials should produce a monument with a good likelihood of surviving for many years.

CORS monuments are continuously subjected to the elements, and any materials used should be able to withstand the exposure (sun exposure, precipitation, temperature variations, corrosive soil conditions, etc.). Most materials are not completely immune to the damaging affects of these processes, but some will survive better than others.

Depending on the size and shape of a monument, thermal expansion can be an important design consideration. Thermal expansion of materials can impact both the scale and shape of a structure, thereby changing a monument's height and/or position. The taller a monument is, the more prone it is to these changes. Changes in a structure's shape occur when differential heating, caused by partial sun-shading, results in varying amounts of expansion throughout the structure. Concrete and steel have comparable coefficients of expansion (approximately 6 parts per million per degree Fahrenheit). For instance, a structure that is 33 ft. (10 m) tall and is exposed to an inter-seasonal temperature change of 100 degrees F (56 C) will change in length by about 0.24 in. (6 mm). For a concrete or steel monument that is about 6.6 ft. (2 m) tall, the same temperature change scenario will result in a change of only 0.004 in. (1 mm). See Book 2 for additional information on the thermal expansion properties of several materials.

Whenever metal is placed in an environment that includes moisture, salts, and oxygen, electrolysis can occur. A combination of dissimilar metals is particularly vulnerable to this process. The corrosive effects of electrolysis can compromise the integrity of a structure, and steps should be taken to prevent this process. By selecting the proper types of metal for specific site conditions and by avoiding the juxtaposition of dissimilar metals, electrolysis can be rendered a non-issue in most instances.

Many different construction materials could conceivably be used in a CORS monument. These include various types of metals (e.g., stainless steel, galvanized steel, aluminum, invar), concrete, stone, wood, and others. Each candidate material has advantages and disadvantages regarding its suitability for use in a CORS monument. The selection of an optimal design and set of materials must include a consideration of these issues.

Antenna Mounting Issues

Several considerations impact the design of a CORS monument antenna mount. It must provide forced-centering, thereby locating the antenna at a repeatable horizontal position, even when the antenna is removed and reattached or replaced. It should provide a stable and level surface upon which the base of the antenna sits, thereby ensuring a repeatable antenna reference point height. The mount should allow the antenna to be oriented to true north, as required for proper baseline processing and usage of antenna phase models. To preserve the inherent radiometric characteristics of the antenna, the amount of metal directly contacting the antenna should be minimized.

Miscellaneous Issues

There are many other issues that play a role in the overall design of a CORS facility. These additional issues include aspects such as data characteristics (format, availability, quality control, reliability, transmission), peripheral utilities/hardware (power, telephone, on-site computer, backup power source), security, and others. The Team felt that its mandated focus on details pertaining to developing a monumentation system eliminated most of these additional concerns from the scope of this group. National CORS site selection information can be found in the document "National Geodetic Survey CORS System: Station Selection Criteria", dated February 1, 1999 (Book 2).

Recommendations

The Team determined that it is impossible to generate a CORS monument design that is appropriate for all types of site conditions and configurations. The recommendations eventually adopted by the Team, and presented here, were deemed to be appropriate for the widest range of situations that are likely to be met. There are some CORS installations that will require either a modification of the proposed design or, in some instances, a completely different approach.

The two basic elements that comprise a monument are the monument structure (the component that provides the physical support, stability, and connection to the surface of the earth) and the antenna mount (the component that allows the antenna to be physically connected to the monument structure). The Team worked on designing these two elements separately, keeping in mind that they would eventually need to be joined together for the final configuration.

Monument Structure

PAT 20 recommends a poured-in-place concrete pier monument for most future National CORS installations. Concrete piers are in use by various organizations, and the Team feels that this is the optimal general-purpose design. The Team's research indicated that a properly designed concrete pier monument will provide a high level of positional stability as well as a relatively benign signal environment. In addition, this type of monument is straightforward and relatively inexpensive to install. The important design characteristics of a pier monument were identified as the shape, depth, height, diameter, type of concrete, presence of reinforcement material, and installation procedure.

To provide good stability, the majority of the structure's concrete should be located in the below ground portion of the structure. The Team recommends a step-tiered cylindrical design in which the diameter and the depth of the sub-surface portion are greater than the diameter and the height of the above-surface portion. The transition between the two profiles takes place at ground level. For the sub-surface portion of the monument, the Team decided on a poured-in-place design utilizing an augered hole. The connection between the monument and the surrounding soil is likely to be greater with this kind of design than it would be if a form were utilized for the installation. In order to mitigate signal multipath, the diameter of the above-surface structure was chosen so that it is less than the diameter of most GPS antennas that might be mounted on the monument. To provide for structural continuity between the sub-surface and above-surface portions, the concrete should be poured in one session. A cylindrical construction form (such as a Sonotube), held in place by a temporary support, can be used when the concrete is poured for the above ground portion of the monument. The Sonotube can be removed once the concrete has sufficiently hardened.

The monument dimensions decided upon are: a minimum depth of 10 ft. (3.0 m) by a minimum diameter of 1.5 ft. (0.46 m) for the sub-surface portion and a height of 5 ft. (1.5 m) by a diameter of 1 ft. (0.3 m) for the above-surface portion. The minimum depth of 10 ft. (3.0 m) provides for an adequate mass of concrete, attachment to soil that is not influenced by frost penetration, and isolation from near-surface soil instabilities. This depth allows the monument to be classified with "B" stability ("monuments which generally hold their elevations fairly well") as documented in the NGS publication "Input Formats and Specifications of the National Geodetic Survey Data Base, Volume I. Horizontal Control Data." The above-surface diameter of 1 ft. (0.3 m) is less than that of most GPS antenna ground planes, thereby minimizing signal reflections from the top of the monument but still providing adequate stability and structural strength. The height of 5 ft. (1.5 m) places the antenna in the realm of what is believed to be an optimal distance above ground, from a multipath-mitigation standpoint. This height is very close to the configuration that is used in the antenna phase-center modeling work that has been performed by NGS. This similarity in signal environment is an important contributor to the success of the models for subsequent data reduction. The height of 5 ft. (1.5 m) will also facilitate the use of differential leveling to establish an orthometric height for the monument. A ratio of 2:1 of the depth-to-height provides good stability, with the monument's center of mass located well beneath the mid-point of the structure.

Having determined the dimensional characteristics of the monument, the Team addressed the type of concrete that would be used and whether the structure should include any kind of reinforcement within the concrete. Pertinent issues pertaining to some fundamentals of concrete are presented in Book 2. By examining this information and discussing requirements with concrete professionals, the Team decided that Type IIIA portland cement and 3/4- to 1-1/2-in. aggregate would have the appropriate strength, thermal expansion, and curing characteristics for a monument structure.

Concrete has high compressive strength but, by itself, has limited tensile and shear strength. To provide additional structural integrity, the Team decided that reinforcement material should be included within the concrete. The main purpose of the reinforcement is to provide the structure with shear strength at ground level where the monument diameter steps from 1.5 ft. (0.46 m) to 1 ft. (0.3 m). Due to the concerns about minimizing the amount of metal in close proximity to the GPS antenna, the Team felt that traditional rebar should be avoided. Marshall Industries Composites, Inc., produces a structural reinforcing material called C-Bar (See Book 2 for information about C-Bar). It is available in various size rods and is designed specifically as a non-metallic alternative to traditional rebar for concrete applications in which metal should be avoided. A reinforcement rod assembly constructed of C-Bar and embedded in the concrete at the time of construction will provide the reinforcement value of traditional rebar without compromising the GPS signal environment. The Team believes that the inclusion of C-Bar into the design is a low-

cost and simple means of enhancing the durability of the monument without compromising the GPS signal environment.

The Team's recommended design is very similar to the BFEC "Nelson Pier" monument that was discussed previously in this report.

See Figure 20 for the recommended monument structure design. Detailed instructions and specifications for constructing the monument structure are in Appendix B.

Design Variations

Although the design recommendations presented here will be usable for a wide range of site conditions, there may be specific situations where this design must be modified or, in some cases, completely abandoned. For example, when bedrock is encountered during the drilling of the monument hole or when there is exposed bedrock at the surface, the bedrock should be incorporated into the structure. By drilling into the bedrock and cementing the lower ends of the C-Bar reinforcing bars into the drill holes, it will be possible to anchor the upper portion of the monument to the bedrock. This will provide an extremely stable monument foundation.

Another situation that might require a slight design modification is where the monument is subject to an extremely wide range of temperatures. Whenever this is likely to occur, the installation of insulation around the above-ground portion of the monument might help to mitigate thermal expansion-induced movement of the structure. This will help to ensure a high-level of positional stability. If possible, the insulation should not be so bulky that it extends beyond the outer edge of the antenna. Some multipath signals might be reflected from the top of the insulation to the antenna, if the diameter of the insulation exceeds the diameter of the antenna.

Whenever a modification to the existing design is anticipated, there are several key considerations that should be kept in mind. First and foremost, the monument should be stable. It should hold its position well over daily, seasonal, and multi-year time scales. The monument should also have a minimal effect on the incoming GPS signals. This requires that the amount of metal in the structure be kept as small as possible. In addition, the top of the monument should be smaller than the diameter of the GPS antenna that will be used. Whenever possible, the height of the antenna should be approximately 5 ft. (1.5 m) above ground level.

Antenna Mount

The antenna mount component of the CORS monumentation system is the mechanism for attaching the GPS antenna to the monument structure. One goal in designing the antenna mount was, once again, to minimize the amount of metal and thus to mitigate GPS signal corruption. DuPont makes an acetal resin (a crystalline plastic) material called Delrin that is strong, impact resistant, and rigid. Delrin comes

in a variety of shapes and stocks and is machinable. It can be used as an alternative to many kinds of metal in situations where the presence of metal is problematic. See Book 2 for additional information about Delrin.

PAT 20 recommends the use of a custom-made antenna mount consisting of a rotating tribrach adapter mounted on a Delrin base. The antenna mount base, which must be custom-machined, consists of three notched Delrin legs (recommended dimensions are 1 in. (2.54 cm) diameter and 12 in. (0.3 m) long that are threaded into the underside of a circular Delrin platform (recommended dimensions are 6 in. (0.15 m) diameter and 1 in. (2.54 cm) thick). To allow for the antenna attachment and its orientation to north, a standard commercially available rotating tribrach adapter can be attached to the Delrin platform. To attach the rotating tribrach adapter to the platform, the standard tribrach studs are replaced with threaded studs that are screwed into the top of the Delrin platform and secured to the tribrach adapter with set screws. A locking screw secures the tribrach adapter plug once the antenna is oriented to true north.

When the monument is installed, the antenna adapter assembly can be integrated into the pier by pushing the Delrin legs into the wet concrete at the center of the monument top, so that the tribrach adapter and the top ½ in. (1.25 cm) of the circular Delrin platform protrude above the top of the concrete. This integration of the antenna mount into the monument structure minimizes the space beneath the antenna that might form a resonance cavity. Although the tribrach adapter is made of metal, the relatively small amount should have minimal impact on the signal environment.

See Figure 21 for the recommended antenna mount design. Detailed instructions and specifications for constructing the antenna mount are in Appendix B.

Reference Marks

PAT 20 was instructed also to address the issue of the CORS reference marks. The current NGS policy is to establish two stations within 0.6 mi (1 km) of the National CORS. The reference marks, which may be either existing or newly-established stations, must either be existing vertical control points or they must be tied to the vertical control network with conventional leveling observations. In addition to any leveling work, GPS ties are made between all combinations of the following stations: the two reference marks, the CORS, and the nearest Federal Base Network (FBN) station.

PAT 20 recommends that NGS continue with its current policy and procedures regarding National CORS reference marks.

Figure 20

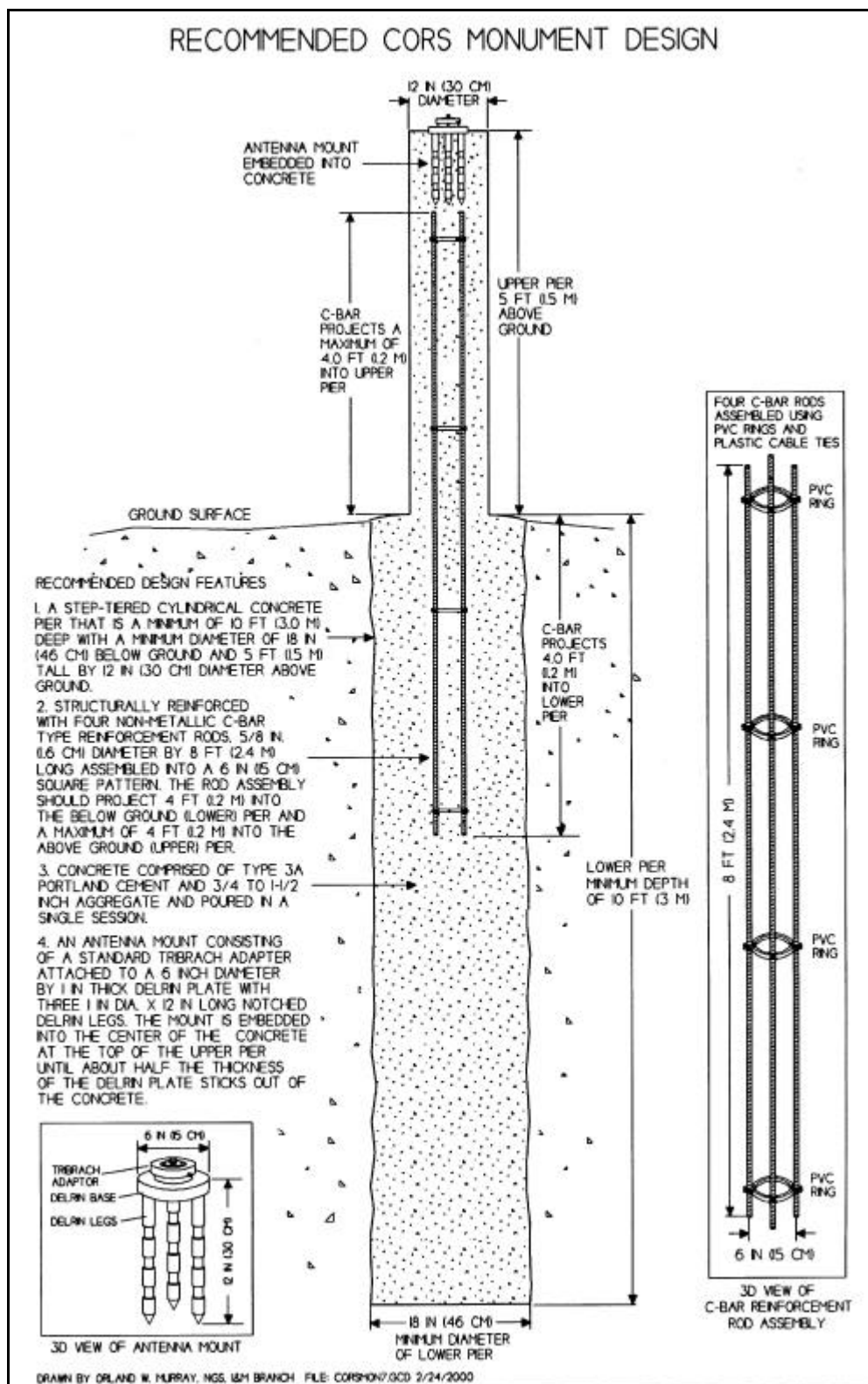
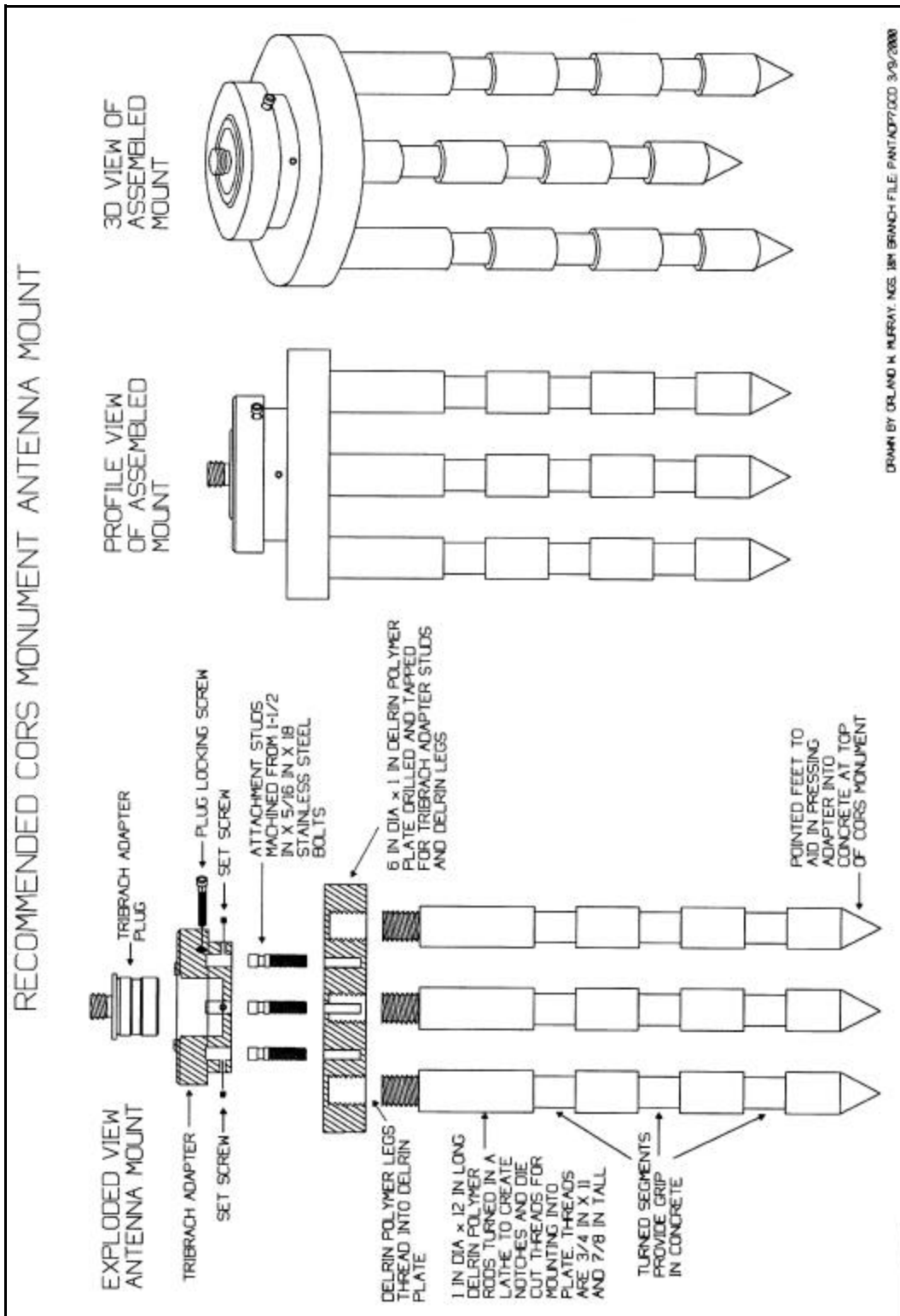


Figure 21



Prototype Monument Installation

On November 23-24, 1999, several members of PAT 20, with the assistance of NGS personnel from the Instrumentation and Methodologies Branch, installed a prototype CORS monument at the NGS facility in Corbin, Virginia. This prototype is based on the design recommendations developed by PAT 20 and presented in this report. The only difference between the recommended design and the prototype design is in the concrete reinforcement assembly. The recommendations specify an assembly that is 8 ft. (2.4 m) in length and constructed from C-Bar reinforcement rods. When the prototype components were being fabricated, 5-ft.-long (1.5 m) rods made of Delrin (the same material used for the antenna mount base) were used to make the reinforcement assembly. Although the Delrin assembly will provide the desired reinforcement to the concrete structure, C-Bar is more specifically designed for this kind of application. A 21-in. (0.53 m) diameter auger was used to drill the hole for the prototype monument. The dimensions of the resultant hole were 22 in. (0.56 m) diameter by 11 ft. 4 in. (3.45 m) deep. Both of these dimensions exceed the nominal values specified in the recommendations. The total cost of materials and services for the prototype monument installation was \$688.80. The labor involved in installing the monument amounted to about 24 staff-hours on the part of NGS employees.

Detailed information on the prototype construction procedures, itemized cost, and an as built drawing are included in the "Report on the Installation of the National CORS Prototype Monument" (Appendix A).

Conclusion

PAT 20 has examined many examples of existing CORS monuments, identified, and examined the important issues that impact the design of a monument, developed recommendations for a monumentation system design, and installed a prototype monument based on the recommendations.

PAT 20 recommends the following National CORS monument design: a step-tiered cylindrical concrete pier that is a minimum depth of 10 ft. (3.0 m) by a minimum diameter of 1.5 ft. (0.46 m) below ground level and a height of 5 ft. (1.5 m) by a diameter of 1 ft. (0.3 m) above ground, with an antenna mount consisting of a rotating tribrach adapter attached to a non-metallic base that is integrated into the concrete pier.

The Team believes that this design will be suitable for a wide range of site conditions and should provide the high level of horizontal and vertical stability required for National CORS applications. This kind of monument has an excellent chance for long term survivability. The monument materials (concrete, C-Bar reinforcement rods, Delrin stock, and tribrach adapter) are readily available and affordable. The preparation of materials and installation procedure are relatively straightforward and require only a limited amount of specialized equipment and technique. The diameter and height of the monument, along with the minimal amount of metal involved, provide a benign GPS signal environment. The antenna can be locked in a true north orientation and will be force-centered to a repeatable position whenever it is removed and replaced.

PAT 20 recommends that NGS continue with its current policy and procedures regarding the establishment of National CORS reference marks.