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Best Practices for GNSS NRTK Service Providers Operating in Nova Scotia

March 03, 2016

Version History

Version	Release Date	Modifications	Editor
1.0	Dec.2012	Original Document	Jason Bond
2.0	Oct. 2013	Based upon Guidelines for GNSS Active Control Stations draft document	Jason Bond
2.1	Mar. 2016	Addition of section on grounding of antenna cable at egress point, Section 3.5 Addition of station uptime best practice, Section 7.0 Addition of Appendix 5: Antenna Mast Guidelines	Jason Bond

Contents

Acknowledgement

Monument design information used in this document is based upon the *Guidelines for New and Existing Continuously Operating Reference Stations (CORS)* National Geodetic Survey, National Ocean Survey, NOAA, Silver Spring, MD 20910, February 2006 (http://geodesy.noaa.gov/CORS/Establish_Operate_CORS.shtml). As the need for guidelines for Global Navigation Satellite Systems Active Control Stations (or synonymously, CORS) arose in the Province of Nova Scotia, the NOAA document was discovered and its value was quickly recognized. Rather than invest significant effort to try and replicate the NGS's efforts, the document has been modified to suit the needs of the Province. The Province of Nova Scotia gratefully acknowledges the strong foundation of knowledge that the NGS has provided.

The Nova Scotia Coordinate Referencing program welcomes feedback on the content of this document. Please contact us at:

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Preface

At the time of preparing this document, it was recognized that Active Control Stations (ACSs) offered new opportunities for delivering the Nova Scotia Coordinate Referencing System (NSCRS) program. In order to put the technology in place, a review was conducted of best practices in the industry. These guidelines draw upon National Geodetic Survey (NGS) guidelines and the principles described within are generally accepted as best practice in the GNSS user community. The purpose of the guidelines is to help ensure a certain level of performance for NSCRS users. Specifically, it was desired to protect the interests of Nova Scotia Land Surveyors who are the gateway to land administration processes in Nova Scotia.

1.0 Introduction

The provision of a coordinate referencing system and access to its data has been a mandate of the Province since at least the mid 1960's. The Nova Scotia Coordinate Referencing System (NSCRS) is the foundation upon which all of the Province's geographic information relies. When functioning at a high level, the NSCRS leads to better asset management and infrastructure development. It is the role of the Province to represent the best interest of its citizens by ensuring that accuracy and widespread access to the Nova Scotia Coordinate Referencing System are provided on an ongoing basis.

Global Navigation Satellite Systems (GNSS) Active Control Stations (ACSs) and GNSS, network real-time kinematic service have emerged to play a key role in establishing and giving access to coordinate referencing systems around the world. As Nova Scotia looks to embrace the technology, it is important that best practices for establishing GNSS ACSs in the Nova Scotia Active Control Stations network (NSACS) and for offering GNSS network real-time kinematic (NRTK) services be put in place. This document has been compiled for that purpose. This document is also meant to handshake the *Guidelines for RTK GNSS Surveying in Canada* document available from Natural Resources Canada. By clearly defining the roles of both service providers and end users, more consistent outcomes are likely to be achieved.

These guidelines aim to:

a) Minimize monument stability concerns;
b) Minimize ACS coordinate assignment concerns;
c) Minimize GNSS signal distortion at ACSs; and
d) Maximize the quality of calculated positions, in accordance with models used in processing GPS data, to obtain centimeter to sub-centimeter level accuracy.

These guidelines are intended to foster the development of the NSACS network and to promote GNSS NRTK services that offer a high level of integrity for its users.

2.0 Definitions

The following conventions have been adopted for this document:

- **Active Control Station**: GNSS hardware that is permanently setup over a coordinated reference mark for the purpose of distributing corrections for Differential GNSS positioning.
- **Antenna Phase Center (APC)**: the electrical point, within or outside an antenna, at which the GPS signal is measured. The realization of the phase center is determined by the set of antenna phase center variations (PCV) corrections to account for the non-ideal electrical response as a function of elevation and azimuth angles.
- **Antenna Reference Point (ARP):** The point on the exterior of the antenna to which the antenna height is measured.
- **Antenna eccentricity**: The vertical and horizontal distances from the mark to the ARP.
- **Monument**: The structure (e.g., pillar, building…etc.), including the mount, which keeps the GPS antenna attached to earth's surface
- **Mount**: the device used to attach the antenna to the monument
- **Mark**: a unique and permanent point on the monument to which the antenna reference point is measured. This mark shall remain invariant with respect to the monument.
- **Shall**: compliance is required
- **Should**: compliance is strongly recommended, but not required
- **Site operator**: Person responsible for operating an ACS site
- **Site log**: Plain ASCII file that contains all historical information about a site and details the equipment and monument used.

3.0 ACS Monument Guidelines

No monument is perfect. There are, however, designs that are known to cause (or will likely cause) degradation in data quality, which should be avoided. The guidelines in the following sub-sections will help to ensure that ACS deliver high data quality. In general, the following factors should be considered in order of importance when choosing the best location for an ACS monument:

1. Monument stability
2. Satellite visibility
3. Data degradation factors
4. Equipment security
5. Proximity to power and communications

3.1 Monument Stability

An ACS monument should be designed to maximize its stability (maintain a fixed position in three dimensions) and minimize measurement of near-surface effects. The uppermost part of the ground is subject to the greatest amount of motion (e.g., soil expansion and contraction due to changes in water saturation, frost heave, soil weathering). Generally, increasing the depth of the monument improves its stability. Ensuring that an antenna is well anchored to the ground through the monument is essential so that the position and velocity associated with a given site represents the crustal position and velocity of the site, not just that of the antenna. Detailed discussion of benchmark stability and monument can be found in GSD (1978), NOAA (1978) and USACE (2012).

ACS sites should be designed to minimize the impact of:

- Caverns, sink holes, and mines
- Areas where there is active fluid/gas pumping
- Frost heave, shrinking and swelling of soil and rock
- Soil expansion and contraction
- Slope instability
- Soil consolidation
- Motion intrinsic to a monument e.g. thermal expansion and contraction

If the soil and geological conditions are questionable, a conservative, “worst case” scenario should be assumed.

3.2 Location

Choose an open area with minimal obstructions and minimum likelihood of change in the environment surrounding the monument. Avoid sites with future tree or shrub growth, building additions, rooftop additions, new antenna masts, satellite dishes, parking lots, chain link fences…etc. Also avoid nearby (within 30 m) reflectors such as vehicles, metal walls and metal signs which can cause signal multipath.

3.3 Obstructions

Obstructions should be kept below 10 degrees above the horizon from the ARP and there should be minimal obstructions from 0 to 10 degrees (see Figure 1). The greater the volume through which uninterrupted/unreflected signal can reach the antenna, the greater the likelihood of a robust position estimate.

Lightning rods, broadcast antennas or other objects should not extend above the antenna or be anywhere within 3 m of the antenna and all should be below the 0 degree of the horizontal surface containing the ARP.

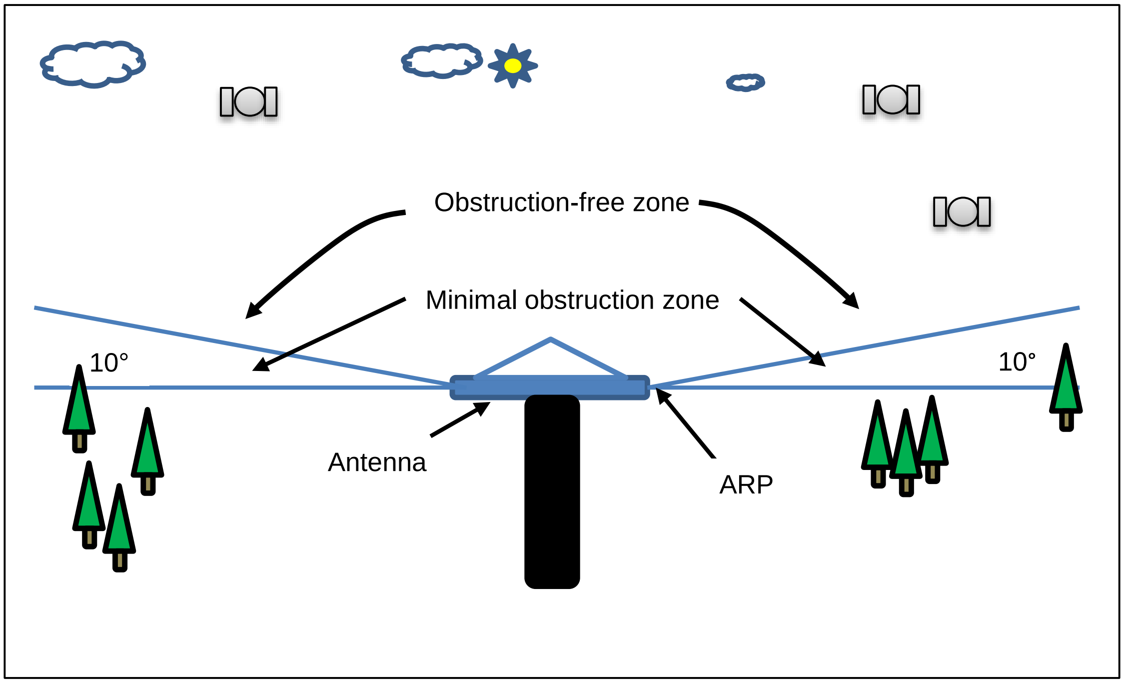

Figure 1: Obstruction-Free Zone around the Antenna

3.4 Radio Frequency Environment

The signals received by a ACS antenna and receiver can be detrimentally affected by interference from other radio frequency sources (e.g. TV, microwave, FM radio stations, cellular telephones, VHF and UHF repeaters, RADAR, high voltage power lines). This can cause additional noise, intermittent or partial loss of lock or even render sites inoperable. Every effort should be made to avoid proximity to such equipment and all such equipment must be documented in the site log.

3.5 Antenna Setup

A device shall exist between the monument and the antenna so that:

a) the antenna to be levelled and oriented to north; and

b) if the antenna is changed, the new ARP can be returned to the exact same point in 3-dimensional space as the previous ARP or the change in position between the mark and the ARP shall be measured to within ±1 mm.

If the antenna is simply attached to a threaded rod, the new antenna may not return to the same 3-D position or may be oriented differently (the latter would be immaterial only if the phase center variation model is perfectly symmetrical). Both events would require a new position to be computed, which is undesirable. The antenna shall be leveled to within 0.15 degrees or 2.5 mm/meter (this is easily achieved using a good quality spirit level available in most hardware stores). Tribrach's are not permitted, as there is no mechanism to lock the adjustable wheels in place. A number of devices exist that will do this (see Figure 2). For example:

www.ngs.noaa.gov/CORS/Articles/modifying_a_tribrach_adaptor.pdf
www.unavco.org/facility/project_support/permanent/equipment/mounts/levelingmount.html
www.unavco.org/facility/project_support/permanent/equipment/mounts/scignmount.html

Figure 2: Antenna Mount

The antenna shall be oriented to true north using the convention of aligning the antenna cable attachment point, unless the antenna has a different inscribed North point. Remember that declination is the angle between magnetic north and true north. A magnetic declination calculator for setting a compass correctly is available at: http://www.ngdc.noaa.gov/seg/geomag/jsp/Declination.jsp. The declination used shall be recorded in the log file (see Section 6.2. Site Log). All antenna phase center patterns assume an oriented antenna, and phase center values can differ between north and east by up to a centimeter.

The antenna cable should not be under tension. Looping the first section of cable next to the antenna and attaching it to the mount can best avoid this problem. If the cable is not encased in conduit, then care should be taken that it will not move around and be damaged. Take particular care at any point where the cable is subject to increased friction, e.g. edges and egress points. Typical GPS antenna cables for ACS (RG213/RG214) have a signal loss of 9 db/100ft/30m at 1Ghz. Total loss for installed length of cable at an ACS shall be 9 db or less, implying a maximum cable length of 100ft/30m. If a longer cable is needed then a lower loss cable shall be used (The type, manufacturer, and length of cable shall be listed in the Site Log, see 6.2).

The antenna cable should directly connect to the receiver, lightning arrestor and antenna. No connectors should be inserted to convert connector types (E.g., TNC to N-type). The junction point of the antenna cable and antenna after the two have been connected should be sealed with waterproof material (E.g., butyl wrap). Site operators shall insert a lightning arrestor in the antenna cable between the antenna and the receiver with its own independent ground. Additionally, the antenna cable should be grounded as close to the cable egress point as possible. A grounding kit like the one illustrated in Figure 3 can be used to avoid introducing a break in the cable. These measures should protect the receiver in the event of a lightning strike on or near the antenna. For more information, the Canadian Electrical Code should be consulted.. The following URL may be helpful which indicates the potential signal loss created by a poorly selected arrestor:
http://www.unavco.org/facility/project_support/permanent/equipment/lightning/lemp_report.html.

Figure 3: Example Antenna Cable Grounding Kit

When the antenna is not in a secure location, a security mechanism is required to minimize the chance of the antenna assembly being removed. Schmidt *et al.* (2000) provide an example of a security mechanism.

3.6 Ground-based Monuments

3.6.1 Pillars

ACS pillar-type monuments adhere to the following guidelines:

i. Should be approximately 1.5 m above the ground surface to mimic the geometry used at NGS's antenna phase center calibration facility. In the event that obstructions exist, a taller monument may be necessary.
ii. Shall have a deep foundation (e.g., concrete or bedrock), that extends at least 4 m below the frost line (see Appendix 4) and/or the center of mass of the pillar shall be below the frost line.
iii. The top of the pillar should be narrower than the widest part of the antenna, and the smaller the surface the better. In constructing the pillar, consider that future antennas may be smaller; hence the narrower the top of the pillar the better. The distance between the top of the pillar (if it has a surface) and the antenna should be less than 5 cm or greater than 1 GPS wavelength (~20 cm). This will allow enough room to manipulate a leveling and orienting device. These recommendations apply to the top of the pillar only; a very narrow pillar would be unstable and not recommended, however tapered pillars are good. These guidelines will mitigate multipath issues. The steel pillar design illustrated in Schmidt *et al.* (2000) is recommended (see Figure 4).

Figure 4: GPS pedestal monument (Schmidet et al., 2000)

Figure 5 illustrates a concrete pillar styled monument.

Figure 5: Ground based, concrete pillar monument

3.6.2 Braced

Braced monuments (see Figure 6) are especially stable and well anchored to the ground, although they more expensive than pillars. Extensive diagrams with details of all aspects of constructions are available through UNAVCO at:
http://pboweb.unavco.org/?pageid=45
http://www.unavco.org/facility/project_support/permanent/monumentation/deepdrilled.html
http://www.unavco.org/facility/project_support/permanent/monumentation/sdbm.html

Figure 6: Braced monument (UNAVCO, 2012)

3.7 Roof-based Monuments

3.7.1 Building Characteristics

Masonry buildings or buildings constructed of structural steel sitting on a concrete foundation are permitted. Solid brick or reinforced concrete buildings are recommended. The building should be at least 5 years old to increase the likelihood that all primary settling of the building has occurred. There should be no visible cracks on the outside or inside walls. To minimize the effects of thermal expansion as well as multipath issues, the following guidelines are used:

i. Buildings taller than two stories are not recommended.
ii. Buildings constructed of wood are not permitted.
iii. Metal frame buildings with metal walls are not permitted.
iv. Metal roofs should be avoided.

3.7.2 Location and Attachment to a Building

The following guidelines are used for locating and attaching ACS hardware to buildings:

i. Stainless steel or galvanized steel is recommended for longevity (Angle iron or circular pipe). Aluminum is not recommended as it has approximately twice the thermal expansion of steel/concrete (See Appendix 1 for sample coefficient of thermal expansion values).

ii. The antenna mount shall be bolted directly to the main part of the building; a load-bearing wall near a corner is recommended.

iii. The use of epoxy and threaded lock adhesives fasteners (bolts/anchors/rods) is strongly recommended.

iv. Mounting on a chimney is not recommended unless it has been filled with concrete or if it is particularly robust.

v. The mount should not interfere with the building's replaceable roof. This will minimize the chance that the mount will be disturbed when the roof is replaced.

vi. Attaching laterally to a load bearing wall:

   a. The mount should extend about 0.5 m above the roofline and be attached to the building for a length of at least 1 m, with at least 2 anchors/bolts (3 or more is preferred). The ratio of freestanding part to bolted part should be 1:2 or greater.

   b. The bolts/anchors shall penetrate directly through the mount (no u-bolts or unistrut brackets with metal ties/clamps). Spacers to keep the mount from sitting flush against the wall are acceptable.

vii. Attaching vertically to a master wall:

   a. A bolt or rod shall be anchored into a load-bearing wall.

   b. Take care not to void a roof warranty.

   c. Avoid metal flashing on a parapet wall.

viii. Aesthetics should be considered before leaving a site, especially when leasing equipment space. Masts should be blended into the natural color scheme of the building. Dark colours should be avoided to minimize thermal effects. Paint will also help to avoid corrosion of some materials.

Figure 7 illustrates an antenna mast attached to a load bearing wall, which uses through bolts four mounting (Figure 8).

Figure 7: Antenna mast connected to a load bearing wall

Figure 8: Through-bolts for mounting antenna mast

Despite having metal siding, the building in Figure 9 has a concrete inner wall. The antenna mast is mounted to the concrete inner wall using through bolts (Figure 10).

Figure 9: Metal Siding with Concrete Inner Wall Installation

Figure 10: Through bolts in concrete

Some locations, such as the one shown in Figure 11, necessitate some ingenuity. Nearby obstructions made the best choice for antenna location at the top of the spire. The antenna is fastened directly to structural steel.

Figure 11: Spire installation

4.0 Equipment

Site operators shall keep all receiver firmware current. Network administrators should be notified before planned updates occur. It is strongly recommended that equipment be upgraded and/or replaced as technology changes (e.g., new GPS signals are added). Equipment changes should, however, be minimized as they have the potential of resulting in a change in position.

4.1 Antenna

A consistent phase center and ARP for the antenna is essential to relate the GPS measurements to the reference mark on the monument. Ignoring the phase center variations can lead to errors of several centimeters. All analysis of GPS data shall be performed using an NGS-validated phase center model, including in the calculation of the official positional coordinates for an ACS site. Antennas shall be inspected at least annually for damage.

The antenna used for an ACS shall be:

i. Geodetic grade, preferably choke ring.

ii. Track GPS L1/L2 and GLONASS L1/L2

iii. Have -40°C to + -55°C operating temperature

iv. Be waterproof

v. Be able to mitigate snow accumulation without negatively impacting the stability of the Antenna Phase Centre.

vi. Have an NGS calibrated phase center model. If a radome is installed, then a custom antenna and radome pair calibration shall be performed for the antenna phase center model.

vii. Use an amplified signal splitter causing minimal signal distortion and having channel isolation, when required.

4.2 Receivers

ACS receivers shall have the following characteristics:

i. Track GPS L1/L2 signals and GLONASS L1/L2 signals and be capable of tracking modern signals (GPS L2C/L5, Galileo, Compass).

ii. Track at least 14 satellites on L1 and L2 above 0 degrees

iii. Provide L1 C/A-code pseudorange or P-code pseudorange and L1 and L2 full wavelength carrier phase

iv. Sample at a frequency of at least 1 Hz

v. Support NTRIP client and server (supporting at least 10 simultaneous clients) functionality

vi. Support RTCM SC104 versions 2.x and 3.x input/output

vii. -40°C to + 55°C operating temperature

viii. Power Consumption < 10 W

ix. L1 and L2 carrier phase measurement precision < 2 mm (RMS)

x. Data storage capacity for at least 24 hours of 1 Hz raw data

xi. Ethernet interface

Receivers shall be configured so that:

i. Smoothing is not applied to the observables

ii. Tracking occurs with an elevation cutoff angle of 0 degrees

iii. Observations are recorded at a sampling interval of at least 1 Hz.

iv. Hourly blocks (strongly preferred), or 24 hr blocks of data are logged according to GPS time.

v. Tracking occurs for all satellites regardless of health status since the US Department of Defense's criteria for designating an unhealthy satellite is not always applicable to ACS users.

4.3 Uninterruptible Power Supply

All ACSs shall have an uninterruptible power supply that will provides at least 24 hours of back up operating time for the receiver and any other equipment necessary to archive at least 24 hours of raw data at the receiver sampling interval.

5.0 Communications and Data Archiving

All data transfers between the ACSs and the GNSS NRTK Service Provider's site shall be done via the internet. Real-time GNSS corrections data shall be transmitted using Network Transport of RTCM Internet Protocol (NTRIP). The data shall be retrievable immediately after the hour if logging hourly or after 24h00 GPS time. The GNSS NRTK Service Provider's web and FTP server shall operate 24 hours a day. The GNSS NRTK Service Provider's shall make the data available in RINEX format (Version 2 or higher) indefinitely. The GNSS NRTK Service Provider's shall also store the native data format.

All file names and associated dates shall be recorded with respect to **GPS time**, **not local time**. Most GPS receivers will convert UTC to GPS time without user input. The recommended directory structure at the GNSS NRTK Service Provider's site is to use the following conventions and be in lowercase:

Native data:

/base_directory/native/yyyy/ddd/ssss/ssssdddh[mm].[c]

RINEX data:

/base_directory/rinex/yyyy/ddd/ssss/ssssdddh[mm].yyt.[c]

If the GNSS NRTK Service Provider wants to deliver RINEX observation, meteorological, navigation…etc. files as a group of files, the files within the archive shall be **uncompressed** and the archive should be labeled:

ssssdddh[mm].yy.c

Files should use the following convention all in lowercase, which follows the RINEX convention:

ssssdddh[mm].yyt.[c]

The following symbology is used:

base_directory: any directory on the site operator's ftp server where data are going to be stored.

ssss: the four-character site ID

ddd: the GPS day of year

yyyy: four digit GPS year

h: a letter that corresponds to an hour-long GPS time block (see below) or 0 (zero) for a full 24hr GPS time block.

00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
a	b	c	d	e	f	g	h	I	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x

mm: applies only to sites that record in less than 1 hour time blocks and consists of the minutes after the hour that the file begins e.g. if 30 minute files are collected then 00 and 30 would be used.

yy: the last two digits of four digit GPS year (e.g. 2004 is 04)

t: the file type as:

Type	Description
o	Observation
d	Observation Hatanaka compressed. The source code for creating and uncompressing this format is available at: ftp://terras.gsi.go.jp/software/RNXCMP
m	Meteorological
n	Navigation
s	Summary
c	Compression is optional, but recommended to save bandwidth. One of the following formats shall be used: a) zip – zip b) gz – gzip GNU zip (preferred) and available at: http://www.gnu.org/software/gzip/gzip.htm c) Z – UNIX compressed

The native binary files will have manufacturer specific extensions but should mimic the aforementioned format as closely as possible.

6.0 Site Metadata

6.1 Digital Photographs

A set of sharply focused digital photographs (at least 1 megapixel images) are required to evaluate and document a site. When taking photographs, remember that their purpose is to give a clear view of the equipment being used, how it is assembled, as well as the space around it for someone who has not visited the site. Photographs **shall use the filename specified in bold** between the dashes – (where ssss is the 4-charcter site ID). The convention for azimuth direction is 000 - north, 090 - east, 180 – south and 270 - west. Jpg format is preferred. The photographs shall include:

a) ssss_**monu**.jpg – A photograph showing the monument (pillar/braced/building) and antenna. The ground surface of the building or monument and antenna shall be visible.
b) ssss_**mark**.jpg – A photograph showing the mark. If no unique mark exists then a photograph of the threaded section of the mount, either laterally or from above the monument should be taken. If the site is actively collecting data then **DO NOT REMOVE** the antenna and ignore this requirement.
c) ssss_**ant_monu**.jpg – A close-up photograph that shows how the antenna is attached to the monument.
d) Four oriented photographs taken at the height of the ARP surface. The antenna should be included in the photograph but it should not significantly block the ability to view what lies behind the antenna, stand about 3-5 m away. If this is not possible place the camera directly at the top center of the antenna, and point the camera in the required direction:

    i. ssss_ant_000.jpg – North (000)
    ii. ssss_ant_090.jpg – East (090)
    iii. ssss_ant_180.jpg – South (180)
    iv. ssss_ant_270.jpg – West (270)
    v. If photographs from additional directions are useful please use the appropriate azimuth in the file name.

If the antenna is on a roof, you shall also include the following:

a) ssss_**ant_bldg**.jpg – A photograph showing “clearly” how the antenna is attached to the building.
b) ssss_**ant_roof**.jpg – A photograph showing the antenna and the roof surface.
c) ssss_**ant_sn**.jpg – A close-up photograph of the antenna showing its model and serial number.
d) ssss_**rec_sn**.jpg – A close-up photograph of the receiver showing its model and serial number.
e) ssss_**rec**.jpg – A photograph of the receiver location.

These photographs shall be updated if the equipment changes or changes occur in the physical space around the antenna.

6.2 Site Log

The site log should follow the format specified by the International Global Navigation Satellite System Service (IGS). This file contains all the historical information about a site and details the equipment and monument used. **The site log is of equal importance as the GNSS data collected at a site**. Detailed instructions are given in Appendix 2. Fill out **ALL** parts for which you have information. **DO NOT DELETE** any empty or inapplicable sections. These files shall be “machine readable” and therefore shall be saved as **ASCII files and have the**

exact spacing as described in the instructions (Appendix 2). **Most entries can only be on one line**, if more information is needed please enter it in the Additional Information part of each section.

7.0 Day-to-Day Quality Control Information

GNSS NRTK Service Providers shall:

a) Perform data integrity checks on a daily basis to detect unstable ACS sites

b) Perform data integrity checks on a daily basis to detect sites that are not operating.

c) Report ACS that have sudden movements as unstable. As a rule of thumb, ACS that move:

   i. more than 5 mm horizontally or 10 mm vertically in less than 1 hour or
   ii. more than 10 mm horizontally and 15 mm vertically in a 24 hour period

   should be regarded as unstable.

d) Report to clients any data performance issues affecting normal GNSS NRTK services within 24 hours.

It is highly recommended that GNSS NRTK Service Providers provide clients with the ability to view station uptime so that they can confirm data integrity during the course of a survey.

8.0 Server Infrastructure

GNSS RTK Service Providers shall use redundant server infrastructure for delivering NSACS data to users. Each server should be connected to an uninterruptible power supply that can deliver at least 2 hours of operation time in the event of a power outage. The service delivery system should be scalable to support potentially thousands of users.

9.0 Coordinate Assignment

GNSS RTK Service Providers shall use ACS coordinates certified by the appropriate government agency.

10.0 Credentials

GNSS RTK Service Providers engage in geomatics engineering services by collecting and managing geographically referenced information which directly impacts other engineering, construction and land administration activities. Companies conducting engineering services are required to register within the provincial jurisdiction in which they operate. In Canada, engineers and technologies benefit from reciprocity agreements between the provinces, making it easier for a professional registered in one jurisdiction to register in another.

GNSS RTK Service Providers should have within their organization either a:

a) Geomatics Engineer licensed to practice in the Province of Nova Scotia (P.Eng. registered with the Association of Professional Engineers of Nova Scotia); or

b) Certified Geomatics Engineering Technologist (registered as a C.E.T. with TechNova) with a minimum of 5 years of relevant geomatics experience.

In either case, the designated individual(s) shall have completed courses in Geodesy, Mapping and Adjustments (each course comprised of a full year of credit hours) as part of their formal education. Having such capacity will ensure that:

i. The company offering GNSS RTK Services has the capability to address technical issues that arise during the normal course of business

ii. The company adheres to local standards of practice

11.0 Compliance Checklist

The following checklist shall be used when evaluating compliance to the best practices described within this document.

Best Practice	Compliant?
Monument Design	
- Uses stable locations	
- Avoids obstructions	
- Avoids signal interference	
- Top of monuments smaller than antennas	
- Uses appropriate building materials	
- Uses appropriate mounting techniques	
Antenna Setup	
- Uses orientation / leveling devices	
- Orientates antennas to North	
- Ensures antenna cables are not under tension	
- Meets antenna loss specifications	
- Uses security mechanisms	
- Uses lightning protection	
Equipment	
- Uses appropriate antennas	
- Uses appropriate receivers	
- Uses UPSs	
Communications and Data Archiving	
- Uses appropriate communications protocol	
- Archives data in an easily understood and accessible format	
Site Metadata	
- Provides appropriate site metadata	
- Provides a site log	
Quality Control	
- Provides data integrity checks to detect unstable monuments	
- Provides data integrity checks to detect ACSs that are not operating	
- Informs clients of data performance issues within 24 hours of detection	
Server Infrastructure	
- Uses redundant server infrastructure	
- Uses UPSs	
Coordinate Assignment	
- Uses certified coordinates	
Credentials	
- Has appropriate staffing to meet technical needs of the business	

Appendix 1: Evaluation Form for an ACS Site

Related Section	Data Quality and Geographic Location	N/A	Invalid	Modify	Accept
4.0	24 hours of data				
4.0	TEQC results				
4.0	Distance to nearest ACS				

Additional Comments:

Related Section	Site Location, Obstructions and Radio Frequencies	N/A	Invalid	Modify	Accept
5.2	Location				
5.3	Obstructions				
5.4	Radio Frequency Environment				

Additional Comments:

Related Section	Antenna Setup	N/A	Invalid	Modify	Accept
5.5	Levelling and orienting device				
5.5	Antenna level				
5.5	Antenna oriented to North				
5.5	Antenna cable tension				

Additional Comments:

Related Section	Ground-based Monument	N/A	Invalid	Modify	Accept
5.6.1	Width of top of pillar narrower than antenna				

5.6.2	Braced monument				

Additional Comments:

Related Section	**Roof-based Monument**	**N/A**	**Invalid**	**Modify**	**Accept**
5.7.1	Masonry Building				
5.7.2	Type of attachment bolts				
5.7.2	Ratio of bolted length to free standing length				

Additional Comments:

Related Section	**Equipment**	**N/A**	**Invalid**	**Modify**	**Accept**
6.1	Valid antenna type				
6.1	Valid radome type				
6.2	Valid receiver type				
6.3	Suitable uninterruptible power supply				

Additional Comments:

Related Section	**Site Metadata – Digital Photographs**	**N/A**	**Invalid**	**Modify**	**Accept**
8.1	Monument (pillar/braced/building) and antenna: **ssss_monu**				
8.1	Mark: **ssss_mark**				
8.1	Antenna attached to monument: **ssss_ant_monu**				
8.1	View of 000 (north): **ssss_ant_000**				
8.1	View of 090 (east): **ssss_ant_090**				
8.1	View of 180 (south): **ssss_ant_180**				
8.1	View of 270 (west): **ssss_ant_270**				
8.1	Antenna attached to the building: **ssss_ant_bldg** (if applicable)				
8.1	Antenna and the roof surface: **ssss_ant_roof** (if applicable)				
8.1	Antenna model and serial number: **ssss_ant_sn**				
8.1	Receiver model and serial number: **ssss_rec_sn**				

8.1	Receiver location: **ssss_rec**				
8.1	Resolution and size of photographs				

Additional Comments:

Related Section	Site Metadata – Site Log	N/A	Invalid	Modify	Accept
8.2	Detailed monument information				
8.2	Height of monument and dimensions of material				
8.2	Dimensions of building/monument foundations				
8.2	Description of materials used				
8.2	Date Installed				
8.2	Receiver name and serial number match photograph				
8.2	Receiver install and removed dates are valid				
8.2	Antenna name and serial number match photograph				
8.2	Antenna install and removed dates are valid				
8.2	Antenna cable type and length				
8.2	Contact information				

Additional Comments:

Related Section	Web Page Content	N/A	Invalid	Modify	Accept
9.1	RINEX files				
9.1	Photographs				
9.1	Site log				
9.1	Quality Control				
9.1, 9.2	Appropriate web links				

Additional Comments:

Appendix 2: Instructions for Completing the Site Log

The Site Log template provided by the International GNSS Service is used for the NSACS: http://igscb.jpl.nasa.gov/igscb/station/general/blank.log .

Instructions for completing the Site Log are found here: ftp://igscb.jpl.nasa.gov/pub/station/general/sitelog_instr.txt .

Examples of Site Log files can are found here: http://igscb.jpl.nasa.gov/igscb/station/log/ .

Appendix 3: Coefficients of Thermal Expansion

Presented is a subset of coefficients of thermal expansion from Eng. Toolbox [2012]:

Product	**Linear Temperature Expansion Coefficient - *α*-**	
	(10^{-6} m/m K)	*(10^{-6} in/in °F)*
ABS (Acrylonitrile butadiene styrene) thermoplastic	73.8	41
ABS -glass fiber-reinforced	30.4	17
Acetal	106.5	59.2
Acetal - glass fiber-reinforced	39.4	22
Acrylic, sheet, cast	81	45
Acrylic, extruded	234	130
Alumina	5.4	3.0
Aluminum	22.2	12.3
Antimony	10.4	5.8
Brass	18.7	10.4
Brick masonry	5.5	3.1
Bronze	18.0	10.0
Cast Iron Gray	10.8	6.0
Cement	10.0	6.0
Chromium	6.2	3.4
Clay tile structure	5.9	3.3
Cobalt	12	6.7
Concrete	14.5	8.0
Concrete structure	9.8	5.5
Copper	16.6	9.3
Copper, Beryllium 25	17.8	9.9
Diamond (Carbon)	1.18	0.66
Epoxy, castings resins & compounds, unfilled	55	31
Glass, hard	5.9	3.3
Glass, Pyrex	4.0	2.2
Glass, plate	9.0	5.0
Gold	14.2	8.2
Granite	7.9	4.4
Graphite, pure	7.9	4.4
Invar	1.5	0.8
Iridium	6.4	3.6
Iron, pure	12.0	6.7

Product	**Linear Temperature Expansion Coefficient - *α*-**	
	(10^{-6} m/m K)	*(10^{-6} in/in ^{o}F)*
Iron, cast	10.4	5.9
Iron, forged	11.3	6.3
Lead	28.0	15.1
Marble	5.5 - 14.1	3.1 - 7.9
Masonry	4.7 - 9.0	2.6 - 5.0
Nickel	13.0	7.2
Polyvinyl chloride (PVC)	50.4	28
Silver	19.5	10.7
Steel	13.0	7.3
Steel Stainless Austenitic (304)	17.3	9.6
Steel Stainless Austenitic (310)	14.4	8.0
Steel Stainless Austenitic (316)	16.0	8.9
Steel Stainless Ferritic (410)	9.9	5.5
Tin	23.4	13.0
Titanium	8.6	4.8
Tungsten	4.3	2.4
Zinc	29.7	16.5

Appendix 4: Frost Depth Information

Presented are a map of freezing index values in Canada (Figure 12) and a table of corresponding frost depths (Figure 13) based on data from Environment Canada [Urecon, 2012].

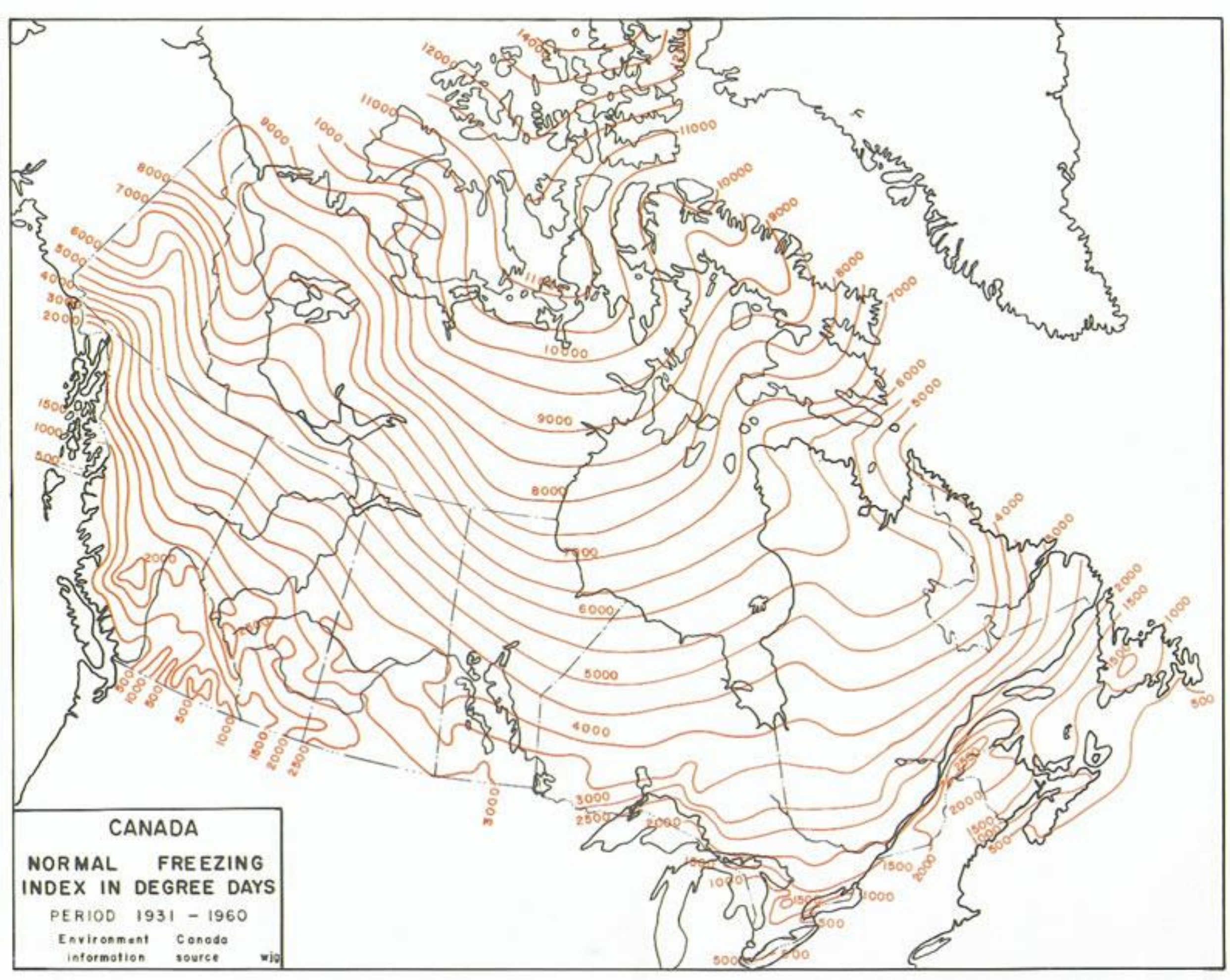

Figure 12: Normal Freezing Index in Degree Days, Canada

Freezing Index Degree days	Estimated Frost Depth in meters
400	0.66
450	0.71
500	0.76
550	0.81
600	0.86
650	0.91
700	0.96
750	1.00
800	1.05
850	1.09
900	1.14
950	1.18
1000	1.21
1050	1.25
1100	1.29
1150	1.32
1200	1.36
1250	1.39
1300	1.43
1350	1.47
1400	1.50
1450	1.54
1500	1.57
1550	1.62

Figure 13: Freezing Index Degree and Associated Frost Depth

Appendix 5: Antenna Mast Design

The majority of antenna masts installed for the NSACS are attached to exterior walls using 2 or more mount points. Figure 14 and Figure 15 illustrate a typical scenario for mounting a mast to an exterior wall. The main variation in design for each site is caused by the height of above the top mount that is required to get above obstructions on the roof. This height impacts the overall length of the antenna mast in order to maintain a ratio of at least 2:1 for the attached section to the cantilever section.

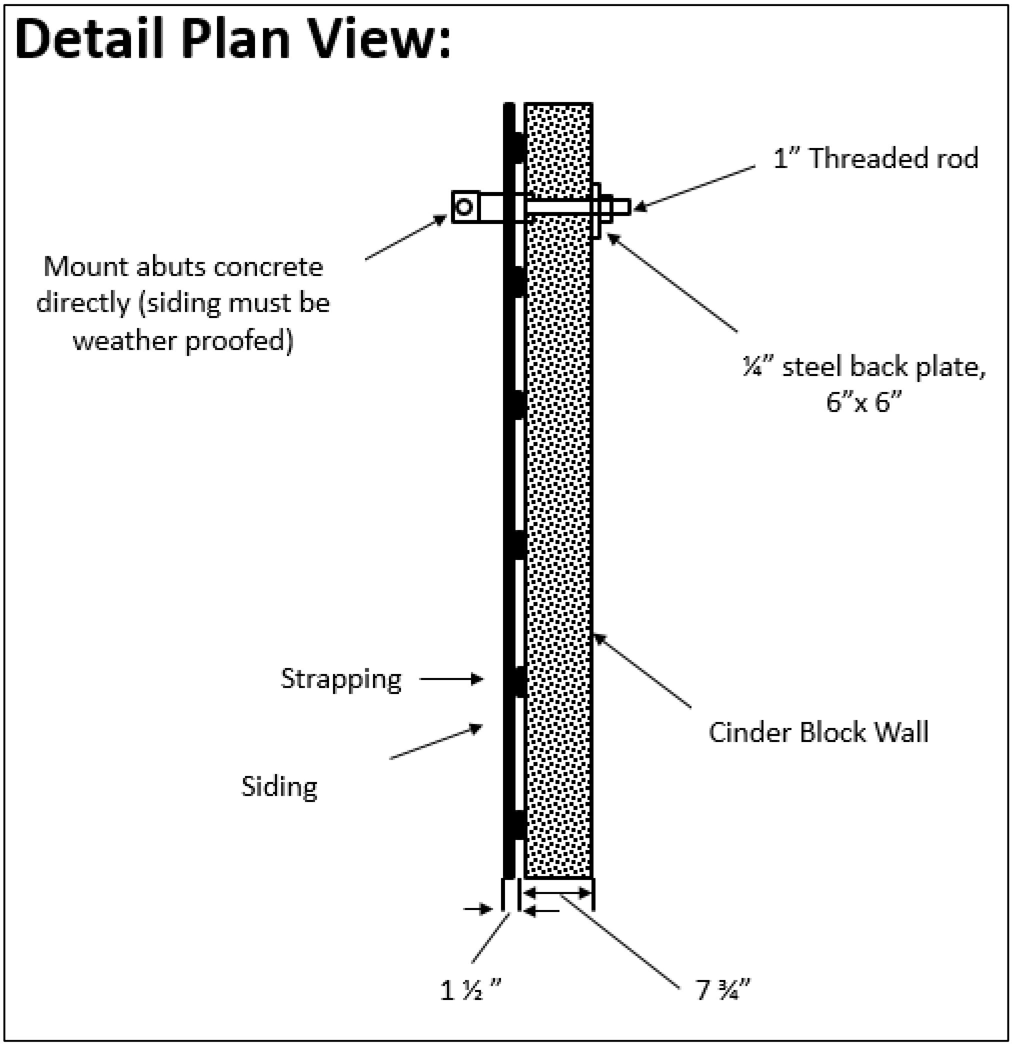

Figure 14: Plan view of an Antenna Mount Installation

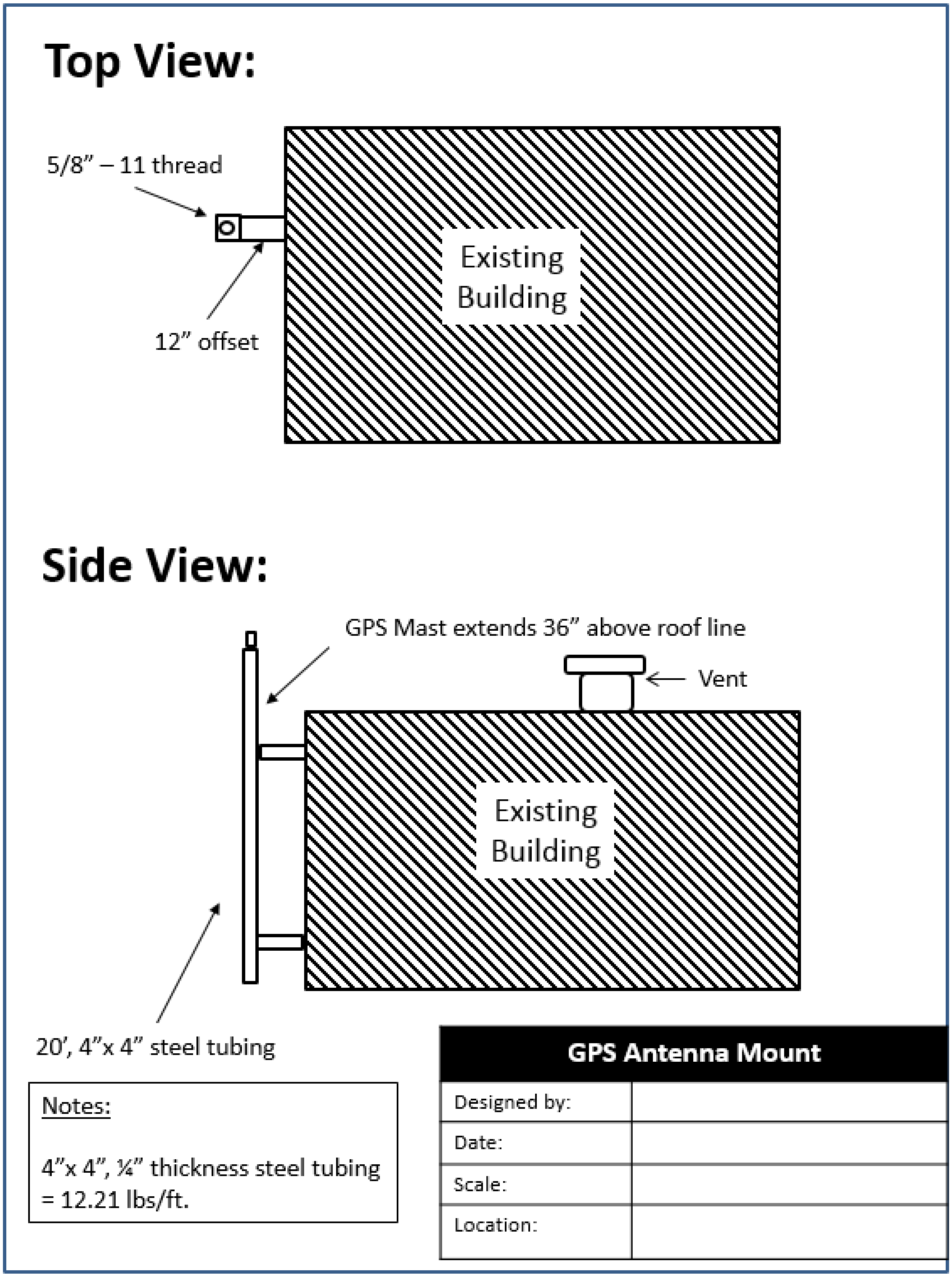

Figure 15: Example Exterior Wall Installation

Below are general GPS antenna mast design guidelines that have been determined through structural loading analysis which take into account wind loading conditions in Nova Scotia:

a) Install the mounts at the horizontal and vertical intersections of the mortar between the cinder blocks
b) Use 3” x 3”,¼” thickness HSS for the mounts (or larger if any of the criteria are exceed below).
c) Use 1” rods threaded rods (or larger) for the mounts
d) Use 3 mounts whenever possible.
e) Minimize mount lengths. Do not exceed 30 cm (12”) mount lengths. If longer mounts are required, consider further structural analysis.
f) Back plates should be a minimum of 15 cm x 15 cm (6” x 6”). Larger is better.
g) Use a minimum of 2:1 ratio of anchored section to free standing section. When this is not possible, use stiffener plates and/or cable ties to secure the free standing section to achieve the desired ratio.
h) Steel should be galvanized with a minimum zinc coating of 600 g/m2
i) Do not exceed 13’ above the top mount when using 1” bolts and either 2 or 3 mounts (deflection limit exceed, also applicable to welded mounts)
j) Do not exceed 8’ above the top mount when using 3/4” bolts and either 2 or 3 mounts (deflection limit exceed, also applicable to welded mounts).

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