

CHAPTER 5

GNSS & Control

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Sec. 5.01 General

*The Global Positioning System (GPS) technology is the system created and maintained by the United States. GLONASS is the Russian counterpart to GPS. These two systems combined are now referred to as Global Navigational Satellite System (GNSS) and continues to advance and improve its capabilities which has become a common tool for surveying that is not only “smaller, lighter and faster” but has the ability to perform geodetic control surveying in a fraction of the time as compared to classical terrestrial survey methods with a total station for example. GNSS has enabled surveyors the ability to establish control for a project from known existing control that may be miles away. VDOT utilizes GNSS for securing control values for primary control as well as photo control. VDOT allows other uses of GNSS specifically, the use of Real-Time Kinematic (RTK) GNSS surveying for photo control, right-of-way and corridor baseline stakeout, and also topographic collection when standard industry guidelines are followed. Other divisions within VDOT are also utilizing GNSS in one form or another to collect data for their specific needs.

As with any surveying tool, certain guidelines, specifications and methodologies must be adhered to. The intent of this section of the survey manual is to assist the surveyor in the mission planning, collection and processing GNSS data for VDOT survey projects. The surveyor should consult the publications, “**Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques, Version 5.0: May 11, 1988**” Reprinted with corrections: August 1, 1989, published by the Federal Geodetic Control Committee (FGCC) and also the “**Standards and Specifications for Geodetic Control Networks**” as published by the Federal Geodetic Control Committee (FGCC), Rockville MD, September 1984. Additionally a number of memoranda from the National Geodetic Survey should be followed as a guide when establishing new survey control. Specifically NOAA Technical Memorandum NOS NGS 58, Guidelines for establishing Ellipsoid Heights, and NOAA Technical Memorandum NOS NGS 59, Guidelines for establishing GPS-Derived Orthometric Heights. This chapter was prepared heavily in parts, from these NGS publications. VDOT will continue its procedures to generate, via GNSS survey techniques, state plane coordinates and orthometric heights in U.S. Survey Feet for its Route Survey projects. These values shall be converted to the VDOT Project Coordinates, which are also given in the U.S. Survey foot. For more on Project coordinates, see [Section 5.07](#) regarding LD-200 cards in this chapter. It is important to remember however that legacy projects, projects started or completed before 2014, will reflect a variety of coordinate configurations and VDOT survey control from older projects should be used with this understanding.

Sec. 5.02 GNSS Equipment

The GNSS geodetic receivers used for static survey operations shall receive both carrier frequencies transmitted by the current constellation of GNSS satellites and shall have the capability of tracking a minimum of eight GNSS satellites simultaneously. The receivers shall have the capability to receive and decode the C/A code and the P-code data on the L1 frequency and the P-code in the L2 frequency. The receivers should have the means to use the encrypted P-code.

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Dual frequency receivers are required for precision surveys to correct for the effects of ionospheric refraction where the magnitude of the error may range from 1 to 10 ppm. The receivers must record the phase of the satellite signals, the receiver clock times and the signal strength or quality of the signal. The phase center of the antenna, which is constant and unique to the antenna model, should be known from the manufacturer. It is best not to use different antenna models during a survey, as the phase center will create a bias in the elevations of survey points. If the receiver does not have a known phase center database relating to antenna type, the user should have the ability to enter the measurement components for the phase center height of the antenna. The measurement components are a measured height above a survey point to a mark on an adapter (or to a corner of the antenna) and the fixed constant distance from an adapter mark to the phase center of the antenna (provided by the manufacturer). [Figure 5-A](#), is an example from the NGS illustrating the different antenna measurements required for different antenna types. ***Fixed Height Tripods are recommended for use during *GNSS missions to avoid measurement or transcription errors.*** These GNSS receivers should be programmable and have several I/O ports. The software should be able to convert the data to RINEX-3 format for use with other GNSS systems and software.

Sec. 5.03 GNSS Networks and Accuracy Standards

In general, the GNSS Network will consist of known points and all points to be surveyed, allowing loop closures to be calculated from processing procedures utilizing data from a minimum of two sessions that form a loop. A known point would be a point that has a known position and/or elevation. A HARN Station, a CORS site, a NGS vertical station, a USGS monument tied to NAVD88 datum or, especially in VDOT's case, an existing survey station from an existing project, would be considered a known point. A minimum of three known points shall be included in the observing scheme. The three known points should be based on or originate from a common datum. In some cases, it is acceptable to use available software to convert elevations to the NAVD88 datum. The location of the new control points shall depend on the optimum layout to carry out the required needs of the survey.

The “**Geometric Geodetic Accuracy Standards and Specifications for Using GNSS Relative Positioning Techniques**”, version 5.0 by the Federal Geodetic Control Committee (FGCC), is VDOT's source for the definition of accuracy standards and the specifications and procedures to achieve those standards. When requested, any surveyor performing a GNSS survey for VDOT that must comply with an accuracy standard, shall adhere to the standards and specifications as published by the FGCC.

The accuracy standard for the survey will depend on several factors. These factors include, but are not limited to:

- number of receivers available for the project
- the “mission plan” or observation scheme
- satellite availability and geometry
- signal strength
- network geometry
- observation duration

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Sec. 5.04 General Specifications for *GNSS Surveys

In general, this section is intended to be a guide for any surveyor who is providing VDOT with GNSS data. These procedures are general minimum requirements that must be met by the surveyor in order for the GNSS survey data to be accepted by VDOT. These procedures are for static and rapid static GNSS observations and techniques. Please refer to “**Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques**” for more specific criteria not covered here. When experience and field conditions allow for alternative procedures, at the discretion of the surveyor in charge, then documentation will be provided demonstrating the accuracy obtained and the procedures followed.

1. **GNSS Survey Project Datum.** Unless otherwise instructed, **ALL VDOT GNSS CONTROL SURVEYS SHALL BE REFERENCED TO THE CURRENT PUBLISHED NATIONAL SPATIAL REFERENCE SYSTEM (NSRS) ADJUSTMENT AND THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88) SHALL BE THE ELEVATION DATUM.** Only horizontal NAD 83 coordinates and control data observed by GNSS methods from reference stations included in the NSRS will be accepted by VDOT. The NSRS contains GNSS stations and data published from the following network observations: Continuously Operating Reference Stations (CORS), Federal Base Network (FBN) surveys, Cooperative Base Network (CBN) surveys, Area Navigation Approach (ANA) airport surveys, and “Blue-booked” User Densification Network (UDN) GNSS surveys.
2. **GNSS Network Control Procedures.** All GNSS Network Control and Field Survey procedures will conform to the standards as defined in this section, for routine VDOT surveys, shown hereon as **2a** through **2o**. The intent of these procedures is to produce GNSS surveys and data for the **Project Control Monumentation** that meets a geometric accuracy of 1:100,000 at the 68% confidence interval. A list of specifications is included as [Figure 5-P](#), for easy reference.
 - 2a. A minimum of three (3) GNSS receivers shall be used simultaneously during all Static & Rapid Static GNSS sessions.
 - 2b. Existing or known points that will be used to control the survey shall be occupied simultaneously during the initial observation sessions. This is a check to ensure that existing, known or network control has not been disturbed and that the published values are, indeed correct. This is an integral part of the mission plan.
 - 2c. Horizontal networks shall be connected to a minimum of two (2) NGS B-order (or higher) stations (see #1 of this section). At least one benchmark shall be used and held fixed for surveys where horizontal values will be paramount. The use of eccentric horizontal stations is not permitted.

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2d. Vertical networks shall be connected to a minimum of three (3) third-order (or higher) bench marks. At least two of the benchmarks shall be near the project boundary to help determine the geoid separation of the project area.

2e. Sight (or station) pairs that are to be established by *GNSS methods to provide azimuths for the survey shall be inter-visible and spaced no less than 600 feet apart. Azimuth pairs that are to be established by GNSS methods shall be spaced approximately one mile apart at a minimum and no more than 3 miles apart. Each sight (or station) pair and each azimuth pair shall be occupied at least **twice** simultaneously and separated by a minimum of one-half hour to create a redundant, direct connection between project control points. A sample network scheme is included as [Figure 5-B](#).

2f. **During** each session, a minimum of 5 satellites shall be observed simultaneously. The Geometry Dilution of Precision (GDOP) shall never be greater than 6 at any time during the observation session. The Position Dilution Precision (PDOP) shall never be greater than 4 at any time during the observation session. Acceptable GDOP & PDOP values can be achieved through good mission planning practices and utilization of mission planning software.

2g. Each session's, data sampling shall have an epoch time interval of 5 seconds for Rapid Static survey procedures and 15 seconds for Static survey procedures. Satellite signals shall be observed from a minimum of 2 quadrants that are diagonally opposite from each other during Rapid Static survey missions. Satellite signals shall be observed from a minimum of 3 quadrants during a Static survey mission. This requirement shall be met while monitoring data collection in the field. It will also be verified by the GDOP value.

2h. Satellite receivers and processing software shall be programmed such that any satellite data below an elevation mask of 15 degrees shall not be used in the processing of baseline vectors. Any data below the 15-degree elevation mask would be questionable due to effects of atmospheric refraction.

2i. During reconnaissance and each observation session, careful notes or obstruction diagrams (see [Figure 5-C](#)) shall be recorded for any obstructions that are 20 degrees or higher above the horizon. Proper mission planning can minimize the effects of any obstructions and maximize the opportunity for a productive observation session.

2j. The geoid model **to be** used shall be the **2012A Geoid Model**. This version shall be the model used for determining the geoid separation for each project control point and subsequent elevation.

2k. The ellipsoid model **to be** used for determining elevation of the ellipsoid, shall be the **WGS 1984** ellipsoid model.

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2l. VDOT requires that the final adjusted coordinates for the *GNSS project shall be the product of a three-dimensional least squares adjustment software package.

2m. Static observation procedures shall be required for all baselines with a length of 20 kilometers (km) or longer. For a baseline length between 20 and 50 kilometers, observation sessions shall be at a minimum, 2.5 hours plus one minute per kilometer of baseline length for that session. For a baseline length between 50 and 100 kilometers, observation sessions shall be at a minimum, 3.5 hours plus one minute per kilometer of baseline length for that session. Proper mission planning and point site selections are vital to the success of the observing session.

2n. Rapid Static observation procedures may be used for all baselines shorter than 20 kilometers (km) in length. Observation sessions shall be at a minimum, 15 minutes plus one minute per kilometer of baseline length for that session. Proper mission planning and point site selections are vital to the success of the observing session. From a conservative standpoint, it is strongly recommended to add additional time to minimize the effect of solar activity, atmospheric refraction and unhealthy satellites.

2o. The determination of observation duration is the responsibility of the Surveyor of responsible charge, and will be a function of the spacing of known control, distance of known control to survey project control, and the length of the project corridor among other factors. Again, if control is farther than 20 kilometers from the project, static observation procedures will be used.

3. **Securing Photogrammetry Control.** Securing control for photogrammetry will also follow the same guidelines as listed above. If control is nearby, the photogrammetry mission can be accomplished with rapid static observation procedures using “leap-frog” or traversing techniques through the control such that direct measurements are made between consecutive targets. Intermittent ties to the existing, known control and/or the monumented project control should be made during the mission. Proper mission planning techniques will develop the best results and checks for the mission. **The adjustment of photogrammetry control should be independent of the VDOT Project Control Monumentation adjustment.**

4. **Utilizing RTK GNSS on VDOT Projects.** At the time of this revision to the Survey manual, VDOT is currently allowing the use of Real-Time Kinematic (RTK) GNSS surveying equipment and procedures capable of achieving a 2-cm positional accuracy. RTK GNSS surveying techniques utilizing a base station on established control such as a VDOT project control point, a HARN point, or dialing into a subscription RTK service for corrections for securing photo control and topography will be acceptable to VDOT when measures are taken to insure similar accuracy results as would be achieved by using Static or Rapid-Static procedures outlined in this manual*. Prior to securing photo control, the surveyor shall have a base unit set on known control and shall check the values at another control point with the roving unit.

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The surveyor must provide proof of photo control points being measured at least twice by RTK methods, spot-checked by conventional survey methods, and that the positional differences are insignificant. The surveyor shall verify that the positional accuracy meets or exceeds the survey specifications. RTK techniques are relatively new and therefore are continually evolving as field practices and experience present improved methods of collection. *RTK surveying techniques are being improved almost daily and are too numerous to outline in this manual. Therefore it is incumbent on, and the responsibility of, the surveyor with responsible charge providing data to VDOT to secure results that would meet similar accuracy standards as other methods outlined herein. It is also required that documentation demonstrating the method of collection, status of base station control, ties to the CORS or HARN, if used, as well as the accuracy acquired, shall be provided along with the deliverable survey data. Any questions regarding field procedures may be directed to VDOT's Geodetic Surveys Engineer.

5. **Utilizing OPUS on VDOT Projects:**

*This ***Online Positioning User Service (OPUS)*** provides simple access to high-accuracy National Spatial Reference System (NSRS) coordinates. By uploading a data file collected with a survey-grade GPS receiver you can obtain an NSRS position via email.

OPUS requires minimal user input and uses software which computes coordinates for NGS' Continuously Operating Reference Station (CORS) network. The resulting positions are accurate and consistent with other NSRS users.

Your solution is sent privately via email, and, if you choose, can also be shared publicly via the NGS website. To use properly, please familiarize yourself with all the information provided on the National Geodetic Survey website <http://www.ngs.noaa.gov/OPUS/>.

As with RTK GNSS procedures outlined above it is permissible to use OPUS for establishing data for VDOT Projects as long as measures and care are taken to achieve similar accuracy results that meet or exceed the accuracy results that would otherwise be achieved by using Static or Rapid-Static procedures outlined in this manual.

The responsible charge surveyor shall verify that the positional accuracy meets or exceeds the required survey specifications. OPUS techniques are relatively new and therefore are continually evolving as field practices and experience present improved methods of collection. OPUS surveying techniques are being improved almost daily and are too numerous to outline in this manual. Therefore it is incumbent on, and the responsibility of, the surveyor with responsible charge providing data to VDOT to secure results that would meet similar accuracy standards as other methods outlined herein. It is also required that documentation demonstrating the method of collection, status of base station control used, ties to the CORS or HARN, as well as the accuracy acquired, shall be provided along with the deliverable survey data. OPUS provides an

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adjustment report and this report shall be include in the documentation provided to VDOT. Any questions regarding field procedures may be directed to VDOT's Geodetic Surveys Engineer.*

Data File of dual-frequency GPS (L1/L2) full-wavelength carrier observables:

- Static data only; the antenna must remain unmoved throughout the observing session.
- 15-minutes of data or more, up to 48-hours, but not crossing UTC midnight more than once.
- Files under 2 hours, processed as rapid-static, must include the P2 and either P1 or C1 observables.
- GLONASS or Galileo observables may be included; though only the GPS are used.
- Any elevation cut-off or mask angle; though only satellites more than 10° above the horizon are used.
- Recording (epoch) rates of 1, 2, 3, 5, 10, 15, or 30 seconds; though all are decimated to 30 seconds.
- RINEX 2.x data format, or many raw data formats
- Compressed UNIX, gzip, pkzip, or Hatanaka formats are allowed, including multiple file archives (all must share the same antenna type & height).

Antenna

Selecting your antenna will engage the appropriate antenna calibration model, to counter the unique measurement biases inherent in each antenna's design. Take care! Choosing an incorrect antenna may result in a height error as large as 80 cm vertical, 1 cm horizontal. Tip: [Use antenna calibration](#) to find an exact match.

Antenna Height

Enter the vertical height in meters of your Antenna Reference Point (ARP) above the mark you are positioning, as shown in the image at right. The ARP for your antenna, usually the center of the base or tripod mount, is illustrated in [antenna calibration](#) images. If you enter a 0.0 antenna height, your ARP position will be returned.*

Sec. 5.05 Quality Control Procedures

This section of the Survey Manual will assist the surveyor with the minimum field practices to ensure quality GNSS survey data for VDOT. As with any high-tech measuring device, certain standards of care should be followed in the use and maintenance of the equipment. The following are a few of the procedures that are followed by VDOT surveyors to help minimize positioning and field errors and ensure a good quality with the field collected data.

- a. The tribrach, for each unit, should periodically be checked so that the antenna is being centered accurately over the point. This can usually involve adjustment of the optical plummet and, in the worst case, the spirit level.

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- b. Care should be taken when setting a control monument or station, (see [Figure 5-D](#)) so that the effect of obstructions or canopy can be minimized. The monument and disk, or iron pin should be set according to normal VDOT procedures.
- c. A site log form (see [Figure 5-E](#)) has been developed by VDOT for VDOT surveyors to corroborate data entered into the receiver. One site-log form shall be filled out for each receiver for each occupation. The pertinent data includes: the date, observer, receiver #, station occupied (name), beginning antenna height, the antenna offset, session start time, start intermediate and end minimum QI & satellite number, end session time, end antenna height and comments. The form is self-explanatory. It is the responsibility of the surveyor operating the receiver to complete each form. The QI is the Quality Index of the satellite signal being received from each satellite. Regarding VDOT's equipment, Leica System 300, a value of 99 is best. Regarding Leica's System 500, a QI of 99 is best and anything below 92 is unacceptable. The norm for this system is either 99 or 92. VDOT requires knowledge of which value is lowest and from which satellite. This knowledge will assist with processing baselines later on. The comment section is for the surveyor operating the receiver to describe any problems affecting the satellite data or satellite signal received.
- d. The antenna height will be measured in meters. Measurements for antenna height shall be taken at the beginning and end of each session. If a station is to be occupied simultaneously through more than one session. The antenna will be reset over the station and a new antenna height at the beginning and end of each session will be measured. **It is the responsibility of the surveyor to insure that the antenna height measured in the field is recorded correctly on the site log form and entered correctly into the receiver. *Site log forms should be filled out in the field during the session.** Please refer to [Figure 5-A](#), for assistance with the components of the antenna height measurements.
- e. Prior to every new project, the memory card of the receiver should be formatted (or cleared) once it has been definitely proven that the data has been downloaded and saved. It shall be the priority of the person who downloads the mission data to clear the cards of data only after a successful download and back up has been verified. Verification of a successful download will consist of examining mission data for session times, antenna height, and baseline quality and saving the data to another source or location.
- f. Two-way radios shall not be used within 25 feet of the GNSS receiver. Vehicles will be parked a minimum of 50 feet away from the GNSS receiver.
- g. Every member of the GNSS survey mission should know his or her responsibilities, session starting and ending times, station locations and basic operation of the GNSS equipment.

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Sec. 5.06 Deliverables

All *GNSS “subject data” for VDOT contracted surveys (either primary control or photogrammetric control) *whether they are performed by VDOT staff or Consultants, shall be delivered to, or at least copied to VDOT’s Geodetic Surveys Engineer for a quality control check and evaluation. This information will be delivered to the Geodetic Surveys Engineer **before** the entire VDOT survey is due.

The subject data that is to be delivered to the Geodetic Surveys Engineer shall include, at a minimum, every item on the list depicted below.

- a. A sketch, on 8 ½” X 11” sheet of paper, containing the known network control points (NGS, USGS, etc.) and the project control, with ID’s.
- b. A copy of data sheets published for each known network control point used in the adjustment. This data sheet shall include station name, Geographic Coordinates, ellipsoidal heights, orthometric heights, published state plane coordinates, “how to reach” descriptions and point description. A copy of an NGS data sheet is acceptable for the known control points. The same format is acceptable for the project control points. Photogrammetric control points shall be identified on the project control sketch **only**. Descriptions or measured swing-ties for photo control **shall not** be included or delivered to VDOT’s Geodetic Surveys Engineer.
- c. A constrained three-dimensional adjustment report showing the latitude and longitude of all horizontal points, all benchmarks, and all ellipsoidal heights held fixed shall be delivered to VDOT’s Geodetic Surveys Engineer. The report should depict how the adjustment affects each point and the residuals of each baseline vector.
- d. A listing of final adjusted geographic coordinates, ellipsoidal heights, and geoid separations for each station, including stations held fixed. The final adjusted geographic coordinates shall be listed with their respective positional error.
- e. A listing of *the final adjusted state plane coordinates with orthometric heights *in U.S. Survey feet, including stations held fixed.
- f. All copies of site log forms, either VDOT’s **OR** a similar form, as prepared by field surveyors.
- g. All copies of any obstruction diagrams ([Figure 5-C](#)), if not included with site logs.
- h. A copy of the mission plan. This mission plan will include session times, occupation duration and types of receivers used with manufacturer’s standard antenna phase-center offset included.
- i. A one-page summary of the *GNSS mission. The report should include:

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- reasons for fixing and floating stations,
 - evaluation of adjustment results,
 - Total man-hours spent by crew and processor and overall assessment of the mission and performance of equipment.
- j. All completed LD-200 cards (latest version, see [Figure 5-F](#)).
- k. One *digital copy of original GNSS raw data in Leica, Trimble, Topcon, or RINEX-3 format. This data can be delivered on a CD or via FTP server if the client has an existing FTP account with VDOT.

Sec. 5.07 **LD-200 Card (Rev. 8/00)**

As of 7/01/99, VDOT reverted to preparing surveys and design plans in imperial units, using the **U.S. Survey Foot**. This meant revisions to the survey manual. It also meant revising the LD-200 card. GNSS has become a major tool for surveyors. The old LD-200 card did not have enough supporting data for a surveyor to use. Some new revisions include: adding Latitude and Longitude (out to 5 decimal places), the Geoid and ellipsoid heights, control station or VDOT project station that adjusted values are based on, horizontal closure and the sketch and detailed description (on back of printed version, below on electronic version). This new LD-200 Horizontal Control card (see [Figure 5-F](#)) will help the surveyor by giving more background knowledge of the coordinate origin and inspire more surveyors to turn in an electronic version of the card and data. The card is a cell in the Microstation cell library (see **Appendix A**).

Sec. 5.08 **Basis of the State Plane Coordinate System**

To make full use of the State Plane Coordinate System, one must understand how the plane coordinates of any given point are directly related to the geodetic coordinates (latitude and longitude) of that point. First, it should be understood that the latitude of a point is the angular difference between that point and the equator. The longitude of a point is the angular difference between that point and the zero meridian, which arbitrarily passes through Greenwich, England. Virginia is divided into two (2) Lambert Conformal Conic Projection zones, North and South. The dividing line runs along latitude of 38°. **The Code of Virginia §55-288.1** divides the zones along the county lines, as listed on [Figure 5-G](#). A point is positioned using GNSS methods and the position is referenced to a geodetic coordinate system, latitude and longitude. The Geodetic Coordinates are directly related to the Virginia State Plane Coordinate System by definition in **The Code of Virginia §55-292** (see [Figure 5-H](#)).

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For example, if we need to define a point in Louisa, Virginia, the latitude can be defined as the angular difference between that point and the equator as shown in [Figure 5-I](#). Similarly, the longitude can be defined as the angular difference from Greenwich, England, as shown in [Figure 5-J](#). This point would be defined as 38° North latitude and 78° West longitude. This would relate our point in Louisa, Virginia to any other point on the surface of the earth. This is a very precise and universally accepted method of defining positions on the surface of the earth. However, while the system of geodetic coordinates is precise, the computations associated with them are unnecessarily complex when one is dealing with a relatively small area on the face of the earth, and it becomes expedient to establish a simpler model of the earth while still maintaining acceptable accuracy. This can be accomplished by utilizing the VDOT State Plane Coordinate System, which is based on NAD83 coordinate values.

This plane coordinate system allows the use of relatively simple theories and formulae of plane geometry and trigonometry used by surveyors since the beginning of history for the measurement of land and structures on the earth's surface.

The interstate highway system that we enjoy today is one of the prime contributing factors to the establishment of the Virginia State Plane Coordinate System and similar systems employed by all the other states in the United States. State and Federal engineers agreed that plane coordinate systems would be established to allow accurate surveys to be performed, which with the proper corrections applied, would be accurate, nationwide. In addition, the various zones in these systems would be small enough so that if no corrections were applied, positional accuracy within the respective zones would exceed 1 part in 10,000.

Sec. 5.09 Depiction of Two Coordinate Zones

[Figure 5-K](#) is a graphic representation of the State of Virginia showing the two coordinate systems. Refer to the Virginia South Zone and note that the line intersects the surface of the earth at two points similar to the way the long chord of a curve intersects the P. C. and P. T. of that curve. Likewise, the distance along the line from $36^{\circ} 46'$ to Point A would be shorter than the distance along the arc from $36^{\circ} 46'$ to Point A. The relationship between these two distances would give us a scale factor to apply to distances measured along the arc to reduce them to distances along the line. At $36^{\circ} 46'$ and $37^{\circ} 58'$ these corrections would be expressed as 1.0000000 multiplied by the distance measured. As you move to the center of the zone; this factor decreased to 0.9999454. As you proceed South from $36^{\circ} 46'$ to the North Carolina line, the correction increased to about 1.0000464. You will note that this variation from high to low gives a possible difference in 1000 feet of 0.10 feet, which was the required accuracy for the coordinate system. This basic idea holds true for the Virginia North Zone.

Sec. 5.10 Relation of Grid North and True North

All lines or meridians of longitude run through the North and South Pole. Therefore, they cannot be parallel. The central meridian for the State of Virginia is $78^{\circ} 30'$ West longitude for both the North and South Zones. This means that throughout both zones grid north is exactly parallel to the $78^{\circ} 30'$ West longitude, central meridian. The angular difference between the true north and grid north is called the θ (theta) angle. [Figure 5-L](#) shows this graphically.

Sec. 5.11 The VDOT Project Coordinate System

*Beginning June 1, 2014 all new VDOT Projects will be based on the new VDOT Project Coordinate System outlined below (Now known as “VDOT Project Coordinates-2014”). To convert Virginia State Plane Coordinates (based on the US Survey Foot) to VDOT Project Coordinates-2014, the coordinates will need to be multiplied by the combined Scale & Elevation Factor for each specific project. One method of obtaining the scale factor for each project will be to submit GNSS data to OPUS (NGS utility) for each primary control point on the project. Submitting “Static” data to OPUS (minimum 2- hour occupations per point) will be required. Once the OPUS results are obtained, take the average of the combined factors under the State Plane Coordinates for the primary control points. Once this step is done, the inverse function (1/x) should be applied, resulting in the Combined Scale Factor for the project (9 decimal places- Example= 1.000000009).

This is only one method of obtaining the scale factor for a project. Regardless of the method used, the procedure shall be described in detail in the project notes as well in the Project Deliverables (Sec. 5.06).[◇]

Special Note on Projects that predate June 1, 2014:[◇]

Projects completed or started prior to January 1, 2014 should continue to use the former language below.

The VDOT Coordinate System is based on **NAD83 METRIC values** as defined in **The Code of Virginia §55-292** (see [Figure 5-H](#)). To convert NAD83 METRIC to VDOT Project coordinates (Imperial Units), first depending on the zone you are working in, subtract 1,000,000 meters from the South Zone Northing value (or 2,000,000 meters from the North Zone Northing value). Next, subtract 2,500,000 meters from the Easting value. Next, multiply the Northing and Easting values by 3.28083333333 (the conversion for the U. S. Survey Foot as defined in **The Code of Virginia §55-290**, see [Figure 5-M](#)). Last, multiply the Northing and Easting values by the Combined County Scale & Elevation Factor. [Figure 5-N](#) is a list of the combined scale and elevation factor for the counties. This produces VDOT Project Coordinates (in Imperial Units) for a given project. A reverse of this procedure will transform VDOT Project Coordinates back the original NAD83 METRIC values. See [Figure 5-F](#), showing the use of the above procedures as depicted on a LD-200 Horizontal Control Station Reference Card.

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Sec. 5.12 *Airborne GNSS

1. Airborne GNSS techniques can be used to acquire supplemental control for use on photogrammetric projects.
2. It is important to maintain Reference Base Stations over known control points during the duration of the flight.
3. These Reference Stations should be spaced 10 to 25 kilometers from the project. The entire project should be reachable within this range.
4. The range of 10 to 25 kilometers should be scrutinized keeping in mind the accuracy needs of the project. A general rule of thumb, under optimal conditions, would be about 1 cm of residual per 10 kilometers of baseline distance. Bear in mind, there usually are other factors involved that could result in an increase in your residual values. i.e. a poor GDOP value
5. If multiple Reference Stations are required, then no part of the project should be farther than 10 to 25 kilometers from at least one of the Reference Stations.
6. Reference Stations as well as Rovers should be set to collect one second epoch data.

Sec. 5.13 Horizontal and Vertical Control [<sect\(UPC#\)>](#)

Horizontal

Permanent Horizontal Control Monuments shall be set on all surveys for highways for all systems, including closed surveys. Data available for setting horizontal control will be sent with the survey authorization, or as schedules permit the Global Positioning System (GPS) will be initiated by the Geospatial Program Manager with the authorization memorandum. The Survey Manager will assure that the Land Surveyor Supervisor has sufficient data for control.

A **minimum** of four (4) monuments shall be set on each projects greater than 1 mile in length, the amount of control shall be discussed with District Survey Manager prior to field work commencing. Standard VDOT disks are to be set in concrete with re-bar or other metal added to assist in relocation with a metal detector and/or rod & caps may be used with the permission of the Survey Manager or Geospatial Program Manager.

A **minimum** of three (3) monuments shall be set on projects less than 1 mile in length. Rod & Caps may be used on projects less than 1 mile in length if approved by the District Survey Manager or Geospatial Program Manager and control is placed outside the limits of construction.

Rod & cap shall be used to set all traverse points, unless ground conditions are not suitable. Swing ties to other objects should be obtained as evidence for re-establishment of all monumentation set.

Any new survey that will not be tied into any existing VDOT survey projects, shall be tied to the appropriate system as outlined in Chapter 17 of the Coded of Virginia Section [55-287](#) and into the most current NGS vertical datum. The **Global Navigation Satellite System**

* Rev. 7/15

(GNSS) should be utilized whenever it is practical to do so. Unless specifically directed by the Geospatial Program Manager, any survey that is an extension of, or will tie into, an existing VDOT survey project will be constrained to the datum of the existing survey project.

Monuments should be tied to State plane and project coordinate values shown to the nearest one thousandth foot (**0.001-ft**) and vertical control to the nearest one hundredth foot (**0.01-ft**). The maximum error for vertical control shall in no case be greater than five hundredths foot (**±0.05-ft**) times the square root of the loop distance in miles.

Form LD-200 (Horizontal Control Reference Card) ([Figure 5-F](#)) shall be completed for all permanent monuments set for horizontal control, for referencing purposes. When the cards have been completed by VDOT personnel or consultants, the original copy will be uploaded into ProjectWise and an email sent to the State Geodetic Survey Engineer and the appropriate District immediately upon completion of the control with a link to the ProjectWise folder. Control will not be considered complete until all deliverables outlined in Chapter 10 are provided.

Vertical - Leveling and Securing Elevations [<setl\(UPC#\)>](#)

All location survey leveling will be secured by the use of Total Station methods and procedures or differential leveling as applicable. Elevations for all location surveys shall be based on GPS, U.S.G.S. or N.G.S. **U.S. Survey Feet** datum. **The use of assumed vertical is not acceptable.** This is important, and no departure from this rule is authorized. The kind and source of datum should always be included in the Survey Report. When a survey is authorized, the Survey Manager or Land Survey Supervisor or Consultant shall be responsible for finding the location, description and elevation of any available government benchmarks.

A series of benchmarks must be established throughout the project at intervals of approximately one thousand feet (**1000 ft.**). A benchmark should also be established also near all future structures (bridges, box culverts) and at all road intersections. These benchmarks must be as permanent as possible, located on solid structure bases or in the bases of trees not likely to be disturbed by construction. **A benchmark will never be set in a utility pole.**

A complete description, including project coordinates and station plus and distance from the construction centerline (if available) as well as accurate description of the object on which the benchmark is located, must be given. Each benchmark established shall be tied horizontally and vertically. In all cases, any benchmark established must be turned on, in order to be properly tied to the line of levels. Check levels must be run unless a permanent benchmark is convenient to both ends of the project. If a government benchmark is found near each end of the job and intermediate benchmarks are tied in by reason of turns, then a tie-in with the permanent benchmarks near each end of the project could serve as an adequate check. Elevations on *VDOT Control Monuments* should be read also when benchmark levels are being run.

The maximum error in differential leveling (benchmark levels) shall in no case be greater than five-hundredths (**±0.05**) of a foot times the square root of the length of the level run in miles (**±0.05 ft. X xM**), where **M** is the loop length in miles. For profile leveling, the maximum error of a benchmark elevation previously established shall be no greater than plus or minus two

hundredths of a foot (± 0.02 ft.) times the square root of the distance in stations from the preceding benchmark.

Sec. 5.14 **Traverse baselines** [<sectl\(UPC#\)>](#)

The traverse baselines should be established to be functional relative to the safety and geometric alignment of the survey corridor of the project.

Traverse baselines will be included in a VDOT Survey control file. All traverse closures will be reported in the survey location report. Traverse baseline will only show bearing and distance. To help eliminate confusion, no stationing shall be shown. All plus and offsets will be referenced from the construction centerline. Horizontal and vertical control points shall be shown on the plan sheets.

Figure 5-A

ILLUSTRATION FOR ANTENNA HEIGHT MEASUREMENTS:

I. Instructions for Fixed-Height Tripods:

Measure & record the length (A) and other offsets, if any, between the tripod and Antenna Reference Point (ARP) (B) and/or between the tripod and datum point (Q).

$$\text{Antenna Height} = H = A_1 + B_1 - Q$$

II. Instructions for Slip-Leg Tripod:

NOTE: For Leica measuring hooks, use the instructions below.

$$\text{Leica Measuring Hook} = H = A_2 + B_2$$

1. Measure the Slant Height

Before and after the observation session, measure the slope distance from the mark at least three notches on the Bottom of Ground Plane (BGP) using two independent rulers (e.g. metric and imperial). Record measurements in the table below, and compute the average.

Measure S	Notch #_	Notch #_	Notch #_	Average
Before, cm				
Before, inch				
After, cm				
After, inch				
Note: cm = Inch x (2.54)		Overall average, cm		

$$S = \text{_____ cm}$$

2. Record the Antenna Radius (R) and the Antenna Constant (C)

The antenna radius is the horizontal distance from the Antenna Reference Point (ARP) to the measurement notch. The antenna constant is the vertical distance from the ARP to the BGP. See your Antenna specification manual for exact measurements.

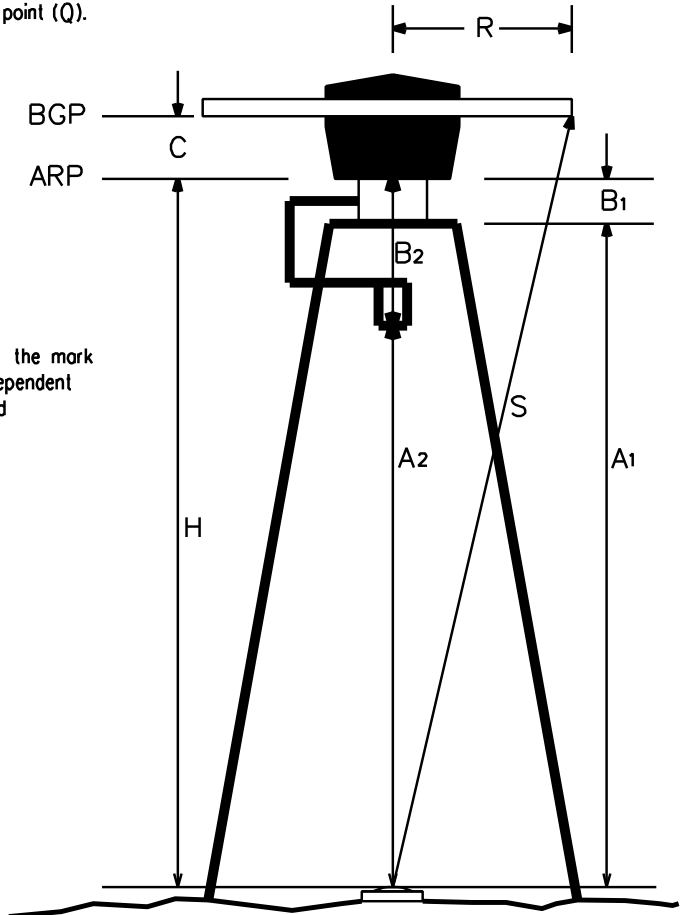
$$R = \text{_____ cm}$$

$$C = \text{_____ cm}$$

3. Compute Antenna Height (H)

Use the following Pythagorean formula:

$$\text{Antenna Height } H = ((\sqrt{S^2 - R^2}) - C) - Q$$



Detail of Mark

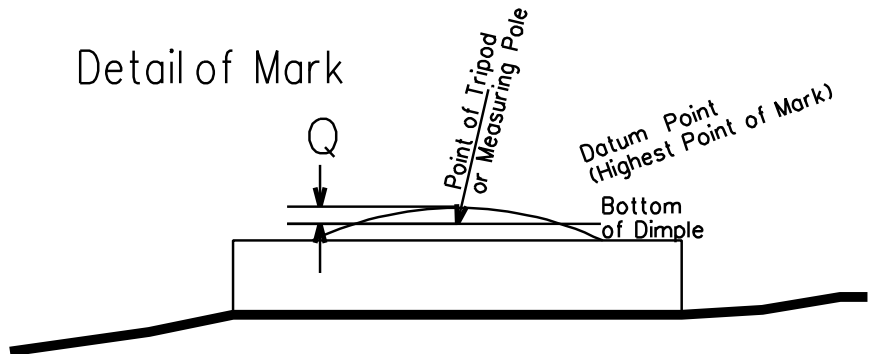
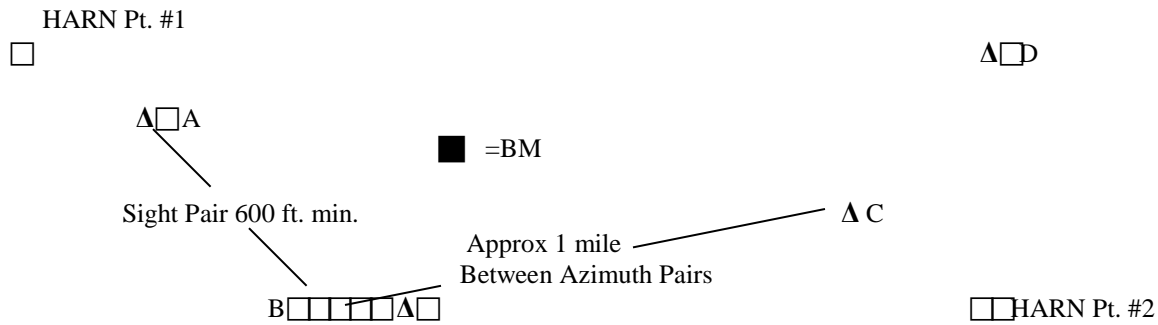


Figure 5-B



A,B,C,D = VDOT Route Survey Control Points; Coordinates to be Determined
HARN #1 to HARN #2 = 17 km ■ = BM on NAVD88 datum; GDOP = 2.5; 6 Satellites
HARN Points Have Known X, Y & Z Values

Observation Session #1, 4 Receivers, Duration 30 Minutes Minimum, Use Rapid Static Procedures, Occupy HARN #1, HARN#2, BM & A.

Observation Session #2, 4 Receivers, A-C = 3 km, Duration 15 Minutes Minimum, Use Rapid Static Procedures, Occupy BM, A, B & C.

Observation Session #3, 4 Receivers, B-D = 3 km, Duration 15 Minutes Minimum, Use Rapid Static Procedures, Occupy B, C, D & BM.

Observation Session #4, 4 Receivers, Duration 30 Minutes Minimum, Use Rapid Static Procedures, Occupy HARN #1, HARN#2, BM & D.

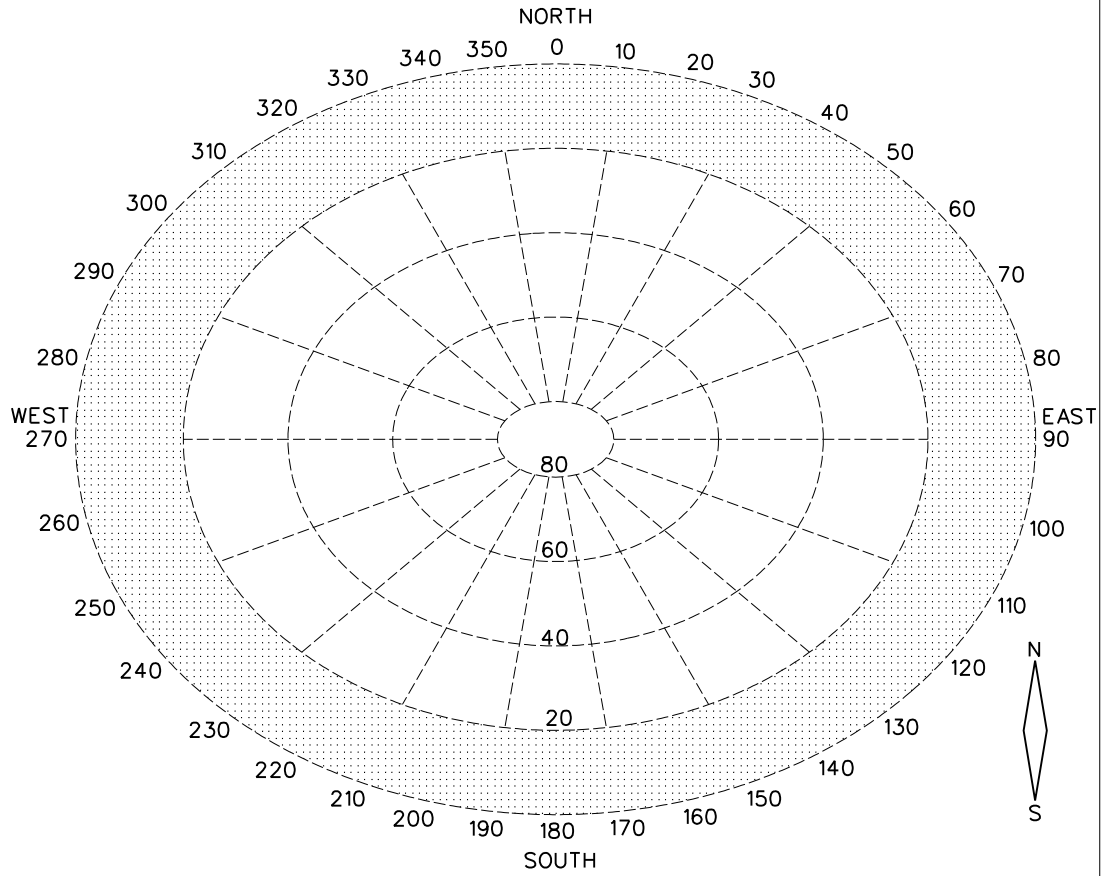
Observation Session #5, 4 Receivers, Duration 15 Minutes Minimum, Use Rapid Static Procedures, Occupy A, B, C & D.

Figure 5-B is an example of one observing session scheme. This illustrates one way to design a mission, but a mission is not limited to one scheme to accomplish the same results. An observing scheme should be developed to meet your specific accuracy standard criteria. The best source of information to develop observing session scheme or mission plan is “**Geometric Geodetic Accuracy Standard and Specifications for Using GNSS Relative Positioning Techniques**”. FGCC ver. 5.0 8/19/89.

Figure 5-C

GPS 610

GPS SATELLITE VISIBILITY
OBSTRUCTION DATA SHEET



ACRN _____
 OLD\OSN _____
 ELEVATION _____ (m) / f
 LATITUDE _____ (N) / S NAD27
 LONGITUDE _____ E / W (NAD83)
 STATION NAME _____

DATE _____
 ORGANIZATION _____
 MAP SCALE _____
 MAP SHEET _____
 OBSERVER _____
 Observer's height _____ ft. / in. / m
 at time of observation

NOTES:

Indicate distance, direction, frequency, and power of known RF sources.
 Show peripheral marks and required ties.
 Show the distance to the nearest edge of all obstructions over 20° and/or indicate antenna height needed to clear obstructions at 20°.

Figure 5-D

Stamped VDOT Disk Set In Concrete
Flush With the Ground Line

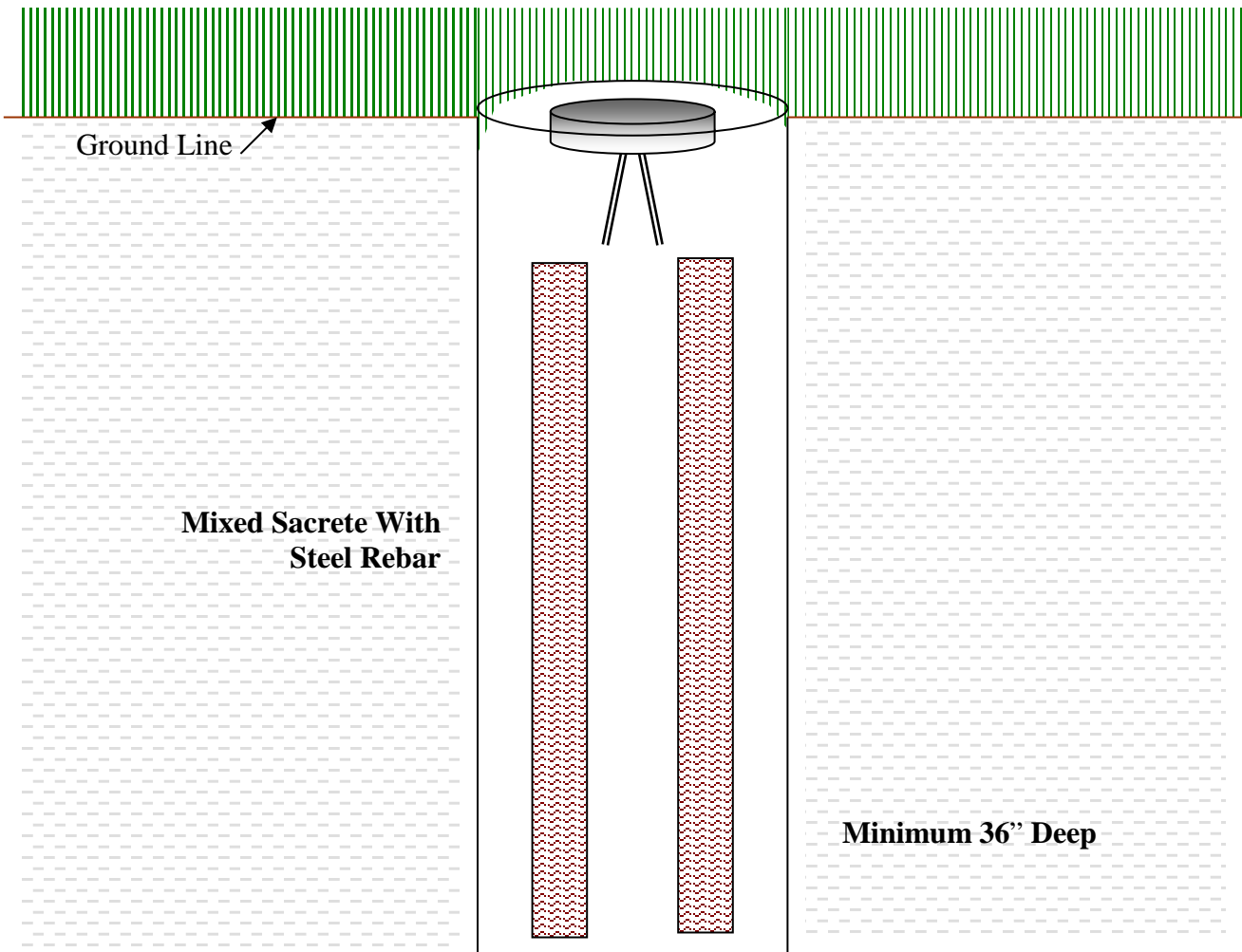


Figure 5-F

LD-200 (REV. 10/2014) Virginia Department of Transportation Horizontal Control Control Station I.D. : _-__ Date : _-_-	
VDOT Project Coordinates (2014) East (X) : _____ft. North (Y) : _____ft. Elevation : _____ft.	VA State Plane Coordinates : NAD 83-U.S. Survey Feet East (X) : _____ft. North (Y) : _____ft. Ortho. Elevation (H) : _____ft. Zone : North_ South_ (place an 'X' beside one)
Project Specific Combined Scale Factor: 1. _____ (8 Decimal Places)	Project Information Project Number : _____ Route : _ City/County : _____ Established By : _____
Latitude : _° _' ____" N (5 Decimal Places) Longitude : _° _' ____" W (5 Decimal Places) Geoid Separation (N) : _____ Ellipsoid Height (h) : _____ Horizontal Datum : _____ Year : ____ Vertical Datum : _____ Geoid : ____ Azimuth to Station : ____ Is ____' ____" Control Based On: Station (Name/PID) _____ or Project (Monument No.) : _____	To convert Virginia State Plane Coordinates to VDOT Project Coordinates, use the following formula : * Multiply the Easting And Northing Values (For Both Zones) by the Project Specific Combined Scale Factor. (Located above left) * Reverse this Procedure to convert VDOT Project Coordinates (2014) to NAD 83 - U.S. Survey Feet
DETAILED SKETCH (Not to Scale)	
LD-200 (REV. 10/2014)	

*Sample Horizontal Control Card "LD-200"

Figure 5-G

§ 55-288.1. North and South Zones.

For the purpose of the use of these systems, the Commonwealth is divided into a “North Zone” and a “South Zone.”

The area now included in the following counties and cities shall constitute the North Zone: the Counties of Arlington, Augusta, Bath, Caroline, Clarke, Culpeper, Fairfax, Fauquier, Frederick, Greene, Highland, King George, Loudoun, Madison, Orange, Page, Prince William, Rappahannock, Rockingham, Shenandoah, Spotsylvania, Stafford, Warren and Westmoreland; and the Cities of Alexandria, Fairfax, Falls Church, Fredericksburg, Harrisonburg, Manassas, Manassas Park, Staunton, Waynesboro, and Winchester.

The area now included in the following counties and cities shall constitute the South Zone: the Counties of Accomack, Albemarle, Alleghany, Amelia, Amherst, Appomattox, Bedford, Bland, Botetourt, Brunswick, Buchanan, Buckingham, Campbell, Carroll, Charles City, Charlotte, Cheterfield, Craig, Cumberland, Dickenson, Dinwiddie, Essex, Floyd, Fluvanna, Franklin, Giles, Gloucester, Goochland, Grayson, Greensville, Halifax, Hanover, Henrico, Henry, Isle of Wight, James City, King and Queen, King William, Lancaster, Lee, Louisa, Lunenburg, Mathews, Mecklenburg, Middlesex, Montgomery, Nelson, New Kent, Northampton, Northumberland, Nottoway, Patrick, Pittsylvania, Powhatan, Prince Edward, Prince George, Pulaski, Richmond, Roanoke, Rockbridge, Russell, Scott, Smyth, Southampton, Surry, Sussex, Tazewell, Washington, Wise, Wythe, and York; and the Cities of Bedford, Bristol, Buena Vista, Charlottesville, Chesapeake, Clifton Forge, Colonial Heights, Covington, Danville, Emporia, Franklin, Galax, Hampton, Hopewell, Lexington, Lynchburg, Martinsville, Newport News, Norfolk, Norton, Petersburg, Poquoson, Portsmouth, Radford, Richmond, Roanoke, Salem, South Boston, HR, Virginia Beach, and Williamsburg.

Figure 5-H

§ 55-292. Definition of Systems by National Ocean Survey/National Geodetic Survey; adopted.

For purposes of more precisely defining the Virginia Coordinate System of 1927, the following definition by the National Ocean Survey/National Geodetic Survey is adopted:

The Virginia Coordinate System of 1927, North Zone, is a Lambert conformal projection of the Clarke spheroid of 1896, having standard parallels at north latitudes 38°02' and 39°12', along which parallels the scale shall be exact. The origin of coordinates is at the intersection of the meridian 78°30' west of Greenwich with the parallel 37°40' north latitude, such origin being given the coordinates: $x = 2,000,000'$, and $y = 0'$.

The Virginia Coordinate System of 1927, South Zone, is a Lambert conformal projection of the Clarke spheroid of 1896, having standard parallels at north latitudes 36°46' and 37°58', along which parallels the scale shall be exact. The origin of coordinates is at the intersection of the meridian 78°30' west of Greenwich with the parallel 36°20' north latitude, such origin being given the coordinates: $x = 2,000,000'$ and $y = 0'$.

For purposes of more precisely defining the Virginia Coordinate System of 1983, the following definition by the National Ocean Survey/National Geodetic Survey is adopted:

The Virginia Coordinate System of 1983, North Zone, is a Lambert conformal conic projection based on the North American Datum of 1983, having standard parallels at north latitudes 38°02' and 39°12', along which parallels the scale shall be exact. The origin of coordinates is at the intersection of the meridian 78°30' west of Greenwich and the parallel 37°40' north latitude. The origin being given the coordinates: $x = 3,500,000$ meters and $y = 2,000,000$ meters.

The Virginia Coordinate System of 1983, South Zone, is a Lambert conformal conic projection based on the North American Datum of 1983, having standard parallels at north latitudes 36°46' and 37°58', along which parallels the scale shall be exact. The origin of coordinates is at the intersection of the meridian 78°30' west of Greenwich and the parallel 36°20' north latitude. This origin is given the coordinates: $x = 3,500,000$ meters and $y = 1,000,000$ meters.

Figure 5-1

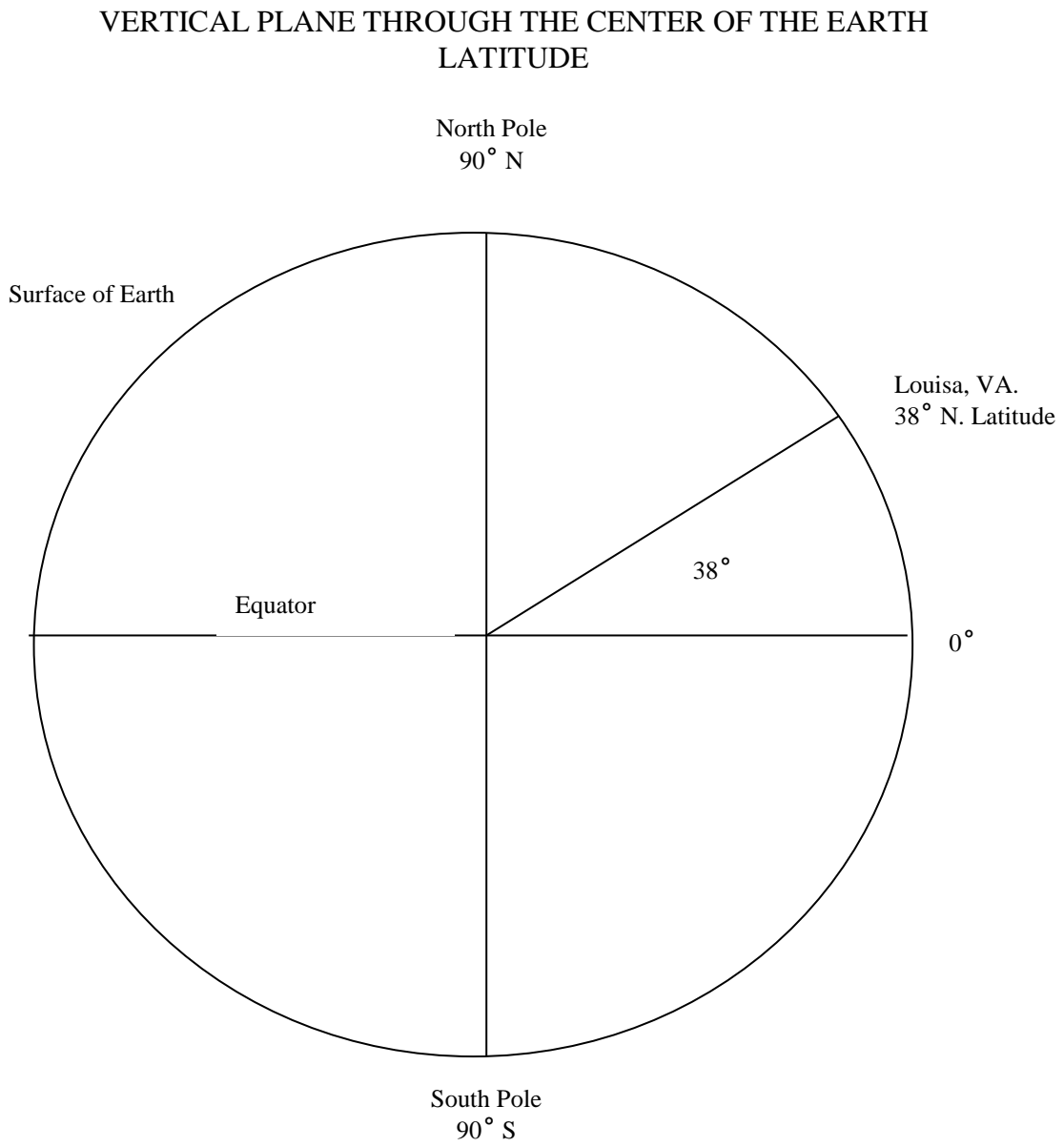


Figure 5-J

**HORIZONTAL PLANE THROUGH THE CENTER OF THE EARTH
LONGITUDE**

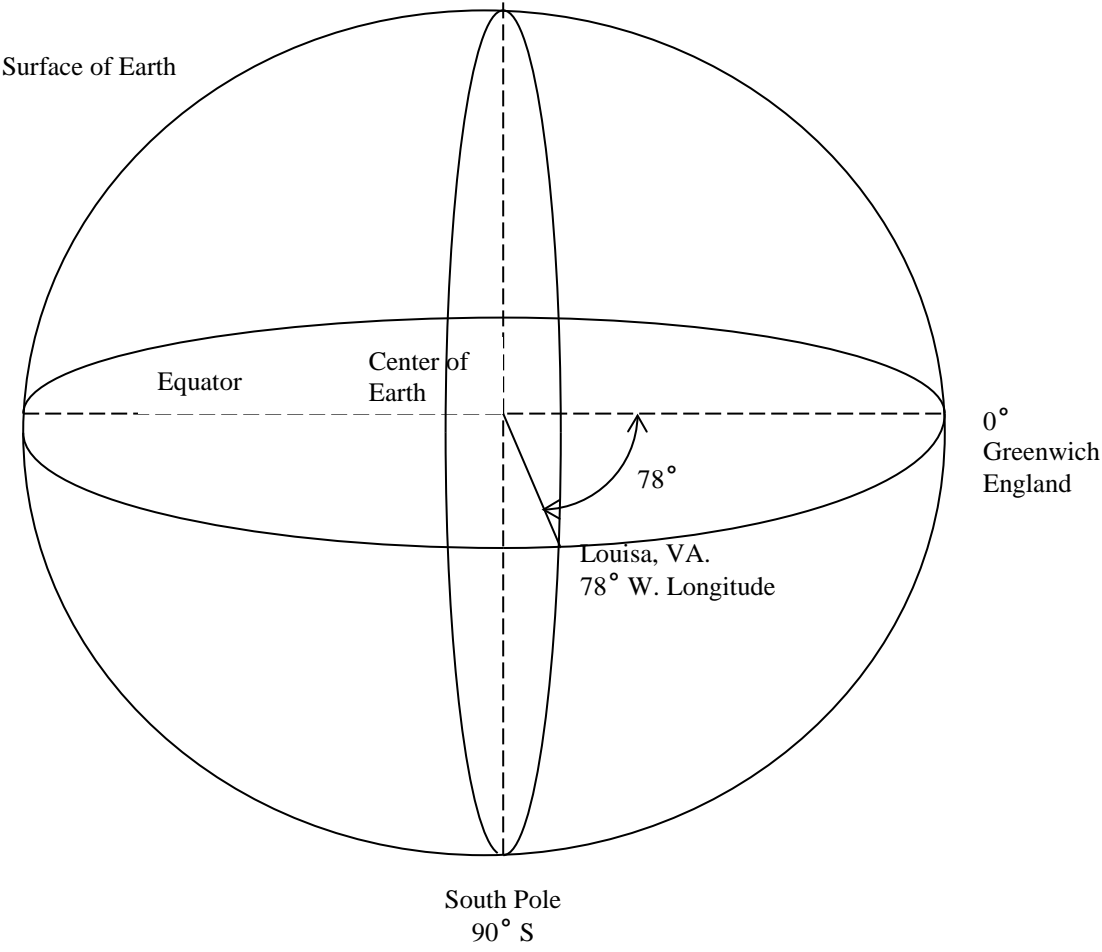


Figure 5-K

PROFILE VIEW
VIRGINIA STATE PLANE COORDINATE SYSTEM

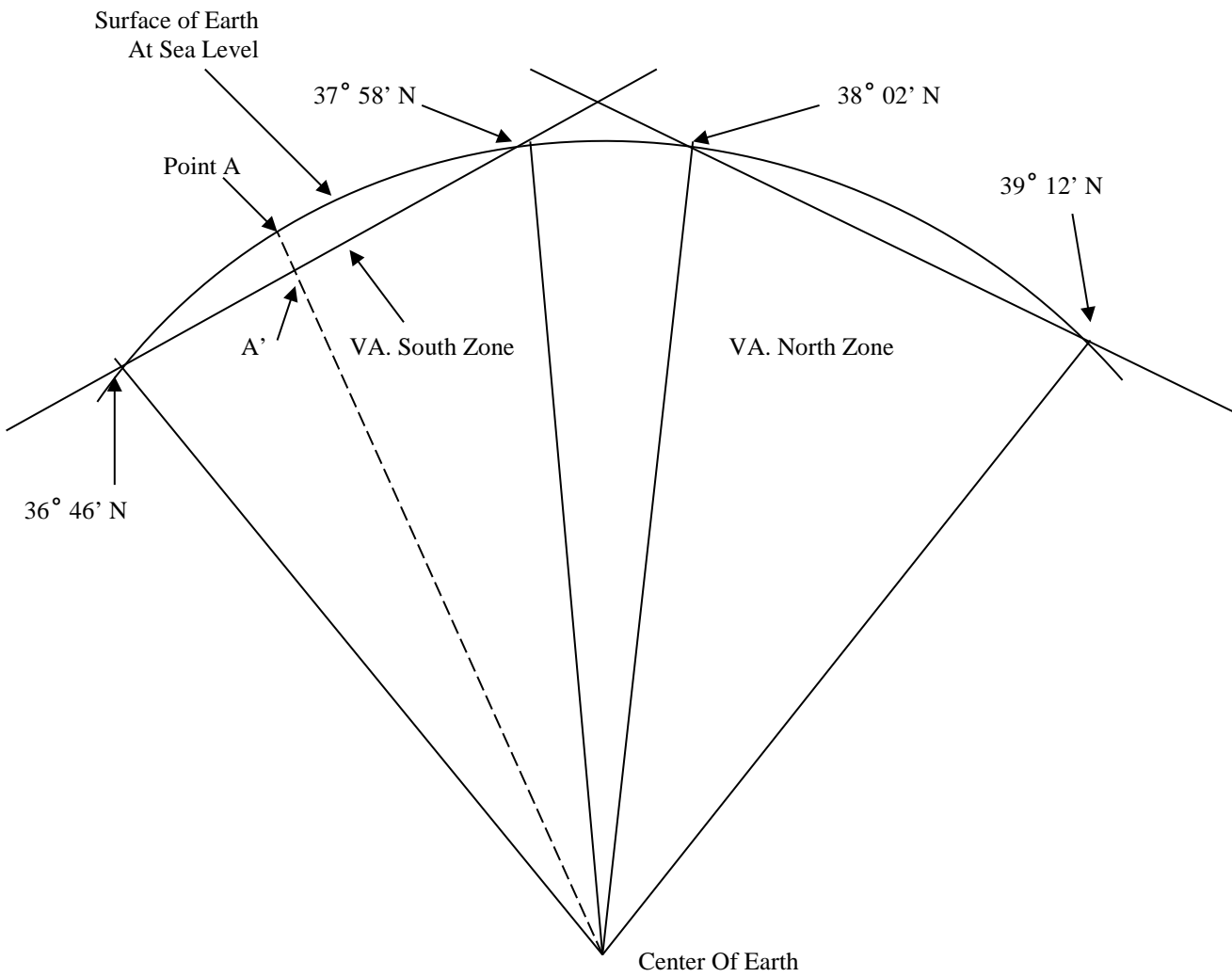


Figure 5-L

RELATIONSHIP BETWEEN TRUE NORTH &
GRID NORTH

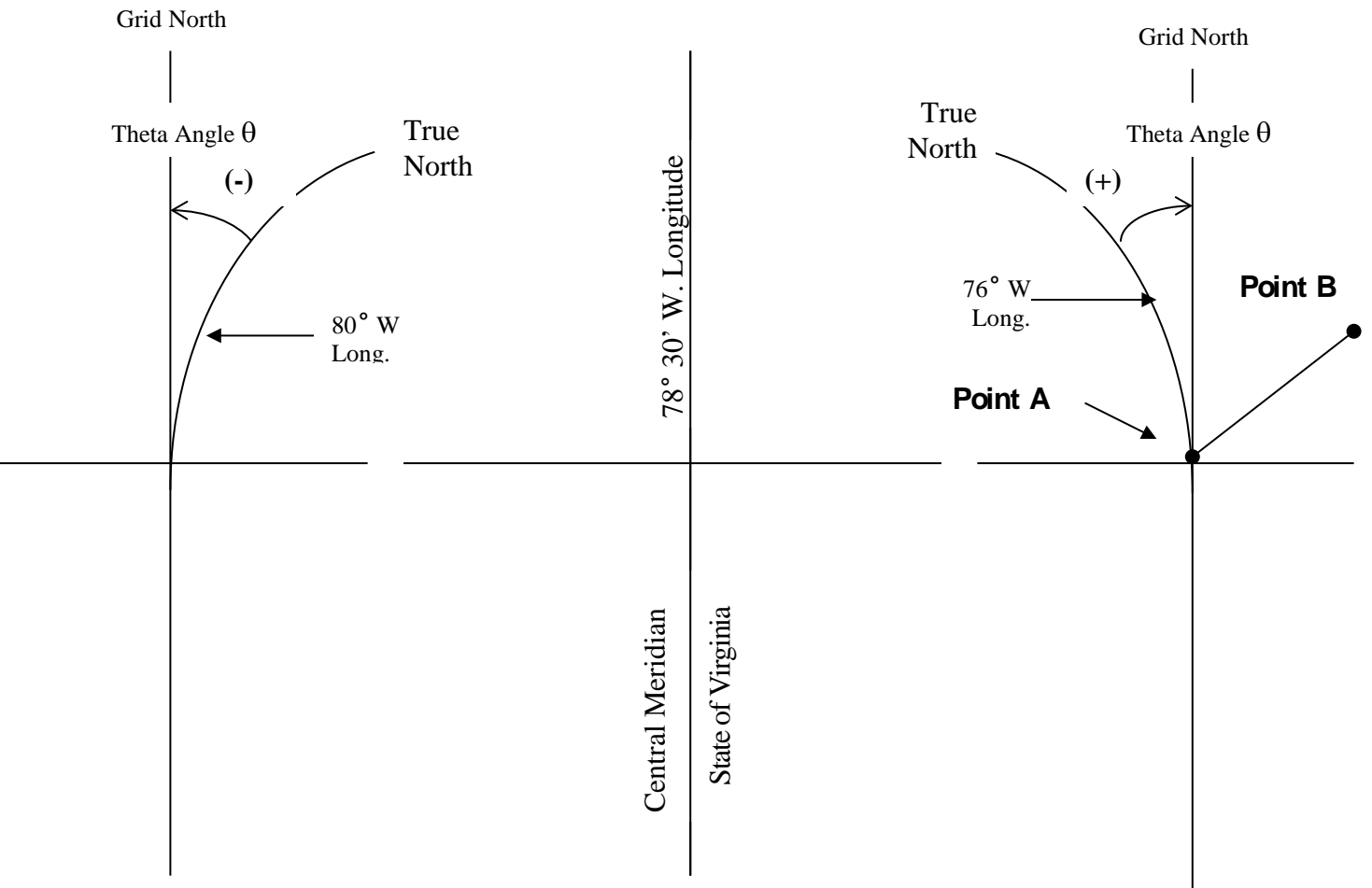


Figure 5-M

§ 55-290. Plane Coordinates used in Systems.

The plane coordinates of a point on the earth's surface, to be used in expressing the position or location of such point in the appropriate zone of these systems, shall be expressed in U.S. survey feet and decimals of a foot. One of these distances, to be known as the "x-coordinate," shall give the position in an east-and-west direction; the other, to be known as the "y-coordinate," shall give the position in a north-and-south direction. These coordinates shall be made to depend upon and conform to the coordinate values for the monumented points of the North American Horizontal Geodetic Control Network as published by the National Ocean Survey/National Geodetic Survey, or its successors, and whose plane coordinates have been computed on the systems defined in this chapter. Any such station may be used for establishing a survey connection to either Virginia Coordinate System.

When converting coordinates in the Virginia Coordinate System of 1983 from meters and decimals of a meter to feet and decimals of a foot, the U.S. survey foot factor (one foot equals 1200/3937 meters) shall be used. This requirement does not preclude the continued use of the International foot conversion factor (one foot equals 0.3048 meters) in those counties and cities where this factor was in use prior to July 1, 1992. The plat or plan shall contain a statement of the conversion factor used and the coordinate values of a minimum of two project points in feet.

Figure 5-N
COMBINED SCALE AND ELEVATION FACTOR FOR THE COUNTY

000	1.00006	Arlington	054	1.00002	Louisa
001	1.00004	Accomack	055	1.00005	Lunenburg
002	1.00002	Albemarle	056	1.00007	Madison
003	1.00015	Alleghany	057	1.00005	Mathews
004	1.00007	Amelia	058	1.00000	Mecklenburg
005	1.00009	Amherst	059	1.00005	Middlesex
006	1.00008	Appomattox	060	1.00015	Montgomery
007	1.00009	Augusta	061	1.00000	City of HR
008	1.00012	Bath	062	1.00007	Nelson
009	1.00009	Bedford	063	1.00005	New Kent
010	1.00017	Bland	064	1.00000	Nor. Ches. Ports.
011	1.00011	Botetourt	065	1.00004	Northampton
012	1.00001	Brunswick	066	1.00002	Northumberland
013	1.00015	Buchanan	067	1.00007	Nottoway
014	1.00007	Buckingham	068	1.00006	Orange
015	1.00007	Campbell	069	1.00010	Page
016	1.00001	Caroline	070	1.00004	Patrick
017	1.00011	Carroll	071	1.00002	Pittsylvania
018	1.00006	Charles City	072	1.00006	Powhatan
019	1.00006	Charlotte	073	1.00007	Prince Edward
020	1.00006	Chesterfield	074	1.00006	Prince George
021	1.00004	Clarke	075	1.00000	City of VA Beach
022	1.00017	Craig	076	1.00006	Prince William
023	1.00007	Culpeper	077	1.00014	Pulaski
024	1.00007	Cumberland	078	1.00009	Rappahannock
025	1.00014	Dickenson	079	1.00001	Richmond
026	1.00005	Dinwiddie	080	1.00013	Roanoke
027	1.00004	City of Hampton	081	1.00008	Rockbridge
028	1.00001	Essex	082	1.00011	Rockingham
029	1.00006	Fairfax	083	1.00012	Russell
030	1.00008	Fauquier	084	1.00011	Scott
031	1.00012	Floyd	085	1.00009	Shenandoah
032	1.00004	Fluvanna	086	1.00015	Smyth
033	1.00009	Franklin	087	1.00000	Southampton
034	1.00004	Frederick	088	1.00004	Spotsylvania
035	1.00017	Giles	089	1.00006	Stafford
036	1.00005	Gloucester	090	1.00005	Surry
037	1.00005	Goochland	091	1.00003	Sussex
038	1.00011	Grayson	092	1.00019	Tazewell
039	1.00007	Greene	093	1.00007	Warren
040	1.00000	Greensville	094	1.00004	City of Newport News
041	1.00002	Halifax	095	1.00009	Washington
042	1.00004	Hanover	096	1.00002	Westmoreland
043	1.00006	Henrico	097	1.00015	Wise
044	1.00003	Henry	098	1.00014	Wythe
045	1.00016	Highland	099	1.00005	York
046	1.00002	Isle of Wight			
047	1.00005	James City			
048	1.00004	King George			
049	1.00004	King & Queen			
050	1.00004	King William			
051	1.00003	Lancaster			
052	1.00006	Lee			
053	1.00005	Loudoun			

Figure 5-O

COUNTY CODE NUMBER REFERENCE FOR CITIES AND TOWNS

City or Town Code				County Location	District
100	Alexandria	C	000	Arlington	Nova
101	Big Stone Gap	T	097	Wise	Bristol
102	Bristol	C	095	Washington	Bristol
103	Buena Vista	C	081	Rockbridge	Staunton
104	Charlottesville	C	002	Albemarle	Culpeper
105	Clifton Forge	C	003	Alleghany	Staunton
106	Colonial Heights	C	020	Chesterfield	Richmond
107	Covington	C	003	Alleghany	Staunton
108	Danville	C	071	Pittsylvania	Lynchburg
109	Emporia	C	040	Greensville	HR
110	Falls Church	C	029	Fairfax	NOVA
111	Fredericksburg	C	088	Spotsylvania	Fredericksburg
112	Front Royal	T	093	Warren	Staunton
113	Galax	C	017	Carroll	Salem
114	Hampton	C	027	City of Hampton	HR
115	Harrisonburg	C	082	Rockingham	Staunton
116	Hopewell	C	074	Prince George	Richmond
117	Lexington	C	081	Rockbridge	Staunton
118	Lynchburg	C	015	Campbell	Lynchburg
119	Marion	T	086	Smyth	Bristol
120	Martinsville	C	044	Henry	Salem
121	Newport News	C	094	City of Newport News	HR
122	Norfolk	C	064	City of Norfolk	HR
123	Petersburg	C	026	Dinwiddie	Richmond
124	Portsmouth	C	064	City of Portsmouth	HR
125	Pulaski	T	077	Pulaski	Salem
126	Radford	C	060	Montgomery	Salem
127	Richmond	C	020	Chesterfield	Richmond
128	Roanoke	C	080	Roanoke	Salem
129	Salem	C	080	Roanoke	Salem
130	South Boston	C (T)	041	Halifax	Lynchburg
131	Chesapeake	C	064	City of Chesapeake	HR
132	Staunton	C	007	Augusta	Staunton
133	HR	C	061	Nansemond	HR
134	Virginia Beach	C	075	City of Virginia Beach	HR
135					
136	Waynesboro	C	007	Augusta	Staunton
137	Williamsburg	C	047	James City	HR
138	Winchester	C	034	Frederick	Staunton
139	Wytheville	T	098	Wythe	Bristol
140	Abingdon	T	095	Washington	Bristol
141	Bedford	C	009	Bedford	Salem
142	Blackstone	T	067	Nottoway	Richmond
143	Bluefield	T	092	Tazewell	Bristol
144	Farmville	T	073	Prince Edward	Lynchburg
145	Franklin	C	087	Southampton	HR
146	Norton	C	097	Wise	Bristol
147	Poquoson	C	099	York	HR
148	Richlands	T	092	Tazewell	Bristol

149	Vinton	T	080	Roanoke	Salem
150	Blacksburg	T	060	Montgomery	Salem
151	Fairfax	C	029	Fairfax	NOVA
152	Manassas Park	C	076	Prince William	NOVA
153	Vienna	T	029	Fairfax	NOVA
154	Christiansburg	T	060	Montgomery	Salem
155	Manassas	C	076	Prince William	NOVA
156	Warrenton	T	030	Fauquier	Culpeper
157	Rocky Mount	T	033	Franklin	Salem
158	Tazewell	T	092	Tazewell	Bristol
159	Luray	T	069	Page	Staunton
160	Accomack	T	001	Accomack	HR
161	Alberta	T	012	Brunswick	Richmond
162	Altavista	T	015	Campbell	Lynchburg
163	Amherst	T	005	Amherst	Lynchburg
164	Appalachia	T	097	Wise	Bristol
165	Appomattox	T	006	Appomattox	Lynchburg
166	Ashland	T	042	Hanover	Richmond
167	Belle Haven	T	001	Accomack	HR
168	Berryville	T	021	Clarke	Staunton
169	Bloxom	T	001	Accomack	HR
170	Boones Mill	T	033	Franklin	Salem
171	Bowling Green	T	016	Caroline	Fredericksburg
172	Boyce	T	021	Clarke	Staunton
173	Boydton	T	058	Mecklenburg	Richmond
174	Boykins	T	087	Southampton	HR
175	Branchville	T	087	Southampton	HR
176	Bridgewater	T	082	Rockingham	Staunton
177	Broadway	T	082	Rockingham	Staunton
178	Brodnax	T	012	Brunswick	Richmond
178	Brodnax	T	058	Mecklenburg	Richmond
179	Brookneal	T	015	Campbell	Lynchburg
180	Buchanan	T	011	Botetourt	Salem
181	Burkeville	T	067	Nottoway	Richmond
182	Cape Charles	T	065	Northampton	HR
183	Capron	T	087	Southampton	HR
184	Cedar Bluff	T	092	Tazewell	Bristol
185	Charlotte C. H.	T	019	Charlotte	Lynchburg
186	Chase City	T	058	Mecklenburg	Richmond
187	Chatham	T	071	Pittsylvania	Lynchburg
188	Cheriton	T	065	Northampton	HR
189	Chilhowie	T	086	Smyth	Bristol
190	Chincoteague	T	001	Accomack	HR
191	Claremont	T	090	Surry	HR
192	Clarksville	T	058	Mecklenburg	Richmond
193	Cleveland	T	083	Russell	Bristol
194	Clifton	T	029	Fairfax	NOVA
195	Clinchport	T	084	Scott	Bristol
196	Clintwood	T	025	Dickenson	Bristol
197	Clover	T	041	Halifax	Lynchburg
198	Coeburn	T	097	Wise	Bristol
199	Colonial Beach	T	096	Westmoreland	Fredericksburg
200	Columbia	T	032	Fluvanna	Culpeper
201	Courtland	T	087	Southampton	HR
202	Craigsville	T	007	Augusta	Staunton

203	Crewe	T	067	Nottoway	Richmond
204	Culpeper	T	023	Culpeper	Culpeper
205	Damascus	T	095	Washington	Bristol
206	Dayton	T	082	Rockingham	Staunton
207	Dendron	T	090	Surry	HR
208	Dillwyn	T	014	Buckingham	Lynchburg
209	Drakes Branch	T	019	Charlotte	Lynchburg
210	Dublin	T	077	Pulaski	Salem
211	Duffield	T	084	Scott	Bristol
212	Dumfries	T	076	Prince William	NOVA
213	Dungannon	T	084	Scott	Bristol
214	Eastville	T	065	Northampton	HR
215	Edinburg	T	085	Shenandoah	Staunton
216	Elkton	T	082	Rockingham	Staunton
217	Exmore	T	065	Northampton	HR
218	Fincastle	T	011	Botetourt	Salem
219	Floyd	T	031	Floyd	Salem
220	Fries	T	038	Grayson	Bristol
221	Gate City	T	084	Scott	Bristol
222	Glade Spring	T	095	Washington	Bristol
223	Glasgow	T	081	Rockbridge	Staunton
224	Glen Lyn	T	035	Giles	Salem
225	Gordonsville	T	068	Orange	Culpeper
226	Goshen	T	081	Rockbridge	Staunton
227	Gretna	T	071	Pittsylvania	Lynchburg
228	Grottoes	T	082	Rockingham	Staunton
228	Grottoes	T	007	Augusta	Staunton
229	Grundy	T	013	Buchanan	Bristol
230	Halifax	T	041	Halifax	Lynchburg
231	Hallwood	T	001	Accomack	HR
232	Hamilton	T	053	Loudoun	NOVA
233	Haymarket	T	076	Prince William	NOVA
234	Haysi	T	025	Dickenson	Bristol
235	Herndon	T	029	Fairfax	NOVA
236	Hillsboro	T	053	Loudoun	NOVA
237	Hillsville	T	017	Carroll	Salem
238	Holland	T	061	Nansemond	HR
239	Honaker	T	083	Russell	Bristol
240	Independence	T	038	Grayson	Bristol
241	Iron Gate	T	003	Alleghany	Staunton
242	Irvington	T	051	Lancaster	Fredericksburg
243	Ivor	T	087	Southampton	HR
244	Jarratt	T	091	Sussex	HR
244	Jarratt	T	040	Greensville	HR
245	Jonesville	T	052	Lee	Bristol
246	Keller	T	001	Accomack	HR
247	Kenbridge	T	055	Lunenburg	Richmond
248	Keysville	T	019	Charlotte	Lynchburg
249	Kilmarnock	T	051	Lancaster	Fredericksburg
249	Kilmarnock	T	066	Northumberland	Fredericksburg
250	LaCrosse	T	058	Mecklenburg	Richmond
251	Lawrenceville	T	012	Brunswick	Richmond
252	Lebanon	T	083	Russell	Bristol
253	Leesburg	T	053	Loudoun	NOVA
254	Louisa	T	054	Louisa	Culpeper

255	Lovettsville	T	053	Loudoun	NOVA
256	Madison	T	056	Madison	Culpeper
257	McKenney	T	026	Dinwiddie	Richmond
258	Melfa	T	001	Accomack	HR
259	Middleburg	T	053	Loudoun	NOVA
260	Middletown	T	034	Frederick	Staunton
261	Mineral	T	054	Louisa	Culpeper
262	Monterey	T	045	Highland	Staunton
263	Montross	T	096	Westmoreland	Fredericksburg
264	Mt. Crawford	T	082	Rockingham	Staunton
265	Mt. Jackson	T	085	Shenandoah	Staunton
266	Narrows	T	035	Giles	Salem
267	Nassawadow	T	065	Northampton	HR
268	New Castle	T	022	Craig	Salem
269	New Market	T	085	Shenandoah	Staunton
270	Newsoms	T	087	Southampton	HR
271	Nicklesville	T	084	Scott	Bristol
272	Occoquan	T	076	Prince William	NOVA
273	Onancock	T	001	Accomack	HR
274	Onley	T	001	Accomack	HR
275	Orange	T	068	Orange	Culpeper
276	Painter	T	001	Accomack	HR
277	Pamplin City	T	006	Appomattox	Lynchburg
277	Pamplin City	T	073	Prince Edward	Lynchburg
278	Parksley	T	001	Accomack	HR
279	Pearisburg	T	035	Giles	Salem
280	Pembroke	T	035	Giles	Salem
281	Pennington Gap	T	052	Lee	Bristol
282	Phenix	T	019	Charlotte	Lynchburg
283	Pocahontas	T	092	Tazewell	Bristol
284	Port Royal	T	016	Caroline	Fredericksburg
285	Pound	T	097	Wise	Bristol
286	Purcellville	T	053	Loudoun	NOVA
287	Quantico	T	076	Prince William	NOVA
288	Remington	T	030	Fauquier	Culpeper
289	Rich Creek	T	035	Giles	Salem
290	Ridgeway	T	044	Henry	Salem
291	Round Hill	T	053	Loudoun	NOVA
292	Rural Retreat	T	098	Wythe	Bristol
293	Saint Charles	T	052	Lee	Bristol
294	Saint Paul	T	097	Wise	Bristol
295	Saltville	T	086	Smyth	Bristol
296	Saxis	T	001	Accomack	HR
297	Scottsburg	T	041	Halifax	Lynchburg
298	Scottsville	T	002	Albemarle	Culpeper
298	Scottsville	T	032	Fluvanna	Culpeper
299	Shenandoah	T	069	Page	Staunton
300	Smithfield	T	046	Isle of Wight	HR
301	South Hill	T	058	Mecklenburg	Richmond
302	Stanardsville	T	039	Greene	Culpeper
303	Stanley	T	069	Page	Staunton
304	Stephens City	T	034	Frederick	Staunton
305	Stony Creek	T	091	Sussex	HR
306	Strasburg	T	085	Shenandoah	Staunton
307	Stuart	T	070	Patrick	Salem

308	Surry	T	090	Surry	HR
309	Tangier	T	001	Accomack	HR
310	Tappahannock	T	028	Essex	Fredericksburg
311	The Plains	T	030	Fauquier	Culpeper
312	Timberville	T	082	Rockingham	Staunton
313	Toms Brook	T	085	Shenandoah	Staunton
314	Troutdale	T	038	Grayson	Bristol
315	Troutville	T	011	Botetourt	Salem
316	Urbanna	T	059	Middlesex	Fredericksburg
317	Victoria	T	055	Lunenburg	Richmond
318	Virgilina	T	041	Halifax	Lynchburg
319	Wachapreague	T	001	Accomack	HR
320	Wakefield	T	091	Sussex	HR
321	Warsaw	T	079	Richmond	Fredericksburg
322	Washington	T	078	Rappahannock	Culpeper
323	Waverly	T	091	Sussex	HR
324	Weber City	T	084	Scott	Bristol
325	West Point	T	050	King William	Fredericksburg
326	Whaleyville	T	061	Nansemond	HR
327	White Stone	T	051	Lancaster	Fredericksburg
328	Windsor	T	046	Isle of Wight	HR
329	Wise	T	097	Wise	Bristol
330	Woodstock	T	085	Shenandoah	Staunton
331	Hurt	T	071	Pittsylvania	Lynchburg
			044	Henry	Salem
333	Collinsville	UUP	076	Prince William	NOVA
			076	Prince William	NOVA
335	Quantico Station	UUP	025	Dickenson	Bristol
			004	Amelia	Richmond
			010	Bland	Bristol
338	West Gate	UUP	018	Charles City	Richmond
339	Clinchco	T	024	Cumberland	Lynchburg
			036	Gloucester	Fredericksburg
			037	Goochland	Richmond
			048	King George	Fredericksburg
UUP	Uninc. Urb. Place		049	King and Queen	Fredericksburg
			057	Mathews	Fredericksburg
			062	Nelson	Lynchburg
			063	New Kent	Richmond
			072	Powhatan	Richmond
			089	Stafford	Fredericksburg

Figure 5-P

***GNSS Survey Specifications for Project Monumentation**

Specification	Static	Rapid (or Fast) Static
General Specifications		
Minimum number of reference stations used to control the survey - Minimum Order of station	Horz. - 2 NSRS B-order Vert. - 3 NSRS 3rd-order	Horz. - 2 NSRS B-order Vert. - 3 NSRS 3rd-order
Maximum distance from survey boundary to reference stations	50 km	20 km
Minimum number of dual frequency GNSS receivers used simultaneously	3	3
Mission Planning & Field Observation Specifications		
Minimum number of satellites observed simultaneously at all stations	5	5
Maximum GDOP / PDOP during observation session	6 / 4	6 / 4
Minimum number of simultaneous occupations of reference stations	2	2
Minimum number of simultaneous occupations of sight pairs	2	2
Minimum number of simultaneous occupations of azimuth pairs	2	2
Minimum time between sight and azimuth pair repeat observations	30 minutes	30 minutes
Minimum Spacing of Sight Pairs / Azimuth Pairs	600 ft. / 1 mile	600 ft. / 1 mile
Epoch interval for data sampling during observation session	15 seconds	5 seconds
Minimum satellite mask angle above the horizon for collection and processing	15 degrees	15 degrees
Satellite signals received from minimum number of quadrants	3	2 diagonally opposite
Obstruction diagrams completed for obstructions higher than	20 deg. above horizon	20 deg. above horizon
Minimum observation time at station	2.5 hours	15 minutes
Antenna height measurement in meters at beginning and end of session?	YES	YES
Processing and Adjustment Specifications		
Fixed Integer solution required for all baselines?	YES	YES
Ephemeris used for processing	Broadcast or Precise	Broadcast or Precise
Maximum misclosure per loop in any one component (x,y,z) not to exceed	5 cm	5 cm
Maximum misclosure per loop in terms of loop length not to exceed	30 ppm	30 ppm
Maximum allowable residual in any one component (x,y,z) in a properly constrained least squares network adjustment not to exceed	3 cm	3 cm
Maximum baseline length misclosure allowable in a properly constrained least squares network adjustment	30 ppm	30 ppm

* Rev. 7/15