TxDOT GPS User's Manual

Texas Department of Transportation

Revised August 2005

TxDOT GPS User’s Manual
August 2005

Manual Notices

Manual Notice 2005-1

To:	Users of TxDOT Information Resources
From:	Judy Skeen, P. E., Director, Information Systems Division
Manual:	*TxDOT GPS User’s Manual*
Effective Date:	August 1, 2005

Purpose

To provide the Global Positioning Systems (GPS) information governing the operation standards used by Texas Department of Transportation (TxDOT). These standards are the policies and guidelines set forth by TxDOT regarding Global Positioning Systems processes and procedures.

The intent of this manual is for use by TxDOT employees and TxDOT consultants. Development of this manual provides TxDOT employees and contractors with the concepts, policies, standards, procedures, and practices that govern Global Positioning System functions.

Contents

This manual provides information on the use of Global Positioning System (GPS) technology to perform densification surveys at the State and District level down to small-scale mapping projects. The manual provides an index for quickly locating specific information in the field. Additionally, Appendix B provides a glossary for definitions of terms.

Supersedes

The online *TxDOT GPS User’s Manual* supersedes the *TxDOT GPS Manual of Practice*, dated June 2004.

Instructions

Users are encouraged to print this manual double-sided. To ensure manual currency, check the publishing date of printed manuals against the manual found on the General Services Division (Online Manuals) website.

Contact

Please address your comments, concerns, or questions regarding this manual's information policies, guidelines, procedures, and practices to the TxDOT Standing Committee on Surveying (SCOS).

Copyright Notice

Published by the Information Systems Division (ISD)

Chapter 1
Introduction

Contents:

Section 1
Overview

Summary

The *TxDOT GPS User’s Manual* is referred to as the *GPS User’s Manual* through all chapters of this manual. The *GPS User’s Manual* contains information that governs the operational standards used by Texas Department of Transportation (TxDOT). These standards are the policies and guidelines set forth by TxDOT regarding Global Positioning Systems (GPS) processes and procedures.

Section 2 of this chapter presents all chapter descriptions.

The *GPS User’s Manual* is primarily intended to be accessed online. The online version takes precedence over printed copies, changes, updates and edits. However, paper copies may be used in the field. Copies should be checked for currency date. Caution should be taken not to rely on the printed version due to ongoing updates and/or changes.

The information within this manual is governed by the laws and standards of information security. Please refer to the *Information Security Manual* for specific security information.

Documentation of Authority

The following documents authorize the TxDOT *GPS User’s Manual* and the activities it covers:

- ♦ *TxDOT Directive 5-92*, TxDOT Manual System
- ♦ *Executive Order 1-89*, Policy and Procedures Communication
- ♦ *TxDOT Policy Statement 2-96*, Information Security

Laws and Standards

The *GPS User’s Manual* provides the information that TxDOT GPS and survey resource users need to comply with applicable legal and policy requirements. Based on federal and state laws, state standards and agency policy, this manual draws upon the following:

- ♦ *Texas Government Code*, Section 2203.004, Requirement to Use State Property for State Purposes
- ♦ *Texas Government Code*, Section 403.275, Liability for Property Loss

Purpose of the TxDOT GPS User's Manual

This manual is intended for use by TxDOT surveyors as well as consultants. This manual was developed to provide TxDOT employees and contractors with the concepts, policies, standards, procedures, and practices that govern Global Positioning System (GPS) functions. It is not the intention of this manual to document all technical procedures used within the department.

Scope

This manual provides guidance to the surveyor in the use of GPS technology to perform densification surveys at the state and district level down to small-scale mapping projects. It sets out the criteria and specifications for TxDOT and consultant surveyors to follow.

Organization of Chapters

Chapters 2-8 are similar in organization and address a general aspect of GPS surveying and related information. Each chapter has:

- a chapter overview
- numbered sections for major topics
- unnumbered subsections describing concepts and policies relevant to the section topic.

Some chapters also contain procedures with step-by-step directions for successfully completing tasks related to the section topic.

Subsequent sections are numbered sequentially within each chapter and contain related information associated with the chapter topic. Each chapter is titled to describe its content.

Subsections contain detailed information that describes concepts, policies, standards, and procedures related to the section topic. Concepts and policies a user needs to know to successfully complete a procedure are presented before the procedure, and procedures are presented in tables with step-by-step (step/action) directions for completing a task.

This manual is designed to be published and accessed electronically. The manual is divided into an introductory chapter and chapters that address specific GPS topics.

Table 1.1 TxDOT GPS User's Manual Organization

Element	Purpose
Chapter 1	Identifies and provides manual information and organization. Additionally, it identifies the authorities, laws, and standards that govern the manual.
Chapters 2 – 8	Provide TxDOT GPS policies and procedures
Appendix A	References
Appendix B	Glossary

Section 2

Chapter Descriptions

About this Section

The following subsections describe the contents of Chapters 2-8 of the *GPS User's Manual*. The hyperlinks found in this section will lead the reader to the "Overview" section of a chapter.

Chapter 2, Background

Chapter 2 provides background on surveying with GPS, including accuracy, error sources, and the process for handling errors. It presents information on surveying vertical networks with GPS and the basic differences of conventional and GPS methods.

Chapter 3, Accuracy Standards

Chapter 3 discusses local and network accuracy and provides information on the concepts, guidelines, standards and specifications, as well as methodologies associated with GPS survey accuracy standards. Additionally, it provides tables to illustrate coordinate tolerances and historical accuracy.

Chapter 4, Equipment and Resources

Chapter 4 presents information regarding the use of GPS instruments and equipment. It includes discussions on the requirements for accurate and consistent data collection for a variety of instruments and equipment. This chapter also provides information on Internet resources.

Chapter 5, Network Design

Chapter 5 discusses network design and includes the determination of the number and location of existing control stations for network constraints, as well as selection of new project control stations, and relative dispersion of network observations.

Chapter 6, GPS Survey Specifications

Chapter 6 covers specifications involved in the planning of a project, field data acquisition methods, field survey operations and procedures, data processing, analysis of the data, and documentation. This chapter also provides information on monumentation, survey methods, field survey operations and procedures, and data processing.

Chapter 7, Units, Data, and Metadata

Chapter 7 provides information regarding the units used in TxDOT work, horizontal and vertical datum, adjustment factors, requirements for delivering metadata lists and files, and provisions for conversions and transformations.

Chapter 8, Project Documentation and Deliverables to TxDOT

Chapter 8 TxDOT requirements for project documentation and deliverables are outlined in this chapter. Specifications on technical reports, digital data; control point data sheets and validation surveys are presented.

Appendix A, References

Appendix A contains a comprehensive list of references used in the preparation of this manual.

Appendix B, Glossary

Appendix B contains extensive GPS survey related terms and definitions.

Hyperlinks

Hyperlinks in this manual may appear as red, underlined text or as Web addresses. These hyperlinks take the reader to related information found within this manual, another manual, or outside the TxDOT Manual System.

How to Get Help

The district survey coordinators are available to answer questions and discuss procedures and specifications outlined in this manual. Additionally, the Information Systems Division provides a helpdesk number, which offers survey help from the Automated Survey Support Unit. Users may access the helpdesk by calling (512) 302-2350, press 3 for engineering support, and then 4 for surveying support.

As GPS technology advances, changes in the manual will be necessary. If there is a need for updates or corrections, please notify the district survey coordinator. TxDOT employees will also be able to find contact information for an area SCOS representative on the intranet Web site (crossroads) under the miscellaneous link, “TxDOT Surveying and Mapping.”

Printing

Please print double-sided.

Caution: Readers who rely on any printed portions of the manual should check the online manual regularly for revisions.

Chapter 2
Background

Contents:

Section 1
Overview

Purpose

The purpose of this chapter is to provide the user with general information regarding the use of GPS for design grade surveying. Outlined survey processes provide an understanding of relationships and their components.

Section 2

Surveying with GPS

Survey Background Information

All GPS surveying techniques are based upon interferometric observations of radio signals from a network of orbiting satellites. These signals are processed to compute station positions by trilateration: the positions of the satellites and computed ranges are used to determine the antenna position.

These positions are computed in an Earth-centered Earth-Fixed (ECEF) Cartesian coordinate (x, y, z) system, which can be converted to geodetic curvilinear coordinates (latitude, longitude, and ellipsoidal height). With the addition of a geoid height model, orthometric heights can be computed.

Accuracy of a GPS Survey

The accuracy of a GPS survey is dependent upon many complex, interactive factors, including:

- observation technique used, e.g., static vs. kinematic, code vs. phase, etc.
- amount and quality of data acquired
- GPS signal strength and continuity
- ionospheric and tropospheric conditions
- station site stability, obstructions, and multipath
- satellite orbit used, e.g., predicted vs. precise orbits
- satellite geometry, described by the dilution of precision (DOP)
- network design, e.g., baseline length and orientation
- processing methods used, e.g., double vs. triple differencing, etc.

Error Sources in a GPS Survey

Error sources in a GPS survey include the following:

- *reference position errors* - coordinate, monument stability, crustal motion
- *antenna position errors* - equipment setup, phase center variation and offsets
- *satellite position errors* - orbit ephemeris errors
- *timing errors* - satellite or receiver clock errors
- *signal path errors* - atmospheric delay and refraction, multipath
- *signal recording errors* - receiver noise, cycle-slips

- *human errors* - field or office blunders
- *computing errors* - processing and statistical modeling errors.

Operational Procedures

Identify and minimized *all* errors by redundancy, analysis, and careful operational procedures including:

- the repetition of measurements under independent conditions
- make redundant ties to multiple, high-accuracy control stations
- ensure geodetic-grade instrumentation, field procedures, and office procedures are used
- ensure processing with the most accurate station coordinates, satellite ephemerides, and atmospheric and antenna models available.

Caution: Be aware that these procedures cannot disclose all problems.

Section 3

Surveying Vertical Networks with GPS

Overview

The use of GPS for vertical network surveys requires an understanding of the relationship between conventional and GPS height systems, and problems unique to the vertical component of a GPS measurement.

Conventional trigonometric, spirit, or compensator leveling measures the relative elevations of points above an undulating equipotential surface called the geoid, which is close to, but not the same as, "mean sea level." The model of this undulated geoid surface, currently in use by TxDOT, is GEOID03. TxDOT uses the NAVD88 vertical datum for orthometric height (elevation) measurements from this geoid surface (GEOID03) and it has superceded the old NGVD datum of 1929. Elevations measured by conventional leveling are orthometric heights.

Ellipsoid Measurements

In contrast, GPS measures the relative heights of points above a smooth, mathematically simple surface called an ellipsoid. An example of an ellipsoidal reference surface is GRS80, the defining ellipsoid for NAD 83. Elevations derived from GPS measurements are ellipsoidal heights minus the separation between the geoid and ellipsoid.

The ellipsoidal (h) and orthometric (H) heights are closely related by the geoid height (N), the separation between the two reference surfaces, as shown in Figure 2-1 below. Geoid heights can be derived from GPS observations on bench marks, where both the ellipsoidal and orthometric heights have been measured for the same point. A network of GPS bench mark observations, gravity observations, and elevation models are used to develop a geoid model. From this model, geoid heights at other points in the area can be estimated. The accuracy of these geoid heights is dependant upon the accuracies of the various measurements used to construct the model.

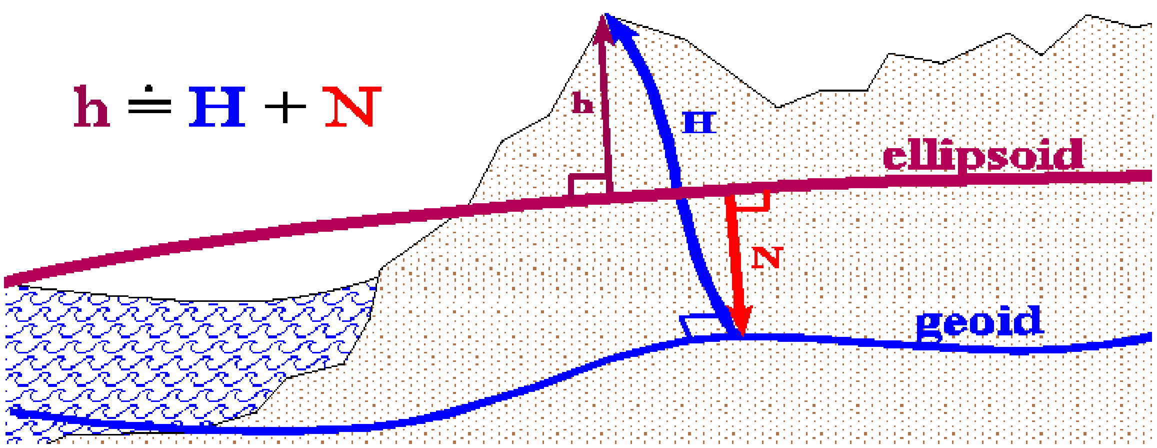

Figure 2-1. Relationship between ellipsoidal (h), orthometric (H), and geoid (N) heights.

Note that in the continental United States the ellipsoid is above the geoid; therefore N in Figure 2-1 is negative. Also, note that the height equation h = H + N is only an approximation as the orthometric height is measured along a curved plumb line normal to the geoid surface, while the ellipsoidal and geoid heights are measured along straight lines normal to the ellipsoid surface. For land surveying applications, the height error associated with this approximation will always be less than one centimeter.

Height Component

The height component of a GPS survey measurement is also affected by relatively poor geometric strength for trilateration, as the earth blocks all satellite signals from the hemisphere below the horizon. This imbalance makes ranging much more critical for determining vertical. Slight ranging errors from multipath or atmospheric conditions are more problematic with this poor geometry.

Accordingly, GPS height accuracies for a survey are typically 1½ - 3 times worse than GPS horizontal accuracies, depending on data quality and baseline length. Increased redundancy of observations under independent conditions is useful for identifying errors.

Because of the need for four or more vertical control points (and in some cases, all four quadrants) to establish good GPS elevations, many times it will be more economical to run conventional level loops.

Section 4
Coordinate Systems

Overview

Many spatial activities, such as navigation, mapping, and surveying, use geographic coordinates to describe the position of objects. Whenever two activities share a common coordinate system, their data can be more readily compared and exchanged.

For this reason, federal and state mapping products are referenced to two standard coordinate systems: the North American Datum of 1983 (NAD 83) for horizontal positions and ellipsoid heights, and the North American Vertical Datum of 1988 (NAVD 88) for orthometric heights. Surveys are referenced to these datums through measurements to control points of the National Spatial Reference System (NSRS).

National Spatial Reference System (NSRS) and Continuously Operating Reference Stations (CORS)

The NSRS is a set of geographic point attributes that provides a consistent framework to coordinate all spatial activities. The NSRS includes a nationwide network of Continuously Operating Reference Stations (National CORS), statewide Federal & Cooperative Base Networks (FBN/CBN), regional User Densification Networks (UDN), and other historic vertical and horizontal control. Figure 2-2 illustrates the CORS Network stations in Texas and some nearby stations in adjoining states. In Texas, TxDOT operates the majority of CORS stations.

Cooperative CORS Stations

Also noteworthy is the rapidly growing system of Cooperative CORS stations. Links to the data from these stations are available on the NGS Web site. Because of the reduced quality control (QC), limited hours of operation and less permanent nature of these stations, it is important that the surveyor be thoroughly familiar with those stations in their own area before depending on them. Also, note that Cooperative CORS coordinates are less accurate than CORS coordinates.

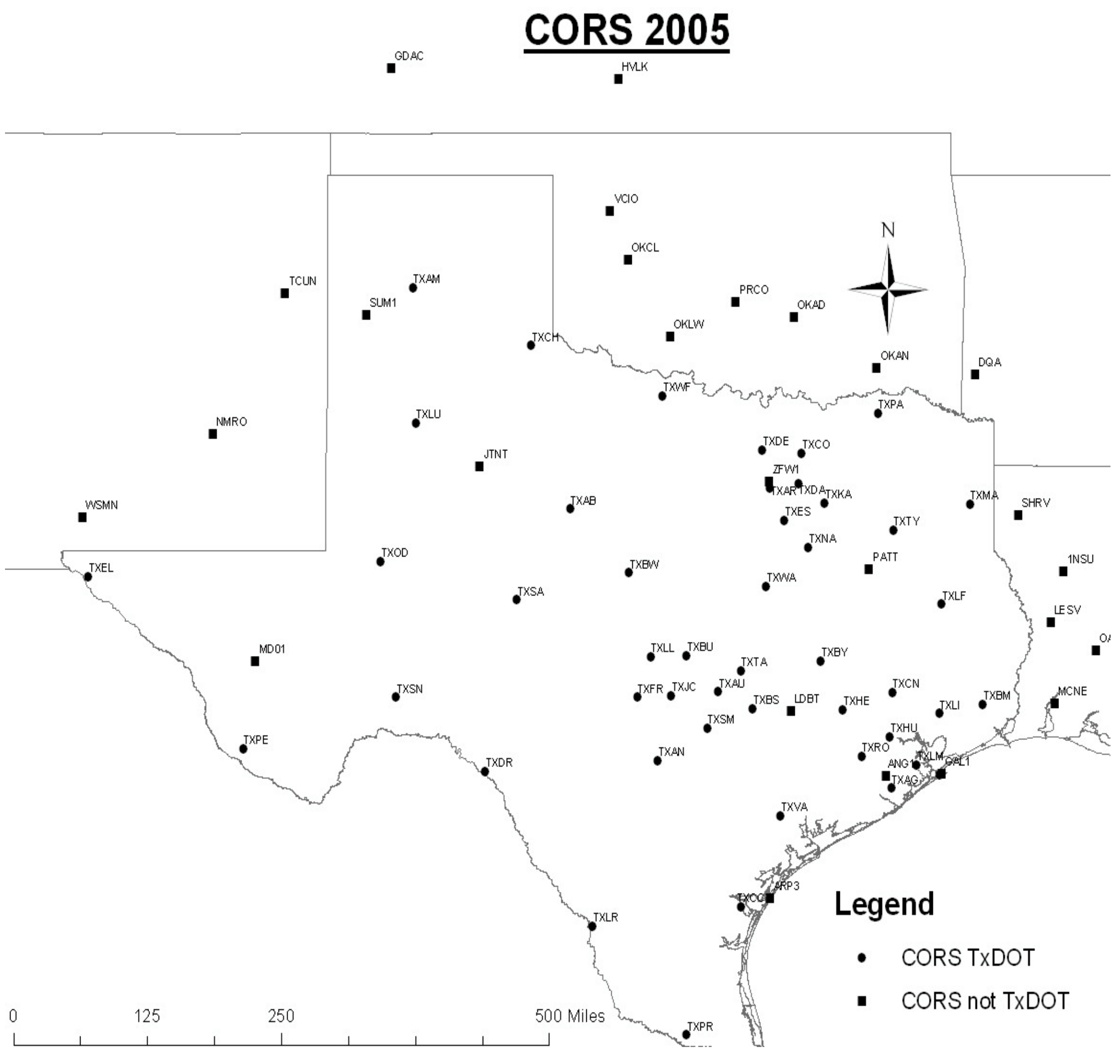

Figure 2-2. CORS Stations.

FBN and CBN

Federal Base Network stations (FBN) (75 to 125 km spacing) or Cooperative Base Network (CBN) stations (25 to 30 km spacings) are B order accuracy and make up the HARN network. These HARN stations have been observed using GPS and have been either used previously as reference stations in the adjustment of the old conventionally surveyed federal monuments or they are newly placed monuments. There are about four hundred of these listed by NGS in Texas.

(continued...)

FBN and CBN *(continued)*

This manual uses and/or references specific information from the following publications:

- 1989 Federal Geodetic Control Subcommittee (FGCS) document “DRAFT Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques”
- the 1998 NOAA Technical Memorandum “NGS-58, Guidelines for Establishing GPS-Derived Ellipsoid Heights,”
- the May 15, 2000 “Preliminary DRAFT Guidelines for Geodetic Network Surveys Using GPS,”
- and numerous other federal/state guidelines and specifications listed in Appendix A, References.

Chapter 3
Accuracy Standards

Contents:

Section 1
Overview

Summary

This chapter provides concepts, guidelines and methodologies associated with TxDOT's GPS survey accuracy standards. This chapter also contains guidelines intended to assist users with achieving consistency and accuracy, using GPS dynamic technologies.

Section 2
GPS Survey Accuracy

Overview

The accuracy of classical triangulation network surveys has been described by a proportional standard, e.g., 1:10,000, which reflected the distance-dependant nature of terrestrial surveying error. The accuracy of GPS surveys, being less distance dependant requires different accuracy standards.

Federal Geographic Data Committee Methodology

The use of multiple standards creates difficulty in comparing the accuracy of coordinate values obtained by different survey methods. In recognition of these difficulties, the Federal Geographic Data Committee (FGDC) has changed its methodology for reporting the accuracy of horizontal and vertical coordinate values. Defining the new reporting standard is the two sigma (2σ) confidence intervals: a circle for horizontal uncertainty, and a linear value for vertical uncertainty.

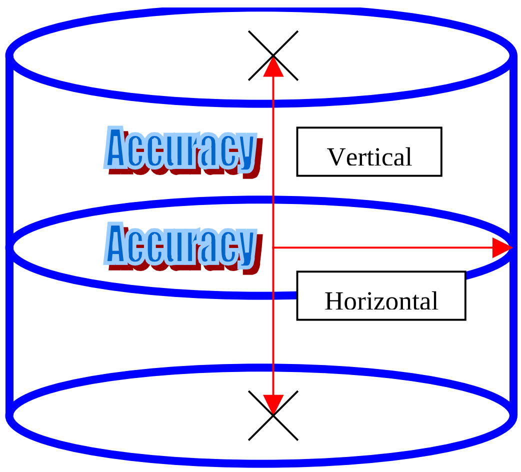

Figure 3-1. 3-D Accuracy

Section 3

Local and Network Accuracy

Standards

The new standards support both local and network accuracies:

- ♦ The *local accuracy* of a control point is a value that represents the uncertainty in the coordinates of the control point relative to the coordinates of other directly connected, adjacent control points at the 95-percent (2σ) confidence level.
  - The reported local accuracy is an approximate average of the individual local accuracy values between a control point and other observed control points used to establish the coordinates of the control point (i.e. the adjacent stations directly tied to the control point).
- ♦ The *network accuracy* of a control point is a value that represents the uncertainty in the coordinates of the control point with respect to the geodetic datum at the 95-percent confidence level.
  - For National Spatial Reference System (NSRS) network accuracy classification, the datum is considered to be best expressed by the geodetic values at the Continuously Operating Reference Stations (CORS) supported by NGS. By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.

Local accuracy is best adapted to check relations between nearby control points; for example, a surveyor checking closure between two NSRS points is most interested in a local accuracy measure.

Positional Tolerance and Associated Coordinates

On the other hand, someone constructing a GIS will often need some type of positional tolerance associated with a set of coordinates. Network accuracy measures how well coordinates approach an ideal, error-free datum. The following two tables are reproduced from National Geodetic Survey’s “Guidelines for Geodetic Network Surveys Using GPS,” 5/15/00 - Preliminary DRAFT.

(continued...)

Positional Tolerance and Associated Coordinates *(continued)*

In the following table, the word "Expected" is used because the values given are estimates.

Table 3.1 Expected Survey Accuracies (2σ) for NGS Control

Positional Component	FBN/CBN	UDN	Height (2cm)	Height (5cm)
Horizontal Position	1 cm	various	1 cm	2 cm
Ellipsoidal Height	2 cm	various	2 cm	5 cm
Orthometric Height	3 cm	various	2 cm	5 cm

The table below provides positional accuracy history.

Table 3.2 History of Positional Accuracy (2σ) for NGS Control

Network	Time Span	Network Accuracy	Local Accuracy
NAD27	1927-1986	10 meters	First Order (1:100,000)
NAD83	1986-1991	1 meter	First Order (1:100,000)
HARN	1991-1997	0.1 meter	B Order First Order (1:1,000,000) A Order (1:10,000,000)
CORS	1996-Present	0.01 meter	0.01 meter*

* The best value NGS has; so they are assumed to be zero.

Federal Geodetic Data Committee (FGDC) Standards

Based on the *Geospatial Positioning Accuracy Standards*, the FGDC-STD-007-1998, Part 2: *Standards for Geodetic Networks* prepared by the FGDC, the following accuracy standards supercede and replace the accuracy standards found in FGCC 1984 and FGCC 1988 (see Appendix A, References). The classification standard for geodetic networks is based on accuracy.

(continued...)

Federal Geodetic Data Committee (FGDC) Standards *(continued)*

The table of accuracy standards for horizontal, ellipsoid height, and orthometric height is as follows:

Table 3.3 FGDC Accuracy Standards

Accuracy Classification	95 % Confidence
1- Millimeter	0.001 meters
2-Millimeter	0.002 meters
5-Millimeter	0.005 meters
1-Centimeter	0.010 meters
2-Centimeter	0.020 meters
5-Centimeter	0.050 meters
1-Decimeter	0.100 meters
2-Decimeter	0.200 meters
5-Decimeter	0.500 meters
1-Meter	1.000 meters
2-Meter	2.000 meters
5-Meter	5.000 meters
10-Meter	10.000 meters

TxDOT Standards

TxDOT has numerous survey accuracy requirements based on the type of project being surveyed. Listed in the table below are seven levels with typical types of surveys for each. The level of survey accuracy will be used as a standard throughout this manual to define the quality of the survey measurements for a particular application.

The seven levels, of course, are of equal or less accuracy than the A and B order federal monuments, which could be considered Level 0 in the TxDOT scheme. A Level 0 is shown in some of the charts only to show the relationship of the NGS points to the seven TxDOT levels.

(continued...)

TxDOT Standards *(continued)*

Table 3.4 TxDOT Level of Survey Accuracy

TxDOT Level of Accuracy	Typical Applications
Level 0	CORS, FBN, CBN (this level overseen by NGS)
Level 1	Statewide/district-wide Control Densification, RRP Network Stations (until recognized as NGS CORS), Cooperative CORS sites
Level 2	Primary Project Control, Control for Airborne GPS for Photogrammetry or LiDAR Data Gathering
Level 3	Photogrammetric Control Panels, Boundary Corners, ROW, and Local Control
Level 4	Wing Panels for Horizontal Positions*, Topography, Stakeout
Level 5	Sub-meter Mapping for GIS (includes inventory and locative surveys)
Level 6	1 – 5 Meter Mapping for GIS (includes inventory and locative surveys)
Level 7	> 5 Meter Mapping for GIS (includes inventory and locative surveys)

* Vertical positions for wing panels fall in Level 3. However, if panel elevations have been determined by differential leveling, horizontal positions, if needed, can be determined with Level 4 GPS observation.

In the interest of keeping its position information integrated properly with the NSRS, TxDOT will require all new Level 1 (“B” order densification) control, which is established to be referenced to a minimum of four (4) of the closest A or B order stations surrounding the station.

Two of these may be publicly accessible FBN or CBN stations but at least two *must* be CORS stations. CORS stations, with their downloadable data, are economical to use and are the most accurate stations available. The ties to the CORS, FBN and CBN stations will serve as the method to determine the network accuracy.

(continued...)

TxDOT Standards *(continued)*

Table 3.5 TxDOT Local Accuracy Classification

Level of Survey Accuracy *	**Level 0**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Local Accuracy Class. (m)	0.02	0.02	0.05	0.10	0.10
Base Error (m) *e*	0.008	0.008	0.010	0.010	0.010
Ppm *p*	2	4	10	20	50
Minimum baseline length (m) *d*	10000	3000	400	150	150
Maximum baseline length (m) *d*	20,000	10,000	10,000	5,000	3,000
Maximum allowable error based on *minimum* baseline length (m) *s*	0.022	0.014	0.011	0.010	0.013
Maximum allowable error based on *maximum* baseline length (m) *s*	0.041	0.041	0.10	0.10	0.15
NGS Classification Range (See Table 3.7)	VI	VI	VII	VII	VIII

* This table does not apply to mapping grade levels 5, 6 and 7.

Based on the level of survey accuracy listed in Table 3.4, Table 3.5 may be used as the standard for future classification of surveys performed for TxDOT. The maximum allowable errors listed on the following page are based on:

- All connected and unconnected baselines (vectors) within the minimally constrained and fully constrained network adjustments must comply with the 3-D relative positional error (s) required for the desired level of survey accuracy classification.

(continued...)

TxDOT Standards *(continued)*

Equation for determining maximum relative positional error at the 95% confidence level:

$$s = \sqrt{e^2 + (d \times p \times 10^{-6})^2}$$

Where,

s = Maximum allowable relative positional error (m) at the 95% (2σ) confidence level
e = Base error in meters (m)
p = Parts per million (ppm)
d = Distance in meters (m)

New NGS GPS Accuracy Standards:

Table 3.6 NGS Accuracy Standards

Classification	Minimum Geometric Accuracy Standard at 2 σ
	Less than or equal to:
AA	0.003 m + 1:100,000,000
A	0.005 m + 1:10,000,000
B	0.008 m + 1:1,000,000
First	0.010 m + 1:100,000
Second, Class I	0.020 m + 1:50,000
Second, Class II	0.030 m + 1:20,000
Third	0.050 m + 1:10,000

The following table provides the classification range and confidence levels for accuracy standards:

Table 3.7 NGS Accuracy Standards for Horizontal Position, Ellipsoid Height, and Orthometric Height

Classification Range	95 % Confidence Level in Meters
Range 0	Reserved for CORS
Range I	< 0.001
Range II	0.001 – 0.002
Range III	0.002 – 0.005
Range IV	0.005 – 0.010
Range V	0.010 – 0.020
Range VI	0.020 – 0.050
Range VII	0.050 – 0.100

(continued...)

TxDOT Standards*(continued)*

Table 3.7 NGS Accuracy Standards for Horizontal Position, Ellipsoid Height, and Orthometric Height

Classification Range	95 % Confidence Level in Meters
Range VIII	0.100 – 0.200
Range IX	0.200 – 0.500
Range X	0.500 – 1.000
Range XI	1.000 – 2.000
Range XII	2.000 – 5.000
Range XIII	5.000 – 10.000
Range XIV	> 10.000 **

** Ranges larger than XIII will be developed jointly with other subcommittees within FGDC.

Section 4
Standards and Specifications

Standards and Specifications Issues

There are two issues, which are significant within the manuals' standards and specifications.

First, least squares analysis is the primary process by which the stated project conclusions are justified. However, this process is *only* valid with sufficient redundancy and correct assumptions made regarding the probability of errors.

Second, the processing of raw GPS observables has been the subject of much innovation and experimentation. This trend is certain to continue, as GPS technology is extremely dynamic and changing constantly.

It is the responsibility of the professional in charge to employ techniques, which are appropriate for the project and to provide verification that the stated conclusions are valid.

The use of these *standards and specifications* are recommended and do not relieve the surveyor from making decisions or using professional judgment during the course of the field survey and the subsequent data processing to obtain the desired results.

Carefully document the procedures, techniques, and results for every step.

Accuracy Levels and Specifications

Experience has shown that current receivers and software have the capability to achieve geodetic-quality accuracy levels under certain conditions and restrictions. Specifications for performing control surveys using kinematic techniques require greater observational and occupational redundancies and checks than usually specified by the manufacturers. The specifications provide sufficient observational and occupational redundancy to detect blunders and quantitatively demonstrate accuracy achievement for a survey.

The accuracy reporting requirements of this document are in accordance with accuracy reporting requirements of the Federal Geographic Data Committee's "Geospatial Positioning Accuracy Standards," FGDC-STD-007-1998.

Statistical Analyses

In accordance with new federal positioning standards, these specifications rely heavily on the use of statistical analyses to determine the accuracy of a GPS survey. Regardless of how the observations for a particular survey were obtained, the completed survey must provide the following information:

- elimination or reduction of known and potential systematic error sources
- sufficient occupational and observational redundancy to clearly demonstrate the stated accuracy
- adequate baseline processing and evaluation, network (least squares) adjustment, and data evaluation
- sufficient documentation to allow verification of the results.

Terminology

In dealing with GPS equipment manufacturers, federal agencies and long time surveyors, we find phrases and terminology used in different and confusing ways. For the purpose of this manual, a “GPS observation” is an uninterrupted recording of satellite data at one station and the created file of raw data. A “GPS session” is a number of observations run simultaneously for creating baselines.

Chapter 4
Equipment and Resources

Contents:

Section 1
Overview

Summary

This chapter presents valuable information regarding the use of GPS instruments and equipment. It includes discussions on the requirements for accurate and consistent data collection for a variety of instruments and equipment. Basic instrumentation for TxDOT GPS control surveys includes multiple sets of receivers, antennas, and fixed-height and/or variable height tripods. To minimize equipment biases, use of identical equipment is encouraged whenever possible.

Section 2

Instruments

GPS Receiver

The receivers used for network surveys should record the full-wavelength carrier phase and signal strength of both the L1 and L2 frequencies, and track at least eight satellites simultaneously on parallel channels. L1 only receivers are acceptable only for baselines less than 10 km. Ties to CORS sites should be made with dual-frequency instruments if base lines are longer than 10 km. Receivers should have sufficient memory and battery power to record 6-hours of data at 5-second epochs. Receivers should contain the latest manufacturer's firmware upgrades.

GPS Antenna

The antennas should have stable phase centers and be designed to minimize multipath interference. All antenna models used should undergo antenna calibration by the National Geodetic Survey (NGS). Users should consult user's manual for other specifications.

NGS Geodetic Services Division maintains a GPS Antenna Calibration Web site for calibrating a variety of antennas.

When processing GPS baselines, the user must apply the appropriate GPS antenna phase center offsets. Inappropriate phase center offsets can introduce up to 10 cm of error in the baseline.

GPS antenna ground planes should be utilized according to manufacturer specifications. Ground planes must be utilized for all stations when performing TxDOT Level 1 and Level 2 surveys. For other surveys, a ground plane must be used at the base station and should be utilized in areas where there might be significant multipath. Many new antenna models have built in ground planes.

GPS-RTK Rover Rod

A fixed height rover rod should be used and if possible, it should be the same height as any fixed height tripods on the project – usually 2-meters. Make a physical measurement in the field notes to verify it has been checked. Also, check the level bubble on the rod before and after each project.

Tripods

The tripods must facilitate precise offset measurements between the mark datum point and the antenna reference point (ARP). Fixed-height rods or fixed height tripods are preferable and required for certain surveys due to the decreased potential for antenna centering and height measurement errors. All tripods should be examined for stability with each use. Ensure that hinges, clamps, and feet are secure and in good repair. Test the fixed-height tripods for stability, plumb alignment, and height verification at the start and end of each project.

Tribrachs

Tribrachs and rod levels should be field calibrated before use on each project and should be checked at the end of the project. Any data not bracketed by a successful calibration check are suspect. Professional Tribrach calibration, usually scheduled once a year with regular use is a reasonable interval for maintaining the accuracy of the instrument.

Instrumentation Requirements

Summarized below are instrumentation and data collection requirements:

Table 4.1 Instrumentation Requirements

Level of Survey *	Level 0	Level 1	Level 2	Level 3	Level 4
GPS Receivers					
Dual Frequency	Required	Required	Required	Recommended	Recommended
Single Frequency	Not Acceptable	Not Acceptable	Not Acceptable	Acceptable	Acceptable
GPS antennas	Ground plane Required	Ground plane Required	Ground plane Required	Ground plane Optional	Ground plane Optional
Tripods	Fixed H.I. Required	Fixed H.I. or Variable	Fixed H.I. or Variable	Fixed H.I. or Variable	Fixed H.I. or Variable
3d ant. H.I. and centering pos. tolerance	0.2 cm	0.2 cm	0.3 cm	0.4 cm	0.4 cm
Minimum # of GPS receivers**	3	3	2	2	2
RTK acceptable	No	No	No	No***	Yes

* This chart does not apply to mapping level surveys Levels 5, 6 and 7.
** Minimum # of receivers simultaneously logging data during a session not including CORS.
*** Acceptable if points are located from more than one control point at different times.

Personnel

All field personnel should be trained in the avoidance of systematic errors during field operations. Field personnel often work alone and must be prepared to make wise, on-the-spot decisions regarding mark identification and stability, equipment use and troubleshooting, and antenna setup. Office personnel should be familiar with geodetic concepts and least squares adjustments. Personnel should participate in any available certification and training activities.

All boundary control survey projects performed for TxDOT will be performed under charge of a Texas Registered Professional Land Surveyor (RPLS). Personnel requirements for various types of surveys may vary from one TxDOT district to another. The use of certified survey technicians (CST's) is encouraged not to fulfill any requirements, but to aid in the efficiency of operations with the use of goal-oriented employees.

Section 3

Internet Resources

The CORS Site

Using the CORS reference stations insures that all project control points are on a recognized network. It may not seem important at the time, but it also puts the TxDOT project on the NSRS at no extra cost. In fact, it saves sending extra people to the field and buying or renting extra GPS receivers.

For the extra few minutes it takes to download data, the office technician may as well include several additional CORS stations beyond the one or two required by the specifications. Refer to Figure 2-2 for a map of CORS stations as of this writing or visit the NGS Web site www.ngs.noaa.gov under the CORS/OPUS heading for an all-inclusive and current map.

Retrieving Data from the CORS Site

Retrieve CORS data from NGS from the NGS Web site at: www.ngs.noaa.gov/CORS.

The User Friendly CORS site (UFCORS) allows the user to download all the data desired in just one file containing the number of hours needed from a start time entered on the online form and, at the user's request, can include the coordinates and ephemeris in one simple zipped download. It is not necessary to convert to Universal Time Coordinate (UTC) time or sort through the coded file names. All files available from NGS are in RINEX format.

Should users need to use individual hourly files, a typical NGS RINEX data file from a CORS station appears with this naming convention: {SSSS} {DDD} {H} . {YY} {T}

Where SSSS is the four (4)-character site identifier:

DDD is the day of year

H is a letter that corresponds to an hour-long UTC time block

YY is the year
T is the file type
Example: txan3350.01o

For daily files, the format would be {SSSS}{DDD}{H}0.{YY}{T}.

Obtaining Coordinates from the CORS Site

Coordinates for the station needed can also be found on the Web site by clicking the appropriate site on the map then choosing “coordinates” from the left hand menu. The coordinate data sheet has two sections.

The top section contains the position information for the antenna reference point (ARP) and the bottom section, the information for the L1 phase center of the GPS antenna. It is important to use the ARP coordinates for the held position in processing.

The antenna type at the CORS station (needed during processing) is included in the header of the downloaded file. In addition, each section of the coordinate listing contains the ITRF position and the NAD83 position. Be sure to use the NAD83 position information.

If the PID of a station is known, the coordinates can also be found in the NGS database for the National Spatial Reference System. By starting from the NGS home page, click on “datasheets” in the five selections at the top. Click on the DATASHEETS retrieval link and click on the PIDs. To retrieve the appropriate data sheet, *key* in the PID.

Remember, there may be as many as three (3) separate data sheets associated with a station:

- a data sheet for the monument on the ground (if one exists)
- a data sheet for the L1 phase center of the antenna (the point at which data is actually collected) and finally,
- the ARP (the mounting surface of the antenna).

Each of these points has its own PID.

OPUS

The Online Positioning User Service (OPUS) is the newest addition to NGS’ Geodetic Tool Kit. OPUS allows users to submit their GPS data files in RINEX format to NGS, where the data will be processed to determine a position using NGS computers and software. Each RINEX file submitted is processed with respect to three (3) National CORS sites or Cooperative CORS sites.

Any stations in a TxDOT network that contain two (2) or more hours of raw GPS data can be processed at this Web site. The tie sites selected may not be the nearest to the users’ site but are selected by distance, number of observations, site stability, etc. Users have the option to select their own CORS sites. The ITRF and NAD83 coordinates, as well as Universal Transverse Mercator (UTM) and SPC Northing and Easting report position data back to the user via e-mail.

(continued...)

OPUS *(continued)*

TxDOT recommends that users check the results of the processing and adjustment on new points with this NGS service. As a minimum, at least one station should be checked in every network. OPUS positions are usually within one or two tenths of a foot. However, they may be less precise in areas of one-direction-only ties.

Use this to verify the NAD83 HARN position and ellipsoid height. Orthometric heights may not tie, based on whether the elevation was established before or after the original Texas HARN network was created.

NGS Description of OPUS

The National Geodetic Survey operates the Online Positioning User Service (OPUS) as a means to provide GPS its user's easier access to the National Spatial Reference System (NSRS).

OPUS allows users to submit their GPS data files in RINEX format to NGS, where the data is processed to determine a position using NGS computers and software. Each RINEX file submitted is processed with respect to three (3) CORS sites.

The sites selected may not be the nearest to the users' site but are selected by distance, number of observations, site stability, etc. Users have the option to select their own CORS sites. The position for data will be reported back to the user via e-mail in both ITRF and NAD83 coordinates, as well as UTM and SPC Northing and Easting coordinates.

NGS OPUS Requirements

OPUS is completely automatic. Users are required to enter only a minimal amount of information. OPUS requires the following:

- e-mail address to receive results
- RINEX file that the user wants to process (which may be selected using the browse feature)
- antenna type used to collect this RINEX file (selected from a list of calibrated GPS antennas)
- height of the Antenna Reference Point (ARP) above the monument or mark that user is positioning
- as an option, users may also enter the state plane coordinate code if they want SPC Northing and Easting.

Once the information is completed, click the *upload button* to send the data to NGS. User's results will be e-mailed in a few minutes. Upload one RINEX file at a time.

(continued...)

NGS OPUS Requirements *(continued)*

Read through each of the OPUS Help Links. It is important that users understand how to correctly submit their data and how to interpret the results. For inquires or comments, use the OPUS e-mail button.

OPUS is intended for use in the conterminous U.S., Alaska, and Hawaii. It is NGS policy not to publish geodetic coordinates outside the U.S. without the agreement of the affected countries.

Useful Web Sites

Below is a list of Web site addresses which may be accessed for further information regarding GPS-related activities. Click the hyperlink to access the Web site for the following:

GPS Antenna Information	http://www.ngs.noaa.gov/ANTCAL/index.shtml
GPS Orbital Data	http://www.ngs.noaa.gov/GPS/GPS.html
GPS Overview	http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
National Geodetic Survey	http://www.ngs.noaa.gov/
NGS Data Sheets	http://www.ngs.noaa.gov/cgi-bin/datasheet.prl
NGS CORS Data	http://www.ngs.noaa.gov/CORS/
NGS PC Software	http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml
OPUS	http://www.ngs.noaa.gov/OPUS/
Space Weather	http://www.sec.noaa.gov/today.html
TxDOT RRP Data	http://www.dot.state.tx.us/isd/gps/gps.htm
USCG	http://www.navcen.uscg.gov/

Retrieving Data from TxDOT

Retrieving CORS data from the original TxDOT maintained stations (RPS's) can be done from the Internet using the following TxDOT Web address: http://www.dot.state.tx.us/isd/gps/gps.htm.

TxDOT posts files in both RINEX and Trimble formats. RINEX file naming convention is standard but a TxDOT data file in Trimble format will have a different naming convention. TxDOT is in the transition of updating the GPS data distribution web page. The "FileFormat.txt" file included on the Web site will contain the latest information for naming convention and the "Position_update.doc" contains the original TxDOT coordinates as well as antenna heights (for use of the actual monument rather than the ARP). Always refer to these documents when processing data from the TxDOT Web site.

Files in Trimble format are available in six (6) hour increments or four (4) files per day and files in RINEX format are available hourly. Note that Julian dates are based on Universal Time Coordinate (UTC). The is no provision for combining files before download. Data is kept for six (6) months and data older than six (6) months must be retrieved from NGS.

If all the CORS reference stations in the network the user is building are original TxDOT RRP'S, and if users have need for maintaining the TxDOT position used in the mid 1990's, TxDOT still adjusts some of the newer RRP's to the original unchanged coordinates of that time and makes them available on the "Position_update.doc" file above. Some RRP location at the outer edges of the state may differ from the NGS positions (epoch 2002) by a couple of centimeters. Remember to us H.I.'s when holding the actual monument rather than the usual ARP position. Also, note that these H.I.'s are to the phase center of the antenna.

Chapter 5
Network Design

Contents:

Section 1

Overview

Summary

Network design includes: 1.) the determination of the number and location of existing control stations for network constraints; 2.) the selection of new project control stations, and 3.) the relative dispersion of network observations.

Network design has relevance for concerns regarding the elimination and/or reduction of potential error sources, as well as for providing adequate ties to the existing geodetic reference system (NAD83). These concerns may be addressed by the choice of which existing control stations should be included, as well as the planning of the new station locations and network observation periods. GPS derived orthometric heights are particularly sensitive to the distribution of observations and network constraints.

Section 2

Design Features

Control

To meet a network or local accuracy level, a GPS project must be connected to sufficiently accurate and well-distributed existing control.

All of the control stations to which the network will be constrained must have positions known on the NAD83 datum. Control stations of the state HARN adjustment are generally used; however, certain special projects may have a legitimate need for another geodetic reference. Use the appropriate datum adjustment as recommended by the TxDOT district surveyor or survey coordinator.

The minimum number of horizontal and vertical constraints is stated in Table 5.1, with their location being distributed in different quadrants relative to the center of the project. Where existing NGS or TxDOT horizontal and/or vertical control on a common datum and epoch is available, all such stations lying within a few kilometers of the survey's boundaries should, if possible, be included in the survey if they meet the horizontal accuracy requirements. Second order or better is generally required for vertical.

Orthometric Height

Requirements for orthometric height constraints are dependent upon geoid slope, project extent, desired accuracy, and the density of the gravity database. These issues are addressed under the subsection, Orthometric Height Determination in Chapter 6, Section 7.

In general, vertical control for Level 1 and Level 2 networks require a minimum of 4, preferably 5 published vertical control stations. They should be situated on the outside corners of the project at a minimum.

In other words, at least one bench mark should be fixed in each of the four (4) quadrants of the survey area, such that nearly all of the newly surveyed stations will fall inside a boundary drawn around the outside benchmarks. Additional benchmarks inside the perimeter will aid in strengthening the adjustment.

Network Baseline

TxDOT recognizes there are arguments for and against the use of dependent (trivial) baselines in a network. TxDOT recommends not using dependent baselines.

For any given multiple receiver session, there are n(n-1)/2 total vectors possible, where n = the number of GPS receivers observing simultaneously. The number of independent vectors is n-1.

Using only the independent baselines:

- prevents adjusting the same observations more than once and misstating the network degrees of freedom in the least squares adjustment
- makes it easier to troubleshoot and evaluate the network and locate deviant baselines.

Accuracy Standards for Network Baseline

For a station to qualify for an accuracy classification, network or local, it must meet the listed accuracy standards, relative to all other stations in the network and/or datum, whether or not there was a direct connection between them.

The table below outlines requirements for network design.

Table 5.1 Minimum TxDOT Network Design Specifications

Level of Accuracy *	Level 0	Level 1	Level 2	Level 3
Minimum Number of Closest Direct CORS Ties	2	2	1	0
Minimum Number of Total FBN/CBN /CORS Station Ties	4	4	3	2**
Minimum Number of Horizontal Station Ties	4	4 (Level 0 ties)	3 (Level 1 or 0)	2 (Level 0,1, or 2)
Minimum Number of Vertical Ties (2nd order or better)	6	5	4	2
Minimum Number of Occupations Per Station	2	2	2	2
Minimum Number of Repeat BL's (% of all BL's)	50%	40%	30%	20%
Time Offset Between Observations (Occupations ***)	± 4 hrs	± 3 hrs	± 2 hrs	± 1 hr
Minimum Satellite Elevation Mask	15 Degrees	15 Degrees	13 Degrees	13 Degrees
Minimum Number of Quadrants for H Station Ties	4	4	3	2
Minimum Number of Quadrants for V Station Ties	4	4	4	2
Type of Ephemeris Required	precise	precise	rapid or precise	broadcast or better

* Level 4, 5, 6 and 7 surveys are generally not network surveys – network requirements do not apply

** These should be at least be indirect ties to CORS, FBN or CBN stations – they may be surveyed from Level 2 stations, which have been directly tied to CORS, FBN or CBN stations

*** To qualify for a new occupation, the observer must remove the GPS receiver at the station and a completely new setup over that station must take place.

(continued...)

Accuracy Standards for Network Baseline *(continued)*

As mentioned in the Chapter 3 of this manual, FBN and CBN stations are statewide GPS survey networks that form the highest order of monumented control for the NSRS. These are A and B order points. NGS-maintained FBN stations at 100 km station spacing and volunteer-densified CBN points at 25-50 km spacing are included in the Table 5.1 and serve as control for regional and local surveys.

Ideally, the time offset between observations should be 24 hours plus 3 – 9 hours before the second observation in order to “see” a completely different satellite constellation. A more practical approach for scheduling observations with a minimum of overlap is to remember that the satellite positions repeat about every 12 hours (actually they advance in position about four minutes a day). Scheduling with this in mind, could result in substantial savings in time and cost. Also, it should be noted that whenever possible, a different receiver should be used at that station for the repeat observation.

Example of a Network Design Procedure

Network Design Example:

1. Roughly locate both new points and existing control on a map showing roads to use in moving the observers around the project.
2. From reconnaissance and mission planning software, determine the best times to observe.
3. For each session, draw the independent baselines chosen to be observed on map. Move through the project until all points have been observed.
4. Observing the rules for time differences, plan the repeated occupations and observations. Consider redundancy requirements.
5. Measure and record antenna height in two different units at the beginning and before the end of each session.
6. Fill out observation sheet each session.
7. Every one moves every session (where practical).

Chapter 6
GPS Survey Specification

Contents:

Section 1
Overview

Scope

The specifications outlined in this chapter cover the planning of the project, field data acquisition methods, field survey operations and procedures, monumentation, survey methods, data processing, analysis of the data, and documentation.

The uses of these specifications, along with the manufacturer's specifications, provide a means for the surveyor to evaluate the survey and to verify the specified accuracy standard achievement.

Section 2

Specifications

Overview

The specifications within this chapter ensure that a survey performed with GPS technology is repeatable, meets accuracy requirements, and referenced to the National Spatial Reference System (NSRS) by providing the following:

- elimination or reduction of known and potential systematic error sources
- occupational (station) and observational (baseline) redundancy to clearly demonstrate the stated accuracy
- baseline processing, data adjustment and data analysis to clearly demonstrate the stated accuracy
- documentation demonstrating verification of the results.

GPS survey specifications continually evolve with the advancements in equipment and techniques. Changes to these specifications are expected as these advancements occur. The size, scope, and site conditions of a project may also require variations from these specifications.

Remember, any variations from these specifications should be designed to meet the above criteria and to achieve the accuracy standard of the survey; as required by this manual. All variations *must* be pre-approved by TxDOT and documented in the project report.

Section 3

Planning

Overview

Planning is probably the most important part of the performance of a control survey utilizing GPS survey measurement techniques. Proper planning will give one added confidence that quality data will be collected. Regardless of the level of the survey, the items listed below should be addressed before the field data collection process begins.

Reconnaissance

Prior to the commencement of any TxDOT survey, all significant aspects of the project should be understood so that the project can be performed effectively and efficiently. Based on the TxDOT level of survey to be performed, go to Chapter 4, Table 4.1 and Chapter 5, Table 5.1 and review the specifications for the project.

Perform a reconnaissance survey of the site to:

- determine the location and sky visibility of existing and new control stations
- pick the locations for new stations making sure satellites can be recorded in a minimum of three quadrants
- look at logistics of project and determine transportation required
- gain permission to access station(s) on private land
- if applicable, the surveyor should notify law enforcement of their activities; record sky visibility chart data and access requirements for all stations
- look for any objects that could be sources for radio interference
- look for any multipath conditions that may affect data collection.

Monumentation for New Stations

All monumentation for new Level 1 points are to be in accordance with the following NGS publications.

Concrete Marks, from *NGS Operations Handbook and Manual of Geodetic Triangulation,* S.P. 247

Setting a Survey Disk in Bedrock or a Structure from NOAA Manual NOS, NGS 1, *Geodetic Bench Marks*

Setting a NGS 3-D Monument Based on Revised NGS 3-Dimensional (3-D) *Rod Mark* [Draft Version] by: Curtis L. Smith, National Geodetic Survey, July, 1996

It is recommended that new Level 2 points also follow these construction specifications, but the TxDOT surveyor in charge may call for less stringent requirements.

Naming Convention for Level 1 and Level 2 Monuments

The recommended naming convention for Level 1 and Level 2 monuments is as follows:

Example: 1580032

Table 6.1 Naming Convention

Digits	Indication
158	♦ The first three (3) digits indicate the county in which the monument was set. ♦ This is the standard county code used by TxDOT (see Figure 6-5, 6-6).
0032	♦ The next four digits indicate the point number of this particular monument. ♦ It is specific for this county and there can be no duplicates in the county.

Some districts use variations of this by including a prefix or suffix.

Figure 6-2 and Figure 6-3 are sample data sheets for documenting the monuments likely to be used in the future. There must be a data sheet for all Level 1 and Level 2 monuments. Districts may use their own data sheet form, but it must contain all the horizontal and vertical geodetic data of this sample data sheets. An RPLS signature and seal is recommended for data sheets for Level 1 and Level 2 GPS monuments.

Co. No.	County Name	Co. No.	County Name	Co. No.	County Name	Co. No.	County Name
1	Anderson	65	Donley	129	Karnes	192	Reagan
2	Andrews	66	Kenedy	130	Kaufman	193	Real
3	Angelina	67	Duval	131	Kendall	194	Red River
4	Aransas	68	Eastland	66	Kenedy	195	Reeves
5	Archer	69	Ector	132	Kent	196	Refugio
6	Armstrong	70	Edwards	133	Kerr	197	Roberts
7	Atascosa	71	Ellis	134	Kimble	198	Robertson
8	Austin	72	El Paso	135	King	199	Rockwall
9	Bailey	73	Erath	136	Kinney	200	Runnels
10	Bandera	74	Falls	137	Kleberg	201	Rusk
11	Bastrop	75	Fannin	138	Knox	202	Sabine
12	Baylor	76	Fayette	139	Lamar	203	San Augustine
13	Bee	77	Fisher	140	Lamb	204	San Jacinto
14	Bell	78	Floyd	141	Lampasas	205	San Patricio
15	Bexar	79	Foard	142	LaSalle	206	San Saba
16	Blanco	80	Fort Bend	143	Lavaca	207	Schleicher
17	Borden	81	Franklin	144	Lee	208	Scurry
18	Bosque	82	Freestone	145	Leon	209	Shackelford
19	Bowie	83	Frio	146	Liberty	210	Shelby
20	Brazoria	84	Gaines	147	Limestone	211	Sherman
21	Brazos	85	Galveston	148	Lipscomb	212	Smith
22	Brewster	86	Garza	149	Live Oak	213	Somervell
23	Briscoe	87	Gillespie	150	Llano	214	Starr
24	Brooks	88	Glasscock	151	Loving	215	Stephens
25	Brown	89	Goliad	152	Lubbock	216	Sterling
26	Burleson	90	Gonzales	153	Lynn	217	Stonewall
27	Burnet	91	Gray	154	Madison	218	Sutton
28	Caldwell	92	Grayson	155	Marion	219	Swisher
29	Calhoun	93	Gregg	156	Martin	220	Tarrant
30	Callahan	94	Grimes	157	Mason	221	Taylor
31	Cameron	95	Guadalupe	158	Matagorda	222	Terrell
32	Camp	96	Hale	159	Maverick	223	Terry
33	Carson	97	Hall	160	McCulloch	224	Throckmorton
34	Cass	98	Hamilton	161	McLennan	225	Titus
35	Castro	99	Hansford	162	McMullen	226	Tom Green
36	Chambers	100	Hardeman	163	Medina	227	Travis
37	Cherokee	101	Hardin	164	Menard	228	Trinity
38	Childress	102	Harris	165	Midland	229	Tyler
39	Clay	103	Harrison	166	Milam	230	Upshur
40	Cochran	104	Hartley	167	Mills	231	Upton
41	Coke	105	Haskell	168	Mitchell	232	Uvalde
42	Coleman	106	Hays	169	Montague	233	Val Verde
43	Collin	107	Hemphill	170	Montgomery	234	Van Zandt
44	Collingsworth	108	Henderson	171	Moore	235	Victoria
45	Colorado	109	Hidalgo	172	Morris	236	Walker
46	Comal	110	Hill	173	Motley	237	Waller
47	Comanche	111	Hockley	174	Nacogdoches	238	Ward
48	Concho	112	Hood	175	Navarro	239	Washington
49	Cooke	113	Hopkins	176	Newton	240	Webb
50	Coryell	114	Houston	177	Nolan	241	Wharton
51	Cottle	115	Howard	178	Nueces	242	Wheeler
52	Crane	116	Hudspeth	179	Ochiltree	243	Wichita
53	Crockett	117	Hunt	180	Oldham	244	Wilbarger
54	Crosby	118	Hutchinson	181	Orange	245	Willacy
55	Culberson	119	Irion	182	Palo Pinto	246	Williamson
56	Dallam	120	Jack	183	Panola	247	Wilson
57	Dallas	121	Jackson	184	Parker	248	Winkler
58	Dawson	122	Jasper	185	Parmer	249	Wise
59	Deaf Smith	123	Jeff Davis	186	Pecos	250	Wood
60	Delta	124	Jefferson	187	Polk	251	Yoakum
61	Denton	125	Jim Hogg	188	Potter	252	Young
62	DeWitt	126	Jim Wells	189	Presidio	253	Zapata
63	Dickens	127	Johnson	190	Rains	254	Zavala
64	Dimmit	128	Jones	191	Randall		

Figure 6-1. List of the standard county designator codes used by TxDOT.

Control Point Data Sheet Form

Texas Department of Transportation

December 2004

POINT NAME ________________ DATE ______________

LOCAL NAME (if any) ______________ COUNTY ______________

HORIZONTAL***NAD83(93)***
UNITS

Length _______
Angle _______

Geodetic: Latitude ___________ Longitude _____________
STATE PLANE: Northing ___________ Easting _____________
State Plane Zone _______ Scale _____________
Mapping Angle _______ Combined Factor _______
SURVEYED FROM: a) __________ b) ___________ c) ___________
INTERVERSIBLE POINT NAME: ____________________________
AZIMUTH & DISTANCE TO INTERVISIBLE POINT: ___________
____

VERTICAL ***NAVD88***
UNITS ELEVATION: _________________

Length _____

[ ] Conventional 3-wire leveling
[ ] GPS from at least three 2nd order or better benches (GEOID___)
[ ] GPS from 3rd order or less benches (GEOID___)

SURVEYED FROM: a) ________ b) _________ c) ___________

HISTORY DATE ACTIVITY

DATE	ACTIVITY
___________	_______________________________________
___________	_______________________________________
___________	_______________________________________
___________	_______________________________________
___________	_______________________________________

TYPE OF MARK
Description: ____
Publicly Accessible: [ ] Yes [ ] No GPSable [ ] Yes [ ] Marginally [ ] No

DESCRIPTION

DATE	FROM/TO
_________	____
_________	____
_________	____
_________	____

Figure 6-2. TxDOT Control Point Data Sheet.

GPS Control Point

TxDOT GPS CONTROL POINT

Station Name:		Date:
Monument Type:		
City:		
County:		State:
Project:		
Directions from Major Highway Intersection to Control Point		
Azimuth	Grid Azimuth	Distance (Ft)
SURVEYED FROM USGS/NGS MONUMENTS:		
SIGN AND SEAL PLAT		
Surveyor:		
Prepared By:	COMPANY NAME, ADDRESS, PHONE #	

Adjusted Horizontal Control Data			
Order:	Survey Method GPS __ TRAV __ OTHER __		
Combined Adjustment Factor:			
NAD83 (1993) State Plane Grid Data		Coordinates (U.S. Survey Ft)	Convergence
State:	Texas		
Zone:			
Code:			
SURFACE DATA		Coordinates (U.S. Survey Ft.)	Surface Adjustment Factor
State:	Texas		

GEODETIC DATA	Position	NAD83 (1983)	Elev. (Ft)
	Latitude:		
	Longitude:		
FIELD SKETCH:			

Figure 6-3. Sample project specifications control point.

Satellite Health and Availability

Only healthy satellites should be observed during the course of data collection. The satellite health situation can be checked by accessing the latest GPS status message from the USCG web site at http://www.navcen.uscg.gov/. This status message can also determine if there were problems after the data collection period is over.

There are times of the day when the numbers of satellites available will vary. Especially with real-time kinematic (RTK) positioning planning a work around for these times greatly increases productivity and the quality of results. Most, if not all, GPS software packages include a utility allowing the user to predict satellite coverage. A minimum of five (5) satellites are to be logged for any GPS work. In order to project satellite availability, the software will require a recent ephemeris file.

One internet site for obtaining this file is:
http://www.trimble.com/planningsoftware_ts.asp?Nav=Collection-8425

Sky Visibility

Prior to data collection, the surveyor should look at each station to determine the extent, if any, of sky visibility obstructions greater than ten (10) degrees above the horizon. This survey should include obstructions in all four (4) quadrants of the sky.

If there are obstructions, the most desirable place for those obstructions to be located is northward of the station to be surveyed because of the design of the satellite constellation. If there is an obstruction in that area, it could still be a source of multipath at the GPS antenna. Therefore, the obstruction should be located.

Satellite Geometry

The geometric quality of a constellation of satellites is measured by
Position Dilution of Precision (PDOP). It is also measured by
Geometric Dilution of Precision (GDOP). The difference between PDOP and GDOP is that GDOP considers time, where PDOP only considers geometry.

The user should be aware of the manufacturer's recommendations of maximum DOP values for the various types of surveys the user will perform. The vertical component of the GPS position is the most likely component to lack in quality if the DOP values are high. Therefore, if performing a vertical control survey, collect data with conservative DOP values.

(continued...)

Satellite Geometry *(continued)*

One way to ensure that quality data are collected for the vertical is to collect satellite data that includes at least one satellite that is tracked greater than seventy (70) degrees above the horizon. However, a VDOP of less than 4.0 is all that is required. A PDOP of over 6.0 should probably be considered to be too great for usable data, making a PDOP of over 7.0 is unacceptable. Static data during periods of high DOP values should be deleted. Performance of RTK is more demanding and should not be done at PDOP values of 4 or greater.

Space Weather Considerations

A highly active ionosphere can have more severe implications for GPS observations. Magnetic storms and solar radiation storms will affect the signal-to-noise ratio (SNR) and may cause initialization problems with real-time kinematic (RTK) positioning and noisy data in static observations.

One measure of space weather activity is the scale developed by NOAA. Their Web site address, www.sec.noaa.gov/NOAAscales/, will predict activity on a scale of 1 to 5 with anything above 1 (one) becoming a hindrance to quality data collection.

The Costello Geomagnetic Index charts are found at http://www.sec.noaa.gov/rpc/costello/ Kp index of five (5) or more may cause problems and GPS surveying should not be done at six (6) or above. RTK should not be done at a Kp index of five (5) or greater.

Section 4

Monumentation

Overview

The knowledge of important considerations, which ensure the stability and continued usability of monuments, is vital to successful monumentation. The references to procedures and guidelines presented within this section aid the user in properly establishing a GPS survey monument.

Monumentation Guidelines

For monumentation guidelines, refer to Appendix A of this manual or the National Geodetic Web site at http://www.ngs.noaa.gov/.

Section 5
Survey Methods

Static Positioning

Static positioning typically uses a network or a multiple baseline approach for positioning. It may consist of multiple receivers, multiple baselines, multiple observational redundancies and multiple sessions. After processing the data to obtain baselines, a least squares adjustment of the results is required. This method provides the highest accuracy achievable and requires the longest observation times – from an hour to five hours or longer.

Static positioning is primarily used for ties to the NSRS when observing for TxDOT Level 1 and 2 surveys. However, this technique could be used for the other levels listed in Chapter 3, Table 3.4 of this manual using project control points.

FastStatic (Rapid Static) Positioning

The method of faststatic/rapid static positioning requires shorter occupation times than static positioning (i.e. 15 to 20+ minutes) and may use a radial baseline technique, network technique, or a combination of the two. Baseline lengths may not exceed ten (10) kilometers for L1 only receivers and twenty (20) kilometers for L1/L2 receivers.

Accuracy degrades at a predictable rate with this type of survey; therefore, longer baselines may be used when design survey quality is not needed. Please refer to the manufacturer’s specifications for minimum occupation times, number of satellites observed, and minimum amount of cycle slip free data collected for this type of data collection method.

FastStatic requires a least squares adjustment or other multiple baseline statistical analysis capable of producing a weighted mean average of the observations. More than one base station will be used to provide redundancy for each vector.

FastStatic or rapid static techniques could be used for observing Levels 3 & 4 listed in Chapter 3, Table 3.4 of this manual. It provides baselines that do not exceed the maximum distances stated above in the first paragraph of this subsection.

Post-Processed Kinematic (PPK) Positioning

Post-processed kinematic survey methods provide the surveyor with a technique for high production measurements and can be used in areas with minimal obstructions of the satellites. PPK uses significantly reduced observation times (i.e. 0.5 to 3 minutes, usually 10-30 seconds per point) compared to static or faststatic/rapid static observations.

This method requires a *least squares adjustment* or other multiple baseline statistical analysis capable of producing a weighted mean average of the observations. Post-processed kinematic positioning may be used for Level 4 listed in Chapter 3, Table 3.4 of this manual.

Real-time Kinematic (RTK) Positioning

Real-time kinematic positioning is similar to a PPK or a total station radial survey. RTK does not require post processing of the data to obtain a position solution. This allows for real-time surveying in the field and allows the surveyor to check the quality of measurements without having to process the data.

Real-time kinematic (RTK) positioning may be used for Levels 3 and 4 listed in Chapter 3, (Table 3.4 TxDOT Level of Survey Accuracy) of this manual. Level 3 surveys require that a second observation be made after losing and regaining initialization. Additionally, Level 3 surveys require that a second base station be set up for the purpose of creating a second baseline. Most GPS units will allow the averaging or adjustment of the two or more baselines while remaining at the point.

Level 4 surveys; however, will accept the single radial baseline solution (see Chapter 4, Table 4.1, Instrumentation Requirements). The surveyor must also follow the TxDOT redundancy requirements (see Section 6 of this chapter, RTK for Topographical Surveys) and the equipment manufacturer’s prescribed methods.

Real-time surveying technology may utilize single or dual-frequency (L1/L2) techniques for initialization, but the subsequent RTK survey is accomplished using only the L1 carrier phase frequency. Therefore, all RTK surveys are currently subject to the limitations of the L1 frequency, which is ten (10) kilometers from the base station. There may be circumstances where this maximum range may be extended. Permission to extend this range will be extended at the TxDOT project surveyor’s discretion.

Radio transmission and cell phones are the most common way of providing the communication link between the base and rover.

Section 6

Field Survey Operations and Procedures

Overview

Field survey operations should be performed using the manufacturer's recommended receiver settings and observation times. Operations under adverse conditions, such as under a tree canopy or around urban environments where multipath conditions are high, may require longer observation times than specified by the manufacturer.

TxDOT Survey Levels

As noted in Chapter 3, TxDOT has divided its design grade GPS surveying into seven (7) levels to facilitate understanding of the type and scope of the survey, and to aid in developing specifications.

Level 1 Surveys

Level 1 is the highest order of TxDOT GPS survey. It is reserved for multi-project points and other statewide or district-wide densification of the FBN and CBN points. Since it is tied to the NSRS, these marks will augment the CORS stations and will aid in control of all subsequent TxDOT survey levels. The department will not usually set these on the speculation that they might be needed, but usually as an adjunct to a major project.

Level 1 points should be established by static survey methods. These points may be established at the same time as other survey levels are being performed. However, the points, and resulting baseline vectors used in the network should be processed to derive the baseline solutions and be adjusted by least squares, independently of the other survey ties. The horizontal quality of these points would be comparable to first order or better conventional points and up to B order GPS quality.

The Level 1 points will place accurate control closer to the project, shortening subsequent observation times and improving accuracy. It will offer the surveyor more flexibility for using rapid static/faststatic, kinematic and RTK survey methods for the other aspects of the survey. It provides an adequate amount of reference (base) station locations, ties subsequent points together, allows for expanding the area of the survey, and provides accurate checks throughout the survey project.

All Level 1 points should be referenced (tied) to at least four (4) FBN/CBN/CORS stations, two (2) of which should be CORS stations.

(continued...)

Level 1 Surveys *(continued)*

The current national reference datum is the North American datum of 1983. TxDOT places all new projects on this datum and it is recommended that the HARN adjustment, noted by NAD83 (2003), be used. Be sure the adjustment specified by the district survey coordinator is used – some situations dictate previously used datum adjustments.

All Level 1 points should conform to the requirements outlined in Tables 4.1, 5.1, 6.2, 6.6, and 6.8 of this manual to include the following requirements:

- referenced to at least the two (2) closest CORS control stations, located in two quadrants, relative to the survey project area and additional FBN or CBN published horizontal control stations for a total of at least 4 stations – one or more in each of at least three (3) of the quadrants of the project area
- referenced to five (5) or more published vertical control stations of second order or better, located in all four (4) quadrants, relative to the survey project area if vertical is required for the survey
- all new stations are established by two (2) or more independent baselines
- all stations must be occupied a minimum of two (2) times
- baselines should have a fixed integer double difference solution or adhere to the manufacturer's specifications for baseline lengths, exceeding the fixed solution criteria (i.e. float solution may be the best solution for baselines in excess of 100 km, depending on manufacturer specifications and recommendations)
- any station pair used as azimuth or bearing reference for use with conventional survey measurements during the course of any other survey level should be included in a network or measured as a radial line with a minimum of two (2) independent baselines
- the district network must be a geometrically closed figure; therefore, single radial (spur) lines or side shots to points are not acceptable. (Radial lines are acceptable only for setting azimuth marks).

Level 2 Surveys

This level includes primary project control and control for airborne aerial photography or LiDAR data gathering. These points in the project area are tied to the NSRS through Level 1 control points and/or CORS and FBN/CBN points, if they fall within about sixty (60) miles of the project. A primary project control network usually is established by the static survey method. The primary project control network may be established at the same time the other survey Levels are being performed. However, the points and resulting baseline vectors used in the primary project control network should be processed to derive the baseline solutions and be adjusted by least squares, independently of the other survey ties.

(continued...)

Level 2 Surveys *(continued)*

Primary project control network is designed to meet the following purposes:

- provides a framework to reference the survey to a datum, a mapping projection, and the NSRS
- serves as the basis for all lower survey levels
- allows for the use of conventional survey equipment by always providing an azimuth or intervisible point
- provides control points to serve as geodetic control in a TxDOT project.

A well-designed primary project control network will offer the surveyor more flexibility for using kinematic and RTK survey methods for the other aspects of the survey. It provides an adequate amount of reference (base) station locations, ties subsequent points together, allows for expanding area of the survey and provides accurate checks throughout the survey project. It may be as simple as two well-placed, intervisible points for use with conventional equipment.

All primary project control networks should be referenced (tied) to at least three (3) horizontal stations, two of which should be the close CORS/FBN/CBN points. Any available statewide/district-wide densification points qualify as holding points for the primary project control points.

All Level 2 networks should conform to the requirements outlined in Tables 4.1, 5.1, 6.2, 6.6, and 6.8 of this manual to include the following requirements:

- referenced to three (3) or more CORS/FBN/CBN or Level 1 control densification horizontal control stations, located in three (3) or more quadrants, relative to the survey project area
- referenced to four (4) or more benchmarks (second order or better) in four (4) quadrants for orthometric heights
- all new stations are established by two (2) or more independent baselines
- all stations must be occupied a minimum of two times
- baselines have a fixed integer double difference solution or adhere to the manufacturer's specifications for baseline lengths exceeding the fixed solution criteria (i.e., float solution may be the best solution for baselines in excess of 100 km depending on manufacturer specifications and recommendations)
- any station pair used as azimuth or bearing reference for use with conventional survey measurements during the course of any other survey level should be included in a network or measured radially with a minimum of two (2) independent baselines
- the primary project control network must be a geometrically closed figure; therefore, single radial (spur) lines or side shots to points are not acceptable (radial lines are acceptable only for distant azimuth marks).

Level 3 Surveys

This level of surveying work and points includes photogrammetric control panels, boundary corners, right of way (ROW) corners, local control, setup points for topographical surveys, laser-scan control points, azimuth marks less than one half mile from the station and other points requiring similar accuracy.

Level 3 stations can be tied to TxDOT Level 1 network stations, TxDOT Level 2 network stations or NSRS stations first order or better.

In some situations, these points can be surveyed using any one of the GPS survey methods described herein.

All Level 3 points should conform to the requirements outlined in Tables 4.1, 5.1, 6.2, 6.6, and 6.8of this manual to include the following requirements:

- ♦ referenced to two (2) or more TxDOT Level 1 or Level 2 stations, NSRS FBN or CBN published horizontal control stations, located in two (2) or more quadrants, relative to the survey project area (post-processed RTK is acceptable when done from two (2) separate base stations)
- ♦ all new stations are established by two (2) or more independent baselines
- ♦ all stations must be occupied a minimum of two times
- ♦ baselines should have a fixed integer double difference solution
- ♦ any station pair used as azimuth or bearing reference for use with conventional survey measurements during the course of any other survey level should be included in a network or measured with a minimum of two independent baselines
- ♦ Level 3 control must be part of a geometrically closed figure; therefore, single radial (spur) lines or side shots to points are not acceptable
  - radial lines are only acceptable and required for station pairs where one of the stations will be primarily used as an azimuth mark
- ♦ all stations tied with RTK should be measured twice with a new initialization in between the two ties.
  - at the minimum time difference specified in Chapter 5, Table 5.1, a second set of measurements should be taken
  - this will yield a total of four sets of independent observations (two pair) at each point
  - in most cases, each pair will be measured from different base station locations.

Level 4 Surveys

Level 4 survey work includes wing panels for horizontal position only (see Chapter 3, Table 3.4), side shots for topographical survey and stake-out. Survey methods used can be RTK or fast/rapid static observations from higher-level points.

All Level 4 points should conform to the requirements outlined in Tables 4.1, 5.1, 6.2, 6.6, and 6.8 of this manual to include the following requirements:

- ♦ Be referenced to one or more TxDOT Level 1, 2 or 3 stations, NSRS FBN or CBN published horizontal control stations.
- ♦ At least 10% of the Level 4 points should be checked with a second observation after a new initialization.
- ♦ Each time an initialization is done for the first time or as a result of a complete loss of lock on the satellites, the previous station surveyed must be surveyed a second time with a new initialization.

Level 5 Surveys

Level 5 surveys include mapping grade work that is held to sub-meter network accuracy. Examples of this type of work include locative and inventory data gathering for a GIS system.

Equipment used will generally be code based GPS receivers, enabled to receive real-time corrections from base station positions. In many cases, Coast Guard beacons, OmniStar, Racal and other third party providers of differential corrections, will provide the necessary component for spatial data for other than design and construction use. If the situation warrants, data can also be post-processed.

Level 6 Surveys

Level 6 surveys include mapping grade work that may not be sub-meter but is at least within five meters network accuracy. Examples of this type of work include locative and inventory data gathering for a GIS system where positional information is not as critical as for a Level 5 survey.

Equipment used will generally be code based GPS receivers, enabled to receive real-time corrections from base station positions but at farther distances from the base or with less stringent parameters.

Level 7 Surveys

Level 7 work includes very rough positioning with an autonomous fix, usually using a handheld consumer type GPS receiver. Positions will generally be good to within thirty (30) meters. Raw GPS data cannot be stored and retrieved for post-processing as with equipment used in all other TxDOT levels of surveys.

Field Quality Control

There are several areas to be addressed as far as quality control for the field data acquisition GPS surveys. Quality control measures ensure that the field measurements are performed correctly. There are three (3) sources for error in any survey, whether it is a GPS survey or a conventional survey. These sources for error are blunders, systematic errors, and random errors.

The goal of quality control is to eliminate the blunders and the systematic errors. Then, all that is left are random errors. With a good network design and a sufficient number of redundant measurements, the random errors can be handled and minimized to yield the best possible final result.

The following table identifies field data collection information:

Table 6.2 Field Data Acquisition Requirements

Level of Survey Accuracy****	Level 0	Level 1	Level 2	Level 3	Level 4
Minimum Elevation Mask in Degrees (Collection)	10	13	13	10	13
Acceptable Survey Method	S	S	S, R/F	S, R/F, PPK, RTK	R/F, PPK, RTK
Maximum DOP Value*	M	M	M	M	M
If adj. Tripod, then Minimum. Number H.I. Measurements**	6	6	6	6	6
Maximum H.I. Height Difference Between Measurements	3mm	3mm	4mm	4mm	5mm
Minimum Number GPS Receivers***	3	3	3	2	2
Photo or Pencil Rubbing Required for all Stations Except CORS	Y	Y	N	N	N

* M denotes Manufacturer recommended value.
** Measurements to be divided between beginning and end of session. Measurements should be made in two different units.
*** Minimum # of receivers simultaneously logging data during a session not including CORS.
**** This chart is not applicable to Levels 5-7 mapping grade surveys.

Monument Identification

During the reconnaissance phase or in the course of the field survey, a monument could easily be improperly identified. This may result in the wrong monument being observed, or the wrong identifier used in the field notes, or digital data collection file. This error can be controlled by requiring pencil rubbings or photos at the time reconnaissance is performed and during the course of the survey.

Each time a new or an existing station is observed, a pencil rubbing or photo should be taken at the time of the observation for Level 1 surveys. For all other levels, this practice is at the discretion of the party chief.

Data Collection Forms

A sample GPS log sheets is shown in Figure 6-4 on the next page. Please use this form or a similar one. A way to link the form to the data file is important to the processing person. In this case, the form requests the GPS receiver’s default file name on the line *8-digit filename*.

A form can be tailored to the needs of the survey crew depending on their experience and proficiency. The collection of weather and meteorological data may be necessary if the project worked on is to be included in the NSRS (bluebooked).

One data sheet per observation *must* be turned in to the processing person. This is especially true now that most receivers no longer allow for the entering of antenna heights without the use of a data collector.

Texas Department of Transportation

GPS Log Sheet

Operator Name: ______________________________

Observation Date: ______________________________

Station Name: ______________________________

8 digit File Name (if known) ______________________________

Antenna Height:

1st measurement ______________________

Meters ______

2nd measurement ______________________

Survey Ft.______

3rd measurement ______________________

Average ______________________

Measured to: Bottom of notch ____ Top of notch ____ Antenna ref. point ______

Antenna Type ______________________________

Actual start time ______________________________

Actual stop time ______________________________

4 digit receiver number ______________________________

Notes:

____

____

____

____

____

____

____

____

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Figure 6-4. Sample GPS Log Sheet.

Data Collection Forms *(continued)*

If adjustable height tripods are used, the height of the antenna above the mark should be measured. This measurement should take place at a minimum of three (3) locations around the ground plane, in two (2) separate units, at the beginning of the observing session, and again at the end of the observing session. The H.I. *must* be recorded in a field book or on log sheets for every occupation.

Static Observation Field Procedures

All control stations and boundary corners should be occupied a minimum of two times during the course of a survey. Table 5.1 in Chapter 5 outlines how those occupations should be accomplished.

The normal collection rate (epoch) is 5 seconds for static observations, but for long observation times of more than about 3 hours, 15 second epochs are acceptable. For observations of less than half an hour, 5 second epochs are preferable. For fast/rapid static observations, 5 seconds is required. RTK is done at 1 second.

Longer baselines will require longer observations on end points. Minimum observation times for Levels 2 and 3 are listed in Table 6.3. Allowances should be made for difficult setups that may have less satellite visibility or high PDOP.

Level 1 surveys usually involve long distances and will almost always require observation times of 4 to 6 hours and at least two occupations.

The following table illustrates minimum observation times:

Table 6.3 Minimum Observation Times for Surveys Levels 2 and 3

Length of Baseline	Minimum observation time *
less than 10 km	45 min
10 to 40 km	1 hr
40 to 100 km	2 hr
100 to 200 km	3 hr
more than 200 km	4 hr or more

* Assuming at least 5 satellites and PDOP of less than 6.0.

RTK Field Procedures

Real-time kinematic (RTK) allows close-in surveying without the requirement of line of sight to the control point. This is very cost effective for Level 4 surveys, and with more stringent requirements RTK can be used for Level 3 surveys.

Set up the base station on a control point with known x, y, z coordinates (all control points must have GPS-static quality horizontal values and differential leveled vertical values). The selection of the base station sites during the project planning phase will greatly affect the success of the RTK observations. If a poor base station site is selected, there will likely be problems throughout the entire survey.

The following information identifies parameters of base station sites:

- ♦ Select a site with good sky visibility down to (ten) 10 degrees from the horizon.
- ♦ Be aware of high power transmitters, such as microwave, TV stations, military installations, high voltage transmission power lines, etc.
- ♦ Be aware of multipath caused by radio wave reflective objects, such as trees, buildings, large signboards, and chain link fences, etc.

If there are no useable control points in the immediate area, or much is to be gained by setting a new control point for the base station, a position can be obtained for the base station setup by means of a calibration from other control points. The survey may be started on just the autonomous position after setting up the base station on the newly placed mark.

With a successful initialization at each of at least three (3) control points, perform a forced coordinate position or *calibration* by keying in the proper coordinates for each point. This will propagate the correct coordinates to the base station. The *calibration* control points must be within about three (3) miles of the base and in at least two (2) separate quadrants.

The calibrated base station coordinates will only be as good as the quality of the chosen *calibration* points and are a poor substitute for the assurance of a pre-surveyed control point.

The surveyor logs the following base station setup into the field notes:

- ♦ station name and/or number
- ♦ receiver and antenna type
- ♦ antenna measurement method (i.e. bottom of notch, bottom of antenna, etc.)
- ♦ record antenna H.I. measurements at the beginning and end of each setup
  - if using a fixed height tripod, make and record a measurement to verify that the fixed height has been checked

(continued...)

RTK Field Procedures *(continued)*

- record the local time that the base station is started and stopped
- record any problems encountered during the course of the survey with the base station.

TxDOT VHF radios at the base station may transmit at full power but the TxDOT UHF transmitters are restricted to two watts. The private sector does not have this 2 watt restriction on their itinerate frequencies. The FCC radio license is for *data* transmissions. This means TxDOT's radios have to stop transmitting when voice transmissions are being made. Be sure the transmitter is equipped with a blocker. Have the proper license and carry a copy with the equipment.

Rover Settings

Configure equipment settings for the type of project to be surveyed. It is a good idea to have all the possible options available while collecting data. In many cases, not every option is used. However, if needed, they will be available.

Some options are to:

- store raw observables at the base to allow for post-processing of the base position should the need arise
- store vector information to allow the RTK data to be adjusted with least squares should the need arise
- set up the survey to allow for post-processed kinematic data should the radio link be lost on a few shots.

Rover Initialization

There are several ways to initialize a kinematic survey. They can include a known baseline; use of an initializer bar; a new point; and an on-the-fly (OTF) initialization.

After the first OTF initialization, observe a point. This can be a temporary mark or a point in the survey. Discard the first OTF initialization and OTF re-initialize with the H.I. changed by more than two feet or move more than forty feet away from the point to be used as a check.

After the new OTF initialization has been accomplished, return to the point being used as a check and re-shoot it. Compare the first and second shots. Are they within an acceptable tolerance?

(continued...)

Rover Initialization *(continued)*

If the points check, proceed with data collection with the confidence in surveying with a correct initialization. If the error between the two points is beyond the expected error, one or both of the OTF initializations used for a check are incorrect. OTF re-initializations at any of the positions previously used cannot be reused.

The location *must* change by a difference of more than two feet of H.I. or, more likely, move more than forty feet away in a different direction. This will usually provide enough information to identify the OTF initialization that is incorrect. Once the problem is solved begin the survey. This procedure *must* be repeated with any loss of initialization.

Each time a re-initialization is done as a result of a complete loss of lock on satellites, the first station surveyed thereafter must be surveyed a second time with a new initialization from which the survey can continue if the two initializations agree.

(continued...)

Rover Initialization *(continued)*

CONTROL / MONUMENTATION (F/G/U SPOTS,BREAKS)

AT	Aerial Target (F)
AZ	Azimuth Mark (Existing) (F)
AZM	Azimuth Mark (New) (F)
BAZ	Bench Mark (Azimuth) (F)
BC	Brass Cap (F)
BM	Benchmark (New) (F)
BMAG	Benchmark (Magnetic) (F)
BOX	Box Panel (Flight) (F)
BREF	Benchmark (Reference) (F)
BTMP	Benchmark (Temporary) (F)
BTRA	Benchmark (Traverse) (F)
BTRI	Benchmark (Triangulation) (F)
CHM	Chiseled, Drilled or Plug Mark (F)
CHP	Chiseled Plus (SCRIBE) (F)
CMKR	Concrete Marker (Cast Type I) (F)
CNP	Construction Point (Temp) (F)
COLN	County Line * (F,*F)
CP	Control Point (F)
CTR	Country Line * (F,*F)
CTRS	Center Sec Corner (F)
DM	Disk Mon. Rod with Cap (Type III) (F)
GPS	GPS Monument (Add Number as Pd:) (F)
HP	Horizontal Panel (F)
HGP	Hour Glass Panel (F)
HM	NGS Marker (Horizontal Only) (F)
HPV	Flight Panel (Vertical Only) (F)
HT	Hub \ tack (F)
HVM	NGS Marker (Horizontal & Vertical) (F)
IB	Iron Bar (Also see IR) (F)
IP	Iron Pipe (Also see IB) (F)
IR	Iron Rod (F)
LOT	Lot Corner (F)
MON	Concrete Monument (Poured Type II) (F)
NAIL	Nail (60d,Conc,W\Shiner) (F)
NGS	NGS Marker (Horizontal Only) (F)
NS	Nail and Shiner (F)
PAR	Parcel * (F,*F)
PARRM	Parcel (Remainder) * (F,*F)
PARTK	Parcel (Take) * (F,*F)
PCR	Property Corner (G)
PK	PK Nail (F)
PL	Subdivision/Block/Lot/Prop Line *(F,*F)
PLAT	Plat Corner (F)
PPT	Principal Point (F)
RB	Ring & Bolt (F)
RBAR	Reinforcement Bar (F)
RM	Reference Marker (F)
ROW	Right of Way (Proposed) * (F,*F)
ROWE	Right of Way (Existing) * (G,*F)
RRSP	Rail Road Spike (F)
SECT	Section Corner (F)
SPIN	Cotton Spindle (F)
STA	Survey Station (F)
STB	State Border * (F,*F)
TPT	Traverse/Turn Point ** (F,*F)
VM	NGS Marker (Vertical Only) (F)
VPT	Vertical Panel Point (Flight Point) (F)
WING	Wing Panel Point (Vertical Control) (F)
WIT	Witness Corner (F)

AS-BUILT

AC	Air Conditioner * (F,*F)
ANT	Antenna (F)
BEN	Bench/bus Stop * (F,*F)
BIKE	Bikeway * (G,*G)
BLB	Billboard * (G,*F)
BPL	Brace Pole (G)
CEM	Cemetery * (G,*F)
CG	Cattle Guard * (G,*G)
COL	Column (G)
FAU	Faucet (F)
FP	Flag Pole (F)
GRL	Camp Stove / Grill (F)
HCR	Handicap Ramp * (G,*F)
HR	Handrail * (F,*F)
INC	Incinerator * (F,*F)
MAR	Marsh * (G,*G)
MB	Mailbox (F)
PIR	Piling/Pier * (G,*F)
PIT	Pit, Fill, * (G,*G)
PLAY	Playground * (G,*G)
PMT	Parking Meter (F)
POL	Swimming Pool * (G,*G)
POLE	Pole (Generic) (G)
QRY	Quarry * (G,*G)
RNS	Ruins * (F,*F)
ROCK	Rock Wall * (G,*G)
RW	Wall (Retaining) * (G,*G)
SDSH	Satellite Dish (F)
SEP	Septic Tank/Cover (F)
SPK	Sprinkler Head (F)
STP	Steps * (G,*G)
SWL	Wall (Seawall) * (G,*G)
TB	Telephone Booth (F)
TD	Trash Disposal, Dumpster (F)
TOIL	Toilet (Portable) (F)
TRL	Trail * (G,*G)
WEL	Water Well/Pump (F)
WML	Windmill (F)

TxDOT 2K

BUILDINGS

BLD	Buildings (Foundation, Wall, Etc.) * (G,*G)
BRN	Barn * (G,*G)
G	Garage * (G,*G)
H	House * (G,*G)
PHSE	Pump House* (G,*G)
POR	Porch * (G,*G)
ROOF	Roof Tops * (Goes to ZONE 6) (F,*F)
SHED	Shed * (G,*G)
SIL	Silo* (G,*G)
STC	Storm Cellar * (F,*F)

FENCES

BFN	Brick Fence * (G,*G)
CBFN	Cinder Block Fence * (G,*G)
CFN	Chain Link Fence * (G,*F)
FN	Fence (Generic) * (G,*F)
GAT	Gate * (G,*F)
NW	Noise Wall * (G,*F)
PFN	Picket Fence * (G,*F)
PST	Post (Generic) (G)
RWFN	Rock Wall Fence * (G,*G)
WDFN	Wood Fence * (G,*F)
WFN	Wire Fence * (G,*F)
WP	Wooden Post (G)

DRAINAGE

CAN	Canal * (G,*G)
CBS	Catch Basin * (G,*G)
CCH	Concrete Channel * (G,*G)
CH	Channel * (G,*G)
CI	Curb Inlet * (G,*G)
CLV	Culvert (Box) * (G,*F)
CMP	Corrugated Metal Pipe * (G,*F)
DBI	Ditch Bottom Inlet * (G,*G)
DI	Drop Inlet * (G,*G)
DPV	Ditch Pavement * (G,*G)
EWL	End Wall * (G,*G)
FL	Flow Line * (G,*G)
FLM	Flume * (G,*G)
FLR	Flared End Section * (G,*G)
GAU	Stream or Tide Gauge (F)
GI	Gutter Inlet * (G,*G)
GUT	Gutter Flow Line * (G,*G)
HDW	Headwall (Add PD) * (G,*G)
HDWB	Headwall (Back) * (G,*G)
HDWF	Headwall (Face) * (G,*G)
INS	Invert Storm Sewer (Goes to ZONE 3) (F)
JB	Junction Box (G)
MES	Mitered End Section * (G,*G)
PCLV	Culvert (Pipe) * (G,*F)
PRH	Pipe Runner (Horizontal) * (G,*G)
PRV	Pipe Runner (Vertical) * (G,*G)
RCP	Reinforced Concrete Pipe * (G,*F)
RIP	Rip Rap (Top or Bottom) * (G,*G)
SDF	Special Drain Features (Add PD) * (G,*F)
SDL	Storm Water Drain Line * (G,*F)
SET	Safety End Treatment * (G,*G)
SEW	Special End Wall * (G,*G)
SPL	Spillway * (G,*G)
STM	Storm Drain Pipe * (G,*F)
STRU	Structure * (G,*G)
WNG	Wing Wall * (G,*G)
YD	Yard Drain * (G,*F)

TOPOGRAPHY

BDT	Ditch (Back) * (G,*G)
BNK	Bank (Top, Bottom) * (G,*G)
CST	Center of Stream * (G,*G)
DTB	Ditch (Bottom) * (G,*G)
DTT	Ditch (Top) * (G,*G)
ED	Earthen Dam * (G,*G)
EW	Edge of Water * (G,*F)
FT	Footing (Conc. For Signs) * (G,*G)
GB	Grade Break * (G,*G)
HI	High Point (G)
LEV	Levee * (G,*G)
LO	Low Point (G)
MIS	Miscellaneous Line * (Add PD) (G,*G)
MISC	Miscellaneous Point (No Code) (Add PD) (G)
NG	Natural Ground ** (G,*G)
PATH	Path * (G,*G)
RIDG	Ridge Line * (G,*G)
SE	Spot Elev. (Generic) (Also see NG) (G)
SLPB	Slope (Bottom) * (G,*G)
SLPT	Slope (Top) * (G,*G)
SW	Sidewalk * (G,*G)
UA	User Defined (Point or Line) * (Add PD) (U,*U)
UB	User Defined (Point or Line) * (Add PD) (U,*U)
UC	User Defined (Point or Line) * (Add PD) (U,*U)
WE	Water Elevation * (G,*F)
WEB	Web Wall * (Goes to ZONE 1) (G,*G)

ROADWAY

ABUT	Bridge Abutment * (Goes to Zone 1) (G,*G)
AS	Attenuation System * (G,*G)
ASPH	Asphalt (G)
BAS	Bridge Approach Slab * (Zone 1) (G,*G)
BL	Baseline (Also see CL) * (F,*F)
BORE	Drill Cores, Test Holes (F)
CBT	Concrete Traffic Barrier (Temp) * (F,*F)
CCR	Curb Cut Ramp * (G,*G)
CL	Center Line * (G,*G)
CPV	Concrete Pavement * (G,*G)
CR	Center of Road (Crown) * (G,*G)
CRB	Curb (Back) * (G,*G)
CTB	Concrete Traffic Barrier (Permanent) * (G,*G)
DR	Dirt Road * (G,*G)
DRV	Driveway (Pd: Type) * (G,*G)
DSN	Sign (Double Support) (Add Width as PD:) (F)

ROADWAY (Continued)

EC	Edge of Concrete * (G,*G)
ECPV	Edge of Concrete Paving * (G,*G)
EG	Edge of Gravel * (G,*G)
EP	Edge of Pavement * (G,*G)

Figure 6-5. TxDOT Feature Codes.

(continued...)

Rover Initialization *(Figure 6-5 TxDOT Feature Codes continued)*

GF	Guard Fence * (G,*F)
GFC	Guard Fence (Concrete) * (G,*F)
GP	Guard Post (F)
GRC	Guardrail (Cable) * (G,*F)
GRV	Gravel Road * (G,*G)
ISL	Island * (G,*G)
LL	Lane Line * (G,*G)
PC	Point of Curvature (G)
PCC	Point of Continuous Curve (G)
PE	Private Entrance * (G,*F)
PI	Point of Intersection (G)
PKL	Parking Lot * (G,*G)
POC	Point on Curve (G)
POT	Point on Tangent (G)
PRC	Point of Reverse Curve (G)
PT	Point of Tangency (G)
RP	Radius Point (G)
SHD	Shoulder * (G,*G)
SLB	Slab * (G,*G)
TRX	Tractor Crossing * (G,*G)

Bridge Elements (All Features Go To Zone 2 UNO)

BAJ	Bridge Armor Joint * (G,*G)
BAS	Bridge Approach Slab * (Zone 1) (G,*G)
BBT	Bridge Bent * (G,*G)
BCL	Bridge Centerline * (G,*G)
BCRB	Bridge Curb * (G,*G)
BE	Bridge Elements * (G,*G)
BGUT	Bridge Gutter * (G,*G)
BOV	Bridge Overhang * (G,*G)
BPS	Bridge Stripe Solid * (G,*G)
BPSD	Bridge Stripe Dashed * (G,*G)
BRL	Bridge Rail (Metal, Concrete) * (G,*G)
BSE	Bridge Spot Elevation (G,*G)
BSW	Bridge Sidewalk * (G,*G)
BTR	Bridge Truss (Railroads) * (G,*G)
DECK	Bridge Deck * (G,*G)

RAILROAD

RR	Railroad Tracks * (G,*G)
RRCB	Railroad Control Box (F)
RRMP	Railroad Milepost (F)
RRSS	Railroad Signal Standard (F)
RRSW	Railroad Switch (F)
RRX	Railroad Crossing Sign (F)
SS	Signal/Span Wire Support/Mast Arm (F)

TRAFFIC

CAB	Cable in Pavement Detector * (G,*F)
DA	Directional Arrow (Pavement Marking) * (G,*F)
HMLT	High Mast Lighting Tower (F)
LB	Light Base (F)
LP	Small Light Pole (F)
ML	Match Line (G)
MP	Marker Post (F)
PBX	Pull Box (F)
PS	Paint Stripe (Solid) * (G,*G)
PSB	Pedestrian Signal Box (F)
PSD	Paint Stripe (Dashed) * (G,*G)
PSDY	Paint Stripe Yellow (Dashed) * (G,*G)
PSY	Paint Stripe Yellow (Solid) * (G,*G)
SCP	Signal Control Panel (F)
SGN	Sign and Pole (Single) (F)
SPED	Signal Pedestal (F)
SS	Signal/Span Wire Support/Mast Arm (F)
TSLP	Traffic Signal Light Pole (Single) (F)
TSP	Traffic Separator * (G,*F)

VEGETATION (TREES) / LANDSCAPING

DRIP	Tree Drip Lines * (G,*F)
ISP	Irrigation Stand Pipe (G)
HDG	Hedge * (G,*F)
OP	Ornamental Plant (G)
ORCH	Orchard/Grove * (G,*F)
OTR	Orchard Trees (G)
PINE	Coniferous Tree (G)
PLT	Planter * (G,*F)
SHB	Shrub (G)
STMP	Tree Stump (F)
TFO	Tree Farm Outline * (G,*F)
TR	Tree (G)
TRE	Tree, Larger Than TR (G)
TREE	Tree, Larger Than TRE (G)
TREES	Tree, Larger Than TREE (G)
WDS	Edge of Trees/Woods * (G,*F)

UTILITIES - ELECTRIC, TELEPHONE & CABLE

CNDE	Conduit Electric * (G,*F)
CNDT	Conduit Telephone * (G,*F)
CPED	Cable TV Pedestal (F)
CSB	Cable TV Service Box (F)
CTV	Cable TV Line * (G,*F)
EM	Electric Meter (F)
ENP	Encasement Pipe * (F,*F)
EPED	Electrical Pedestal (F)
ES	Easement Lines * (G,*F)
FOC	Fiber Optic Cable * (G,*F)
GPL	Guy Pole (Deadman) (G)
GUY	Guy Anchor (G)
HV	High Voltage Transmission Line * (G,*F)
HVTL	Transmission Line Tower Leg (G)
INE	Invert Electric (Flow Line) (ZONE 3) (F)
INT	Invert Telephone (Flow Line) (ZONE 3) (F)
JBE	Junction Box (Electric) (G)
JBT	Junction Box (Telephone) (G)
LS	Luminare Standard (F)
MHE	Manhole (Electric) (G)
MHT	Manhole (Telephone) (G)
OE	Power Line (Overhead Elec.) * (G,*F)
OT	Telephone Line (Overhead) * (G,*F)
PBX	Pull Box (F)
PP	Power Pole (G)
PPED	Power Pedestal (F)
SPLE	Service Pole Electric (G)
SPLT	Service Pole Telephone (G)
TP	Telephone Pole (G)
TPED	Telephone Pedestal (F)
TRNS	Transformer (F)
TWR	Tower, Single Column (F)
UE	Power Line (Underground) * (G,*F)
UT	Telephone Line (Underground) * (G,*F)

UTILITIES – WATER, WASTEWATER & GAS

AGT	Above Ground Tank * (F,*F)
ES	Easement Lines * (G,*F)
FC	Filler Cap (G)
FH	Fire Hydrant (F)
GL	Gas Line * (G,*F)
GM	Gas Meter (F)
CO	Clean Out (F)
GPI	Gas Pump Island * (G,*G)
GPU	Gas Pump (F)
GV	Gas Valve (F)
INW	Invert Waste Water (FL) (ZONE 3) (F)
MH	Manhole (Generic) (G)
MHS	Manhole (Storm Drain) (G)
MHW	Manhole (Wastewater) (G)
PIP	Pipe Line * (G,*F)
SDL	Storm Water Drain Line * (G,*F)
SDS	Sewage Dump Station * (G,*F)
TC	Tank Cover (Gas) (F)
UGT	Underground Tank Gas * (G,*F)
VA	Vent (Air) (F)
VC	Valve Cover Generic (F)
VCG	Valve Cover Gas (F)
VCW	Valve Cover Water (F)
VENT	Vent (Generic) (F)
VG	Vent (Gas) (F)
VLV	Valve (Generic) (F)
VS	Vent (Septic) (F)
VW	Vent (Wastewater) (F)
WL	Water Line * (G,*F)
WM	Water Meter (F)
WV	Water Valve (F)
WW	Wastewater Line * (G,*F)

UTILITIES - SUE (All Features Go To Zone 3)

SUC	SUE Buried Cable TV * (F,*F)
SUCO	SUE Clean Out (F)
SUCPED	SUE Cable Pedestal (F)
SUCV	SUE Casing Vent (F)
SUE	SUE Buried Electric * (F,*F)
SUFH	SUE Fire Hydrant (F)
SUFM	SUE Buried Force Main * (F,*F)
SUG	SUE Buried Gas – Oil * (F,*F)
SUG2	SUE Buried Steam Petroleum * (F,*F)
SUG3	SUE Buried Steam Petroleum * (F,*F)
SUG4	SUE Buried Steam Petroleum * (F,*F)
SUGM	SUE Gas Meter (F)
SUGV	SUE Gas Valve (F)
SUHHT	SUE Telephone Hand hole (F)
SUMHE	SUE Electric Manhole (F)
SUMHT	SUE Telephone Manhole (F)
SUMP	SUE Meter Pole (F)
SUOE	SUE Overhead Electric * (F,*F)
SUPP	SUE Power Pole (F)
SUPPR	SUE Power Pole w Riser (F)
SUSM	SUE Sanitary Manhole (F)
SUSS	SUE Buried Storm Water * (F,*F)
SUSSI	SUE Storm Sewer Inlet (F)
SUSSM	SUE Storm Sewer Manhole (F)
SUT1	SUE Buried Telephone Line * (F,*F)
SUT2	SUE Buried Telephone Line * (F,*F)
SUT3	SUE Buried Telephone Line * (F,*F)
SUT4	SUE Buried Fiber Optics * (F,*F)
SUTPED	SUE Telephone Pedestal (F)
SUW	SUE Buried Water * (F,*F)
SUW2	SUE Buried Water * (F,*F)
SUW3	SUE Buried Water * (F,*F)
SUW4	SUE Buried Water * (F,*F)
SUW5	SUE Buried Water * (F,*F)
SUW6	SUE Buried Water * (F,*F)
SUW7	SUE Buried Water * (F,*F)
SUW8	SUE Buried Water * (F,*F)
SUWM	SUE Water Meter (F)
SUWMH	SUE Water Manhole (F)
SUWS	SUE Water Stubout (F)
SUWV	SUE Water Valve (F)
SUWVB	SUE Water Valve Box (F)
SUWW	SUE Buried Waste Water * (F,*F)

* Indicates a LINEAR pattern
** Indicates a LINEAR pattern

TxDOT 2K
Feature Code List

Figure 6-6. TxDOT Feature Codes continued.

RTK for Wing Panels

Before starting to survey the panels, use the rover to check into at least one other control point with known x, y, z coordinates (all control points must have GPS-static quality horizontal values and preferably, differential leveled vertical values). These checks should be logged in the field book and in the data collector device. Also make and log checks during the course of the day. If any check shots are greater than 0.10 feet horizontally or 0.12 feet vertically, the problem should be resolved.

Wing panel surveys are in the Level 3 category and must therefore adhere to those requirements including positioning from a second base station. However, on occasion the elevations are derived from spirit leveling from the control, but horizontal is still asked for. In this case, a Level 4 RTK survey is acceptable.

RTK for Topographical Surveys

Connectivity of survey chains is required for topographical surveys and the use of TxDOT feature codes is mandatory. This TxDOT list is available in Trimble format as *txdot2k.fcl* (see Chapter 8, Digital Data) and in CAiCE format as *txdot2k.ftb*. A printed list of the TxDOT feature codes is available and is shown in Figure 6-5 and Figure 6-6.

At no time should the rover exceed a distance of three (3) miles from the base in a topographical survey using radial baselines.

With RTK topographical surveys, any time initialization is lost and reestablished, a previously occupied point should be redone as a check. At least one in every ten (10) points of the survey should be redone with a new initialization at a later time. This would result in a total of at least 10% of the stations receiving a second occupation.

Section 7

Data Processing

Overview

In the scope of these specifications, GPS data processing includes the review and cataloging of collected data files, processing phase measurements to determine baseline vectors and/or unknown positions, and performing adjustments and transformations to the processed vectors and positions.

Each step requires quality control analysis, using statistical measures and professional judgment, to achieve the desired level of confidence. Each of these steps is also very dependent upon the measurement technique, the GPS receiver, and antenna types; the observables recorded, and the processing software.

The point position (absolute) coordinates of the initial station, held fixed in each baseline solution, must be referenced to the datum for the satellite orbits and must be known, horizontally and vertically better than ten (10) meters.

Ideally, all baselines should be processed with the initial published position of the CORS station or the highest accuracy station in the network. From that initial coordinate (NAD83) HARN latitude, longitude, and ellipsoid height) all baselines should be processed, seeding each of the new stations based on the results of the baseline processing from the known stations. While technically WGS84 is the datum of GPS, the NAD83 datum may be accepted as an identical substitute for surveying in Texas.

Orbit Ephemeris

Always use an ephemeris other than the broadcast or predicted ephemeris when processing. The type of orbit ephemeris used can have an effect on the quality of processed baselines. The longer the baseline, the greater the effect can be. For baselines exceeding twenty (20) kilometers, use either the rapid or the precise ephemerides.

(continued...)

Orbit Ephemeris *(continued)*

All of the ephemerides are available in the SP3 format at the following Web site: http://igscb.jpl.nasa.gov/components/prods_cb.html

The naming convention of the orbit files are as follows:

Table 6.4 Orbit Files Naming Convention Example: lgxwwwd hh.sp3

where x =	type of orbit (p=precise, r=rapid, u=ultra rapid
where www =	GPS week
where d =	Day of week (0=Sunday)
where hh	UTC hour

The following table illustrates ephemeris types, their availability, and accuracy:

Table 6.5 Ephemerides Availability and Accuracy

Ephemeris Type	When Available	Product Accuracy
Precise	13 days	5 cm
Rapid	17 hours	5 cm
Ultra Rapid	3 hours	5 cm
Predicted	Real-time	10 cm
Broadcast	Real-time	200cm

In the event that the baseline processing software only accepts the binary orbit file type (EF18), the following web site will translate the ASCII SP3 format file: http://www.ngs.noaa.gov/GPS/GPS.html

(continued...)

Orbit Ephemeris *(continued)*

The table below lists the requirements for the use of the various types of ephemerides.

Table 6.6 Baseline Processing Requirements

Level of Survey Accuracy*	Level 0	Level 1	Level 2	Level 3	Level 4
Minimum Elevation Mask in Degrees (Processing)**	18	15	15	15	13
Use Broadcast (B), UltraRapid (U), Rapid (R), Precise (P) Ephemerides	P	P or R	P, R or U	P, R, U or B	P, R, U or B
Accuracy of WGS84 Position Held Fixed in Each BL Solution (see Overview, Ch. 6 Sec. 7)	2.5m	10m	10m	10m	10m
Processing Must Account for Phase Center Offsets	Y	Y	Y	Y	Y
Maximum Number of Rejected Simultaneous Phase Observations	5%	10%	10%	10%	10%

* This table does not apply to levels 5-7 mapping grade surveys.
** Under certain conditions when an acceptable solution cannot be determined with the minimum elevation mask, the data may include space vehicles (satellites) less than the minimum elevation cutoff.

Atmospheric Error Reduction

A standard model for ionospheric group delay and tropospheric zenith delay, using broadcast coefficients, may be used for all baseline processing. Ionospheric modeling for Ll carrier phase measurements has shown reduction in the group delay of 50 to 60 percent.

The remaining unmodeled error, due to group delay, is expected to be 1 to 2 ppm.

Ionospheric-free processing using a linear combination of Ll and L2 carrier should be considered for baselines over 5-25km depending on the manufacturer hardware and software. Follow manufacturer recommendations for ionospheric free processing. This is generally included in the processing software defaults and does not require user intervention.

Baseline Processing

All baseline processing should be accomplished using NGS-developed PAGES software or other interactive, graphics producing software by other vendors that produces results equivalent to PAGES. TxDOT surveyors can get help from the Information Systems Division (ISD) on Trimble *TGO* processing software. Trimble's TGO software includes an adjustment program also supported by ISD. See Table 6.6 for baseline processing requirements.

For sessions of an hour or more, process data using 15 or 30-second epochs (5 second may be used, but probably does not add anything to the accuracy) and a 13-18 degree elevation mask outlined in Table 6.8. In no case will an elevation mask be applied that is greater than twenty (20) degrees above the horizon. For sessions less than an hour, static and faststatic observations may be processed using 5 or 15 second epochs. However, when operating FastStatic at the minimum observation time (8 to 20 minutes) use 5 second data. The use of shorter epochs may improve the ease of baseline processing.

Final processing should consist of fixing all integers for each baseline less than 40 kilometers. For baselines less than 5-10 kilometers, the L1 fixed solution may be the best choice. For baselines greater than 40 kilometers, but less than 200 kilometers, a session may consist of a set of partially fixed integers and may also include float solutions where no integers could be fixed. For baselines greater than 200 kilometers, the final solution should be an ionospheric free ambiguity float L1/L2 solution. In all cases, the user should refer to their manufacturer specifications if conflicts exist within the section of the specifications.

The quality of acquired data should be determined from the double difference residual plots and the RMSE values. Final coordinates and their quality assessment should be determined by loop closure analysis, least squares adjustment, analysis of repeated baselines, and free adjustment residuals.

Troubleshooting Problematic Baselines

A problematic baseline can be defined as a line observed with two carrier-phase GPS receivers, L1 or L1/L2, and the baseline solution does not meet the manufacturer's specification for quality. For short lines determined to need a double different fixed solution, or for longer lines, other solutions are acceptable as specified in Table 6.8. In most cases, the problematic baseline was observed with enough satellites for a long enough time period, but the quality indicators show the line to be unacceptable.

The first thoughts may be to re-observe the line. However, this should be the user's last resort. There are enough tools available in the baseline processing software to allow one to examine the observational information to detect obvious problems.

(continued...)

Troubleshooting Problematic Baselines *(continued)*

The following are suggestions on what to look for when troubleshooting problematic baselines:

- ♦ Look at the plot of all satellites during the observing session; there is a plot for each receiver. Software packages differ, but common to most is a plot showing each satellite observed, one below the other.
- ♦ What to look for:
  - When a cycle slip occurs, or there is a loss of lock due to obstructions, there will be a break in the line on the graph for that particular satellite.
  - A short break indicates a cycle slip, a longer break; an obstruction.
  - If too many breaks have occurred, eliminate that satellite and try the baseline solution again. In many cases, this solves the problem.
- ♦ Look at the plot of satellites for both receivers.
  - Was the start and stop time approximately the same, or did one receiver start or stop too early or too late?
  - Start and stop times can be changed to encompass only common observing times and then re-observe the baseline.
- ♦ Satellites with a high signal-to-noise ratio (SNR) can cause problems. In many cases, a high SNR occurs when the satellite is close to the horizon. It is possible to have a satellite low on the horizon for the entire session. In that case, the satellite should be eliminated from the solution, then resolve the baseline.
- ♦ Another way to eliminate high SNR on satellites low to the horizon is to raise the elevation mask for the baseline solution.
- ♦ If the length of the session is short, perhaps too short, try a baseline solution with a shorter epoch than normal.
  - If the default on the baseline solution is thirty (30) seconds, try fifteen (15) seconds. This will increase the number of single, double, and triple differences needed to resolve the baseline.
- ♦ If all the above suggestions fail, resolve the baseline using a more precise ephemeris than was started with.
- ♦ As a last resort, the baseline must be re-observed. Be sure to select a time period different from the original observed time. Look at sky plots and select a time with many satellites and an area free of obstructions.

Baseline Analysis

Prior to performing a least squares adjustment on the network or traverse, the GPS processed baselines should be analyzed for possible errors using three (3) tools:

- ♦ evaluation of the results of each individual baseline
- ♦ comparison of all redundant baselines
- ♦ generation and analysis of loop closure reports.

To facilitate the error detection process, vector data should be displayed with the horizontal and vertical components separated. Table 6.8 summarizes all of the requirements for baseline (vector) analysis.

Baseline Processing Reports

The user should pay close attention to the evaluation of the baseline processing reports. Additionally, the user should be ready to explain to TxDOT the various aspects of the report and summarize what to look for, as far as how to evaluate the quality of the processed vectors.

These reports should display such items as:

- ♦ the elevation cut off angle
- ♦ the type of tropospheric and ionospheric models used
- ♦ a priori and a posteriori baseline errors
- ♦ the common satellites used
- ♦ GDOP and/or PDOP values
- ♦ RMS error of the baseline
- ♦ the presence or absence of cycle slips in the data; etc.

Depending on the baseline length, use the following specifications for the final acceptable baseline type:

Table 6.7 Final Acceptable Specifications

Baseline Length	Desired Final Solution
Less than 5 km	L1 Only Fixed Solution
5-20 km	L1 Only Fixed or L1/L2 IonoFree Fixed Solution
20-50 km	L1/L2 IonoFree Fixed Solution
50-90 km	L1/L2 IonoFree Fixed or Float Solution
Greater than 90 km	L1/L2 IonoFree Float Solution

Comparison of Redundant Baselines

Comparison of redundant baselines is an excellent way of detecting blunders in a network.

There are two (2) types of redundant baselines to consider.

- ♦ The first is the comparison between two (2) or more measured baselines between the same two (2) stations.
- ♦ The second is the comparison between the published baseline and the measured values. Table 6.8 describes the way redundant baselines to test for validity.

Loop Closure Reports

Running loop closures on a network of baselines is another validation check for blunders and ill-fitting baselines. Again, Table 6.8 (Pre-adjustment Baseline Analysis Requirement) describes several tests to run when creating and evaluating loop closures.

When running loop closures for any level of survey, each closure must contain at least one baseline each from two (2) separate observing sessions. Loop closures run around baselines from the same session containing at least one (1) dependent baseline that is an unacceptable closure for any survey performed.

(continued...)

Loop Closure Reports *(continued)*

The table below provides tests for loop closures:

Table 6.8 Pre-adjustment Baseline Analysis Requirements

Level of Survey Accuracy*	Level 1	Level 2	Level 3	Level 4
Baseline Processing	-	-	-	-
Processing Requirements	M	M	M	M
Maximum Standard Deviation of the Range Residuals in the BL Solution (RMSE)	2cm	2cm	4cm	6cm
Redundant BL's	-	-	-	-
Differences Between Repeat Unadjusted Baselines Computed and Compared	Y [a]	Y [a]	Y [a]	Y [a]
Differences Between Known and Observed Baselines Computed and Compared	Y [b]	Y [b]	Y [b]	Y [b]
Loop Closures				
Baselines from Independent Observing Sessions, Not Less than	2 [c]	2 [c]	2 [c]	2 [c]
Loop Length, Not to Exceed (km)	600	500	200	n/a
Number of Loop Closures Required Per Project	2	2	2 [d]	2 [d]
Maximum Number of Legs in any Loop	10	10	10 [d]	10 [d]
Maximum Misclosure for Any Single Loop (ppm)	5 [e]	12.5 [e]	25 [d e]	75 [d e]
Maximum Average Project Loop Misclosure (ppm)	4 [f]	8 [f]	16 [d f]	50 [d f]
Maximum Misclosure in Any Component; Not to Exceed (cm)	*10*	10	10 [d]	n/a

* This table does not apply to mapping grade Levels 5, 6 and 7.

(continued...)

Loop Closure Reports *(continued)*

Notes for Table 6.8 Data (Baseline) Analysis Requirements:

M - The processing software user should follow the specifications published from the manufacturer in processing the observational data. The percentage of unacceptable baselines, processed within each session of data, should not exceed 33% of the total number of independent baselines possible for each session. If this percentage is exceeded, the session should be repeated or ignored providing there is a sufficient amount of redundancy remaining in the network.

a - Repeat baseline closures should be computed for each repeat baseline combination. The absolute value of the difference in each baseline component and the distance dependent error (parts per million) are analyzed to determine if blunders exist. The difference in each vector component is compared to the rejection threshold (RT). The RT includes a base error and length dependent error that corresponds to the survey level. In addition, the results of the repeat baseline measurements should be compared to the instrument specifications stated by the manufacturer.

Equation for determining base errors:

$$RT_{ppm} = \sqrt{e^2 + \left(SL_{ppm} * d * 10^{-6}\right)^2 / 2 * 10^6}$$

Where:

e = Base error is 0.008m for survey level 0 & 1. Base error is 0.01m for survey levels 2- 4.

SLppm = Survey Level (i.e. Level 0- 4)

d = Distance in meters (m)

b - Similar to the repeat baseline closures, known minus observed baseline closures provide insight on the location and possible cause of outliers. The differences between the known vector and the observed vector components are compared to the same rejection threshold presented for repeat baseline closures.

c - Computational loops should be composed of those baselines that close upon themselves in the shortest distance possible.

d - Not required if survey method is PPK or RTK.

e - In any component (X,Y,Z), the maximum misclosure, in terms of loop length, should not exceed this value in terms of parts per million (ppm). Take the misclosure divided the loop length times 1,000,000 to calculate each loop's ppm.

(continued...)

Loop Closure Reports *(continued)*

f - In any component (X,Y,Z), the average misclosure, in terms of loop length, should not exceed this value in terms of parts per million (ppm). To calculate this, take the sum of all of the loop closure ppm’s and divide by the number of loops to yield the average loop closure in ppm’s.

Data Adjustment Analysis

The purpose of a least-squares adjustment is to estimate and remove random errors; provide a single solution even when there is redundant data; minimize corrections made to the observations; detect blunders and large errors; and generate information for analysis, including estimates of precision.

The network adjustment occurs in two major steps:

The *first step* is the minimally constrained or free adjustment, which acts as a quality control check of the user's observations. The purpose of the minimally constrained adjustment is to check the internal consistency of the network; detect blunders or ill-fitting observations; and obtain accurate observation error estimates.

The *second step* is the fully constrained adjustment. The purpose of the fully constrained adjustment is to reference the network to existing control (datum); verify existing control; produce network transformation parameters (optional); and obtain accurate coordinate error estimates.

Both steps are required to obtain a complete adjustment and to provide confidence in the results.

Minimally Constrained Adjustment

A minimally constrained adjustment (MCA) is an adjustment with only one control point held fixed in the survey network. Holding one control point fixed, shifts observations to the correct location within the chosen datum. Not fixing a control point forces the software to perform a free adjustment. A free adjustment is accomplished by minimizing the size of the coordinate shift throughout the network. This equates to a mean coordinate shift of 0 (zero) in all dimensions.

A minimally constrained or free adjustment acts as one quality control check on the network. This adjustment helps to identify bad observations in the network. If an observation does not fit with the rest of the observations, it is highlighted as an outlier. The minimally constrained or free adjustment also checks on how well the observations hold together as a cohesive unit.

All minimally constrained adjustments must be performed in the WGS-84 datum. Since all GPS observations are made on the WGS-84 datum, the adjustment of the observations should be tied closely to the WGS-84 datum. Realistic error estimates for tribrach centering and H.I. measurement should also be factored into the minimally constrained adjustment.

(continued...)

Minimally Constrained Adjustment *(continued)*

The following minimally constrained adjustments should be done for Level 1 and Level 2 surveys. The required reports and/or spreadsheets are listed.

An MCA to determine network reference accuracy:

- Submit a minimally constrained adjustment holding the closest CORS fixed – use the NAD83 CORS coordinate in latitude, longitude, and ellipsoid height.
- Create a spreadsheet (or select a report) to compare the published CORS coordinates to the coordinates determined in the MCA.

An MCA to determine local HARN relationship if applicable:

- Submit a minimally constrained adjustment holding the highest order (1st priority) and most central to the project (2nd priority) HARN station.
- Create a spreadsheet (or select a report) that shows the comparison between the measured values and the published values of other HARN stations included in the survey.

An MCA to show the relationship of benchmarks used in the survey:

- Submit a minimally constrained adjustment holding the highest order (1st priority), highest stability monument (2nd priority), and most central (3rd priority) to the project vertical control stations.
- Create a spreadsheet (or select a report) showing differences between published orthometric heights (elevations) and measured values.

The minimally constrained adjustment is an iterative process. Perform the minimally constrained adjustment to check the observations for internal consistency and estimates errors for all observations.

If bad observations are found, they should appear as outliers in a histogram of standardized residuals. If bad observations are discovered, they should be removed, one at a time, starting with the largest, so that the statistics of the network are not skewed.

An adjustment should then be performed again. Errors are estimated again. In the subsequent adjustments, the estimated error may be rescaled to produce more realistic error estimates.

These procedures should be repeated until the results meet the following conditions:

- all outliers have been removed from the network
- observations have the most accurate error estimates possible; and observations are adjusted such that they fit together well.

(continued...)

Minimally Constrained Adjustment *(continued)*

During the iteration process, two least squares statistics should be used to gauge progress:

- *Reference factor* – The reference factor shows how well the observations, along with their respective error estimates, are working together. Once the reference factor approaches 1.00, the errors in the observations are properly estimated and all observations have received their appropriate adjustments.
- *Chi-square test* – Typically when the reference factor approaches 1.00, the chi-square test of network error estimates, degrees of freedom, and level of confidence will pass. At this point, there is confidence that the network observations are working together and that there are no large errors remaining in the network.

Once the minimally constrained adjustment has been completed, move on to the fully constrained adjustment to fit the observations to the local control datum.

Fully Constrained Adjustment

The fully constrained adjustment (FCA) transforms the network of observations to the control points in the network. Once the network is fixed to those control points, adjusted coordinates based on the project datum (using the appropriate datum adjustment as recommended by TxDOT) for all other points in the network can then be determined.

Use this step to check that the existing control fits together well. The minimally constrained adjustment (MCA) showed that the observations fit together and a fairly rigid network is defined. It is assumed that if any large errors are present in the fully constrained adjustment, the source is non-homogeneous control points (values). Any ill-fitting control points should not be fixed (constrained).

When designing the network, it is good practice to use a minimum of three (3) horizontal control points and four (4) vertical control points because two (2) horizontal and three (3) vertical control points are required to define transformation parameters. The additional horizontal and vertical control points can be used to check the consistency of the adjustment and defined transformation parameters. Adding additional control points builds more confidence in the calculated parameters. Levels 1 and 2 do require these three (3) horizontal coordinates and four (4) elevations at a minimum.

In the fully constrained adjustment, begin fixing the control values to determine how well the rigid network of observations fit the control. Essentially, the adjustment determines if the network of observations fit the network of fixed control points given some error estimate. These error estimates consist of the error estimates along with the applied scalar and set-up errors. The transformation parameters should then be calculated to allow the observations to fit to the control.

(continued...)

Fully Constrained Adjustment *(continued)*

The following fully constrained adjustments (FCA) for Level 1 and Level 2 should be delivered along with the listed spreadsheets or reports.

An FCA to determine local accuracy for horizontal positions only:

- Submit a fully constrained adjustment fixing a minimum of three (3) horizontal stations as noted above.
- Submit a spreadsheet (or select a report) showing the comparison between the MCA above and the FCA for horizontal position.

An FCA to determine local accuracy for orthometric heights (elevations):

- If there are unexpected differences in the MCA and published values for vertical, submit a fully constrained adjustment fixing a minimum of 4 benchmarks.
- In many cases, a fully constrained adjustment will not be required for the final elevations of a control survey.
- If the differences between the published and measured values of the MCA holding one benchmark fixed, fall within the acceptable error limits of a particular level of survey, the MCA elevations will be acceptable as the final results of the survey.

The following subsection explains the subject in further detail.

Orthometric Height Determination

For all levels of survey in TxDOT projects, orthometric height determination must include the latest available geoid model (GEOID03 currently). Geoid models are used to compute the separations between the ellipsoid and geoid. Using the latest geoid model will insure the best possible orthometric height differences between stations established by GPS methods.

When performing the fully constrained adjustments, if multiple orthometric heights are going to be fixed, then the horizontal and vertical adjustments must be done separately. During the horizontal adjustment only three (3) verticals should be fixed. During the vertical adjustment, only two (2) horizontals should be fixed.

The network design process and preplanning phase is critical to avoiding the pitfalls in geoid modeling. Inconsistencies in the local vertical control network due to subsidence, disturbed monuments, or dissimilar control sources, *must* not be allowed to contaminate the computed trend parameters.

(continued...)

Orthometric Height Determination *(continued)*

Caution: Failure to exercise extreme caution in this step can introduce significant errors into the computed heights.

For instance, a local area of subsidence, if not detected, could be entirely absorbed within the rotation parameters for the bias group. Errors in the geoid model or GPS ellipsoid heights could be similarly masked.

The analysis of the geoid modeling must identify the magnitude of vertical discrepancies and apply corrections to the geoid model and vertical constraints, which are appropriate to its source. This can only be accomplished with abundant levels of redundancy and careful analysis. The following table provides additional requirements specific to the geoid modeling process.

In addition to using the latest geoid model, the surveyor should use the latest National Vertical Datum, NAVD88 height values to control the project's adjusted heights. Also recommended is that the surveyor be familiar with NGS' guidelines for establishing GPS-derived ellipsoid heights when performing GPS surveys.

(continued...)

Orthometric Height Determination *(continued)*

There are three (3) general requirements for establishing GPS-derived orthometric heights on TxDOT projects:

Table 6.9 GPS-Derived Orthometric Requirements

Project vertical control	♦ will require the fixing of a geoid model for determining elevations with GPS ♦ surrounds the project with valid NAVD 88 bench marks, i.e., minimum number of stations is four (4) for Levels 3 and above, one in each corner of project ♦ users may have to extend well outside the project area to do this – maybe even run an additional level loop ♦ level 4 surveys are generally RTK and baseline distances kept under 10 kilometers are short enough that geoid undulation can be dealt with by using the most recent NGS Geoid model to determine elevations during data collection from a base station with valid orthometric height ♦ at the TxDOT surveyor's discretion, very confined RTK work within less than a couple of kilometers may not require the use of a geoid model if the base station has a valid orthometric height.
For large project areas	♦ there should be no points set farther than 20 kilometers of an occupied first or second order benchmark (or previously set GPS benchmark).
For projects located in mountainous regions	♦ occupy valid bench marks at the base and the summit of mountains, even if distance is less than 20 km.

(continued...)

Orthometric Height Determination *(continued)*

When processing the data, there are five (5) steps to follow for estimating GPS-derived orthometric heights:

Table 6.10 Steps in Processing the Data

Step	Action
1	Perform a 3-D minimally-constrained, least squares adjustment of the GPS survey project, i.e., constrain one latitude, one longitude, and one orthometric height value.
2	Using the results from the adjustment in procedure 1 above, detect and remove all data outliers. The user should repeat procedures 1 and 2 until all data outliers are removed.
3	Compute differences between the set of GPS-derived orthometric heights from the minimally constrained adjustment (using the latest National geoid model, e.g., GEOID03) from procedure 2 above and the published NAVD 88 benchmarks.
4	Using the results from step 3 of this table, determine which bench marks have valid NAVD 88 height values. This is the *most important step* of the procedure. Determining which bench marks have valid heights is critical to computing accurate GPS-derived orthometric heights. The user should include a few extra NAVD 88 bench marks in case some are inconsistent, i.e., are not valid NAVD 88 height values
5	Using the results from step 4 of this table, perform a fully constrained adjustment holding all valid known values fixed to arrive at the resulting elevations.

The following table provides adjustment analysis information:

Table 6.11 Office Procedures Guidelines

Adjustment Analysis Criteria	1 cm Horizontal 2 cm Vertical*	2 cm Horizontal 5 cm Vertical
Maximum variance of unit weight (1.0 ideal)	1.5	1.5
Minimum degrees of freedom per station	2 degrees of freedom	1 degree of freedom
Standard deviation of observation residuals, cm	.01 cm	0.1 cm
Standard error of baseline components, cm	.01 cm	0.1 cm
Standardized residuals - pass chi square test - pass tau criterion	yes yes	yes yes
Maximum % observations rejected	10%	10%

*Local Network Accuracy

Chapter 7
Units, Datum and Metadata

Contents:

Section 1
Overview

Purpose

The purpose of this chapter is to provide the reader with specifications and guidelines covering essential GPS survey information.

Section 2

Units and Datum

Units

Unless otherwise instructed, latitude and longitude will be presented as degrees, minutes, and seconds. Direction indicators N or W will prefix the value and seconds will be carried out five places right of the decimal where accuracy is to approximately .001 feet.

The coordinate system used by TxDOT is the State Plane Coordinate System in NAD83; however, units of length will be in U.S. Survey Feet rather than meters. Horizontal coordinates should be carried out to .001 ft., unless otherwise instructed.

Processing and adjusting GPS data may be done in the metric system but all project data must be delivered in U.S. Survey Feet.

Conversion from meters to U. S. Survey Feet must be made using the following formula:

Meters * 3937/1200 = U. S. Survey Feet

The factor is 3.280833333333 and working with SPC's in the millions, one *must* carry the factor out to 12 places to the right of the decimal as shown.

Datum

All geodetic surveying with GPS will be done in the NAD83 horizontal datum. An adjustment was done in Texas (using GPS), which resulted in the 1993 HARN network. The network was extended to nearly all old, conventionally surveyed federal monumentation. Projects should be referenced to the published HARN coordinates of NGS monumentation.

Elevations will be referenced to the NAVD88 vertical datum.

Surface Coordinates vs. State Plane Grid Coordinates

Depending on how far north or south the project falls in the state plane zone and depending on the elevation of the area; GPS coordinates in the State Plane Coordinate System most likely will need to be adjusted so that lengths measured on the surface will coincide with lengths inversed on the surface projection (state plane grid). An exception to this is when RTK work is done *after* calibrating the equipment to control in already existing surface coordinates.

(continued...)

Surface Coordinates vs. State Plane Grid Coordinates *(continued)*

The TxDOT surveyor or engineer for the project may calculate a combined adjustment factor (CAF) to be used on the project. The surveyor or engineer also might dictate that a standard, county-wide TxDOT Surface Adjustment Factor (SAF) be used or may ask a consultant to calculate their own. It is not important what method is used to arrive at the factor, but it *is* absolutely necessary that the factor used is included in the metadata notes.

Highway projects with several CAF's pose no problem when all coordinates can be backed down to SPC's so everything will match. The juncture of two systems; however, needs to be well identified so that all measurements stop or begin at a common point. Stationing must not cross this line without a station equation. Cut and fill volumes can't be calculated across the line. Only State Plane Coordinates can be used seamlessly.

If coordinates have been truncated for easier calculations or for identification, they must be returned to their full configuration before delivery. This is not only for standardization; it is so that the coordinates will work in the seed files for microstation as well.

Section 3
Metadata

Identifying Delivered Coordinates

All coordinates files or lists delivered, whether hardcopy or in digital medium, must contain metadata indicating the CAF (or SAF), horizontal datum and adjustment, vertical datum (geoid model if applicable), units of measure and the date of the field work. This would include hard copy drawings, CAD drawings, the data sheets, and each sheet containing coordinates in a report, and ASCII or LandXML files. See Chapter 8, Section 2, regarding individual data sheets for new control points.

Conversions and Transformations

Where design survey accuracy is required, TxDOT will not accept any datum transformations. There is no way to accurately transfer NAD27 coordinates to NAD83 datum. CORPSCON and other conversion software programs are based on NADCON algorithms, which perform a rubber sheeting adjustment that is not accurate.

If a change to the NAD83 project datum is needed for comparison of old surveys, two (2) control points can be resurveyed (GPS or conventional) from references in the new datum. Then, a translation-rotation-scale can be done holding to the two (2) points common to both datum. Or, if original raw GPS data is available, it can be reprocessed holding the new datum coordinates rather than the original datum coordinates.

Both CORPSCON and AASHTOW are SDMS Processor are acceptable software programs for the mathematical conversion of: a.) Metric to US Survey Foot (or visa-versa) b.) SPC zones to adjoining SPC zones c.) UTM to SPC's and d.) Latitude/Longitude to SPC's. In addition to these strictly mathematical conversions, they provide useable combined adjustment factors (CAF) at the specific location of a point if the elevation is included in the input.

Chapter 8
Project Documentation and Deliverables to TxDOT

Contents:

Section 1
Overview

Purpose

The purpose of this chapter is to provide guidelines and policy under which TxDOT employees and contractors prepare project documentation and deliverables.

Scope

TxDOT requirements for project documentation and deliverables are outlined in this chapter. Specifications on technical reports, digital data, control point data sheets, and validation surveys are presented.

Section 2
Project Documentation

Printed Technical Reports

A technical report must be prepared and submitted to the TxDOT district surveyor by the surveyor, in responsible charge, as documentation of the successful completion of the GPS survey project. The printed technical report should include the following:

- ♦ make and model of the GPS receivers, antennas, and related equipment
- ♦ short narrative of the requirements of the survey
- ♦ listing of the control utilized and how the control compared against the field measurements
- ♦ statement that the survey met the standards and specifications set out in this document
  - statement should also include that the survey was performed under the direct supervision of the Texas Registered Professional Land Surveyor (RPLS) along with the surveyors registration number, seal, and date prepared
- ♦ chronological summary of all field operations
- ♦ software program generated report regarding the baseline processing results and the software and version number used
- ♦ software program generated report regarding the network adjustment results including a summary of covariance’s, standard deviation or values and the software and version number used
- ♦ network diagram map showing the network configuration as designed
- ♦ final observing schedule
- ♦ observation logs (should be one log sheet per observation)
- ♦ loop closure results
- ♦ results of Minimally Constrained Adjustment (see Chapter 6, “Minimally Constrained Adjustment” for details of deliverables)
- ♦ results of Fully Constrained Adjustment (see Chapter 6, Fully Constrained Adjustment for details of deliverables)
- ♦ photographs or pencil rubbings of stations; if required (Level 1)
- ♦ completed data sheet for each point surveyed as a Level 1 station (see Chapter 6, Figure 6-2 TxDOT Control Point Data Sheet and Figure 6-3 Sample Project Specifications Control Point

(continued...)

Printed Technical Reports *(continued)*

- survey field notes to include a sketch of each point surveyed as a Level 2 or 3 station
- list of the NSRS points and TxDOT reference stations observed in the survey (whether used in the final adjustment or not)

An ASCII file of final coordinates by station (including notes on datum, geoid model, epoch, units, etc. as outlined in Chapter 7). The most often requested format is:

- name, northing, easting, elevation, feature code (if used)
- an ASCII file of the final position information (same as above) in lat/lon
- SDMS format CAL or PAC file.

If it is necessary, documentation variation from these specifications may be used.

Digital Data

In addition to the printed material, the surveyor in responsible charge of the project should submit the following digital data on a recordable *read only* CD:

- raw GPS files in Trimble .DAT or RINEX format (should be one file per individual observation and files should be able to be matched to the appropriate observation log sheet)
- zipped or archive file of the processing/adjustment program's project directory – this must allow opening the project for review or continuation.

The following are reports from the processing/adjustment program:

- results of minimally constrained adjustment (MCA)
- results of final fully constrained adjustment (must show held positions)
- ASCII file of final coordinates in format: name, northing, easting, elevation, feature code (if used)
- an ASCII file of ellipsoid heights for points with vertical determinations
- adjustment report showing network reference factor, ratios of precision, chi square test result, etc.
  - if topo data collected with RTK is included as a deliverable, it should be in SDMS format and include figure numbers and/or survey chains
  - TxDOT supported, TGO software, exports directly to the SDMS format. There must be point connectivity (break lines) and the standard TxDOT feature codes must be used

(continued...)

Digital Data *(continued)*

- current list is the "txdot2k" feature code list. The list, along with figure number prompts (that appear as attributes) is available at district offices in Trimble format for Trimble TSC1, TSCe and ACU data collectors. The file name is "txdot2k.fcl". Other data collector firmware may export SDMS format.

Control Point Data Sheets

A data sheet should be provided for individual Level 1 and Level 2 control points. It should contain information noted below:

Table 8.1 Control Point Data Sheets

Established by	contractor company
Date established	date monumented
TxDOT Level of Survey	e.g. Level 2
Horizontal Datum	e.g. NAD83
Horizontal Adjustment	e.g. '93 HARN
State Plane Projection Zone	e.g. Tx South Central 4204
Vertical datum	e.g. NAVD88
Geoid model used	e.g. GEOID03 or GEOID99
Units	US Survey foot
County name	e.g. Bexar
Station name	e.g. 0150102
Latitude	Latitude to 5 decimal places
Longitude	Longitude to 5 decimal places
Northing	two decimal places
Easting	two decimal places
Ellipsoid height	two decimal places
Elevation	two decimal places
Convergence angle	nearest second
Elevation factor	ten decimal places
Combined Adjustment Factor	ten decimal places
Survey method for vertical	GPS or leveling
General location	e.g. S Loop 1604 W & FM2790
To Reach description	how to get to station from a well known intersection
Type of Mark	iron rod, brass disc, etc
Stamping	what is actually stamped on the disk
Stations directly tied	list up to three closest stations directly tied

Sample data sheets are included in Chapter 6, Figure 6-2 and Figure 6-3. The district surveyor may have a particular, preferred form to be used.

Section 3

Project Deliverables

Validation Surveys

On rare occasions, TxDOT may require users to perform a validation survey. The validation survey provides evidence that the equipment and software are able to meet the minimum standards for a given level of survey. TxDOT may require this survey if the GPS equipment that is being used has not been approved/tested by FGCS. TxDOT may also require this survey to be performed by new users to acquaint both parties with their aptitudes for working together.

The validation survey should include calibration checks for mechanical and optical equipment, such as fixed height tripods and tribrachs. There most likely will be two (2) tests run similar to the following:

1. ***Short Baseline Test –*** Using a total station, accurately measure distances along a baseline in five (5) foot increments for as many receivers as will be used on the project. Set temporary points along the baseline.
   - All of these points should be set at precisely the same elevation. Use differential leveling techniques to be sure the elevations are the same.
   - Setup all receivers at the same time and measure points using the same technique as would be used for the level of survey to be surveyed to.
   - Occupy all of these points a second time using a different receiver setup at each point. Separate the first occupation time with the second occupation time by three (3) hours.

♦ After the data collection is complete, process all of the baselines. Compare the processed results with the designed location of the points.
   - All stations should compare horizontally and vertically within the specifications outlined by the manufacturer and with the local positional accuracy requirements for the level of survey being worked on.

2. ***Long Baseline Test –*** Take each receiver to be utilized for a given survey to a known A or B order control station with a 1st Order, Class II or higher NAVD88 Adjusted Elevation and with an A or B category monument stability.
   - Occupy this station for a minimum of two (2) hours, two times with a minimum of three (3) hours separating the independent observations. Repeat that process for all receivers working on a given project.

(continued...)

Validation Surveys *(continued)*

- ♦ On completion of the data collection, download the corresponding two (2) closest CORS sites to the monument(s) occupied.
  - Use software to process the baselines from the CORS sites to the known monument(s).
  - Perform a minimally constrained adjustment and compare the measured location of the station(s) with the published values.
  - If there are discrepancies, it might be of interest to obtain an OPUS position also.

All stations should compare horizontally (latitude & longitude) and vertically (ellipsoid height) within the specifications outlined by the manufacturer and with the local positional accuracy requirements for the level of survey being worked on.

Appendix A
References

Introduction

These references are a listing of authors and works associated with the information found within this manual. This appendix provides users with information for further reading.

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Appendix B
Glossary

Introduction

This appendix contains the definitions of most, but not all GPS related terms. The terms and their descriptions below are explained as used/intended in the context of this manual. Other, or more elaborate, descriptions may exist for the terms listed.

1-sigma – 1-sigma is one standard error from the mean.

A

a posteriori errors – A posteriori errors are the a priori errors multiplied by the standard error of unit weight (reference factor) resulting from a network adjustment.

a priori errors – A priori errors are the errors estimated for observations prior to a network adjustment.

accuracy – Accuracy is the closeness of a measurement to the actual (true) value of the quantity being measured.

adjusted values – Adjusted values are the values derived from observed data (measurement) by applying a process of eliminating errors in that data in a network adjustment.

adjustment – Adjustment is the process of determining and applying corrections to observations for the purpose of reducing errors in a network adjustment.

adjustment convergence – Adjustment convergence occurs when the network adjustment has met the defined residual tolerance or last ditch residual tolerance within a defined number of iterations.

algebraic sign – An algebraic sign is a sign (+ or -) associated with a value which designates it as a positive or negative number.

algorithm – An algorithm is a set of rules for solving a problem in a finite number of steps.

almanac – An almanac is data transmitted by a GPS satellite that includes orbit information on all the satellites, clock correction, and atmospheric delay parameters. The almanac facilitates rapid SV acquisition. The orbit information is a subset of the ephemeris data with reduced precision.

ambiguity – Ambiguity is the unknown integer number of cycles of the reconstructed carrier phase contained in an unbroken set of measurements. The receiver counts the radio waves (from the satellite as they pass the antenna) to a high degree of accuracy. However, it has no information on the number of waves to the satellite at the time it started counting. This unknown number of wavelengths between the satellite and the antenna is the ambiguity. Ambiguity is also known as integer ambiguity or integer bias.

antenna height – Antenna height is the height of a GPS antenna phase center above the point being observed. The uncorrected antenna height is measured from the observed point to a designated point on the antenna, and then corrected to the true vertical manually or automatically in the software.

antenna phase correction – The antenna phase correction is the phase center for a GPS antenna is neither a physical nor a stable point. The phase center for a GPS antenna changes with respect to the changing direction of the signal from a satellite. Most of the phase center variation depends on satellite elevation. Modeling this variation in antenna phase center location allows a variety of antenna types to be used in a single survey. Antenna phase center corrections are not as critical when two of the same antennas are used since common errors cancel out.

antenna phase center – Antenna phase center is the electronic center of the antenna. It often does not correspond to the physical center of the antenna. The radio signal is measured at the Antenna Phase Center.

anti-spoofing (AS) – Anti-spoofing is a feature that allows the U.S. Department of Defense to transmit an encrypted Y-code in place of P-code. Y-code is intended to be useful only to authorized (primarily military) users. AS is used with selective availability to deny the full precision of GPS to civilian users.

autonomous positioning – Autonomous positioning is a mode of operation in which a GPS receiver computes position fixes in real time from satellite data alone, without reference to data supplied by a base station. Autonomous positioning is the least precise positioning procedure a GPS receiver can perform, yielding position fixes that are precise to ±100 meters horizontal RMS when selective availability is in effect, and to ±10-20 meters when it is not. This is also known as absolute positioning and point positioning.

azimuth – The azimuth is a surveying observation used to measure the angle formed by a horizontal baseline and geodetic north. When applied to GPS observations, it refers to a normal section azimuth.

B

base station – A base station is an antenna and receiver set up on a known location. It is used for real-time kinematic (RTK) or differential surveys. Data can be recorded at the base station for later Postprocessing. In GPS surveying practice, the user may observe and compute baselines (that is, the position of one receiver relative to another). The base station acts as the position from which all other unknown positions are derived.

baseline – A baseline is the position of a point relative to another point. In GPS surveying, this is the position of one receiver relative to another. When the data from these two receivers is combined, the result is a baseline comprising a three-dimensional vector between the two stations.

bench mark – A bench mark is a relatively permanent object, natural or artificial, bearing a marked point whose elevation above or below an adopted datum is known. Usually designated a BM, such a mark is sometimes further qualified as a PBM (permanent benchmark) or as a TBM (temporary benchmark).

C

CAF – Combined Adjustment Factor – CAF is the product of the scale factor and the elevation factor. The CAF times the surface distance yields the corresponding distance on the State Plane grid.

Cartesian coordinates – See Fixed Earth-Centered-Earth Cartesian coordinates.

chi-square test – Chi-square is an overall statistical test of the network adjustment. It is a test of the sum of the weight squares of the residuals, the number of degrees of freedom and a critical probability of 95 percent or greater. The purpose of this test is to reject or to accept the hypothesis that the predicted errors have been accurately estimated.

clock offset – Clock offset is the constant difference in the time reading between two clocks. In GPS, usually refers to offset between SV clocks and the clock in the user's receiver.

closure – Closure is an agreement between measured and known parts of a network.

coarse acquisition – A course acquisition is a pseudorandom noise (PRN) code modulated onto an L1 signal.

(C/A) code – C/A code helps the receiver compute the distance from the satellite.

code – Code is the GPS code and is a pseudorandom noise (PRN) code that is modulated onto the GPS carrier signals. The C/A code is unclassified and is available for use by civilian applications. The P code is also known and unclassified, but may be encrypted for national defense purposes. Code measurements are the basis of GPS navigation and positioning. Code also is used in conjunction with carrier phase measurements to obtain more accurate survey quality baseline solutions.

CBN – Cooperative Base Network. CBN consists of B order stations set in cooperation with various governmental agencies for the purpose of densifying the National Spatial Reference System.

component – A component is one of the three surveying observations used to define a three-dimensional baseline between two control points. The same baseline can be defined by azimuth, delta height, and distance (in ellipsoid coordinates); by delta X, delta Y, and delta Z in (Earth Centered Cartesian coordinates); and by delta north, delta east, and delta up (in local plane coordinates).

constellation – A constellation is a specific set of satellites used in calculating positions: three satellites for 2D fixes, four satellites for 3D fixes. It is all of the satellites visible to a GPS receiver at one time. The optimum constellation is the constellation with the lowest PDOP. See also PDOP.

constrained – Constrained is a way to hold (fix) a quantity (observation and coordinate) as true in a network adjustment.

constraint – Constraint is external limitations imposed upon the adjustable quantities (observations and coordinates) in a network adjustment.

contour line – A contour line is an imaginary line on the ground, all points of which are above or below a specified datum.

contour interval – A contour interval is a predetermined difference in elevation (vertical distance) at which contour lines are drawn. The contour interval is usually the same for maps of the same scale.

contour map – A contour may is a map that portrays relief by means of contour lines.

control – A control is a system of points whose relative positions have been determined from survey data.

control point – A control point is a point whose position (horizontal or vertical) has been determined from survey data. It is used as a base for a dependent survey.

control stations – Control stations are stations whose position (horizontal or vertical) has been determined from survey data and is used as a base for a dependent survey.

control survey – A control survey is a survey that provides positions (horizontal or vertical) of points to which supplementary surveys are adjusted.

conventional observation – A conventional observation is an observation in the field obtained using a total station or theodolite.

coordinates – Coordinates are linear or angular quantities, or both, which designate the position on a point in relation to a given reference frame.

correlated – When observations are correlated, there are two or more observations (or derived quantities), which have at least one common source of error.

CORS - Continuously Operating Reference Station – CORS is a network of the highest quality horizontal stations, forming the National Spatial Reference System and providing the public with continuous raw GPS data.

covariance – Covariance is a measure of the correlation of errors between two observations or derived quantities. Covariance also refers to an off-diagonal term (that is, not a variance) in a variance-covariance matrix.

covariance matrix – A matrix that defines the variance and covariance of an observation. The elements of the diagonal are the variance and all elements on either side of the diagonal are the covariance.

covariant values – This is the publication of the propagated (computed) a posteriori errors in azimuth, distance, and height between pairs of control points resulting from a network adjustment. The term covariant indicates that this computation involves the use of covariant terms in the variance-covariance matrix of adjusted control points.

cycle slip **–** A cycle slip is an interruption in a receiver's lock onto a satellite's radio signals. A cycle slip requires the re-estimation of integer ambiguity terms during baseline processing.

D

data collector – A data collector is a handheld electronic field notebook. It connects to a total station, level, or GPS receiver to receive and temporarily store raw data.

data logging – Data logging is the process of recording satellite data in a file stored in the receiver, a data collector, or on a PC card.

data message – A data message is a message, included in the GPS signal, that reports on the location and health of the satellites, as well as any clock correction. It includes information about the health of other satellites as well as their approximate position.

datum – Datum is a mathematical model of the earth designed to fit part or all of the geoid. It is defined by the relationship between an ellipsoid and a point on the topographic surface established as the origin of the datum. It is usually referred to as a geodetic datum. The size and shape of an ellipsoid, and the location of the center of the ellipsoid with respect to the center of the earth, usually define world geodetic datums.

datum transformation – Datum transformation defines the transformation that is used to transform the coordinates of a point defined in one datum to coordinates in a different datum. There are a number of different datum transformation methods:

- seven-parameter
- three-parameter (also referred to as Molodensky)

datum grid/multiple regression – Datum grid/multiple regression are datum transformations, usually convert data collected, in the WGS-84 datum (by GPS methods) onto datums used for surveying and mapping purposes in individual regions and countries.

de-correlate – To de-correlate is to remove the covariances between observations. This may be done through elaborate orthogonal transformations, or by computing separate horizontal and vertical adjustments.

deflection of the vertical – A deflection of the vertical is the angular difference between the upward direction of the plumb vertical line (vertical) and the perpendicular (normal) to the ellipsoid.

degrees of freedom – Degrees of freedom is a measure of the redundancy in a network.

delta elevation – Data elevation is the difference in elevation between two points.

delta N, delta E, – Delta N and delta E are coordinate differences, expressed in a Local Geodetic Horizon delta U coordinate system.

delta X, delta Y, delta Z – Delta X, Y, and Z are coordinate differences, expressed in a Cartesian coordinate system.

differential positioning – Differential positioning is the precise measurement of the relative position of two receivers that are tracking the same satellites simultaneously.

discrepancy - (1) Discrepancy is the difference between duplicate or comparable measures of a quantity. (2) Discrepancy is the difference between computed values of a quantity obtained by different processes in the same survey.

DOP – Dilution of Precision. DOP is an indicator of the quality of a GPS position. It takes account of each satellite's location relative to the other satellites in the constellation, and their geometry in relation to the GPS receiver. A low DOP value indicates a higher probability of accuracy.
Standard DOPs for GPS applications are:

- PDOP Position (three coordinates)
- HDOP Horizontal (two horizontal coordinates)
- VDOP Vertical (height only)
- TDOP Time (clock offset only)

doppler shift – A doppler shift is the apparent change in frequency of a signal caused by the relative motion of satellites and the receiver.

double differencing – Double differencing is an arithmetic method of differencing carrier phases simultaneously measured by two receivers tracking the same satellites. This method removes the satellite and receiver clock errors.

DTM – Digital Terrain Model. DTM is a representation in graphic form, on the computer, of the terrain through the area being surveyed.

dual-frequency – A dual frequency is a type of receiver that uses both L1 and L2 signals from GPS satellites. A dual-frequency receiver can compute more precise position fixes over longer distances and under more adverse conditions because it compensates for ionospheric delays.

E

easting – Easting is an eastward reading of grid values. Easting is read left to right on a grid (X-axis).

elevation – Elevation is the height above mean sea level or the vertical distance above the geoid. Elevation is sometimes referred to as the orthometric height.

elevation mask – An elevation mask is an angle which is normally set from 10-20 degrees. If a user tracks satellites from above this angle, interference caused by buildings, trees, and multipath errors is avoided.

ellipsoid – Ellipsoid is a mathematical model of the earth formed by rotating an ellipse around its minor axis. For ellipsoids that model the earth, the minor axis is the polar axis, and the major axis is the equatorial axis.

- An ellipsoid is defined by specifying the lengths of both axes, or by specifying the length of the major axis and the flattening.
- Two quantities define an ellipsoid; these are usually given as the length of the semi-major axis, a, and the flattening, where b is the length of the semi-minor axis.

ellipsoid distance – An ellipsoid distance is the length of the normal section between two points. Ellipsoid distance is not the same as the geodesic distance.

ellipsoid height – An ellipsoid height is the distance, measured along the normal, from the surface of the ellipsoid to a point.

ephemeris – An ephemeris is a set of data that describes the position of a celestial object as a function of time. Each GPS satellite periodically transmits a broadcast ephemeris describing its predicted positions through the near future, uploaded by the control segment. Postprocessing programs can also use an ultra rapid, rapid or precise ephemeris, which describes the exact positions of a satellite in the past.

epoch – An epoch is the measurement interval of a GPS receiver. The epoch varies according to the survey type.

epoch date – The epoch date is the date, usually expressed in decimal years, for which published coordinates and data are valid.

epoch interval – Epoch interval is the measurement interval used by a GPS receiver; also called a cycle.

error – An error is the difference between the measured value of a quantity and its true value. Surveying errors are generally divided into three categories: blunders, systematic errors, and random errors. Least squares analysis is used to detect and eliminate blunders and systematic errors, and least squares adjustment is used to measure and properly distribute random error.

error ellipse – An error ellipse is a coordinate error ellipse is a graphical representation of the magnitude and direction of the error of network adjusted points.

events – Events are represented as a record of the occurrence of an event, such as the closing of a photogrammetric camera's shutter. A GPS receiver can log an event mark containing the time of the event and an alphanumeric comment entered through the keypad to describe the event. An event can be triggered through the keypad or by an electrical signal input on one of the receivers' ports.

F

fast ambiguity resolution – Fast ambiguity resolution is rapid static or fast static GPS surveying techniques, utilizing multiple observables (dual-frequency carrier phase, C/A and P codes) to resolve integer ambiguities, with shortened observation periods. The method may also be used for observations with the receiver in motion known as on-the-fly ambiguity resolution.

FastStatic – FastStatic is a method of GPS surveying using occupations of up to 20 minutes to collect GPS raw data, then postprocessing to achieve sub-centimeter precisions. Typically the occupation times vary based on the number of satellites (SVs) in view. FastStatic is also referred to as RapidStatic.

FBN – Federal Base Network – An FBN consists of A and B order stations set by the NGS for the purpose of densifying the National Spatial Reference System.

FCA – An FCA is a fully constrained adjustment.

feature codes – Feature codes are abbreviations used to define an object collected during a radial survey.

FGDC – A Federal Geodetic Data Committee.

fixed – See <u>constrained</u>.

fixed earth-centered-earth – An earth- centered is a Cartesian coordinate system used by the WGS-84 reference frame. In this coordinate system, fixed refers to the center of the system that is at the earth's center of mass. The z-axis is coincident with the mean rotational axis of the earth and the x-axis passes through 0 x N and 0 x E. The y-axis is perpendicular to the plane of the x and z-axes.

fixed coordinates – Fixed coordinates are point coordinates that do not move when performing a network adjustment.

fixed elevation – A fixed elevation is an elevation obtained, either as a result of tide observations or previous adjustment of leveling, which is held at its accepted value in any subsequent adjustment.

fixed position – A fixed position is an adjusted value of the position of a point on the earth. The positions obtained by the adjustment are called adjusted positions, and when used a control for other survey work they are called fixed positions.

fixed solution – A fixed solution is a solution obtained when the baseline processor is able to resolve the integer ambiguity search with enough confidence to select one set of integers over another. It is called a fixed solution because the ambiguities are all fixed from their estimated float values to their proper integer values.

flattening – A flattening is a mathematical expression of the relative lengths of the major and minor axes of an ellipsoid.

flattening inverse – A flattening inverse is an expression of the flattening that is easier to read and edit.

float solution – A float solution is a solution obtained when the baseline processor is unable to resolve the integer ambiguity search with enough confidence to select one set of integers over another. It is called a float solution because the ambiguity includes a fractional part and is non-integer.

free adjustment – Performs a network adjustment in which no point (coordinate) is constrained. The network adjustment uses inner constraints.

frequency – Frequency is the size and spread of residuals in a data set; graphically shown in distribution histograms.

fully constrained – Fully constrained is a network adjustment in which all points in the network that are part of a larger control network are held fixed to their published coordinate values. Fully constrained is used to merge smaller with larger control networks and old to newer networks.

G

GDOP - Geometric Dilution of Precision – GDOP is the relationship between errors in user position and time and errors in satellite range. See also DOP.

geodetic azimuth – A geodetic azimuth is the angle between the geodetic meridian and the tangent to the geodesic line of the observer, measured in the plane perpendicular to the ellipsoid normal of the observer; clockwise from north.

geodetic datum – A geodetic datum is a mathematical model designed to fit part or all of the geoid. It is defined by the relationship between an ellipsoid and a point on the topographic surface established as the origin of a datum.

- The size and shape of an ellipsoid and the location of the center of the ellipsoid with respect to the center of the earth define world geodetic datums. Various datums have been established to suit particular regions.
- For example, European maps are often based on the European datum of 1950 (ED-50). Maps of the United States are often based on the North American Datum of 1927 or 1983 (NAD-27, NAD-83). All GPS coordinates are based on the WGS-84 datum surface.

geographic (geodetic) coordinates – Latitude, longitude, and ellipsoid height.

geoid – A geoid is the surface of gravitational equipotential that closely approximates mean sea level. It is not a uniform mathematical shape, but is an irregular figure.

- Generally, the elevations of points are measured with reference to the geoid. However, points fixed by GPS methods have heights established in the WGS-84 datum (a mathematical figure).
- The relationship between the WGS-84 datum and the geoid must be determined by observation, as there is no single mathematical definition that can describe the relationship. The user must utilize conventional survey methods to observe the elevation above the geoid, and then compare the results with the height above the WGS-84 ellipsoid at the same point.
- By gathering a large number of observations of the separation between the geoid and the WGS-84 datum (geoidal separation), grid files of the separation values can be established.
- This allows the interpolation of the geoidal separation at intermediate positions. Files containing these grids of geoidal separations are referred to as geoid models. Given a WGS-84 position that falls within the extents of a geoid model, the model can return the interpolated geoidal separation at this position.

geoid model – A geoid model is a mathematical representation of the geoid for a specific area, or for the whole earth. The software uses the geoid model to generate geoid separations for the user's points in the network.

geoid separation – Geoid separation is the distance between the ellipsoid and geoid at a given point.

geomatics – Geomatics is the design, collection, storage, analysis, display, and retrieval of spatial information. The collection of spatial information can be from a variety of sources, including GPS and terrestrial methods. Geomatics integrates traditional surveying with new technology-driven approaches, making geomatics useful for a vast number of applications.

GPS - Global Positioning System – A GPS is based on a constellation of twenty-four (24) satellites orbiting the earth at a very high altitude.

GPS baseline – A GPS baseline is a three-dimensional measurement between a pair of stations for which simultaneous GPS data has been collected and processed with differencing techniques.

- Represented as delta X, delta Y, and delta Z; or azimuth, distance, and delta height.

GPS observation – A GPS observation is an uninterrupted collection of GPS data at a particular point in the field. A number of observations are done simultaneously in a session to create baselines by processing the data.

GPS raw data – GPS raw data is the data collected by a GPS receiver for the purpose of processing at a later time.

GPS time – GPS time is a measure of time used by the NAVSTAR GPS system. GPS time is based on Universal Time Coordinated (UTC) but does not add periodic *leap seconds* to correct for changes in the earth's period of rotation.

GPS week – A GPS week is an incremental number of weeks, starting at 0 hour UTC on the date January 6, 1980. April 6, 1007 is the first day of GPS week 900.

gravity void – A gravity void is a block or area of blocks within the gravity measurement database without observations. A geoid model relying upon this database would be weak and possibly in error at these blocks.

grid – A grid is a two-dimensional horizontal rectangular coordinate system, such as a map projection.

grid azimuth – A grid azimuth is measured from grid north.

grid conversion – A grid conversion is the conversion between geographic and map projection coordinates.

grid coordinates – Grid coordinates are the numbers of a coordinate system that designates a point on a grid.

grid declination - The angular difference in direction between grid north and true north at any given place.

grid position – Grid position are the grid coordinates of a point.

ground control – Ground control, in photomapping, is the control obtained from surveys as distinguished from control obtained by photogrammetric methods.

grid distance – The grid distance is the distance between two points that is expressed in mapping projection coordinates.

ground distance – Ground distance is the distance (horizontal distance with curvature applied) between two ground points.

ground plane – A ground plane is a large flat metal surface, or electrically charged field, surrounding a GPS antenna used to deflect errant signals (multipath) reflected from the ground and other near-by objects.

GRS 80 guard stake – A GRS 80 guard stake is a stake driven near a point usually sloped with the top of the guard stake over the point. The guard stake protects, and its markings identify the point.

H

HDOP – Horizontal Dilution of Precision.

height measurement – A height measurement is a measuring tool supplied with an external GPS antenna and used rod for measuring the height of the antenna above a point.

H.I. – Height of instrument. H.I. is synonymous with antenna heights for GPS.

histogram – A histogram is a graphical display of the size and distribution of residuals in a network adjustment.

horizontal datum – In plane surveying, the grid system of reference used for the horizontal control of an area: defined by the easting and northing of one station in the area, and the azimuth from this selected station to an adjacent station.

horizontal – A horizontal is a point with horizontal coordinate accuracy only. The control point elevation or ellipsoid height is of a lower order of accuracy or is unknown.

horizontal distance – A horizontal distance is the distance between two points, computed horizontally from the elevation of either point.

horizontal position – A horizontal position is a point with horizontal coordinates only.

HTDP – Horizontal Time Dependent Positioning model. HTDP is a computer database and interpolation program developed by NGS to predict horizontal displacements between coordinate points over time. The program can work backwards in time where it includes earthquake parameter or forward in time where only the secular motion is analyzed.

hub – A hub is a wooden stake set in the ground, with a tack or other marker to indicate the exact position. A guard stake protects and identifies the hub.

I

independent – An independent is the subnetworks, observations, and control points not connected by geometry or errors. This term is the opposite of correlated.

independent baseline – An independent baseline is a non-trivial baseline. Those vectors determined from differencing common phase measurements only once. For any given session there are n – 1 independent vectors where n is the number of receivers operating.

inner constraint – An inner constraint is a network adjustment computed without fixing any point coordinates.

integer ambiguity – Integer ambiguity is the whole number of cycles in a carrier phase pseudorange between the GPS satellite and the GPS receiver.

integer search – Integer search is the GPS baseline processing, whether real-time or postprocessed, requires fixed integer solutions for the best possible results. The software which processes the GPS measurements used to derive a baseline does an integer search to obtain a fixed integer solution. The search involves trying various combinations of integer values and selecting the best results.

iono free – Ionospheric free solution (IonoFree). IonoFree is a solution that uses a combination of GPS measurements to model and remove the effects of the ionosphere on the GPS signals. This solution is often used for high-order control surveying, particularly when observing long baselines.

ionosphere – The ionosphere is part of the atmosphere 80 to 120 miles above the earth's surface. It affects the accuracy of GPS measurements, if the user measures long baselines using single-frequency receivers.

ionosperic delay – An ionopheric delay is a signal delay or acceleration as a wave propagates through the ionosphere. Phase delay depends upon the electron content and affects the carrier signal. Group delay depends upon the dispersion in the ionosphere as well, and affects the code signal.

ionospheric modeling – Ionospheric modeling is the time delay caused by the ionosphere varies with respect to the frequency of the GPS signals and affects both the L1 and L2 signals differently. When dual frequency receivers are used the carrier phase observations for both frequencies can be used to model and eliminate most of the ionospheric effects. When dual frequency measurements are not available an ionospheric model broadcast by the GPS satellites can be used to reduce ionospheric affects. The use of the broadcast model, however, is not as effective as the use of dual frequency measurements.

iteration – An iteration is a complete set of adjustment computations that includes the formation of the observation equations, normal equations, coordinate adjustments, and computation of residuals.

K

K reduced column – K reduced column is an abbreviated version of the normal equations in which the profile equations are reordered to minimize the computer memory required to store all nonzero elements.

kinematic surveying – Kinematic surveying is a method of GPS surveying using short Stop and Go occupations, while maintaining lock on at least 4 satellites. It can be done in real-time or postprocessed to centimeter precisions.

known point initialization – A known point initialization is used in conjunction with kinematic initialization. If two known points are available, the baseline processor can calculate an inverse between the two points and derive an initialization vector. This initialization vector, with known baseline components, is used to help solve for the integer ambiguity. If the processor is able to successfully resolve this ambiguity a fixed integer solution is possible, yielding the best solutions for kinematic surveys.

L

L1 – L1 is the primary L-band carrier used by GPS satellites to transmit satellite data. Its frequency is 1575.42 MHz. It is modulated by C/A code, P code, and a Navigation Message.

L2 – L2 is the secondary L-band carrier used by GPS satellites to transmit satellite data. Its frequency is 1227.6 MHz. It is modulated by P code and a Navigation Message.

latitude – (1) latitude the angular distance north or south of the equator. (2) latitude, in plane surveying, is the amount that one end of a line is north or south of the other end. As the plane coordinates of a point are known as the easting and northing of the point, the latitude is the difference between the northings of the two ends of the line, which may be either plus or minus.

least squares – A mathematical method for the adjustment of observations, based on the theory of probability. In this adjustment method, the sum of the squares of all the weighted residuals is minimized.

level of confidence – A level of confidence is a measure of the confidence in our results, expressed in a percentage or sigma.

level datum – A level datum is a level surface to which elevations are referred. The generally adopted level datum for leveling in the United States is mean sea level. For local surveys, an arbitrary level datum is often adopted and defined in terms of an assumed elevation for some physical mark (bench mark).

level net – Level net are lines of spirit leveling connected together to form a system of loops or circuits extending over an area. Level net is also called a vertical control net.

level of significance – A level of significance is an expression of probability. A one-sigma (standard) error is said to have a level of significance of 68 percent. For one-dimensional errors, a 95 percent level of significance is expressed by a 1.96 sigma, and a percent level of significance is expressed by a 2.576 sigma.

local ellipsoid – A local ellipsoid is the ellipsoid specified by a coordinate system. The WGS-84 coordinates are first transformed onto this ellipsoid; then converted to grid coordinates.

local geodetic coordinates – A local geodetic coordinate is the latitude, longitude, and height of a point. The coordinates are coordinates expressed in terms of the local ellipsoid.

local geodetic – A local geodetic is at any point, a plane at the ellipsoid height of a given point, which is horizon parallel to the tangent plane to the ellipsoid at that point. Coordinate values for the local geodetic horizon are expressed as North, East, and Up. The LGH is used for rotating EC Cartesian Coordinate differences, before modeling a baseline on the ellipsoid. Azimuth values computed from LGH components must be corrected for skew normals as part of modeling on the ellipsoid.

loop closure – Loop closures provide an indication as to the amount of error in a set of observations within a network.

- A loop closure is calculated by selecting a point from which one or more observations were taken, adding one of those observations to the point’s coordinates, and calculating coordinates of the second point based on that observation.
- This process is repeated one or more times around a loop, finally ending at the original starting point. If there were no errors in the observations, the final calculated coordinate would be exactly the same as the original starting coordinate.
- By subtracting the calculated coordinate from the original coordinate a misclosure is determined. Dividing this error by the length of the line allows the error to be expressed in parts per million.
- This technique can also be used between two different points when both points are known with a high degree of accuracy. This is also known as a traverse closure.

M

major axis – See ellipsoid.

mapping angle – Mapping angle is the angle between grid north on a mapping projection and the meridian of longitude at a given point. Also know as convergence.

mapping projection – Mapping projection is a rigorous mathematical expression of the curved surface of the ellipsoid on a rectangular coordinate grid.

mask angle – Cut-off angle. A mask angle/cut-off angle is the point above the observer's horizon below which satellite signals are no longer tracked and/or processed. Ten to twenty degrees is typical.

MCA – minimally constrained adjustment.

mean sea level – A mean sea level is the mean height of the surface of the ocean for all stages of the tide. Used as a reference for elevations.

meridian – A meridian is a north-south line from which longitudes (or departures) and azimuths are reckoned.

minimally constrained – A minimally constrained network is a network adjustment in which only enough constraints to define the coordinate system are employed. It is used to measure internal consistency in observations.

minor axis – See ellipsoid.

modeling – Modeling is the expressing of an observation and its related errors mathematically and geometrically on some defined coordinate system, such as an ellipsoid.

monument – A monument is any object or collection of objects (physical, natural, artificial) that indicates the position on the ground of a survey station.

multipath – A multipath is an interference that occurs when GPS signals arrive at an antenna after traveling different paths. The signal traveling the longer path yields a larger pseudorange estimate and increases the error. Multiple paths may arise from reflections from structures near the antenna.

N

NAD27 – North American Datum of 1927

NAD83 – North American Datum of 1983

narrow-lane – A narrow-lane is a linear combination of L1 and L2 carrier phase observations (L1 + L2) that is useful for canceling out ionospheric effects in collected baseline data. The effective wavelength of the narrow-lane is 10.7 centimeter.

NAVD88 – North American Vertical Datum of 1988.

NAVDATA – NAVDATA is the 1500-bit navigation message broadcast by each satellite. This message contains system time, clock correction parameters, ionospheric delay model parameters, and details of the satellite's ephemeris and health. The information is used to process GPS signals to obtain user position and velocity.

network – A network is a set of baselines. See also subnetwork.

network adjustment – A network adjustment is a solution of simultaneous equations designed to achieve closure in a survey network by minimizing the sum of the weighted squares of the residuals of the observations.

network status – Network status is an indication that a particular observation will be included in the adjustment. Network means that it is included in the adjustment and non-network means that it is excluded from the adjustment.

NGVD29 – National Geodetic Vertical Datum of 1929.

NMEA – National Marine Electronics Association. The NMEA 0183 Standard defines the interface for marine electronic navigational devices. This standard defines a number of *strings* referred to as NMEA strings that contain navigational details such as positions.

NSRS – National Spatial Reference System.

normal – A normal in geodesy is the straight line perpendicular to the surface of the ellipsoid.

normal distribution curve – A normal distribution curve is a graphical illustration of the theoretical distribution of random variables around an expected value according to probability theory. It is used with histograms.

northing – A northing is a northward reading of a grid value.

O

observation residual – An observation residual is the correction applied to an observation, as determined by the adjustment.

observation – An observation is an uninterrupted collection of GPS data at a particular point in the field. A number of observations are done simultaneously in a session to create baselines by processing the data.

occupation time – An occupation time is the amount of time required on a station, or point, to achieve successful processing of a GPS baseline. The amount of time will vary depending on the surveying technique, the type of GPS receiver used, and the precision required for the final results. Occupation times can vary from a couple of seconds (kinematic surveys) to several hours (control or deformation surveys that require the highest levels of precision and repeatability).

occupied station – An occupied station is a traverse or triangulation station over which a theodolite or an engineer transit is set up for the measurement of angles at this station. It is also a station at which angles have been measured.

offset line – An offset line is a supplementary line close to, and usually parallel to a main survey line to which it is referenced by measured offsets. When the line for which data is desired is in such position that it is difficult to measure over it, the required data is obtained by running an offset line in a convenient location and measuring offset from it to salient points on the other line.

order of accuracy – An order of accuracy is a mathematical ratio defining the general accuracy of the measurements made in a survey. The orders of accuracy for surveys are divided into four classes named: first-order, second-order, third-order, and fourth-order.

origin – An origin is the intersection of axes in a coordinate system. It is the point of beginning.

orthometric height – An orthometric height is the distance between a point and the surface of the geoid. It is usually called the elevation.

OTF search method – On-the-fly (OTF) search method is a GPS baseline processing, whether real-time or postprocessed, requires fixed integer solutions for the best possible results. (See integer search.)

- Historically, this search was done using measurements collected while two or more receivers were stationary on their respective points. Modern receivers and software can use the measurements collected while the roving receiver is moving. Because the receiver is moving, the data is described as collected On-the-fly (OTF) and the integer search using this data is an OTF search.

outlier – An outlier is an observation which is identified by statistical analysis as having a residual too large for its estimated error. The term derives from the graphical position of an observation in a histogram.

over- determined – An over-determined network is a network for which more measurements have been made than are necessary to compute the coordinates of the network. It is related to redundancy.

P

P-code – A P-code is the *precise* code transmitted by the GPS satellites. Each satellite has a unique code that is modulated onto both the L1 and L2 carrier waves. The P-code is replaced by a Y-code when Anti-Spoofing is active.

parallax – A parallax is a change in positions of the image of an object with respect to the telescope cross hairs when the observer's eye is moved. This can be practically eliminated by careful focusing.

parameter – A parameter is an independent variable in terms of which the coordinates of points on a line or surface are given. See unknowns.

parity – Parity is a form of error checking used in binary digital data storage and transfer. Options for parity checking include even, odd, or none.

PDOP – Position Dilution of Precision. A PDOP is a unitless figure of merit expressing the relationship between the error in user position, and the error in satellite position. Geometrically, PDOP is proportional to 1 divided by the volume of the pyramid formed by lines running from the receiver to four satellites that are observed. Values considered "good" for positioning are small, for example 3. Values greater than 7 are considered poor. Thus, small PDOP is associated with widely separated satellites.

- PDOP is related to horizontal and vertical DOP by:
  - $PDOP^2 = HDOP^2 + VDOP^2$

PDOP cutoff – A receiver parameter specifying a maximum PDOP value for positioning. When the geometric orientation of the satellites yields a PDOP greater than the mask value, the receiver stops computing position fixes.

PDOP mask – A PDOP mask is the highest PDOP value at which a receiver will compute positions.

phase center – See antenna phase correction.

phase center models – Phase center models are models used to apply a correction to a GPS signal based on a specific antenna type. The correction is based on the elevation of the satellite above the horizon and models electrical variations in the antenna phase center location. These models are useful for eliminating errors introduced when identical antennas are not used at both the base and rover points. See also antenna phase correction.

phase difference processing – Relative positioning. Phrase difference processing is a computation of the relative difference in position between two points by the process of differencing simultaneous reconstructed carrier phase measurements at both sites. The technique allows cancellation of all errors which are common to both observers, such as clock errors, orbit errors, and propagation delays. This cancellation effect provides for determination of the relative position with much greater precision than that to which a single position (pseudorange solution) can be determined.

picture point – A picture point in surveying is a terrain feature that is easily defined on an aerial photograph. Its horizontal or vertical positions have been determined by survey measurements. Picture points are marked on the aerial photographs by the surveyor and are used by the photomapper.

plane coordinates – See grid coordinates.

plane survey – A plane survey is a survey in which the effect of the curvature of the earth is almost entirely neglected, and computations of the relative positions of the stations are made using the principles of plane geometry and plane trigonometry.

plumbing – Plumbing is the act of aligning the antenna or instrument along a vertical line (plumb line) perpendicular to the equipotential surface of earth's gravity field.

point positions – See autonomous positioning.

positions – Positions are the place occupied by a point on the surface of the earth. Positions are data that defines the location of a point with respect to a reference system.

postprocess – Postprocess is to process satellite data on a computer after it has been collected.

PPM - Parts per million – PPM is a standardized representation of a scale error in distance measurements. A 1 PPM error would result in 1 millimeter of measurement error for every 1000 meters of distance traveled.

precise ephemeris – See ephemeris.

precision – Precision is a measure of how closely random variables tend to cluster around a computed value. High precision implies small residuals. It is usually expressed as one part in, or alternatively, as parts per million.

prime meridian – A prime meridian is the initial or zero median from which longitudes are reckoned. At an international conference in 1884, the Greenwich Meridian was adopted by most countries as the prime meridian for the earth.

prime vertical – A prime vertical is a vertical circle perpendicular to the plane of the celestial meridian. The plane of the prime vertical cuts the horizon in the east and west points.

PRN – Pseudorandom number – (1) A sequence of digital 1's and 0's that appear to be randomly distributed like noise, but that can be exactly reproduced. PRN codes have a low autocorrelation value for all delays or lags except when they are exactly coincident. (2) Each NAVSTAR satellite can be identified by its unique C/A and P pseudorandom noise codes, so the term *PRN* is sometimes used as another name for GPS satellite or SV.

probability – Probability is a statistical percentage expressing what portion of a hypothetical number of observations will fall within the defined limits. It is sometimes called level of significance.

probable value – A probable value is the adjusted value for observations and other quantities, assuming that the adjustment has been done correctly. It is the closest approximation to true value that is possible.

projection – A projection is used to create flat maps that represent the surface of the earth or parts of the Earth's surface.

propagated error – The propagated errors are computed errors derived from estimated observational errors and expressed in terms of coordinate positions. Propagated coordinate errors may, in turn, be propagated into relative errors in azimuth, distance, and delta height between points.

pseudorange – A pseudorange is a measure of the apparent propagation time from the satellite to the receiver antenna, expressed as a distance. The apparent propagation time is determined from the time shift required to align a replica of the GPS code generated in the receiver with the received PGS code.

- The time shift is the difference between the time of signal reception (measured in the receiver time frame) and the time of emission (measured in the satellite time frame). Pseudorange is obtained by multiplying the apparent signal-propagation time by the speed of light.
- Pseudorange differs from the actual range by the amount that the satellite and receiver clocks are offset, by propagation delays, and other errors including those introduced by selective availability.

pseudostatic GPS – Pseudostatic GPS, also known a pseudo-kinematic and repeat occupation, is a relative positioning technique which relies upon two or more simultaneous observations at a point pair, separated by some time interval (typically 60 minutes or more), in order to solve the integer bias terms from the change in satellite geometry occurring between the repeat observations.

Q

quality acceptance test – A quality acceptance test is one or more software evaluation tests, performed on raw GPS measurement data, to determine if the data passes or fails a set of tolerance values that the user defines. These tests either remove data from further processing or mark data requiring quality improvements.

QC records – Quality Control records. QC records are used with precise positioning applications. This receiver option allows a user to process RTCM-104 corrections and satellite data in real time to provide position precision statistics.

R

ratio – A ratio is used during initialization. The receiver determines the integer number of wavelengths for each satellite. For a particular set of integers, it works out the probability that it is the correct set.

- ♦ Ratio is the ratio of the probability of correctness of the currently best set of integers to the probability of correctness of the next-best set.
- ♦ Thus, a high ratio indicates that the best set of integers is much better than any other set. This gives us confidence that it is correct. The ratio must be above 5 for new point and OTF initializations.

RDOP – Relative Dilution of Precision.

real-time kinematic (RTK) – Real-time kinematic is a method of GPS surveying in real-time using short (stop and go) occupation, while maintaining lock on at least 4 satellites. The real-time kinematic method requires a wireless data link between the base and rover receivers.

rectangular – A rectangular are coordinates in any system in which the axes of reference intersect coordinates at right angles.

K reduced column – K reduced column is an abbreviated version of the normal equations in which the profile equations are reordered to minimize the computer memory required to store all nonzero elements.

redundancy – Redundancy is the amount by which a control network is over-determined, or has more observations than are needed to strictly compute its parts.

redundancy number – Redundancy number is a measure of the degrees of freedom in a portion, rather than the entirety, of a control network.

redundant baselines – Redundant baseline is a baseline observed to a point that has already been connected to the network by other observations. A redundant baseline can be either an independent re-observation of a previous measurement, or an observation to a point from another base. It is redundant because it provides more information than is necessary to uniquely determine a point. Redundant observations are very useful. They provide a check on the quality of previous measurements.

redundant – Redundant is a repeated observation or an observation which contributes to over-observation determining a network.

reference factor – See standard error of unit weight.

reference frame – A reference frame is the coordinate system of a datum.

reference station – A reference station is a base station.

reference variance – A reference variance is the square of the reference factor.

relative errors – A relative errors are errors and precisions expressed for and between pairs of network-adjusted control points.

relative precision – The relative precision is defined as a measure of the tendency of a set of numbers to cluster about a number determined by the set (e.g. the mean). The usual measure is the standard deviation with respect to the mean.

- ♦ Relative precision denotes the tendency for the various components (X, Y, Z) between one station and other stations in the network to be clustered about the adjusted values.
- ♦ Current custom is to express relative precision at the two-standard deviation (95% confidence) level. This may be stated in terms of a relative error ellipse or as a proportion of the separation distance (e.g. 10 ppm or 1:100,000).

residual – A residual is the correction or adjustment of an observation to achieve overall closure in a control network. It is also, any difference between an observed quantity and a computed value for that quantity.

RINEX – Receiver INdependent EXchange format – A RINEX is a standard GPS raw data file format used to exchange files from multiple receiver manufacturers.

RMS – Root Mean Square – A RMS expresses the accuracy of point measurement. It is the radius of the error circle within which approximately 68% of position fixes are found. It can be expressed in distance units or in wavelength cycles.

RMSE – Root Mean Square Error.

rotated meridian – A rotated meridian is a zone constant for the oblique Mercator mapping projection.

rotation – In transformations, a rotation is an angle through which a coordinate axis is moved around the coordinate system origin.

rover – Rover is any mobile GPS receiver and field computer that is collecting data in the field. The position of a roving receiver can be differentially-corrected relative to a stationary base GPS receiver.

RTCM – Radio Technical Commission for Maritime Services. RTCM is a commission established to define a differential data link for the real-time differential correction of roving GPS receivers.

RTK – A real-time kinematic is a type of GPS survey.

S

SAF – Surface Adjustment Factor. SAF is a published TxDOT-developed value for each county which, when multiplied times a distance on the State Plane grid, yields the corresponding distance on the surface.

satellite geometry – A satellite geometry is a position and movement of GPS satellites during a GPS survey.

scalar – In least squares, a scalar is a value applied to the variances (errors) based on the required level of confidence.

scale – A scale is a multiplier used on coordinate and other linear variables, such as for map projections and transformations.

SDMS – Survey Data Management System. SDMS is a data collection software and data processing software maintained by AASHTO.

secular motion – A secular motion is that portion of crustal motion which is continuous and at a constant velocity. Secular motion is uniformly predictable over time and is independent of any seismic events.

selective availability (S/A) – SA is an artificial degradation of the GPS satellite signal by the U.S. Department of Defense. The error in position caused by S/A can be up to 100 meters.

semimajor axis – Semimajor is one-half of the major axis.

semiminor axis – Semiminor is one-half of the minor axis.

session – A session is a period during which a number of GPS receivers log satellite data simultaneously for the purpose of creating baselines.

set-up error – Set-up errors are errors in tribrach centering or height of instrument at a control point.

sideshot – A sideshot is an observed baseline with no redundancy.

sigma – Sigma is a mathematical symbol or term for standard error.

single-frequency – Single-frequency is a type of receiver that only uses the L1 GPS signal. There is no compensation for ionospheric effects.

site calibration – Site calibration is a process of computing parameters which establishing the relationship between WGS-84 positions (latitude, longitude and ellipsoid height) determined by GPS observations and local known coordinates defined by a map projection and elevations above mean sea level. The parameters are used to generate local grid coordinates from WGS-84 (and vice-versa) real-time in the field when using RTK surveying methods.

skyplot – A skyplot is a polar plot that shows the paths of visible satellites for the time interval selected for the graph. The elevation of the satellite is represented in the radial dimension and the azimuth is shown in the angular dimension. The result depicts the satellite's path as it appears to an observer looking down from a place directly above the survey point.

solution types – Solution types refer to a description of both the data and techniques used to obtain baseline solutions from GPS measurements. Typical solution types include descriptions such as code, float, and fixed. These describe techniques used by the baseline processor to obtain a baseline solution. Solution types also may include descriptions such as L1, L2, wide-lane, narrow-lane, or ionospheric free. These describe the way the GPS measurements are combined to achieve particular results. For more information, see the references on GPS processing for a more in depth discussion of these terms and techniques.

slope distance – A slope distance is the distance in the plane parallel to the vertical difference (slope) between the points.

SNR – Signal-to-Noise Ratio.

standard deviation – A standard deviation is a standard error. Surveying applications use the conventional formula for sample standard deviation. Standard deviation is a measure of the strength of a satellite signal. SNR ranges from 0 (no signal) to around 35.

standard error – A standard error is a statistical estimate of error, according to which 68 percent of an infinite number of observations will theoretically have absolute errors less than or equal to this value.

standard error of unit weight – A standard error of unit weight is a measure of the magnitude of observational residuals in an unit weight adjusted network as compared to estimated pre-adjustment observational errors.

State Plane Coordinates – State plane coordinates are special definitions of Transverse Mercator and Lambert conformal mapping projections adopted by statute in the USA. There is one set of such zones for NAD-27, and another for NAD-83.

static (surveying) – Static is a method of GPS surveying using long occupations (hours in some cases) to collect GPS raw data, then postprocessing to achieve sub-centimeter precisions.

static network – A static network is a network that describes the geometry and order in which GPS baselines collected using static and fast static techniques are organized and processed. The baseline processor first examines the project for points with the highest quality coordinates, and then builds the processing network from those points. The result is a set of static baselines that are derived using accurate initial coordinates.

status – Status is every observation and set of keyed-in coordinates for a point has a status field (available in the *Summary* page of the *Properties* window). The status can be enabled, enabled as check, or disabled:

- Enabled observations and coordinates are always used by recomputation in determining the calculated position for the point.
- Enabled as check observations and coordinates are only used if there are no Enabled ones Disabled observations and coordinates are never used.

stochastic model – A stochastic model is a general reference to the techniques used to estimate errors in a network adjustment.

survey observation – A survey observation are the measurements made at or between control points using surveying equipment (conventional or GPS).

SV – satellite or space vehicle.

systematic errors – Systematic errors are errors that occurs with the same sign. They are often the same magnitude in a number of related observations.

T

target – A target is any object to which the instrument is pointed. A target may be a plumb bob or cord, a nail in the top of a stake, a taping arrow, a range pole, a pencil, or any other object that will provide a sharply defined, stationary point or line. A target usually placed vertically over an unoccupied transit station.

tau (value) – A tau is a value computed from an internal frequency distribution based upon the number of observations, degrees of freedom, and a given probability percentage (95%). This value is used to determine if an observation is not fitting with the others in the adjustment. If an observation's residual exceeds the tau, it is flagged as an outlier. Tau values are known as tau lines in the histogram of standardized residuals; vertical lines left and right of the center vertical line.

tau criterion – A tau criterion is Allen Pope's statistical technique for detecting observation outliers.

TDOP – Time Dilution of Precision.

terrestrial observation – A terrestrial observation is an observation in the field using a laser rangefinder or conventional instrument.

tie – A tie is a survey connection from a point of known position to a point whose position is desired.

total station – A total station is an electronic theodolite that provides both angle and distance measurements and displays them automatically.

TOW – Time of Week. TOW is measured in seconds from midnight Saturday night/Sunday morning GPS time.

tracking – The process of receiving and recognizing signals from a satellite.

transformation – A transformation is the rotation, shift, and scaling of a network to move it from one coordinate system to another.

transformation group – A transformation group is a selected group of observations used to compute transformation parameters unique to that group of observations. Typically, the observations within the group are the same type with similar errors and measured using a common method.

transformation parameters – Transformation parameters is a set of parameters derived for a network adjustment or user-parameters defined, that transform one datum to another. Typically with GPS the parameters are generated to transform WGS-84 to the local datum.

transit station – A mark over which the instrument is, has been, or will be accurately positioned for use.

tribrach – A tribrach is a centering device used for mounting GPS antennas and other survey instruments on survey tripods.

tribrach centering errors – Tribrach centering errors are errors associated with centering (plumbing) the tribrach over errors the observed point. These errors are estimated. The estimate is based on surveying the quality of surveying methods and should be conservative.

turning points – Turning points are temporary points of known elevation.

tropo correction – Tropospheric correction. Tropo correction/tropospheric correction is the correction applied to a satellite measurement to correct for tropospheric delay.

tropo model – Tropospheric model – A tropo model occurs when GPS signals are delayed by the troposphere. The amount of the delay will vary with the temperature, humidity, pressure, height of the station above sea level, and the elevation of the GPS satellites above the horizon. Corrections to the code and phase measurements can be made using a tropo model to account for these delays.

U

UDN – User Densification Network. A UDN is a station set by the public that have been "bluebooked" by the NGS for the purpose of providing additional control stations adjusted to the National Spatial Reference System.

univariate – Univariate is a mathematical function describing the behavior of one-dimensional random errors in:

- angle
- distance
- difference in height
- elevation
- ellipsoid height

universal time – Universal time is local solar mean time at Greenwich Meridian. Some commonly used versions of Universal Time are:

- UT0 – Universal Time as deduced directly from observations of stars and the fixed numerical relationship between Universal and Sidereal Time; 3 minutes56.555 seconds.
- UT1 – UT0 corrected for polar motion.
- UT2 – UT1 corrected for seasonal variation in the earth's rotation rate.
- UTC – Universal Time Coordinated; uniform atomic time system kept very closely to UT2 by offsets. Maintained by the U.S. Naval Observatory. GPS time is directly relatable to UTC. UTC-GPS = 9 seconds (in 1994).

URA – User Range Accuracy. A URA is the contribution to the range-measurement error from an individual error source (apparent clock and ephemeris prediction accuracies), which is converted to range units; assuming that the error source is uncorrelated with all other error sources.

unknowns – The computed adjustments to coordinates and transformation parameters; also used to compute observation residuals.

US National Geodetic Survey – This is the United States government agency that maintains the national geodetic datum and all geodetic survey control networks within the US and its territories.

US Survey Foot – 1200/3937 meter. The official unit of linear measure for NAD-27.

UTC – Universal Time Coordinated. UTC is a time standard based on local solar mean time at the Greenwich meridian. See also GPS time.

V

variance – The square of the standard error.

variance factor – Reference variance, variance of unit weight. A statistical measure of how close the observation residuals match the predicted errors. It is the square root of the sum of the weighted squares of the residuals divided by the degrees of freedom. If the errors in a network have been weighted correctly, the variance factor will approach 1.0.

variance component – A least-squares technique for estimating the relative error estimation of different portions of a network.

variance group – A variance group is one of the groups of observations for which variance component estimation is being used in a network adjustment.

variance-covariance – A variance-covariance is the set of numbers expressing the variances and covariances matrix in a group of observations.

VDOP – Vertical Dilution of Precision.

vector – A vector is a three-dimensional line between two points.

vertical – A vertical is similar to the normal, except that it is computed from the tangent plane to the geoid instead of the ellipsoid.

vertical adjustment – A vertical adjustment is a network adjustment of vertical observations and coordinates only.

vertical control – A Vertical control is an established benchmarks.

vertical control point – A vertical control point is a point with vertical coordinate accuracy only. The horizontal position is of a lower order of accuracy or is unknown.

W

WAAS – Wide Area Augmentation System. WASS is a satellite-based system that broadcasts GPS correction information. WAAS capable GPS receivers can track WAAS satellites. WAAS is synonymous with the European Geostationary Navigation Overlay (EGNOS) and Japan's Multifunctional Transport Satellite Space-based Augmentation System (MSAS).

weight – The weight is the inverse of the variance of an observation.

weights – The set of weights, or the inverse of the variance-covariance matrix of correlated observations.

WGS-84 – World Geodetic System (1984). WGS-84 is the mathematical ellipsoid used by GPS since January 1987.

wide-lane – A wide-lane is a linear combination of L1 and L2 carrier phase observations (L1 - L2). This is useful for its low effective wavelength (86.2 cm) and for finding integer ambiguities on long baselines.

X

X, Y and Z – In the Earth-Centered Cartesian system, X refers to the direction of the coordinate axis running from the system origin to the Greenwich Meridian; Y to the axis running from the origin through the 90× east longitude meridian, and Z to the polar ice cap. In rectangular coordinate systems, X refers to the east-west axis, Y to the north-south axis, and Z to the height axis.

Y

Y-code – Y-code is an encrypted form of the information contained in the P-code. Satellites transmit Y-code in place of P-code when anti-spoofing is in effect.

Z

zenith – The zenith is the point at which a line opposite in direction from that of the plumb line (at a given point on the Earth's surface), meets the celestial sphere.

zenith angle – A zenith angle is the angle measured positively from the observer's zenith to the object observed.

zenith delay – A zenith is the delay, caused by the troposphere, of a GPS signal observed from a satellite directly overhead. As a satellite approaches the horizon, the signal path through the troposphere becomes longer and the delay increases.

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