Survey Manual

Chapter 3

GPS/GNSS Surveys

Colorado Department of Transportation
January, 2008

TABLE OF CONTENTS

Chapter 3 – Global Positioning System / Global Navigation Satellite System

CDOT Survey Manual January, 2003

CDOT Survey Manual January, 2003

3.1 GPS/GNSS Survey Specifications

3.1.1 General

The purpose of this chapter is to define the specifications that shall be followed while performing GPS/GNSS surveys for CDOT by CDOT surveyors or contract consultant surveyors. As advances in GPS technology are made in hardware and processing software that prove a higher degree of accuracy is more easily attained, new specifications for CDOT shall be developed and sections of this chapter shall be revised to stay current with those advances.

For brevity, GPS/GNSS shall be referred to as GPS throughout the Survey Manual.

Any variation from the specifications shall have the prior approval of the Region Survey Coordinator.

3.1.2 GPS Methods

A wide variety of GPS survey methods are accepted by CDOT. These methods vary in the type of equipment used, length of observation times, and the accuracy that is attained. GPS survey methods that are most commonly used within CDOT include but are not limited to the following:

1. Static
2. Fast Static
3. Real Time Kinematic (RTK)
4. Post Processed Kinematic (PPK)

3.1.3 Specifications

The specifications included in this chapter are based on the Geometric Geodetic Accuracy Standards and Specifications (GGASS) as published by the Federal Geodetic Control Committee (FGCC) and the Geospatial Positioning Accuracy Standards as published by the Federal Geographic Data Committee (FGDC).

These standards and specifications have been modified to best suit the needs of CDOT.

3.1.4 Specification Types

There are two types of specifications that shall be followed while performing GPS surveys for CDOT as follows:

1. FGDC/FGCC Standards and Specifications - for surveys that are submitted for inspection and acceptance into the National Spatial Reference System (NSRS) database by federal approval (See 23 CFR 630.402 – Geodetic, for additional information.)

2. CDOT Specifications - for surveys that are not to be submitted for inspection and acceptance into the national database by federal approval.

NGS Index of FGDC Accuracy Standards:
http://www.fgdc.gov/standards/standards_publications/index_html
The above link provides downloads of the following FGDC Accuracy Standards.

CDOT Survey Manual

CDOT Survey Manual January, 2003

3.1.5 Colorado High Accuracy Reference Network (CHARN)

All GPS surveys for CDOT shall be referenced and tied into the Colorado High Accuracy Reference Network (CHARN) as defined by the National Geodetic Survey (NGS) National Spatial Reference System (NSRS). Order of surveys are defined by the NGS Geometric Relative Positioning Accuracy Standards as published in the Geometric Geodetic Accuracy Standards and Specifications for using GPS Relative Positioning Techniques by the Federal Geodetic Control Committee (FGCC), printed May 11, 1989, reprinted with corrections August 1, 1989.

The U.S. Department of Commerce - National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), National Geodetic Survey (NGS) provides geodetic control throughout the United States. Although known by other agency names in the past, the National Geodetic Survey (NGS) is the primary source for geodetic data in Colorado.

NGS defines and manages the National Spatial Reference System (NSRS) - the framework for latitude, longitude, height, scale, gravity, and orientation throughout the United States. NSRS provides the foundation for transportation, communication, and defense systems, boundary and property surveys, land records systems, mapping and charting, and a multitude of scientific and engineering applications. NGS also conducts research to improve the collection, distribution, and use of spatial data.

The NSRS is a system of permanently monumented survey marks and their corresponding geodetic data referenced to the North American Datum of 1983 (NAD 83). The NSRS is made up of Federal Base Networks (FBN), Cooperative Base Networks (CBN) and User Densification Networks (UDN), all of which are known as Colorado's High Accuracy Reference Network (CHARN), and Colorado's CHARN Densification surveys (CHARND) as defined by CDOT in cooperation with NGS.

Coverage of the NSRS by NGS in Colorado (See Appendix National Spatial Reference System (NSRS), for additional information):

A Order survey marks 1:10,000,000 plus 0.1 ppm (100 km or 62 mile spacing)	18
B Order survey marks 1:1,000,000 plus 1 ppm (25 - 50 km or 15 - 30 mile spacing)	218
1st Order survey marks B Order Class 2 defined by CDOT as 1:500,000 plus 2 ppm (10 km or 6 mile spacing) (reported on NGS's datasheets as First Order 1:100,000 plus 1 ppm)	1346
2nd Order Class I & II survey marks 1:50,000 plus 20 ppm - 1:20,000 plus 50 ppm	7
3rd Order survey marks 1:10,000 plus 100 ppm	90
Total	1679

CDOT Survey Manual January, 2003

The number of survey marks stated above are those included in NGS's national database for Colorado on May 28, 2002, and may not represent those survey marks that have been destroyed or added.

NGS/NOAA Datasheets:
http://www.ngs.noaa.gov/cgi-bin/datasheet.prl
The above link provides for searching and downloading of datasheets for CHARN stations.

In areas where the CHARN has not yet been established or is lost, a CHARN Densification survey (CHARND) shall be performed under the FGDC/FGCC standards as outlined by the Region Survey Coordinator and NOAA/NGS. (See CHARN Densification Surveys (CHARND), for additional information.)

Any other type of survey performed for CDOT that will be submitted for acceptance into the NSRS national database by inspection and approval of the federal government shall be performed under the correct and current federal governments agencies standards and specifications.

3.1.6 GPS Equipment

Required GPS equipment specifications used for the various types of GPS surveys are outlined in this chapter.

3.1.7 GPS Reports

All reports generated from any GPS survey shall be submitted to the Region Survey Coordinator for review and shall be filed in the region survey office records for the project. Reports shall bear the signature and seal of the professional land surveyor in responsible charge and contain a statement that the report was prepared under his/her direct supervision and checking.

Static and Fast Static survey reports shall include the following:

1. Project report
2. Names of individuals and their duties
3. Project sketch or map showing project location and project network
4. Station descriptions
5. Station photographs
6. Station obstruction diagrams
7. Observation logs
8. Equipment logs stating manufacture, model, serial numbers and equipment settings
9. Raw observations
10. Baseline processing results
11. Loop closures
12. Repeat baseline analysis
13. Least square minimum constrained adjustment results
14. Least square full constrained adjustment results
15. Elevation report of GPS derived elevations compared with differential leveled elevations
16. Geodetic Coordinate Report including but not limited to the following for each point:

    a. Point name
    b. Latitude and longitude
    c. State plane coordinates in North American Datum of 1983(92)
    d. Ellipsoid height

CDOT Survey Manual January, 2003

e. Differential leveled North American Vertical Datum 1988 elevation
f. Mapping angle (convergence)
g. Scale factor
h. Point description
i. Project Item Coding System (PICS) format GPS control file
j. Statement of processing software and version, geoid model, ellipsoid, project sea level factors, project scale factors, project combined factors, metric to English conversion factors, project truncation coordinate reduction factors

17. Project Coordinate Report including but not limited to the following for each point:

    a. Point name
    b. Modified state plane northing
    c. Modified state plane easting
    d. Differential leveled North American Vertical Datum 1988 elevation
    e. Point description
    f. Project Item Coding System (PICS) format project control file
    g. Project Item Coding System (PICS) format tabulation of monuments MON.TXT file in both feet and meters including a GPS file

    h. For CDOT Class A – Primary surveys, a primary control coordinate comparison report of the final adjusted control coordinates and ground distances between 68% of all directly connected intervisible adjacent control monuments should be verified to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class A – Primary survey by conventional survey methods such as a total station with an electronic distance meter. (See CDOT Class A – Primary Surveys, for additional information.)

RTK and PPK survey reports shall include the following:

1. Project report
2. Names of individuals and their duties
3. Project sketch or map showing project location
4. Equipment logs stating manufacture, model, serial numbers and equipment settings
5. Calibration report for all points used in the calibration, rotation, scale factor, horizontal and vertical residuals, geoid model (See RTK Site Calibrations, for additional information.)
6. Primary control checks immediately after each initialization, during roving while initialized, and before ending the initialization session
7. Post processed report for any points located with PPK
8. Project Coordinate Report including but not limited to the following for each point:

    a. Point name
    b. Modified state plane northing
    c. Modified state plane easting
    d. North American Vertical Datum 1988 elevation (See GPS Derived Orthometric Heights (Elevations), for additional information.)
    e. Point TMOSS code
    f. Project Item Coding System (PICS) format RAW file
    g. Project Item Coding System (PICS) format RTE (feet) or RTM (meter) file

    h. For CDOT Class B – Secondary surveys final RTK or PPK project coordinates for 100% of the following survey monuments shall be verified to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey by observing

CDOT Survey Manual January, 2003

each survey monument with a minimum of two independent RTK or PPK observation sessions (*i.e.* two separate initializations) with substantially different GPS constellations (*i.e.* substantially different times of the day). The base receiver should reference a different primary project control monument for the second session. If dual bases are used to reference two primary control monuments 100% of the following survey monuments shall be observed by a minimum of one RTK or PPK observation session from each base reference station (See CDOT Class B – Secondary Surveys, for additional information.):

i. Secondary Control monuments
ii. Photo Control monuments (center and wing points) *
iii. Public Land Survey System monuments
iv. Right-of-Way monuments
v. Etc.

* Unless approved otherwise by the Region Survey Coordinator all GPS Photo Control monuments (center and wing points) shall be observed only by Static or Fast Static survey methods and procedures in accordance with this chapter. (See Chapter 4 – Aerial Surveys, for additional information.)

9. For CDOT Class B – Secondary surveys final RTK or PPK project coordinates for a minimum of 68%* of the following survey monuments shall be verified to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey by observing each survey monument with a minimum of two independent RTK or PPK observation sessions (*i.e.* two separate initializations) with substantially different GPS constellations (*i.e.* substantially different times of the day). The base receiver should reference a different primary project control monument for the second session. If dual bases are used to reference two primary control monuments 100% of the following survey monuments shall be observed by a minimum of one RTK or PPK observation session from each base reference station (See CDOT Class B – Secondary Surveys, for additional information.)

    a. Property Boundary monuments
    b. Easement monuments
    c. Survey Alignment monuments
    d. Etc.

*Minimum verification of 68% of the above listed monuments may be increased to 100% by the Region Survey Coordinator.

Any reports required for GPS surveys needing federal approval shall be submitted to the correct federal agency for review and approval according to the agencies standards and procedures, and to the Region Survey Coordinator for review and filing in the region survey office records for the project.

3.1.8 GPS Control Monument Database

The GPS Control Monument Database is a statewide database designed to integrate CDOT GPS Primary Control Monument data into the Division of Transportation Development (DTD) / Geographic Information system (GIS). Only CDOT Primary Control Monuments are to be included in this database.

The GPS control monument data must have been determined by a GPS Primary Control Survey performed by CDOT, or consultant surveyors, in accordance with the CDOT Survey Manual. The data

CDOT Survey Manual

CDOT Survey Manual January, 2003

will then be made available for internal CDOT individuals to view, map, download, print, or email through the CDOT GIS Arcview program Maps2.

Each Region shall be responsible for maintaining their own database. The database is designed to allow each Region the flexibility to control specific items such as rounding of numbers, control monument descriptions, zones, and elevation datums.

Each Region shall submit one Access database file containing their entire database to Project Development / ROW Services during the months of January and July of each year, with the first submittal scheduled for January, 2004.

See GPS/GIS Users Group CDOT GPS Control Monument Database Instructions for additional information.

GPS/GIS Users Group Internal Web Page
http://internal/gpsgisug/

3.1.9 GPS Operations Manual

Each region shall have and maintain a GPS Operating Manual for the purpose of establishing equipment configuration settings and information sharing. Each region's manual shall include but not be limited to the following:

1. CDOT GPS contact information / names

2. GPS technical support contact information

3. GPS radio frequencies settings and FCC license information

4. GPS equipment settings for various equipment configurations to perform the following GPS surveys:

    a. Static
    b. Fast Static
    c. RTK
    d. PPK

CDOT Survey Manual January, 2003

3.2 Error Sources in GPS

3.2.1 General

Although measurement errors in GPS can never be completely eliminated, through proper planning, procedures, redundant checks and repeat measurements errors can be isolated, identified and kept to a minimum.

3.2.2 Multipath

Multipath results from the interference of a GPS signal that has reached the receiver's antenna by two or more different paths, usually caused by one path being bounced or reflected off of a surface. The effects of multipath occurs at all GPS receivers used to perform the survey (*e.g.* base and rovers). While performing any GPS survey multipath must be kept to a minimum at all receivers.

Sources of multipath include but are not limited to the following:

1. Mountains
2. Towers
3. Buildings
4. Bodies of water
5. Chain link fences
6. Vehicles
7. Signs
8. Snow
9. Ground surface
10. Overhead utility lines

The effects of multipath can be reduced by the following methods:

1. Be aware of your surroundings, do not set GPS points in areas with multipath.

2. Collect data for longer periods of time.

3. Collect data with multiple sessions with substantially different GPS constellations (*i.e.* substantial different times of the day, this is necessary since the satellite constellation geometry repeats itself every 12 hours.)

4. Move the base to a different primary control monument for RTK or PPK sessions.

5. Use an antenna ground plane.

6. Raise the elevation mask to get above the surface causing the multipath (most GPS processing software allows for the elevation mask to be raised while processing, but not lowered).

3.2.3 Ionosphere

The ionosphere is a layer of the atmosphere filled with charged particles. Satellite signals passing through this layer of atmosphere are subject to ionospheric refraction resulting in a change in the speed of the GPS signal as it passes through the ionosphere.

CDOT Survey Manual January, 2003

The effects of the ionosphere for baseline lengths under 10 kilometers are almost equal to each other at both receivers, therefore ionospheric modeling is not necessary for processing of these baselines. For baseline lengths over 10 kilometers the ionosphere is not equal to each other at both receivers, therefore ionospheric modeling is necessary. Ionospheric modeling is accomplished by multi channel tracking dual frequency receivers.

CDOT requires multi channel tracking dual frequency receivers for all GPS surveys.

3.2.4 Positional Dilution of Precision (PDOP)

Satellite geometry is a numerically expressed number known as the positional dilution of precision (PDOP) and is caused solely by the geometry of the satellites in relation to the observer of those satellites. Proper satellite geometry is critical for accurate GPS measurements through the planning of GPS surveys to be performed during times of optimum satellite geometry.

3.2.5 Equipment Error

Poorly maintained GPS equipment can introduce errors. Although not all error in GPS equipment can be completely eliminated, the error caused by GPS equipment shall be kept to a minimum by the scheduled maintenance checking, and calibration of GPS equipment on a continual basis.

3.2.6 Precise Ephemeris

The satellites orbit (navigation files) sent by the satellites clock may be off by a few millisecs and its position could be off by as much 20 meters. A precise orbit is calculated after the fact by several analysis centers around the world and is good to 7 centimeters. The precise ephemeris is typically available 7 days after the observations are completed.

For the final processing of CDOT Class A – Primary surveys a precise ephemeris should be used.

US Coast Guard Navigation Center:
http://www.navcen.uscg.gov/?pageName=gpsEphemerisInfo
The above link provides information on obtaining a precise ephemeris.

National Geodetic Survey Precise GPS Orbits
http://www.ngs.noaa.gov/orbits/
The above link provides information on obtaining a precise ephemeris.

3.2.7 Human Error

The greatest contributor to error in GPS measurement is human error. Care must be taken while performing any GPS survey to keep human error to a minimum by proper procedures, redundant checks, repeat measurements and GPS observation log reports.

The following are some examples of human error:

1. Misreading antenna height measurements

2. Transposing numbers entered electronically and/or on the GPS observation log

CDOT Survey Manual January, 2003

3. Rushing observations

4. Poor centering and leveling over points

5. Observing the wrong survey point (for example, observing a reference mark instead of the actual mark itself)

6. Incorrect equipment configuration settings

CDOT Survey Manual January, 2003

3.3 GPS Equipment Checking and Calibration

3.3.1 General

Checking and calibration of all types of survey equipment is essential to obtain and maintain the tolerances required in this chapter. At the beginning of any survey all survey equipment needed to perform the survey shall be checked and calibrated by the professional land surveyor in responsible charge of the survey under his/her direct supervision and/or checking. All survey equipment shall be checked and calibrated once every six months thereafter and as needed during the course of the survey, whichever comes first.

Errors due to poorly maintained or malfunctioning equipment will not be accepted. If any equipment errors are found to exist they must be reported to the Region Survey Coordinator prior to the start of the survey. These errors will need to be verified and eliminated prior to performing any survey. For surveys lasting longer than 6 months, the checking and calibration of equipment shall be repeated to show that the equipment is staying within acceptable tolerances as required in this manual.

3.3.2 Checking and Calibration

Following are the types of checking and calibration of equipment that are accepted by CDOT:

1. Equipment Maintenance
2. Federal Published Calibration Baseline Check
3. Existing CDOT Project Control Check
4. Zero Baseline Check

An authorized equipment vendor or manufacturers service department shall perform calibration of GPS survey equipment.

3.3.3 Equipment Maintenance

At the beginning of any survey and once every 6 months thereafter, all necessary survey equipment needed to perform the survey shall be checked and adjusted by the professional land surveyor in responsible charge of the survey under his/her direct supervision and/or checking. All equipment shall be checked once every six months and as needed during the course of the survey, whichever comes first.

Checks and adjustments shall include but are not limited to those outlined in Calibration and Checking above and the following:

1. Tripods - nuts and bolts are tight, no loose or broken legs, tripod head is tight, flat, and not damaged.

2. Fixed Height Tripods - level bubbles are in adjustment, rod is not bent or damaged, height of rod is correct as reportedly measured, legs are secure.

3. Rods - level bubbles are in adjustment, rod is not bent or damaged, height of rod is correct as reportedly measured, and adjustable rod height clamps are secure.

4. Tribrachs - optical plummets are in adjustment, level bubble is in adjustment, no lose legs, no loose or missing screws, bottom head is flat and not damaged.

CDOT Survey Manual January, 2003

5. Collimators - level bubble is in adjustment, top and bottom heads are both flat with no damage.

6. Cables - no cuts, breaks, pinch marks or damage.

7. Receivers - no cracks or visible signs damage.

8. Receiver Antennas - if equipped with a ground plane it is not bent or warped, no cracks or visible signs of damage.

9. Ground planes should produce a plane that when leveled varies no more then +/- 0.003 meters when measured at three notches approximately 120 degrees apart. Ground planes that are warped more than +/- 0.003 meters shall not be used for any CDOT GPS surveys.

3.3.4 Federal Published Calibrated Baseline Check

The National Geodetic Survey (NGS) conducts a cooperative program that provides surveyors with a means for calibrating and checking of errors in Electronic Distances Measuring Instruments (EDMI). Publications are available through NGS on the procedures for checking of EDMI against a Federal Calibrated Baseline. The same procedures used for checking of EDMI are adopted and used for checking of GPS equipment for Static, Fast Static, RTK, and PPK methods. The observed unadjusted baseline lengths shall meet or exceed the manufacturers ratings for the equipment used when checked against a calibrated baseline both horizontally and vertically.

NGS/NOAA
http://www.ngs.noaa.gov/CBLINES/calibration.html
The above link provides information and downloads of Federal Published Calibrated Baselines.

The basic procedures to perform a calibrated baseline check of GPS equipment in either Static or Fast Static mode is as follows:

1. A minimum of two receivers are setup on any two calibrated baseline marks.

2. Either a Static or Fast Static survey is performed with simultaneous observations collected at each mark with the same equipment configurations (*i.e.* elevation mask, epochs, sync time, maximum PDOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.

3. After the first session is completed the receivers are moved and setup on each calibrated baseline mark so that each published baseline length is observed at least twice.

4. This procedure is repeated as many times as needed until all equipment that shall be used for the survey has collected simultaneous data observations at each calibrated baseline mark.

5. The data is downloaded and processed with the use of GPS processing software with the same procedures and settings that will be used for the survey.

6. The unadjusted baselines lengths and vertical differences are calculated and compared to the published calibrated baseline lengths and vertical differences.

CDOT Survey Manual January, 2003

7. For the equipment to be considered as being in adjustment the final unadjusted baselines lengths and vertical differences shall meet or exceed the manufacturers ratings for the equipment.

The basic procedures to perform a calibrated baseline check of GPS equipment in RTK mode is as follows:

1. A base receiver is setup on any one of the calibrated baseline marks.

2. A rover receiver collects data at each calibrated baseline mark with the same equipment configuration (*i.e.* elevation mask, epochs, sync time, maximum PDOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.

3. After the rover has collected data at each calibrated baseline mark the base receiver is moved and setup on each calibrated baseline mark and the rover collects data at each calibrated mark.

4. This procedure is repeated as many times as needed until both a base and a rover receiver have occupied all calibrated baseline marks and data has been collected at all calibrated baseline marks.

5. The data is downloaded into the GPS processing software with the same procedures and settings that will be used for the survey.

6. The unadjusted baselines lengths and vertical differences are calculated and compared to the published calibrated baseline lengths and vertical differences.

7. For the equipment to be considered as being in adjustment the final unadjusted baselines lengths and vertical differences shall meet or exceed the manufacturers ratings for the equipment.

3.3.5 Existing CDOT Primary Control Check

While collecting data in either RTK or PPK mode, the checking of existing CDOT primary control monuments shall be completed to ensure the data being collected meets or exceeds the Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. This check is intended to serve as a quality control check during the survey and is not to be used in place of a calibrated baseline check. A primary control check report shall be submitted for all existing primary control checks (See GPS Reports, for additional information). Primary control checks should be performed at the following times:

1. Immediately after each initialization
2. During roving while initialized
3. Before ending the initialization session

Primary control monument checks shall be performed as follows:

1. The RTK rover shall be placed on a primary control monument mark and leveled.

2. RTK data shall be collected with the same equipment configuration (*i.e.* elevation mask, epochs, sync time, maximum PDOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.

CDOT Survey Manual January, 2003

3. The horizontal and vertical difference between the record primary control data and the collected RTK data shall be verified by either inversing the two locations or by use of a RTK stakeout mode that calculates and reports the difference within the data collector.

4. The horizontal and vertical difference shall be stored for inclusion into the primary control check report.

5. The horizontal and vertical differences should meet or exceed the Minimum Horizontal and Vertical Accuracy Tolerances required for the survey or the RTK setup will be checked for errors and the process repeated.

3.3.6 Zero Baseline Check

The zero baseline check serves as an optional supplemental equipment check. This check is performed to check the antenna phase center of GPS antennas, and for noise carried through the GPS antennas and cables. All receivers, antennas, and cables that will be used while performing the survey should be checked. Publications available on the procedures for performing this type of check from various manufacturers such as Trimble.

The basic procedure for performing a zero baseline check of GPS equipment is as follows:

1. Multiple receivers are connected to a single receiver antenna through the use of a "Splitter Cable".

2. Either a Static or Fast Static session is performed.

3. When the first session is completed each receiver, receiver antenna, and cable that will be used during the survey is rotated through the next session until all equipment has been used in conjunction with each other.

4. The data is downloaded and processed with the use of GPS processing software and the unadjusted baselines are calculated.

5. For the equipment to be considered as being in adjustment the final unadjusted baselines lengths should not exceed 0.002 meters.

CDOT Survey Manual January, 2003

3.4 GPS Survey Methods

3.4.1 23 CFR 630.402 - Geodetic

(a) Geodetic surveys along Federal-aid highway routes may be programmed as Federal-aid highway projects.

(b) All geodetic survey work performed as a Federal-aid highway project will conform to National Ocean Survey (NOS) specifications. NOS will, as the representative of FHWA, be responsible for the inspection and verification of the work to ascertain that the specifications for the work have been met. Final project acceptance by FHWA will be predicated on a finding of acceptability by NOS.

3.4.2 CHARN Densification Surveys (CHARND)

The following CHARND standards and guidelines are available at the following web sites:

NGS/NOAA:
http://www.ngs.noaa.gov/
The above link provides information on NGS/NOAA home page.

FGCC Standards and Specifications for Geodetic Control Networks
http://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodetic-control-networks.htm
The above link provides FGCC specs.

NGS Index of FGDC Accuracy Standards:
http://www.fgdc.gov/standards/standards_publications/index_html
The above link provides downloads of the following FGDC Accuracy Standards:

Part 1: Reporting Methodology
Part 2: Standards for Geodetic Networks
Part 3: National Standard for Spatial Data Accuracy
Part 4: Standards for Architecture, Engineering, Construction (A/E/C) Management

Policy of the National Ocean service regarding the incorporation of Geodetic Data of other organizations into the National Geodetic Survey database:
http://www.ngs.noaa.gov/INFO/incorp_data.shtml
The above link provides information on the format, accuracy, monumentation etc. that is acceptable to NGS for inclusion into the national database.

NGS Draft GPS Survey Manual:
http://www.ngs.noaa.gov/PROJECTS/GPSmanual/
The above link provides a NGS draft manual for the following three areas of “bluebooking” surveys:

1. Equipment
    a. Equipment Specifications, Calibration and Care
    b. Troubleshooting Guide
    c. Equipment Check List
2. Observations
    a. Planning
    b. Procedures

CDOT Survey Manual January, 2003

    c. Observer Check List
3. Data
    a. Forms
    b. Download, Reformatting and Shipping Instructions
    c. Processing

Input Formats and Specifications of the National Geodetic Survey Data Base, The NGS "Bluebook":
http://www.ngs.noaa.gov/FGCS/BlueBook/
The above link provides information on NGS "bluebooking" procedures and standards:

1. Volume I – Horizontal Control
2. Volume II – Vertical Control
3. Volume III – Gravity Control
4. Annexes

NGS Mark Recovery Entry:
http://www.ngs.noaa.gov/ngs-cgi-bin/recvy_entry_www.prl
The above link provides for entry of NGS Mark Recoveries

D-File Processing Handbook:
http://www.ngs.noaa.gov/PC_PROD/DDPROC4.XX/dformat.documentation.html
The above link provides information on the D-File format for submitting mark descriptions by WDDPROC.

WDDPROC:
http://www.ngs.noaa.gov/PC_PROD/DDPROC4.XX/ddproc.menu.html
The above link provides information for the NGS WDDPROC description program.

NGS PC Software:
http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml
The above link provides information on NGS software such as the Adjust Package, Adjust Utilities, CALIBRAT, CORPSCON, etc.

Trimble GPS Data Recourses:
http://www.trimble.com/gpsdataresources.shtml
The above link provides information on obtaining a current ephemeris almanac.

US Coast Guard Navigation Center:
http://www.navcen.uscg.gov/gps/precise/default.htm
The above link provides information on obtaining a precise ephemeris.

National Geodetic Survey Precise GPS Orbits
http://www.ngs.noaa.gov/orbits/
The above link provides information on obtaining a precise ephemeris, typically available 7 days after observations.

Prior to the start of any CDOT CHARND survey the Region Survey Coordinator and the National Geodetic Survey/National Oceanic Atmosphere Administration (NGS/NOAA) shall be contacted and a general plan for the survey shall be submitted to NGS for approval. The general plan shall be in conformance with the FGDC/FGCC standards as outlined by the Region Survey Coordinator and NGS/NOAA.*

CDOT Survey Manual January, 2003

*** NGS project approvals may be obtained online by submitting your project to:**

> **NGS Project Development Branch**
> http://www.ngs.noaa.gov/PROJECTS/proposals/project1.shtml
>
> Additional blue book submittal information
> http://www.ngs.noaa.gov/FGCS/BlueBook/pdf/Annex_L.pdf

Once the general plan has been submitted and approved reconnaissance work may begin. All existing CHARN, CHARND marks and Federal NAVD 1988 Benchmarks, including but not limited to NGS and United States Geological Survey (USGS) Benchmarks, shall be recovered within and surrounding the project area as outlined in the general plan. All existing marks used to reference or “Tie In” the survey shall be of the same or higher accuracy as required for the survey. Any existing marks located on private land or that requires private land to be crossed for access to the mark, shall have Permission to Enter Property Forms completed (See Chapter 2 - General Procedures, for additional information). For each mark searched for and either found or determined to be lost, a Mark Recovery Form shall be completed and entered into NGS/NOAA mark recovery database. Each found mark shall have a Station Visibility Diagram and photographs of the mark taken.

After all existing marks have been recovered site selection for the establishment of new marks may begin. The network shall be made of existing and/or new network marks monumented on the ground in a six mile grid for county wide areas, or at six mile intervals along the highway corridors, county and city roads. When feasible the site selection for new marks is to be located on public land with access to the mark by public access. Any new mark site selection located on private land or that requires private land to be crossed for access to the mark, shall have a Permission to Enter Property Form completed and an easement for access, installation and maintenance of the mark shall be acquired in CDOT’s name for the benefit of the public for the purpose of performing a land survey. While selecting a site it is critical to keep in mind the overall objective of the CHARND network is to provide a highly accurate network with stable monumentation that will stand for a substantial duration of time and be of value not only to the highway project itself, but for all surveying activity within the area, be it government or private surveys.

For the setting of new network marks the location providing for a non-obstructed sky and stability of the monumentation shall be of the utmost important, (See Control Monumentation Site Selection, for additional information).

See Table 3-1:

NGS/NOAA defines the stability of marks as follows:

Vertical Stability Code	Definition
A	Monuments of the most reliable nature which are expected to hold their position/elevation well
B	Monuments which probably hold their positions/elevations well
C	Monuments which may hold their positions/elevations well, but which are commonly subject to surface ground movements

CDOT Survey Manual

CDOT Survey Manual January, 2003

D	Monuments of questionable or unknown reliability

Table 3-1

The Region Survey Coordinator and NGS/NOAA shall concur with the location, stability rating, and monumentation of new network marks before they are established in the field. Underground utility locates shall be marked on the ground surrounding the new mark site prior to the installation of the mark. If underground utilities conflict with the establishment of the new mark a new site selection shall be made. After the mark has been established a Station Visibility Diagram and WDDPROC description in D-file format shall be completed for acceptance into the NGS database by NGS/NOAA.

Once all existing and new network marks have been recovered and/or established the GPS field survey may begin following the outline as approved by the Region Survey Coordinator and NGS/NOAA. The basic procedures for the survey are as follows:

1. A GPS network shall be designed in accordance with CDOT Specifications, FGDC/FGCC standards and approved by the Region Survey Coordinator and NGS/NOAA.

2. A GPS schedule shall be designed for the coordination of receivers, operators, observation times, satellite availability, the logistics of the project and approved by the Region Survey Coordinator and NGS/NOAA. A current almanac shall be used for planning the survey.

3. A presurvey densification meeting shall be held by the GPS project surveyor in responsible charge for the survey with all receiver operators to review the project, methods, and procedures. Each operator shall be provided with all the necessary mark recovery information, schedule, and forms for their marks. The GPS survey coordinator will ensure that operators are trained in the operation of their receiver, data collection, setups, takedowns, and moves to and from each mark.

4. All GPS receivers and equipment shall be checked for errors and/or defects in accordance with CDOT procedures as approved by NGS/NOAA (See Equipment Calibration and Checking, for additional information).

5. Receivers must be capable of recording data for post processing. Multi channel tracking dual frequency receivers are required. Receivers and post processing software must be specified by the manufacture to be suitable for high accuracy Static surveys.

6. Simultaneous observations shall be collected for a duration of at least 2 ½ hours for each GPS session with the same receiver configuration such as elevation mask (typically set at 15 degrees), epochs, sync time (typically set at 15 seconds), maximum PDOP (typically set at 6) and satellite tracking for each receiver.

7. Each receiver antenna should have a ground plane in place.

8. Each antenna tripod shall be either an adjustable leg or a fixed height tripod with sand bags or weights attached to the tripod legs and hubs driven solidly into the ground for the tripod legs to be setup on for support and to minimize movement of the tripod.

9. Whenever feasible all antennas should be of the same make and model.

Once the field survey has been completed the data shall be downloaded and processed with GPS post processing software using a precise ephemeris (See Precise Ephemeris, for additional information) in

CDOT Survey Manual January, 2003

accordance with the accuracy standards as outlined and modified by CDOT and NGS/NOAA for CHARND.

See Table 3-2:

The survey shall be checked for errors and be verified to meet or exceed the following accuracy requirements:

CDOT/NGS Order B Class 2	
PPM:	+/- 2
Line-Length Dependent Error	1:500,000
Precision at 95% confidence level	0.004 meters

Table 3-2

The GPS network shall be "bluebooked" using NGS Adjust and other software programs to include all GPS reports as required for inspection by NGS/NOAA. (See Appendix NGS Bluebook Submission Checklist, for additional information).

The NGS Adjust program performs a least squares adjustment on horizontal, vertical angle, and/or GPS observations. The program comprises six data checking programs in addition to the adjustment software. This software package has numerous options, such as choice of ellipsoid, and includes sample input data.

Once a CHARND mark has been "bluebooked" and accepted by NGS/NOAA into the national database the mark is classified on the NGS datasheet as having a Horizontal First Order classification with a precision of 1:100,000. This is due to the fact that the NGS horizontal accuracies have been modified by CDOT and NGS does not have an Order B Class 2 classification.

3.4.3 Static GPS Surveys

Static survey methods shall be used for either CHARN densification surveys, or as an option for CDOT project control surveys when the required Minimum Horizontal Accuracy Tolerance is for a CDOT Class A - Primary or CDOT Class B - Secondary survey. Static surveys allows for systematic errors to be resolved when high accuracy positions are required by collecting simultaneous data between stationary receivers for an extended period of time during which time the satellite geometry changes. Static survey methods require the creation of a GPS network and a schedule for the coordination of receivers, operators, observation times and the logistics of the project.

Receivers must be capable of recording data for post processing. Multi channel tracking dual frequency receivers are required. Receivers and post processing software must be specified by the manufacture to be suitable for high accuracy Static surveys. The Static Horizontal and Vertical Accuracy Tolerances specified by the manufacture shall meet or exceed the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey.

Static equipment requirements:

1. Only extended leg tripods or fixed height tripods shall be used for any Static survey.

CDOT Survey Manual January, 2003

2. Antennas should have a ground plane in place for Static surveys.

3. Whenever feasible, all antennas for the survey should be of the same make and model.

4. As a guideline CDOT recommends an epoch setting of 1 second and a sync time setting of 15 seconds for all Static surveys.

3.4.4 Fast Static GPS Surveys

Fast Static survey methods shall be used for CDOT project control as an option to Static survey methods when the required Minimum Horizontal Accuracy Tolerance is for a CDOT Class A - Primary or CDOT Class B - Secondary survey. Fast Static surveys allow for systematic errors to be resolved when high accuracy positions are required by collecting simultaneous data between stationary receivers for a shorter period of time than that of Static surveys. For Fast Static surveys, observation times are typically 8 to 20 minutes and are determined at the time of the field survey by the number of satellites available. Fast Static survey methods allows for the creation of a GPS network in a “Leap Frog” pattern. Each baseline between adjacent intervisible control monuments along a transportation corridor must be observed at least twice.

Receivers must be capable of recording data for post processing. Multi channel tracking dual frequency receivers are required. Receivers and post processing software must be specified by the manufacture to be suitable for high accuracy Fast Static surveys. The Fast Static Horizontal and Vertical Accuracy Tolerances specified by the manufacture shall meet or exceed the CDOT Minimum Horizontal and Vertical Tolerances as required for the survey.

See Table 3-3:

Typical CDOT Fast Static time duration settings:

Fast Static Observations	
Minutes of simultaneous observations	Minimum number of satellites (SV)
8 minutes	6 SV
15 minutes	5 SV
20 minutes	4 SV (not recommended)

Table 3-3

Fast Static equipment requirements:

1. Only adjustable leg tripods or fixed height tripods shall be used for any Fast Static survey.

2. Whenever feasible, all antennas for the survey should be of the same make and model.

3. Antennas should have a ground plane in place for Fast Static surveys.

CDOT Survey Manual January, 2003

4. As a guideline CDOT recommends an epoch setting of 1 second and a sync time setting of 5 seconds for all Fast Static surveys.

3.4.5 RTK GPS Surveys

RTK survey methods shall not be used for any survey project requiring CDOT Minimum Horizontal Accuracy Tolerances for a CDOT Class A - Primary survey.

RTK surveys are a “Radial” type survey that utilizes two or more receivers with at least one receiver remaining stationary over a known (reference or base station) project control monument. Other receivers (rovers) are moved from point to point collecting data in a short amount of time. Reference stations shall be of the same or higher accuracy as required for the RTK survey. RTK surveys measure the baselines from the reference station to the roving receivers point. A radio at the reference station broadcast the position of the reference point to the rovers and the system processes the baselines in “Real Time” allowing for project coordinate information to be gathered and analyzed during the actual field survey.

Receivers must be capable of being connected to a radio at the reference station for broadcasting and to a radio at the rover for receiving the reference station broadcast. Multi channel tracking dual frequency receivers are required. Receivers must be specified by the manufacture to be suitable for RTK surveys. The RTK Horizontal and Vertical Accuracy Tolerances specified by the manufacture shall meet or exceed the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey.

Care needs to be taken in the field to ensure that the RTK calibration, base station, and project control points have been set up correctly to allow the RTK data being collected to meet or exceed the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. (See Existing CDOT Primary Control Checks, and GPS Reports, for additional information).

Multipath at the reference station and at the rovers, re-initializations and loss of radio link must be kept to a minimum through project scheduling and organization of the “Best Use” survey method that should be used for the logistics of the survey project. It should be kept in mind that RTK surveys are just another tool available to complete a survey project and should only be used only when the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey can be met or exceeded.

As a guideline CDOT recommends an epoch setting of 1 second.

3.4.6 RTK Site Calibrations

RTK site calibration establishes the relationship between the latitude, longitude, and ellipsoid height (WGS-84 positions) observed with GPS and the final adjusted local project control northing, easting and differential leveled elevation (local project control) for each point. The relationship between these coordinate systems is defined by a series of mathematical parameters. Conversions are applied during the calibration through a process of least squares that allows for future WGS-84 positions determined by GPS observations to be converted to local project control coordinates.

The site calibration is performed to obtain the parameters that allow for the conversion from WGS-84 coordinates to local project control coordinates and back again within the data collector in real time. The local project control coordinate values of the control points are used in the calibration to generate residuals of the GPS derived observations. The GPS derived coordinates will not be used because known local project control values already exist for the control points and remain fixed.

CDOT Survey Manual January, 2003

To perform a site calibration a minimum of 3 horizontal control points are required, a minimum of 5 horizontal control points are recommended for redundancy. Each of these horizontal control points must have WGS-84 positions that were observed by either a GPS Static or Fast Static network, as well as having final adjusted project control coordinate values. To perform a vertical calibration at least 4 vertical control points are required, a minimum of 5 vertical control points are recommended for redundancy. The vertical calibration is the last part of the calibration to be computed. The vertical calibration makes the GPS derived orthometric heights (GPS derived elevations) match as closely as possible with the control differential elevations. (See GPS Derived Orthometric Heights (Elevations), for additional information).

The site calibrations consist of the following horizontal conversion parameters:

1. Rotation – All of the horizontal points in the calibration are used to calculate the centroid (geographic center) about which a rotation of all horizontal GPS points are rotated by the same angular amount.

2. Translation – All of the horizontal points in the calibration have their WGS-84 positions moved in the same direction and the same distance so they will match closer to the final local project control coordinates.

3. Scale – A scale factor is calculated using a ratio of the true distances between the local project control coordinates, and the distances calculated between the GPS derived WGS-84 positions for the same points. This ratio is the scale factor.

Once the above conversion parameters have been determined and a best fit of the observed GPS derived WGS-84 positions with the local project control coordinates has been calculated, minor discrepancies between the GPS derived WGS-84 positions and the local project control coordinates will still exist. These discrepancies are called the “Residuals” and should be relatively small. The residuals are very helpful in deciding whether the site calibration is satisfactory or not. It is recommended that these residuals be no larger than the accuracy tolerance of the Static or Fast Static control survey that was performed for the control points, and shall not exceed the accuracy tolerance for the RTK survey being performed.

3.4.7 PPK GPS Surveys

PPK survey methods shall not be used for any survey project requiring CDOT Minimum Horizontal Accuracy Tolerances for a CDOT Class A – Primary survey.

PPK surveys are a “Radial” type survey similar to an RTK survey, however there is no radio at either the reference station or the rover to broadcast and the system does not process the baselines in real time. PPK utilizes two or more receivers with at least one receiver remaining stationary over a known (reference or base station) project control monument. Other receivers (rovers) are moved from point to point collecting data in a short amount of time. Reference stations shall be of the same or higher accuracy as required for the PPK survey. PPK surveys measures the baselines from the reference station to the roving receivers. Data is collected at both the reference station and at the rover receivers. The data is downloaded into a GPS processing software program to process the baselines.

Receivers must be capable of collecting data at the reference station and at the rover for downloading into a GPS processing program. Multi channel tracking dual frequency receivers are required. Receivers must be specified by the manufacture to be suitable for PPK surveys. The PPK Horizontal and Vertical

CDOT Survey Manual January, 2003

Accuracy Tolerances specified by the manufacture shall meet or exceed the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey.

Care needs to be taken in the field to ensure that the PPK calibration, base station, and project control points have been set up correctly to allow the PPK data being collected to meet or exceed the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey. (See Existing CDOT Primary Control Checks, and GPS Reports, for additional information).

Multipath at the reference station and at the rovers must be kept to a minimum through project scheduling and organization of the "Best Use" survey method that should be used for the logistics of the survey project. It should be kept in mind that PPK surveys are just another tool available to complete a survey project and should only be used only when the CDOT Minimum Horizontal and Vertical Accuracy Tolerances as required for the survey can be met or exceeded.

As a guideline CDOT recommends an epoch setting of 1 second and a sync time setting of 5 seconds for all PPK surveys.

3.4.8 GPS for GIS Mapping Grade Surveys

GIS mapping grade receivers shall not be used to meet any CDOT Horizontal or Vertical Accuracy Tolerance for a CDOT Class A - Primary, CDOT Class B – Secondary, CDOT Class C - TMOSS or CDOT Class D - TMOSS survey. A GIS mapping grade receiver is defined for CDOT use as one that is unable to produce a post processed result within a horizontal accuracy tolerance of 0.050 meters at a ninety five percent (95%) confidence level.

For information and procedures for GIS mapping please refer to CDOT Corridor GIS Data Standards and Guidance Manual.

For information on how to obtain a copy of this manual please contact:

Lou Henefeld
CDOT Division Transportation Development/Geographic Information System
1325 South Colorado Boulevard
Denver, Colorado 80222 louis.henefeld@dot.state.co.us

CDOT Survey Manual January, 2003

3.5 Static and Fast Static Network Design

3.5.1 Required Existing Control Monumentation

As stated earlier GPS surveys for all CDOT projects shall be referenced and tied into the CHARN. All existing control monumentation used to reference or "Tie In" the survey shall be of the same or higher accuracy as required for the survey.

A minimum of three existing horizontal control monuments shall be used to reference the survey, five are recommended for redundancy. These existing horizontal control monuments should be located outside the survey project area to encompass the entire project and provide for good network geometry throughout the network project area.

A minimum of one existing North American Vertical Datum of 1988 control monument shall be used to reference the survey, four are recommended for redundancy. If feasible, the existing vertical control monuments should be located in all four quadrants of the survey and encompass the entire project.

3.5.2 Network Geometry

A network consists of a set of baselines between network points. Networks can be described as having the following network design:

1. Good Network Geometry – A network design that allows for the network to have computed loop closures around small closed figures. If the loop misclosure is high it indicates that there is a problem with at least one of the baselines in the loop. Good network geometry allows other loop closures to be done that identify and isolate problematic baselines in order that they can be easily removed.

2. Bad Network Geometry – A network design that allows for loop closers to be computed that will show a problem exists within the network, but does not allow the problematic baselines to be identified, isolated and removed.

3. Poor Network Geometry – A network design that allows for coordinates to be computed for the unknown points, but does not identify any errors that may exist in the network. This will result in baseline errors going undetected and propagating through the rest of the network.

All GPS networks shall be designed with good network geometry.

For highway corridor control networks that are geometrically long and narrow, it is recommended that control network points be established outside of the highway corridor on monumentation such as Public Land Survey System (PLSS) monuments to strengthen the overall network geometry. Permission to Enter Property Forms shall be completed if required. Once these control network points have been incorporated into the control network survey they can then be used during RTK calibrations to strengthen the RTK calibration without the need to re-occupy the monument.

3.5.3 Redundancy of Networks

Redundancy provides for quality control checks of a network and also provides for the desired confidence in the results obtained from the survey. Each network shall be designed to have a sufficient

CDOT Survey Manual January, 2003

amount of redundancy built into the network in accordance with the methods and procedures as required in this chapter to detect and isolate blunders and/or errors.

Redundancy of a network is achieved by the following:

1. Establish a minimum of four horizontal and vertical primary control monuments for each project encompassing the entire project.

2. Good network geometry built throughout the entire network

3. A minimum of two independent baselines between each control monument

4. Interconnecting closed loops

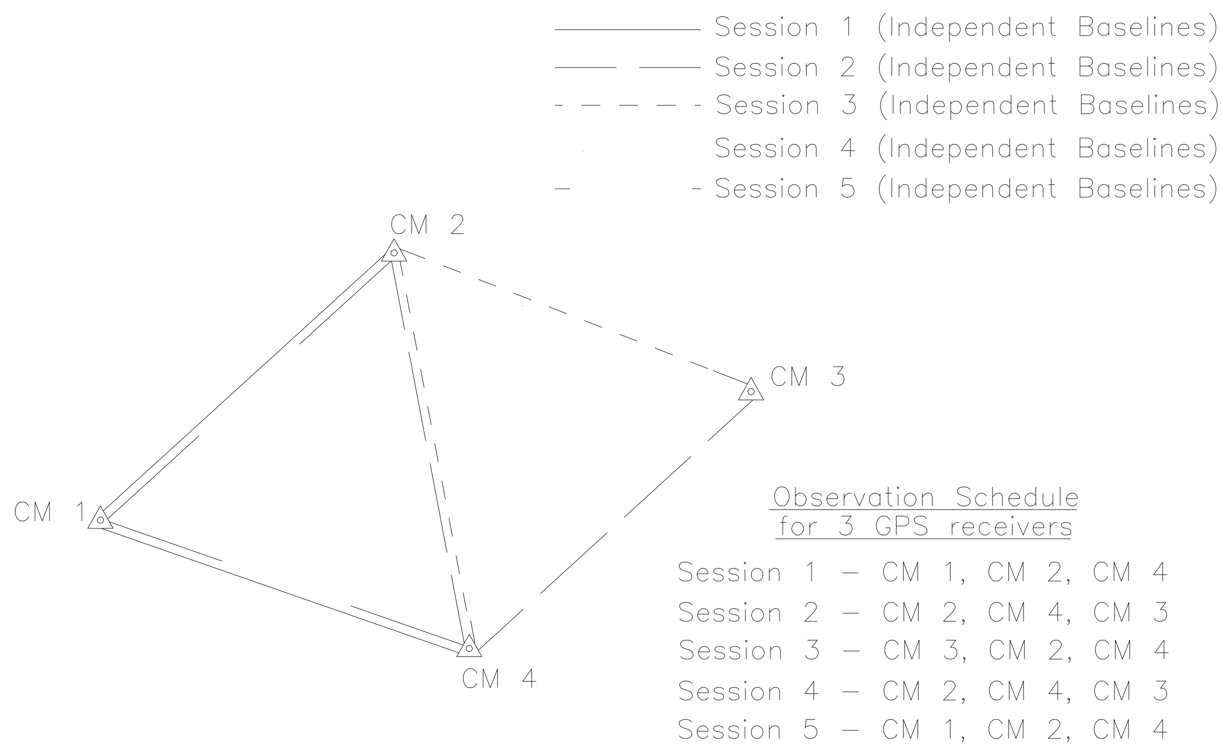
5. Repeat baselines measurement

3.5.4 Independent (Non-Trivial) Baselines

Static and Fast Static networks shall be designed as to process at a minimum two independent (non-trivial) baselines (vectors) between each adjacent control monument. For each session of simultaneous observations there is one less independent baseline than there are receivers.

An example is given for a control network consisting of four control monuments (CM) observed with three receivers. There must be five sessions to allow for two independent baselines to be measured between each control monument. Notice that for each session the receivers are moved to a different control monument, this allows for additional redundancy to be built into the network.

See Figure 3-1:



CDOT Survey Manual

CDOT Survey Manual January, 2003

Figure 3 – 1

3.5.5 Network Loops

Networks shall contain only closed loops. A closed loop is a series of at least three independent connecting baselines that start and end on the same point with each loop having at least one baseline in common with another closed loop to prevent a break in the network. Closed loops shall include observed baselines from at least two observation sessions.

3.5.6 Twenty Percent Rule

For any two control monuments where the distance between the two control monuments is less than 20% of the total distance as measured along a series of closed connected loops to connect the two control monuments, there should be at least two independent baselines measured between the two control monuments.

See Figure 3-2:

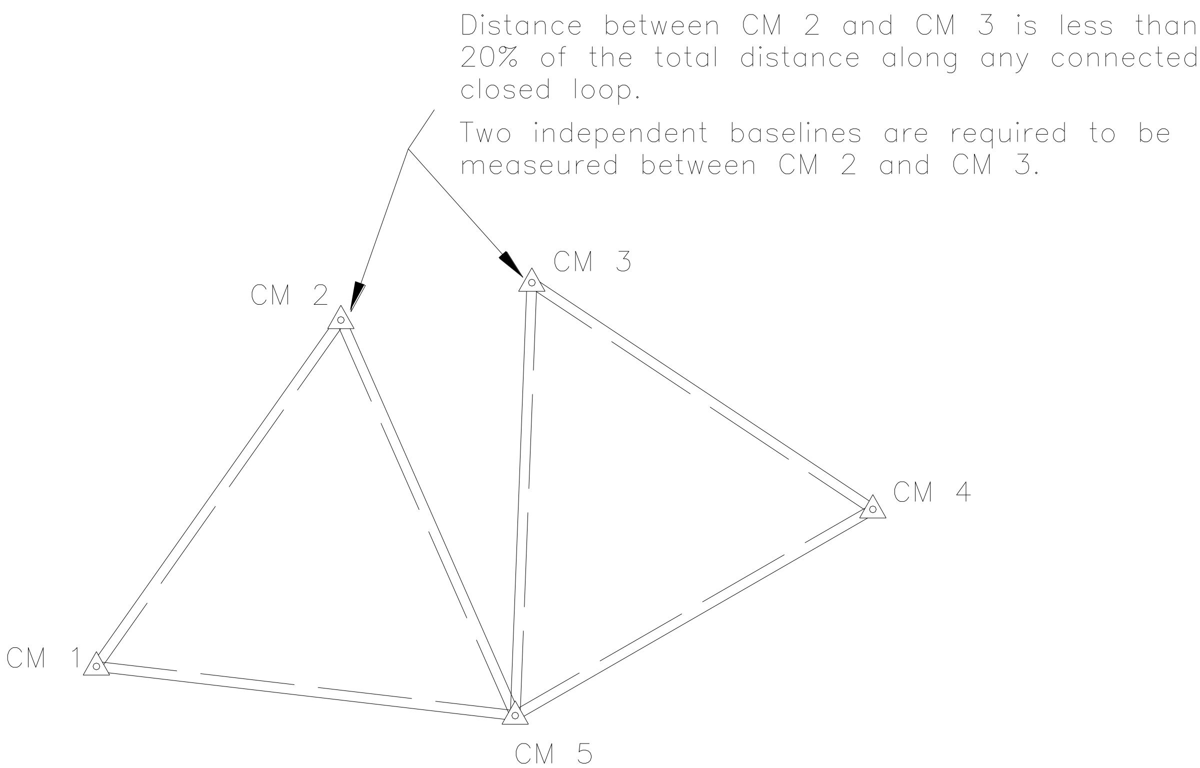


Figure 3 – 2

CDOT Survey Manual January, 2003

3.6 GPS Planning

3.6.1 Control Monumentation Site Selection

It is critical that before setting any control monumentation the project needs are identified. This is typically done through the initial scoping of the project to determine the projects limits, factors, and requirements. After the scoping has been completed the project surveyor shall identify areas to install CDOT Type 2 control monuments. The following considerations should be taken into account when choosing a site for installing control monumentation:

1. Sites should be free of vertical obstructions blocking the horizon such as buildings, overhangs, terrain, trees, fences, utility poles, overhead lines, or any other visible obstructions, non-obstructed skies 15 degrees above the horizon is best.

2. Sites located close to radio transmitters including cellular phone equipment may disrupt satellite signal reception.

3. Sites close to large flat surfaces such as signs, fences, glass, or utility boxes should be avoided.

4. Sites shall provide direct line of site between adjacent control monuments.

5. Sites shall not exceed 0.6 mile between adjacent intervisible control monuments.

6. Establish a minimum of four primary control monuments for each project.

7. If feasible, sites should not be disturbed by future construction activities and should be outside the design toe of slopes and top of cuts for the project.

8. Sites shall be located within the existing highway Right-of-Way.

9. If a site is located outside the existing highway Right-of-Way Permission to Enter Property Forms shall be completed and an easement for access, installation, and maintenance of the control monument shall be acquired in CDOT's name for the benefit of the public for the purpose of performing a land survey.

After the monumentation sites are identified for installation each site shall be marked and utility locates called for. (See Chapter 2 – General Procedures, Underground Utility Locates Prior to Installing Monumentation, for additional information.)

3.6.2 Ephemeris

A GPS ephemeris is the predictions of current satellite positions. Accurate GPS planning is only accomplished when a current ephemeris is used for the GPS planning.

Current ephemeris can be obtain by the following methods:

1. Downloading the ephemeris from the internet
2. Observing the satellites for a minimum of 15 minutes and downloading from the receiver

CDOT Survey Manual January, 2003

Trimble:
http://www.trimble.com/gpsdataresources.shtml
The above link provides information and downloads to obtain a current ephemeris almanac.

3.6.3 Satellite Geometry

A minimum of four satellites are required to survey with GPS. A minimum of five satellites is recommended. The configuration of the visible satellites the receiver is able to track in relation to each other will make a significant difference in the data that is being collected. Satellite geometry is expressed as a numeric value known as Dilution of Precision (DOP). Good satellite geometry will have small DOP values while poor satellite geometry will have large DOP values. As a guideline DOP values of six or lower are recommend for CDOT GPS surveys. The ideal satellite geometry is one which has the visible satellites distributed throughout the sky. Good satellite geometry will yield a higher precision.

Satellite geometry factors that must be considered when planning a GPS survey are:

1. Number of satellites available
2. Minimum elevation angle above the horizon (elevation mask)
3. Obstructions limiting satellite visibility
4. Position Dilution of Precision (PDOP)
5. Vertical Dilution of Precision (VDOP)
6. Horizontal Dilution of Precision (HDOP)

United States Coast Guard, Navigation Center:
http://www.navcen.uscg.gov/
Or call for a 24 hour recorded message: 1-703-313-5907
The above link provides satellite information and important messages for all GPS users.

3.6.4 Elevation Mask

An elevation mask is the lowest elevation above the observer's horizon that a satellites data is recorded. Most obstructions below a set elevation mask can be ignored, however multipath can still be produced from a surface below the set elevation mask. Elevation mask also help to minimize the atmospheric noise in the data. Satellites that are high in the sky will have less atmospheric noise than satellites low in the sky and very close to the observer's horizon. By having an elevation mask set, the noise in the GPS satellite signals is kept to a minimum. Most GPS processing software allows for the elevation mask to be raised while processing, but not lowered.

As a guideline CDOT recommends an elevation mask setting of 15 degrees for all GPS surveys.

3.6.5 Weather Conditions

Generally, weather conditions do not affect GPS surveying, however the following conditions must be considered when planning a GPS survey:

1. GPS Observations should never be conducted during an electrical storm.

2. Significant changes in weather or unusual weather conditions should be noted either in the field notes, data collector, or receiver.

CDOT Survey Manual January, 2003

3. Horizontal and vertical GPS observations can at times be affected by severe snow, hail and rain storms, high accurate GPS surveys should not be conducted during these periods.

4. Sunspots or magnetic storms can affect GPS observations, care needs to be taken to avoid GPS surveying during these periods.

5. A five digit weather code is used to summarize the general weather conditions

See Table 3-4:

Weather Codes:

Weather Code	0	1	2
Problem	No Problem encountered	Problem encountered	Not used
Visibility	Good (over 15 miles)	Fair (7 to 15 miles)	Poor (under 7 miles)
Temperature	Normal (32^{o} F to 80^{o} F)	Hot (over 80^{o} F)	Cold (under 32^{o} F)
Cloud Cover	Clear (under 20%)	Cloudy (20% to 70%)	Overcast (over 70%)
Wind	Calm (under 5 mph)	Moderate (5 to 15 mph)	Strong (over 15 mph)

Table 3-4

NOAA Space Weather Now:
http://www.swpc.noaa.gov/SWN/
The above link provides information for space weather activities and warnings.

Sun Spots and Geomagnetic Storm Warnings:
http://members.tripod.com/~Post_119_Gulfport_MS/space.html
The above link provides information of space weather activities and warnings.

NGS GPS Calendar
http://www.ngs.noaa.gov/CORS/Gpscal.shtml
The above link provides information along with current and past GPS calendars.

CDOT Survey Manual January, 2003

3.7 GPS Vertical Procedures

3.7.1 Antenna Height Measurement

Blunders in antenna height measurements are a common source of error in GPS surveys. All GPS surveys are three-dimensional whether the vertical component will be used or not and care needs to be taken during any GPS survey when measuring the antenna height. Antenna height measurements determine the height from the survey monument mark to the phase center of the GPS antenna.

There are three types of antenna height measurements done for CDOT GPS surveys:

1. Fixed height tripod rods - To be used for Static, Fast Static, RTK, and PPK surveys. Preferred over adjustable height tripods for Static and Fast Static surveys.

2. Adjustable height tripods - To be used for Static, Fast Static, RTK, and PPK surveys.

3. Adjustable height rods - To be used only for RTK and PPK surveys.

See Figure 3-3:

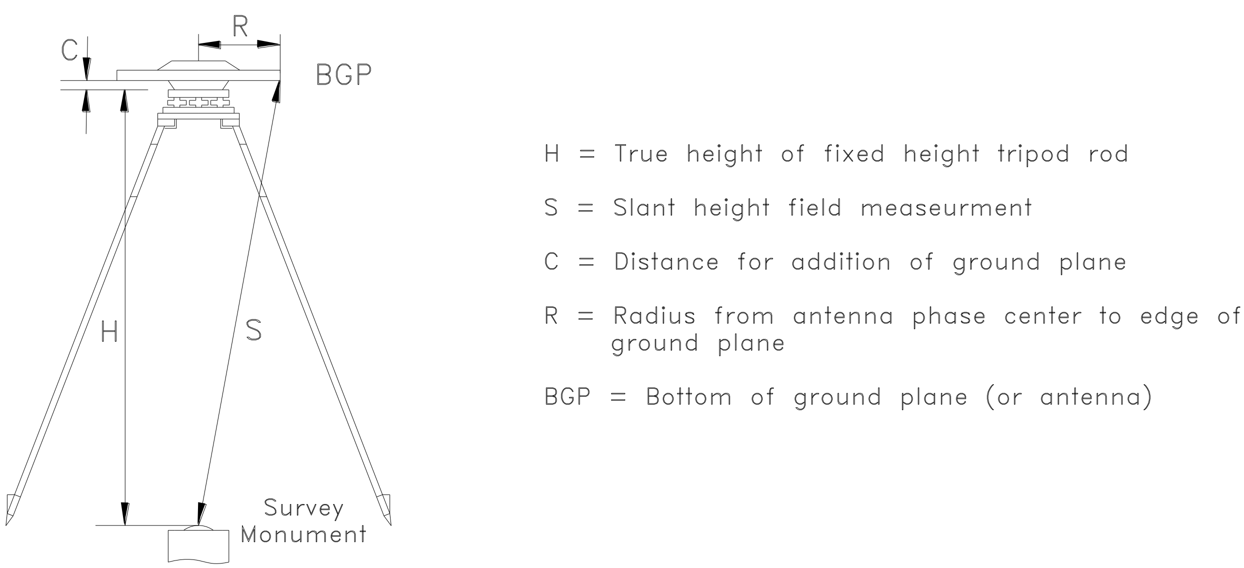


Figure 3 – 3

Fixed height tripod rod antenna height measurement procedures:

1. The length of fixed height tripod rods shall be verified each day prior to the beginning of any observation sessions (See “H” Figure 3-3).

CDOT Survey Manual 32 January, 2008
CDOT Survey Manual January, 2003

2. Care needs to be taken to ensure the correct antenna type, antenna height measurement type, and antenna height measurements are entered into the data collector correctly.

3. The following is recorded on the observation log sheet for each observation setup:

    a. Antenna type
    b. Antenna height measurement type
    c. Antenna height measurement in both meters and feet

4. When downloading the data into a GPS post processing software program the following shall be verified for each observation session:

    a. Antenna type
    b. Antenna height measurement type
    c. Antenna height measurement in both meters and feet

Adjustable height tripod antenna height measurement procedures:

1. The tripod is setup over the survey monument mark and leveled using a precision level prior to the observations session.

2. Independent antenna heights shall be measured on a slant with a manufacturers approved antenna height measurement rod in meters at three separate locations on the antenna or the antenna ground plane, at approximately 120 degrees apart from each measurement (See "S" Figure 3-3).

3. All three antenna height measurements shall not vary +/- 0.003 meters or the tripod setup shall be checked for level.

4. After checking and re-leveling the tripod, if the antenna height measurements are still not within the +/- 0.003 meters tolerance the antenna ground plane shall be checked for warping. Ground planes that are warped more than +/- 0.003 meters shall not be used for any GPS surveys (See Equipment Maintenance, for additional information).

5. Once the three antenna height measurements are within the +/- 0.003 meter tolerance all three measurements are recorded on the observation log sheet.

6. The mean of the three antenna height measurements is calculated and recorded on the observation log sheet.

7. The antenna height measurement is directly measured again in feet and recorded on the observation log sheet.

8. The mean of the antenna height measurement in meters is verified by comparing the measurement recorded on the observation log sheet in feet. The two shall not vary by +/- 0.02 feet or the antenna height shall be re-measured.

9. Care needs to be taken to ensure the correct antenna type, antenna height measurement type and the mean antenna height measurement is entered into the data collector correctly.

10. The following is recorded on the observation log sheet for each observation setup:

    a. Antenna type

CDOT Survey Manual January, 2003

    b. Antenna height measurement type
    c. Three antenna height measurements in meters
    d. Calculated mean antenna measurement in meters
    e. Antenna height measurement in feet

11. When downloading the data into a GPS post processing software program the following shall be verified for each observation session:

    a. Antenna type
    b. Antenna height measurement type
    c. Mean antenna height measurement is within +/- 0.02 feet of the measurement recorded on the observation log sheet in feet.

Adjustable height rods antenna height measurement procedures:

1. The length of adjustable height rods including the distance for the addition of the antenna (See "C" Figure 3-3) shall be verified each day prior to the beginning of any observation sessions.

2. For adjustable height rods that are graduated either in meters, feet, or both, the graduations shall be verified that the height reading of the rod includes the correct distance for the addition of the antenna.

3. Adjustable height rods shall be checked continually for lose rods height clamps and tightened as necessary to avoid the rod height from slipping during the duration of the survey (See Equipment Maintenance, for additional information).

4. Care needs to be taken to ensure that any changes made in the height of the adjustable height rod is entered into the data collector and that the correct antenna type, antenna height measurement type and antenna height measurement is entered into the data collector correctly.

5. When downloading the data from a PPK survey into a GPS post processing software program the following shall be verified for each observation session:

    a. Antenna type
    b. Antenna height measurement type
    c. Antenna height measurement in both meters and feet

When a station is occupied during two or more back-to-back observation sessions without the equipment moving to another point, the entire antenna tripod setup shall be taken down, re-setup and re-leveled for each new observation session.

For stations that are occupied during two of more observations session with the tripod remaining stationary for the point but with new equipment being used for the observation session (such as antennas and receivers) the legs of the tripod shall be broken down and the setup re-leveled for an antenna height substantially different than that of the previous antenna height for each new observation session.

Adjustable antennas height rods shall not be used for any Static or Fast Static survey.

CDOT Survey Manual January, 2003

3.7.2 GPS Derived Orthormetric Heights (Elevations)

GPS is a three-dimensional system and errors in the vertical component of GPS measurements will effect the horizontal positions. Due to this fact all GPS surveys for any type of CDOT survey shall measure the vertical component even if the vertical is not a requirement for the survey. GPS derived orthometric heights (elevations) are compiled from ellipsoid heights as determined by GPS observations and modeled geoid heights using the most current geoid model available.
In order to convert elevations from Global Positioning System (GPS) into ground elevations it is necessary to apply geoid height corrections as depicted by the latest geoid model for the area of interest. The National Geodetic Survey (NGS) is the primary source for defining and maintaining geoid models. NGS updates geoid models on a 3-year cycle (*e.g.* GEOID 93, GEOID 96, GEOID 99).

The NGS Geoid Page:
http://www.ngs.noaa.gov/GEOID/
The above link provides downloads for the latest NGS/NOAA approved geoid models.

NGS Geodetic Tool Kit
http://www.ngs.noaa.gov/TOOLS/
The above link provides downloads for the latest NGS/NOAA tools.

Trimble Geoid Files:
http://www.trimble.com/support_trl.asp?pt=&Nav=Collection-71
The above link provides downloads for the latest geoid models for Trimble products.

NOAA Guidelines for Establishing GPS-Derived Orthometric Heights
Technical Memorandum Version 4.3:
http://www.ngs.noaa.gov/PUBS_LIB/NGS-58.html
The above link provides information and guidelines for establishing GPS derived ellipsoid heights.

Because of distortions in vertical control networks, lack of high accurate benchmarks and errors in the geoid height models, GPS derived heights can be difficult to validate. GPS derived heights will generally be +/- three times worst than the horizontal. However, comparable results between GPS derived heights and elevations obtained directly by differential leveling techniques are obtainable and for now is the best way to determine the accuracies of the vertical component in GPS measurements.

See Figure 3-4:

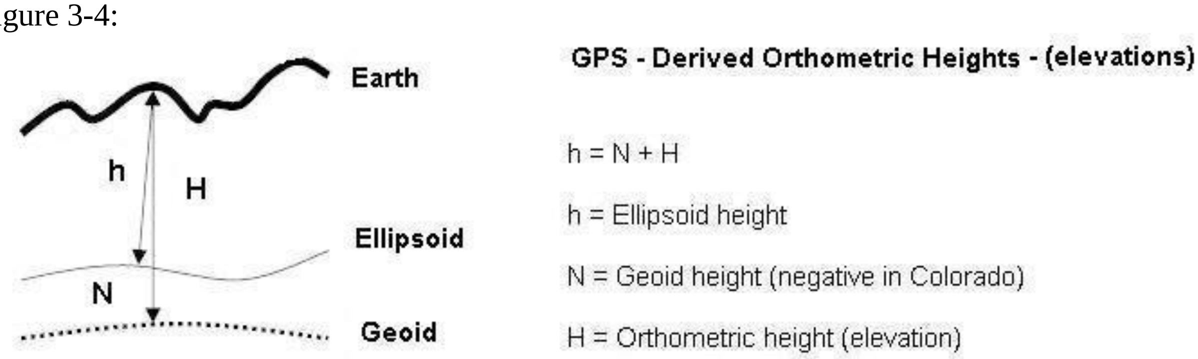


Figure 3 – 4

Due to the fact that highway corridors have GPS control networks established on the ground with GPS control monuments spaced a maximum distance of 0.6 mile that have latitudes, longitudes, ellipsoid

CDOT Survey Manual January, 2003

heights and differential leveled elevations, a geoid model is not required to be imported into an RTK systems data collector to obtain GPS derived orthometric heights while performing an RTK survey inside a control network, however it is recommended (See GPS Reports, for additional information). If no geoid model is used the undulation of the geoid with respect to the ellipsoid is resolved to produce a simple planar geoid model for the project area. By using the latest geoid model available the GPS derived heights will be related to the geoid resulting in elevations that will better fit the Earth's surface.

If accurate elevations are needed outside the control network a differential level loop should be ran to provide control and checks of the vertical component.

See NGS National Height Modernization Program (NHMP) in this chapter for additional information.

3.7.3 CDOT Class A – Primary Vertical Surveys

All CDOT Class A – Primary vertical surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static or Fast Static survey meeting the Minimum Vertical Accuracy Tolerance for a CDOT Class A - Primary Survey (See Chapter 5 – Preliminary Surveys, for additional information).

For any CDOT Class A – Primary vertical survey or any primary control monument that requires accurate elevations be obtained beyond the GPS equipment manufacturers stated vertical accuracy tolerance, differential leveling shall be used to obtain North American Vertical Datum 1988 elevations by the methods, procedures, and Minimum Vertical Accuracy Tolerance as required in Chapter 5 – Preliminary Surveys of this manual.

Unless approved otherwise by the Region Survey Coordinator no CDOT Class A - Primary vertical survey or primary control monument that requires accurate elevations shall have the elevations established by GPS derived heights.

For post processing of any CDOT Class A - Primary vertical survey or any Static or Fast Static survey, a minimal constrained adjustment shall be completed by holding fixed only one three-dimensional control mark having a published Latitude, Longitude, ellipsoid height and a North American Vertical Datum 1988 elevation of the either the same or higher accuracy than that of the survey being performed. The minimal constrained adjustment shall verify that the vertical component for the ellipsoid heights are within an acceptable tolerance for the survey at the ninety five percent (95%) confidence level, or the survey data shall be checked for blunders, errors and corrected.

Once the minimal constrained adjustment is at an acceptable accuracy tolerance level as required for the survey, a current geoid model shall be imported into the software and the geoid separations calculated. A fully constrained adjustment is then performed by incorporating and holding fixed only one additional differential leveled vertical control mark at a time. For each vertical control mark that is added and held fixed, the entire network shall be re-adjusted and verified to be within an acceptable vertical tolerance level for the survey by comparing the GPS derived orthometric heights to the differential leveled elevations. This process is repeated as many times as needed until all differential leveled vertical control marks have been incorporated into the survey and are held fixed.

3.7.4 CDOT Class B – Secondary Vertical Surveys

All CDOT Class B – Secondary vertical surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static, Fast Static, RTK or PPK

CDOT Survey Manual January, 2003

survey meeting the Minimum Vertical Accuracy Tolerance for a CDOT Class B - Secondary survey (See Chapter 5 – Preliminary Surveys, for additional information).

For survey monuments that require accurate elevations be obtained beyond the GPS equipment manufacturers stated vertical accuracy tolerance, 100% of all GPS derived elevations shall be verified or supplemented with elevations by a more accurate survey method as follows:

1. Differential leveled elevations in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

2. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

3.7.5 CDOT Class C – TMOSS Vertical Surveys

All CDOT Class C – TMOSS vertical surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static, Fast Static, RTK or PPK survey meeting the Minimum Vertical Accuracy Tolerance for a CDOT Class C – TMOSS survey (See Chapter 5 – Preliminary Surveys, for additional information).

For TMOSS locations that require accurate elevations be obtained beyond the GPS equipment manufacturers stated vertical accuracy tolerance, 100% of all GPS derived elevations shall be verified or supplemented with elevations by a more accurate survey method as follows:

1. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

2. Differential leveled elevations in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

3.7.6 CDOT Class D – TMOSS Vertical Surveys

All CDOT Class D – TMOSS vertical surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static, Fast Static, RTK or PPK survey meeting the Minimum Vertical Accuracy Tolerance for a CDOT Class D – TMOSS survey (See Chapter 5 – Preliminary Surveys, for additional information).

For TMOSS locations that require accurate elevations be obtained beyond the GPS equipment manufacturers stated vertical accuracy tolerance, 100% of all GPS derived elevations shall be verified or supplemented with elevations by a more accurate survey method as follows:

1. Differential leveled elevations in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

2. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as required in Chapter 5 – Preliminary Surveys.

CDOT Survey Manual January, 2003

3.8 GPS Horizontal Procedures

3.8.1 Minimum Horizontal Accuracy Tolerance Table

All GPS surveys for CDOT shall meet the Minimum Horizontal Accuracy Tolerance Table as shown Chapter 5 – Preliminary Surveys of this manual, for either a CDOT Class A - Primary, Class B - Secondary, Class C - TMOSS, or Class D - TMOSS survey.

3.8.2 CDOT Class A – Primary Horizontal Surveys

All CDOT Class A – Primary horizontal surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter for either a Static or Fast Static survey meeting the Minimum Horizontal Accuracy Tolerance for a CDOT Class A – Primary survey (See Chapter 5 – Preliminary Surveys, for additional information).

No RTK or PPK survey shall be performed for any CDOT Class A - Primary survey.

For the final processing of any CDOT Class A – Primary horizontal survey a precise ephemeris should be used. (See Precise Ephemeris, for additional information).

Final adjusted horizontal project control coordinates and ground distances between 68% of all directly connected intervisible adjacent control monuments should be verified to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class A – Primary survey by conventional survey methods such as a total station with an electronic distance meter. (See GPS Reports, for additional information.)

3.8.3 CDOT Class B – Secondary Horizontal Surveys

All CDOT Class B – Secondary horizontal surveys performed with GPS shall be performed in accordance with the methods and procedures as required in this chapter either for a Static, Fast Static, RTK or PPK survey meeting the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey (See Chapter 5 – Preliminary Surveys, for additional information).

Final RTK or PPK project coordinates for 100% of the following survey monuments shall be verified (See GPS Reports, for additional information) to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey by observing each survey monument with a minimum of two independent RTK or PPK observation sessions (*i.e.* two separate initializations) with substantially different GPS constellations (*i.e.* substantially different times of the day). The base receiver should reference a different primary project control monument for the second session. If dual bases are used to reference two primary control monuments 100% of the following survey monuments shall be observed by a minimum of one RTK or PPK observation session from each base reference station:

1. Secondary Control monuments
2. Photo Control monuments (center and wing points) *
3. Public Land Survey System monuments
4. Right-of-Way monuments
5. Etc.

* Unless approved otherwise by the Region Survey Coordinator all GPS Photo Control monuments (center and wing points) shall be observed only by Static or Fast Static survey methods and procedures in accordance with this chapter. (See Chapter 4 – Aerial Surveys, for additional information.)

CDOT Survey Manual January, 2003

Final RTK or PPK project coordinates for a minimum of 68%* of the following survey monuments shall be verified (See GPS Reports, for additional information) to be within the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey by observing each survey monument with a minimum of two independent RTK or PPK observation sessions (*i.e.* two separate initializations) with substantially different GPS constellations (*i.e.* substantially different times of the day). The base receiver should reference a different primary project control monument for the second session. If dual bases are used to reference two primary control monuments 100% of the following survey monuments shall be observed by a minimum of one RTK or PPK observation session from each base reference station:

1. Property Boundary monuments
2. Easement monuments
3. Survey Alignment monuments
4. Etc.

* Minimum verification of 68% of the above listed monuments may be increased to 100% by the Region Survey Coordinator.

3.8.4 CDOT Class C – TMOSS Horizontal Surveys

All CDOT Class C - TMOSS horizontal surveys performed with GPS shall be performed in accordance with the methods and procedures as required in the chapter for either a Static, Fast Static, RTK or PPK survey meeting the Minimum Horizontal Accuracy Tolerance for a CDOT Class C – TMOSS survey for the feature being located (See Chapter 5 – Preliminary Surveys, for additional information).

3.8.5 CDOT Class D – TMOSS Horizontal Surveys

All CDOT Class D – TMOSS horizontal surveys performed with GPS shall be performed in accordance with the methods and procedures as required in the chapter for either a Static, Fast Static, RTK or PPK survey meeting the Minimum Horizontal Accuracy Tolerance for a CDOT Class D – TMOSS survey for the feature being located (See Chapter 5 – Preliminary Surveys, for additional information).

3.8.6 Process for State Plane Coordinate Reduction

For CDOT Class A - Primary surveys, once the final adjusted state plane nothing and easting coordinates have been calculated the reduction of state plane coordinates to modified project northing and easting coordinates shall be done in the following order:

1. State plane coordinates shall be in meters.

2. One or more base points are selected to calculate the project latitude, longitude, elevation, elevation factor, scale factor, combined factor and zone. Either one base point may be selected or the average of all points may be used. The zone selected shall be either the North, South or Central zone in accordance with Article 52, CRS, Colorado Coordinate System, and as approved by the Region Survey Coordinator.

3. Final adjusted state plane coordinates in meters are reduced to modified ground coordinates in meters using the above calculated factors.

CDOT Survey Manual January, 2003

4. Modified ground coordinates in meters (as calculated above) are truncated in both the northing and easting for an even number value such as 200,000 meters in the northing and 400,000 meters in the easting.

5. Truncated modified ground coordinates in meters are converted to U.S. Survey Feet in accordance with Article 52, CRS, Colorado Coordinate System, using the following conversion factor: One meter equals 3937/1200 feet.

Only after modified ground coordinates in Meters have been truncated shall they be converted to US survey feet. This allows conversion to and from U.S. Survey Feet to Meters, or Meters to U.S. Survey Feet without having to truncate the coordinates, and provides a standard procedure for converting state plane coordinates to modified ground coordinates for CDOT use.

CDOT Survey Manual January, 2003

3.9 Project Control Diagram and Land Survey Control Diagram

3.9.1 Project Control diagram

All CDOT Class A – Primary surveys performed by GPS methods shall have a Project Control Diagram (PCD) completed and filed with the Region Survey Coordinator in accordance with Chapter 5 – Preliminary Surveys.

3.9.2 Land Survey Control Diagram

All CDOT Class B – Secondary surveys performed by GPS methods shall have a Land Survey Control Diagram (LSCD) completed and filed with the Region Survey Coordinator and deposited in the records with the appropriate county clerk's office in accordance with Chapter 5 – Preliminary Surveys.

Aerial surveys are excluded from this requirement.

3.9.3 TMOSS Surveys

All CDOT Class C – TMOSS and CDOT Class D – TMOSS surveys performed by GPS methods shall have the final TMOSS survey shown on the Project Control Diagram and/or the Land Survey Control Diagram in accordance with Chapter 5 – Preliminary surveys.

CDOT Survey Manual January, 2003

3.10 NAD83(NSRS2007) National Readjustment

3.10.1 General

On February 10, 2007 NOAA's National Geodetic Survey (NGS) released its NAD83(NSRS2007) readjusted horizontal positions and ellipsoid heights of the National Spatial Reference System (NSRS) to achieve centimeter level consistency with the published NAD83 framework as defined by the latest Continuously Operating Reference Stations CORS realization. Using high accuracy GPS data only the readjustment improves the accuracy and consistency of the NSRS and provides a new *Local* and *Network Accuracy* definition for each coordinate.

NGS Readjustment
http://www.ngs.noaa.gov/NationalReadjustment/
The above link provides data and information on the National Readjustment.

CDOT Survey Manual January, 2003

3.11 NGS National Height Modernization Program (NHMP)

3.11.1 General

Height Modernization is a program within NOAA's National Geodetic Survey (NGS) that provides accurate height information by integrating Global Positioning System (GPS) technology with existing survey techniques. For years, GPS has been used to determine accurate positions (latitude and longitude), but now, by following Height Modernization standards, specifications and techniques, GPS can efficiently establish accurate elevations for all types of positioning and navigational needs.

NGS National Height Modernization Program (NHMP)
http://www.ngs.noaa.gov/heightmod/index.shtml
The above link provides information and project specifications to initiate a Height Mod Project or Program.

NOAA Guidelines for Establishing GPS-Derived Orthometric Heights
Technical Memorandum Version 4.3:
http://www.ngs.noaa.gov/PUBS_LIB/NGS-58.html
The above link provides information and guidelines for establishing GPS derived ellipsoid heights.

See GPS Derived Orthormetric Heights (Elevations) in this chapter for additional information.

CDOT Survey Manual

CDOT Survey Manual January, 2003

3.12 Continually Operating Reference Stations (CORS)

3.12.1 General

The National Geodetic Survey (NGS) coordinates a network of Continuously Operating Reference Stations (CORS) that provide GPS carrier phase and code range measurements that can be applied directly to GPS surveys in support of 3-dimensional positioning.

Prior to the NOAA's NGS National Readjustment in 2007, the CORS system enabled positioning accuracies that approached a few centimeters (approximately 6 centimeters horizontally) relative to the National Spatial Reference System (NSRS). In March 2002, NGS upgraded NAD 83 positions and velocities for all CORS sites so they equal the transformed values of the more recently computed International Terrestrial Reference Frame of 2000 (ITRF00) positions and velocities.

The National Readjustment, released on February 10, 2008, provides horizontal coordinates and ellipsoid heights simultaneously readjusted to achieve centimeter consistency with the published NAD83 framework as defined by the latest CORS realization. Therefore, the NAD83(NSRS2007) published coordinates and CORS coordinate data are realized as one of the same in accordance with NGS specifications and accuracy tolerances. NGS will continually update all CORS positions to be relative to the ITRF00 annually each year.

All CDOT GPS surveys are referenced and tied into CHARN through the NSRS as defined by the National Geodetic Survey (NGS) National Spatial Reference System (NSRS). Positions obtained by GPS surveys referencing CORS sites may not be relative to the CHARN as monumented on the ground, in particular where GPS data did not exist for use in the National Readjustment. The surveyor will need to take a close look at whether using a CORS station in conjunction with CHARN or CHRAND marks will help to strengthen the GPS survey or degrade it.

Additionally, ellipsoid heights obtained from CORS may not agree with the CHARN or CHARND. A NGS Height Modernization should be initiated to undertake simultaneous leveling and GPS activities.

3.12.2 CORS Stations use for Static, Fast Static, RTK, or PPK Surveys

CORS stations shall not be used for performing any CDOT Static, Fast Static, RTK, or PPK survey unless approved in advance by the Region Survey Coordinator.

Before any CORS station will be approved for use by the Region Survey Coordinator, the following shall be reviewed and a determination made:

1. The Minimum Horizontal and Vertical Accuracy Tolerance of the GPS survey being performed.

2. The horizontal and vertical accuracy of the CORS station data.

3. How the CORS station is mounted and what it is mounted on.

4. Multipath conditions of the CORS station.

5. The CORS station antenna type.

6. The distance of the CORS station relative to the highway corridor primary control network and the GPS survey being performed.

CDOT Survey Manual January, 2003

7. The overall strength of the geometry of the CORS station relative to the highway corridor primary control network and the GPS survey being performed.

8. Sync time the CORS station is broadcasting on relative to the sync time of the GPS receivers performing the survey.

After the above has been reviewed and a determination made to use a CORS station, the stations used shall be verified as to strengthen the GPS network and not degrade it in relation to the CHARN and/or CHARND by performing a minimal constrained adjustment of the GPS network.

If the CORS station data is determined to degrade the GPS network the CORS station shall not be used as part of the network.

NGS/NOAA CORS
http://www.ngs.noaa.gov/CORS/
The above link provides information and downloads of CORS station files.

NGS Cooperative CORS
http://www.ngs.noaa.gov/CORS/
The above link provides information about COOP CORS specifications.

CDOT Survey Manual January, 2003

3.13 On-line Positioning User Service (OPUS)

3.13.1 General

The National Geodetic Survey operates the On-line Positioning User Service (OPUS) as a means to provide GPS users 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 will be processed to determine a position using NGS computers and software. Each RINEX file that is submitted will be processed with respect to 3 CORS sites. The sites selected may not be the nearest to your site but are selected by distance, number of observations, site stability, etc. The position for your data will be reported back to you via email in both ITRF and NAD83 coordinates as well as UTM and State Plane Coordinates (SPC) northing and easting.

3.13.2 OPUS use for Static, Fast Static, RTK, or PPK Surveys

The National Geodetic Survey On-line Positioning User Service (OPUS) shall not be used for producing any final horizontal and/or vertical (X,Y & Z) positions for any CDOT Static, Fast Static, RTK or PPK survey.

It may be used as a tool for verification of the final horizontal and/or vertical positions (X, Y & Z) obtain from these types of surveys.

CDOT Survey Manual

CDOT Survey Manual January, 2003

3.14 References

CDOT Survey Manual – CDOT, 1992

CDOT Right of Way Manual – CDOT, July 2002

Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques – Version 5.0: May 11, 1988, Reprinted with minor corrections: August 1, 1989

Geospatial Positioning Accuracy Standards Part 1: Reporting Methodology – FGDC-STD-007.1-1998, Federal Geographic Data Committee

Geospatial Positioning Accuracy Standards Part 2: Standards for Geodetic Networks - FGDC-STD-007.2-1998, Federal Geographic Data Committee

Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy - FGDC-STD-007.3-1998, Federal Geographic Data Committee

Geospatial Positioning Accuracy Standards Part 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management - FGDC-STD-007.4-2002, Federal Geographic Data Committee

NGS Draft GPS Survey Manual – Last updated on May 8, 2000

Input Formats and Specifications of the National Geodetic Survey Data Base, The NGS "Bluebook" – Last update on March 29, 2002

Policy of the National Ocean service regarding the incorporation of Geodetic Data of other organizations into the National Geodetic Survey database – September 1994, Addendum 1 approved by the NGS Executive Steering Committee March 26, 1977

Standards and Guidelines for Cadastral Surveys Using Global Positioning System Methods – Bureau of Land Management, May 9, 2001 Version 1.0

Global Positioning System (GPS) Survey Specifications – California Department of Transportation, Survey Manual, Chapter 6, June 1997

Control Surveys - California Department of Transportation, Survey Manual, Chapter 9, May 1998

Survey and Mapping Product Training, GPSurvey – Trimble, Part Number: 33143-10 Edition A, Copyright 1998, Trimble Navigation

Real-Time Kinematic Surveying Training Manual – Trimble, Part Number: 33142-40 Revision A, September 2001, Copyright 1998-2001, Trimble Navigation Limited

Introduction to Real Time Surveying, Product Training – Trimble, Part Number: 33142-20, Revision A, Copyright 1998-1999, Trimble Navigation Limited

An Evaluation of the High Accuracy Reference Network Relative to the Continuously Operating Reference Stations – by Kathryn O. Milbert, NGS/NOS/NOAA.

CDOT Survey Manual January, 2003